Springbank Off-Stream Storage Project Preliminary Design Report

Appendix E - Structural

September 25, 2020

Stantec

Prepared for:
Alberta Transportation
3rd Floor – Twin Atria Building
4999 – 98 Avenue
Edmonton, AB T6B 2X3

Prepared by:

Stantec Consulting Services Ltd
Calgary, AB

Project Number 110773396

Sign-off Sheet

This document entitled Springbank Off-Stream Storage Project – Preliminary Design Report – Appendix E – Structural was prepared by Stantec Consulting Ltd. ("Stantec") for the account of Alberta Transportation (the "Client"). Any reliance on this document by any third party is strictly prohibited. The material in it reflects Stantec's professional judgment in light of the scope, schedule and other limitations stated in the document and in the contract between Stantec and the Client. The opinions in the document are based on conditions and information existing at the time the document was published and do not take into account any subsequent changes. In preparing the document, Stantec did not verify information supplied to it by others. Any use which a third party makes of this document is the responsibility of such third party. Such third party agrees that Stantec shall not be responsible for costs or damages of any kind, if any, suffered by it or any other third party as a result of decisions made or actions taken based on this document.

Prepared by____
(signature)
Enrique Farfan, PhD, PE, Structural Engineer

Prepared by ____
(signature)
Chrispin Gabriel, PE, Structural Engineer

Prepared by ____
(signature)
Jaquelin Hunter, P.Eng., Structural Engineer

Prepared by ____
(signature)
Frederick Lux III, PE, Senior Structural Engineer

Sign-off Sheet

PROFESSIONAL ENGINEER
BLAIR FRASER
ALBERTA

2020-09-25

Authenticated by ____

(signature)

Blair Fraser P.Eng., Senior Structural Engineer

PERMIT TO PRACTICE
STANTEC CONSULTING LTD.

Signature ________________________

Date 25/Sept/2020

PERMIT NUMBER: P 0258

The Association of Professional Engineers and Geoscientists of Alberta

Validated by ____

(signature)

Dave Crawford P.Eng., Senior Structural Engineer

Springbank Off-Stream Storage Project Structural Design Report

Diversion Inlet

Prepared for:

Alberta Transportation
3rd Floor – Twin Atria Building
4999 – 98 Avenue
Edmonton, AB T6B 2X3

Prepared by:

Stantec Consulting Ltd
Calgary, AB

Project Number 110773396

September 25, 2020

Table of Contents

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

1.0 INTRODUCTION

1.1 PURPOSE

This Structural Design Report (SDR) describes stability assessment, structural analyses and design of the Diversion Inlet, which is part of the Springbank Off-stream Storage Project (SR1). The SDR consolidates and documents the design philosophy, relevant criteria, primary design parameters, and reference source of data used for design. The Diversion Inlet was sized to meet stability requirements and major structural members were designed for conformance with structural criteria.

1.2 PROJECT OVERVIEW

SR1 is a flood diversion system comprised of a diversion structure, a diversion channel and off-stream dry storage reservoir (no permanent pool). When in operation, SR1 will divert and temporarily store excess flood water from the Elbow River and release it back into the river system in a controlled manner. SR1 will work in tandem with the downstream Glenmore Reservoir to limit flood flows downstream of Glenmore to less than 170 m^3/s for up to SR1's design event - the 2013 flood or its equivalent.

Elements of the project are:

- Diversion Structure on the Elbow River consisting of, from left to right when looking downstream, gated Diversion Inlet structure leading to a Diversion Channel, gated Service Spillway located on the Elbow River, adjacent Auxiliary Spillway and a Floodplain Berm. A Debris Deflection Barrier is in the headwater of the Diversion Structure to protect the Diversion Inlet from flood debris.

- Diversion Channel leading from the Elbow River at the Diversion Inlet to the Off-stream Storage Reservoir with an Emergency Spillway along the channel and Channel Outlet at end of the channel.

- Off-stream Storage Dam with Low-Level Outlet Works.

1.3 DESIGN OBJECTIVES

The primary objective of the Diversion Inlet is to prevent flow from entering the Diversion Channel except during flood events when the operation plan calls for diversion flows. The fixed crest at Elevation 1211.5 m is designed to be above the typical 1:2-year peak discharge water surface in the Elbow River and acts as a control weir during flood operation. The inlet gates will normally remain in the closed position.

Since the Diversion Channel and Storage Reservoir have limited capacities, the Diversion Inlet must also be capable of restricting Diversion Channel inflow during extreme events including the IDF for the Off-stream Storage Dam-(OSSD), emergency conditions, and unplanned operations. To achieve this, the breast wall and head wall provide a permanent physical barrier from Elevation 1215.5 m to Elevation 1219.0 m to prevent overtopping of the Diversion Structure when the inlet gates are closed.

The Diversion Inlet abutment and training walls retain embankment fills, serve as water barriers, and prevent overtopping during flood events. For this reason, the walls were designed as concrete hydraulic structures to address stability, strength, and serviceability considerations for multiple operating conditions.

Gate operation requires hoist equipment to be positioned directly above the lift gates with sufficient clearance to raise the bottom of the gate above Elevation 1215.5 m. The gate hoist bridge serves as a mounting surface for the hoist equipment platform and deck grating. The hoist bridge is designed with sufficient stiffness to control deflection within the range of equipment tolerance and personnel comfort during hoist operations. The hoist bridge consists of steel plate girders spanning 20 m from pier to abutment with infill bracing to provide lateral stability and deck grating support. The girders have been sized for normal operating loads as well as hoist overload conditions with bottom of steel located at Elevation 1220.25 m to provide adequate clearance for the lift gate in the fully raised position. Steel bar grating was provided to facilitate pedestrian access and maintenance activities for hoist equipment.

To effectively operate and maintain lift gates and hoist equipment, vehicle and pedestrian access is required to the gates An access bridge spanning from breast wall to head wall consisting of precast deck panels has been included to provide a 6 m wide travel lane for vehicle access. The panels were designed for heavy equipment wheel loads, and the breast wall and head wall were designed to carry crane outrigger loads anticipated during construction and maintenance activities. Steel bar grating was incorporated in the deck design to improve visibility to areas below the bridge deck, and individual panels will be removable (with appropriate equipment), if necessary, for maintenance activities.

1.4 GENERAL ARRANGEMENT

The Diversion Inlet is a gated concrete structure located on the left bank of the Elbow River at the entrance to the Diversion Channel. The primary elements of the Diversion Inlet include:

- Left abutment retaining walls and embankment transitions;
- Concrete monoliths with two 20 m wide gate bays with a center pier divider and fixed crest at Elevation 1211.5 m;

- Two 20 m wide by 4 m tall vertical lift gates with dual wire rope drum and hoist supported by a hoist bridge spanning the full 20 m bay width;
- Access bridge comprised of bridge deck, breast wall, and head wall, which provides access to gate equipment, vehicle access across the Diversion Channel entrance, and serves as a debris and overtopping barrier during extreme flood events;
- Stilling basin concrete monoliths with chute blocks, baffle piers, and end sill to provide energy dissipation; and
- Right abutment retaining walls and embankment transitions.

An isometric view of the Diversion Inlet is shown in Figure 1, a general arrangement is shown on Drawing S-150 and detailed drawings of the monoliths and retaining walls are depicted on Drawings S-300 to S-369.

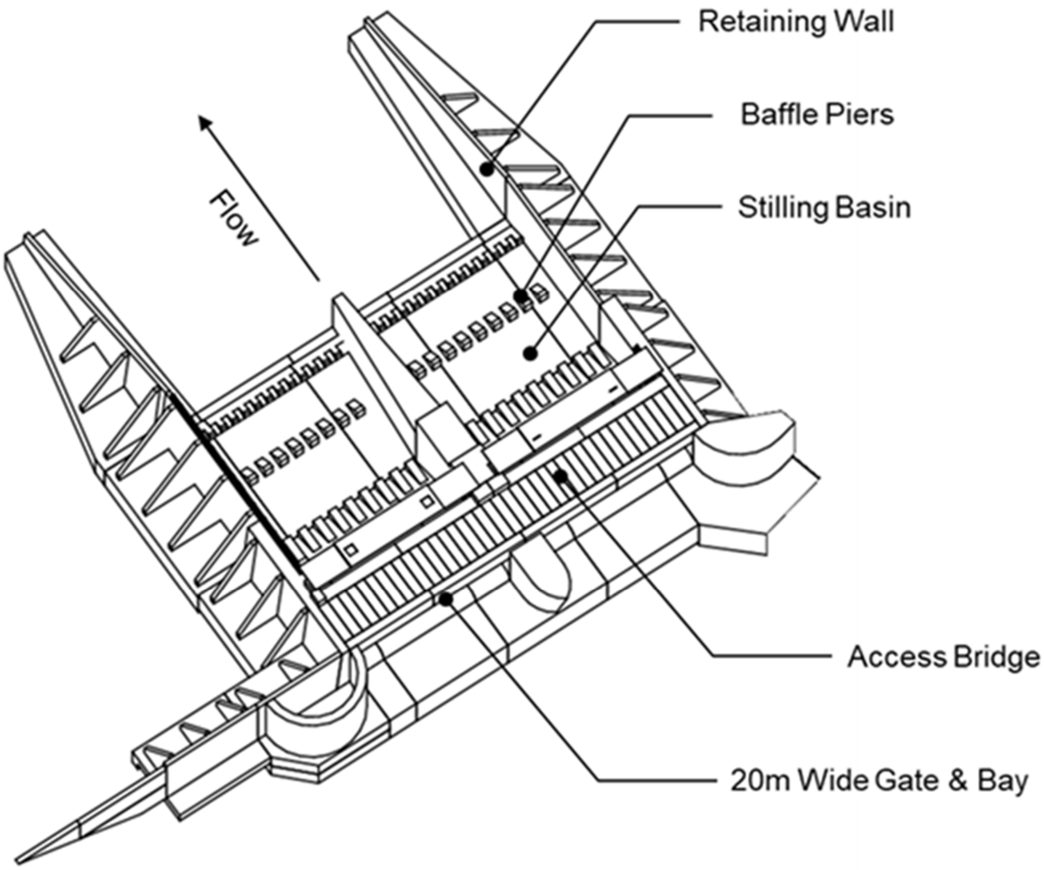


Figure 1. Diversion Inlet General Arrangement

1.5 BASIS FOR STRUCTURE LAYOUT

The Diversion Inlet layout and sizing were based on hydrotechnical evaluation to establish overall geometry, top of dam elevation, and hydraulic profiles to set crest elevation, stilling basin floor and blocks, and sizing of the gates.

The base elevation for each monolith or retaining wall was selected based on existing bedrock profile, stability requirements, and constructability considerations. At the Diversion Inlet, estimated top of rock is well above the hydraulic profile, so there is no upper bound on concrete/rock interface. The lower bound was based on concrete mass needed to provide stability. The concrete/rock interface was identified as a uniform bench to define the limit of excavation and simplify foundation preparation.

Lateral limits of individual monoliths and possible joint locations were selected to maintain base mat aspect ratios between 1:1 and 1.75:1, provide adequate toe for retaining wall and abutment segments, and satisfy stability requirements.

The abutments, approach walls, and training walls are concrete gravity structures using either counterfort or cantilever retaining walls depending on wall height. In general, walls with stem heights more than 6.5 m required counterforts to provide adequate stiffness and lateral load path.

2.0 CODES AND STANDARDS

In accordance with "Terms of Reference" for this project, the design complies with current Alberta Transportation (AT) Design Standards and current AT Design and Construction Bulletins. By reference in AT Standards, Canadian Dam Association (CDA) Dam Safety Guidelines and Technical Bulletin Nos. 1 through 9 provided primary guidance for design of the project including the hydraulic structures. Other recognized industry standards referenced in the AT/CDA Guidelines were used to supplement aspects of the design that the AT/CDA Guidelines do not address. Such references include the US Army Corps of Engineers (USACE) Engineering Manuals and US Bureau of Reclamation (USBR) Design Standards. In case of conflicting criteria, AT provisions were used unless a "more stringent" requirement was deemed appropriate based on engineering judgement.

Where referenced by AT and CDA, the National Building Code of Canada (NBCC) and Alberta Building Code (ABC) were used to obtain certain design loads (wind, snow, live, vehicle), and develop load combinations associated with strength and serviceability. NBCC and ABC provisions were used primarily for evaluation of individual elements such as gratings, ladders, and other ancillary structures.

The following codes, guidelines, and standards were identified for use on this project:

2.1 PROJECT STANDARDS

- Alberta Government, Terms of Reference (TOR0015997) for "Flood Mitigation Works, Springbank Off-Stream Storage Project (SR1) (WAC0078983), Addendum No. 2," August 1, 2014.
- AT's "Engineering Consultant Guidelines for Highway Bridge and Water Projects, Volume 1- Design & Tender" - 2011.
- AT's "Engineering Consultant Guidelines for Highway Bridge and Water Projects, Volume 2- Design & Tender" - 2011.
- AT's Civil Works Master Specifications for Construction of Provincial Water Management Projects.

2.2 DAM DESIGN AND SAFETY

- Province of Alberta Water Act – Water (Ministerial) Regulation - Regulation 205/98 (consolidated up to 185/2015).
- AT's "Water Control Structures Selected Design Guidelines" – Nov. 2004

- Canadian Dam Association Dam Safety Guidelines (CDA) 2007 with 2013 Revisions.
- CDA – Technical Bulletins:
    1. Inundation, Consequences, and Classification for Dam Safety, 2007
    2. Surveillance of Dam Facilities, 2007
    3. Flow Control Equipment for Dam Safety, 2007
    4. Retracted & Replaced by "Guidelines for Public Safety Around Dams," 2011
    5. Dam Safety Analysis and Assessment, 2007
    6. Hydrotechnical Considerations for Dam Safety, 2007
    7. Seismic Hazard Considerations for Dam Safety, 2007
    8. Geotechnical Considerations for Dam Safety, 2007
    9. Structural Considerations for Dam Safety, 2007
- USACE - Stability Analysis of Concrete Structures - EM 1110-2-2100, December 2005
- USACE – Earthquake Design and Evaluation of Concrete Hydraulic Structures - EM 1110-2-6053, 1 May 2007
- USACE - Gravity Dam Design - EM 1110-2-2200, June 1995
- USACE – Retaining and Flood Walls – EM 1110-2-2502, 29 September 1989
- USBR – Design Standards No. 14, Appurtenant Structures for Dams (Spillways and Outlet Works) Design Standards, Chapters 1 to 3, August 2014
- USBR – Design of Small Dams, 3rd Edition, 1987
- USBR – Design of Gravity Dams, 1976
- FEMA – Best Practices Technical Manuals

2.3 BUILDING CODE & PERSONNEL SAFETY

- Alberta Building Code (ABC) 2014
- National Building Code of Canada (NBCC) 2015
- Alberta Occupational Health and Safety Code (OHS code).

2.4 STRUCTURAL ANALYSIS, DESIGN AND MATERIAL SPECIFICATIONS

- Concrete Materials and Methods of Concrete Construction, CSA A23.1-14 & A23.2 -14
- Design of Concrete Structures, CSA A23.3-14
- Design of Steel Structures, CSA S16-14
- Welded Steel Construction, CSA W59-13
- Canadian Foundation Engineering Manual, Canadian Geotechnical Society – 4th Ed., 2006
- Canadian Highway Bridge Design Code
- Alberta Transportation Bridge Design Criteria
- Reinforcing Steel Institute of Canada, Standards Practice Manual

3.0 PROJECT DATA

3.1 LOCATION

The project is located in the Springbank area of Rocky View County, Alberta, CA, southwest of the City of Calgary in Township 24 (Range 04/03, W5M).

Latitude	51.050504 N
Longitude	114.401436 W
Elevation	1180 to 1220 m

3.2 FOUNDATION PARAMETERS

Site characterization is based on geologic assessment of the project site, exploratory borings, laboratory testing of project samples, and geotechnical engineering judgment. The following foundation parameters, derived from Brazeau formation data, are described in Preliminary Design Report, Appendix D - Geotechnical Assessment Report, Chapter 10,

Rock Classification sandstone/mudstone/shale/claystone

Recommended Concrete/Bedrock Interface	EL. 1207 or lower	
Bedrock Unit Weight	25.6 kN/m^3	
Bedrock Friction Angle (Rock/Rock Interface) (φ)	26 Deg.	
Concrete/Rock Interface Friction Angle (φ)	26 Deg.	
Cross Bed Friction Angle (φ) – Passive Wedge	24 Deg.	
Ultimate Bearing Capacity (σ_{ult})	1915 kPa	
Allowable Bearing Capacity – Usual	1270 kPa	(σ_{ult}/1.5 $_{SF}$)
Allowable Bearing Capacity – Unusual	1470 kPa	(σ_{ult}/1.3 $_{SF}$)
Allowable Bearing Capacity – Extreme	1740 kPa	(σ_{ult}/1.1 $_{SF}$)

Cohesion: In accordance with CDA Guidelines Technical Bulletin No. 7 (Geotechnical) and Technical Bulletin No. 8 (Structural), cohesion was not included in the sliding stability analysis, and acceptance criteria is based on sliding factors for friction only resistance.

3.3 HYDROTECHNICAL PARAMETERS

Performance of the Diversion Structure and Diversion Channel was assessed using numerical and physical modeling. Hydraulic calculations and detailed modeling used in the design of individual hydraulic structures and other components are presented in the Preliminary Design Report, Appendices C and F. The various operating scenarios to be assessed for the Diversion Inlet were based on an Extreme Dam Hazard Classification with the separation between the Usual and Unusual Conditions being the 100-year flood and the 1000-year frequency flood dividing the Unusual and Extreme conditions. Table 1 provides a summary of the hydrotechnical parameters for selected operating scenarios used in the design and stability analyses of the Diversion Inlet.

Table 1. Diversion Inlet Hydrotechnical Parameters

Operating Scenario	Diversion Inlet Discharge (m^3/s)	Headwater Elevation (m)	Tailwater Elevation (m)
Usual Condition			
Normal Operation (No Diversion) *160 m^3/s inflow*	0	1212.1	1207.5 (basin floor)
Diversion Operation *100-Year Flood*	600	1215.8	1213.1
Unusual Condition			
Diversion Operation *2013 Flood*	600	1215.8	1213.1
No Diversion *2013 Flood*	0	1216.2	1207.5 (basin floor)
Emergency Closure No Diversion *1000-Year Flood*	0	1217.0	1207.5 (basin floor)
Maintenance *100-Year Flood*	272 (one bay)	1215.8	1211.0
Extreme - Flood			
PMF without Diversion	0	1217.8	1207.5 (basin floor)
PMF with Uncontrolled Diversion	872	1216.6	1214.4
Extreme – Seismic (Post-Seismic Condition)			
EDGM – Normal Operation *160 m^3/s inflow*	0	1212.1	1207.5 (basin floor)
EDGM – Diversion Operation *100-Year Flood*	600	1215.8	1213.1

3.4 CLIMATE DATA

3.4.1 Snow

Snow Load data for this project was obtained from Ontario Climate Centre – Environment Canada.

- Ground snow load, snow component (S_s) =1.7 kPa
- Ground snow load, rain component (S_r) =0.1 kPa
- Snow load, Importance factor (I_s) =1.25

3.4.2 Frost Considerations

Frost depth was determined in accordance with ABC and is shown in PDR, Appendix D - Geotechnical Assessment Report.

- Minimum design frost depth of 2.0 m
- Non-frost susceptible backfill - Gravel and clean sands

3.4.3 Temperature Variations

Monthly temperature data for use in the evaluation was obtained from the Calgary International Airport records, which is considered representative of typical temperature ranges at project site.

3.4.4 Wind

A wind load of 0.48 kPa was determined for use at the site based on the Alberta Building Code.

4.0 CONSTRUCTION MATERIALS

4.1 CONCRETE AND CONCRETE ACCESSORIES

- **Structural Concrete – Class A1**
  30 MPa @ 28 days, (AT Civil Works Specifications)
  General use reinforced concrete where thermal control and volume change are not a concern.

- **Structural Concrete – Class B1**
  30 MPa @ 90 days, (AT Civil Works Specifications)
  General use reinforced concrete where thermal control and volume change need to be considered (typically thickness > 600 mm)

- **High Performance Concrete – Class HPC**
  45 MPa @ 28 days (AT Bridge Construction Specifications)
  Reinforced concrete elements needing high strength, durability or in corrosive environment. Typical elements include precast concrete and bridge parapets.

- **Mass Concrete – Class M**
  20 MPa @ 90 days, 30 MPa @ 180 days (New mixture to be specified)
  Unreinforced concrete for monoliths, slabs, piers and retaining walls where thermal control and volume change need to be considered (typically thickness >1500 mm).

- **Foundation Concrete - Class F**
  15 MPa @ 28 days, (AT Civil Works Specifications)
  For use in foundation preparation such as mud mats and low strength fill.

- **Grout**
  Premixed structural non-shrink grout for equipment bases.

- **Preformed Expansion Joint Filler**
  ASTM D1752, Type I, Closed-cell sponge rubber.

- **Bond Breaker**
  Bituminous paint conforming to CGSB 37.2-88.

- **Waterstops**
  PVC ribbed profile with minimum rated hydrostatic head of 373 KPa based on joint type.

4.2 METALS

- **Steel Reinforcement** - CAN/CSA-G30.18, Grade 400W deformed bars
- **Structural Steel** - CSA-G40.21, Grade 300W or 350W
- **Stainless Steel** - ASTM A276
- **Miscellaneous Metals** (stairs, ladders, handrails) - Galvanized steel
- **Grating** - Galvanized steel – serrated bar grating

4.3 EARTHWORK MATERIALS

The Diversion Inlet structure will be constructed on a rock foundation. Soil backfill parameters are based on terminology in AT's Civil Works Master Specification 02330 – Earthwork Materials and described in the PDR, Appendix D - Geotechnical Assessment Report.

Design values for specified material include:

Impervious Fill

Unit Weight (-)	21 kN/m^3
Internal Friction Angle (-)	18 deg

Granular Fill

Unit Weight (-)	21 kN/m^3
Internal Friction Angle (-)	34 deg

Glacial Till

Unit Weight (-)	20 kN/m^3
Internal Friction Angle (-)	27 deg

Rock Fill

Unit Weight (-)	22 kN/m^3
Internal Friction Angle (-)	20 deg

Siltation (Equivalent Fluid)

Unit Weight Vertical (-)	19 kN/m^3
Unit Weight Horizontal (-)	13 kN/m^3

5.0 STRUCTURAL ANALYSIS APPROACH

For the purposes of analysis, the Diversion Structures was divided into individual monoliths based on geometry, size, joint location, and loading considerations. The monoliths were analyzed as either concrete gravity sections (gate structures, piers, and stilling basin) or retaining walls (wing walls, training walls, and abutments). Each monolith is evaluated for global stability, strength, and serviceability.

Global stability was assessed using the rigid body analysis method and application of unfactored loads. This method uses the summation of forces applied to the monolith to determine resultant location, foundation bearing pressures, and sliding resistance along identified potential failure plane(s). Analysis methodology and acceptance criteria are described in further detail in later sections of this report.

Reinforced concrete design of members, except for bridge components, was performed according to Design of Concrete Structures, CSA A23.3-14 with the additional requirements of the CSA's SEED Document – *Structural Design of Wastewater Treatment Plants-2018* for revisions addressing service load conditions, water tightness, shrinkage and temperature reinforcement, and crack control. The Seed Document contains references to ACI 350M-06 for modifying CSA A23.3-14. For bridge components, such as the Diversion Inlet access bridge, reinforced concrete design was performed according to Alberta Transportation Bridge Design Criteria supplemented by the Canadian Highway Bridge Design Code.

Finite Element Models (FEMs) were used to validate manual calculations, identify potential stress concentrations, and assess additional serviceability concerns such as localized deflection, need for thermal stress relief, and stress redistribution not captured in manual calculations. Mitigation of alkali-aggregate reaction (AAR) potential and thermal crack control for mass concrete placements were addressed through design detailing and material specifications.

5.1 DESIGN TOOLS AND SOFTWARE

Microsoft Excel - 2010 - version: 14.0.7166.5000

Mathcad 15.0 - 2013 - version: MC15_M030_20131216

SAP2000 v21 version: 21.0.2

Revit 2019.2.1 version/build: 19.2.10.7

6.0 LOADS

6.1 DEAD LOADS (D)

Permanent loads on the structure include concrete structure weight, fixed equipment, backfill, and water. Unit weights for principal materials are included in Table 2.

Table 2. Dead Load Unit Weights

Material	Unit Weight	Source
Water	9.81 kN/m^3	CSA S6-14, Table 3.4
Concrete	23.5 kN/m^3	AT WCS Design Guide 4.2
Steel	77.0 kN/m^3	AT WCS Design Guide 4.2
Backfill – Glacial Till	20.0 kN/m^3 (moist unit weight)	4.3 - Earthwork Materials
"	22.0 kN/m^3 (saturated unit weight)	4.3 - Earthwork Materials
"	12.2 kN/m^3 (buoyant unit weight)	4.3 - Earthwork Materials

6.2 HYDROSTATIC LOADS (H)

Both horizontal and vertical components of water load were used based on water surface elevation for the load condition considered. Upstream and downstream water surface elevations are described in Hydrotechnical Parameters, Section 3.3. The water surface elevations were considered to be hydrostatic pressures without kinematic effects. Headwater was considered the water surface elevation at the upstream face of the structure. Tailwater was either maximum tailwater elevation indicated on tailwater rating curves, or a reduced tailwater elevation to account for hydraulic jump depending on load condition considered and which condition produced a more adverse effect on the structure.

6.3 UPLIFT PRESSURE (U)

The following uplift pressures were considered for analysis of sliding, floatation, bearing capacities and resultant location. For the overflow weir monoliths and stilling basins, uplift was assumed to vary from 100 percent of headwater pressure at upstream edge of slab to 100 percent of tailwater pressure at downstream edge of slab applied over 100 percent of the base. For retaining walls, the uplift was assumed to vary from 100 percent of water pressure at face of the foundation heel to 100 percent of water pressure at face of the foundation toe applied over 100% of the base.

For analysis of overturning capacity and floatation for gravity structures, stilling basins and retaining walls, uplift pressure was considered to vary proportionally along the length of concrete structure/rock contact surface. For sliding and bearing capacity analysis of gravity structures and retaining walls, uplift was assumed to vary along the length of the linear sliding failure plane under consideration (horizontal concrete/rock contact, or through rock if structure contact with rock was keyed or sloped)

The foundation interface was assumed to have zero tensile capacity. For bases where stability calculations indicated bearing pressures less than zero, the foundation interface was assumed to crack, and 100 percent of the hydrostatic pressure was applied over the area of the cracked foundation, then vary linearly to 100 percent of tailwater pressure. For seismic evaluations, uplift loading remained unchanged from the pre-earthquake condition to the post-earthquake evaluation unless seismic loading resulted in a cracked foundation, in which case full hydrostatic pressure was applied to the entire area of the cracked foundation during the post-earthquake evaluation.

6.3.1 Seepage Reduction Measures

The underlying rock was identified as highly weathered and fractured. To minimize uplift potential, seepage reduction measures included using an upstream apron, cut-off keys, and drainage piping below the stilling basin slab that discharges to the downstream Diversion Channel.

Where seepage reduction measures were provided, such as drains, a reduced uplift pressure was used for stability analyses for the Usual Load Condition only. For stability analyses of other load conditions, the seepage reduction measures were conservatively neglected.

6.4 EARTH PRESSURE (E)

Soil loads include both vertical and horizontal forces due to backfill, sediment, and siltation. Physical Model Sedimentation Studies indicate there is little accumulation of sediment adjacent to the structures so loads associated with Sediment/Siltation are excluded from the structural analysis.

Vertical force associated with soil mass above the structure is included with Dead Load based on vertical projection of footing or structure below the soil. Soil mass was based on moist unit weight for material above the waterline and buoyant unit weight for material below the waterline. Vertical force associated with water above the structure are calculated separate from the soil mass.

Horizontal force associate with soil were based on at-rest condition represented by the empirical relationship:

$K_o = 1 - \sin\theta$ where: K_o = At-rest lateral pressure coefficient(*)
θ = Soil friction angle

**In accordance with EM 1110-2-2100 and EM 1110-2-2502 to use At-Rest Coefficient (K_o)*

6.5 LIVE LOADS (V)

The principal loads on the Diversion Inlet Structure include Vehicle Load on the access deck between gate piers, Vehicle or Heavy Equipment Loads adjacent to retaining walls, and Hoist/Equipment Loads associated with gate operation. Live Loads described in this section were considered transitory loads.

Transitory loads were used for strength design of individual structure elements but were not included in stability analyses. Parameters below are general guidance however; bridge elements will be designed in accordance with AT Bridge Design Criteria and CSA S-6.

Table 3. Vehicle, Hoist, and Surcharge Live Loads

Description	Live Load	Source
Vehicle (Vertical Application)	CL-625	CSA-S6-14, Section 3.8.3
Vehicle (Horizontal Application)	CL-625	CSA-S6-14, Section 3.8.3
Dynamic Load Allowance (Increase)	0.5	CSA-S6-14, Section 3.8.4.5.3
Traffic Barrier Load (TL-2 Performance)	50 kN Transverse, 20 kN Longitudinal, 10 kN Vertical	CSA-S6-14 Section 12
Vehicle Guardrails	22 kN @ 500 mm above grade	2014 ABC, 4.1.5.15
Bracing Force (Equivalent Static Force)	180 kN applied at deck surface	Minimum CL-W loading x 1.25
Crane Surcharge	CL-800	CSA-S6-14 & AT Bridge Provisions
Gate Hoist & Equipment	Refer to Appendix E - Structural for DI, SS and LLOW	Appendices E.1, E.2 and E.5
Heavy Equipment Surcharge	15.0 kPa (Equivalent 0.75 m soil)	AT WCS, Section 4.9

Heavy Equipment Surcharge was applied to retaining wall design as a separate load condition to account for future modifications such as building additions, long-term material storage, or top-of-wall modifications. This load is not applied simultaneously with Vehicle Loads.

6.6 HYDRODYNAMIC LOADS (HD)

Hydrodynamic loads include wave action, sub-atmospheric pressure at the fixed crest, and hydraulic dissipater forces. For the Diversion Inlet, these forces have been excluded from stability analysis since they are considered insignificant or of a localized nature.

- Wave action is not included due to the short-term duration and relatively short fetch.
- Sub-atmospheric pressure is not included since there is insufficient head to develop sub-atmospheric pressure on the fixed crest.
- Hydraulic dissipater forces are localized forces addressed in the hydraulic design of stilling basin and chute blocks.

6.7 DEBRIS AND IMPACT LOADS (I_M)

Impact loads associated with debris flows were based on geometry of the Diversion Structure conservatively assuming the Debris Deflection Barrier was not in place. Debris impact and drift loads were derived from 2D hydraulic modelling of the Diversion Inlet based on various flood events as described in PDR, Appendix C – Hydraulics.

6.8 ICE LOADS (I)

Three types of ice load to consider for the Diversion Inlet structure design include Static Ice Load (I_s), Dynamic Ice Loading (I_d), and Ice Accretion Load (I_v).

Static Ice Load (I_s) is a result of water surface freezing with application of horizontal load as an ice sheet expands and confinement increases. Static Ice Loading has the potential to occur at low flow conditions, particularly within the stilling basin. Static ice loading is applied in Usual Load Cases that address winter operating conditions.

Dynamic Ice Loading (I_d) is a result of moving ice floe impacting the structure. Dynamic Ice Loading was not considered as a design load case because the Diversion Structures do not have a permanent pool.

Ice Accretion Load (I_v) occurs when ice bonds to the structure and must be broken as water level rises. Ice Accretion Load associated with water level rise was not considered for the Diversion Structures due to small order of magnitude relative to hydrostatic loading and low probability of occurring simultaneous with spring and summer flooding.

Frost Heave. Vertical ice loading associated with "frost heave" is a realistic consideration. The structures are normally in a dewatered or low-water state with freeze/thaw action tending to open rock joints and concrete/rock interface and subject the structure to increased uplift potential. To minimize frost heave loading potential and remove this condition from the analysis, foundation interfaces will be located below the identified frost depth of 2.0 m for this site and drainage provided to reduce the formation of ice in the foundation.

Table 4. Ice Loads

Ice Condition	Load	Source
Static Ice (applied to structure)	150 kN/m @ 0.3 m below WS	AT WCS Design Guide 4.5.1.1
Static Ice (applied to gates)	75 kN/m @ 0.3 m below WS	AT WCS Design Guide 4.5.1.1
Ice Accretion	Per requirements of ABC for affected structures	ABC

6.9 SEISMIC – EARTHQUAKE LOADS (Q)

The seismic classification for the Diversion Inlet is based on Stantec's *Seismic Hazard Assessment - Springbank Off-Stream Dam and Reservoir Report* dated November 28, 2016. Since the hazard classification for this structure is Extreme (Diversion Channel and Off-stream Storage Dam) the seismic parameters are based on an Earthquake Design Ground Motion (EDGM) with an Annual Exceedance Probability (AEP) of 1/10,000 resulting in Peak Ground Acceleration (PGA) of 0.26 g for horizontal application and PGA of 0.15 for vertical application.

This project site is situated in an area of low to moderate seismic activity. Consequently, CDA Guidelines, Section 6.5 allow for the seismic stability analysis of concrete gravity structures to be completed using a pseudo-static approach (coefficient method). This method applies a seismic force to a rigid body with the objective of determining sliding and overturning response of the structure. Since the pseudo-static method does not recognize the oscillatory nature of seismic loads, accepted practice is to perform the stability calculations using sustained acceleration values equivalent to 2/3 of the peak acceleration values.

When performing concrete stress analyses, the objective is to determine the tensile crack length induced by the inertia forces applied to the structure, so peak acceleration is used to calculate seismic coefficients. This approach assumes an instantaneous acceleration spike can induce cracking but is not sustained long enough to develop significant displacement along the crack plane. If no significant displacement occurs, the dynamic stability is maintained.

6.9.1 Seismic Effects on Concrete Mass

The horizontal force required to accelerate the concrete mass is calculated as:

$Q_h = k_h \times W$ where:

Q_h = Horizontal seismic load (kN)
k_h = Horizontal seismic coefficient
W = Structure mass (kg)
PGA = Peak ground acceleration= 0.26g

For Stability Analysis (Table 5): k_h = 2/3 x 0.26 = 0.17
For Member Analysis (Table 6): k_h = 1.0 x 0.26 = 0.26

The vertical force required to accelerate the concrete mass is calculated as:

$Q_v = k_v \times W$ where:

Q_v = Vertical seismic load (kN)
k_v = Horizontal seismic coefficient = 0.56*k_h
W = Structure mass (kg)

For Stability Analysis (Table 5): k_v = 2/3 x (0.56*k_h) = 0.10
For Member Analysis (Table 6): k_v = 1.0 x (0.56*k_h) = 0.15

Since an earthquake produces oscillating forces, the horizontal PGA and vertical PGA cannot occur at the same time. To account for this in the stability calculations, three separate combinations of vertical and horizontal seismic combinations were considered, but only the maximum value was reported. The three combinations of vertical and horizontal seismic load are as follows:

Table 5. Stability Analysis – Seismic Coefficients

Seismic Combination	Horizontal	Vertical
100% Horiz., No Vert.	1.0*k_h = 0.17	-
100% Horiz., 30% Vert.	1.0*k_h = 0.17	0.3*k_v = 0.03
30% Horiz., 100% Vert.	0.3*k_h = 0.05	1.0*k_v = 0.10

Table 6. Stress Analysis – Seismic Coefficients

Seismic Combination	Horizontal	Vertical
100% Horiz., No Vert.	1.0*k_h = 0.26	-
100% Horiz., 30% Vert Horiz.	1.0*k_h = 0.26	0.3*k_v = 0.05
30% Horiz., 100% Vert.	0.3*k_h = 0.08	1.0*k_v = 0.15

6.9.2 Seismic Effects on Water (H_E)

Using a pseudo-static method, hydrodynamic effects on water were approximated by using the Westergaard method to calculate the seismic water force (H_E). The calculated hydrodynamic force is additive to the hydrostatic water pressure force. The distribution is parabolic with the line of action for the force H_E at 0.4h above the base of the water column. Detailed explanation of method can be found in Section 4-7.e, EM 1110-2-2100.

$$H_E = \left(\frac{7}{12}\right) * k_{h/v} * \gamma_w * h^2$$

where:
H_E = Seismic water force (kN)
$k_{h/v}$ = horizontal/vertical seismic coefficient
γ_w= unit weight of water (kN/m^3)
h = depth of water (m)

Note: The Westergaard method assumes an infinite waterbody length in the horizontal direction, which is a reasonable simplifying assumption for most conditions. For the unique case where seismic acceleration of water in the cross-stream direction is considered to evaluate divider walls and training walls, the Westergaard method will conservatively overestimate the hydrodynamic force.

6.9.3 Seismic Effect on Soils

Dynamic soil pressures and associated forces were analyzed assuming non-yielding backfills and an elastic response using the Wood's method. As referenced in Section 5-5.a.1, EM 1110-2-2100, and verified by project specific calculation (Appendix D), this method can be expected to have dynamic soil pressures greater than those predicted by the Mononobe-Okabe method for yielding backfills.

The use of Wood's method is considered reasonable and was used for analysis of gate bays that have relatively short backfills (<4 m) consisting primarily of rock fill for erosion protection. The use of Wood's method may be overly conservative for taller retaining walls with height ranging above 4 m with backfill consisting of granular fills and/or glacial till materials.

For conditions where seismic load cases control the wall design, dynamic soil pressures and associated forces were analyzed assuming yielding backfills and an elastic response using the Mononobe-Okabe method. This method uses active soil pressure during seismic conditions to assess stability.

Mononobe-Okabe Method for Yielding Backfill: This method assumes a wedge of soil bounded by the structure and an assumed soil failure plane moves as a rigid body with the same horizontal acceleration. The driving (active) wedge force is calculated based on a combined static and dynamic pressure coefficient (K_{AE}) but must then be divided into static and dynamic components for cases where the water table is above the backfill. Detailed explanation of this method can be found in Appendix G, EM 1110-2-2100.

$$P_{PE} = \frac{1}{2} K_{PE} \gamma (1 - k_v) h^2 \tag{G-3}$$

$$K_{PE} = \frac{\cos^2(\phi - \psi - \theta)}{\cos\psi \cos^2\theta \cos(\psi - \theta + \delta)\left[1 - \sqrt{\frac{\sin(\phi + \delta)\sin(\phi - \psi + \beta)}{\cos(\beta - \theta)\cos(\psi - \theta + \delta)}}\right]^2} \tag{G-4}$$

γ = unit weight of soil
k_v = vertical acceleration in g's
h = height of structure
ϕ = internal friction angle of soil
$\psi = \tan\left(\frac{k_h}{1-k_v}\right)$ = seismic inertia angle
k_h = horizontal acceleration in g's
θ = inclination of interface with respect to vertical (this definition of θ is different from θ in Coulomb's equations)
δ = soil-structure friction angle
β = inclination of soil surface (upward slopes away from the structure are positive)

(c) Simplifying Conditions. For the usual case where k_v, δ, and θ are taken to be zero, the equations reduce to:

$$K_{AE} = \frac{\cos^2(\phi - \psi)}{\cos^2\psi\left[1 + \sqrt{\frac{\sin\phi \sin(\phi - \psi - \beta)}{\cos\beta \cos\psi}}\right]^2} \tag{G-5}$$

6.10 CLIMATIC CONDITIONS

6.10.1 Snow Loads (S)

Snow loads were considered insignificant compared to hydrostatic loads and were not considered for stability of the Diversion Inlet structures. Snow loads were included in load combinations for component design of the head wall, breast wall, bridge deck, hoist support and access platforms. Snow Load data is listed in Section 3.4.1 above.

6.10.2 Thermal Loads (T)

Temperature changes will influence the overflow weir monoliths and retaining walls. Thermal effects will be evaluated during Final Design to determine joint condition, concrete mixture, monolith sizing, and lift heights for concrete structures.

6.10.3 Wind (W)

Wind loads were considered insignificant compared to hydrostatic loads and were not considered for stability of the Diversion Inlet structure. Wind loads were included in load combinations for component design of the head wall, breast wall, bridge deck, gate hoist bridge and access platforms. Additionally, wind loads during construction (prior to placement of backfill), will be included for retaining walls and divider pier components. Wind Load data is listed in Section 3.4.4 above.

7.0 STABILITY ANALYSIS

Representative monoliths and retaining walls were analyzed for load conditions applicable to the Diversion Inlet as identified in Section 7.3. Analysis methodology is as follows:

7.1 METHODOLOGY

7.1.1 Overturning and Bearing Stress

The Rigid Body Method (conventional gravity method) was used for the analysis of overturning and bearing stress criteria. Overturning was evaluated as a percentage of base that remains in compression and not a safety factor. This method is outlined in Section 7.2 of CDA Technical Bulletin No. 9 and further described in USACE EM 1110-2-2100. It uses a vector summation of all forces, including uplift, acting on the monolith to determine the vector resultant force (V), resultant force eccentricity (e) within the base, and moment (Ve/S) based on an elastic and homogeneous rectangular beam analogy. Stresses were calculated as indicated below and stability was assured by maintaining the resultant force eccentricity within acceptance criteria limits for various loading conditions.

$$\sigma = \frac{V}{A} \pm \frac{Ve}{S}$$

Where: σ = Applied bearing pressure at each end of base (kN/m^2)
V = Summation of forces normal to base (kN)
A = Base area in compression (m^2)
e = Eccentricity of normal load about centroid of base in compression (m)
S = Section modulus of base area in compression (m^3)

7.1.2 Sliding

The sliding factor of safety was calculated for each load case using the limit equilibrium method as outlined in Section 7.2 of CDA Technical Bulletin No. 9. This method reduces to the equation shown below for a single wedge system with a horizontal sliding plane, along the concrete/rock interface (CRI) or through rock/rock failure plane as identified for each hydraulic structure. For inclined sliding planes projecting from the base of shear key to bottom base slab at the toe, vertical and horizontal forces are resolved into components normal and parallel to the sliding plane. Rock mass between the inclined plane and structure base is included in the dead load summation (EM 1110-2-2100). For this project, cohesion was conservatively assumed to be zero and sliding acceptance criteria for sliding were based only friction angle.

$$SSF = \frac{(V tan\varphi + c\ A)}{H}$$

Where: SSF = Sliding Safety Factor
V = Summation of vertical loads including uplift (kN)
$tan\ \varphi$ = Coefficient along sliding plane being considered
c = Cohesion at concrete/rock or rock/rock interface (assumed as 0) (kN/m^3)
A = Base area in compression (m^2)
H = Summation of horizontal forces (kN)

7.1.3 Floatation

The floatation factor of safety was determined for components of the project such as stilling basins and apron slabs as outlined in Section 8.5, AT WCS. The factor of safety against floatation is defined as ratio of resisting gravity force to driving uplift force. The possible resistance due to friction between adjacent structures or between structure and backfill was neglected unless shear provisions were provided.

$$FSF = \frac{\Sigma N}{\Sigma U}$$

Where: FSF = Factor of Safety against Floatation
ΣN = Summation of normal forces
ΣU = Summation of uplift forces

7.2 ACCEPTANCE CRITERIA

The following acceptance criteria are based on AT WCS Chapter 8, CDA Table 6-4, and CDA Technical Bulletin No. 8, Section 6.0. The load cases to be evaluated are divided into five categories as listed in Table 5.

Usual Condition: Those conditions under which the structure is intended to serve during normal operations and further defined as a condition that has a high likelihood of occurring within the design life of the structure. For the Diversion Inlet, this includes flood events up to the 100-year frequency flood for the extreme dam hazard classification.

Unusual Condition: Those conditions that occur infrequently and may stress the structure more, under certain aspects, than normal conditions and may occur within the design life of the structure. Unusual load conditions include construction conditions, maintenance conditions, flood events between the 100-year and 1000-year frequency, infrequent earthquake events other than the MDE, and plugged drain conditions for Usual Load Cases.

Extreme – Flood: Extreme Load Conditions have a very remote likelihood of occurring with the design life of the structure. For the SR1 project, it is defined as those floods that occur from the 1000-year frequency event up to the structure's IDF. For the Diversion Inlet, the PMF is considered the IDF with the Diversion Inlet gates open or closed.

Extreme – Earthquake: For the SR1 project, the Extreme - Earthquake load condition to be assessed is the MDE as it has a very remote likelihood of occurring with the design life of the structure. The MDE is applied to the Usual Condition load cases. The Extreme – Earthquake condition is used to establish Post-Earthquake condition of the hydraulic structure. Thus, there are no stability acceptance criteria for this condition.

Post-Earthquake: The Post-Earthquake condition assesses the stability of the hydraulic structure following the applied seismic event based on earthquake induced cracking at the foundation/ structural interface and within the structure so that it is still capable of resisting the Usual Loading.

Table 7. Acceptance Criteria for Hydraulic Structures

Loading Combination	Position of Resultant Force (Percent of Base in Compression)[1]	Normal Compression Stress[2]	Sliding Safety Factor (Friction Only)	Floatation Safety Factor
Usual	Middle third of the base: 100% compression	<0.3 x f_c	≥1.5	≥1.5
Unusual	Middle third of the base: 100% compression	<0.5 x f_c	≥1.3	≥1.3
Extreme Flood	Within middle half of the base, and all other acceptance criteria must be met	<0.5 x f_c	≥1.1	≥1.1
Extreme Earthquake	Within the base, except where an instantaneous occurrence of resultant outside the base may be acceptable	<0.9 x f_c	Note [3]	
Post-Earthquake	Within middle half of the base	<0.5 x f_c	≥1.0	≥1.1

[1] Foundation bearing stress is compared to allowable stress determined from Geotechnical Investigation

[2] Where f_c = compressive strength of concrete

[3] The earthquake load case is used to establish post-earthquake condition of the structure

7.3 LOAD CONDITIONS

Load conditions varied for various Diversion Inlet structures based on configuration and location of applied load. The following sections summarize load conditions for various structures.

7.3.1 Diversion Inlet – Gate Structure

Table 8. Gate Structure – Load Conditions

Usual Load Cases		
U1	Usual Condition – Normal Operation Prior to Initiation of Diversion (Winter) Design inflow 160 m³/s with DI gates closed (no diversion) + Ice Accretion Headwater: EL 1212.1 Tailwater: EL 1207.5 (stilling basin top of concrete)	D+H+E+U+I
U2	Usual Condition – Diversion Operation – 100 Year Frequency Flood Inflow 765 m³/s with DI gates open diverting 600 m³/s + Debris Impact Headwater: EL 1215.8 Tailwater: EL 1213.1 (at 600 m³/s)	D+H+E+U+I
Unusual Load Cases		
UN1	Unusual Condition – Diversion Operation – 2013 Design Flood Inflow 1240 m³/s with DI gates open diverting 600 m³/s + Debris Impact Headwater: EL 1215.8 Tailwater: EL 1213.1 (at 600 m³/s)	D+H+E+U+I
UN2	Unusual Condition – No Diversion – 2013 Design Flood Inflow 1240 m³/s with DI gates closed (no diversion) + Debris Impact Headwater: EL 1216.2 Tailwater: EL 1207.5 (stilling basin top of concrete)	D+H+E+U
UN3	Unusual Condition – Emergency Closure – 1000 Year Frequency Flood Inflow 1930 m³/s with DI gates closed (no diversion) Headwater: EL 1217.0 Tailwater: EL 1207.5 (stilling basin top of concrete)	D+H+E+U
UN4	Unusual Condition – Maintenance / single DI gate bay dewatered 100 Year Frequency Flood – Inflow 765 m³/s diversion of 275 m³/s though one gate Headwater: EL 1215.8 Tailwater: EL 1211.0	D+H+E+U
Extreme - Flood		
E1	Extreme Condition – PMF Inflow 2770 m³/s with DI gates closed (no diversion) Headwater: EL 1217.8 Tailwater: EL 1207.5 (stilling basin top of concrete)	D+H+E+U
E2	Extreme Condition – PMF with DI gates remaining open Inflow 2770 m³/s with diversion of +/-870 m³/s through two gates Headwater: EL 1216.6 Tailwater: EL 1214.1	D+H+E+U+I
Extreme – Earthquake used to develop Post-Seismic Condition		
Post-Seismic		
E3*	Extreme Condition – EDGM applied to U1 Load Case If E3 loading results in cracked base modify structure to prevent cracked base. Headwater: EL 1212.1 Tailwater: EL 1207.5 (stilling basin top of concrete)	Load Case$_{U1}$ + Q
E4*	Extreme Condition – EDGM applied to U2 Load Case If E4 loading results in cracked base modify structure to prevent cracked base. Headwater: EL 1215.8 Tailwater: EL 1213.1 (at 600 m³/s)	Load Case$_{U2}$ + Q
Notes		
D	Dead Load: Includes weight of concrete (C), water (H), and gates (G)	
H	Hydrostatic Loads: See each load case for various Headwater and Tailwater conditions.	
E	Earth / Sediment / Siltation Loads: Include horizontal and vertical loads	
U	Uplift Load: Varies linearly from Headwater to Tailwater pressure across plane of analysis	
I	Static Ice Load <u>or</u> Impact Load: Apply one or the other depending on load case	
Q	Seismic Load: Design Earthquake load * Seismic evaluation to consider simultaneous vertical and horizontal for three combinations.	

7.3.2 Diversion Inlet - Stilling Basins

Table 9. Stilling Basin – Load Conditions

F1 Usual (U2)	Usual Condition – Diversion Flow 600 m³/s Water Weight based on: TWEL = 1213.1 Linear Uplift based on: HWEL = 1215.8, TWEL = 1213.1 and drains effective	(D+H) / U
F2 Unusual (UN4)	Unusual Condition – Construction /Maintenance/ single gate bay dewatered Water Weight based on: Not Included for this condition Linear Uplift based on: HWEL = 1215.8 , TWEL = 1211.0 and drains effective (275 m³/s one gate diversion)	D / U
F3 - Extreme	Extreme Condition – 2013 Design Flood with Drain Failure and DI Gates Closed Water Weight based on: Not Included for this condition Linear Uplift based on: HWEL = 1215.8 (at upstream end of gate block) TWEL = 1207.5	D / U
Notes		
D	Dead Load: Includes concrete (C), water (H)	
H	Hydrostatic Loads: See each load case for various Headwater and Tailwater conditions.	
U	Uplift Load	

7.3.3 Diversion Inlet – Retaining Walls

Table 10. Retaining Walls – Load Conditions

Usual Load Cases		
U1	Usual Condition – At-Rest Soil Loading Groundwater at 0.5 m above drain centerline	D+H+U+E
Unusual Load Cases		
UN1	Unusual Condition – At-Rest Soil Loading + Equipment Surcharge Groundwater at 0.5 m above drain centerline	D+H+U+E+L
UN2	Unusual Condition – At-Rest Soil Loading – Ineffective Drain Groundwater and uplift at 2013 Design Flood HWEL or TWEL depending on location of wall Section being analyzed.	D+H+U+E
Seismic		
E1	Extreme Condition – Seismic Load Groundwater at 0.5 m above drain centerline	D+H+U+E+Q
Notes		
D	Dead Load: Includes concrete (C), backfill (E),	
H	Hydrostatic Load: Groundwater 0.5 m above drain centerline, use buoyant weight of soil on heel.	
U	Uplift Load	
E	Earth / Backfill / Sediment / Siltation: Include horizontal and vertical loads	
I	Static Ice Load <u>or</u> Impact Load: Apply one or the other depending on load case	
L	Live Loads: Equipment Surcharge	
Q	Seismic Load: Design Earthquake load * Seismic evaluation to consider simultaneous vertical and horizontal for three combinations.	

7.4 SUMMARY OF STABILITY ANALYSES

Stability analyses for the Diversion Inlet gate structures, stilling basins and retaining walls were performed in accordance with criteria and procedures outlined in the CDA Technical Bulletin No. 9, "Structural Considerations for Dam Safety", and the USACE EM 1110-2-2100 "Stability Analysis of Concrete Structures." Each section was evaluated for Usual, Unusual, Extreme, and Post-Seismic loading conditions representing potential conditions the structure will experience during its design life. Summaries of the stability calculation results are presented in the sections that follow. Refer to the Appendices for stability calculations and results.

7.4.1 Gate Structures

The Diversion Inlet Gate Structures were analyzed as two distinct monoliths encompassing, Gate Crest Blocks (DI-2A/2B & DI-4A/4B) and Center Pier Blocks (DI-3A/3B).

The Gate Crest Blocks consist of an apron slab at Elevation 1210.0 m, with a foundation key extending down to Elevation 1204.0 m. The apron slab is monolithic with the gate crest at Elevation 1211.5 m with underside of concrete at Elevation 1207.0 m. Downstream of the gate, the gate slab slopes down to the stilling basin at Elevation 1207.5 m. The minimum slab thickness of the block is 2 m, and the total block length is 24.2 m, including the apron slab. Downstream limit of the gate blocks is located at joint between gate bay and stilling basin. An upstream key is provided primarily for erosion protection. It was not considered effective for uplift reduction but was used to provide additional sliding resistance.

The Center Pier Blocks are supported on a foundation with the same geometry as the Gate Crest Blocks, but include a 4.0 m wide center pier extending to Elevation 1218.0 m. The Center Pier supports the head wall/breast wall and associated bridge deck, as well as the hoist bridge. The breast wall/head wall sections extend from Elevation 1215.5 m (underside of concrete) to Elevation 1219.0 m (top of bridge deck, not considering curb or guardrail). The Center Pier extends to support the hoist bridge at Elevation 1220.25 m. The analysis included loads from breast wall, head wall, access deck, and vertical lift gates. Gate load applied to the center pier includes ½ of gate span on either side of pier.

The stability analyses for the structures were performed using a Mathcad spreadsheet. Results of the analyses are summarized in Tables 11 and 12 and calculations are included in Appendix E.1-1.

Table 11. Gate Crest Blocks (DI-2A/2B & DI-4A/4B) – Stability Analysis Summary

Load Case	Headwater Elevation (m)	Tailwater Elevation (m)	Hydro-static Uplift Force (kN)	Floatation Safety Factor (FSF)		Sliding Safety Factor (SSF)		Foundation Bearing Stress		% Base in Compression
				Req	Calc	Req	Calc	Upstream (Heel) (kPa)	Downstream (Toe) (kPa)	
Usual Load Cases										
U1 Normal Operation	1212.1	1207.5	16523	1.5	1.7	1.5	6.1	93	72	100
U2 Diversion Operation *100 Yr. Flood*	1215.8	1213.1	23617	1.5	1.5	1.5	2.7	88	85	100
Unusual Load Cases										
UN1 Diversion Operation *2013 Flood*	1215.8	1213.1	23617	1.3	1.5	1.3	2.7	88	85	100
UN2 No Diversion *2013 Flood*	1216.2	1207.5	27247	1.3	1.3	1.3	1.7	95	45	100
UN3 No Diversion *1000 Yr. Flood*	1217.0	1207.5	23502	1.3	1.5	1.3	2.1	96	79	100
UN4 Construction/ Maintenance	1215.8	1211.0	23617	1.3	1.5	1.3	2.5	81	84	100
Extreme – Flood										
E1 PMF without Diversion	1217.8	1207.5	24642	1.1	1.5	1.1	1.9	92	80	100
E2 PMF with Diversion	1216.6	1214.1	25440	1.1	1.5	1.1	2.5	85	86	100
Extreme – Earthquake used to determine Post-Seismic Condition										
E3 EDGM applied to U1	1212.1	1207.5	16523	1.1	1.5 (E3.3)	1.0	1.33 (E3.2)	65 (E3.2)	103 (E3.1)	100
E4 EDGM applied to U2	1215.8	1213.1	23617	1.1	1.4 (E4.3)	1.0	1.01 (E4.2)	55 (E4.2)	120 (E4.1)	100

Notes:
1. See Appendix E.1 for definition of monolith description, analysis methodology, and stability calculations.
2. Analysis assumes inclined sliding plane, interface friction angle Φ = 26 degrees, and no cohesion.
3. Reported seismic results are controlling values for the three combinations of vertical and horizontal seismic load considered.

Table 12. Center Pier Monolith – Stability Analysis Summary

Load Case	Headwater Elevation (m)	Tailwater Elevation (m)	Uplift Force (kN)	Floatation Safety Factor (FSF) Req	Floatation Safety Factor (FSF) Calc	Sliding Safety Factor (SSF) Req	Sliding Safety Factor (SSF) Calc	Foundation Bearing Stress Upstream (Heel) (kPa)	Foundation Bearing Stress Downstream (Toe) (kPa)	% Base in Compression
Usual Load Cases										
U1 Normal Operation *160 m^3/s*	1212.1	1207.5	17900	1.5	3.0	1.5	37.9	155	160	100
U2 Diversion Operation *100 Yr. Flood*	1215.8	1213.1	25600	1.5	2.4	1.5	5.8	130	181	100
Unusual Load Cases										
UN1 Diversion Operation *2013 Flood*	1215.8	1213.1	19690	1.3	3.1	1.3	5.5	130	181	100
UN2 No Diversion *2013 Flood*	1216.2	1207.5	29518	1.3	2.0	1.3	3.4	135	143	100
UN3 No Diversion *1000 Yr. Flood*	1217.0	1207.5	25461	1.3	2.4	1.3	3.2	125	186	100
UN4 Construction/ Maintenance *100 Yr. Flood*	1215.8	1211.0	25585	1.3	2.3	1.3	8.2	169	136	100
Extreme – Flood										
E1 PMF without Diversion	1217.8	1207.5	26696	1.1	2.3	1.1	2.6	126	197	100
E2 PMF with Diversion	1216.6	1214.4	27560	1.1	2.2	1.1	4.6	131	184	100
Extreme – Earthquake used to determine Post-Seismic Condition										
E3 EDGM applied to U1	1212.1	1207.5	17900	1.1	2.7 (E3.3)	1.0	1.9 (E3.2)	90 (E3.2)	229 (E3.1)	100
E4 EDGM applied to U2	1215.8	1213.1	25600	1.1	2.2 (E4.3)	1.0	1.4 (E4.2)	61 (E4.2)	254 (E4.1)	100

Notes:

4. See Appendix E.1 for definition of monolith description, analysis methodology, and stability calculations.
5. Analysis assumes inclined sliding plane, interface friction angle Φ = 26 degrees, and no cohesion.
6. Reported seismic results are controlling values for the three combinations of vertical and horizontal seismic load considered.

7.4.2 Stilling Basins

The Diversion Inlet stilling basin consists of a 2.0 m thick by 18.0 m long concrete slab with 1.5 m high baffle piers and 1.0 m high end sill. The stilling basin slab is at Elevation 1207.5 m with underside of slab at Elevation 1205.5 m. A 1.0 m thick downstream cutoff wall extends to Elevation 1203.5 m. The upstream end of the slab supports the downstream end of the gate blocks and center pier block.

When the minimum Floatation Safety Factor was unable to be met through the dead weight of the structure, anchors were required to resist the uplift pressure. The required anchor force was calculated when anchors were needed to resist uplift pressure. The floatation analyses for the structure were performed using a Mathcad spreadsheet.

Floatation analysis results indicate a need for anchorage of the stilling basin into the foundation bedrock. The required anchor force is within the capability of conventional active or passive ground anchors. The controlling Load Case for the stilling basin anchors is F1 (Usual - Diversion Flow). Results of the analyses are summarized in Table 13 and calculations are included in Appendix E.1-2.

Table 13. Stilling Basin – Floatation Analysis Summary

Load Case	Headwater/ Tailwater Elevation (m)	Vertical Force Down (kN)	Uplift Force (kN)	Floatation Safety Factor (FSF)		Anchor Force Required
				Required	Calculated	
F1 Usual Diversion Flow	1215.8 / 1213.1	18322	17534	1.50	1.04	36.9
F2 Unusual Const./Dewatered	1215.8 / 1211.0	10152	11654	1.30	0.87	23.1
F3 Extreme Ineffective Drain	1215.8 / 1207.5	10152	7989	1.10	1.27	0

7.4.3 Gate Abutment and Retaining Walls

Retaining walls serve as the left and right gate abutment walls enclosing the gate and stilling basin blocks. The gate abutment walls consist of Blocks 1A through 1E (Right Abutment) and 5A through 5E (Left Abutment). Each retaining wall consists of a counterforted or cantilever wall with varying thickness and stepped top of footing elevation.

Blocks 1A/1B and 5A/5B retaining walls serve as the gate abutments and support the breast wall, head wall, access bridge deck, and the hoist bridge. The counterfort walls extend from top of footing Elevation 1208.5 m to top of wall Elevation 1219.0 m. The gate monoliths were detailed as half-width piers with fixed crest base mat. Only 50% of the gate load is applied to each wall.

Separate stability calculations in the direction of flow were not prepared since stability in the upstream-downstream direction is proportional to the Diversion Inlet center pier. The gate abutments were analyzed as counterfort retaining walls to resist embankment loads in the cross-stream direction with fixed crest base mat acting as the toe. FEM of these monoliths was used to consider simultaneous hydraulic and embankment loading to evaluate interaction in two orthogonal directions.

Blocks 1C/1D/1E and 5C/5D/5E retaining walls enclose the Diversion Inlet stilling basin and extend 27.2 m downstream of the stilling basin, providing transition to the Diversion Channel. The wall extends from top of footing Elevation 1207.5 m varying from top of wall Elevation 1219.0 m to 1209.5 m. The footing is 2.0 m thick with a stepped heel key varying from 4.0 m deep to 2.5 m deep. Block 1C/1D and 5C/5D retaining walls vary between 0.8 m thick and 0.5 m thick and have 0.5 m thick counterforts at 4.0 m spacing. The downstream retaining walls do not include counterforts at shorter sections . Due to the variation in geometry, Blocks 1D/1E and 5D/5E were analyzed at 3 sections (upstream end, midsection and downstream end). Blocks 1E and 5E were considered to be part of Blocks 1D and 5D (downstream end) during analysis.

The transition from the gated structure to the left abutment consists of Blocks 6 through 9 to form a water barrier. Block 6 retaining wall extends from top of footing Elevation 1210.0 m to top of wall Elevation 1219.0 m. The wall varies in thickness between 1.0 m to 0.5 m thick. The footing is 1.5 m thick, with a 2.5 m deep heel key. The wall has 0.5 m thick counterforts at 3.5 m spacing.

Four representative sections were identified to capture the range of retaining wall geometry and loading conditions for the overall structure. These representative sections are indicated on Figure 2 and described as follows.

- Section DI-6: Counterfort wall serving as part of left abutment. This section was selected to determine point at which counterforts are required due to increasing differential fill heights.
- Section DI-5B (DI-1B similar, opposite): Counterfort wall serving as the part of the Diversion Inlet Gate Structure training wall. Compared to other wall sections, this section has a thicker stem to carry access bridge and gate loads, reduce deflection, and thicker footing to match the gate bay concrete profile.
- Section DI-5C (DI-1C similar, opposite): Counterfort wall integral with stilling basin. This is one of the tallest wall sections and subjected to potential unbalance water load when Diversion Inlet gates are closed and diversion flow is terminated.

- Section DI-5D (DI-1D similar, opposite): Counterfort wall or cantilever wall serving as a downstream training wall and slope protection. This section was selected to determine wall height where counterforts were no longer required. Section DI-5D was analyzed at 3 sections to account for the geometric variability of the retaining wall. Section DI-1D and DI-5D (downstream), also known as DI-1E and DI-5E, respectively, were selected to determine wall height where counterforts are no longer required.

Section DI-7 shown in **Error! Reference source not found.** is a concrete core wall acting as a seepage barrier between head pond and Diversion Channel. It is surrounded and supported by embankment fill on both sides. Structural stability analysis of this wall was not needed due to the embankment support.

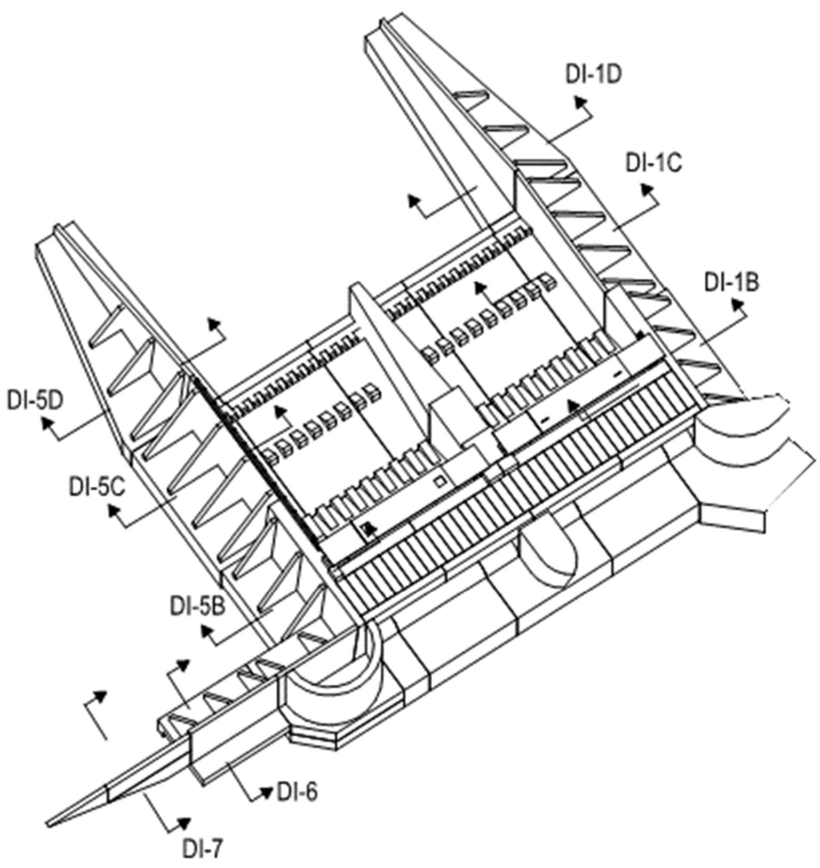


Figure 2. Diversion Inlet Retaining Wall Key Plan

Stability analyses were performed in accordance with the structural design criteria outlined previously using a Mathcad spreadsheet. Each of the four representative wall sections was evaluated for Usual, Unusual, and Extreme loading conditions representing the potential range of conditions the structure will be exposed to during its design life. In accordance with guidelines for hydraulic structures, at-rest soil pressures were used for all Load Case calculations except active soil pressures were used when considering Seismic Load Cases.

The principal factors affecting the structural design of the walls include significant driving force associated with high groundwater conditions; poor rock quality along the foundation interface; relatively weak material (glacial till) anticipated in the backfill zone of influence; and potential for significant uplift pressure when water levels recede faster than pore pressure can dissipate. Design calculations indicate that retaining walls are most sensitive to groundwater conditions, concrete shear capacity of stem walls, and sliding stability provided by foundation shear keys.

For all loading conditions considered, floatation factors of safety are above required, 100 percent of the base is in compression, and sliding factors of safety are above required. Stability results indicate that sliding stability is the primary concern due to the low friction angle at the concrete/rock interface and rock/rock bedding planes. To achieve stability results within the limits of acceptance criteria, a shear key at the heel of footing, and a wall drain system are required. The structural shear key ensures an inclined base sliding analysis is valid, and the wall drain system significantly reduces load associated with groundwater. The controlling load case is Load Case UN2 (high groundwater due to ineffective drain).

Results of analyses are summarized in Table 14 and calculations are included in Appendix E.1-3.

Table 14. Retaining Walls – Stability Analysis Summary

Load Case	Headwater (Heel) Elevation (m)	Tailwater (Toe) Elevation For Uplift (m)	Uplift Force (kN)	Floatation Safety Factor (FSF)		Sliding Safety Factor (SSF)		Foundation Bearing Stress		% Base in Compression
				Req	Calc	Req	Calc	Upstream (Heel) (kPa)	Downstream (Toe) (kPa)	
WALL BLOCK DI-6										
U1 Normal Operation	1213.1	1212.1	494	1.5	3.38	1.5	2.24	76	281	100
UN1 Equip. Surcharge	1213.1	1212.1	494	1.3	3.54	1.3	1.95	58	322	100
UN2 Ineffective Drain	1216.2	1216.2	811	1.3	2.1	1.3	1.34	26	279	100
E1 Seismic	1213.1	1212.1	494	1.1	3.05	1.0	1.78	48	276	100
WALL BLOCK DI-1B/DI-5B										
U1 Normal Operation	1212.0	1210.0	645	1.5	3.99	1.5	2.40	153	228	100
UN1 Equip. Surcharge	1212.0	1210.0	645	1.3	4.12	1.3	2.03	143	256	100
UN2 Ineffective Drain	1215.8	1215.8	1212	1.3	2.16	1.3	1.30	98	203	100
E1 Seismic	1212.0	1210.0	645	1.1	3.60	1.0	1.69	108	236	100

Table 14 Retaining Walls – Stability Analysis Summary (Continued)

Load Case	Headwater (Heel) Elevation (m)	Tailwater (Toe) Elevation For Uplift (m)	Uplift Force (kN)	Floatation Safety Factor (FSF)		Sliding Safety Factor (SSF)		Foundation Bearing Stress		% Base in Compression
				Req	Calc	Req	Calc	Upstream (Heel) (kPa)	Downstream (Toe) (kPa)	
WALL BLOCK DI-1C/DI-5C										
U1 Normal Operation	1210.5	1207.5	529	1.5	5.00	1.5	2.34	151	263	100
UN1 Equip. Surcharge	1210.5	1207.5	529	1.3	5.21	1.3	2.02	137	298	100
UN2 Ineffective Drain	1214.5	1214.5	1171	1.3	2.31	1.3	1.30	97	226	100
E1 Seismic	1210.5	1207.5	529	1.1	4.52	1.0	1.96	123	250	100
WALL BLOCK DI-1D/DI-5D (Upstream)										
U1 Normal Operation	1210.0	1207.5	733	1.5	4.25	1.5	2.21	148	346	100
UN1 Equip. Surcharge	1210.0	1207.5	733	1.3	4.41	1.3	2.02	135	382	100
UN2 Ineffective Drain	1213.5	1213.5	1338	1.3	2.37	1.3	1.31	103	322	100
E1 Seismic	1210.0	1207.5	733	1.1	3.84	1.0	1.85	113	338	100
WALL BLOCK DI-1D/DI-5D (Mid-section)										
U1 Normal Operation	1210.0	1207.5	507	1.5	2.97	1.5	4.09	92	239	100
UN1 Equip. Surcharge	1210.0	1207.5	507	1.3	3.12	1.3	3.26	81	273	100
UN2 Ineffective Drain	1213.5	1213.5	926	1.3	1.67	1.3	1.30	31	244	100
E1 Seismic	1210.0	1207.5	507	1.1	2.68	1.0	2.53	57	250	100
WALL BLOCK DI-1D/DI-5D (Downstream)										
U1 Normal Operation	1209.5	1207.5	265	1.5	2.17	1.5	6.92	53	96	100
UN1 Equip. Surcharge	1209.5	1207.5	265	1.3	2.35	1.3	3.93	54	115	100
UN2 Ineffective Drain	1209.5	1209.5	323	1.3	1.77	1.3	3.60	53	79	100
E1 Seismic	1209.5	1207.5	265	1.1	1.96	1.0	1.88	30	110	100

Notes:
1. See Appendix E.1 for definition of wall section description, analysis methodology, and stability calculations.
2. Analysis assumes inclined sliding plane, interface friction angle Φ = 26 degrees, and no cohesion.
3. Seismic results utilize active soil pressure coefficients for stability values reported.

8.0 STRENGTH EVALUATION AND DESIGN

Strength evaluation of individual elements or members of structures and monoliths was used to verify member sizes based on application of factored loads as described in ABC with some adjustments for more severe conditions or loads not included in the ABC.

Reinforced concrete design, except for bridge components, was performed according to Design of Concrete Structures, CSA A23.3-14 with the additional requirements of the CSA's SEED Document – *Structural Design of Wastewater Treatment Plants-2018* for revisions addressing service load conditions, water tightness, shrinkage and temperature reinforcement, and crack control. The Seed Document contains references to ACI 350M-06 for modifying CSA A23.3-14. For bridge components, such as the Diversion Inlet access bridge, reinforced concrete design was performed according to Alberta Transportation Bridge Design Criteria supplemented by the Canadian Highway Bridge Design Code.

Structural steel design was performed according to Design of Steel Structures, CSA S16-14, and codes for welding, materials, and other pertinent references.

In general, structural analysis and design was performed manually using Mathcad or Excel spreadsheets. For complex structures, a commercial Three-Dimensional Finite Element Model (FEM) was used to evaluate multiple load combinations, identify stress concentrations, and generate shear and moment values for design of individual elements. The FEM was supplemented with manual calculations to verify/validate model results and where necessary, refine the analysis of individual elements. Based on model output, a combination of manual calculation and commercial software were used for strength design. Additional elements evaluated as part of strength design included joint detailing, equipment anchorage, and embedded parts.

The Diversion Inlet is designed as a mass concrete gravity structure sized primarily for stability. Most elements exceed 2 m in thickness and are surface reinforced for crack control and durability rather than strength. Each element is checked to confirm calculated stress from factored loads do not exceed member capacity. Some elements which are subjected to higher stress and controlled by strength design include:

- Head wall/breast wall which is designed as a beam spanning 20 m from abutment to pier and subjected primarily to dead load, vehicle load, and lateral hydraulic load
- Access deck panels which span 4.5 m from breastwall to headwall and subjected primarily to vehicle and equipment loading
- Gate hoist bridge spanning 20 m and subjected primarily to dead load and hoist load

- Concrete gate slots, gate hoist bridge end supports, and head wall/breast wall end supports which are subjected to concentrated bearing forces

For each of these elements, preliminary strength calculations were performed to acquire order-of-magnitude stress and establish basis for preliminary member sizing. Strength calculations to develop reinforcement sizing and steel detailing will be performed during Final Design.

The retaining wall monoliths will be detailed during Final Design using commercially available finite element software with beam, shell, and solid elements where appropriate.

Footings are designed as a structural slab on an elastic foundation as the stability analysis concluded that the foundations are in compression based on the value of the subgrade modulus. The critical sections considered for evaluation of shear and moment are at half the footing thickness as measured from the face of the wall for the toe and at the face of the wall for the heel. In general, footing geometry was dictated by the gate bay limit of excavation, and desired hydraulic profile resulting in footing thicknesses exceeding 1.5 to 2.0 m with relatively low stress at the critical sections.

Cantilever stem walls are designed as a cantilever beam fixed at the footing interface. The critical sections considered for evaluation were at base of stem, 1/3 of the stem height, and 2/3 of the stem height. Wall thickness increases from top to bottom with thickness ranging from 0.5 to 2.0 m, respectively. Due to increased thickness and increased load near the base of walls, shear strength becomes a controlling factor, and transverse shear reinforcement (cross ties) will be required.

Counterfort stem walls are designed as continuous beams spanning horizontally between counterforts, with only the lower portions of the stem exhibiting plate (2-way spanning) action and designed as a cantilever from the footing to a height approximately half of the counterfort spacing.

Counterfort heels are designed with a similar load path as the stem. The portion of footing closest to the stem acts as a cantilever beam, and the portion which is further from the stem by more than half of counterfort spacing, is designed as a continuous beam spanning between counterforts.

Counterforts are designed as cantilever deep beams fixed at the footing interface. The wall serves as the beam flange, and the flange width is calculated as the lesser of 12 times the thickness of the wall or half the distance between the counterforts using equation 10.3.3 of CSA 23.3 (2018). The counterfort is considered to act as the stem of tee beam and is fixed at its base. The tee beam is sized so that the neutral axis of the tee beam is located within the flange. The depth of the tee beam is the perpendicular distance between the sloping face of the counterfort and the vertical face of the retaining wall. Critical sections for evaluation of counterfort shear and moments include the foundation interface and the third points of the counterfort.

9.0 SERVICEABILITY

Structural serviceability concerns with the Diversion Inlet relate primarily to concrete durability, shrinkage control, relief of internal stresses associated with volume changes, and deflection of access deck and gate hoist bridge.

Shrinkage control and volume changes are addressed primarily with placement sequence, mix design, surface reinforcement, and material specifications. The preliminary design includes joint locations that define monoliths with balanced aspect ratios and placements less than 12 m to 18 m in any one direction. Expanded guidance related to placement sequence and horizontal joint locations will be addressed will be addressed during Final Design.

Allowance for thermal expansion/contraction is critical for gate operation These affects are addressed primarily through second stage concrete placements occurring after initial concrete shrinkage has occurred and detailing of clearance within the gate slot.

Gate hoist bridge stiffness and member size are controlled by deflection limits established for hoist equipment. Hoist support deflection must be uniform to minimize secondary loads on shaft and gears and within limits of comfort of personnel working on the gate hoist platform. Lateral deflection of the gate itself and head wall must be controlled to maintain integrity and contact of gate seals.

Serviceability criteria for the bridge deck will be in accordance with AT Bridge Standards and sized for heavy equipment loading.

Serviceability concerns for the retaining walls relate to concrete durability, shrinkage, crack control, volume changes, and wall deflections. Durability, shrinkage, and crack control are achieved primarily through reinforcement placement, high reinforcement ratios, and use of high load factors that account for both strength and serviceability in accordance with CSA SEED document. Volume changes are addressed primarily with placement sequence, mix design, surface reinforcement, and material specifications. The retaining walls include vertical joints at locations of footing geometry change, and at locations needed to maintain horizontal wall lengths less than 12 m to 18 m. Expanded guidance related to placement sequence and horizontal joint locations will be addressed as part of constructability review during Final Design.

Wall deflections are controlled using counterforts to provide rigidity by reducing wall and footing spans and using at-rest soil pressure when sizing wall elements. Locations where wall deflection is critical includes walls serving as gate bay abutments, walls adjacent to access roads and control building foundation, and walls along the upstream face that must maintain tight joints for water retention. Wall deflections will be addressed during Final Design.

10.0 CONSTRUCTION CONSIDERATIONS

Construction specifications and details for the Diversion Inlet will be furthered during Final Design. The following items have been identified as construction considerations for the Diversion Inlet:

- Dewatering of excavated areas will be required to sufficiently enable construction of the Diversion Inlet. The services of a specialist dewatering contractor may be needed.
- Excavation will be in competent bedrock. All soil, including alluvium, talus and other unconsolidated deposits should be removed to expose unweathered or slightly weathered bedrock. Excavation should be performed by mechanical means only; blasting will not be permitted.
- Foundation preparation will require special care in cleaning and preparation of concrete/rock interface. Care must be taken during excavation of the foundation to identify unsuitable rock conditions or weak bedding planes that could impact stability. Loose material and rock overhangs will need to be removed. Small voids will be filled with dental concrete. Once ready, foundation protection will be placed over exposed rock.
- If extensive jointing/fracturing is observed after excavation of the foundation, consolidation grouting may be required.
- Shear keys are required to maintain adequate sliding stability for gate monoliths and retaining walls. Care should be taken during excavation of the shear key trenches to identify unsuitable rock conditions or weak bedding planes that could compromise capacity of the shear key.
- Anchors, along with a foundation underdrain to relieve uplift pressures, will be required to maintain adequate factors of safety against floatation in the stilling basin. Static anchors drilled and grouted in a grid pattern prior to placement of the stilling basin concrete are proposed.
- Lift joints in the base mats and footings will be required to reduce placement thickness, control heat of hydration, reduce crack potential, and develop hydraulic profile. Changes in mix design will be required to provide lower cement ratio and larger aggregate in mass concrete placements, with higher strength and smaller aggregate mix placed as part of the reinforced "surface skin".
- Vertical joints in gate bays and stilling basins will be spaced and detailed so that "closure grouting" needed to accommodate shrinkage during initial curing is not needed.
- Horizontal joints in the retaining wall stems will be required to reduce placement height to avoid potential for aggregate separation, improve access for adequate vibration, reduce

potential for form bulging, and allow for fill placement to progress in stages with wall construction.

- Joint preparation will require attention to proper installation of water stops, shear keys, dowels, and reinforcement. Joint alignment and water-tight integrity are critical for reducing water levels on the back side of retaining walls.

- Gate slots, access bridge, and gate hoist beams at the Diversion Inlet will require combinations of concrete block outs, anchor bolts, and embedded parts in first and second stage concrete placements. Placement tolerance for some of these items are tighter than typical heavy construction tolerance due to fit and operating clearance requirements.

- Procurement lead-time for gate components will likely be driven by steel availability and fabrication schedules. An allowance of 12 to 18 months is recommended to account for design, shop drawing review/approval, fabrication, testing, and delivery.

- Placement of free draining backfill, filter material, and drain systems are critical for minimizing groundwater levels behind the walls. Material selection and installation methods will require strict quality control and monitoring.

- Fill placement and compaction methods must be reviewed and monitored to ensure wall movement does not occur during construction.

- Construction sequencing will be required to ensure the Diversion Inlet and gates are fully functional before a tie-in with Diversion Channel is made.

Appendix E.1-1 GATE BLOCKS AND CENTER PIER

Calculation Section I

Results Summary Table (overview)

Table E.1-1.1 – Diversion Inlet Center Pier – Stability Analysis

(Seepage Free Surface at Toe Point O, except UN2 End of Stilling Basin)

Load Case	Headwater Elevation (m)	Tailwater Elevation (m)	Hydro-static Uplift Force (kN)	Floatation Safety Factor (FSF)		Sliding Safety Factor (SSF)		Foundation Bearing Stress		% Base in Compression
				Req	Calc	Req	Calc	Upstream (Heel) (kPa)	Downstream (Toe) (Kpa)	
Usual Load Cases										
U1 Normal Operation	1212.1	1207.5	17900	1.5	3.0	1.5	37.9	155	160	100
U2 Diversion Operation *100 Yr. Flood*	1215.8	1213.1	25600	1.5	2.4	1.5	5.8	130	181	100
Unusual Load Cases										
UN1 Diversion Operation *2013 Flood*	1215.8	1213.1	19690	1.3	3.1	1.3	5.5	130	181	100
UN2 No Diversion *2013 Flood*	1216.2	1207.5	29518	1.3	2.0	1.3	3.4	135	143	100
UN3 No Diversion *1000 Yr. Flood*	1217.0	1207.5	25461	1.3	2.4	1.3	3.2	125	186	100
UN4 Construction/ Maintenance	1215.8	1211.0	25585	1.3	2.3	1.3	8.2	169	136	100
Extreme – Flood										
E1 PMF without Diversion	1217.8	1207.5	26696	1.1	2.3	1.1	2.6	126	197	100
E2 PMF with Diversion	1216.6	1214.4	27560	1.1	2.2	1.1	4.6	131	184	100
Extreme – Earthquake used to determine Post-Seismic Condition										
E3 EDGM applied to U1	1212.1	1207.5	17900	1.1	2.7 (E3.3)	1.0	1.9 (E3.2)	90 (E3.2)	229 (E3.1)	100
E4 EDGM applied to U2	1215.8	1213.1	25600	1.1	2.2 (E4.3)	1.0	1.4 (E4.2)	61 (E4.2)	254 (E4.1)	100

Notes:
1. See Appendix E.1 for definition of monolith description, analysis methodology, and stability calculations.
2. Analysis assumes horizontal sliding plane, interface friction angle Φ = 26 degrees, and no cohesion.
3. Reported seismic results are controlling values for the three combinations of vertical and horizontal seismic load considered.

Table E.1-1.2 – Diversion Inlet Gate Slab – Stability Analysis

Load Case	Headwater Elevation (m)	Tailwater Elevation (m)	Hydro-static Uplift Force (kN)	Floatation Safety Factor (FSF)		Sliding Safety Factor (SSF)		Foundation Bearing Stress		% Base in Compression
				Req	Calc	Req	Calc	Upstream (Heel) (kPa)	Downstream (Toe) (kPa)	
Usual Load Cases										
U1 Normal Operation	1212.1	1207.5	16523	1.5	1.7	1.5	6.1	93	72	100
U2 Diversion Operation *100 Yr. Flood*	1215.8	1213.1	23617	1.5	1.5	1.5	2.7	88	85	100
Unusual Load Cases										
UN1 Diversion Operation *2013 Flood*	1215.8	1213.1	23617	1.3	1.5	1.3	2.7	88	85	100
UN2 No Diversion *2013 Flood*	1216.2	1207.5	27247	1.3	1.3	1.3	1.7	95	45	100
UN3 No Diversion *1000 Yr. Flood*	1217.0	1207.5	23502	1.3	1.5	1.3	2.1	96	79	100
UN4 Construction/ Maintenance	1215.8	1211.0	23617	1.3	1.5	1.3	2.5	81	84	100
Extreme – Flood										
E1 PMF without Diversion	1217.8	1207.5	24642	1.1	1.5	1.1	1.9	92	80	100
E2 PMF with Diversion	1216.6	1214.1	25440	1.1	1.5	1.1	2.5	85	86	100
Extreme – Earthquake used to determine Post-Seismic Condition										
E3 EDGM applied to U1	1212.1	1207.5	16523	1.1	1.5 (E3.3)	1.0	1.33 (E3.2)	65 (E3.2)	103 (E3.1)	100
E4 EDGM applied to U2	1215.8	1213.1	23617	1.1	1.4 (E4.3)	1.0	1.01 (E4.2)	55 (E4.2)	120 (E4.1)	100

Notes:
1. See Appendix E.1 for definition of monolith description, analysis methodology, and stability calculations.
2. Analysis assumes horizontal sliding plane, interface friction angle Φ = 26 degrees, and no cohesion.
3. Reported seismic results are controlling values for the three combinations of vertical and horizontal seismic load considered.

Calculation Section II

Results Summary Table (detailed)

DIVERSION INLET CENTER PIER STABILITY SUMMARY (DI-3A3B)													
Load Combination	Σ Vertical (kN)	Σ Horizontal (kN)	Σ Moments (kN*m) Inclined Plane	Eccentricity, e Inclined Plane (m)	σ @ Toe (kN/m2) Inclined Plane	σ @ Heel (kN/m2) Inclined Plane	Base in Compression %	FS Sliding Required	Calculated FS Inclined Plane	Σ Vertical Without Uplift (kN)	Σ Uplift (kN)	FS Floatation Required	FS Floatation Calculated
U1	36222	7270	602996	0.06	160	155	100	1.5	37.94	54122	17900	1.5	3.02
U2	35159	10683	565714	0.70	181	130	100	1.5	5.78	60759	25600	1.5	2.37
UN1	41064	10880	492591	0.40	181	130	100	1.3	5.50	60754	19690	1.3	3.09
UN2	29623	12099	529062	0.80	143	135	100	1.3	3.40	59141	29518	1.3	2.00
UN3	34625	13872	558046	0.88	186	125	100	1.3	3.25	60086	25461	1.3	2.36
UN4	33566	9137	551797	0.53	136	169	100	1.3	8.16	59151	25585	1.3	2.31
E1	34328	15796	542461	1.10	197	126	100	1.1	2.57	61024	26696	1.1	2.29
E2	34217	11532	548419	0.83	184	131	100	1.1	4.61	61777	27560	1.1	2.24
E3.1	36222	19071	538784	1.67	96	229	100	1.0	2.04	54122	17900	1.1	3.02
E3.2	34637	19071	518789	1.74	90	225	100	1.0	1.94	52537	17900	1.1	2.94
E3.3	30938	10810	517084	2.48	166	119	100	1.0	4.54	48838	17900	1.1	2.73
E4.1	35159	23546	498440	2.36	67	254	100	1.0	1.47	60759	25600	1.1	2.37
E4.2	33451	23546	476270	2.48	61	250	100	1.0	1.41	59051	25600	1.1	2.31
E4.3	29466	14542	471632	1.46	89	189	100	1.0	2.47	55066	25600	1.1	2.15

DIVERSION INLET GATE BLOCKS STABILITY SUMMARY (DI-2A2B & DI-4A4B)													
Load Combination	Σ Vertical (kN)	Σ Horizontal (kN)	Σ Moments (kN*m) Inclined Plane	Eccentricity, e Inclined Plane (m)	σ @ Toe (kN/m2) Inclined Plane	σ @ Heel (kN/m2) Inclined Plane	Base in Compression %	FS Sliding Required	Calculated FS Inclined Plane	Σ Vertical Without Uplift (kN)	Σ Uplift (kN)	FS Floatation Required	FS Floatation Calculated
U1	11352	4852	305651	-0.53	72	93	100	1.5	6.14	27875.2	16523	1.5	1.7
U2	12259	7495	309563	-0.08	85	88	100	1.5	2.66	35876	23617	1.5	1.5
UN1	12259	7495	309563	-0.08	85	88	100	1.3	2.66	35876	23617	1.3	1.5
UN2	7255	8472	278816	-1.46	45	95	100	1.3	1.66	34501.7	27247	1.3	1.3
UN3	12273	9178	320388	-0.40	79	96	100	1.3	2.05	35776	23503	1.3	1.5
UN4	10807	7495	287700	0.10	84	81	100	1.3	2.53	34424	23617	1.3	1.5
E1	12404	9885	322531	-0.37	80	92	100	1.1	1.85	37046	24642	1.1	1.5
E2	11809	7918	302263	0.02	86	85	100	1.1	2.48	37249	25440	1.1	1.5
E3.1	11352	11785	282333	0.83	103	68	100	1.0	1.39	27875.2	16523	1.1	1.7
E3.2	10534	11785	271597	0.89	101	65	100	1.0	1.33	27057	16523	1.1	1.7
E3.3	8624	6932	262871	0.01	74	74	100	1.0	2.45	25147.2	16523	1.1	1.5
E4.1	12259	15304	283616	1.35	120	60	100	1.0	1.05	35876	23617	1.1	1.5
E4.2	11279	15304	270043	1.47	118	55	100	1.0	1.01	34896	23617	1.1	1.5
E4.3	8993	9838	256536	0.68	89	64	100	1.0	1.53	32610	23617	1.1	1.4

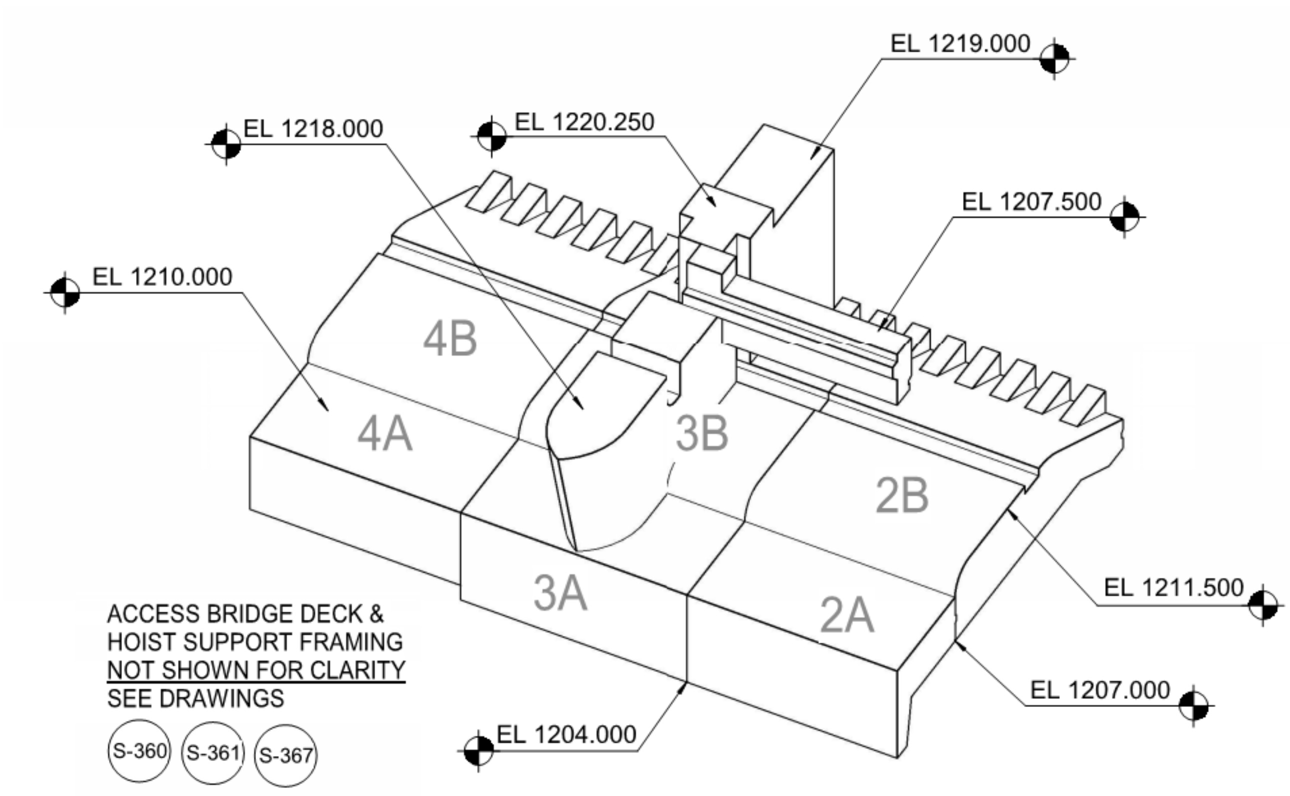
Calculation Section III

DI-3A/3B Center Pier Stability Calculations

Project Number: 110773396
Project Title: SR1 Project
Client: Alberta Transportation
Engineer: Dave Crawford, Derek Cheuk Date: 2018/12/17
Checker: Sean Xiao Date: 2019/01/08

Sliding Stability, Bearing Capacity and Overturning Stability Analysis for: Diversion Inlet Monolith (3A+3B) Center Pier

Structure Isometric:



BLOCKS 2A, 2B,3A, 3B, 4A & 4B 3D VIEW

DIVERSION INLET - MONOLITHS (3A+3B) - CENTER PIER

REGION COLOR CONVENTION	User Input	Calculation Highlights	Results

DIVERSION INLET DEIMENSIONAL INPUT PARAMETERS

BASE SECTION PROPERTIES

Base Length: $L_b := 24.20m$ $\quad Kern := \frac{L_b}{6} = 4.03\,m$

Stilling Basin Length: (Effective Drain at Toe Point O, except UN2) $L_{sb} := 0m$ $\quad Ecc_{midhalf} := \frac{L_b}{4} = 6.1\,m$

Base Width: $W_b := 13.00m$

Area of Base: $A_b := L_b \cdot W_b = 314.6\,m^2$

Section Modulus of Base: $S_b := \frac{W_b \cdot L_b^2}{6} = 1268.9\,m^3$

PIERS

Pier Nose Height: $h_{pn} := 8.00m$

Area of Curved Pier Nose Section: $A_{pnc} := 9.71m^2$ (From Bluebeam Area Measurement)

Pier Nose Width and Uniform Section: $w_{pn} := 4.00m$

Pier Nose Area at Top: $A_{pnt} := A_{pnc} + \left(w_{pn} \cdot 4.43m\right) = 27.4\,m^2$

Pier Nose Area at Bottom: $A_{pnb} := A_{pnc} + \left(w_{pn} \cdot 2.43m\right) = 19.4\,m^2$

Total Pier Nose Volume: $V_{pn} := \frac{A_{pnt} + A_{pnb} + \sqrt{A_{pnt} \cdot A_{pnb}}}{3} \cdot h_{pn} = 186.5 \cdot m^3$

Pier Height Upstream of Gates: $h_{pug} := 8.0m$

Pier Plan Area Upstream of Gates: $A_{pug} := w_{pn} \cdot 7.50m = 30\,m^2$

Total Pier Volume Upstream of Gates: $V_{pug} := A_{pug} \cdot h_{pug} = 240.0 \cdot m^3$

Pier Height at Gate Slot: $h_{pgs} := 8.00m$

Pier Plan Area at Gate Slot: $A_{pgs} := 1.50m \cdot 2.5m = 3.75\,m^2$

Total Pier Volume at Gate Slot: $V_{pgs} := A_{pgs} \cdot h_{pgs} = 30.0 \cdot m^3$

Pier Width Downstream of Gates: $w_{pdg} := 4.00m$

Pier Elevation Area Downstream of Gates: $A_{pdg} := 86.7m^2$ (From Bluebeam Area Measurement)

Total Pier Volume Downstream of Gates: $V_{pdg} := A_{pdg} \cdot w_{pdg} = 346.8 \cdot m^3$

BRIDGE DECK

Bridge Deck Width:	$w_{bd} := 5.00m$	
Bridge Deck Section Area	$A_{bd} := (22 - 5 \cdot 1.2) \cdot 0.51 \cdot m^2 - 13 \cdot 3\pi \frac{0.28^2}{4} m^2$	(AT SL-510 Void Slab Arrangement See A-S360)
Total Bridge Deck Volume:	$V_{bd} := w_{bd} \cdot A_{bd} = 28.8 \cdot m^3$	$A_{bd} = 5.8\,m^2$
Breastwall Elevation Area:	$A_{bw} := 4.789m^2$	(From Bluebeam Area Measurement)
Breastwall Length:	$L_{bw} := \frac{20.00}{2} \cdot 2m$	(2 Beastwalls simply supported by Center Pier)
Total Breastwall Volume:	$V_{bw} := A_{bw} \cdot L_{bw} = 95.8 \cdot m^3$	
Headwall Elevation Area:	$A_{hw} := 5.58m^2$	(From Bluebeam Area Measurement)
Headwall Length:	$L_{hw} := \frac{20.00}{2} \cdot 2m$	(2 Beastwalls simply supported by Center Pier)
Total Headwall Volume:	$V_{hw} := A_{hw} \cdot L_{hw} = 111.6 \cdot m^3$	
Hoist Bridge supports on Center Pier	(conservatively ignored for Stability checks)	

FOOTINGS (BOF_{base} EL = 1207.0)

Bottom of Key (Footing Heel) Elevation:	$BOF_{elev} := 1204.00m$	<========== *(Critical Design Parameter)*
Apron Slab Top of Concrete Elevation at Edge of Slab:	$TOC_{as} := 1210.00m$	
Fixed Crest Top of Concrete Elevation at Downstream Face:	$TOC_{fce} := 1207.50m$	(TOC Elevation of DI Stilling Basin)
Fixed Crest Top of Concrete Elevation at Center of Footing:	$TOC_{fcc} := 1211.50m$	
Bottom of Footing Elevation @ Toe:	$BOF_{toe} := 1205.50m$	<============= *(Critical Design Parameter)* *(Point O @ TOE: BOFtoe = EL.1205.5)*
Footing Concrete Base Elevation (typ,, Except Heel Key and Toe):	$BOF_{base} := 1207.0 \cdot m$	
Fixed Crest Footing Elevation Area:	$A_{fc} := 68.5m^2$	(From Bluebeam Area Measurement)
Fixed Crest Footing Width:	$w_{fc} := 13.00m$	
Total Fixed Crest Footing Volume:	$V_{fc} := A_{fc} \cdot w_{fc} = 890.5 \cdot m^3$	
Apron Slab Footing Dimensions:	$w_{as} := 13.00m$ $L_{as} := 6.20m$	
Apron Slab Elevation Area:	$A_{as} := L_{as} \cdot (TOC_{as} - BOF_{base}) = 18.6\,m^2$	
Total Apron Slab Footing Volume:	$V_{as} := A_{as} \cdot w_{as} = 241.8 \cdot m^3$	
Shear Key Depth (below Toe EL):	$Key_d := BOF_{toe} - BOF_{elev} = 1.5\,m$	
Shear Key Dimensions:	$Key_{w.t} := 1.5m$ $Key_l := 13m$ $Key_{w.b} := 1.0m$	$Key_w := \frac{Key_{w.t} + Key_{w.b}}{2}$
Total Shear Key Volume:	$V_{key} := (Key_d + BOF_{base} - BOF_{toe}) \cdot Key_w \cdot Key_l = 48.8 \cdot m^3$	

FOUNDATION PARAMETERS

Granular Fill Internal Angle of Friction: $\phi := 34 \cdot \frac{\pi}{180} = 0.593$ (Section 5.3, Design Criteria)

Friction Angle at Base Concrete / Rock Interface: $\phi_{rock} := 26$ (Section 5.2, Design Criteria)

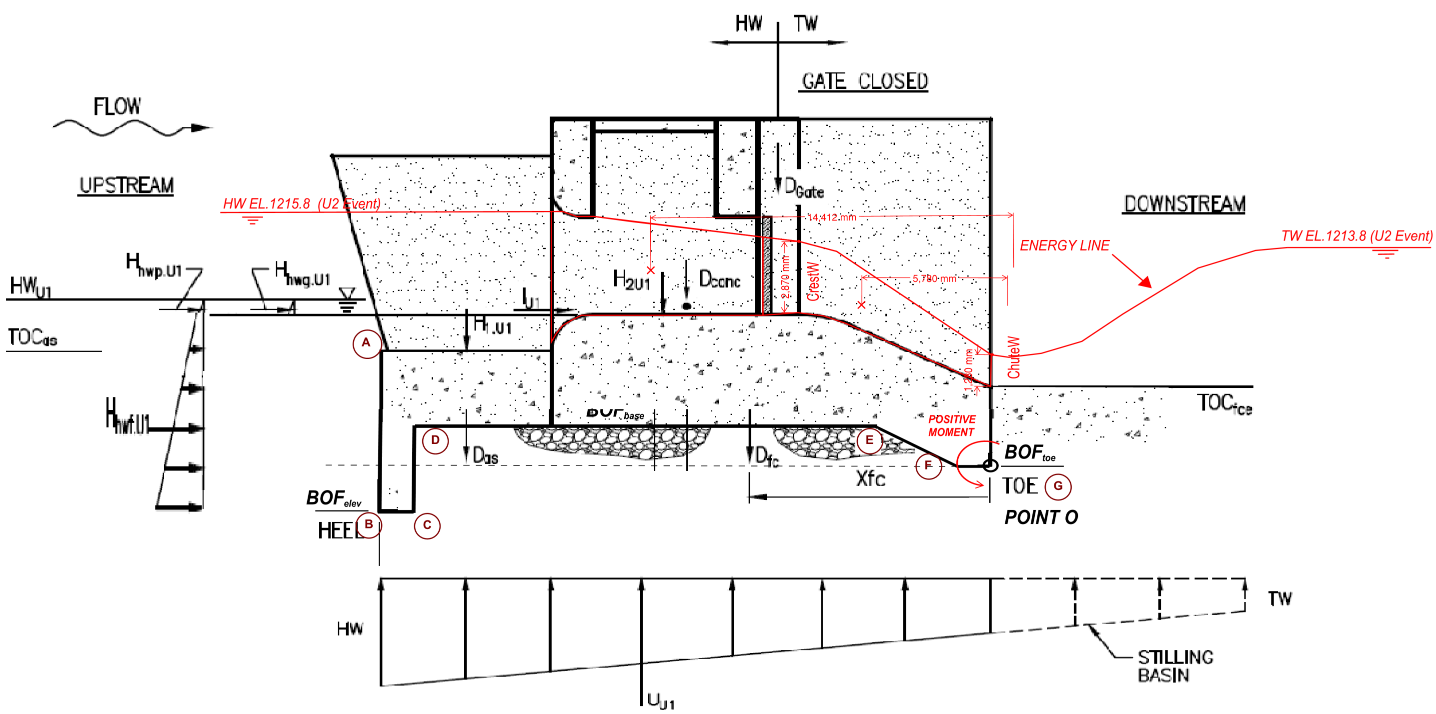
Base Friction Coefficient: $\tan_{\phi} := \tan\left(\phi_{rock} \frac{\pi}{180}\right) = 0.488$ radians

Line-of-Seepage Parameters $L_{AB} := 0$ $L_{BC} := 1 \cdot m$ $L_{CD} := 3.04 \cdot m$ (Assuming Cracking for Overturning)

Seepage Line:
A-B-C-D-E-F-G-End of Stilling Basin

$L_{DE} := 18.22 \cdot m$ $L_{EF} := 3.35 \cdot m$

$X_{EF} := 2.99 \cdot m$ $L_{FG} := 1.5 \cdot m$ $L_{sb} = 0$



MATERIAL PROPERTIES

Unit Weight of Concrete: $\gamma_c := 23.5 \frac{kN}{m^3}$ (Section 7.1, Design Criteria)

Unit Weight of Rock Fill: $\gamma_r := 22.0 \frac{kN}{m^3}$ (Section 5.3, Design Criteria)

Rip Rap Backfill, Refer Dwg. C-214 $\phi_{backfill} := \left(20 \frac{\pi}{180}\right) = 0.3$ radians

Unit Weight of Water: $\gamma_w := 9.81 \frac{kN}{m^3}$ (Section 7.2, Design Criteria)

CONCRETE DEAD LOADS

Pier Nose: $D_{pn} := V_{pn} \cdot \gamma_c = 4383.3 \cdot kN$

Pier Upstream of Gates: $D_{pug} := V_{pug} \cdot \gamma_c = 5640.0 \cdot kN$

Gate Slot: $D_{pgs} := V_{pgs} \cdot \gamma_c = 705.0 \cdot kN$

Pier Downstream of Gates: $D_{pdg} := V_{pdg} \cdot \gamma_c = 8149.8 \cdot kN$

Bridge Deck: $D_{bd} := V_{bd} \cdot \gamma_c = 676.6 \cdot kN$

Breastwall: $D_{bw} := V_{bw} \cdot \gamma_c = 2250.8 \cdot kN$

Headwall: $D_{hw} := V_{hw} \cdot \gamma_c = 2622.6 \cdot kN$

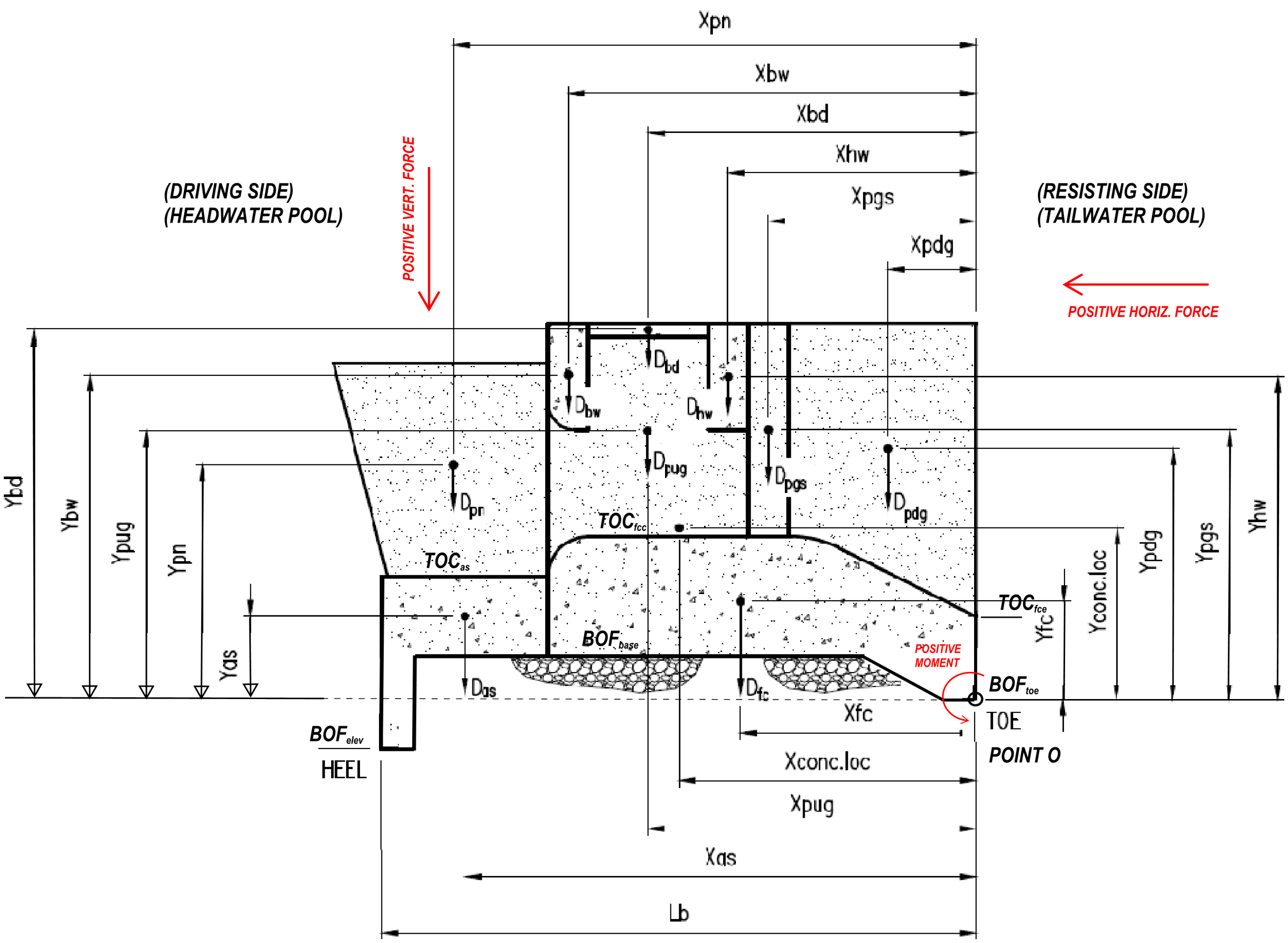
Fixed Crest Footing: $D_{fc} := V_{fc} \cdot \gamma_c = 20926.8 \cdot kN$

Apron Slab Footing: $D_{as} := V_{as} \cdot \gamma_c = 5682.3 \cdot kN$

Key: $D_{key} := V_{key} \cdot \gamma_c = 1145.6 \cdot kN$

Total Concrete Dead Loads:

$$D_{conc} := D_{pn} + D_{pug} + D_{pgs} + D_{pdg} + D_{bd} + D_{bw} + D_{hw} + D_{fc} + D_{as} + D_{key} = 52182.8 \cdot kN$$



VARIABLES AND SIGN CONVENTION

MOMENT ARM FROM TOE TO CENTROID OF COMPONENT

Distance from Toe to COG Pier Nose: $X_{pn} := 21.52m$ (From Bluebeam Measurements)

Dist. from Toe to COG Pier U/S of Gates: $X_{pug} := 14.25m$

Distance from Toe to COG of Gate Slot: $X_{pgs} := 9.75m$

Dist. from Toe to COG Pier D/S of Gates: $X_{pdg} := 4.15m$

Dist. from Toe to COG of Bridge Deck: $X_{bd} := 14.5m$

Dist. from Toe to COG of Breastwall: $X_{bw} := 17.23m$

Distance from Toe to COG of Headwall: $X_{hw} := 11.25m$

Dist. from Toe to COG of Fixed Crest: $X_{fc} := 9.948m$

Dist. from Toe to COG of Apron Slab: $X_{as} := 21.10m$

Dist. from Toe to COG of Heel Key: $X_{key} := \left(L_b - \frac{Key_w}{2}\right) = 23.6\,m$

MOMENT ARM FROM BASE OF FOOTING TO CENTROID OF COMPONENT

Dist. from Base to COG of Pier Nose: $Y_{pn} := 8.69m$

Dist. from Base to COG Pier U/S of Gates: $Y_{pug} := 9.713m$ (From Bluebeam Measurements, TYP.)

Dist. from Base to COG of Gate Slot: $Y_{pgs} := 10.38m$

Dist. from Base to COG Pier D/S of Gates: $Y_{pdg} := 8.77m$

Dist. from Base to COG of Bridge Deck: $Y_{bd} := 13.25m$

Dist. from Base to COG of Breastwall: $Y_{bw} := 11.49m$

Dist. from Base to COG of Headwall: $Y_{hw} := 11.62m$

Dist. from Base to COG of Fixed Crest: $Y_{fc} := 3.35m$

Dist. from Base to COG of Apron Slab: $Y_{as} := 3.0m$

Dist. from Base to COG of Heel Key: $Y_{key} := \frac{BOF_{base} + BOF_{elev}}{2} - BOF_{toe} = 0.00\,m$

Distance From Toe to COG of Concrete Dead Loads:

$$X_{conc.loc} := \frac{\left(\left(\begin{array}{l} X_{pn} \cdot D_{pn} + X_{pug} \cdot D_{pug} + X_{pgs} \cdot D_{pgs} + X_{pdg} \cdot D_{pdg} + X_{bd} \cdot D_{bd} \cdots \\ + X_{bw} \cdot D_{bw} + X_{hw} \cdot D_{hw} + X_{fc} \cdot D_{fc} + X_{as} \cdot D_{as} + X_{key} \cdot D_{key} \end{array}\right)\right)}{D_{conc}} = 12.43\,m$$

Distance Above Base to COG of Concrete Dead Loads:

$$Y_{conc.loc} := \frac{\left(Y_{pn} \cdot D_{pn} + Y_{pug} \cdot D_{pug} + Y_{pgs} \cdot D_{pgs} + Y_{pdg} \cdot D_{pdg} + Y_{bd} \cdot D_{bd} + Y_{bw} \cdot D_{bw} + Y_{hw} \cdot D_{hw} + Y_{fc} \cdot D_{fc} + Y_{as} \cdot D_{as} + Y_{key} \cdot D_{key}\right)}{D_{conc}}$$

ROCK SECTION MOBILIZED FOR INCLINDED SLIDING FAILURE

Area of Rock Section Mobilized: $A_{rs} := 46.22m^2$ (From Bluebeam Measurement)

Rock Mass Mobilized: $V_{rs} := A_{rs} \cdot \gamma_r \cdot W_b = 13218.9 \cdot kN$

(Pore pressure taken along assumed inclined sliding plane)

Distance from Toe to COG of Rock Section: $L_{rs} := 13.96m$ (From Bluebeam Measurement)

VERTICAL LIFT GATE

Dead Load of Vertical Lift Gate: $D_{Gate} := 580 \cdot \frac{2}{2} kN$ (Drawing Q-202 dated 03-31-2017 Gate Load on Monolith 3A3B pending Gate position of individual Load Case)

Distance from Toe to COG of Gate: $X_{gate} := X_{pgs} = 9.75\,m$

Distance from Base to Centroid of Vertical Lift Gate:

$$Y_{gate} := \left[\left(TOC_{fcc} - BOF_{toe} \right) + \frac{1215.5 \cdot m - TOC_{fcc}}{2} \right] = 8\,m$$

(Distance from base to halfway between the bottom of the headwall and the top of the Fixed Crest.)

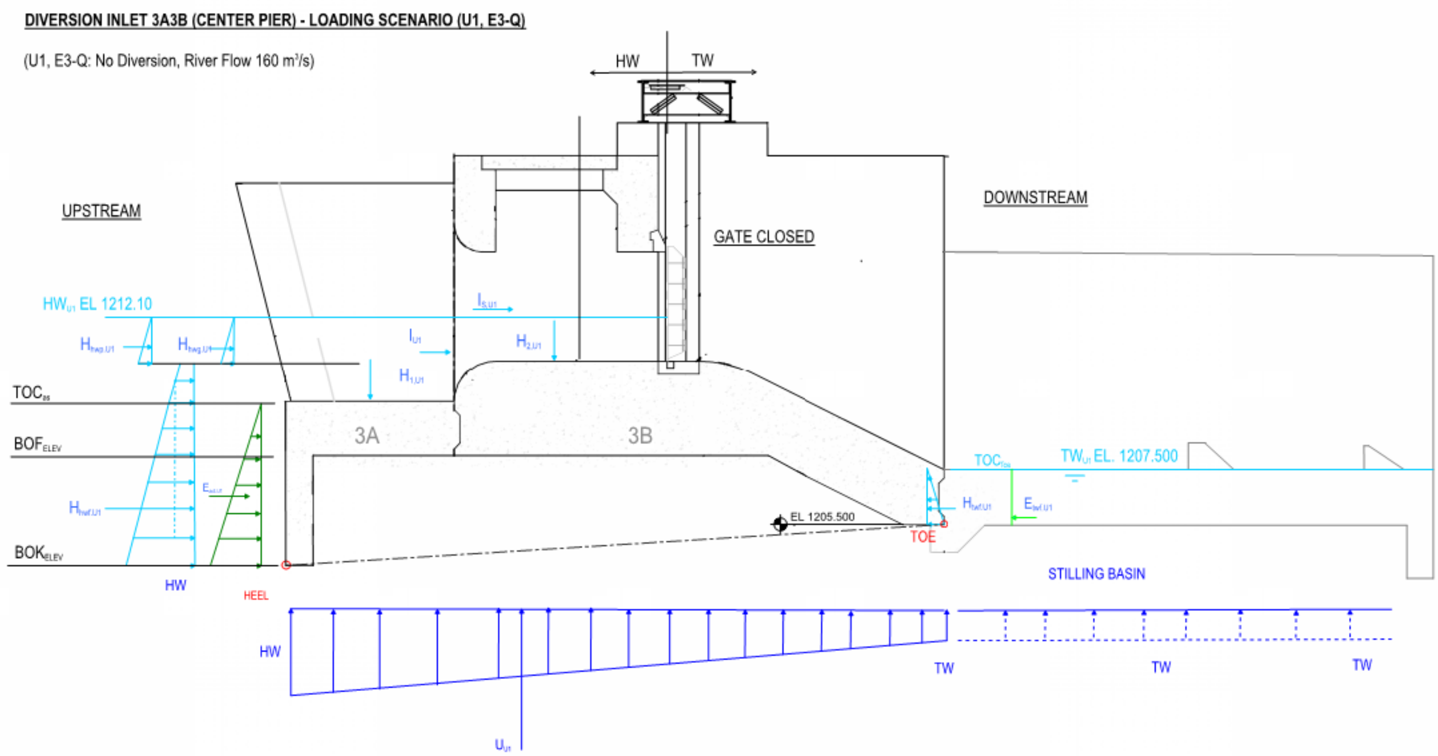
Diversion Structure 2D Hydraulic Model Results

Tabular Summary of Diversion Structure 2D Hydraulic Model Results
Applicable or Relevant Scenarios: Diversion Inlet (DI) - Gate Structure
Prepared: 17 October 2018

Water Surface Over DI Gate Bay - Gate Open

Scenario	Total Inflow (m^3/s)	Service Spillway Discharge (m^3/s)			Diversion Inlet Discharge (m^3/s)			Auxiliary Spillway Discharge (m^3/s)	Head water (m)	Service Spillway Tailwater (m)	Diversion Inlet Tailwater (m)*	Notes		Headwater at breast wall (m)	Critical depth at D/S radius (m)	Depth at Basin Toe (m)	Diversion Inlet Tailwater at end of basin (m)*
		Left Gate	Right Gate	Total	Left Gate	Right Gate	Total										
160 m^3/s, No Diversion **(U1, E3-Q)**	160	91	69	160	n/a	n/a	0	n/a	1212.1	1211.8	n/a	Diversion Inlet gates closed and Service Spillway gates fully open		DI Gates Closed	n/a	n/a	n/a
100-yr Event, No Diversion **(UN2)?** Use or 2013 event?	765	400	370	770	n/a	n/a	0	n/a	1214.5	1213.6	n/a	Diversion Inlet gates closed and Service Spillway gates fully open	May delete as 2013 event may control	DI Gates Closed	n/a	n/a	n/a
100-yr Event, Diverting up to 600 m^3/s **(U2, E4-Q)**	765	140	27	167	296	305	601	n/a	1215.8	1211.9	1213.1	Diversion Inlet gates open, Service Spillway left crest gate at EL 1213.4 m and right crest gate at EL 1215.0 m		d = 4.31 EL 1215.81	y_c = 2.87 EL = 1214.37	toe submerged d_{toe} = 1.28 EL = 1208.78	d_{tw} = 5.6 EL = 1213.1
100-yr Event, Diversion Inlet Maintenance **(UN4)**	765	474	23	497	0	274	274	n/a	1215.8	1212.7	1211.0	Left DI gate closed and right DI gate open; and Service Spillway gates fully open		d = 4.30 EL 1215.8	y_c = 2.67 EL 1214.17	d_{toe} = 1.16 EL 1208.66	d_{tw} = 3.5 EL 1211.0
~~100-yr Event, DI Gates Fail to Close (Not Critical Load Case)~~	765	309	219	529	123	116	238	n/a	1213.6	1213.2	1210.7	Diversion Inlet gates open and Service Spillway gates fully open.	May delete as not critical load case	n/a			
2013 Event, No Diversion **(UN2)** Auxiliary Spillway at point of overtopping	1240	648	597	1245	n/a	n/a	0	n/a	1216.2	1214.0	n/a	Diversion Inlet gates closed and Service Spillway gates fully open. AS at point of overtopping	2013 Design flood controls over 100-year flood? But DI gates are open during peak passage.	DI Gates Closed	n/a	n/a	n/a
2013 Event, Diverting up to 600 m^3/s **(UN1)**	1240	498	137	634	307	303	610	n/a	1215.8	1213.1	1213.1	Diversion Inlet gates open; Service Spillway left crest gate at EL 1210.0 m and right crest gate at EL 1213.5 m	TOR 2013 design flood requirement	d = 4.3 EL 1215.8	y_c = 2.87 EL 1214.37	toe submerged d_{toe} = 1.28 EL 1208.78	d_{tw} = 5.6 EL 1213.1
1000-yr Event, No Diversion **(UN3)** Auxiliary Spillway cover eroded	1930	759	708	1467	n/a	n/a	0	463	1217.0	1214.7	n/a	Diversion Inlet gates closed and Service Spillway gates fully open. Auxiliary Spillway cover layer eroded	But are DI gates open during peak passage????	DI Gates Closed	n/a	n/a	n/a
1000-yr Event, Diverting up to 600 m3/s, **(UN3a)?** Auxiliary Spillway cover eroded	1930			0			0					Diversion Inlet gates **regulating** and Service Spillway gates fully open. Auxiliary Spillway cover layer eroded	Is this the requirement for 1000-year event?	d = 4.31 EL 1215.81	y_c = 2.87 EL 1214.37	toe submerged d_{toe} = 1.28 EL 1208.78	d_{tw} = 5.6 EL 1213.1
1000-yr Event, DI Gates Fail to close, **(UN3a)?** Auxiliary Spillway cover eroded	1930	631	492	1124	341	337	677	129	1215.8	1214.0	1213.5	Diversion Inlet gates open and Service Spillway gates fully open. Auxiliary Spillway cover layer eroded	Not realistic - compounding probabilities	n/a			
~~Diversion Structure IDF Event- 1/3 Between 1000-yr and PMF, No Diversion.~~ AS cover eroded.	2210	812	758	1570	n/a	n/a	0	640	1217.3	1214.9	n/a	Diversion Inlet gates closed and Service Spillway gates fully open. Auxiliary Spillway cover layer eroded	Regulatory requirement for SS and AS, not pertinent to DI.	DI Gates Closed	n/a	n/a	n/a
~~Diversion Structure IDF Event- 1/3 Between 1000-yr and PMF, DI Gates Fail to Close.~~ AS cover eroded	2210	684	532	1215	375	371	746	249	1216.1	1214.2	1213.8	Diversion Inlet gates open and Service Spillway gates fully open. Auxiliary Spillway cover layer eroded	Not realistic - compounding probabilities	n/a			
PMF Event, No Diversion **(E1-F)** AS cover eroded.	2770	911	854	1765	n/a	n/a	0	1001	1217.8	1215.3	n/a	Diversion Inlet gates closed and Service Spillway gates fully open. Auxiliary Spillway cover layer eroded	But are DI gates open during peak passage????	DI Gates Closed	n/a	n/a	n/a
PMF Event, Diverting up to 600 m^3/s **(E2-F)?** AS cover eroded.	2770			0			0					Diversion Inlet gates **regulating** and Service Spillway gates fully open. Auxiliary Spillway cover layer eroded	This is the regulatory requirement for PMF at extreme hazard	d = 4.31 EL 1215.81	y_c = 2.87 EL 1214.37	toe submerged d_{toe} = 1.28 EL 1208.78	d_{tw} = 5.6 EL 1213.1
PMF Event, DI Gates Fail to Close **(E2-F) Determines Diversion Channel max capacity ???**	2770	783	593	1376	435	434	869	521	1216.6	1214.5	1214.4	Diversion Inlet gates open and Service Spillway gates fully open. Auxiliary Spillway cover layer eroded	Not realistic - compounding probabilities	d = 5.1 EL 1216.6	y_c = 3.4 EL 1214.9	toe submerged d_{toe} = 1.76 EL 1209.26	d_{tw} = 6.9 EL 1214.4

U1 DESIGN CASE



ACCEPTANCE PARAMETERS

Required Factor of Safety for Sliding:	$FS_{req.U1.sl} := 1.5$	(Without Cohesion) (Section 8.1, Design Criteria)
Resultant Within Middle Third of Base:	$e \le \frac{L_b}{6} \wedge e \ge \frac{-L_b}{6}$	(100% Base in Compression, Design Criteria)
Allowable Rock Bearing Pressure:	$\sigma_{allow.U1} := 1270 \cdot \frac{kN}{m^2}$	(Section 5.2, Design Criteria)
Required Factor of Safety for Flotation:	$FS_{req.U.flt} := 1.5$	
Overturning Min Required Resultant Ratio:	$\frac{X_{R.U}}{Horizontal\_Width\_of\_Base} > 0.33$	(100% Base in Compression, EM 1110-2-2502)

INPUT PARAMETERS **U1 CASE**

Headwater Elevation: $HW_{U1} := 1212.10m$

Tailwater Elevation: $TW_{U1} := 1207.50m$

(Water Elevations based on Diversion Structure 2D Hydraulic Model Results. See page 7 and Section 8.2, Design Criteria)

Crest Water Elevation (No Diversion)

Chute Block Water Elevation (No Diversion)

Bottom of Key (Footing Heel) Elevation: $BOF_{elev} = 1204\,m$ <============= *(Critical Design Parameter)*

Apron Slab Top of Concrete Elevation at Edge of Slab: $TOC_{as} = 1210\,m$

Fixed Crest Top of Concrete Elevation at Downstream Face: $TOC_{fce} = 1207.5\,m$

Fixed Crest Top of Concrete Elevation at Center of Footing: $TOC_{fcc} = 1211.5\,m$

Bottom of Footing Elevation @ Toe: $BOF_{toe} = 1205.5\,m$ <============= *(Critical Design Parameter)*
(Point O @ TOE: BOFtoe = EL.1205.5)

VERTICAL LIFT GATE

Lift Gate Position per Hydraulic Criteria $poss_{U1} := 1$

(poss = 1 if gate is closed
0 if gate is open)

(When Gate is Closed, it sits on Sill, tributary weight 4.5m*2/20m = 45% of Unit Assembly ; when Gate is Open, simply supported on Center Pier)

DEAD LOAD SUMMATION:

$$Gate_{R.U1} := \begin{cases} 1 & \text{if } poss_{U1} = 0 \\ 0.45 & \text{otherwise} \end{cases}$$

(Monolith Reaction for Wheel Gate)

$$\Sigma V_{DL.U1} := D_{conc} + Gate_{R.U1}\, D_{Gate} = 52443.8 \cdot kN$$

$$\Sigma M_{DL.U1} := D_{conc} \cdot X_{conc.loc} + Gate_{R.U1} \cdot D_{Gate} \cdot X_{gate} = 651119.6 \cdot kN \cdot m$$

LATERAL WATER LOADS

U1 CASE

HEADWATER (DRIVING):

Water Depth on Pier at Heel: $D_{hwp.U1} := HW_{U1} - TOC_{as} = 2.10\,m$

Water Load Unit Width on Pier: $w_{hwp.U1} := w_{pn} = 4.00\,m$

Total Horizontal Water Load on Pier: $H_{hwp.U1} := \dfrac{-\left(\gamma_w \cdot D_{hwp.U1}{}^2\right)}{2} \cdot w_{hwp.U1} = -86.5 \cdot kN$

Apply Total Pier Water Load at: $H_{hwp.U1.loc} := \dfrac{D_{hwp.U1}}{3} + \left(TOC_{as} - BOF_{toe}\right) = 5.20\,m$

(Point O @ TOE: BOFtoe = EL.1205.5)

Water Depth Above Fixed Crest at Gate: $D_{hwg.U1} := HW_{U1} - TOC_{fcc} = 0.6\,m$

Water Load Unit Width on Gate $w_{hwg.U1} := 2 \cdot \dfrac{20.00}{2}\,m = 20.00\,m$

Apply Load to Gate?: $poss_{U1} = 1$

poss = 1 if gate is closed
0 if gate is open

Total Horizontal Water Load on Gate: $H_{hwg.U1} := \dfrac{-\left(\gamma_w \cdot D_{hwg.U1}{}^2\right)}{2} \cdot w_{hwg.U1} \cdot poss_{U1} = -35.3 \cdot kN$

Apply Total Gate Water Load at: $H_{hwg.U1.loc} := \dfrac{D_{hwg.U1}}{3} + \left(TOC_{fcc} - BOF_{toe}\right) = 6.20\,m$

Water Depth at Heel: $D_{hwf.U1} := HW_{U1} - BOF_{elev} = 8.10\,m$

Water Load Unit With on Footing: $w_{hw.U1} := W_b = 13.00\,m$

Water Load at Bottom of Footing: $H_{hwf.U1.1} := -\left(\gamma_w \cdot D_{hwf.U1}\right) \cdot w_{hw.U1} = -1033\,\dfrac{1}{m} \cdot kN$

Water Load at Top of Footing: $H_{hwf.U1.2} := -\left(\gamma_w \cdot D_{hwg.U1}\right) \cdot w_{hw.U1} = -76.5\,\dfrac{1}{m} \cdot kN$

Total Horizontal Water Load on Footing: $H_{hwf.U1} := \dfrac{\left(H_{hwf.U1.1} + H_{hwf.U1.2}\right) \cdot \left(D_{hwf.U1} - D_{hwg.U1}\right)}{2} = -4160.7 \cdot kN$

Apply Total Footing Water Load at:

$$H_{hwf.U1.loc} := \frac{H_{hwf.U1.2} \cdot \dfrac{\left(TOC_{fcc} - BOF_{elev}\right)^2}{2} + \dfrac{\left(H_{hwf.U1.1} - H_{hwf.U1.2}\right)}{2} \dfrac{\left(TOC_{fcc} - BOF_{elev}\right)^2}{3}}{\dfrac{\left(H_{hwf.U1.2} + H_{hwf.U1.1}\right) \cdot \left(TOC_{fcc} - BOF_{elev}\right)}{2}} - \left(BOF_{toe} - BOF_{elev}\right) = 1.17\,m$$

(Converting horizontal force resultant from HEEL calculation to Point-O@TOE)

LATERAL WATER LOADS (cont.)

U1 CASE

TAILWATER (RESISTING):

Water Depth at toe: $D_{tw.U1} := TW_{U1} - BOF_{elev} = 3.50\,m$

Water Load Unit Width: $W_{twf.U1} := W_b = 13.00\,m$

Total Horizontal Tailwater Load on Footing under Gate Openings, i.e., excluding Pier

Resisting Water on Rear Face of Monolith, i.e., bottom of heel elevation

$COND_{U1} := poss_{U1} = 0 \wedge TW_{U1} \geq TOC_{fcc}$

$$H_{twf.U1} := \begin{cases} \dfrac{\gamma_w \cdot D_{tw.U1}^{\,2}}{2} \cdot \left(W_{twf.U1} - w_{pdg}\right) & \text{if } poss_{U1} = 1 \\ \dfrac{\gamma_w \cdot D_{tw.U1}^{\,2}}{2} \cdot \left(W_{twf.U1} - w_{pdg}\right) & \text{if } poss_{U1} = 0 \wedge TW_{U1} \leq TOC_{fcc} \\ \gamma_w \cdot \left[\dfrac{D_{tw.U1}}{2} + \dfrac{\left(TW_{U1} - TOC_{fcc}\right)}{2}\right] \cdot \left(TOC_{fcc} - BOF_{elev}\right) \cdot \left(W_{twf.U1} - w_{pdg}\right) & \text{if } COND_{U1} \end{cases} = 540.8 \cdot kN$$

Apply Footing Tailwater Load within Gate Openings at:

$$H_{twf.U1.loc} := \begin{cases} \dfrac{D_{tw.U1}}{3} - \left(BOF_{toe} - BOF_{elev}\right) & \text{if } poss_{U1} = 1 \\ \dfrac{D_{tw.U1}}{3} - \left(BOF_{toe} - BOF_{elev}\right) & \text{if } poss_{U1} = 0 \wedge TW_{U1} \leq TOC_{fcc} \\ \dfrac{\left(TOC_{fcc} - BOF_{elev}\right)^2 \cdot \left[\dfrac{\left(TW_{U1} - TOC_{fcc}\right)}{2} + \dfrac{\left(\left(TOC_{fcc} - BOF_{elev}\right)\right)}{6}\right]}{\left(TOC_{fcc} - BOF_{elev}\right)\left[\left(TW_{U1} - TOC_{fcc}\right) + \dfrac{\left(TOC_{fcc} - BOF_{elev}\right)}{2}\right]} - \left(BOF_{toe} - BOF_{elev}\right) & \text{if } COND_{U1} \end{cases} = -0.33 \cdot m$$

Total Horizontal Tailwater Load on Pier:

$$H_{twp.U1} := \frac{\gamma_w \cdot D_{tw.U1}^{\,2}}{2} \cdot w_{pdg} = 240.3 \cdot kN$$

Apply Horizontal Tailwater Load on Pier at:

$$H_{twp.U1.loc} := \frac{D_{tw.U1}}{3} - \left(BOF_{toe} - BOF_{elev}\right) = -0.33 \cdot m$$

$$\Sigma H_{Water.U1} := H_{hwp.U1} + H_{hwg.U1} + H_{hwf.U1} + H_{twf.U1} + H_{twp.U1} = -3501.4 \cdot kN$$

$$\Sigma M_{HWater.U1} := H_{hwp.U1} \cdot H_{hwp.U1.loc} + H_{hwg.U1} \cdot H_{hwg.U1.loc} + H_{hwf.U1} \cdot H_{hwf.U1.loc} \cdots + H_{twf.U1} \cdot H_{twf.U1.loc} + H_{twp.U1} \cdot H_{twp.U1.loc} = -5807.3 \cdot kN \cdot m$$

VERTICAL WATER LOADS

U1 CASE

HEADWATER:

Water Depth on top of fixed crest: $d_{hw.U1} := HW_{U1} - TOC_{as} = 2.10\,m$

Subtract Pier Volume: $S_{pn.U1} := \frac{(A_{pnt} - A_{pnb})}{h_{pn}} = 1.00 \cdot \frac{m^2}{m}$

$$V_{pn.U1} := \frac{\left[\left(S_{pn.U1} \cdot d_{hw.U1} + A_{pnb}\right) + A_{pnb}\right]}{2} \cdot d_{hw.U1} = 43 \cdot m^3$$

Weight of Water (H1) on Approach Slab: $H_{1.U1} := \left(W_{hw.U1} \cdot d_{hw.U1} \cdot L_{as} - V_{pn.U1}\right) \cdot \gamma_w = 1238.5 \cdot kN$

Horiz. Moment Arm for H1 (from toe): $H_{1.U1.loc} := L_b - \frac{L_{as}}{2} = 21.10\,m$

Distance from Gate to Toe: $Dist_{gate} := 10.2 \cdot m$

Cross-sectional Area of Headwater Above Fixed Crest: $A_{fc.hw.U1} := 4.98 m^2$ (From Bluebeam Measurement)

Volume of water Above Fixed Crest: $V_{fc.hw.U1} := \left[A_{fc.hw.U1} \cdot \left(W_{hw.U1} - w_{pn}\right)\right] = 44.8 \cdot m^3$

Weight of Water (H2) on Fixed Crest: $H_{2.U1} := \left(V_{fc.hw.U1}\right) \cdot \gamma_w = 439.7 \cdot kN$

Horiz. Moment Arm for H2 (from toe): $H_{2.U1.loc} := X_{pug} = 14.25\,m$

TAILWATER:

Slope of Crest from D/S of Gate to edge of Stilling Basin: $S_{f.U1} := \frac{\left(TOC_{fcc} - TOC_{fce}\right)}{8.00m} = 0.500$

Height of Tailwater Above Stilling Basin:

$$y_{U1} := \begin{cases} \left(TW_{U1} - TOC_{fce}\right) & \text{if } TW_{U1} \le TOC_{fcc} \\ \left(TOC_{fcc} - TOC_{fce}\right) & \text{otherwise} \end{cases}$$

$y_{U1} = 0.00\,m$

Horizontal Distance of Tailwater Above Sloped Portion of Crest: $x_{U1} := \frac{y_{U1}}{S_{f.U1}} = 0.00\,m$

Cross Sectional Area of Tailwater Above Sloped Portion of Crest: $A_{tw.U1} := \frac{x_{U1} \cdot y_{U1}}{2} = 0\,m^2$

$= 0.00 m^2$ if TW_{U1} is less than or equal to TOC_{fce}

Weight of Water (H3) Above Slope Portion of Crest:

$$H_{3.U1} := \begin{cases} (0.0kN) & \text{if } TW_{U1} \le TOC_{fce} \\ \left[A_{tw.U1} \cdot \left(W_{twf.U1} - w_{pdg}\right)\right] \cdot \gamma_w & \text{if } TOC_{fcc} \ge TW_{U1} > TOC_{fce} \\ \left[A_{tw.U1} + Dist_{gate} \cdot \left(TW_{U1} - TOC_{fcc}\right)\right] \cdot \left(W_{twf.U1} - w_{pdg}\right) \cdot \gamma_w & \text{if } TW_{U1} > TOC_{fcc} \end{cases}$$

$H_{3.U1} = 0.0 \cdot kN$

Horiz. Moment Arm for H3 (from Toe):

$$H_{3.U1.loc} := \begin{cases} (0.00m) & \text{if } TW_{U1} \le TOC_{fce} \\ \left(\frac{1}{3} \cdot x_{U1}\right) & \text{if } TOC_{fcc} \ge TW_{U1} > TOC_{fce} \\ \dfrac{\left[\frac{1}{2} \cdot x_{U1} \cdot y_{U1} \cdot \left(\frac{1}{3}\right) x_{U1} + \left(TW_{U1} - TOC_{fcc}\right) \cdot Dist_{gate} \cdot \left(\frac{Dist_{gate}}{2}\right)\right]}{\left(\frac{1}{2} x_{U1} \cdot y_{U1}\right) + \left(TW_{U1} - TOC_{fcc}\right) \cdot Dist_{gate}} & \text{if } TW_{U1} > TOC_{fcc} \end{cases}$$

$H_{3.U1.loc} = 0.00\,m$

UPLIFT AT INCLINED SLIDING PLANE

U1 CASE

Uplift pressure at Headwater: $U_{HW.U1} := D_{hwf.U1} \cdot \gamma_w = 79.46 \cdot \frac{kN}{m^2}$

Uplift pressure at D/S end of Stilling Basin: $U_{TW.U1} := D_{tw.U1} \cdot \gamma_w = 34.3 \cdot \frac{kN}{m^2}$

Length from U/S Face of Gate Structure to Toe Point O (Effective drain, Lsb = 0*m) $L_{overall} := L_b + L_{sb} = 24.20\,m$ $L_{sb} = 0$

Length of Seepage per Line of Creep $L_{seepage} := L_{BC} + L_{CD} + L_{DE} + L_{EF} + L_{FG} + L_{sb} = 27.1\,m$

Difference between Uplift pressure at Headwater and Uplift Pressure at Toe of Stilling Basin: $U_{diffU1} := U_{HW.U1} - U_{TW.U1} = 45.1 \cdot \frac{kN}{m^2}$

Slope of difference between Uplift pressure at Headwater and Uplift Pressure at Toe of Stilling Basin: $U_{slopeU1} := \frac{U_{diffU1} - Key_d \cdot \gamma_w}{L_{overall}} = 1.26 \cdot \frac{kN}{m^2 \cdot m}$ $Key_d = 1.5\,m$

$$U_{seepageslopeU1} := \frac{U_{diffU1} - Key_d \cdot \gamma_w}{L_{seepage}}$$

Pore Pressure at Base of Gate Structure: $U_{press.toe.gsU1} := U_{TW.U1} + L_{sb} \cdot U_{slopeU1} = 34.3 \cdot \frac{kN}{m^2}$

$$U_{pore.toe.U1} := U_{TW.U1} + U_{seepageslopeU1} \cdot L_{sb} = 34.3 \cdot \frac{kN}{m^2}$$

$$U_{pore.F.U1} := U_{pore.toe.U1} + U_{seepageslopeU1} \cdot L_{FG} = 36 \cdot \frac{kN}{m^2}$$

$$U_{pore.E.U1} := U_{pore.F.U1} - \left(BOF_{base} - BOF_{toe}\right) \cdot \gamma_w + U_{seepageslopeU1} \cdot L_{EF} = 25.1 \cdot \frac{kN}{m^2}$$

$$U_{pore.D.U1} := U_{pore.E.U1} + U_{seepageslopeU1} \cdot L_{DE} = 45.5 \cdot \frac{kN}{m^2}$$

$$U_{pore.C.U1} := U_{pore.D.U1} + \left(BOF_{base} - BOF_{elev}\right) \cdot \gamma_w + U_{seepageslopeU1} \cdot L_{CD} = 78.3 \cdot \frac{kN}{m^2}$$

Uniform uplift due to Tailwater: (rectangular portion) $U_{A.U1} := U_{press.toe.gsU1} \cdot L_b \cdot W_b \cdot -1 = -10801.8 \cdot kN$

Moment Arm for Uplift UA from Toe of Gate Structure: $L_{A.U1} := \frac{L_b}{2} = 12.10\,m$

Uplift - Linear Decrease from HW to TW: (triangular portion) $U_{B.U1} := \frac{1}{2} \cdot \left(U_{HW.U1} - U_{press.toe.gsU1}\right) \cdot L_b \cdot W_b \cdot -1 = -7098.3 \cdot kN$

Moment Arm for Uplift UB from Toe of Gate Structure: $L_{B.U1} := \frac{2}{3} \cdot L_b = 16.13\,m$

Total Resultant Uplift force for Sliding Analysis: $U_{U1} := U_{A.U1} + U_{B.U1} = -17900.1 \cdot kN$

Resultant Location from Toe: $U_{U1.loc} := \frac{U_{A.U1} \cdot L_{A.U1} + U_{B.U1} \cdot L_{B.U1}}{U_{A.U1} + U_{B.U1}} = 13.70\,m$

$$\Sigma V_{water.U1} := H_{1.U1} + H_{2.U1} + H_{3.U1} + U_{U1} = -16221.9 \cdot kN$$

$$\Sigma M_{Vwater.U1} := H_{1.U1} \cdot H_{1.U1.loc} + H_{2.U1} \cdot H_{2.U1.loc} + H_{3.U1} \cdot H_{3.U1.loc} + U_{U1} \cdot U_{U1.loc} = -212822.7 \cdot kN \cdot m$$

Uplift as per Line of Creep Method (Flotation and Overturning)

U1 CASE

$$Uplift_{BC.U1} := \frac{-1}{2} \cdot W_b \cdot \left(U_{HW.U1} + U_{pore.C.U1}\right) \cdot L_{BC} = -1025.7 \cdot kN$$

$$Uplift_{CD.U1} := 0$$

$$Uplift_{DE.U1} := \frac{-1}{2} \cdot W_b \cdot \left(U_{pore.D.U1} + U_{pore.E.U1}\right) \cdot L_{DE} = -8356.4 \cdot kN$$

$$Uplift_{EF.U1} := \frac{-1}{2} \cdot W_b \cdot \left(U_{pore.E.U1} + U_{pore.F.U1}\right) \cdot L_{EF} = -1330 \cdot kN$$

$$Uplift_{FG.U1} := \frac{-1}{2} \cdot W_b \cdot \left(U_{pore.F.U1} + U_{pore.toe.U1}\right) \cdot L_{FG} = -685.9 \cdot kN$$

$$Uplift_{pore.U1} := Uplift_{BC.U1} + Uplift_{DE.U1} + Uplift_{EF.U1} + Uplift_{FG.U1} = -11398 \cdot kN$$

$$Uplift_{FG.U1.loc} := \frac{L_{FG}}{3} \cdot \frac{\left(2 \cdot U_{pore.F.U1} + U_{pore.toe.U1}\right)}{\left(U_{pore.F.U1} + U_{pore.toe.U1}\right)} = 0.76\,m$$

$$Uplift_{EF.U1.loc} := \frac{L_{EF}}{3} \cdot \frac{\left(2 \cdot U_{pore.E.U1} + U_{pore.F.U1}\right)}{\left(U_{pore.E.U1} + U_{pore.F.U1}\right)} + L_{FG} = 3.07\,m$$

$$Uplift_{DE.U1.loc} := \frac{L_{DE}}{3} \cdot \frac{\left(2 \cdot U_{pore.D.U1} + U_{pore.E.U1}\right)}{\left(U_{pore.D.U1} + U_{pore.E.U1}\right)} + L_{FG} + X_{EF} = 14.48\,m$$

$$Uplift_{BC.U1.loc} := \frac{L_{BC}}{3} \cdot \frac{\left(2 \cdot U_{HW.U1} + U_{pore.C.U1}\right)}{\left(U_{HW.U1} + U_{pore.C.U1}\right)} + L_{FG} + X_{EF} + L_{DE} = 23.21\,m$$

U1 CASE

SOIL LOADS

Equivalent Fluid Pressure (EFP):

At rest lateral pressure coefficient: $K_o := 1 - \sin(\phi_{backfill}) = 0.66$ (CFEM 24.1)

Lateral Driving Force (Headwater Side)

(At-rest Soil Pressure to Heel, EM1110--2-2502 Section 3-7)

Depth of Fill at Heel: $t_{hf.U1} := TOC_{as} - BOF_{elev} = 6.00\,m$

Soil Load: $E1_{drive.U1} := \frac{K_o \cdot t_{hf.U1}^{2}}{2} \cdot (\gamma_r - \gamma_w) \cdot W_b \cdot -1 = -1876.9 \cdot kN$

Acting at: $E1_{drive.loc.U1} := \frac{t_{hf.U1}}{3} - (BOF_{toe} - BOF_{elev}) = 0.50\,m$

Lateral Resisting Force (Tailwater Side)

Depth of Fill at Toe: $t_{tf.U1} := TOC_{fce} - BOF_{toe} = 2.00\,m$ (EM1110--2-2502 Fig.4-11)

At-Rest Soil Load: $E2_{resistU1} := \frac{K_o \cdot t_{tf.U1}^{2}}{2} \cdot (\gamma_r - \gamma_w) \cdot W_b = 208.5 \cdot kN$ $E2_{resistU1} := 0$

Acting at: $E2_{resistlocU1} := \frac{t_{tf.U1}}{3} = 0.67\,m$ (Expansion Joint to Stilling Basin, No Sediment in Gap)

$\Sigma H_{soil.U1} := E1_{drive.U1} + E2_{resistU1} = -1668.3 \cdot kN$

$\Sigma M_{soil.U1} := E1_{drive.U1} \cdot E1_{drive.loc.U1} + E2_{resistU1} \cdot E2_{resistlocU1} = -799.4 \cdot kN \cdot m$

ICE / IMPACT LOADS (CONSERVATIVELY ASSUME NO ICE LOADING ON DOWNSTREAM SIDE)

Static Impact Loading on Structure: $I_{S.U1} := 150.0 \frac{kN}{m}$ (Section 7.7, Design Criteria)

Static Impact load on Gates: $I_{G.U1} := 75 \frac{kN}{m}$ (Section 7.7, Design Criteria)

Impact Loading Unit Width on Structure: $W_{S.U1} := 4.00m$

Impact Loading Unit Width on Gates: $W_{G.U1} := 2 \cdot \frac{20.00}{2} m = 20.00\,m$

Total Impact Load on Structure: $I_{U1} := (I_{S.U1} \cdot W_{S.U1} + I_{G.U1} \cdot W_{G.U1}) \cdot -1 = -2100 \cdot kN$

Apply Ice load at: $I_{U1.loc} := (HW_{U1} - BOF_{toe} - 0.30m) = 6.30\,m$

$\Sigma H_{I.U1} := I_{U1} = -2100 \cdot kN$

$\Sigma M_{I.U1} := I_{U1} \cdot I_{U1.loc} = -13230 \cdot kN \cdot m$

SEISMIC LOAD (Not Applicable to this Load Case)

SUMMARY OF LOADS

	Loads	Moment Arm
		U1 CASE
Dead Load of Concrete Structure:	$D_{conc} = 52182.8 \cdot kN$	$X_{conc.loc} = 12.43\,m$
Dead Load of Gate:	$D_{Gate} = 580.0 \cdot kN$	$X_{gate} = 9.75\,m$
Headwater Lateral Load on Pier:	$H_{hwp.U1} = -86.5 \cdot kN$	$H_{hwp.U1.loc} = 5.20\,m$
Headwater Lateral Load on Gate:	$H_{hwg.U1} = -35.3 \cdot kN$	$H_{hwg.U1.loc} = 6.20\,m$
Headwater Lateral Load on Footing:	$H_{hwf.U1} = -4160.7 \cdot kN$	$H_{hwf.U1.loc} = 1.17\,m$
Tailwater Lateral Load:	$H_{twf.U1} = 540.8 \cdot kN$	$H_{twf.U1.loc} = -0.33\,m$
Tailwater Lateral Load on Pier:	$H_{twp.U1} = 240.3 \cdot kN$	$H_{twp.U1.loc} = -0.33\,m$
Water Weight (HW) on Apron Slab:	$H_{1.U1} = 1238.5 \cdot kN$	$H_{1.U1.loc} = 21.10\,m$
Water Weight (HW) on Fixed Crest:	$H_{2.U1} = 439.7 \cdot kN$	$H_{2.U1.loc} = 14.25\,m$
Water Weight (TW) on Fixed Crest:	$H_{3.U1} = 0.0 \cdot kN$	$H_{3.U1.loc} = 0.00\,m$
Uplift:	$U_{U1} = -17900.1 \cdot kN$	$U_{U1.loc} = 13.70\,m$
Upstream (driving) Lateral Soil Load:	$E1_{drive.U1} = -1876.9 \cdot kN$	$E1_{drive.loc.U1} = 0.50\,m$
Downstream (resisting) Lateral Soil Load:	$E2_{resistU1} = 208.5 \cdot kN$	$E2_{resistlocU1} = 0.67\,m$
Ice / Impact Load:	$I_{U1} = -2100.0 \cdot kN$	$I_{U1.loc} = 6.30\,m$

STABILITY ASSESSMENT (SLIDNG, BEARING, FLOTATION AND OVERTURNING): U1 CASE

CHECK SLIDING ALONG HORIZONTAL PLANE THRU TOE,
IGNORING BEDROCK MOBILIZED BY STRUCTURAL HEEL KEY, OR VOID BEHIND KEY

Sum of Vertical Forces:

$\Sigma V_{U1} := \Sigma V_{DL.U1} + \Sigma V_{water.U1} = 36221.9 \cdot kN$

Sum of Horizontal Forces:

$\Sigma H_{U1} := \Sigma H_{Water.U1} + \Sigma H_{soil.U1} + \Sigma H_{I.U1} = -7269.7 \cdot kN$

Sliding Factor of Safety:

$$FS_{HorizSliding.U1} := \frac{\tan_{\phi} \cdot \Sigma V_{U1}}{\left|\Sigma H_{U1}\right|} = 2.43$$

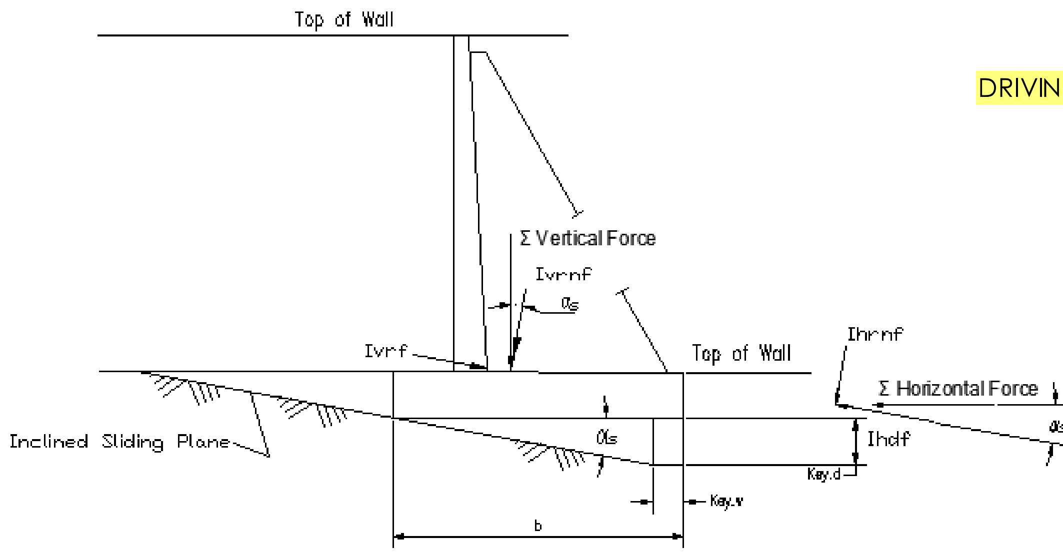
$$FS_{HorizSliding.U1.Check} := \begin{cases} \text{"OKAY"} & \text{if } FS_{HorizSliding.U1} \ge FS_{req.U1.sl} \\ \text{"Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

$FS_{HorizSliding.U1.Check} = \text{"OKAY"}$

CHECK SLIDING ALONG INCLINED SLIDING PLANE FROM HEEL KEY TO TOE,
WITH BEDROCK MASS MOBILIZED BY REINFOCREDE CONCRETE KEY)

RESISTING SIDE

DRIVING SIDE



HEEL

TOE

Ivrf=Inclined Resisting Force
Ivrnf=Inclined Resisting Normal Force
Ihrnf=Inclined Resisting Normal Force
Ihdf=Inclined Driving Force

$$\alpha s := \operatorname{atan}\left(\frac{BOF_{toe} - BOF_{elev}}{L_b - Key_l}\right) = 0.13 \qquad \text{as degrees=} \quad \alpha s \cdot \left(\frac{180}{\pi}\right) = 7.63$$

Resolve $\Sigma Vert_{U1}$ & $\Sigma Horiz_{U1}$

$$\Sigma V_{InclinedU1} := \cos(\alpha s) \cdot \left(\Sigma V_{U1} + V_{rs}\right) + \sin(\alpha s) \cdot \left|\Sigma H_{U1}\right| = 49968.3 \cdot kN$$

$$\Sigma H_{InclinedU1} := \cos(\alpha s) \cdot \left|\Sigma H_{U1}\right| - \sin(\alpha s) \cdot \left(\Sigma V_{U1} + V_{rs}\right) = 642.4 \cdot kN$$

(With properly engineered reinforced concrete Key, horizontal sliding plane thru Toe is protected, critical sliding plane is relocated to the INCLINED SLIDING PLANE FROM HEEL KEY To TOE, Bedrock Mass above this examing plane is mobilized by reinforced concrete key and combined into Structural Wedge.)

Inclined Sliding Plane Length

$$L_{incline} := \left[L_b^{\,2} + \left(BOF_{toe} - BOF_{elev}\right)^2\right]^{0.5} = 24.25\,m$$

Safety Factor for Sliding
Inclined Failure Plane

$$FS_{InclinedlSlidingU1} := \frac{\Sigma V_{InclinedU1} \cdot \tan\left(\phi_{rock} \cdot \frac{\pi}{180}\right)}{\left|\Sigma H_{InclinedU1}\right|} = 37.94$$

$$FS_{InclinedSliding.check.U1} := \begin{cases} \text{"OKAY "} & \text{if } FS_{InclinedlSlidingU1} > FS_{req.U1.sl} \\ \text{"Revise Structure""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

$FS_{InclinedSliding.check.U1} = \text{"OKAY "}$

CHECK ECCENTRICITY ON INCLINED PLANE

U1 CASE

Sum of the Moments:

$$\Sigma M_{rs.U1} := \Sigma M_{DL.U1} + \Sigma M_{HWater.U1} + \Sigma M_{Vwater.U1} + \Sigma M_{I.U1} + \Sigma M_{soil.U1} + V_{rs} \cdot L_{rs} = 602996 \cdot kN \cdot m$$

Eccentricity:

$$e_{U1} := \frac{L_{incline}}{2} - \frac{\Sigma M_{rs.U1}}{\Sigma V_{InclinedU1}} = 0.06\,m$$

Eccentricity Check:

$$e_{check.U1} := \begin{cases} \text{"Okay"} & \text{if } \left|e_{U1}\right| \le Kern \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$$e_{check.U1} = \text{"Okay"}$$

Foundation Bearing Pressures on Inclined Plane:

Bearing Pressure at Heel:

$$\sigma_{heel.U1} := \frac{\Sigma V_{InclinedU1}}{\dfrac{A_b}{\cos(\alpha s)}} - \frac{\Sigma V_{InclinedU1} \cdot e_{U1}}{\dfrac{S_b}{\cos(\alpha s)^2}} = 155.3 \cdot \frac{kN}{m^2}$$

$$\sigma_{heel.U1.check} := \left(\begin{cases} \text{"Okay"} & \text{if } \sigma_{heel.U1} \le \sigma_{allow.U1} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} \right)$$

$$\sigma_{heel.U1.check} = \text{"Okay"}$$

Bearing Pressure at Toe:

$$\sigma_{toe.U1} := \frac{\Sigma V_{InclinedU1}}{\dfrac{A_b}{\cos(\alpha s)}} + \frac{\Sigma V_{InclinedU1} \cdot e_{U1}}{\dfrac{S_b}{\cos(\alpha s)^2}} = 159.6 \cdot \frac{kN}{m^2}$$

$$\sigma_{toe.U1.check} := \begin{cases} \text{"Okay"} & \text{if } \sigma_{toe.U1} \le \sigma_{allow.U1} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$$\sigma_{toe.U1.check} = \text{"Okay"}$$

CHECK FLOTATION

$$Uplift_{sliding.U1} := U_{U1} = -17900.1 \cdot kN$$

$$Uplift_{pore.U1} = -11398 \cdot kN$$

(For conservative, taking maximum values)

$$\left(Uplift_{U1}\right) := \min\left(Uplift_{pore.U1}, Uplift_{sliding.U1}\right) = -17900.1 \cdot kN$$

$$FS_{Flotation.U1} := \frac{D_{conc} + D_{Gate} + H_{1.U1} + H_{2.U1} + H_{3.U1}}{\left|Uplift_{U1}\right|} = 3$$

$$FS_{Flotation.U1.check} := \begin{cases} \text{"OKAY "} & \text{if } FS_{Flotation.U1} > FS_{req.U.flt} \\ \text{"Revise Structure""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

MONOLITH OVERTURNING STABILITY ANALYSIS

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.
Assumptions are made in order to compute overturning stability of indetermine forces on monolith with key;
(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.
(b) The horizontal resisting force acting on the key, P.key, is that required for static equilibrium
(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1 $Ratio_{overturning.allow.Usual} := 0.333$

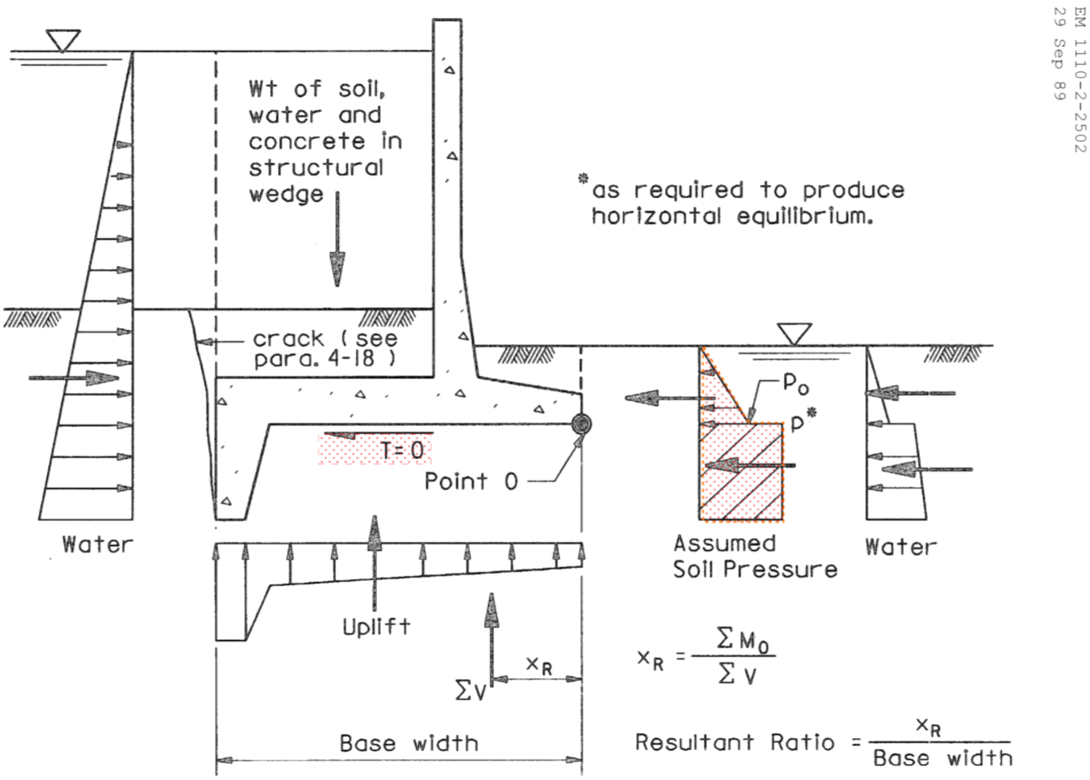


Figure 4-5. Forces for overturning analysis for wall with horizontal base and key

All Vertical Loads Applicable to Overturning Stability Analysis

Total Concrete Dead Loads:	$D_{conc} = 52182.8 \cdot kN$	at:	$X_{conc.loc} = 12.4\,m$
Dead Load of Gate:	$D_{Gate} = 580.0 \cdot kN$		$X_{gate} = 9.75\,m$
Water Weight (HW) on Apron Slab:	$H_{1.U1} = 1238.5 \cdot kN$		$H_{1.U1.loc} = 21.10\,m$
Water Weight (HW) on Fixed Crest:	$H_{2.U1} = 439.7 \cdot kN$		$H_{2.U1.loc} = 14.25\,m$
Water Weight (TW) on Fixed Crest:	$H_{3.U1} = 0.0 \cdot kN$		$H_{3.U1.loc} = 0.00\,m$

Uplift Force from Sliding Analysis. Line of Creep Method applied at presumed inclined sliding line, and subtraction gravity effect to Base of Concrete by Archimedes Principle

$$U_{U1.loc.sliding} := \frac{U_{A.U1} \cdot L_{A.U1} + U_{B.U1} \cdot L_{B.U1} - A_{rs} \cdot w_{as} \cdot \gamma_w \cdot L_{rs}}{U_{A.U1} + U_{B.U1} - A_{rs} \cdot w_{as} \cdot \gamma_w} = 13.76\,m$$

$$U_{U1.sliding} := U_{U1} + A_{rs} \cdot w_{as} \cdot \gamma_w = -12005.7 \cdot kN$$

U1 CASE

Uplift for Overturning Analysis, Line of Creep Method. Pore pressure at base of Concrete $Uplift_{pore.U1} = -11398 \cdot kN$

$$Uplift_{pore.U1.loc} := \frac{\left(Uplift_{BC.U1} \cdot Uplift_{BC.U1.loc} + Uplift_{DE.U1} \cdot Uplift_{DE.U1.loc} + Uplift_{EF.U1} \cdot Uplift_{EF.U1.loc} + Uplift_{FG.U1} \cdot Uplift_{FG.U1.loc}\right)}{Uplift_{pore.U1}}$$

$Uplift_{pore.U1.loc} = 13.1\ m$

Sum of All Water Load for Overturning Analysis

$$\Sigma V_{water.U1.OT} := H_{1.U1} + H_{2.U1} + H_{3.U1} + Uplift_{pore.U1} = -9719.8 \cdot kN$$

All Lateral Loads Applicable to Overturning Stability Analysis

Apply Load to Gate?: $poss_{U1} = 1$ poss = 1 if gate is closed 0 if gate is open

Headwater Lateral Load on Pier: $H_{hwp.U1} = -86.5 \cdot kN$ $H_{hwp.U1.loc} = 5.20\ m$

Headwater Lateral Load on Gate: $H_{hwg.U1} = -35.3 \cdot kN$ $H_{hwg.U1.loc} = 6.20\ m$

Headwater Lateral Load on Footing: $H_{hwf.U1} = -4160.7 \cdot kN$ $H_{hwf.U1.loc} = 1.17\ m$

Total Horizontal Tailwater Load on Pier: $H_{twp.U1} = 240.3 \cdot kN$ $H_{twp.U1.loc} = -0.33\ m$

Total Horizontal Tailwater Load on Footing under Gate Openings, i.e., excluding Pier $H_{twf.U1} = 540.8 \cdot kN$ $H_{twf.U1.loc} = -0.33\ m$

Resisting Water on Rear Face of Monolith, i.e., bottom of heel elevation: *(Point O @ TOE: BOFtoe = EL.1205.5)*

Ice / Impact Load: $I_{U1} = -2100.0 \cdot kN$ at: $I_{U1.loc} = 6.30\ m$

Depth of Fill at Heel Side for Overturning Analysis: $t_{hf.U1} := TOC_{as} - BOF_{toe} = 4.50\ m$

Driving Soil Load for overturning: $$E1_{drive.U1} := \frac{K_o \cdot t_{hf.U1}^{\,2}}{2} \cdot \left(\gamma_r - \gamma_w\right) \cdot W_b \cdot -1 = -1055.7 \cdot kN$$

Acting at: $$E1_{drive.loc.U1} := \frac{t_{hf.U1}}{3} = 1.50\ m$$

Downstream (resisting) Lateral Soil Load as required to produce horizontal equilibrium:

$$E2_{resistU1} := -1 \cdot \left(H_{hwp.U1} + H_{hwg.U1} + H_{hwf.U1} + H_{twp.U1} + H_{twf.U1} + I_{U1} + E1_{drive.U1}\right)$$

$E2_{resistU1} = 6657.1 \cdot kN$

Assumed Resisting Bedrock at middle of Key, passive soil pressure or lateral bearing contract joint at end of Monolith 3A3B $$E2_{resistlocU1} := \frac{-\left(BOF_{toe} - BOF_{elev}\right)}{2} = -0.75\ m$$

Overturning moment by Dead Loads about Point O @ Toe $\Sigma M_{DL.U1} = 651119.6 \cdot kN \cdot m$

Overturning moment by Vertical Water Loads and Uplift, about Point O @ Toe

$$\Sigma M_{Vwater.U1.OT} := H_{1.U1} \cdot H_{1.U1.loc} + H_{2.U1} \cdot H_{2.U1.loc} + H_{3.U1} \cdot H_{3.U1.loc} + Uplift_{pore.U1} \cdot Uplift_{pore.U1.loc} = -117014.3 \cdot kN \cdot m$$

U1 CASE

Overturning moment by Lateral Hydrostatic Forces of Headwater Pool and Tailwater Pool, about Point O @ Toe

$\Sigma M_{HWater.U1} = -5807.3 \cdot kN \cdot m$

Overturning Moment by Impact/Ice Load, about Point O@ Toe

$\Sigma M_{I.U1} = -13230 \cdot kN \cdot m$

Overturning moment by Lateral Soil Forces about Point O @ Toe

$\Sigma M_{soil.U1} := E1_{drive.U1} \cdot E1_{drive.loc.U1} + E2_{resistU1} \cdot E2_{resistlocU1} = -6576.4 \cdot kN \cdot m$

Sum of the Overturning Moments about Point O @ Toe:

$\Sigma M_{U1.OT} := \Sigma M_{DL.U1} + \Sigma M_{HWater.U1} + \Sigma M_{Vwater.U1.OT} + \Sigma M_{I.U1} + \Sigma M_{soil.U1} = 508492 \cdot kN \cdot m$

Sum of Vertical Forces:

$\Sigma V_{U1.OT} := \Sigma V_{DL.U1} + \Sigma V_{water.U1.OT} = 42724.0 \cdot kN$

Distance X_R: EM 1110-2-2502 Eq.4-1

$$X_{R.U1} := \frac{\Sigma M_{U1.OT}}{\Sigma V_{U1.OT}} = 11.9\,m$$

Overturning Resultant Ratio

$$Ratio_{Overturning.U1} := \frac{X_{R.U1}}{L_b} = 0.49$$

EM 1110-2-2502

Table 4-1

Retaining Wall Stability Criteria

Loading Condition	Sliding Factor of Safety, FS	Shear Strength Test Required: Soil Foundation	Shear Strength Test Required: Rock Foundation[3]	Overturning Criteria Minimum Base Area in Compression: Soil Foundation	Overturning Criteria Minimum Base Area in Compression: Rock Foundation
Usual	1.5	(Q &/or S)[2,1]	Direct shear	100%[4]	75%[4]
Unusual	1.33	(Q &/or S)[2,1]	Direct shear	75%[4]	50%[4]
Earthquake	1.1	(Q)	Direct shear	Resultant within base	Resultant within base

Overturning Stability Check

$$Ratio_{Overturning.U1.check} := \begin{cases} \text{"Okay"} & \text{if } Ratio_{Overturning.U1} \geq Ratio_{overturning.allow.Usual} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$Ratio_{Overturning.U1.check} = \text{"Okay"}$

Summary of Extreme Flood Results (Only Report Controlling Load Case)

U1 CASE

U1 Event: Normal Operation

Horiz Sliding Factor of Safety: $FS_{HorizSliding.U1} = 2.43$

Horiz Sliding Factor of Safety Check: $FS_{HorizSliding.U1.Check} = \text{"OKAY"}$

Sliding Factor of Safety: $FS_{InclinedlSlidingU1} = 37.9$

Sliding Factor of Safety Check: $FS_{InclinedSliding.check.U1} = \text{"OKAY "}$

Eccentricity: $e_{U1} = 0.06\,m$

Eccentricity Check: $e_{check.U1} = \text{"Okay"}$

Bearing Pressure At Heel on Inclined Plane: $\sigma_{heel.U1} = 155.3 \cdot \frac{kN}{m^2}$

Bearing Pressure At Heel Check: $\sigma_{heel.U1.check} = \text{"Okay"}$

Bearing Pressure At Toe on Inclined Plane: $\sigma_{toe.U1} = 159.6 \cdot \frac{kN}{m^2}$

Bearing Pressure At Toe Check: $\sigma_{toe.U1.check} = \text{"Okay"}$

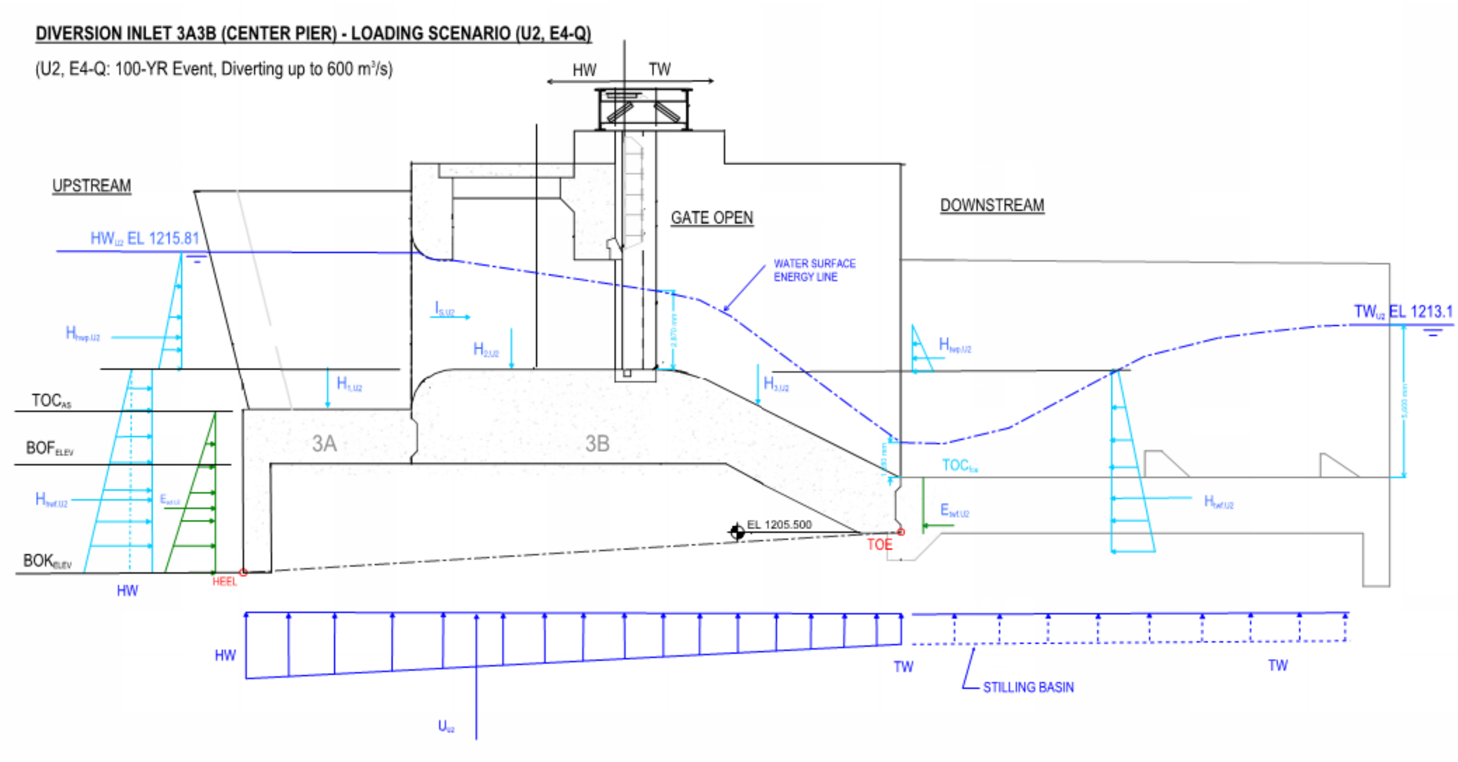
Flotation Factor of Safety: $FS_{Flotation.U1} = 3$

Flotation Factor of Safety Check: $FS_{Flotation.U1.check} = \text{"OKAY "}$

Overturning Resultant Ratio: $Ratio_{Overturning.U1} = 0.49$

Overturning Stability Check: $Ratio_{Overturning.U1.check} = \text{"Okay"}$

U2 DESIGN CASE



ACCEPTANCE PARAMETERS

Required Factor of Safety for Sliding: $FS_{req.U2.sl} := 1.5$ (Without Cohesion) (Section 8.1, Design Criteria)

Resultant Within Middle Third of Base: $e \le \frac{L_b}{6} \wedge e \ge \frac{-L_b}{6}$ (100% Base in Compression, Design Criteria)

Allowable Rock Bearing Pressure: $\sigma_{allow.U2} := 1270.0 \cdot \frac{kN}{m^2}$ (Section 5.2, Design Criteria)

Required Factor of Safety for Flotation: $FS_{req.U.flt} = 1.5$

Overturning Min Required Resultant Ratio: $\frac{X_{R.U}}{Horizontal\_Width\_of\_Base} > 0.33$

U2 CASE

INPUT PARAMETERS

Headwater Elevation: $HW_{U2} := 1215.81m$

Tailwater Elevation: $TW_{U2} := 1213.10m$

(Water Elevations based on Diversion Structure 2D Hydraulic Model Results. See page 7 and Section 8.2, Design Criteria)

Crest Water Elevation, EL.1215.81 $CrestW_{U2} := 2.87 \cdot m$

Chute Block Water Elevation EL.1208.78 $ChuteW_{U2} := 1.28 \cdot m$ $TW_{U2} := TOC_{fce} + ChuteW_{U2} = 1208.8\,m$

Bottom of Key (Footing Heel) Elevation: $BOF_{elev} = 1204.00\,m$

Apron Slab Top of Concrete Elevation at Edge of Slab: $TOC_{as} = 1210.00\,m$

Fixed Crest Top of Concrete Elevation at Downstream Face: $TOC_{fce} = 1207.50\,m$

Fixed Crest Top of Concrete Elevation at Center of Footing: $TOC_{fcc} = 1211.50\,m$

VERTICAL LIFT GATE

Lift Gate Position per Hydraulic Criteria $poss_{U2} := 0$

poss = 1 if gate is closed
0 if gate is open

DEAD LOAD SUMMATION:

$$Gate_{R.U2} := \begin{cases} 1 & \text{if } poss_{U2} = 0 \\ 0.45 & \text{otherwise} \end{cases}$$

Monolith Reaction for Wheel Gate

$\Sigma V_{DL.U2} := D_{conc} + Gate_{R.U2} D_{Gate} = 52762.8 \cdot kN$

$\Sigma M_{DL.U2} := D_{conc} \cdot X_{conc.loc} + Gate_{R.U2} \cdot D_{Gate} \cdot X_{gate} = 654229.9 \cdot kN \cdot m$

LATERAL WATER LOADS

U2 CASE

HEADWATER (DRIVING):

Water Depth on Pier at Heel: $D_{hwp.U2} := HW_{U2} - TOC_{as} = 5.81\,m$

Water Load Unit Width on Pier: $W_{hwp.U2} := w_{pn} = 4.00\,m$

Total Horizontal Water Load on Pier: $H_{hwp.U2} := \dfrac{-\left(\gamma_w \cdot D_{hwp.U2}{}^2\right)}{2} \cdot W_{hwp.U2} = -662.3 \cdot kN$

Apply Total Pier Water Load at: $H_{hwp.U2.loc} := \dfrac{D_{hwp.U2}}{3} + \left(TOC_{as} - BOF_{toe}\right) = 6.44\,m$

Point O @ TOE: BOFtoe = EL.1205.5

Water Depth Above Fixed Crest at Gate: $D_{hwg.U2} := HW_{U2} - TOC_{fcc} = 4.3\,m$

Water Load Unit Width on Gate $W_{hwg.U2} := 2 \cdot \dfrac{20.00}{2}\,m = 20.00\,m$

Apply Load to Gate?: $poss_{U2} = 0$

poss = 1 if gate is closed
0 if gate is open

Total Horizontal Water Load on Gate: $H_{hwg.U2} := \dfrac{-\gamma_w \cdot D_{hwg.U2}{}^2}{2} \cdot W_{hwg.U2} \cdot poss_{U2} = 0 \cdot kN$

Apply Total Gate Water Load at: $H_{hwg.U2.loc} := \dfrac{D_{hwg.U2}}{3} + \left(TOC_{fcc} - BOF_{toe}\right) = 7.44\,m$

Water Depth at Heel: $D_{hwf.U2} := HW_{U2} - BOF_{elev} = 11.81\,m$

Water Load Unit With on Footing: $W_{hw.U2} := W_b$

Water Load at Bottom of Footing: $H_{hwf.U2.1} := -\left(\gamma_w \cdot D_{hwf.U2}\right) \cdot W_{hw.U2} = -1506.1\,\dfrac{1}{m} \cdot kN$

Water Load at Top of Footing: $H_{hwf.U2.2} := -\left(\gamma_w \cdot D_{hwg.U2}\right) \cdot W_{hw.U2} = -549.7\,\dfrac{1}{m} \cdot kN$

Total Horizontal Water Load on Footing: $H_{hwf.U2} := \dfrac{\left(H_{hwf.U2.1} + H_{hwf.U2.2}\right) \cdot \left(D_{hwf.U2} - D_{hwg.U2}\right)}{2} = -7709.2 \cdot kN$

Apply Total Footing Water Load at:

$$H_{hwf.U2.loc} := \frac{\left[H_{hwf.U2.2} \cdot \dfrac{\left(TOC_{fcc} - BOF_{elev}\right)^2}{2} + \dfrac{\left(H_{hwf.U2.1} - H_{hwf.U2.2}\right)}{2} \cdot \dfrac{\left(TOC_{fcc} - BOF_{elev}\right)^2}{3}\right]}{\left[\dfrac{\left(H_{hwf.U2.2} + H_{hwf.U2.1}\right) \cdot \left(TOC_{fcc} - BOF_{elev}\right)}{2}\right]} - \left(BOF_{toe} - BOF_{elev}\right) = 1.67\,m$$

(Converting horizontal force resultant from HEEL calculation to Point-O@TOE)

LATERAL WATER LOADS (cont.)

TAILWATER (RESISTING):

Water Depth at toe: $D_{tw.U2} := TW_{U2} - BOF_{elev} = 4.78\,m$

Water Load Unit Width: $W_{twf.U2} := W_b$

Total Horizontal Tailwater Load on Footing under Gate Openings, i.e., excluding Pier

Resisting Water on Rear Face of Monolith, i.e., bottom of heel elevation:

$COND_{U2} := poss_{U2} = 0 \wedge TW_{U2} \geq TOC_{fcc}$

$$H_{twf.U2} := \begin{cases} \dfrac{\gamma_w \cdot D_{tw.U2}^{\,2}}{2} \cdot \left(W_{twf.U2} - w_{pdg}\right) & \text{if } poss_{U2} = 1 \\ \dfrac{\gamma_w \cdot D_{tw.U2}^{\,2}}{2} \cdot \left(W_{twf.U2} - w_{pdg}\right) & \text{if } poss_{U2} = 0 \wedge TW_{U2} \leq TOC_{fcc} \\ \gamma_w \cdot \left[\dfrac{D_{tw.U2}}{2} + \dfrac{\left(TW_{U2} - TOC_{fcc}\right)}{2}\right] \cdot \left(TOC_{fcc} - BOF_{elev}\right) \cdot \left(W_{twf.U2} - w_{pdg}\right) & \text{if } COND_{U2} \end{cases} = 1008.6 \cdot kN$$

Apply Footing Tailwater Load within Gate Openings at:

$$H_{twf.U2.loc} := \begin{cases} \dfrac{D_{tw.U2}}{3} - \left(BOF_{toe} - BOF_{elev}\right) & \text{if } poss_{U2} = 1 \\ \dfrac{D_{tw.U2}}{3} - \left(BOF_{toe} - BOF_{elev}\right) & \text{if } poss_{U2} = 0 \wedge TW_{U2} \leq TOC_{fcc} \\ \dfrac{\left(TOC_{fcc} - BOF_{elev}\right)^2 \cdot \left[\dfrac{\left(TW_{U2} - TOC_{fcc}\right)}{2} + \dfrac{\left(\left(TOC_{fcc} - BOF_{elev}\right)\right)}{6}\right]}{\left(TOC_{fcc} - BOF_{elev}\right)\left[\left(TW_{U2} - TOC_{fcc}\right) + \dfrac{\left(TOC_{fcc} - BOF_{elev}\right)}{2}\right]} - \left(BOF_{toe} - BOF_{elev}\right) & \text{if } COND_{U2} \end{cases} = 0.09 \cdot m$$

Total Horizontal Tailwater Load on Pier:

$$H_{twp.U2} := \frac{\gamma_w \cdot D_{tw.U2}^{\,2}}{2} \cdot w_{pdg} = 448.3 \cdot kN$$

Apply Horizontal Tailwater Load on Pier at:

$$H_{twp.U2.loc} := \frac{D_{tw.U2}}{3} - \left(BOF_{toe} - BOF_{elev}\right) = 0.09 \cdot m$$

$$\Sigma H_{Water.U2} := H_{hwp.U2} + H_{hwg.U2} + H_{hwf.U2} + H_{twf.U2} + H_{twp.U2} = -6914.6 \cdot kN$$

$$\Sigma M_{HWater.U2} := H_{hwp.U2} \cdot H_{hwp.U2.loc} + H_{hwg.U2} \cdot H_{hwg.U2.loc} + H_{hwf.U2} \cdot H_{hwf.U2.loc} \cdots + H_{twf.U2} \cdot H_{twf.U2.loc} + H_{twp.U2} \cdot H_{twp.U2.loc} = -16989.2 \cdot kN \cdot m$$

VERTICAL WATER LOADS

U2 CASE

HEADWATER:

Water Depth on top of fixed crest: $d_{hw.U2} := HW_{U2} - TOC_{as} = 5.81\, m$

Subtract Pier Volume:

$$S_{pn.U2} := \left[\frac{(A_{pnt} - A_{pnb})}{h_{pn}}\right] = 1.00 \cdot \frac{m^2}{m}$$

$$V_{pn.U2} := \frac{\left[(S_{pn.U2} \cdot d_{hw.U2} + A_{pnb}) + A_{pnb}\right]}{2} \cdot d_{hw.U2} = 129.8 \cdot m^3$$

Weight of Water (H1) on Approach Slab: $H_{1.U2} := (W_{hw.U2} \cdot d_{hw.U2} \cdot L_{as} - V_{pn.U2}) \cdot \gamma_w = 3320.9 \cdot kN$

Horiz. Moment Arm for H1 (from toe): $H_{1.U2.loc} := L_b - \frac{L_{as}}{2} = 21.10\, m$

Distance from Gate to Toe: $Dist_{gate} = 10.2\, m$

Cross-sectional Area of Headwater Above Fixed Crest: $A_{fc.hw.U2} := 29.10 m^2$

(From Bluebeam Measurement, Bound by Energy Line through Crest Water Elevation Crest and Chute Block Water Elevation Chute as defined above)

Volume of water Above Fixed Crest: $V_{fc.hw.U2} := \left[A_{fc.hw.U2} \cdot (W_{hw.U2} - w_{pn})\right] = 261.9 \cdot m^3$

Weight of Water (H2) on Fixed Crest: $H_{2.U2} := (V_{fc.hw.U2}) \cdot \gamma_w = 2569.2 \cdot kN$

Horiz. Moment Arm for H2 (from toe): $H_{2.U2.loc} := 14.412 \cdot m = 14.41\, m$ (From Bluebeam Measurement)

TAILWATER:

Slope of Crest from D/S of Gate to edge of Stilling Basin: $S_{f.U2} := S_{f.U1} = 0.500$

Height of Tailwater Above Stilling Basin: $y_{U2} := TW_{U2} - TOC_{fce} = 1.3\, m$

Cross Sectional Area of Tailwater Above Sloped Portion of Crest: $A_{tw.U2} := 23.86 \cdot m \cdot m = 23.9\, m^2$

(From Bluebeam Measurement, Bound by Energy Line through Crest Water Elevation CrestW and Chute Block Water Elevation ChuteW as defined above)

Weight of Water (H3) Above Slope Portion of Crest: $H_{3.U2} := \left[A_{tw.U2} \cdot (W_{twf.U2} - w_{pdg})\right] \cdot \gamma_w$ $H_{3.U2} = 2106.6 \cdot kN$

Horiz. Moment Arm for H3 (from Toe): $H_{3.U2.loc} := 5.78 \cdot m$ (From Bluebeam Measurement)

UPLIFT AT INCLINED SLIDING PLANE

U2 CASE

Uplift pressure at Headwater: $U_{HW.U2} := D_{hwf.U2} \cdot \gamma_w = 115.86 \cdot \frac{kN}{m^2}$

Uplift pressure at D/S end of Stilling Basin: $U_{TW.U2} := D_{tw.U2} \cdot \gamma_w = 46.9 \cdot \frac{kN}{m^2}$

Length from U/S Face of Gate Structure to Toe Point O (Effective drain, Lsb = 0*m) $L_{overall} = 24.20\,m$ $L_{sb} = 0$

Length of Seepage per Line of Creep $L_{seepage} = 27.1\,m$

Difference between Uplift pressure at Headwater and Uplift Pressure at Toe of Stilling Basin: $U_{diffU2} := U_{HW.U2} - U_{TW.U2} = 69 \cdot \frac{kN}{m^2}$

Slope of difference between Uplift pressure at Headwater and Uplift Pressure at Toe of Stilling Basin: $U_{slopeU2} := \frac{U_{diffU2} - Key_d \cdot \gamma_w}{L_{overall}} = 2.24 \cdot \frac{kN}{m^2 \cdot m}$

$$U_{seepageslopeU2} := \frac{U_{diffU2} - Key_d \cdot \gamma_w}{L_{seepage}}$$

Pore Pressure at Base of Gate Structure: $U_{press.toe.gsU2} := U_{TW.U2} + L_{sb} \cdot U_{slopeU2} = 46.9 \cdot \frac{kN}{m^2}$

$$U_{pore.toe.U2} := U_{TW.U2} + U_{seepageslopeU2} \cdot L_{sb} = 46.9 \cdot \frac{kN}{m^2}$$

$$U_{pore.F.U2} := U_{pore.toe.U2} + U_{seepageslopeU2} \cdot L_{FG} = 49.9 \cdot \frac{kN}{m^2}$$

$$U_{pore.E.U2} := U_{pore.F.U2} - \left(BOF_{base} - BOF_{toe}\right) \cdot \gamma_w + U_{seepageslopeU2} \cdot L_{EF} = 41.9 \cdot \frac{kN}{m^2}$$

$$U_{pore.D.U2} := U_{pore.E.U2} + U_{seepageslopeU2} \cdot L_{DE} = 78.3 \cdot \frac{kN}{m^2}$$

$$U_{pore.C.U2} := U_{pore.D.U2} + \left(BOF_{base} - BOF_{elev}\right) \cdot \gamma_w + U_{seepageslopeU2} \cdot L_{CD} = 113.9 \cdot \frac{kN}{m^2}$$

Uniform uplift due to Tailwater: (rectangular portion) $U_{A.U2} := U_{press.toe.gsU2} \cdot L_b \cdot W_b \cdot -1 = -14752.2 \cdot kN$

Moment Arm for Uplift UA from Toe of Gate Structure: $L_{A.U2} := \frac{L_b}{2} = 12.10\,m$

Uplift - Linear Decrease from HW to TW: (triangular portion) $U_{B.U2} := \frac{1}{2} \cdot \left(U_{HW.U2} - U_{press.toe.gsU2}\right) \cdot L_b \cdot W_b \cdot -1 = -10848.1 \cdot kN$

Moment Arm for Uplift UB from Toe of Gate Structure: $L_{B.U2} := \frac{2}{3} \cdot L_b = 16.13\,m$

Total Resultant Uplift force: $U_{U2} := U_{A.U2} + U_{B.U2} = -25600.2 \cdot kN$

Resultant Location from Toe: $U_{U2.loc} := \frac{U_{A.U2} \cdot L_{A.U2} + U_{B.U2} \cdot L_{B.U2}}{U_{A.U2} + U_{B.U2}} = 13.81\,m$

$$\Sigma V_{water.U2} := H_{1.U2} + H_{2.U2} + H_{3.U2} + U_{U2} = -17603.5 \cdot kN$$

$$\Sigma M_{Vwater.U2} := H_{1.U2} \cdot H_{1.U2.loc} + H_{2.U2} \cdot H_{2.U2.loc} + H_{3.U2} \cdot H_{3.U2.loc} + U_{U2} \cdot U_{U2.loc} = -234242.4 \cdot kN \cdot m$$

U2 CASE

Uplift as per Line of Creep Method (Flotation and Overturning)

$Uplift_{BC.U2} := \frac{-1}{2} \cdot W_b \cdot (U_{HW.U2} + U_{pore.C.U2}) \cdot L_{BC} = -1493.1 \cdot kN$

$Uplift_{CD.U2} := 0$

$Uplift_{DE.U2} := \frac{-1}{2} \cdot W_b \cdot (U_{pore.D.U2} + U_{pore.E.U2}) \cdot L_{DE} = -14238.1 \cdot kN$

$Uplift_{EF.U2} := \frac{-1}{2} \cdot W_b \cdot (U_{pore.E.U2} + U_{pore.F.U2}) \cdot L_{EF} = -1998.4 \cdot kN$

$Uplift_{FG.U2} := \frac{-1}{2} \cdot W_b \cdot (U_{pore.F.U2} + U_{pore.toe.U2}) \cdot L_{FG} = -943.7 \cdot kN$

$Uplift_{pore.U2} := Uplift_{BC.U2} + Uplift_{DE.U2} + Uplift_{EF.U2} + Uplift_{FG.U2} = -18673.3 \cdot kN$

$$Uplift_{FG.U2.loc} := \frac{L_{FG}}{3} \cdot \frac{(2 \cdot U_{pore.F.U2} + U_{pore.toe.U2})}{(U_{pore.F.U2} + U_{pore.toe.U2})} = 0.76\,m$$

$$Uplift_{EF.U2.loc} := \frac{L_{EF}}{3} \cdot \frac{(2 \cdot U_{pore.E.U2} + U_{pore.F.U2})}{(U_{pore.E.U2} + U_{pore.F.U2})} + L_{FG} = 3.13\,m$$

$$Uplift_{DE.U2.loc} := \frac{L_{DE}}{3} \cdot \frac{(2 \cdot U_{pore.D.U2} + U_{pore.E.U2})}{(U_{pore.D.U2} + U_{pore.E.U2})} + L_{FG} + X_{EF} = 14.52\,m$$

$$Uplift_{BC.U2.loc} := \frac{L_{BC}}{3} \cdot \frac{(2 \cdot U_{HW.U2} + U_{pore.C.U2})}{(U_{HW.U2} + U_{pore.C.U2})} + L_{FG} + X_{EF} + L_{DE} = 23.21\,m$$

U2 CASE

SOIL LOADS

Equivalent Fluid Pressure (EFP): (CFEM 24.1)

At rest lateral pressure coefficient: $K_o = 0.66$

At-rest Soil Pressure to Heel, EM1110--2-2502 Section 3-7

Lateral Driving Force (Headwater Side)

Depth of Fill at Heel: $t_{hf.U2} := TOC_{as} - BOF_{elev} = 6.00\,m$

At-Rest Soil Load: $E1_{drive.U2} := \frac{K_o \cdot t_{hf.U2}^2}{2} \cdot (\gamma_r - \gamma_w) \cdot W_b \cdot -1 = -1876.9 \cdot kN$

Acting at: $E1_{drive.loc.U2} := \frac{t_{hf.U2}}{3} - (BOF_{toe} - BOF_{elev}) = 0.50\,m$

Lateral Resisting Force (Tailwater Side)

Depth of Fill at Toe: $t_{tf.U2} := TOC_{fce} - BOF_{toe} = 2.00\,m$

At-Rest Soil Load: $E2_{resistU2} := \frac{K_o \cdot t_{tf.U2}^2}{2} \cdot (\gamma_r - \gamma_w) \cdot W_b = 208.5 \cdot kN$ $E2_{resistU2} := 0$

Acting at: $E2_{resistlocU2} := \frac{t_{tf.U2}}{3} = 0.67\,m$

(Expansion Joint to Stilling Basin, No Sediment in Gap)

$\Sigma H_{soil.U2} := E1_{drive.U2} + E2_{resistU2} = -1668.3 \cdot kN$

$\Sigma M_{soil.U2} := E1_{drive.U2} \cdot E1_{drive.loc.U2} + E2_{resistU2} \cdot E2_{resistlocU2} = -799.4 \cdot kN \cdot m$

ICE / IMPACT LOADS (CONSERVATIVELY ASSUME NO ICE LOADING ON DOWNSTREAM SIDE)

Static Impact Loading on Structure: $I_{S.U2} := 150.0\,\frac{kN}{m}$ (Section 7.7, Design Criteria)

Static Impact load on Gates: $I_{G.U2} := 75\,\frac{kN}{m}$ (Section 7.7, Design Criteria)

Impact Loading Unit Width on Structure: $W_{S.U2} := 4.00m$

Impact Loading Unit Width on Gates: $W_{G.U2} := 2 \cdot \frac{20.00}{2}\,m = 20.00\,m$

Total Impact Load on Structure: $I_{U2} := (I_{S.U2} \cdot W_{S.U2} + I_{G.U2} \cdot W_{G.U2}) \cdot -1 = -2100 \cdot kN$

Apply Ice load at: $I_{U2.loc} := (HW_{U2} - BOF_{toe} - 0.30m) = 10.01\,m$

$\Sigma H_{I.U2} := I_{U2} = -2100 \cdot kN$

$\Sigma M_{I.U2} := I_{U2} \cdot I_{U2.loc} = -21021 \cdot kN \cdot m$

SEISMIC LOAD (Not Applicable to this Load Case)

SUMMARY OF LOADS

U2 CASE

	Loads	Moment Arm
Dead Load of Concrete Structure:	$D_{conc} = 52182.8 \cdot kN$	$X_{conc.loc} = 12.43\,m$
Dead Load of Gate:	$D_{Gate} = 580.0 \cdot kN$	$X_{gate} = 9.75\,m$
Headwater Lateral Load on Pier:	$H_{hwp.U2} = -662.3 \cdot kN$	$H_{hwp.U2.loc} = 6.44\,m$
Headwater Lateral Load on Gate:	$H_{hwg.U2} = 0.0 \cdot kN$	$H_{hwg.U2.loc} = 7.44\,m$
Headwater Lateral Load on Footing:	$H_{hwf.U2} = -7709.2 \cdot kN$	$H_{hwf.U2.loc} = 1.67\,m$
Tailwater Lateral Load:	$H_{twf.U2} = 1008.6 \cdot kN$	$H_{twf.U2.loc} = 0.09\,m$
Tailwater Lateral Load on Pier:	$H_{twp.U2} = 448.3 \cdot kN$	$H_{twp.U2.loc} = 0.09\,m$
Water Weight (HW) on Apron Slab:	$H_{1.U2} = 3320.9 \cdot kN$	$H_{1.U2.loc} = 21.10\,m$
Water Weight (HW) on Fixed Crest:	$H_{2.U2} = 2569.2 \cdot kN$	$H_{2.U2.loc} = 14.41\,m$
Water Weight (TW) on Fixed Crest:	$H_{3.U2} = 2106.6 \cdot kN$	$H_{3.U2.loc} = 5.78\,m$
Uplift:	$U_{U2} = -25600.2 \cdot kN$	$U_{U2.loc} = 13.81\,m$
Upstream (driving) Lateral Soil Load:	$E1_{drive.U2} = -1876.9 \cdot kN$	$E1_{drive.loc.U2} = 0.50\,m$
Downstream (resisting) Lateral Soil Load:	$E2_{resistU2} = 208.5 \cdot kN$	$E2_{resistlocU2} = 0.67\,m$
Ice / Impact Load:	$I_{U2} = -2100.0 \cdot kN$	$I_{U2.loc} = 10.01\,m$

STABILITY ASSESSMENT (SLIDNG, OVERTURNING AND BEARING): U2 CASE

CHECK SLIDING ALONG HORIZONTAL PLANE THRU TOE,
IGNORING BEDROCK MOBILIZED BY STRUCTURAL HEEL KEY , OR VOID BEHIND KEY

Sum of Vertical Forces:

$\Sigma V_{U2} := \Sigma V_{DL.U2} + \Sigma V_{water.U2} = 35159.3 \cdot kN$

Sum of Horizontal Forces:

$\Sigma H_{U2} := \Sigma H_{Water.U2} + \Sigma H_{soil.U2} + \Sigma H_{I.U2} = -10682.9 \cdot kN$

Sliding Factor of Safety:

$$FS_{HorizSliding.U2} := \frac{\tan_{\phi} \cdot \Sigma V_{U2}}{\left|\Sigma H_{U2}\right|} = 1.61$$

$FS_{HorizSliding.U2.Check} :=$ | "OKAY" if $FS_{HorizSliding.U2} \geq FS_{req.U2.sl}$
"Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !" otherwise

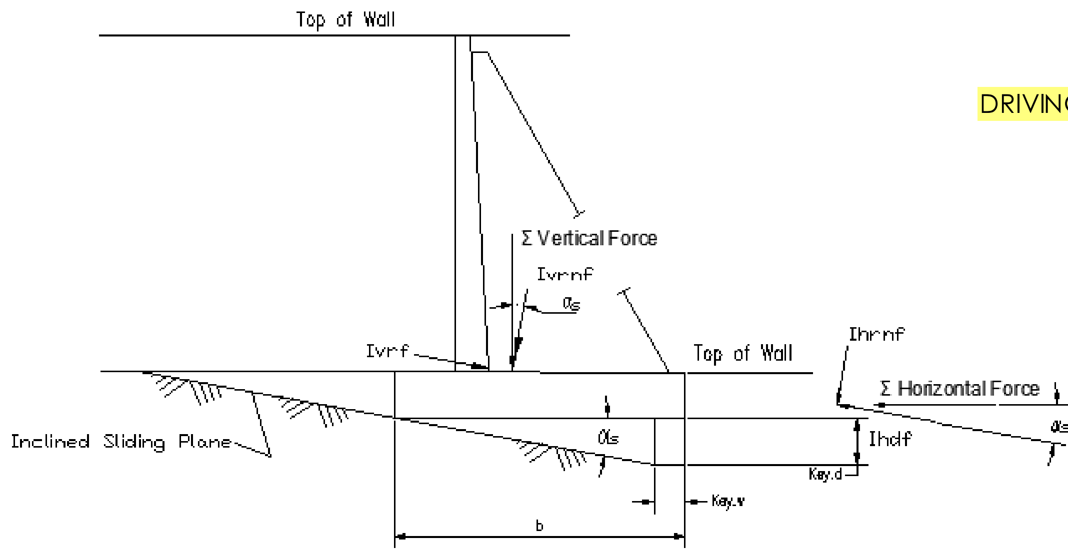
= "OKAY"

$FS_{HorizSliding.U2.Check} =$ "OKAY"

CHECK SLIDING ALONG INCLINED SLIDING PLANE FROM HEEL KEY TO TOE,
WITH BEDROCK MASS MOBILIZED BY REINFOCREDE CONCRETE KEY)

RESISTING SIDE

DRIVING SIDE



HEEL

TOE

Ivrf=Inclined Resisting Force
Ivrnf=Inclined Resisting Normal Force
Ihrnf=Inclined Resisting Normal Force
Ihdf=Inclined Driving Force

$$\alpha s := \operatorname{atan}\left(\frac{BOF_{toe} - BOF_{elev}}{L_b - Key_l}\right) = 0.13$$

as degrees= $\alpha s \cdot \left(\frac{180}{\pi}\right) = 7.63$

Resolve $\Sigma Vert_{U2}$ & $\Sigma Horiz_{U2}$

$$\Sigma V_{InclinedU2} := \cos(\alpha s) \cdot \left(\Sigma V_{U2} + V_{rs}\right) + \sin(\alpha s) \cdot \left|\Sigma H_{U2}\right| = 49368.2 \cdot kN$$

$$\Sigma H_{InclinedU2} := \cos(\alpha s) \cdot \left|\Sigma H_{U2}\right| - \sin(\alpha s) \cdot \left(\Sigma V_{U2} + V_{rs}\right) = 4166.5 \cdot kN$$

(With properly engineered reinforced concrete Key, horizontal sliding plane thru Toe is protected, critical sliding plane is relocated to the INCLINED SLIDING PLANE FROM HEEL KEY To TOE, Bedrock Mass above this examing plane is mobilized by reinforced concrete key and combined into Structural Wedge.)

Inclined Sliding Plane Length $L_{incline} = 24.2 m$

Safety Factor for Sliding
Inclined Failure Plane

$$FS_{InclinedlSlidingU2} := \frac{\Sigma V_{InclinedU2} \cdot \tan\left(\phi_{rock} \cdot \frac{\pi}{180}\right)}{\left|\Sigma H_{InclinedU2}\right|} = 5.78$$

$FS_{InclinedSliding.check.U2} :=$ | "OKAY " if $FS_{InclinedlSlidingU2} > FS_{req.U2.sl}$ = "OKAY "
"Revise Structure"" otherwise

$FS_{InclinedSliding.check.U2} =$ "OKAY "

CHECK ECCENTRICITY ON INCLINED PLANE

U2 CASE

Sum of the Moments:

$$\Sigma M_{rs.U2} := \Sigma M_{DL.U2} + \Sigma M_{HWater.U2} + \Sigma M_{Vwater.U2} + \Sigma M_{I.U2} + \Sigma M_{soil.U2} + V_{rs} \cdot L_{rs} = 565714 \cdot kN \cdot m$$

Eccentricity:

$$e_{U2} := \frac{L_{incline}}{2} - \frac{\Sigma M_{rs.U2}}{\Sigma V_{InclinedU2}} = 0.66\,m$$

Eccentricity Check:

$$e_{check.U2} := \begin{array}{|l} \text{"Okay"} \quad \text{if } \left|e_{U2}\right| \le Kern \\ \text{"Revise Structure"} \quad \text{otherwise} \end{array}$$

$e_{check.U2} = \text{"Okay"}$

Foundation Bearing Pressures on Inclined Plane:

Bearing Pressure at Heel:

$$\sigma_{heel.U2} := \frac{\Sigma V_{InclinedU2}}{\frac{A_b}{\cos(\alpha s)}} - \frac{\Sigma V_{InclinedU2} \cdot e_{U2}}{\frac{S_b}{\cos(\alpha s)^2}} = 130.2 \cdot \frac{kN}{m^2}$$

$$\sigma_{heel.U2.check} := \left(\begin{array}{|l} \text{"Okay"} \quad \text{if } \sigma_{heel.U2} \le \sigma_{allow.U2} \\ \text{"Revise Structure"} \quad \text{otherwise} \end{array} \right)$$

$\sigma_{heel.U2.check} = \text{"Okay"}$

Bearing Pressure at Toe:

$$\sigma_{toe.U2} := \frac{\Sigma V_{InclinedU2}}{\frac{A_b}{\cos(\alpha s)}} + \frac{\Sigma V_{InclinedU2} \cdot e_{U2}}{\frac{S_b}{\cos(\alpha s)^2}} = 180.9 \cdot \frac{kN}{m^2}$$

$$\sigma_{toe.U2.check} := \begin{array}{|l} \text{"Okay"} \quad \text{if } \sigma_{toe.U2} \le \sigma_{allow.U2} \\ \text{"Revise Structure"} \quad \text{otherwise} \end{array}$$

$\sigma_{toe.U2.check} = \text{"Okay"}$

CHECK FLOTATION

$$Uplift_{sliding.U2} := U_{U2} = -25600.2 \cdot kN$$

$$Uplift_{pore.U2} = -18673.3 \cdot kN$$

(For conservative, taking maximum values)

$$\left(Uplift_{U2}\right) := \min\left(Uplift_{pore.U2}, Uplift_{sliding.U2}\right)$$

$$FS_{Flotation.U2} := \frac{D_{conc} + D_{Gate} + H_{1.U2} + H_{2.U2} + H_{3.U2}}{\left|Uplift_{U2}\right|} = 2.4$$

$$FS_{Flotation.U2.check} := \begin{array}{|l} \text{"OKAY "} \quad \text{if } FS_{Flotation.U2} > FS_{req.U.flt} \\ \text{"Revise Structure""} \quad \text{otherwise} \end{array} = \text{"OKAY "}$$

MONOLITH OVERTURNING STABILITY ANALYSIS

U2 CASE

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.
Assumptions are made in order to compute overturning stability of indetermine forces on monolith with key;
(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.
(b) The horizontal resisting force acting on the key, P.key, is that required for static equilibrium
(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1 $Ratio_{overturning.allow.Usual} = 0.33$

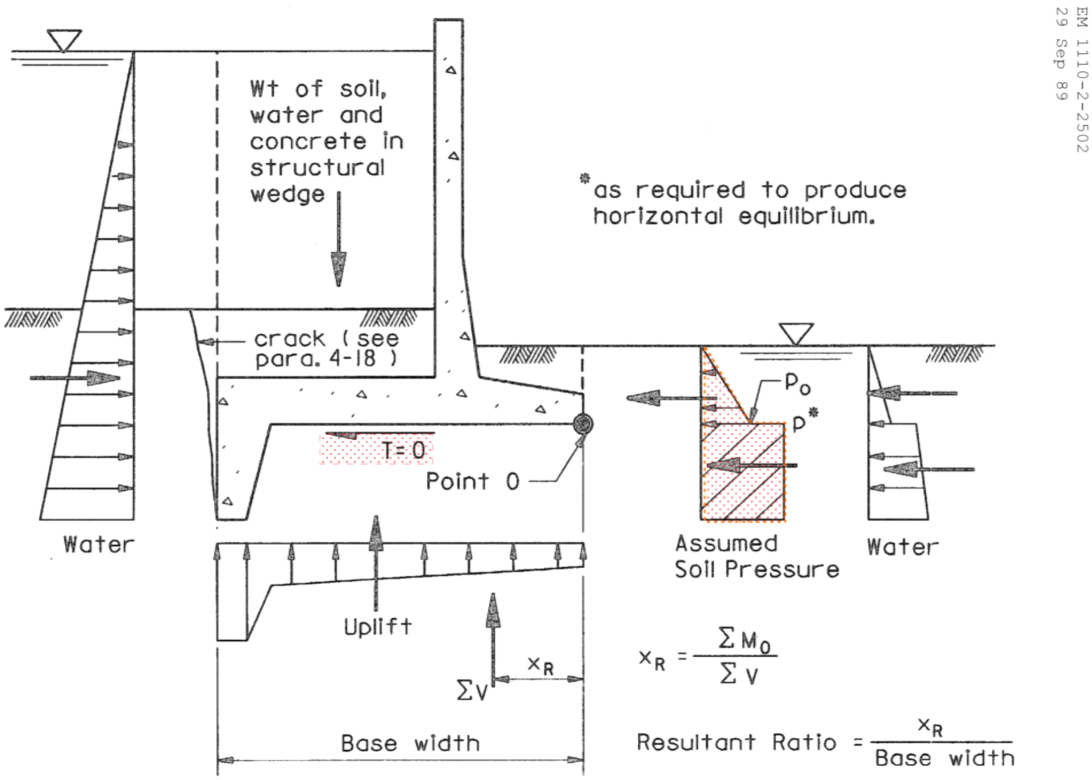


Figure 4-5. Forces for overturning analysis for wall with horizontal base and key

All Vertical Loads Applicable to Overturning Stability Analysis

Total Concrete Dead Loads:	$D_{conc} = 52182.8 \cdot kN$	at:	$X_{conc.loc} = 12.4\,m$
Dead Load of Gate:	$D_{Gate} = 580.0 \cdot kN$		$X_{gate} = 9.75\,m$
Water Weight (HW) on Apron Slab:	$H_{1.U2} = 3320.9 \cdot kN$		$H_{1.U2.loc} = 21.10\,m$
Water Weight (HW) on Fixed Crest:	$H_{2.U2} = 2569.2 \cdot kN$		$H_{2.U2.loc} = 14.41\,m$
Water Weight (TW) on Fixed Crest:	$H_{3.U2} = 2106.6 \cdot kN$		$H_{3.U2.loc} = 5.78\,m$

Uplift Force from Sliding Analysis. Line of Creep Method applied at presumed inclined sliding line, and subtraction gravity effect to Base of Concrete by Archimedes Principle

$$U_{U2.loc.sliding} := \frac{U_{A.U2} \cdot L_{A.U2} + U_{B.U2} \cdot L_{B.U2} - A_{rs} \cdot w_{as} \cdot \gamma_w \cdot L_{rs}}{U_{A.U2} + U_{B.U2} - A_{rs} \cdot w_{as} \cdot \gamma_w} = 13.84\,m$$

$$U_{U2.sliding} := U_{U2} + A_{rs} \cdot w_{as} \cdot \gamma_w = -19705.8 \cdot kN$$

Uplift for Overturning Analysis, Line of Creep Method. Pore pressure at base of Concrete

$Uplift_{pore.U2} = -18673.3 \cdot kN$

$$Uplift_{pore.U2.loc} := \frac{\left(Uplift_{BC.U2} \cdot Uplift_{BC.U2.loc} + Uplift_{DE.U2} \cdot Uplift_{DE.U2.loc} + Uplift_{EF.U2} \cdot Uplift_{EF.U2.loc} + Uplift_{FG.U2} \cdot Uplift_{FG.U2.loc}\right)}{Uplift_{pore.U2}}$$

$Uplift_{pore.U2.loc} = 13.3\,m$

Sum of All Water Load for Overturning Analysis

$\Sigma V_{water.U2.OT} := H_{1.U2} + H_{2.U2} + H_{3.U2} + Uplift_{pore.U2} = -10676.6 \cdot kN$

All Lateral Loads Applicable to Overturning Stability Analysis

Apply Load to Gate?:	$poss_{U2} = 0$	poss = 1 if gate is closed 0 if gate is open
Headwater Lateral Load on Pier:	$H_{hwp.U2} = -662.3 \cdot kN$	$H_{hwp.U2.loc} = 6.44\,m$
Headwater Lateral Load on Gate:	$H_{hwg.U2} = 0.0 \cdot kN$	$H_{hwg.U2.loc} = 7.44\,m$
Headwater Lateral Load on Footing:	$H_{hwf.U2} = -7709.2 \cdot kN$	$H_{hwf.U2.loc} = 1.67\,m$
Total Horizontal Tailwater Load on Pier:	$H_{twp.U2} = 448.3 \cdot kN$	$H_{twp.U2.loc} = 0.09\,m$
Total Horizontal Tailwater Load on Footing under Gate Openings, i.e., excluding Pier	$H_{twf.U2} = 1008.6 \cdot kN$	$H_{twf.U2.loc} = 0.09\,m$

Resisting Water on Rear Face of Monolith, i.e., bottom of heel elevation:

(Point O @ TOE: BOFtoe = EL.1205.5)

Ice / Impact Load: $I_{U2} = -2100.0 \cdot kN$ at: $I_{U2.loc} = 10.01\,m$

Depth of Fill at Heel Side for Overturning Analysis:

$t_{hf.U2} := TOC_{as} - BOF_{toe} = 4.50\,m$

Driving Soil Load for overturning:

$$E1_{drive.U2} := \frac{K_o \cdot t_{hf.U2}^{\,2}}{2} \cdot \left(\gamma_r - \gamma_w\right) \cdot W_b \cdot -1 = -1055.7 \cdot kN$$

Acting at:

$$E1_{drive.loc.U2} := \frac{t_{hf.U2}}{3} = 1.50\,m$$

Downstream (resisting) Lateral Soil Load as required to produce horizontal equilibrium:

$$E2_{resistU2} := -1 \cdot \left(H_{hwp.U2} + H_{hwg.U2} + H_{hwf.U2} + H_{twp.U2} + H_{twf.U2} + I_{U2} + E1_{drive.U2}\right)$$

$E2_{resistU2} = 10070.3 \cdot kN$

Assumed Resisting Bedrock at middle of Key, passive soil pressure or lateral bearing contract joint at end of Monolith 3A3B

$E2_{resistlocU2} := E2_{resistlocU1} = -0.75\,m$

Overturning moment by Dead Loads about Point O @ Toe

$\Sigma M_{DL.U2} = 654229.9 \cdot kN \cdot m$

Overturning moment by Vertical Water Loads and Uplift, about Point O @ Toe

$$\Sigma M_{Vwater.U2.OT} := H_{1.U2} \cdot H_{1.U2.loc} + H_{2.U2} \cdot H_{2.U2.loc} + H_{3.U2} \cdot H_{3.U2.loc} + Uplift_{pore.U2} \cdot Uplift_{pore.U2.loc} = -129095.9 \cdot kN \cdot m$$

U2 CASE

Overturning moment by Lateral Hydrostatic Forces of Headwater Pool and Tailwater Pool,about Point O @ Toe

$\Sigma M_{HWater.U2} = -16989.2 \cdot kN \cdot m$

Overturning Moment by Impact/Ice Load, about Point O@ Toe

$\Sigma M_{I.U2} = -21021 \cdot kN \cdot m$

Overturning moment by Lateral Soil Forces about Point O @ Toe

$\Sigma M_{soil.U2} := E1_{drive.U2} \cdot E1_{drive.loc.U2} + E2_{resistU2} \cdot E2_{resistlocU2} = -9136.3 \cdot kN \cdot m$

Sum of the Overturning Moments about Point O @ Toe:

$\Sigma M_{U2.OT} := \Sigma M_{DL.U2} + \Sigma M_{HWater.U2} + \Sigma M_{Vwater.U2.OT} + \Sigma M_{I.U2} + \Sigma M_{soil.U2} = 477987 \cdot kN \cdot m$

Sum of Vertical Forces:

$\Sigma V_{U2.OT} := \Sigma V_{DL.U2} + \Sigma V_{water.U2.OT} = 42086.2 \cdot kN$

Distance X_R: EM 1110-2-2502 Eq.4-1

$X_{R.U2} := \frac{\Sigma M_{U2.OT}}{\Sigma V_{U2.OT}} = 11.4 m$

Overturning Resultant Ratio

$Ratio_{Overturning.U2} := \frac{X_{R.U2}}{L_b} = 0.47$

EM 1110-2-2502

Table 4-1

Retaining Wall Stability Criteria

Loading Condition	Sliding Factor of Safety, FS	Shear Strength Test Required: Soil Foundation	Shear Strength Test Required: Rock Foundation[3]	Overturning Criteria Minimum Base Area in Compression: Soil Foundation	Overturning Criteria Minimum Base Area in Compression: Rock Foundation
Usual	1.5	(Q &/or S)[2,1]	Direct shear	100%[4]	75%[4]
Unusual	1.33	(Q &/or S)[2,1]	Direct shear	75%[4]	50%[4]
Earthquake	1.1	(Q)	Direct shear	Resultant within base	Resultant within base

Overturning Stability Check

$Ratio_{Overturning.U2.check} := \begin{cases} \text{"Okay"} & \text{if } Ratio_{Overturning.U2} \geq Ratio_{overturning.allow.Usual} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$

$Ratio_{Overturning.U2.check} = \text{"Okay"}$

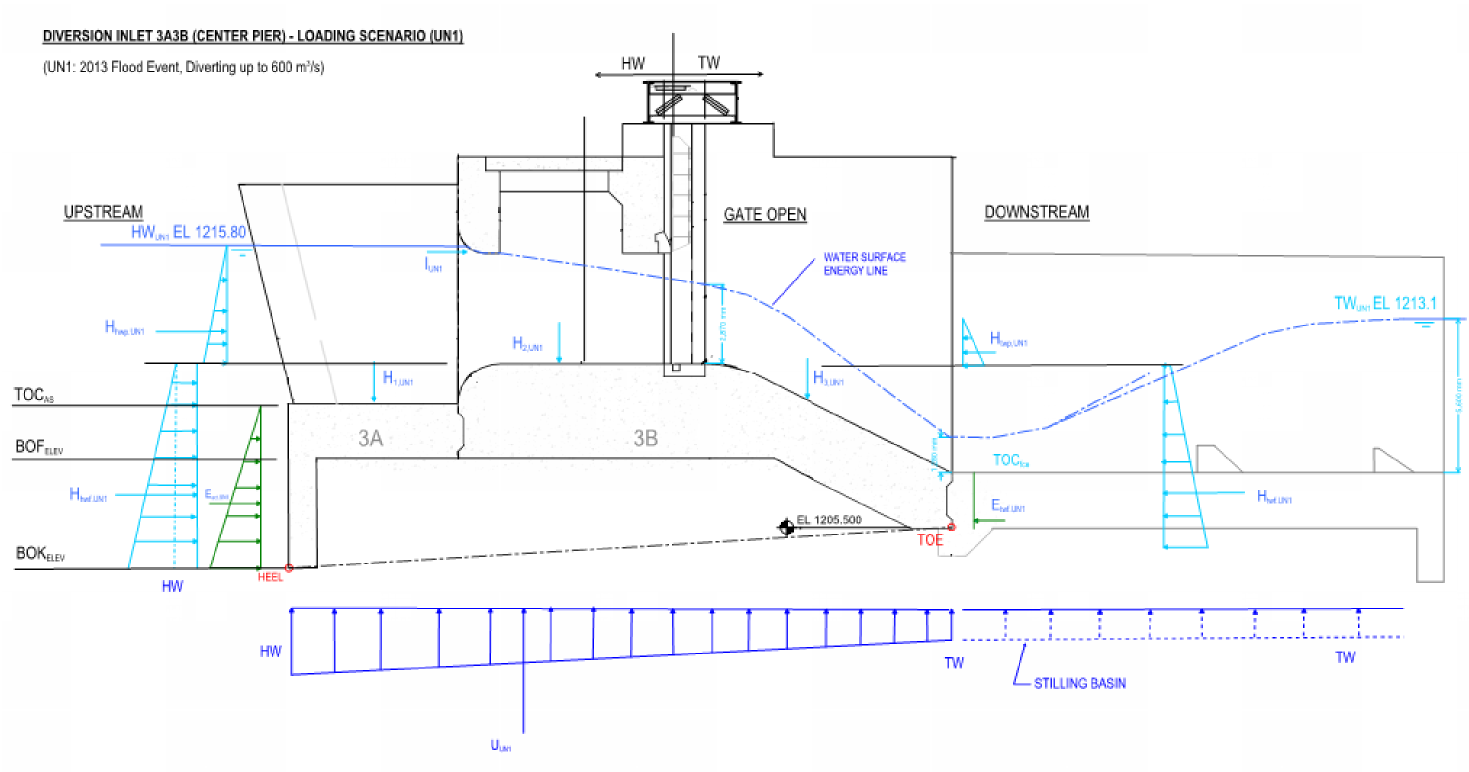
Summary of Extreme Flood Results (Only Report Controlling Load Case)

U2 CASE

U2 Event: Diversion Operation, 100 Yr.Flood

Horiz Sliding Factor of Safety:	$FS_{HorizSliding.U2} = 1.61$
Horiz Sliding Factor of Safety Check:	$FS_{HorizSliding.U2.Check} = \text{"OKAY"}$
Sliding Factor of Safety:	$FS_{InclinedlSlidingU2} = 5.8$
Sliding Factor of Safety Check:	$FS_{InclinedSliding.check.U2} = \text{"OKAY "}$
Eccentricity:	$e_{U2} = 0.66\,m$
Eccentricity Check:	$e_{check.U2} = \text{"Okay"}$
Bearing Pressure At Heel on Inclined Plane:	$\sigma_{heel.U2} = 130.2 \cdot \frac{kN}{m^2}$
Bearing Pressure At Heel Check:	$\sigma_{heel.U2.check} = \text{"Okay"}$
Bearing Pressure At Toe on Inclined Plane:	$\sigma_{toe.U2} = 180.9 \cdot \frac{kN}{m^2}$
Bearing Pressure At Toe Check:	$\sigma_{toe.U2.check} = \text{"Okay"}$
Flotation Factor of Safety	$FS_{Flotation.U2} = 2.4$
Flotation Factor of Safety Check:	$FS_{Flotation.U2.check} = \text{"OKAY "}$
Overturning Resultant Ratio	$Ratio_{Overturning.U2} = 0.47$
Overturning Stability Check	$Ratio_{Overturning.U2.check} = \text{"Okay"}$

UN1 DESIGN CASE



ACCEPTANCE PARAMETERS

Required Factor of Safety for Sliding: $FS_{req.UN1.sl} := 1.3$ (Without Cohesion) (Section 8.1, Design Criteria)

Resultant Within Middle Third of Base: $e \le \frac{L_b}{6} \wedge e \ge \frac{-L_b}{6}$ (100% Base in Compression, Design Criteria)

Allowable Rock Bearing Pressure: $\sigma_{allow.UN1} := 1470.0 \cdot \frac{kN}{m^2}$ (Section 5.2, Design Criteria)

Required Factor of Safety for Flotation: $FS_{req.UN.flt} := 1.3$

Overturning Min Required Resultant Ratio: $\frac{X_{R.UN}}{Horizontal\_Width\_of\_Base} > 0.33$

UN1 CASE

INPUT PARAMETERS

Headwater Elevation: $HW_{UN1} := 1215.80m$

Tailwater Elevation: $TW_{UN1} := 1213.10m$

(Water Elevations based on Diversion Structure 2D Hydraulic Model Results. See page 7 and Section 8.2, Design Criteria)

Crest Water Elevation, EL.1215.81 $CrestW_{UN1} := 2.87 \cdot m$

Chute Block Water Elevation EL.1208.78 $ChuteW_{UN1} := 1.28 \cdot m$ $TW_{UN1} := TOC_{fce} + ChuteW_{UN1} = 1208.8\,m$

Bottom of Key (Footing Heel) Elevation: $BOF_{elev} = 1204.00\,m$

Apron Slab Top of Concrete Elevation at Edge of Slab: $TOC_{as} = 1210.00\,m$

Fixed Crest Top of Concrete Elevation at Downstream Face: $TOC_{fce} = 1207.50\,m$

Fixed Crest Top of Concrete Elevation at Center of Footing: $TOC_{fcc} = 1211.50\,m$

VERTICAL LIFT GATE

Lift Gate Position per Hydraulic Criteria $poss_{UN1} := 0$

poss = 1 if gate is closed
0 if gate is open

DEAD LOAD SUMMATION:

$$Gate_{R.UN1} := \begin{cases} 1 & \text{if } poss_{UN1} = 0 \\ 0.45 & \text{otherwise} \end{cases}$$

Monolith Reaction for Wheel Gate

$$\Sigma V_{DL.UN1} := D_{conc} + Gate_{R.UN1} D_{Gate} = 52762.8 \cdot kN$$

$$\Sigma M_{DL.UN1} := D_{conc} \cdot X_{conc.loc} + Gate_{R.UN1} \cdot D_{Gate} \cdot X_{gate} = 654229.9 \cdot kN \cdot m$$

LATERAL WATER LOADS

UN1 CASE

HEADWATER (DRIVING):

Water Depth on Pier at Heel: $D_{hwp.UN1} := HW_{UN1} - TOC_{as} = 5.80\,m$

Water Load Unit Width on Pier: $W_{hwp.UN1} := w_{pn} = 4.00\,m$

Total Horizontal Water Load on Pier: $H_{hwp.UN1} := \frac{-\left(\gamma_w \cdot D_{hwp.UN1}{}^2\right)}{2} \cdot W_{hwp.UN1} = -660.0 \cdot kN$

Apply Total Pier Water Load at: $H_{hwp.UN1.loc} := \frac{D_{hwp.UN1}}{3} + \left(TOC_{as} - BOF_{toe}\right) = 6.43\,m$

Point O @ TOE: BOFtoe = EL.1205.5

Water Depth Above Fixed Crest at Gate: $D_{hwg.UN1} := HW_{UN1} - TOC_{fcc} = 4.3\,m$

Water Load Unit Width on Gate: $W_{hwg.UN1} := 2 \cdot \frac{20.00}{2} m = 20.00\,m$

Apply Load to Gate?: $poss_{UN1} := 0$

poss = 1 if gate is closed
0 if gate is open

Total Horizontal Water Load on Gate: $H_{hwg.UN1} := \frac{-\left(\gamma_w \cdot D_{hwg.UN1}{}^2\right)}{2} \cdot W_{hwg.UN1} \cdot poss_{UN1} = 0 \cdot kN$

Apply Total Gate Water Load at: $H_{hwg.UN1.loc} := \frac{D_{hwg.UN1}}{3} + \left(TOC_{fcc} - BOF_{toe}\right) = 7.43\,m$

Water Depth at Heel: $D_{hwf.UN1} := HW_{UN1} - BOF_{elev} = 11.80\,m$

Water Load Unit With on Footing: $W_{hw.UN1} := W_b$

Water Load at Bottom of Footing: $H_{hwf.UN1.1} := -\left(\gamma_w \cdot D_{hwf.UN1}\right) \cdot W_{hw.UN1} = -1504.9 \frac{1}{m} \cdot kN$

Water Load at Top of Footing: $H_{hwf.UN1.2} := -\left(\gamma_w \cdot D_{hwg.UN1}\right) \cdot W_{hw.UN1} = -548.4 \frac{1}{m} \cdot kN$

Total Horizontal Water Load on Footing: $H_{hwf.UN1} := \frac{\left(H_{hwf.UN1.1} + H_{hwf.UN1.2}\right) \cdot \left(D_{hwf.UN1} - D_{hwg.UN1}\right)}{2} = -7699.6 \cdot kN$

Apply Total Footing Water Load at:

$$H_{hwf.UN1.loc} := \frac{H_{hwf.UN1.2} \cdot \frac{\left(TOC_{fcc} - BOF_{elev}\right)^2}{2} + \frac{\left(H_{hwf.UN1.1} - H_{hwf.UN1.2}\right)}{2} \cdot \frac{\left(TOC_{fcc} - BOF_{elev}\right)^2}{3}}{\frac{\left(H_{hwf.UN1.2} + H_{hwf.UN1.1}\right) \cdot \left(TOC_{fcc} - BOF_{elev}\right)}{2}} - \left(BOF_{toe} - BOF_{elev}\right) = 1.67\,m$$

(Converting horizontal force resultant from HEEL calculation to Point-O@TOE)

UN1 CASE

LATERAL WATER LOADS (cont.)
TAILWATER (RESISTING):

Water Depth at toe: $D_{tw.UN1} := TW_{UN1} - BOF_{elev} = 4.78\,m$

Water Load Unit Width: $W_{twf.UN1} := W_b$

Total Horizontal Tailwater Load on Footing under Gate Openings, i.e., excluding Pier

Resisting Water on Rear Face of Monolith, i.e., bottom of heel elevation:

$$COND_{UN1} := poss_{UN1} = 0 \land TW_{UN1} \ge TOC_{fcc}$$

$$H_{twf.UN1} := \begin{cases} \dfrac{\gamma_w \cdot D_{tw.UN1}^{\ 2}}{2} \cdot \left(W_{twf.UN1} - w_{pdg}\right) & \text{if } poss_{UN1} = 1 \\ \dfrac{\gamma_w \cdot D_{tw.UN1}^{\ 2}}{2} \cdot \left(W_{twf.UN1} - w_{pdg}\right) & \text{if } poss_{UN1} = 0 \land TW_{UN1} \le TOC_{fcc} \\ \gamma_w \cdot \left[\dfrac{D_{tw.UN1}}{2} + \dfrac{\left(TW_{UN1} - TOC_{fcc}\right)}{2}\right] \cdot \left(TOC_{fcc} - BOF_{elev}\right) \cdot \left(W_{twf.UN1} - w_{pdg}\right) & \text{if } COND_{UN1} \end{cases} = 1008.6 \cdot kN$$

Apply Footing Tailwater Load within Gate Openings at:

$$H_{twf.UN1.loc} := \begin{cases} \dfrac{D_{tw.UN1}}{3} - \left(BOF_{toe} - BOF_{elev}\right) & \text{if } poss_{UN1} = 1 \\ \dfrac{D_{tw.UN1}}{3} - \left(BOF_{toe} - BOF_{elev}\right) & \text{if } poss_{UN1} = 0 \land TW_{UN1} \le TOC_{fcc} \\ \dfrac{\left(TOC_{fcc} - BOF_{elev}\right)^2 \cdot \left[\dfrac{\left(TW_{UN1} - TOC_{fcc}\right)}{2} + \dfrac{\left(\left(TOC_{fcc} - BOF_{elev}\right)\right)}{6}\right]}{\left(TOC_{fcc} - BOF_{elev}\right)\left[\left(TW_{UN1} - TOC_{fcc}\right) + \dfrac{\left(TOC_{fcc} - BOF_{elev}\right)}{2}\right]} & \text{if } COND_{UN1} \end{cases} = 0.09 \cdot m$$

Total Horizontal Tailwater Load on Pier:

$$H_{twp.UN1} := \frac{\gamma_w \cdot D_{tw.UN1}^{\ 2}}{2} \cdot w_{pdg} = 448.3 \cdot kN$$

Apply Horizontal Tailwater Load on Pier at:

$$H_{twp.UN1.loc} := \frac{D_{tw.UN1}}{3} - \left(BOF_{toe} - BOF_{elev}\right) = 0.09 \cdot m$$

$$\Sigma H_{Water.UN1} := H_{hwp.UN1} + H_{hwg.UN1} + H_{hwf.UN1} + H_{twf.UN1} + H_{twp.UN1} = -6902.7 \cdot kN$$

$$\Sigma M_{HWater.UN1} := H_{hwp.UN1} \cdot H_{hwp.UN1.loc} + H_{hwg.UN1} \cdot H_{hwg.UN1.loc} + H_{hwf.UN1} \cdot H_{hwf.UN1.loc} \cdots + H_{twf.UN1} \cdot H_{twf.UN1.loc} + H_{twp.UN1} \cdot H_{twp.UN1.loc} = -16950.8 \cdot kN \cdot m$$

VERTICAL WATER LOADS

UN1 CASE

HEADWATER:

Water Depth on top of fixed crest: $d_{hw.UN1} := HW_{UN1} - TOC_{as} = 5.80\,m$

Subtract Pier Volume: $S_{pn.UN1} := \left[\dfrac{(A_{pnt} - A_{pnb})}{h_{pn}}\right] = 1.00 \cdot \dfrac{m^2}{m}$

$$V_{pn.UN1} := \frac{\left[(S_{pn.UN1} \cdot d_{hw.UN1} + A_{pnb}) + A_{pnb}\right]}{2} \cdot d_{hw.UN1} = 129.5 \cdot m^3$$

Weight of Water (H1) on Approach Slab: $H_{1.UN1} := (W_{hw.UN1} \cdot d_{hw.UN1} \cdot L_{as} - V_{pn.UN1}) \cdot \gamma_w = 3315.4 \cdot kN$

Horiz. Moment Arm for H1 (from toe): $H_{1.UN1.loc} := L_b - \dfrac{L_{as}}{2} = 21.10\,m$

Distance from Gate to Toe: $Dist_{gate} = 10.2\,m$

Cross-sectional Area of Headwater Above Fixed Crest: $A_{fc.hw.UN1} := 29.10m^2$

(From Bluebeam Measurement, Bound by Energy Line through Crest Water Elevation Crest and Chute Block Water Elevation Chute as defined above)

Volume of water Above Fixed Crest: $V_{fc.hw.UN1} := \left[A_{fc.hw.UN1} \cdot (W_{hw.UN1} - w_{pn})\right] = 261.9 \cdot m^3$

Weight of Water (H2) on Fixed Crest: $H_{2.UN1} := (V_{fc.hw.UN1}) \cdot \gamma_w = 2569.2 \cdot kN$

Horiz. Moment Arm for H2 (from toe): $H_{2.UN1.loc} := 14.412 \cdot m = 14.41\,m$ (From Bluebeam Measurement)

TAILWATER:

Slope of Crest from D/S of Gate to edge of Stilling Basin: $S_{f.UN1} := S_{f.U1} = 0.500$

Height of Tailwater Above Stilling Basin: $y_{UN1} := TW_{UN1} - TOC_{fce} = 1.3\,m$

Cross Sectional Area of Tailwater Above Sloped Portion of Crest: $A_{tw.UN1} := 23.86 \cdot m \cdot m = 23.9\,m^2$

(From Bluebeam Measurement, Bound by Energy Line through Crest Water Elevation CrestW and Chute Block Water Elevation ChuteW as defined above)

Weight of Water (H3) Above Slope Portion of Crest: $H_{3.UN1} := \left[A_{tw.U2} \cdot (W_{twf.U2} - w_{pdg})\right] \cdot \gamma_w$ $H_{3.UN1} = 2106.6 \cdot kN$

Horiz. Moment Arm for H3 (from Toe): $H_{3.UN1.loc} := 5.78 \cdot m$ (From Bluebeam Measurement)

UPLIFT AT INCLINED SLIDING PLANE

UN1 CASE

Uplift pressure at Headwater: $U_{HW.UN1} := D_{hwf.UN1} \cdot \gamma_w = 115.76 \cdot \frac{kN}{m^2}$

Uplift pressure at D/S end of Stilling Basin: $U_{TW.UN1} := D_{tw.UN1} \cdot \gamma_w = 46.9 \cdot \frac{kN}{m^2}$

Length from U/S Face of Gate Structure to Toe of Block: effective drain, Lsb = 0*m $L_{overall} = 24.20\,m$ $L_{sb} = 0$

Length of Seepage per Line of Creep $L_{seepage} = 27.1\,m$

Difference between Uplift pressure at Headwater and Uplift Pressure at Toe of Stilling Basin: $U_{diffUN1} := U_{HW.UN1} - U_{TW.UN1} = 68.9 \cdot \frac{kN}{m^2}$

Slope of difference between Uplift pressure at Headwater and Uplift Pressure at Toe of Stilling Basin: $U_{slopeUN1} := \frac{U_{diffUN1} - Key_d \cdot \gamma_w}{L_{overall}} = 2.24 \cdot \frac{kN}{m^2 \cdot m}$

$$U_{seepageslopeUN1} := \frac{U_{diffUN1} - Key_d \cdot \gamma_w}{L_{seepage}}$$

Tailwater Pressure at toe of Gate Structure: $U_{press.toe.gsUN1} := U_{TW.UN1} + L_{sb} \cdot U_{slopeUN1} = 46.9 \cdot \frac{kN}{m^2}$

$$U_{pore.toe.UN1} := U_{TW.UN1} + U_{seepageslopeUN1} \cdot L_{sb} = 46.9 \cdot \frac{kN}{m^2}$$

$$U_{pore.F.UN1} := U_{pore.toe.UN1} + U_{seepageslopeUN1} \cdot L_{FG} = 49.9 \cdot \frac{kN}{m^2}$$

$$U_{pore.E.UN1} := U_{pore.F.UN1} - \left(BOF_{base} - BOF_{toe}\right) \cdot \gamma_w + U_{seepageslopeUN1} \cdot L_{EF} = 41.9 \cdot \frac{kN}{m^2}$$

$$U_{pore.D.UN1} := U_{pore.E.UN1} + U_{seepageslopeUN1} \cdot L_{DE} = 78.3 \cdot \frac{kN}{m^2}$$

$$U_{pore.C.UN1} := U_{pore.D.UN1} + \left(BOF_{base} - BOF_{elev}\right) \cdot \gamma_w + U_{seepageslopeUN1} \cdot L_{CD} = 113.8 \cdot \frac{kN}{m^2}$$

Uniform uplift due to Tailwater: (rectangular portion) $U_{A.UN1} := U_{press.toe.gsUN1} \cdot L_b \cdot W_b \cdot -1 = -14752.2 \cdot kN$

Moment Arm for Uplift UA from Toe of Gate Structure: $L_{A.UN1} := \frac{L_b}{2} = 12.10\,m$

Uplift - Linear Decrease from HW to TW: (triangular portion) $U_{B.UN1} := \frac{1}{2} \cdot \left(U_{HW.UN1} - U_{press.toe.gsUN1}\right) \cdot L_b \cdot W_b \cdot -1 = -10832.7 \cdot kN$

Moment Arm for Uplift UB from Toe of Gate Structure: $L_{B.UN1} := \frac{2}{3} \cdot L_b = 16.13\,m$

Total Resultant Uplift force: $U_{UN1} := U_{A.UN1} + U_{B.UN1} = -25584.8 \cdot kN$

Resultant Location from Toe: $U_{UN1.loc} := \frac{U_{A.UN1} \cdot L_{A.UN1} + U_{B.UN1} \cdot L_{B.UN1}}{U_{A.UN1} + U_{B.UN1}} = 13.81\,m$

$$\Sigma V_{water.UN1} := H_{1.UN1} + H_{2.UN1} + H_{3.UN1} + U_{UN1} = -17593.5 \cdot kN$$

$$\Sigma M_{Vwater.UN1} := H_{1.UN1} \cdot H_{1.UN1.loc} + H_{2.UN1} \cdot H_{2.UN1.loc} + H_{3.UN1} \cdot H_{3.UN1.loc} + U_{UN1} \cdot U_{UN1.loc} = -234108 \cdot kN \cdot m$$

Uplift as per Line of Creep Method (Flotation and Overturning)

UN1 CASE

$$Uplift_{BC.UN1} := \frac{-1}{2} \cdot W_b \cdot \left(U_{HW.UN1} + U_{pore.C.UN1}\right) \cdot L_{BC} = -1491.9 \cdot kN$$

$$Uplift_{CD.UN1} := 0$$

$$Uplift_{DE.UN1} := \frac{-1}{2} \cdot W_b \cdot \left(U_{pore.D.UN1} + U_{pore.E.UN1}\right) \cdot L_{DE} = -14226.1 \cdot kN$$

$$Uplift_{EF.UN1} := \frac{-1}{2} \cdot W_b \cdot \left(U_{pore.E.UN1} + U_{pore.F.UN1}\right) \cdot L_{EF} = -1997.9 \cdot kN$$

$$Uplift_{FG.UN1} := \frac{-1}{2} \cdot W_b \cdot \left(U_{pore.F.UN1} + U_{pore.toe.UN1}\right) \cdot L_{FG} = -943.6 \cdot kN$$

$$Uplift_{pore.UN1} := Uplift_{BC.UN1} + Uplift_{DE.UN1} + Uplift_{EF.UN1} + Uplift_{FG.UN1} = -18659.5 \cdot kN$$

$$Uplift_{FG.UN1.loc} := \frac{L_{FG}}{3} \cdot \frac{\left(2 \cdot U_{pore.F.UN1} + U_{pore.toe.UN1}\right)}{\left(U_{pore.F.UN1} + U_{pore.toe.UN1}\right)} = 0.76\,m$$

$$Uplift_{EF.UN1.loc} := \frac{L_{EF}}{3} \cdot \frac{\left(2 \cdot U_{pore.E.UN1} + U_{pore.F.UN1}\right)}{\left(U_{pore.E.UN1} + U_{pore.F.UN1}\right)} + L_{FG} = 3.13\,m$$

$$Uplift_{DE.UN1.loc} := \frac{L_{DE}}{3} \cdot \frac{\left(2 \cdot U_{pore.D.UN1} + U_{pore.E.UN1}\right)}{\left(U_{pore.D.UN1} + U_{pore.E.UN1}\right)} + L_{FG} + X_{EF} = 14.52\,m$$

$$Uplift_{BC.UN1.loc} := \frac{L_{BC}}{3} \cdot \frac{\left(2 \cdot U_{HW.UN1} + U_{pore.C.UN1}\right)}{\left(U_{HW.UN1} + U_{pore.C.UN1}\right)} + L_{FG} + X_{EF} + L_{DE} = 23.21\,m$$

SOIL LOADS

UN1 CASE

Equivalent Fluid Pressure (EFP):

(CFEM 24.1)

At rest lateral pressure coefficient: $K_o = 0.66$

At-rest Soil Pressure to Heel, EM1110--2-2502 Section 3-7

Lateral Driving Force (Headwater Side)

Depth of Fill at Heel: $t_{hf.UN1} := TOC_{as} - BOF_{elev} = 6.00\,m$

At-Rest Soil Load: $E1_{drive.UN1} := \frac{K_o \cdot t_{hf.UN1}^{2}}{2} \cdot (\gamma_r - \gamma_w) \cdot W_b \cdot -1 = -1876.9 \cdot kN$

Acting at: $E1_{drive.loc.UN1} := \frac{t_{hf.UN1}}{3} - (BOF_{toe} - BOF_{elev}) = 0.50\,m$

Lateral Resisting Force (Tailwater Side)

Depth of Fill at Toe: $t_{tf.UN1} := TOC_{fce} - BOF_{toe} = 2.00\,m$

At-Rest Soil Load: $E2_{resistUN1} := \frac{K_o \cdot t_{tf.UN1}^{2}}{2} \cdot (\gamma_r - \gamma_w) \cdot W_b = 208.5 \cdot kN$ $E2_{resistUN1} := 0$

Acting at: $E2_{resistlocUN1} := \frac{t_{tf.UN1}}{3} = 0.67\,m$

(Expansion Joint to Stilling Basin, No Sediment in Gap)

$\Sigma H_{soil.UN1} := E1_{drive.UN1} + E2_{resistUN1} = -1876.9 \cdot kN$

$\Sigma M_{soil.UN1} := E1_{drive.UN1} \cdot E1_{drive.loc.UN1} + E2_{resistUN1} \cdot E2_{resistlocUN1} = -938.4 \cdot kN \cdot m$

ICE / IMPACT LOADS (CONSERVATIVELY ASSUME NO ICE LOADING ON DOWNSTREAM SIDE)

Static Impact Loading on Structure: $I_{S.UN1} := 150.0 \frac{kN}{m}$ (Section 7.7, Design Criteria)

Static Impact load on Gates: $I_{G.UN1} := 75 \frac{kN}{m}$ (Section 7.7, Design Criteria)

Impact Loading Unit Width on Structure: $W_{S.UN1} := 4.00m$

Impact Loading Unit Width on Gates: $W_{G.UN1} := 2 \cdot \frac{20.00}{2} m = 20.00\,m$

Total Impact Load on Structure: $I_{UN1} := (I_{S.UN1} \cdot W_{S.UN1} + I_{G.UN1} \cdot W_{G.UN1}) \cdot -1 = -2100 \cdot kN$

Apply Ice load at: $I_{UN1.loc} := (HW_{UN1} - BOF_{toe} - 0.30m) = 10.00\,m$

$\Sigma H_{I.UN1} := I_{UN1} = -2100 \cdot kN$

$\Sigma M_{I.UN1} := I_{UN1} \cdot I_{UN1.loc} = -21000 \cdot kN \cdot m$

SEISMIC LOAD (Not Applicable to this Load Case)

SUMMARY OF LOADS

UN1 CASE

	Loads	Moment Arm
Dead Load of Concrete Structure:	$D_{conc} = 52182.8 \cdot kN$	$X_{conc.loc} = 12.43\,m$
Dead Load of Gate:	$D_{Gate} = 580.0 \cdot kN$	$X_{gate} = 9.75\,m$
Headwater Lateral Load on Pier:	$H_{hwp.UN1} = -660.0 \cdot kN$	$H_{hwp.UN1.loc} = 6.43\,m$
Headwater Lateral Load on Gate:	$H_{hwg.UN1} = 0.0 \cdot kN$	$H_{hwg.UN1.loc} = 7.43\,m$
Headwater Lateral Load on Footing:	$H_{hwf.UN1} = -7699.6 \cdot kN$	$H_{hwf.UN1.loc} = 1.67\,m$
Tailwater Lateral Load:	$H_{twf.UN1} = 1008.6 \cdot kN$	$H_{twf.UN1.loc} = 0.09\,m$
Tailwater Lateral Load on Pier:	$H_{twp.UN1} = 448.3 \cdot kN$	$H_{twp.UN1.loc} = 0.09\,m$
Water Weight (HW) on Apron Slab:	$H_{1.UN1} = 3315.4 \cdot kN$	$H_{1.UN1.loc} = 21.10\,m$
Water Weight (HW) on Fixed Crest:	$H_{2.UN1} = 2569.2 \cdot kN$	$H_{2.UN1.loc} = 14.41\,m$
Water Weight (TW) on Fixed Crest:	$H_{3.UN1} = 2106.6 \cdot kN$	$H_{3.UN1.loc} = 5.78\,m$
Uplift:	$U_{UN1} = -25584.8 \cdot kN$	$U_{UN1.loc} = 13.81\,m$
Upstream (driving) Lateral Soil Load:	$E1_{drive.UN1} = -1876.9 \cdot kN$	$E1_{drive.loc.UN1} = 0.50\,m$
Downstream (resisting) Lateral Soil Load:	$E2_{resistUN1} = 0 \cdot kN$	$E2_{resistlocUN1} = 0.67\,m$
Ice / Impact Load:	$I_{UN1} = -2100.0 \cdot kN$	$I_{UN1.loc} = 10.00\,m$

STABILITY ASSESSMENT (SLIDNG, OVERTURNING AND BEARING):

UN1 CASE

CHECK SLIDING ALONG HORIZONTAL PLANE THRU TOE,
IGNORING BEDROCK MOBILIZED BY STRUCTURAL HEEL KEY, OR VOID BEHIND KEY

Sum of Vertical Forces:

$\Sigma V_{UN1} := \Sigma V_{DL.UN1} + \Sigma V_{water.UN1} = 35169.3 \cdot kN$

Sum of Horizontal Forces:

$\Sigma H_{UN1} := \Sigma H_{Water.UN1} + \Sigma H_{soil.UN1} + \Sigma H_{I.UN1} = -10879.6 \cdot kN$

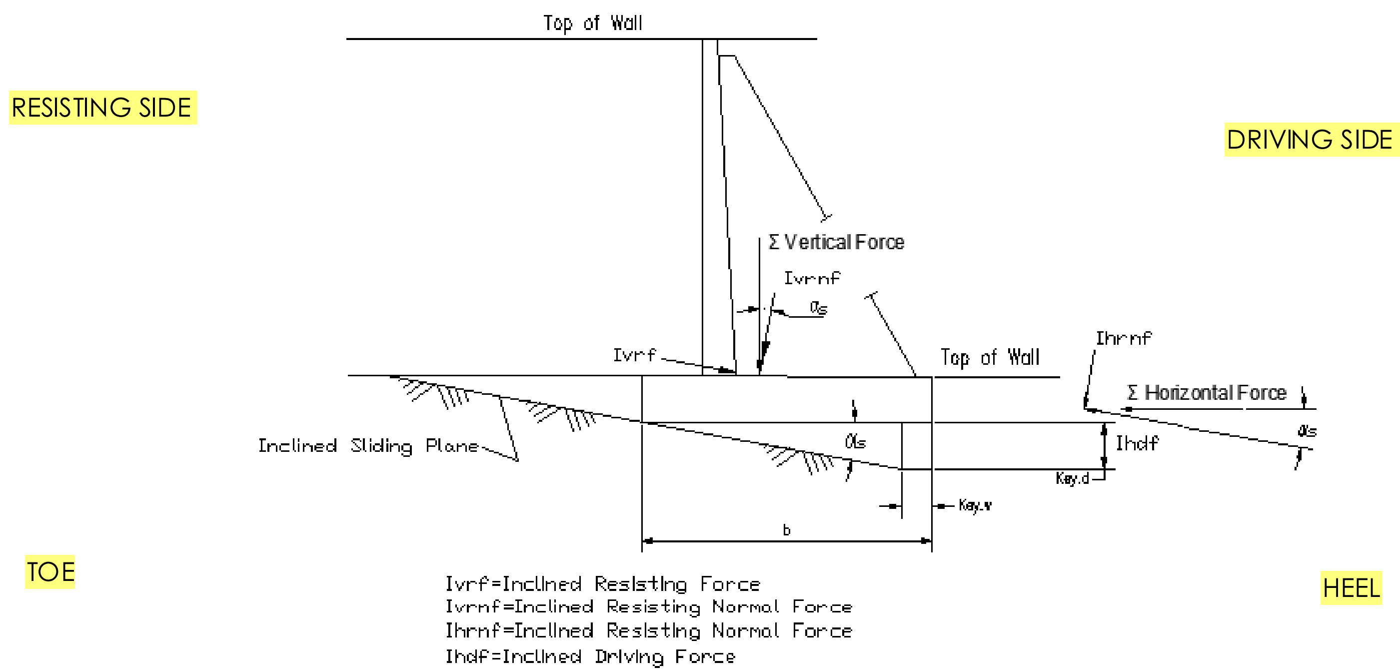
Sliding Factor of Safety:

$$FS_{HorizSliding.UN1} := \frac{\tan_{\phi} \cdot \Sigma V_{UN1}}{\left|\Sigma H_{UN1}\right|} = 1.58$$

$$FS_{HorizSliding.UN1.Check} := \begin{cases} \text{"OKAY"} & \text{if } FS_{HorizSliding.UN1} \geq FS_{req.UN1.sl} \\ \text{"Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

$FS_{HorizSliding.UN1.Check} = \text{"OKAY"}$

CHECK SLIDING ALONG INCLINED SLIDING PLANE FROM HEEL KEY TO TOE,
WITH BEDROCK MASS MOBILIZED BY REINFOCREDE CONCRETE KEY)



$$\alpha s := \operatorname{atan}\left(\frac{BOF_{toe} - BOF_{elev}}{L_b - Key_l}\right) = 0.13$$

as degrees= $\alpha s \cdot \left(\frac{180}{\pi}\right) = 7.63$

Resolve $\Sigma Vert_{UN1}$ & $\Sigma Horiz_{UN1}$

$$\Sigma V_{InclinedUN1} := \cos(\alpha s) \cdot \left(\Sigma V_{UN1} + V_{rs}\right) + \sin(\alpha s) \cdot \left|\Sigma H_{UN1}\right| = 49404.2 \cdot kN$$

$$\Sigma H_{InclinedUN1} := \cos(\alpha s) \cdot \left|\Sigma H_{UN1}\right| - \sin(\alpha s) \cdot \left(\Sigma V_{UN1} + V_{rs}\right) = 4360.1 \cdot kN$$

(With properly engineered reinforced concrete Key, horizontal sliding plane thru Toe is protected, critical sliding plane is relocated to the INCLINED SLIDING PLANE FROM HEEL KEY To TOE, Bedrock Mass above this examing plane is mobilized by reinforced concrete key and combined into Structural Wedge.)

Inclined Sliding Plane Length $L_{incline} = 24.2\,m$

Safety Factor for Sliding
Inclined Failure Plane

$$FS_{InclinedISlidingUN1} := \frac{\Sigma V_{InclinedUN1} \cdot \tan\left(\phi_{rock} \cdot \frac{\pi}{180}\right)}{\left|\Sigma H_{InclinedUN1}\right|} = 5.53$$

$$FS_{InclinedSliding.UN1.check} := \begin{cases} \text{"OKAY "} & \text{if } FS_{InclinedISlidingUN1} > FS_{req.U1.sl} \\ \text{"Revise Structure""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

$FS_{InclinedSliding.UN1.check} = \text{"OKAY "}$

CHECK ECCENTRICITY ON INCLINED PLANE

UN1 CASE

Sum of the Moments:

$$\Sigma M_{rs.UN1} := \Sigma M_{DL.UN1} + \Sigma M_{HWater.UN1} + \Sigma M_{Vwater.UN1} + \Sigma M_{I.UN1} + \Sigma M_{soil.UN1} + V_{rs} \cdot L_{rs} = 565769 \cdot kN \cdot m$$

Eccentricity:

$$e_{UN1} := \frac{L_{incline}}{2} - \frac{\Sigma M_{rs.UN1}}{\Sigma V_{InclinedUN1}} = 0.67\,m$$

Eccentricity Check:

$$e_{check.UN1} := \begin{cases} \text{"Okay"} & \text{if } |e_{UN1}| \le Kern \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$e_{check.UN1} = \text{"Okay"}$

Foundation Bearing Pressures on Inclined Plane:

Bearing Pressure at Heel:

$$\sigma_{heel.UN1} := \frac{\Sigma V_{InclinedUN1}}{\frac{A_b}{\cos(\alpha s)}} - \frac{\Sigma V_{InclinedUN1} \cdot e_{UN1}}{\frac{S_b}{\cos(\alpha s)^2}} = 130 \cdot \frac{kN}{m^2}$$

$$\sigma_{heel.UN1.check} := \left(\begin{cases} \text{"Okay"} & \text{if } \sigma_{heel.UN1} \le \sigma_{allow.UN1} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} \right)$$

$\sigma_{heel.UN1.check} = \text{"Okay"}$

Bearing Pressure at Toe:

$$\sigma_{toe.UN1} := \frac{\Sigma V_{InclinedUN1}}{\frac{A_b}{\cos(\alpha s)}} + \frac{\Sigma V_{InclinedUN1} \cdot e_{UN1}}{\frac{S_b}{\cos(\alpha s)^2}} = 181.3 \cdot \frac{kN}{m^2}$$

$$\sigma_{toe.UN1.check} := \begin{cases} \text{"Okay"} & \text{if } \sigma_{toe.UN1} \le \sigma_{allow.UN1} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$\sigma_{toe.UN1.check} = \text{"Okay"}$

CHECK FLOTATION

$Uplift_{sliding.UN1} := U_{UN1} = -25584.8 \cdot kN$

$Uplift_{pore.UN1} = -18659.5 \cdot kN$

(For conservative, taking maximum values)

$$\left(Uplift_{UN1}\right) := \min\left(Uplift_{pore.UN1}, Uplift_{sliding.UN1}\right)$$

$$FS_{Flotation.UN1} := \frac{D_{conc} + D_{Gate} + H_{1.UN1} + H_{2.UN1} + H_{3.UN1}}{|Uplift_{UN1}|} = 2.4$$

$$FS_{Flotation.UN1.check} := \begin{cases} \text{"OKAY "} & \text{if } FS_{Flotation.UN1} > FS_{req.UN.flt} \\ \text{"Revise Structure""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

MONOLITH OVERTURNING STABILITY ANALYSIS

UN1 CASE

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.
Assumptions are made in order to compute overturning stability of indetermine forces on monolith with key;
(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.
(b) The horizontal resisting force acting on the key, P.key, is that required for static equilibrium
(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1 $Ratio_{overturning.allow.Unusual} := 0.333$

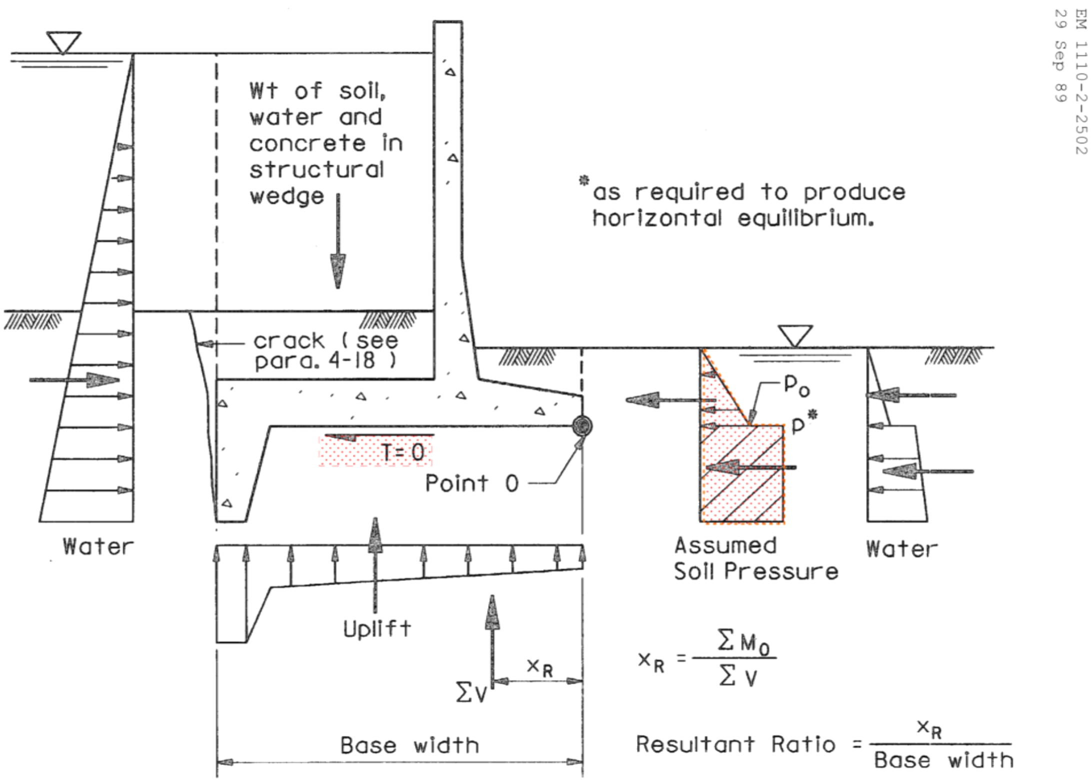


Figure 4-5. Forces for overturning analysis for wall with horizontal base and key

<u>All Vertical Loads Applicable to Overturning Stability Analysis</u>

Total Concrete Dead Loads:	$D_{conc} = 52182.8 \cdot kN$	at:	$X_{conc.loc} = 12.4\,m$
Dead Load of Gate:	$D_{Gate} = 580.0 \cdot kN$		$X_{gate} = 9.75\,m$
Water Weight (HW) on Apron Slab:	$H_{1.UN1} = 3315.4 \cdot kN$		$H_{1.UN1.loc} = 21.10\,m$
Water Weight (HW) on Fixed Crest:	$H_{2.UN1} = 2569.2 \cdot kN$		$H_{2.UN1.loc} = 14.41\,m$
Water Weight (TW) on Fixed Crest:	$H_{3.UN1} = 2106.6 \cdot kN$		$H_{3.UN1.loc} = 5.78\,m$

Uplift Force from Sliding Analysis. Line of Creep Method applied at presumed inclined sliding line, and subtraction gravity effect to Base of Concrete by Archimedes Principle

$$U_{UN1.loc.sliding} := \frac{U_{A.UN1} \cdot L_{A.UN1} + U_{B.UN1} \cdot L_{B.UN1} - A_{rs} \cdot w_{as} \cdot \gamma_w \cdot L_{rs}}{U_{A.UN1} + U_{B.UN1} - A_{rs} \cdot w_{as} \cdot \gamma_w} = 13.84\,m$$

$$U_{UN1.sliding} := U_{UN1} + A_{rs} \cdot w_{as} \cdot \gamma_w = -19690.4 \cdot kN$$

UN1 CASE

Uplift for Overturning Analysis, Line of Creep Method. Pore pressure at base of Concrete

$Uplift_{pore.UN1} = -18659.5 \cdot kN$

$$Uplift_{pore.UN1.loc} := \frac{Uplift_{BC.UN1} \cdot Uplift_{BC.UN1.loc} + Uplift_{DE.UN1} \cdot Uplift_{DE.UN1.loc} + Uplift_{EF.UN1} \cdot Uplift_{EF.UN1.loc} + Uplift_{FG.UN1} \cdot Uplift_{FG.UN1.loc}}{Uplift_{pore.U2}}$$

$Uplift_{pore.UN1.loc} = 13.3\,m$

Sum of All Water Load for Overturning Analysis

$\Sigma V_{water.UN1.OT} := H_{1.UN1} + H_{2.UN1} + H_{3.UN1} + Uplift_{pore.UN1} = -10668.2 \cdot kN$

All Lateral Loads Applicable to Overturning Stability Analysis

Apply Load to Gate?: $poss_{UN1} = 0$ — poss = 1 if gate is closed, 0 if gate is open

Headwater Lateral Load on Pier: $H_{hwp.UN1} = -660.0 \cdot kN$ $H_{hwp.UN1.loc} = 6.43\,m$

Headwater Lateral Load on Gate: $H_{hwg.UN1} = 0.0 \cdot kN$ $H_{hwg.UN1.loc} = 7.43\,m$

Headwater Lateral Load on Footing: $H_{hwf.UN1} = -7699.6 \cdot kN$ $H_{hwf.UN1.loc} = 1.67\,m$

Total Horizontal Tailwater Load on Pier: $H_{twp.UN1} = 448.3 \cdot kN$ $H_{twp.UN1.loc} = 0.09\,m$

Total Horizontal Tailwater Load on Footing under Gate Openings, i.e., excluding Pier: $H_{twf.UN1} = 1008.6 \cdot kN$ $H_{twf.UN1.loc} = 0.09\,m$

Resisting Water on Rear Face of Monolith, i.e., bottom of heel elevation: *(Point O @ TOE: BOFtoe = EL.1205.5)*

Ice / Impact Load: $I_{UN1} = -2100.0 \cdot kN$ at: $I_{UN1.loc} = 10.00\,m$

Depth of Fill at Heel Side for Overturning Analysis: $t_{hf.UN1} := TOC_{as} - BOF_{toe} = 4.50\,m$

Driving Soil Load for overturning: $E1_{drive.UN1} := \frac{K_o \cdot t_{hf.UN1}^2}{2} \cdot (\gamma_r - \gamma_w) \cdot W_b \cdot -1 = -1055.7 \cdot kN$

Acting at: $E1_{drive.loc.UN1} := \frac{t_{hf.UN1}}{3} = 1.50\,m$

Downstream (resisting) Lateral Soil Load as required to produce horizontal equilibrium:

$E2_{resistUN1} := -1 \cdot (H_{hwp.UN1} + H_{hwg.UN1} + H_{hwf.UN1} + H_{twp.UN1} + H_{twf.UN1} + I_{UN1} + E1_{drive.UN1})$

$E2_{resistUN1} = 10058.4 \cdot kN$

Assumed Resisting Bedrock at middle of Key, passive soil pressure or lateral bearing contract joint at end of Monolith 3A3B: $E2_{resistlocUN1} := E2_{resistlocU1} = 0.67\,m$

Overturning moment by Dead Loads about Point O @ Toe: $\Sigma M_{DL.UN1} = 654229.9 \cdot kN \cdot m$

Overturning moment by Vertical Water Loads and Uplift, about Point O @ Toe

$$\Sigma M_{Vwater.UN1.OT} := H_{1.UN1} \cdot H_{1.UN1.loc} + H_{2.UN1} \cdot H_{2.UN1.loc} + H_{3.UN1} \cdot H_{3.UN1.loc} + Uplift_{pore.UN1} \cdot Uplift_{pore.UN1.loc} = -128810.2 \cdot kN \cdot m$$

UN1 CASE

Overturning moment by Lateral Hydrostatic Forces of Headwater Pool and Tailwater Pool,about Point O @ Toe

$\Sigma M_{HWater.UN1} = -16950.8 \cdot kN \cdot m$

Overturning Moment by Impact/Ice Load, about Point O@ Toe

$\Sigma M_{I.UN1} = -21000 \cdot kN \cdot m$

Overturning moment by Lateral Soil Forces about Point O @ Toe

$\Sigma M_{soil.UN1} := E1_{drive.UN1} \cdot E1_{drive.loc.UN1} + E2_{resistUN1} \cdot E2_{resistlocUN1} = 5122 \cdot kN \cdot m$

Sum of the Overturning Moments about Point O @ Toe:

$$\Sigma M_{UN1.OT} := \Sigma M_{DL.UN1} + \Sigma M_{HWater.UN1} + \Sigma M_{Vwater.UN1.OT} + \Sigma M_{I.UN1} + \Sigma M_{soil.UN1} = 492591 \cdot kN \cdot m$$

Sum of Vertical Forces: $\Sigma V_{UN1.OT} := \Sigma V_{DL.UN1} + \Sigma V_{water.UN1.OT} = 42094.6 \cdot kN$

Distance X_R: EM 1110-2-2502 Eq.4-1 $X_{R.UN1} := \dfrac{\Sigma M_{UN1.OT}}{\Sigma V_{UN1.OT}} = 11.7\,m$

Overturning Resultant Ratio $Ratio_{Overturning.UN1} := \dfrac{X_{R.UN1}}{L_b} = 0.48$

EM 1110-2-2502

Table 4-1

Retaining Wall Stability Criteria

Loading Condition	Sliding Factor of Safety, FS	Shear Strength Test Required: Soil Foundation	Shear Strength Test Required: Rock Foundation[3]	Overturning Criteria Minimum Base Area in Compression: Soil Foundation	Overturning Criteria Minimum Base Area in Compression: Rock Foundation
Usual	1.5	(Q &/or S)[2,1]	Direct shear	100%[4]	75%[4]
Unusual	1.33	(Q &/or S)[2,1]	Direct shear	75%[4]	50%[4]
Earthquake	1.1	(Q)	Direct shear	Resultant within base	Resultant within base

Overturning Stability Check

$$Ratio_{Overturning.UN1.check} := \begin{cases} \text{"Okay"} & \text{if } Ratio_{Overturning.UN1} \ge Ratio_{overturning.allow.Unusual} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$Ratio_{Overturning.UN1.check} = \text{"Okay"}$

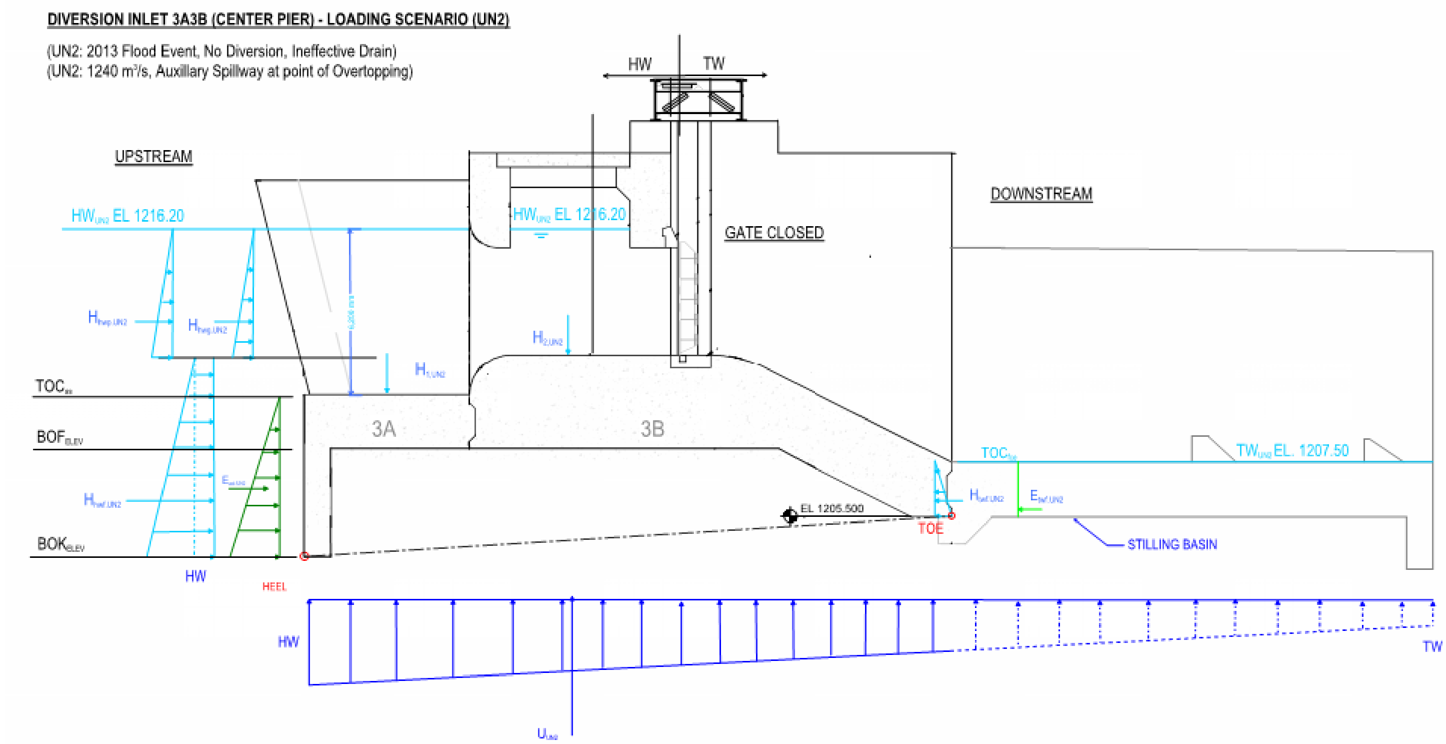
Summary of Extreme Flood Results (Only Report Controlling Load Case)

UN1 CASE

UN1 Event: Diversion Operation, 2013 Flood

Horiz Sliding Factor of Safety:	$FS_{HorizSliding.UN1} = 1.58$
Horiz Sliding Factor of Safety Check:	$FS_{HorizSliding.UN1.Check}$ = "OKAY"
Sliding Factor of Safety:	$FS_{InclinedlSlidingUN1} = 5.5$
Sliding Factor of Safety Check:	$FS_{InclinedSliding.UN1.check}$ = "OKAY "
Eccentricity:	$e_{UN1} = 0.67\,m$
Eccentricity Check:	$e_{check.UN1}$ = "Okay"
Bearing Pressure At Heel on Inclined Plane:	$\sigma_{heel.UN1} = 130 \cdot \frac{kN}{m^2}$
Bearing Pressure At Heel Check:	$\sigma_{heel.UN1.check}$ = "Okay"
Bearing Pressure At Toe on Inclined Plane:	$\sigma_{toe.UN1} = 181.3 \cdot \frac{kN}{m^2}$
Bearing Pressure At Toe Check:	$\sigma_{toe.UN1.check}$ = "Okay"
Flotation Factor of Safety	$FS_{Flotation.UN1} = 2.4$
Flotation Factor of Safety Check:	$FS_{Flotation.UN1.check}$ = "OKAY "
Overturning Resultant Ratio	$Ratio_{Overturning.UN1} = 0.48$
Overturning Stability Check	$Ratio_{Overturning.UN1.check}$ = "Okay"

UN2 DESIGN CASE



ACCEPTANCE PARAMETERS

Required Factor of Safety for Sliding: $FS_{req.UN2.sl} := 1.3$ (Without Cohesion) (Section 8.1, Design Criteria)

Resultant Within Middle Third of Base: $e \le \frac{L_b}{6} \wedge e \ge \frac{-L_b}{6}$

Allowable Rock Bearing Pressure: $\sigma_{allow.UN2} := 1470 \cdot \frac{kN}{m^2}$ (Section 5.2, Design Criteria)

Required Factor of Safety for Flotation: $FS_{req.UN.flt} = 1.3$

Overturning Min Required Resultant Ratio: $\frac{X_{R.UN}}{Horizontal\_Width\_of\_Base} > 0.33$

UN2 CASE

INPUT PARAMETERS

Headwater Elevation: $HW_{UN2} := 1216.20m$

Tailwater Elevation: $TW_{UN2} := 1207.50m$

(Water Elevations based on Diversion Structure 2D Hydraulic Model Results. See page 7 and Section 8.2, Design Criteria)

Crest Water Elevation (No Diversion)

Chute Block Water Elevation (No Diversion)

Bottom of Key (Footing Heel) Elevation: $BOF_{elev} = 1204.00\, m$

Apron Slab Top of Concrete Elevation at Edge of Slab: $TOC_{as} = 1210.00\, m$

Fixed Crest Top of Concrete Elevation at Downstream Face: $TOC_{fce} = 1207.50\, m$

Fixed Crest Top of Concrete Elevation at Center of Footing: $TOC_{fcc} = 1211.50\, m$

VERTICAL LIFT GATE

Lift Gate Position per Hydraulic Criteria: $poss_{UN2} := 1$

poss = 1 if gate is closed
0 if gate is open

DEAD LOAD SUMMATION:

$$Gate_{R.UN2} := \begin{cases} 1 & \text{if } poss_{UN2} = 0 \\ 0.45 & \text{otherwise} \end{cases}$$

Monolith Reaction for Wheel Gate

$$\Sigma V_{DL.UN2} := D_{conc} + Gate_{R.UN2} D_{Gate} = 52443.8 \cdot kN$$

$$\Sigma M_{DL.UN2} := D_{conc} \cdot X_{conc.loc} + Gate_{R.UN2} \cdot D_{Gate} \cdot X_{gate} = 651119.6 \cdot kN \cdot m$$

LATERAL WATER LOADS

UN2 CASE

HEADWATER (DRIVING):

Water Depth on Pier at Heel: $D_{hwp.UN2} := HW_{UN2} - TOC_{as} = 6.20\,m$

Water Load Unit Width on Pier: $W_{hwp.UN2} := w_{pn} = 4.00\,m$

Total Horizontal Water Load on Pier: $H_{hwp.UN2} := \frac{-\left(\gamma_w \cdot D_{hwp.UN2}{}^2\right)}{2} \cdot W_{hwp.UN2} = -754.2 \cdot kN$

Apply Total Pier Water Load at: $H_{hwp.UN2.loc} := \frac{D_{hwp.UN2}}{3} + \left(TOC_{as} - BOF_{toe}\right) = 6.57\,m$

Point O @ TOE: BOFtoe = EL.1205.5

Water Depth Above Fixed Crest at Gate: $D_{hwg.UN2} := HW_{UN2} - TOC_{fcc} = 4.7\,m$

Water Load Unit Width on Gate $W_{hwg.UN2} := 2 \cdot \frac{20.00}{2} m = 20.00\,m$

Apply Load to Gate?: $poss_{UN2} = 1$

poss = 1 if gate is closed
0 if gate is open

Total Horizontal Water Load on Gate: $H_{hwg.UN2} := \frac{-\left(\gamma_w \cdot D_{hwg.UN2}{}^2\right)}{2} \cdot W_{hwg.UN2} \cdot poss_{UN2} = -2167 \cdot kN$

Apply Total Gate Water Load at: $H_{hwg.UN2.loc} := \frac{D_{hwg.UN2}}{3} + \left(TOC_{fcc} - BOF_{toe}\right) = 7.57\,m$

Water Depth at Heel: $D_{hwf.UN2} := HW_{UN2} - BOF_{elev} = 12.20\,m$

Water Load Unit With on Footing: $W_{hw.UN2} := W_b$

Water Load at Bottom of Footing: $H_{hwf.UN2.1} := -\left(\gamma_w \cdot D_{hwf.UN2}\right) \cdot W_{hw.UN2} = -1555.9 \frac{1}{m} \cdot kN$

Water Load at Top of Footing: $H_{hwf.UN2.2} := -\left(\gamma_w \cdot D_{hwg.UN2}\right) \cdot W_{hw.UN2} = -599.4 \frac{1}{m} \cdot kN$

Total Horizontal Water Load on Footing: $H_{hwf.UN2} := \frac{\left(H_{hwf.UN2.1} + H_{hwf.UN2.2}\right) \cdot \left(D_{hwf.UN2} - D_{hwg.UN2}\right)}{2} = -8082.2 \cdot kN$

Apply Total Footing Water Load at:

$$H_{hwf.UN2.loc} := \frac{\left[H_{hwf.UN2.2} \cdot \frac{\left(TOC_{fcc} - BOF_{elev}\right)^2}{2} + \frac{\left(H_{hwf.UN2.1} - H_{hwf.UN2.2}\right)}{2} \frac{\left(TOC_{fcc} - BOF_{elev}\right)^2}{3}\right]}{\left[\frac{\left(H_{hwf.UN2.2} + H_{hwf.UN2.1}\right) \cdot \left(TOC_{fcc} - BOF_{elev}\right)}{2}\right]} - \left(BOF_{toe} - BOF_{elev}\right) = 1.70\,m$$

(Converting horizontal force resultant from HEEL calculation to Point-O@TOE)

LATERAL WATER LOADS (cont.)

TAILWATER (RESISTING):

Water Depth at toe: $D_{tw.UN2} := TW_{UN2} - BOF_{elev} = 3.50\,m$

Water Load Unit Width: $W_{twf.UN2} := W_b$

Total Horizontal Tailwater Load on Footing under Gate Openings, i.e., excluding Pier

Resisting Water on Rear Face of Monolith, i.e., bottom of heel elevation

$COND_{UN2} := poss_{UN2} = 0 \wedge TW_{UN2} \geq TOC_{fcc}$

$$H_{twf.UN2} := \begin{cases} \dfrac{\gamma_w \cdot D_{tw.UN2}^{\,2}}{2} \cdot \left(W_{twf.UN2} - w_{pdg}\right) & \text{if } poss_{UN2} = 1 \\ \dfrac{\gamma_w \cdot D_{tw.UN2}^{\,2}}{2} \cdot \left(W_{twf.UN2} - w_{pdg}\right) & \text{if } poss_{UN2} = 0 \wedge TW_{UN2} \leq TOC_{fcc} \\ \gamma_w \cdot \left[\dfrac{D_{tw.UN2}}{2} + \dfrac{\left(TW_{UN2} - TOC_{fcc}\right)}{2}\right] \cdot \left(TOC_{fcc} - BOF_{elev}\right) \cdot \left(W_{twf.UN2} - w_{pdg}\right) & \text{if } COND_{UN2} \end{cases} = 540.8 \cdot kN$$

Apply Footing Tailwater Load within Gate Openings at:

$$H_{twf.UN2.loc} := \begin{cases} \dfrac{D_{tw.UN2}}{3} - \left(BOF_{toe} - BOF_{elev}\right) & \text{if } poss_{UN2} = 1 \\ \dfrac{D_{tw.UN2}}{3} - \left(BOF_{toe} - BOF_{elev}\right) & \text{if } poss_{UN2} = 0 \wedge TW_{UN2} \leq TOC_{fcc} \\ \dfrac{\left(TOC_{fcc} - BOF_{elev}\right)^2 \cdot \left[\dfrac{\left(TW_{UN2} - TOC_{fcc}\right)}{2} + \dfrac{\left(TOC_{fcc} - BOF_{elev}\right)}{6}\right]}{\left(TOC_{fcc} - BOF_{elev}\right)\left[\left(TW_{UN2} - TOC_{fcc}\right) + \dfrac{\left(TOC_{fcc} - BOF_{elev}\right)}{2}\right]} - \left(BOF_{toe} - BOF_{elev}\right) & \text{if } COND_{UN2} \end{cases} = -0.33 \cdot m$$

Total Horizontal Tailwater Load on Pier:

$$H_{twp.UN2} := \frac{\gamma_w \cdot D_{tw.UN2}^{\,2}}{2} \cdot w_{pdg} = 240.3 \cdot kN$$

Apply Horizontal Tailwater Load on Pier at:

$$H_{twp.UN2.loc} := \frac{D_{tw.UN2}}{3} - \left(BOF_{toe} - BOF_{elev}\right) = -0.33 \cdot m$$

$$\Sigma H_{Water.UN2} := H_{hwp.UN2} + H_{hwg.UN2} + H_{hwf.UN2} + H_{twf.UN2} + H_{twp.UN2} = -10222.3 \cdot kN$$

$$\Sigma M_{HWater.UN2} := H_{hwp.UN2} \cdot H_{hwp.UN2.loc} + H_{hwg.UN2} \cdot H_{hwg.UN2.loc} + H_{hwf.UN2} \cdot H_{hwf.UN2.loc} \cdots + H_{twf.UN2} \cdot H_{twf.UN2.loc} + H_{twp.UN2} \cdot H_{twp.UN2.loc} = -35311.6 \cdot kN \cdot m$$

VERTICAL WATER LOADS

UN2 CASE

HEADWATER:

Water Depth on top of fixed crest: $d_{hw.UN2} := HW_{UN2} - TOC_{as} = 6.20\,m$

Subtract Pier Volume: $S_{pn.UN2} := \left[\frac{(A_{pnt} - A_{pnb})}{h_{pn}}\right] = 1.00 \cdot \frac{m^2}{m}$

$V_{pn.UN2} := \frac{\left[(S_{pn.UN2} \cdot d_{hw.UN2} + A_{pnb}) + A_{pnb}\right]}{2} \cdot d_{hw.UN2} = 139.7 \cdot m^3$

Weight of Water (H1) on Approach Slab: $H_{1.UN2} := (W_{hw.UN2} \cdot d_{hw.UN2} \cdot L_{as} - V_{pn.UN2}) \cdot \gamma_w = 3531.9 \cdot kN$

Horiz. Moment Arm for H1 (from toe): $H_{1.UN2.loc} := L_b - \frac{L_{as}}{2} = 21.10\,m$

Cross-sectional Area of Headwater Above Fixed Crest: $A_{fc.hw.UN2} := 35.85m^2$ (From Bluebeam Measurement)

Volume of water Above Fixed Crest: $V_{fc.hw.UN2} := \left[A_{fc.hw.UN2} \cdot (W_{hw.UN2} - w_{pn})\right] = 322.7 \cdot m^3$

Weight of Water (H2) on Fixed Crest: $H_{2.UN2} := (V_{fc.hw.UN2}) \cdot \gamma_w = 3165.2 \cdot kN$

Horiz. Moment Arm for H2 (from toe): $H_{2.UN2.loc} := X_{pug} = 14.25\,m$

TAILWATER:

Slope of Crest from D/S of Gate to edge of Stilling Basin: $S_{f.UN2} := \frac{(TOC_{fcc} - TOC_{fce})}{8.00m} = 0.500$

Height of Tailwater Above Stilling Basin:

$$y_{UN2} := \begin{cases} (TW_{UN2} - TOC_{fce}) & \text{if } TW_{UN2} \le TOC_{fcc} \\ (TOC_{fcc} - TOC_{fce}) & \text{otherwise} \end{cases}$$

$y_{UN2} = 0.00\,m$

Horizontal Distance of Tailwater Above Sloped Portion of Crest: $x_{UN2} := \frac{y_{UN2}}{S_{f.UN2}} = 0.00\,m$

Cross Sectional Area of Tailwater Above Sloped Portion of Crest: $A_{tw.UN2} := \frac{x_{UN2} \cdot y_{UN2}}{2} = 0\,m^2$

$= 0.00m^2$ if TW_{UN2} is less than or equal to TOC_{fce}

Weight of Water (H3) Above Slope Portion of Crest:

$$H_{3.UN2} := \begin{cases} (0.0kN) & \text{if } TW_{UN2} \le TOC_{fce} \\ \left[A_{tw.UN2} \cdot (W_{twf.UN2} - w_{pdg})\right] \cdot \gamma_w & \text{if } TOC_{fcc} \ge TW_{UN2} > TOC_{fce} \\ \left[A_{tw.UN2} + Dist_{gate} \cdot (TW_{UN2} - TOC_{fcc})\right] \cdot (W_{twf.UN2} - w_{pdg}) \cdot \gamma_w & \text{if } TW_{UN2} > TOC_{fcc} \end{cases}$$

$H_{3.UN2} = 0.0 \cdot kN$

Horiz. Moment Arm for H3 (from toe):

$$H_{3.UN2.loc} := \begin{cases} (0.00m) & \text{if } TW_{UN2} \le TOC_{fce} \\ \left(\frac{1}{3} \cdot x_{UN2}\right) & \text{if } TOC_{fcc} \ge TW_{UN2} > TOC_{fce} \\ \dfrac{\left[\frac{1}{2} \cdot x_{UN2} \cdot y_{UN2} \cdot \left(\frac{1}{3}\right) x_{UN2} + (TW_{UN2} - TOC_{fcc}) \cdot Dist_{gate} \cdot \left(\frac{Dist_{gate}}{2}\right)\right]}{\left(\frac{1}{2} x_{UN2} \cdot y_{UN2}\right) + (TW_{UN2} - TOC_{fcc}) \cdot Dist_{gate}} & \text{if } TW_{UN2} > TOC_{fcc} \end{cases}$$

$H_{3.UN2.loc} = 0.00\,m$

UPLIFT AT INCLINED SLIDING PLANE

UN2 CASE

Uplift pressure at Headwater: $U_{HW.UN2} := D_{hwf.UN2} \cdot \gamma_w = 119.68 \cdot \frac{kN}{m^2}$

Uplift pressure at D/S end of Stilling Basin: $U_{TW.UN2} := D_{tw.UN2} \cdot \gamma_w = 34.3 \cdot \frac{kN}{m^2}$

Length from U/S Face of Gate Structure to Toe of Stilling Basin (UN2: Ineffective Drain) $L_{sb.UN2} := 18 \cdot m + 2 \cdot 2 \cdot m$ $L_{overall.UN2} := L_{overall} + L_{sb.UN2} = 46.20\,m$

Length of Seepage per Line of Creep (UN2: Ineffective Drain) $L_{seepage.UN2} := L_{seepage} + L_{sb.UN2}$

Difference between Uplift pressure at Headwater and Uplift Pressure at Toe of Stilling Basin: $U_{diffUN2} := U_{HW.UN2} - U_{TW.UN2} = 85.3 \cdot \frac{kN}{m^2}$

Slope of difference between Uplift pressure at Headwater and Uplift Pressure at Toe of Stilling Basin: $U_{slopeUN2} := \frac{U_{diffUN2} - Key_d \cdot \gamma_w}{L_{overall.UN2}} = 1.53 \cdot \frac{kN}{m^2 \cdot m}$

$U_{seepageslopeUN2} := \frac{U_{diffUN2} - Key_d \cdot \gamma_w}{L_{seepage.UN2}}$

Tailwater Pressure at toe of Gate Structure: $U_{press.toe.gsUN2} := U_{TW.UN2} + U_{slopeUN2} \cdot L_{sb.UN2} = 68 \cdot \frac{kN}{m^2}$

$U_{pore.toe.UN2} := U_{TW.UN2} + U_{seepageslopeUN2} \cdot L_{sb.UN2} = 66 \cdot \frac{kN}{m^2}$

$U_{pore.F.UN2} := U_{pore.toe.UN2} + U_{seepageslopeUN2} \cdot L_{FG} = 68.1 \cdot \frac{kN}{m^2}$

$U_{pore.E.UN2} := U_{pore.F.UN2} - (BOF_{base} - BOF_{toe}) \cdot \gamma_w + U_{seepageslopeUN2} \cdot L_{EF} = 58.2 \cdot \frac{kN}{m^2}$

$U_{pore.D.UN2} := U_{pore.E.UN2} + U_{seepageslopeUN2} \cdot L_{DE} = 84.4 \cdot \frac{kN}{m^2}$

$U_{pore.C.UN2} := U_{pore.D.UN2} + (BOF_{base} - BOF_{elev}) \cdot \gamma_w + U_{seepageslopeUN2} \cdot L_{CD} = 118.2 \cdot \frac{kN}{m^2}$

Uniform uplift due to Tailwater: (rectangular portion) $U_{A.UN2} := U_{press.toe.gsUN2} \cdot L_b \cdot W_b \cdot -1 = -21383.1 \cdot kN$

Moment Arm for Uplift UA from Toe of Gate Structure: $L_{A.UN2} := \frac{L_b}{2} = 12.10\,m$

Uplift - Linear Decrease from HW to TW: (triangular portion) $U_{B.UN2} := \frac{1}{2} \cdot (U_{HW.UN2} - U_{press.toe.gsUN2}) \cdot L_b \cdot W_b \cdot -1 = -8134.4 \cdot kN$

Moment Arm for Uplift UB from Toe of Gate Structure: $L_{B.UN2} := \frac{2}{3} \cdot L_b = 16.13\,m$

Total Resultant Uplift force: $U_{UN2} := U_{A.UN2} + U_{B.UN2} = -29517.5 \cdot kN$

Resultant Location from Toe: $U_{UN2.loc} := \frac{U_{A.UN2} \cdot L_{A.UN2} + U_{B.UN2} \cdot L_{B.UN2}}{U_{A.UN2} + U_{B.UN2}} = 13.21\,m$

$\Sigma V_{water.UN2} := H_{1.UN2} + H_{2.UN2} + H_{3.UN2} + U_{UN2} = -22820.4 \cdot kN$

$\Sigma M_{Vwater.UN2} := H_{1.UN2} \cdot H_{1.UN2.loc} + H_{2.UN2} \cdot H_{2.UN2.loc} + H_{3.UN2} \cdot H_{3.UN2.loc} + U_{UN2} \cdot U_{UN2.loc} = -270343.3 \cdot kN \cdot m$

Uplift as per Line of Creep Method (Flotation and Overturning)

UN2 CASE

$$Uplift_{BC.UN2} := \frac{-1}{2} \cdot W_b \cdot \left(U_{HW.UN2} + U_{pore.C.UN2}\right) \cdot L_{BC} = -1546.5 \cdot kN$$

$$Uplift_{CD.UN2} := 0$$

$$Uplift_{DE.UN2} := \frac{-1}{2} \cdot W_b \cdot \left(U_{pore.D.UN2} + U_{pore.E.UN2}\right) \cdot L_{DE} = -16897.4 \cdot kN$$

$$Uplift_{EF.UN2} := \frac{-1}{2} \cdot W_b \cdot \left(U_{pore.E.UN2} + U_{pore.F.UN2}\right) \cdot L_{EF} = -2751.7 \cdot kN$$

$$Uplift_{FG.UN2} := \frac{-1}{2} \cdot W_b \cdot \left(U_{pore.F.UN2} + U_{pore.toe.UN2}\right) \cdot L_{FG} = -1307.6 \cdot kN$$

$$Uplift_{pore.UN2} := Uplift_{BC.UN2} + Uplift_{DE.UN2} + Uplift_{EF.UN2} + Uplift_{FG.UN2} = -22503.2 \cdot kN$$

$$Uplift_{FG.UN2.loc} := \frac{L_{FG}}{3} \cdot \frac{\left(2 \cdot U_{pore.F.UN2} + U_{pore.toe.UN2}\right)}{\left(U_{pore.F.UN2} + U_{pore.toe.UN2}\right)} = 0.75\,m$$

$$Uplift_{EF.UN2.loc} := \frac{L_{EF}}{3} \cdot \frac{\left(2 \cdot U_{pore.E.UN2} + U_{pore.F.UN2}\right)}{\left(U_{pore.E.UN2} + U_{pore.F.UN2}\right)} + L_{FG} = 3.13\,m$$

$$Uplift_{DE.UN2.loc} := \frac{L_{DE}}{3} \cdot \frac{\left(2 \cdot U_{pore.D.UN2} + U_{pore.E.UN2}\right)}{\left(U_{pore.D.UN2} + U_{pore.E.UN2}\right)} + L_{FG} + X_{EF} = 14.16\,m$$

$$Uplift_{BC.UN2.loc} := \frac{L_{BC}}{3} \cdot \frac{\left(2 \cdot U_{HW.UN2} + U_{pore.C.UN2}\right)}{\left(U_{HW.UN2} + U_{pore.C.UN2}\right)} + L_{FG} + X_{EF} + L_{DE} = 23.21\,m$$

UN2 CASE

SOIL LOADS

Equivalent Fluid Pressure (EFP): (CFEM 24.1)

At rest lateral pressure coefficient: $K_o = 0.66$

At-rest Soil Pressure to Heel, EM1110--2-2502 Section 3-7

Lateral Driving Force (Headwater Side)

Depth of Fill at Heel: $t_{hf.UN2} := TOC_{as} - BOF_{elev} = 6.00\,m$

At-Rest Soil Load: $E1_{drive.UN2} := \dfrac{K_o \cdot t_{hf.UN2}^2}{2} \cdot (\gamma_r - \gamma_w) \cdot W_b \cdot -1 = -1876.9 \cdot kN$

Acting at: $E1_{drive.loc.UN2} := \dfrac{t_{hf.UN2}}{3} - (BOF_{toe} - BOF_{elev}) = 0.50\,m$

Lateral Resisting Force (Tailwater Side)

Depth of Fill at Toe: $t_{tf.UN2} := TOC_{fce} - BOF_{toe} = 2.00\,m$

At-Rest Soil Load: $E2_{resistUN2} := \dfrac{K_o \cdot t_{tf.UN2}^2}{2} \cdot (\gamma_r - \gamma_w) \cdot W_b = 208.5 \cdot kN$ $\quad E2_{resistUN2} := 0$

Acting at: $E2_{resistlocUN2} := \dfrac{t_{tf.UN2}}{3} = 0.67\,m$

(Expansion Joint to Stilling Basin, No Sediment in Gap)

$\Sigma H_{soil.UN2} := E1_{drive.UN2} + E2_{resistUN2} = -1876.9 \cdot kN$

$\Sigma M_{soil.UN2} := E1_{drive.UN2} \cdot E1_{drive.loc.UN2} + E2_{resistUN2} \cdot E2_{resistlocUN2} = -938.4 \cdot kN \cdot m$

ICE / IMPACT LOADS (CONSERVATIVELY ASSUME NO ICE LOADING ON DOWNSTREAM SIDE)

ICE / IMPACT LOADS NOT APPLIED TO THIS LOAD CASE

Static Impact Loading on Structure: $I_{S.UN2} := 0.0 \dfrac{kN}{m}$ (Section 7.7, Design Criteria)

Static Impact load on Gates: $I_{G.UN2} := 0.0 \dfrac{kN}{m}$ (Section 7.7, Design Criteria)

Impact Loading Unit Width on Structure: $W_{S.UN2} := 4.00 m$

Impact Loading Unit Width on Gates: $W_{G.UN2} := 2 \cdot \dfrac{20.00}{2} m = 20.00\,m$

Total Impact Load on Structure: $I_{UN2} := (I_{S.UN2} \cdot W_{S.UN2} + I_{G.UN2} \cdot W_{G.UN2}) \cdot -1 = 0 \cdot kN$

Apply Ice load at: $I_{UN2.loc} := (HW_{UN2} - BOF_{toe} - 0.30m) = 10.40\,m$

$\Sigma H_{I.UN2} := I_{UN2} = 0 \cdot kN$

$\Sigma M_{I.UN2} := I_{UN2} \cdot I_{UN2.loc} = 0 \cdot kN \cdot m$

SEISMIC LOAD (Not Applicable to this Load Case)

SUMMARY OF LOADS

UN2 CASE

	Loads	Moment Arm
Dead Load of Concrete Structure:	$D_{conc} = 52182.8 \cdot kN$	$X_{conc.loc} = 12.43\,m$
Dead Load of Gate:	$D_{Gate} = 580.0 \cdot kN$	$X_{gate} = 9.75\,m$
Headwater Lateral Load on Pier:	$H_{hwp.UN2} = -754.2 \cdot kN$	$H_{hwp.UN2.loc} = 6.57\,m$
Headwater Lateral Load on Gate:	$H_{hwg.UN2} = -2167.0 \cdot kN$	$H_{hwg.UN2.loc} = 7.57\,m$
Headwater Lateral Load on Footing:	$H_{hwf.UN2} = -8082.2 \cdot kN$	$H_{hwf.UN2.loc} = 1.70\,m$
Tailwater Lateral Load:	$H_{twf.UN2} = 540.8 \cdot kN$	$H_{twf.UN2.loc} = -0.33\,m$
Tailwater Lateral Load on Pier:	$H_{twp.UN2} = 240.3 \cdot kN$	$H_{twp.UN2.loc} = -0.33\,m$
Water Weight (HW) on Apron Slab:	$H_{1.UN2} = 3531.9 \cdot kN$	$H_{1.UN2.loc} = 21.10\,m$
Water Weight (HW) on Fixed Crest:	$H_{2.UN2} = 3165.2 \cdot kN$	$H_{2.UN2.loc} = 14.25\,m$
Water Weight (TW) on Fixed Crest:	$H_{3.UN2} = 0.0 \cdot kN$	$H_{3.UN2.loc} = 0.00\,m$
Uplift:	$U_{UN2} = -29517.5 \cdot kN$	$U_{UN2.loc} = 13.21\,m$
Upstream (driving) Lateral Soil Load:	$E1_{drive.UN2} = -1876.9 \cdot kN$	$E1_{drive.loc.UN2} = 0.50\,m$
Downstream (resisting) Lateral Soil Load:	$E2_{resistUN2} = 0 \cdot kN$	$E2_{resistlocUN2} = 0.67\,m$
Ice / Impact Load:	$I_{UN2} = 0.0 \cdot kN$	$I_{UN2.loc} = 10.40\,m$

STABILITY ASSESSMENT (SLIDNG, OVERTURNING AND BEARING): **UN2 CASE**

CHECK SLIDING ALONG HORIZONTAL PLANE THRU TOE,
IGNORING BEDROCK MOBILIZED BY STRUCTURAL HEEL KEY, OR VOID BEHIND KEY

Sum of Vertical Forces:

$\Sigma V_{UN2} := \Sigma V_{DL.UN2} + \Sigma V_{water.UN2} = 29623.4 \cdot kN$

Sum of Horizontal Forces:

$\Sigma H_{UN2} := \Sigma H_{Water.UN2} + \Sigma H_{soil.UN2} + \Sigma H_{I.UN2} = -12099.2 \cdot kN$

Sliding Factor of Safety:

$$FS_{HorizSliding.UN2} := \frac{\tan_{\phi} \cdot \Sigma V_{UN2}}{\left|\Sigma H_{UN2}\right|} = 1.19$$

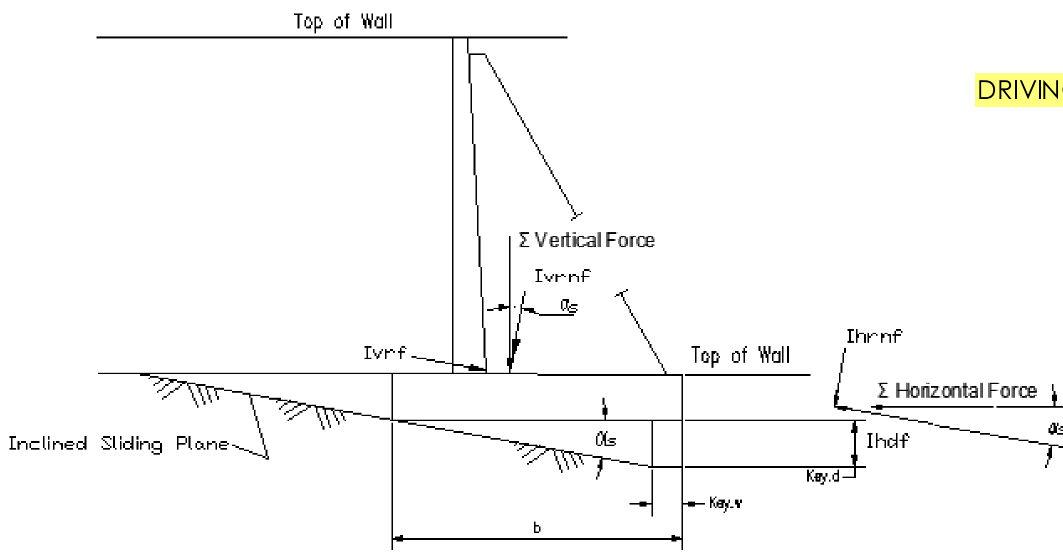
$$FS_{HorizSliding.UN2.Check} := \begin{cases} \text{"OKAY"} & \text{if } FS_{HorizSliding.UN2} \geq FS_{req.UN2.sl} \\ \text{"Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !"} & \text{otherwise} \end{cases}$$

$FS_{HorizSliding.UN2.Check}$ = "Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !"

CHECK SLIDING ALONG INCLINED SLIDING PLANE FROM HEEL KEY TO TOE,
WITH BEDROCK MASS MOBILIZED BY REINFOCREDE CONCRETE KEY)

RESISTING SIDE

DRIVING SIDE



TOE

HEEL

Ivrf=Inclined Resisting Force
Ivrnf=Inclined Resisting Normal Force
Ihrnf=Inclined Resisting Normal Force
Ihdf=Inclined Driving Force

$$\alpha s := \operatorname{atan}\left(\frac{BOF_{toe} - BOF_{elev}}{L_b - Key_l}\right) = 0.13$$

as degrees= $\alpha s \cdot \left(\frac{180}{\pi}\right) = 7.63$

Resolve $\Sigma Vert_{UN2}$ & $\Sigma Horiz_{UN2}$

$$\Sigma V_{InclinedUN2} := \cos(\alpha s) \cdot \left(\Sigma V_{UN2} + V_{rs}\right) + \sin(\alpha s) \cdot \left|\Sigma H_{UN2}\right| = 44069.3 \cdot kN$$

$$\Sigma H_{InclinedUN2} := \cos(\alpha s) \cdot \left|\Sigma H_{UN2}\right| - \sin(\alpha s) \cdot \left(\Sigma V_{UN2} + V_{rs}\right) = 6305.1 \cdot kN$$

(With properly engineered reinforced concrete Key, horizontal sliding plane thru Toe is protected, critical sliding plane is relocated to the INCLINED SLIDING PLANE FROM HEEL KEY To TOE, Bedrock Mass above this examing plane is mobilized by reinforced concrete key and combined into Structural Wedge.)

Inclined Sliding Plane Length $\quad L_{incline} = 24.2 m$

Safety Factor for Sliding
Inclined Failure Plane

$$FS_{InclinedlSlidingUN2} := \frac{\Sigma V_{InclinedUN2} \cdot \tan\left(\phi_{rock} \cdot \frac{\pi}{180}\right)}{\left|\Sigma H_{InclinedUN2}\right|} = 3.41$$

$$FS_{InclinedSliding.UN2.check} := \begin{cases} \text{"OKAY "} & \text{if } FS_{InclinedlSlidingUN2} > FS_{req.UN2.sl} \\ \text{"Revise Structure""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

$FS_{InclinedSliding.UN2.check}$ = "OKAY "

CHECK ECCENTRICITY ON INCLINED PLANE

UN2 CASE

Sum of the Moments:

$$\Sigma M_{rs.UN2} := \Sigma M_{DL.UN2} + \Sigma M_{HWater.UN2} + \Sigma M_{Vwater.UN2} + \Sigma M_{I.UN2} + \Sigma M_{soil.UN2} + V_{rs} \cdot L_{rs} = 529062 \cdot kN \cdot m$$

Eccentricity:

$$e_{UN2} := \frac{L_{incline}}{2} - \frac{\Sigma M_{rs.UN2}}{\Sigma V_{InclinedUN2}} = 0.12\,m$$

Eccentricity Check:

$$e_{check.UN2} := \begin{cases} \text{"Okay"} & \text{if } \left|e_{UN2}\right| \le Kern \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$$e_{check.UN2} = \text{"Okay"}$$

Foundation Bearing Pressures on Inclined Plane:

Bearing Pressure at Heel:

$$\sigma_{heel.UN2} := \frac{\Sigma V_{InclinedUN2}}{\frac{A_b}{\cos(\alpha s)}} - \frac{\Sigma V_{InclinedUN2} \cdot e_{UN2}}{\frac{S_b}{\cos(\alpha s)^2}} = 134.8 \cdot \frac{kN}{m^2}$$

$$\sigma_{heel.UN2.check} := \left(\begin{cases} \text{"Okay"} & \text{if } \sigma_{heel.UN2} \le \sigma_{allow.UN2} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} \right)$$

$$\sigma_{heel.UN2.check} = \text{"Okay"}$$

Bearing Pressure at Toe:

$$\sigma_{toe.UN2} := \frac{\Sigma V_{InclinedUN2}}{\frac{A_b}{\cos(\alpha s)}} + \frac{\Sigma V_{InclinedUN2} \cdot e_{UN2}}{\frac{S_b}{\cos(\alpha s)^2}} = 142.9 \cdot \frac{kN}{m^2}$$

$$\sigma_{toe.UN2.check} := \begin{cases} \text{"Okay"} & \text{if } \sigma_{toe.UN2} \le \sigma_{allow.UN2} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$$\sigma_{toe.UN2.check} = \text{"Okay"}$$

CHECK FLOTATION

$$Uplift_{sliding.UN2} := U_{UN2} = -29517.5 \cdot kN$$

$$Uplift_{pore.UN2} = -22503.2 \cdot kN$$

$$\left(Uplift_{UN2}\right) := \min\left(Uplift_{pore.UN2}, Uplift_{sliding.UN2}\right)$$

(For conservative, taking maximum values)

$$FS_{Flotation.UN2} := \frac{D_{conc} + D_{Gate} + H_{1.UN2} + H_{2.UN2} + H_{3.UN2}}{\left|Uplift_{UN2}\right|} = 2$$

$$FS_{Flotation.UN2.check} := \begin{cases} \text{"OKAY "} & \text{if } FS_{Flotation.UN2} > FS_{req.UN.flt} \\ \text{"Revise Structure""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

MONOLITH OVERTURNING STABILITY ANALYSIS

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.
Assumptions are made in order to compute overturning stability of indetermine forces on monolith with key;
(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.
(b) The horizontal resisting force acting on the key, P.key, is that required for static equilibrium
(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1 $Ratio_{overturning.allow.Unusual} = 0.33$

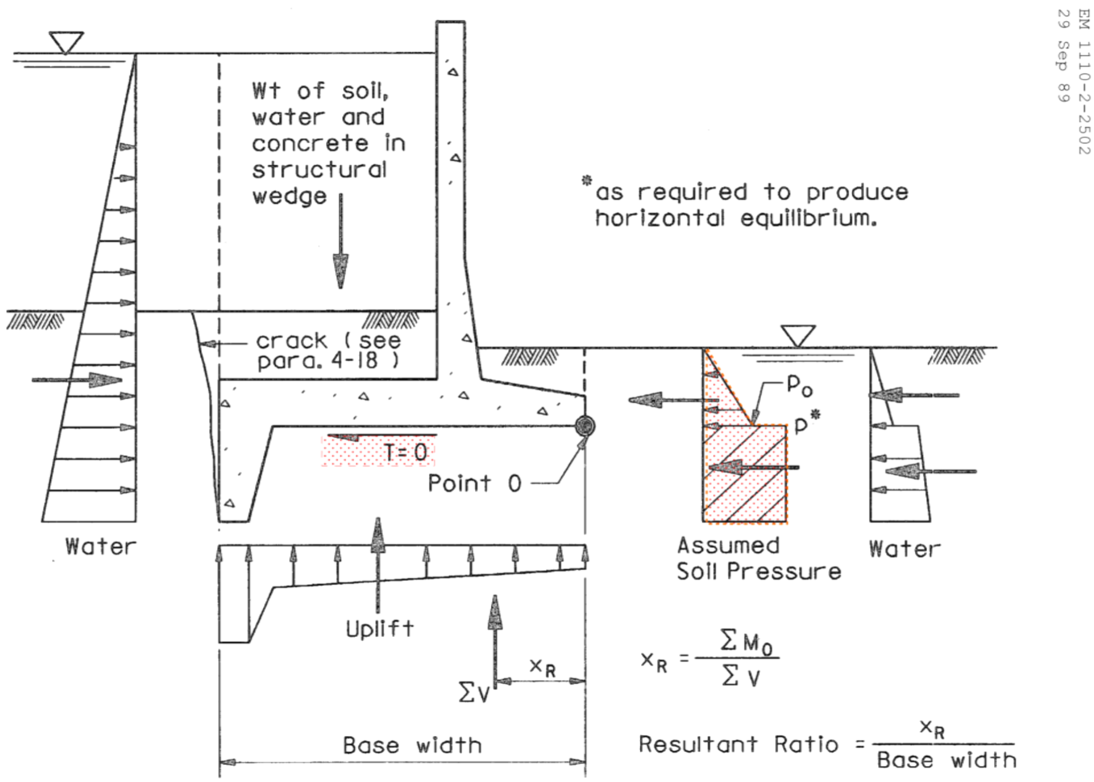


Figure 4-5. Forces for overturning analysis for wall with horizontal base and key

<u>All Vertical Loads Applicable to Overturning Stability Analysis</u>

Total Concrete Dead Loads:	$D_{conc} = 52182.8 \cdot kN$	at:	$X_{conc.loc} = 12.4\,m$
Dead Load of Gate:	$D_{Gate} = 580.0 \cdot kN$		$X_{gate} = 9.75\,m$
Water Weight (HW) on Apron Slab:	$H_{1.UN2} = 3531.9 \cdot kN$		$H_{1.UN2.loc} = 21.10\,m$
Water Weight (HW) on Fixed Crest:	$H_{2.UN2} = 3165.2 \cdot kN$		$H_{2.UN2.loc} = 14.25\,m$
Water Weight (TW) on Fixed Crest:	$H_{3.UN2} = 0.0 \cdot kN$		$H_{3.UN2.loc} = 0.00\,m$

Uplift Force from Sliding Analysis. Line of Creep Method applied at presumed inclined sliding line, and subtraction gravity effect to Base of Concrete by Archimedes Principle

$$U_{UN2.loc.sliding} := \frac{U_{A.UN2} \cdot L_{A.UN2} + U_{B.UN2} \cdot L_{B.UN2} - A_{rs} \cdot w_{as} \cdot \gamma_w \cdot L_{rs}}{U_{A.UN2} + U_{B.UN2} - A_{rs} \cdot w_{as} \cdot \gamma_w} = 13.34\,m$$

$$U_{UN2.sliding} := U_{UN2} + A_{rs} \cdot w_{as} \cdot \gamma_w = -23623.1 \cdot kN$$

UN2 CASE

Uplift for Overturning Analysis, Line of Creep Method. Pore pressure at base of Concrete

$Uplift_{pore.UN2} = -22503.2 \cdot kN$

$$Uplift_{pore.UN2.loc} := \frac{Uplift_{BC.UN2} \cdot Uplift_{BC.UN2.loc} + Uplift_{DE.UN2} \cdot Uplift_{DE.UN2.loc} + Uplift_{EF.UN2} \cdot Uplift_{EF.UN2.loc} + Uplift_{FG.UN2} \cdot Uplift_{FG.UN2.loc}}{Uplift_{pore.UN2}}$$

$Uplift_{pore.UN2.loc} = 12.7\,m$

Sum of All Water Load for Overturning Analysis

$\Sigma V_{water.UN2.OT} := H_{1.UN2} + H_{2.UN2} + H_{3.UN2} + Uplift_{pore.UN2} = -15806.1 \cdot kN$

All Lateral Loads Applicable to Overturning Stability Analysis

Apply Load to Gate?: $poss_{UN2} = 1$ — poss = 1 if gate is closed, 0 if gate is open

Headwater Lateral Load on Pier: $H_{hwp.UN2} = -754.2 \cdot kN$ — $H_{hwp.UN2.loc} = 6.57\,m$

Headwater Lateral Load on Gate: $H_{hwg.UN2} = -2167.0 \cdot kN$ — $H_{hwg.UN2.loc} = 7.57\,m$

Headwater Lateral Load on Footing: $H_{hwf.UN2} = -8082.2 \cdot kN$ — $H_{hwf.UN2.loc} = 1.70\,m$

Total Horizontal Tailwater Load on Pier: $H_{twp.UN2} = 240.3 \cdot kN$ — $H_{twp.UN2.loc} = -0.33\,m$

Total Horizontal Tailwater Load on Footing under Gate Openings, i.e., excluding Pier: $H_{twf.UN2} = 540.8 \cdot kN$ — $H_{twf.UN2.loc} = -0.33\,m$

Resisting Water on Rear Face of Monolith, i.e., bottom of heel elevation:

(Point O @ TOE: BOFtoe = EL.1205.5)

Ice / Impact Load: $I_{UN2} = 0.0 \cdot kN$ at: $I_{UN2.loc} = 10.40\,m$

Depth of Fill at Heel Side for Overturning Analysis:

$t_{hf.UN2} := TOC_{as} - BOF_{toe} = 4.50\,m$

Driving Soil Load for overturning:

$$E1_{drive.UN2} := \frac{K_o \cdot t_{hf.UN2}^{\,2}}{2} \cdot \left(\gamma_r - \gamma_w\right) \cdot W_b \cdot -1 = -1055.7 \cdot kN$$

Acting at:

$$E1_{drive.loc.UN2} := \frac{t_{hf.UN2}}{3} = 1.50\,m$$

Downstream (resisting) Lateral Soil Load as required to produce horizontal equilibrium:

$$E2_{resistUN2} := -1 \cdot \left(H_{hwp.UN2} + H_{hwg.UN2} + H_{hwf.UN2} + H_{twp.UN2} + H_{twf.UN2} + I_{UN2} + E1_{drive.UN2}\right)$$

$E2_{resistUN2} = 11278 \cdot kN$

Assumed Resisting Bedrock at middle of Key, passive soil pressure or lateral bearing contract joint at end of Monolith 3A3B

$E2_{resistlocUN2} := E2_{resistlocU1} = 0.67\,m$

Overturning moment by Dead Loads about Point O @ Toe

$\Sigma M_{DL.UN2} = 651119.6 \cdot kN \cdot m$

Overturning moment by Vertical Water Loads and Uplift, about Point O @ Toe

$$\Sigma M_{Vwater.UN2.OT} := H_{1.UN2} \cdot H_{1.UN2.loc} + H_{2.UN2} \cdot H_{2.UN2.loc} + H_{3.UN2} \cdot H_{3.UN2.loc} + Uplift_{pore.UN2} \cdot Uplift_{pore.UN2.loc} = -165099.2 \cdot kN \cdot m$$

Overturning moment by Lateral Hydrostatic Forces of Headwater Pool and Tailwater Pool,about Point O @ Toe

$\Sigma M_{HWater.UN2} = -35311.6 \cdot kN \cdot m$

Overturning Moment by Impact/Ice Load, about Point O@ Toe

$\Sigma M_{I.UN2} = 0$

Overturning moment by Lateral Soil Forces about Point O @ Toe

$\Sigma M_{soil.UN2} := E1_{drive.UN2} \cdot E1_{drive.loc.UN2} + E2_{resistUN2} \cdot E2_{resistlocUN2} = 5935.1 \cdot kN \cdot m$

Sum of the Overturning Moments about Point O @ Toe:

$\Sigma M_{UN2.OT} := \Sigma M_{DL.UN2} + \Sigma M_{HWater.UN2} + \Sigma M_{Vwater.UN2.OT} + \Sigma M_{I.UN2} + \Sigma M_{soil.UN2} = 456644 \cdot kN \cdot m$

Sum of Vertical Forces: $\Sigma V_{UN2.OT} := \Sigma V_{DL.UN2} + \Sigma V_{water.UN2.OT} = 36637.8 \cdot kN$

Distance X_R: EM 1110-2-2502 Eq.4-1

$$X_{R.UN2} := \frac{\Sigma M_{UN2.OT}}{\Sigma V_{UN2.OT}} = 12.5 m$$

Overturning Resultant Ratio

$$Ratio_{Overturning.UN2} := \frac{X_{R.UN2}}{L_b} = 0.52$$

EM 1110-2-2502

Table 4-1

Retaining Wall Stability Criteria

Loading Condition	Sliding Factor of Safety, FS	Shear Strength Test Required: Soil Foundation	Shear Strength Test Required: Rock Foundation[3]	Overturning Criteria Minimum Base Area in Compression: Soil Foundation	Overturning Criteria Minimum Base Area in Compression: Rock Foundation
Usual	1.5	(Q &/or S)[2,1]	Direct shear	100%[4]	75%[4]
Unusual	1.33	(Q &/or S)[2,1]	Direct shear	75%[4]	50%[4]
Earthquake	1.1	(Q)	Direct shear	Resultant within base	Resultant within base

Overturning Stability Check

$$Ratio_{Overturning.UN2.check} := \begin{cases} \text{"Okay"} & \text{if } Ratio_{Overturning.UN2} \geq Ratio_{overturning.allow.Unusual} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$Ratio_{Overturning.UN1.check} = \text{"Okay"}$

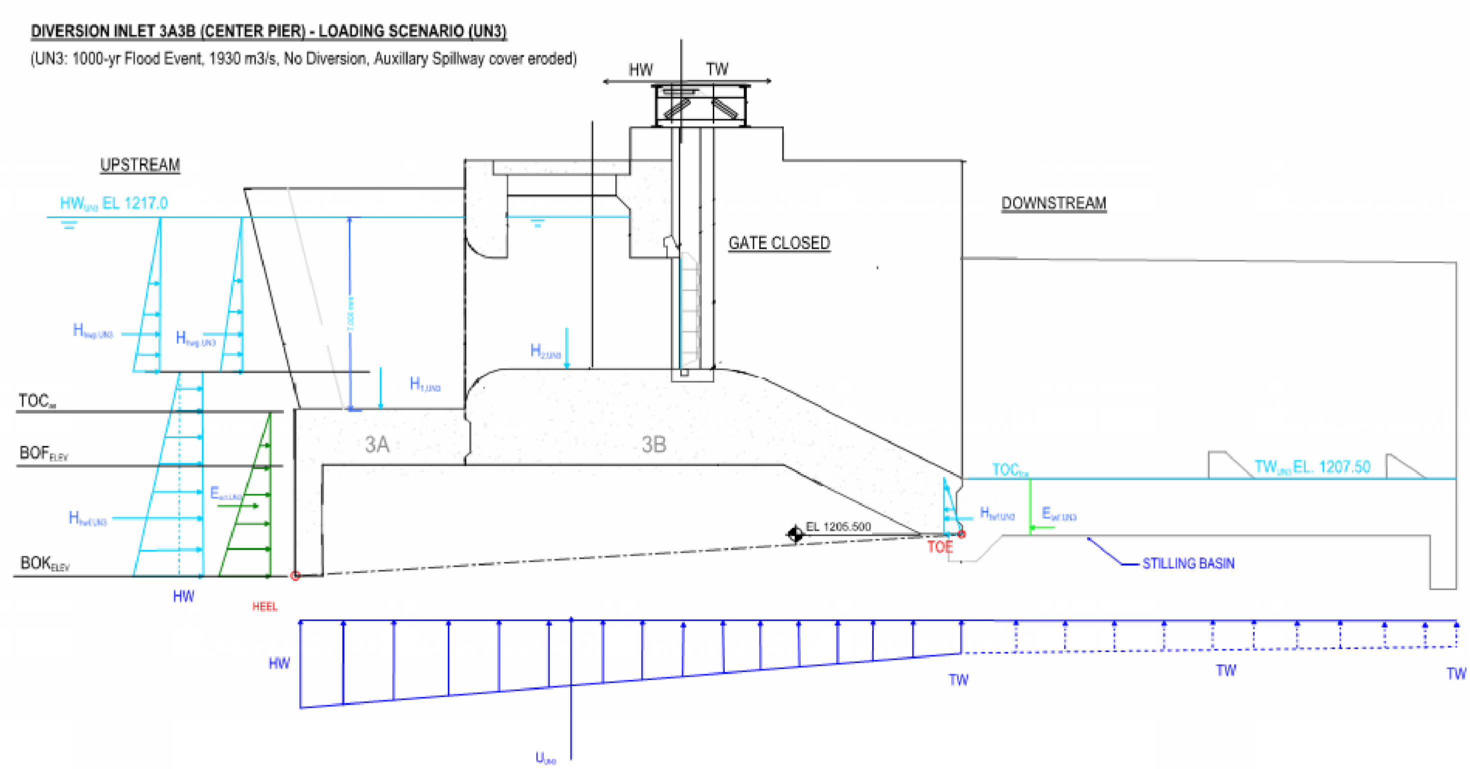
Summary of Extreme Flood Results (Only Report Controlling Load Case)

UN2 CASE

UN2 Event: No Diversion, 2013 Flood

Horiz Sliding Factor of Safety:	$FS_{HorizSliding.UN2} = 1.19$
Horiz Sliding Factor of Safety Check:	$FS_{HorizSliding.UN2.Check}$ = "Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !"
Sliding Factor of Safety:	$FS_{InclinedlSlidingUN2} = 3.4$
Sliding Factor of Safety Check:	$FS_{InclinedSliding.UN2.check}$ = "OKAY "
Eccentricity:	$e_{UN2} = 0.12\,m$
Eccentricity Check:	$e_{check.UN2}$ = "Okay"
Bearing Pressure At Heel on Inclined Plane:	$\sigma_{heel.UN2} = 134.8 \cdot \frac{kN}{m^2}$
Bearing Pressure At Heel Check:	$\sigma_{heel.UN2.check}$ = "Okay"
Bearing Pressure At Toe on Inclined Plane:	$\sigma_{toe.UN2} = 142.9 \cdot \frac{kN}{m^2}$
Bearing Pressure At Toe Check:	$\sigma_{toe.UN2.check}$ = "Okay"
Flotation Factor of Safety	$FS_{Flotation.UN2} = 2$
Flotation Factor of Safety Check:	$FS_{Flotation.UN2.check}$ = "OKAY "
Overturning Resultant Ratio	$Ratio_{Overturning.UN2} = 0.52$
Overturning Stability Check	$Ratio_{Overturning.UN2.check}$ = "Okay"

UN3 DESIGN CASE



ACCEPTANCE PARAMETERS

Required Factor of Safety for Sliding:	$FS_{req.UN3.sl} := 1.3$	(Without Cohesion) (Section 8.1, Design Criteria)
Resultant Within Middle Third of Base:	$e \le \frac{L_b}{6} \wedge e \ge \frac{-L_b}{6}$	
Allowable Rock Bearing Pressure:	$\sigma_{allow.UN3} := 1470.0 \cdot \frac{kN}{m^2}$	(Section 5.2, Design Criteria)
Required Factor of Safety for Flotation:	$FS_{req.UN.flt} = 1.3$	
Overturning Min Required Resultant Ratio:	$\frac{X_{R.UN}}{Horizontal\_Width\_of\_Base} > 0.33$	

INPUT PARAMETERS

UN3 CASE

Headwater Elevation: $HW_{UN3} := 1217.00m$

Tailwater Elevation: $TW_{UN3} := 1207.50m$

(Water Elevations based on Diversion Structure 2D Hydraulic Model Results. See page 7 and Section 8.2, Design Criteria)

Crest Water Elevation (No Diversion)

Chute Block Water Elevation (No Diversion)

Bottom of Key (Footing Heel) Elevation: $BOF_{elev} = 1204.00\,m$

Apron Slab Top of Concrete Elevation at Edge of Slab: $TOC_{as} = 1210.00\,m$

Fixed Crest Top of Concrete Elevation at Downstream Face: $TOC_{fce} = 1207.50\,m$

Fixed Crest Top of Concrete Elevation at Center of Footing: $TOC_{fcc} = 1211.50\,m$

VERTICAL LIFT GATE

Lift Gate Position per Hydraulic Criteria: $poss_{UN3} := 1$

poss = 1 if gate is closed
0 if gate is open

DEAD LOAD SUMMATION:

$$Gate_{R.UN3} := \begin{cases} 1 & \text{if } poss_{UN3} = 0 \\ 0.45 & \text{otherwise} \end{cases}$$

Monolith Reaction for Wheel Gate

$$\Sigma V_{DL.UN3} := D_{conc} + Gate_{R.UN3} D_{Gate} = 52443.8 \cdot kN$$

$$\Sigma M_{DL.UN3} := D_{conc} \cdot X_{conc.loc} + Gate_{R.UN3} \cdot D_{Gate} \cdot X_{gate} = 651119.6 \cdot kN \cdot m$$

LATERAL WATER LOADS

UN3 CASE

HEADWATER (DRIVING):

Water Depth on Pier at Heel: $D_{hwp.UN3} := HW_{UN3} - TOC_{as} = 7.00\,m$

Water Load Unit Width on Pier: $W_{hwp.UN3} := w_{pn} = 4.00\,m$

Total Horizontal Water Load on Pier: $H_{hwp.UN3} := \dfrac{-\left(\gamma_w \cdot D_{hwp.UN3}^{\,2}\right)}{2} \cdot W_{hwp.UN3} = -961.4 \cdot kN$

Apply Total Pier Water Load at: $H_{hwp.UN3.loc} := \dfrac{D_{hwp.UN3}}{3} + \left(TOC_{as} - BOF_{toe}\right) = 6.83\,m$

Point O @ TOE: BOFtoe = EL.1205.5

Water Depth Above Fixed Crest at Gate: $D_{hwg.UN3} := HW_{UN3} - TOC_{fcc} = 5.5\,m$

Water Load Unit Width on Gate: $W_{hwg.UN3} := 2 \cdot \dfrac{20.00}{2}\,m = 20.00\,m$

Apply Load to Gate?: $poss_{UN3} = 1$

poss = 1 if gate is closed
0 if gate is open

Total Horizontal Water Load on Gate: $H_{hwg.UN3} := \dfrac{-\left(\gamma_w \cdot D_{hwg.UN3}^{\,2}\right)}{2} \cdot W_{hwg.UN3} \cdot poss_{UN3} = -2967.5 \cdot kN$

Apply Total Gate Water Load at: $H_{hwg.UN3.loc} := \dfrac{D_{hwg.UN3}}{3} + \left(TOC_{fcc} - BOF_{toe}\right) = 7.83\,m$

Water Depth at Heel: $D_{hwf.UN3} := HW_{UN3} - BOF_{elev} = 13.00\,m$

Water Load Unit With on Footing: $W_{hw.UN3} := W_b$

Water Load at Bottom of Footing: $H_{hwf.UN3.1} := -\left(\gamma_w \cdot D_{hwf.UN3}\right) \cdot W_{hw.UN3} = -1657.9\,\dfrac{1}{m} \cdot kN$

Water Load at Top of Footing: $H_{hwf.UN3.2} := -\left(\gamma_w \cdot D_{hwg.UN3}\right) \cdot W_{hw.UN3} = -701.4\,\dfrac{1}{m} \cdot kN$

Total Horizontal Water Load on Footing: $H_{hwf.UN3} := \dfrac{\left(H_{hwf.UN3.1} + H_{hwf.UN3.2}\right) \cdot \left(D_{hwf.UN3} - D_{hwg.UN3}\right)}{2} = -8847.4 \cdot kN$

Apply Total Footing Water Load at:

$$H_{hwf.UN3.loc} := \frac{\left[H_{hwf.UN3.2} \cdot \dfrac{\left(TOC_{fcc} - BOF_{elev}\right)^2}{2} + \dfrac{\left(H_{hwf.UN3.1} - H_{hwf.UN3.2}\right)}{2} \cdot \dfrac{\left(TOC_{fcc} - BOF_{elev}\right)^2}{3}\right]}{\dfrac{\left(H_{hwf.UN3.2} + H_{hwf.UN3.1}\right) \cdot \left(TOC_{fcc} - BOF_{elev}\right)}{2}} - \left(BOF_{toe} - BOF_{elev}\right) = 1.74\,m$$

Converting horizontal force resultant from HEEL calculation to Point-O@TOE

LATERAL WATER LOADS (cont.)

UN3 CASE

TAILWATER (RESISTING):

Water Depth at toe: $D_{tw.UN3} := TW_{UN3} - BOF_{elev} = 3.50\,m$

Water Load Unit Width: $W_{twf.UN3} := W_b$

Total Horizontal Tailwater Load on Footing under Gate Openings, i.e., excluding Pier

Resisting Water on Rear Face of Monolith, i.e., bottom of heel elevation

$COND_{UN3} := poss_{UN3} = 0 \wedge TW_{UN3} \geq TOC_{fcc}$

$$H_{twf.UN3} := \begin{cases} \dfrac{\gamma_w \cdot D_{tw.UN3}^{\;2}}{2} \cdot \left(W_{twf.UN3} - w_{pdg}\right) & \text{if } poss_{UN3} = 1 \\ \dfrac{\gamma_w \cdot D_{tw.UN3}^{\;2}}{2} \cdot \left(W_{twf.UN3} - w_{pdg}\right) & \text{if } poss_{UN3} = 0 \wedge TW_{UN3} \leq TOC_{fcc} \\ \gamma_w \cdot \left[\dfrac{D_{tw.UN3}}{2} + \dfrac{\left(TW_{UN3} - TOC_{fcc}\right)}{2}\right] \cdot \left(TOC_{fcc} - BOF_{elev}\right) \cdot \left(W_{twf.UN3} - w_{pdg}\right) & \text{if } COND_{UN3} \end{cases} = 540.8 \cdot kN$$

Apply Footing Tailwater Load within Gate Openings at:

$$H_{twf.UN3.loc} := \begin{cases} \dfrac{D_{tw.UN3}}{3} - \left(BOF_{toe} - BOF_{elev}\right) & \text{if } poss_{UN3} = 1 \\ \dfrac{D_{tw.UN3}}{3} - \left(BOF_{toe} - BOF_{elev}\right) & \text{if } poss_{UN3} = 0 \wedge TW_{UN3} \leq TOC_{fcc} \\ \dfrac{\left(TOC_{fcc} - BOF_{elev}\right)^2 \cdot \left[\dfrac{\left(TW_{UN3} - TOC_{fcc}\right)}{2} + \dfrac{\left(TOC_{fcc} - BOF_{elev}\right)}{6}\right]}{\left(TOC_{fcc} - BOF_{elev}\right)\left[\left(TW_{UN3} - TOC_{fcc}\right) + \dfrac{\left(TOC_{fcc} - BOF_{elev}\right)}{2}\right]} - \left(BOF_{toe} - BOF_{elev}\right) & \text{if } COND_{UN3} \end{cases} = -0.33 \cdot m$$

Total Horizontal Tailwater Load on Pier: $H_{twf.UN3.loc} = -0.3\,m$

$$H_{twp.UN3} := \frac{\gamma_w \cdot D_{tw.UN3}^{\;2}}{2} \cdot w_{pdg} = 240.3 \cdot kN$$

Apply Horizontal Tailwater Load on Pier at:

$$H_{twp.UN3.loc} := \frac{D_{tw.UN3}}{3} - \left(BOF_{toe} - BOF_{elev}\right) = -0.33 \cdot m$$

$$\Sigma H_{Water.UN3} := H_{hwp.UN3} + H_{hwg.UN3} + H_{hwf.UN3} + H_{twf.UN3} + H_{twp.UN3} = -11995.2 \cdot kN$$

$$\Sigma M_{HWater.UN3} := H_{hwp.UN3} \cdot H_{hwp.UN3.loc} + H_{hwg.UN3} \cdot H_{hwg.UN3.loc} + H_{hwf.UN3} \cdot H_{hwf.UN3.loc} \ldots + H_{twf.UN3} \cdot H_{twf.UN3.loc} + H_{twp.UN3} \cdot H_{twp.UN3.loc} = -45498.6 \cdot kN \cdot m$$

VERTICAL WATER LOADS

UN3 CASE

HEADWATER:

Water Depth on top of fixed crest: $d_{hw.UN3} := HW_{UN3} - TOC_{as} = 7.00\,m$

Subtract Pier Volume:

$$S_{pn.UN3} := \left[\frac{\left(A_{pnt} - A_{pnb}\right)}{h_{pn}}\right] = 1.00 \cdot \frac{m^2}{m}$$

$$V_{pn.UN3} := \frac{\left[\left(S_{pn.UN3} \cdot d_{hw.UN3} + A_{pnb}\right) + A_{pnb}\right]}{2} \cdot d_{hw.UN3} = 160.5 \cdot m^3$$

Weight of Water (H1) on Approach Slab: $H_{1.UN3} := \left(W_{hw.UN3} \cdot d_{hw.UN3} \cdot L_{as} - V_{pn.UN3}\right) \cdot \gamma_w = 3960.2 \cdot kN$

Horiz. Moment Arm for H1 (from toe): $H_{1.UN3.loc} := L_b - \dfrac{L_{as}}{2} = 21.10\,m$

Cross-sectional Area of Headwater Above Fixed Crest: $A_{fc.hw.UN3} := 41.71 m^2$ (From Bluebeam Measurement)

Volume of water Above Fixed Crest: $V_{fc.hw.UN3} := \left[A_{fc.hw.UN3} \cdot \left(W_{hw.UN3} - w_{pn}\right)\right] = 375.4 \cdot m^3$

Weight of Water (H2) on Fixed Crest: $H_{2.UN3} := \left(V_{fc.hw.UN3}\right) \cdot \gamma_w = 3682.6 \cdot kN$

Horiz. Moment Arm for H2 (from toe): $H_{2.UN3.loc} := X_{pug} = 14.25\,m$

TAILWATER:

Slope of Crest from D/S of Gate to edge of Stilling Basin: $S_{f.UN3} := \dfrac{\left(TOC_{fcc} - TOC_{fce}\right)}{8.00m} = 0.500$

Height of Tailwater Above Stilling Basin:

$$y_{UN3} := \begin{cases} \left(TW_{UN3} - TOC_{fce}\right) & \text{if } TW_{UN3} \le TOC_{fcc} \\ \left(TOC_{fcc} - TOC_{fce}\right) & \text{otherwise} \end{cases}$$

$y_{UN3} = 0.00\,m$

Horizontal Distance of Tailwater Above Sloped Portion of Crest: $x_{UN3} := \dfrac{y_{UN3}}{S_{f.UN3}} = 0.00\,m$

Cross Sectional Area of Tailwater Above Sloped Portion of Crest: $A_{tw.UN3} := \dfrac{x_{UN3} \cdot y_{UN3}}{2} = 0\,m^2$

$= 0.00m^2$ if TW_{UN3} is less than or equal to TOC_{fce}

Weight of Water (H3) Above Slope Portion of Crest:

$$H_{3.UN3} := \begin{cases} (0.0kN) & \text{if } TW_{UN3} \le TOC_{fce} \\ \left[A_{tw.UN3} \cdot \left(W_{twf.UN3} - w_{pdg}\right)\right] \cdot \gamma_w & \text{if } TOC_{fcc} \ge TW_{UN3} > TOC_{fce} \\ \left[A_{tw.UN3} + Dist_{gate} \cdot \left(TW_{UN3} - TOC_{fcc}\right)\right] \cdot \left(W_{twf.UN3} - w_{pdg}\right) \cdot \gamma_w & \text{if } TW_{UN3} > TOC_{fcc} \end{cases}$$

$H_{3.UN3} = 0.0 \cdot kN$

Horiz. Moment Arm for H3 (from toe):

$$H_{3.UN3.loc} := \begin{cases} (0.00m) & \text{if } TW_{UN3} \le TOC_{fce} \\ \left(\frac{1}{3} \cdot x_{UN3}\right) & \text{if } TOC_{fcc} \ge TW_{UN3} > TOC_{fce} \\ \dfrac{\left[\frac{1}{2} \cdot x_{UN3} \cdot y_{UN3} \cdot \left(\frac{1}{3}\right) x_{UN3} + \left(TW_{UN3} - TOC_{fcc}\right) \cdot Dist_{gate} \cdot \left(\frac{Dist_{gate}}{2}\right)\right]}{\left(\frac{1}{2} x_{UN3} \cdot y_{UN3}\right) + \left(TW_{UN3} - TOC_{fcc}\right) \cdot Dist_{gate}} & \text{if } TW_{UN3} > TOC_{fcc} \end{cases}$$

$H_{3.UN3.loc} = 0.00\,m$

UPLIFT AT INCLINED SLIDING PLANE

Uplift pressure at Headwater: $U_{HW.UN3} := D_{hwf.UN3} \cdot \gamma_w = 127.53 \cdot \frac{kN}{m^2}$

Uplift pressure at D/S end of Stilling Basin: $U_{TW.UN3} := D_{tw.UN3} \cdot \gamma_w = 34.3 \cdot \frac{kN}{m^2}$

Length from U/S Face of Gate Structure to Toe of Stilling Basin: $L_{overall} = 24.20\,m$

Length of Seepage per Line of Creep $L_{seepage} = 27.1\,m$

Difference between Uplift pressure at Headwater and Uplift Pressure at Toe of Stilling Basin: $U_{diffUN3} := U_{HW.UN3} - U_{TW.UN3} = 93.2 \cdot \frac{kN}{m^2}$

Slope of difference between Uplift pressure at Headwater and Uplift Pressure at Toe of Stilling Basin:

$$U_{slopeUN3} := \frac{U_{diffUN3} - Key_d \cdot \gamma_w}{L_{overall}} = 3.24 \cdot \frac{kN}{m^2 \cdot m}$$

$$U_{seepageslopeUN3} := \frac{U_{diffUN3} - Key_d \cdot \gamma_w}{L_{seepage}}$$

Tailwater Pressure at toe of Gate Structure: $U_{press.toe.gsUN3} := U_{TW.UN3} + L_{sb} \cdot U_{slopeUN3} = 34.3 \cdot \frac{kN}{m^2}$

$$U_{pore.toe.UN3} := U_{TW.UN3} + U_{seepageslopeUN3} \cdot L_{sb} = 34.3 \cdot \frac{kN}{m^2}$$

$$U_{pore.F.UN3} := U_{pore.toe.UN3} + U_{seepageslopeUN3} \cdot L_{FG} = 38.7 \cdot \frac{kN}{m^2}$$

$$U_{pore.E.UN3} := U_{pore.F.UN3} - \left(BOF_{base} - BOF_{toe}\right) \cdot \gamma_w + U_{seepageslopeUN3} \cdot L_{EF} = 33.7 \cdot \frac{kN}{m^2}$$

$$U_{pore.D.UN3} := U_{pore.E.UN3} + U_{seepageslopeUN3} \cdot L_{DE} = 86.4 \cdot \frac{kN}{m^2}$$

$$U_{pore.C.UN3} := U_{pore.D.UN3} + \left(BOF_{base} - BOF_{elev}\right) \cdot \gamma_w + U_{seepageslopeUN3} \cdot L_{CD} = 124.6 \cdot \frac{kN}{m^2}$$

Uniform uplift due to Tailwater: (rectangular portion) $U_{A.UN3} := U_{press.toe.gsUN3} \cdot L_b \cdot W_b \cdot -1 = -10801.8 \cdot kN$

Moment Arm for Uplift UA from Toe of Gate Structure: $L_{A.UN3} := \frac{L_b}{2} = 12.10\,m$

Uplift - Linear Decrease from HW to TW: (triangular portion) $U_{B.UN3} := \frac{1}{2} \cdot \left(U_{HW.UN3} - U_{press.toe.gsUN3}\right) \cdot L_b \cdot W_b \cdot -1 = -14659.6 \cdot kN$

Moment Arm for Uplift UB from Toe of Gate Structure: $L_{B.UN3} := \frac{2}{3} \cdot L_b = 16.13\,m$

Total Resultant Uplift force: $U_{UN3} := U_{A.UN3} + U_{B.UN3} = -25461.4 \cdot kN$

Resultant Location from Toe: $U_{UN3.loc} := \frac{U_{A.UN3} \cdot L_{A.UN3} + U_{B.UN3} \cdot L_{B.UN3}}{U_{A.UN3} + U_{B.UN3}} = 14.42\,m$

$$\Sigma V_{water.UN3} := H_{1.UN3} + H_{2.UN3} + H_{3.UN3} + U_{UN3} = -17818.6 \cdot kN$$

$$\Sigma M_{Vwater.UN3} := H_{1.UN3} \cdot H_{1.UN3.loc} + H_{2.UN3} \cdot H_{2.UN3.loc} + H_{3.UN3} \cdot H_{3.UN3.loc} + U_{UN3} \cdot U_{UN3.loc} = -231172.6 \cdot kN \cdot m$$

Uplift as per Line of Creep Method (Flotation and Overturning)

UN3 CASE

$Uplift_{BC.UN3} := \frac{-1}{2} \cdot W_b \cdot \left(U_{HW.UN3} + U_{pore.C.UN3}\right) \cdot L_{BC} = -1639.1 \cdot kN$

$Uplift_{CD.UN3} := 0$

$Uplift_{DE.UN3} := \frac{-1}{2} \cdot W_b \cdot \left(U_{pore.D.UN3} + U_{pore.E.UN3}\right) \cdot L_{DE} = -14219.3 \cdot kN$

$Uplift_{EF.UN3} := \frac{-1}{2} \cdot W_b \cdot \left(U_{pore.E.UN3} + U_{pore.F.UN3}\right) \cdot L_{EF} = -1575.1 \cdot kN$

$Uplift_{FG.UN3} := \frac{-1}{2} \cdot W_b \cdot \left(U_{pore.F.UN3} + U_{pore.toe.UN3}\right) \cdot L_{FG} = -711.9 \cdot kN$

$Uplift_{pore.UN3} := Uplift_{BC.UN3} + Uplift_{DE.UN3} + Uplift_{EF.UN3} + Uplift_{FG.UN3} = -18145.4 \cdot kN$

$$Uplift_{FG.UN3.loc} := \frac{L_{FG}}{3} \cdot \frac{\left(2 \cdot U_{pore.F.UN3} + U_{pore.toe.UN3}\right)}{\left(U_{pore.F.UN3} + U_{pore.toe.UN3}\right)} = 0.76\,m$$

$$Uplift_{EF.UN3.loc} := \frac{L_{EF}}{3} \cdot \frac{\left(2 \cdot U_{pore.E.UN3} + U_{pore.F.UN3}\right)}{\left(U_{pore.E.UN3} + U_{pore.F.UN3}\right)} + L_{FG} = 3.14\,m$$

$$Uplift_{DE.UN3.loc} := \frac{L_{DE}}{3} \cdot \frac{\left(2 \cdot U_{pore.D.UN3} + U_{pore.E.UN3}\right)}{\left(U_{pore.D.UN3} + U_{pore.E.UN3}\right)} + L_{FG} + X_{EF} = 14.93\,m$$

$$Uplift_{BC.UN3.loc} := \frac{L_{BC}}{3} \cdot \frac{\left(2 \cdot U_{HW.UN3} + U_{pore.C.UN3}\right)}{\left(U_{HW.UN3} + U_{pore.C.UN3}\right)} + L_{FG} + X_{EF} + L_{DE} = 23.21\,m$$

UN3 CASE

SOIL LOADS

Equivalent Fluid Pressure (EFP): (CFEM 24.1)

At rest lateral pressure coefficient: $K_o = 0.66$

At-rest Soil Pressure to Heel, EM1110--2-2502 Section 3-7

Lateral Driving Force (Headwater Side)

Depth of Fill at Heel: $t_{hf.UN3} := TOC_{as} - BOF_{elev} = 6.00\,m$

At-Rest Soil Load: $E1_{drive.UN3} := \dfrac{K_o \cdot t_{hf.UN3}^{\,2}}{2} \cdot (\gamma_r - \gamma_w) \cdot W_b \cdot -1 = -1876.9 \cdot kN$

Acting at: $E1_{drive.loc.UN3} := \dfrac{t_{hf.UN3}}{3} - (BOF_{toe} - BOF_{elev}) = 0.50\,m$

Lateral Resisting Force (Tailwater Side)

Depth of Fill at Toe: $t_{tf.UN3} := TOC_{fce} - BOF_{toe} = 2.00\,m$

At-Rest Soil Load: $E2_{resistUN3} := \dfrac{K_o \cdot t_{tf.UN3}^{\,2}}{2} \cdot (\gamma_r - \gamma_w) \cdot W_b = 208.5 \cdot kN$ $E2_{resistUN3} := 0$

Acting at: $E2_{resistlocUN3} := \dfrac{t_{tf.UN3}}{3} = 0.67\,m$

(Expansion Joint to Stilling Basin, No Sediment in Gap)

$\Sigma H_{soil.UN3} := E1_{drive.UN3} + E2_{resistUN3} = -1876.9 \cdot kN$

$\Sigma M_{soil.UN3} := E1_{drive.UN3} \cdot E1_{drive.loc.UN3} + E2_{resistUN3} \cdot E2_{resistlocUN3} = -938.4 \cdot kN \cdot m$

ICE / IMPACT LOADS (CONSERVATIVELY ASSUME NO ICE LOADING ON DOWNSTREAM SIDE)

ICE / IMPACT LOADS NOT APPLIED TO THIS LOAD CASE

Static Impact Loading on Structure: $I_{S.UN3} := 0.0 \dfrac{kN}{m}$ (Section 7.7, Design Criteria)

Static Impact load on Gates: $I_{G.UN3} := 0.0 \dfrac{kN}{m}$ (Section 7.7, Design Criteria)

Impact Loading Unit Width on Structure: $W_{S.UN3} := 4.00m$

Impact Loading Unit Width on Gates: $W_{G.UN3} := 2 \cdot \dfrac{20.00}{2} m = 20.00\,m$

Total Impact Load on Structure: $I_{UN3} := (I_{S.UN3} \cdot W_{S.UN3} + I_{G.UN3} \cdot W_{G.UN3}) \cdot -1 = 0 \cdot kN$

Apply Ice load at: $I_{UN3.loc} := (HW_{UN3} - BOF_{toe} - 0.30m) = 11.20\,m$

$\Sigma H_{I.UN3} := I_{UN3} = 0 \cdot kN$

$\Sigma M_{I.UN3} := I_{UN3} \cdot I_{UN3.loc} = 0 \cdot kN \cdot m$

SEISMIC LOAD (Not Applicable to this Load Case)

SUMMARY OF LOADS

UN3 CASE

	Loads	Moment Arm
Dead Load of Concrete Structure:	$D_{conc} = 52182.8 \cdot kN$	$X_{conc.loc} = 12.43\,m$
Dead Load of Gate:	$D_{Gate} = 580.0 \cdot kN$	$X_{gate} = 9.75\,m$
Headwater Lateral Load on Pier:	$H_{hwp.UN3} = -961.4 \cdot kN$	$H_{hwp.UN3.loc} = 6.83\,m$
Headwater Lateral Load on Gate:	$H_{hwg.UN3} = -2967.5 \cdot kN$	$H_{hwg.UN3.loc} = 7.83\,m$
Headwater Lateral Load on Footing:	$H_{hwf.UN3} = -8847.4 \cdot kN$	$H_{hwf.UN3.loc} = 1.74\,m$
Tailwater Lateral Load:	$H_{twf.UN3} = 540.8 \cdot kN$	$H_{twf.UN3.loc} = -0.33\,m$
Tailwater Lateral Load on Pier:	$H_{twp.UN3} = 240.3 \cdot kN$	$H_{twp.UN3.loc} = -0.33\,m$
Water Weight (HW) on Apron Slab:	$H_{1.UN3} = 3960.2 \cdot kN$	$H_{1.UN3.loc} = 21.10\,m$
Water Weight (HW) on Fixed Crest:	$H_{2.UN3} = 3682.6 \cdot kN$	$H_{2.UN3.loc} = 14.25\,m$
Water Weight (TW) on Fixed Crest:	$H_{3.UN3} = 0.0 \cdot kN$	$H_{3.UN3.loc} = 0.00\,m$
Uplift:	$U_{UN3} = -25461.4 \cdot kN$	$U_{UN3.loc} = 14.42\,m$
Upstream (driving) Lateral Soil Load:	$E1_{drive.UN3} = -1876.9 \cdot kN$	$E1_{drive.loc.UN3} = 0.50\,m$
Downstream (resisting) Lateral Soil Load:	$E2_{resistUN3} = 0 \cdot kN$	$E2_{resistlocUN3} = 0.67\,m$
Ice / Impact Load:	$I_{UN3} = 0.0 \cdot kN$	$I_{UN3.loc} = 11.20\,m$

STABILITY ASSESSMENT (SLIDNG, OVERTURNING AND BEARING):

UN3 CASE

CHECK SLIDING ALONG HORIZONTAL PLANE THRU TOE,
IGNORING BEDROCK MOBILIZED BY STRUCTURAL HEEL KEY , OR VOID BEHIND KEY

Sum of Vertical Forces:

$\Sigma V_{UN3} := \Sigma V_{DL.UN3} + \Sigma V_{water.UN3} = 34625.2 \cdot kN$

Sum of Horizontal Forces:

$\Sigma H_{UN3} := \Sigma H_{Water.UN3} + \Sigma H_{soil.UN3} + \Sigma H_{I.UN3} = -13872 \cdot kN$

Sliding Factor of Safety:

$$FS_{HorizSliding.UN3} := \frac{\left(\tan_{\phi} \cdot \Sigma V_{UN3}\right)}{\left|\Sigma H_{UN3}\right|} = 1.22$$

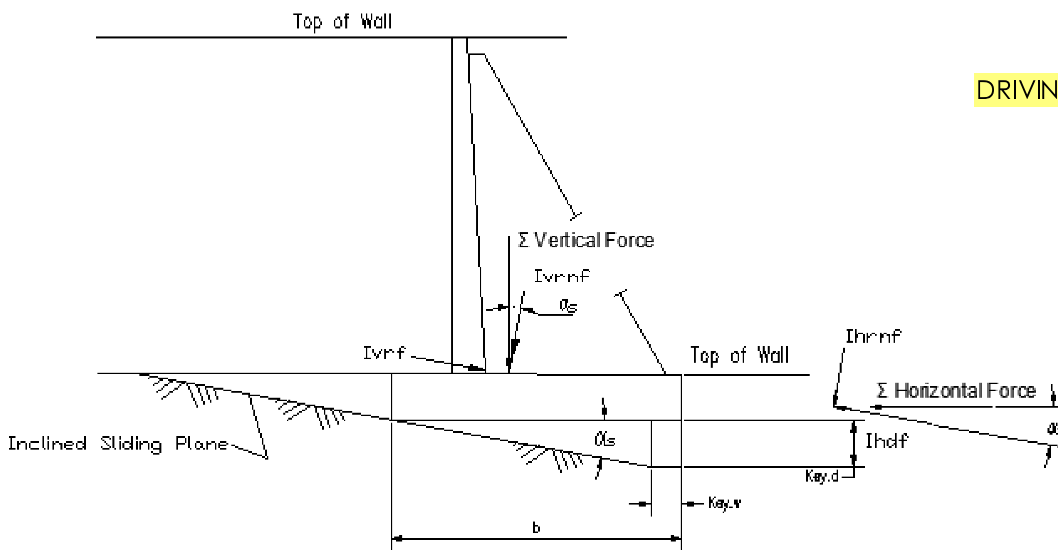
$FS_{HorizSliding.UN3.Check} :=$ | "OKAY" if $FS_{HorizSliding.UN3} \geq FS_{req.UN3.sl}$
"Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !" otherwise

$FS_{HorizSliding.UN3.Check} =$ "Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !"

CHECK SLIDING ALONG INCLINED SLIDING PLANE FROM HEEL KEY TO TOE,
WITH BEDROCK MASS MOBILIZED BY REINFOCREDE CONCRETE KEY)

RESISTING SIDE

DRIVING SIDE



TOE

HEEL

Ivrf=Inclined Resisting Force
Ivrnf=Inclined Resisting Normal Force
Ihrnf=Inclined Resisting Normal Force
Ihdf=Inclined Driving Force

$$\alpha s := \operatorname{atan}\left(\frac{BOF_{toe} - BOF_{elev}}{L_b - Key_l}\right) = 0.13$$

as degrees= $\alpha s \cdot \left(\frac{180}{\pi}\right) = 7.63$

Resolve $\Sigma Vert_{UN3}$ & $\Sigma Horiz_{UN3}$

$$\Sigma V_{InclinedUN3} := \cos(\alpha s) \cdot \left(\Sigma V_{UN3} + V_{rs}\right) + \sin(\alpha s) \cdot \left|\Sigma H_{UN3}\right| = 49262.2 \cdot kN$$

$$\Sigma H_{InclinedUN3} := \cos(\alpha s) \cdot \left|\Sigma H_{UN3}\right| - \sin(\alpha s) \cdot \left(\Sigma V_{UN3} + V_{rs}\right) = 7398.3 \cdot kN$$

(With properly engineered reinforced concrete Key, horizontal sliding plane thru Toe is protected, critical sliding plane is relocated to the INCLINED SLIDING PLANE FROM HEEL KEY To TOE, Bedrock Mass above this examing plane is mobilized by reinforced concrete key and combined into Structural Wedge.)

Inclined Sliding Plane Length $L_{incline} = 24.2 m$

Safety Factor for Sliding Inclined Failure Plane

$$FS_{InclinedlSlidingUN3} := \frac{\Sigma V_{InclinedUN3} \cdot \tan\left(\phi_{rock} \cdot \frac{\pi}{180}\right)}{\left|\Sigma H_{InclinedUN3}\right|} = 3.25$$

$FS_{InclinedSliding.UN3.check} :=$ | "OKAY " if $FS_{InclinedlSlidingUN3} > FS_{req.UN3.sl}$ = "OKAY "
"Revise Structure"" otherwise

$FS_{InclinedSliding.UN3.check} =$ "OKAY "

CHECK ECCENTRICITY ON INCLINED PLANE

UN3 CASE

Sum of the Moments:

$$\Sigma M_{rs.UN3} := \Sigma M_{DL.UN3} + \Sigma M_{HWater.UN3} + \Sigma M_{Vwater.UN3} + \Sigma M_{I.UN3} + \Sigma M_{soil.UN3} + V_{rs} \cdot L_{rs} = 558046 \cdot kN \cdot m$$

Eccentricity:

$$e_{UN3} := \frac{L_{incline}}{2} - \frac{\Sigma M_{rs.UN3}}{\Sigma V_{InclinedUN3}} = 0.80\,m$$

Eccentricity Check:

$$e_{check.UN3} := \begin{cases} \text{"Okay"} & \text{if } \left|e_{UN3}\right| \le Kern \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$e_{check.UN3} = \text{"Okay"}$

Foundation Bearing Pressures on Inclined Plane:

Bearing Pressure at Heel:

$$\sigma_{heel.UN3} := \frac{\Sigma V_{InclinedUN3}}{\frac{A_b}{\cos(\alpha s)}} - \frac{\Sigma V_{InclinedUN3} \cdot e_{UN3}}{\frac{S_b}{\cos(\alpha s)^2}} = 124.9 \cdot \frac{kN}{m^2}$$

$$\sigma_{heel.UN3.check} := \left(\begin{cases} \text{"Okay"} & \text{if } \sigma_{heel.UN3} \le \sigma_{allow.UN3} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} \right)$$

$\sigma_{heel.UN3.check} = \text{"Okay"}$

Bearing Pressure at Toe:

$$\sigma_{toe.UN3} := \frac{\Sigma V_{InclinedUN3}}{\frac{A_b}{\cos(\alpha s)}} + \frac{\Sigma V_{InclinedUN3} \cdot e_{UN3}}{\frac{S_b}{\cos(\alpha s)^2}} = 185.5 \cdot \frac{kN}{m^2}$$

$$\sigma_{toe.UN3.check} := \begin{cases} \text{"Okay"} & \text{if } \sigma_{toe.UN3} \le \sigma_{allow.UN3} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$\sigma_{toe.UN3.check} = \text{"Okay"}$

CHECK FLOTATION

$$Uplift_{sliding.UN3} := U_{UN3} = -25461.4 \cdot kN$$

$$Uplift_{pore.UN3} = -18145.4 \cdot kN$$

$$\left(Uplift_{UN3}\right) := \min\left(Uplift_{pore.UN3}, Uplift_{sliding.UN3}\right)$$

(For conservative, taking maximum values)

$$FS_{Flotation.UN3} := \frac{D_{conc} + D_{Gate} + H_{1.UN3} + H_{2.UN3} + H_{3.UN3}}{\left|Uplift_{UN3}\right|} = 2.4$$

$$FS_{Flotation.UN3.check} := \begin{cases} \text{"OKAY "} & \text{if } FS_{Flotation.UN3} > FS_{req.UN.flt} \\ \text{"Revise Structure""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

UN3 CASE

MONOLITH OVERTURNING STABILITY ANALYSIS

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.
Assumptions are made in order to compute overturning stability of indetermine forces on monolith with key;
(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.
(b) The horizontal resisting force acting on the key, P.key, is that required for static equilibrium
(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1

$Ratio_{overturning.allow.Unusual} = 0.333$

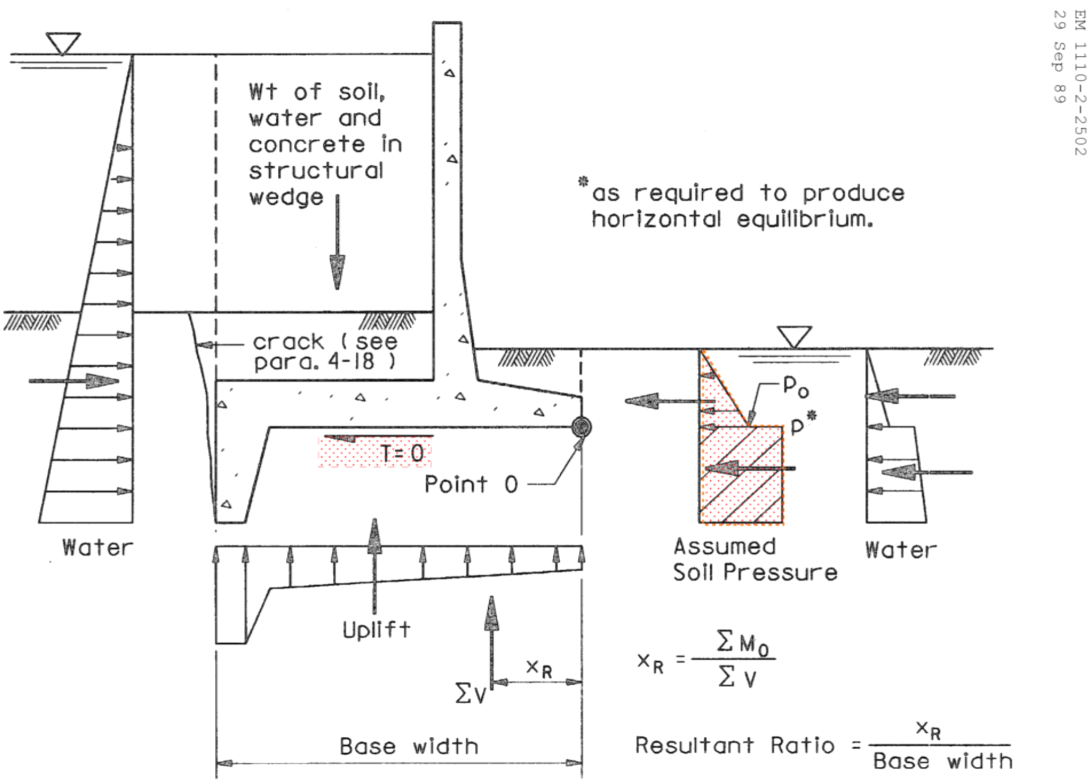


Figure 4-5. Forces for overturning analysis for wall with horizontal base and key

<u>All Vertical Loads Applicable to Overturning Stability Analysis</u>

Total Concrete Dead Loads:	$D_{conc} = 52182.8 \cdot kN$	at:	$X_{conc.loc} = 12.4\,m$
Dead Load of Gate:	$D_{Gate} = 580.0 \cdot kN$		$X_{gate} = 9.75\,m$
Water Weight (HW) on Apron Slab:	$H_{1.UN3} = 3960.2 \cdot kN$		$H_{1.UN3.loc} = 21.10\,m$
Water Weight (HW) on Fixed Crest:	$H_{2.UN3} = 3682.6 \cdot kN$		$H_{2.UN3.loc} = 14.25\,m$
Water Weight (TW) on Fixed Crest:	$H_{3.UN3} = 0.0 \cdot kN$		$H_{3.UN3.loc} = 0.00\,m$

Uplift Force from Sliding Analysis. Line of Creep Method applied at presumed inclined sliding line, and subtraction gravity effect to Base of Concrete by Archimedes Principle

$$U_{UN3.loc.sliding} := \frac{U_{A.UN3} \cdot L_{A.UN3} + U_{B.UN3} \cdot L_{B.UN3} - A_{rs} \cdot w_{as} \cdot \gamma_w \cdot L_{rs}}{U_{A.UN3} + U_{B.UN3} - A_{rs} \cdot w_{as} \cdot \gamma_w} = 14.34\,m$$

$$U_{UN3.sliding} := U_{UN3} + A_{rs} \cdot w_{as} \cdot \gamma_w = -19566.9 \cdot kN$$

Uplift for Overturning Analysis, Line of Creep Method. Pore pressure at base of Concrete $Uplift_{pore.UN3} = -18145.4 \cdot kN$

$$Uplift_{pore.UN3.loc} := \frac{Uplift_{BC.UN3} \cdot Uplift_{BC.UN3.loc} + Uplift_{DE.UN3} \cdot Uplift_{DE.UN3.loc} + Uplift_{EF.UN3} \cdot Uplift_{EF.UN3.loc} + Uplift_{FG.UN3} \cdot Uplift_{FG.UN3.loc}}{Uplift_{pore.UN3}}$$

$Uplift_{pore.UN3.loc} = 14.1\,m$

Sum of All Water Load for Overturning Analysis $\Sigma V_{water.UN3.OT} := H_{1.UN3} + H_{2.UN3} + H_{3.UN3} + Uplift_{pore.UN3} = -10502.6 \cdot kN$

All Lateral Loads Applicable to Overturning Stability Analysis

Apply Load to Gate?: $poss_{UN3} = 1$ poss = 1 if gate is closed, 0 if gate is open

Headwater Lateral Load on Pier: $H_{hwp.UN3} = -961.4 \cdot kN$ $H_{hwp.UN3.loc} = 6.83\,m$

Headwater Lateral Load on Gate: $H_{hwg.UN3} = -2967.5 \cdot kN$ $H_{hwg.UN3.loc} = 7.83\,m$

Headwater Lateral Load on Footing: $H_{hwf.UN3} = -8847.4 \cdot kN$ $H_{hwf.UN3.loc} = 1.74\,m$

Total Horizontal Tailwater Load on Pier: $H_{twp.UN3} = 240.3 \cdot kN$ $H_{twp.UN3.loc} = -0.33\,m$

Total Horizontal Tailwater Load on Footing under Gate Openings, i.e., excluding Pier $H_{twf.UN3} = 540.8 \cdot kN$ $H_{twf.UN3.loc} = -0.33\,m$

Resisting Water on Rear Face of Monolith, i.e., bottom of heel elevation: *(Point O @ TOE: BOFtoe = EL.1205.5)*

Ice / Impact Load: $I_{UN3} = 0.0 \cdot kN$ at: $I_{UN3.loc} = 11.20\,m$

Depth of Fill at Heel Side for Overturning Analysis: $t_{hf.UN3} := TOC_{as} - BOF_{toe} = 4.50\,m$

Driving Soil Load for overturning: $E1_{drive.UN3} := \frac{K_o \cdot t_{hf.UN3}^2}{2} \cdot (\gamma_r - \gamma_w) \cdot W_b \cdot -1 = -1055.7 \cdot kN$

Acting at: $E1_{drive.loc.UN3} := \frac{t_{hf.UN3}}{3} = 1.50\,m$

Downstream (resisting) Lateral Soil Load as required to produce horizontal equilibrium:

$$E2_{resistUN3} := -1 \cdot \left(H_{hwp.UN3} + H_{hwg.UN3} + H_{hwf.UN3} + H_{twp.UN3} + H_{twf.UN3} + I_{UN3} + E1_{drive.UN3}\right)$$

$E2_{resistUN1} = 10058.4 \cdot kN$

Assumed Resisting Bedrock at middle of Key,passive soil pressure or lateral bearing contact joint at end of Monolith 3A3B $E2_{resistlocUN3} := E2_{resistlocU1} = 0.67\,m$

Overturning moment by Dead Loads about Point O @ Toe $\Sigma M_{DL.UN1} = 654229.9 \cdot kN \cdot m$

Overturning moment by Vertical Water Loads and Uplift, about Point O @ Toe

$$\Sigma M_{Vwater.UN3.OT} := H_{1.UN3} \cdot H_{1.UN3.loc} + H_{2.UN3} \cdot H_{2.UN3.loc} + H_{3.UN1} \cdot H_{3.UN3.loc} + Uplift_{pore.UN3} \cdot Uplift_{pore.UN3.loc} = -119844.6 \cdot kN \cdot m$$

UN3 CASE

Overturning moment by Lateral Hydrostatic Forces of Headwater Pool and Tailwater Pool,about Point O @ Toe

$\Sigma M_{HWater.UN3} = -45498.6 \cdot kN \cdot m$

Overturning Moment by Impact/Ice Load, about Point O@ Toe

$\Sigma M_{I.UN3} = 0$

Overturning moment by Lateral Soil Forces about Point O @ Toe

$\Sigma M_{soil.UN3} := E1_{drive.UN3} \cdot E1_{drive.loc.UN3} + E2_{resistUN3} \cdot E2_{resistlocUN3} = 7117 \cdot kN \cdot m$

Sum of the Overturning Moments about Point O @ Toe:

$\Sigma M_{UN3.OT} := \Sigma M_{DL.UN3} + \Sigma M_{HWater.UN3} + \Sigma M_{Vwater.UN3.OT} + \Sigma M_{I.UN3} + \Sigma M_{soil.UN3} = 492893 \cdot kN \cdot m$

Sum of Vertical Forces:

$\Sigma V_{UN3.OT} := \Sigma V_{DL.UN3} + \Sigma V_{water.UN3.OT} = 41941.2 \cdot kN$

Distance X_R: EM 1110-2-2502 Eq.4-1

$$X_{R.UN3} := \frac{\Sigma M_{UN3.OT}}{\Sigma V_{UN3.OT}} = 11.8 m$$

Overturning Resultant Ratio

$$Ratio_{Overturning.UN3} := \frac{X_{R.UN3}}{L_b} = 0.49$$

EM 1110-2-2502

Table 4-1

Retaining Wall Stability Criteria

Loading Condition	Sliding Factor of Safety, FS	Shear Strength Test Required: Soil Foundation	Shear Strength Test Required: Rock Foundation[3]	Overturning Criteria Minimum Base Area in Compression: Soil Foundation	Overturning Criteria Minimum Base Area in Compression: Rock Foundation
Usual	1.5	(Q &/or S)[2,1]	Direct shear	100%[4]	75%[4]
Unusual	1.33	(Q &/or S)[2,1]	Direct shear	75%[4]	50%[4]
Earthquake	1.1	(Q)	Direct shear	Resultant within base	Resultant within base

Overturning Stability Check

$$Ratio_{Overturning.UN3.check} := \begin{cases} \text{"Okay"} & \text{if } Ratio_{Overturning.UN3} \ge Ratio_{overturning.allow.Unusual} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$Ratio_{Overturning.UN3.check} = \text{"Okay"}$

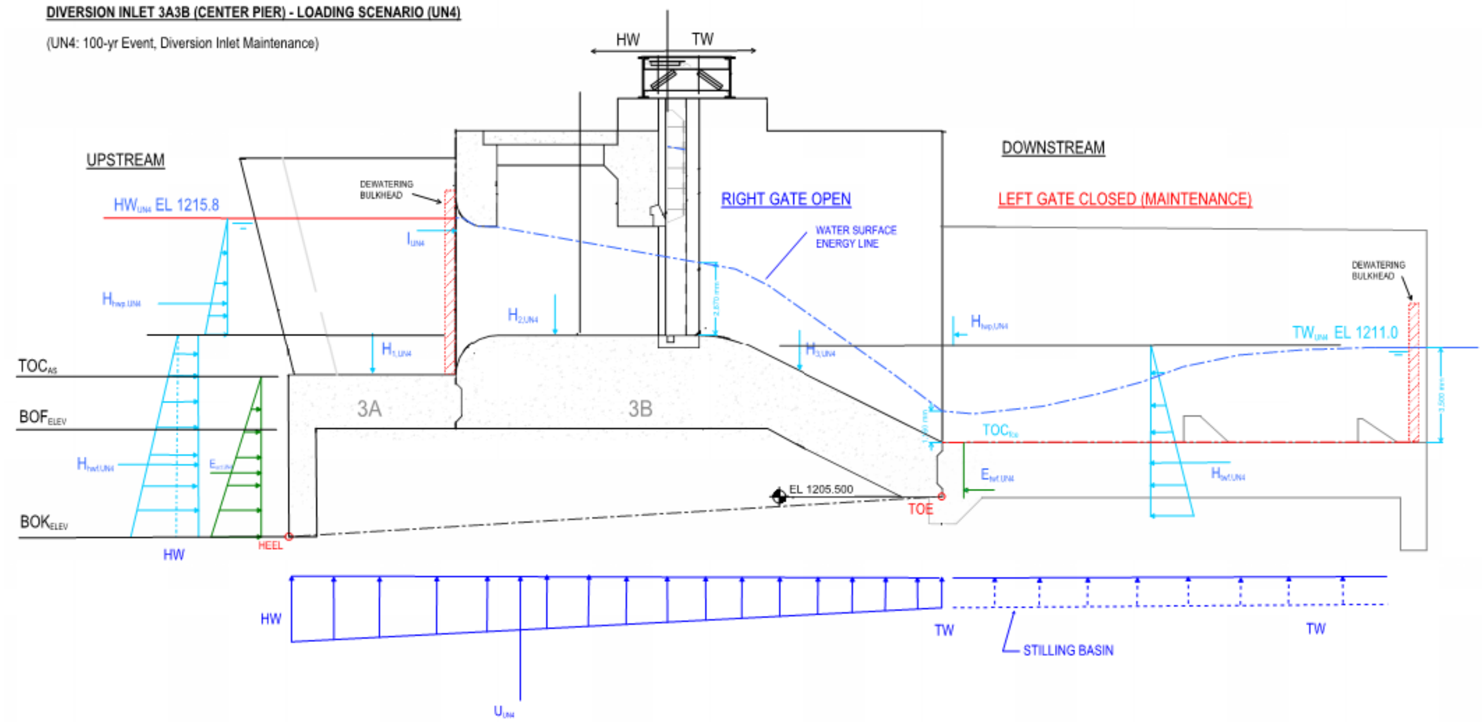
Summary of Extreme Flood Results (Only Report Controlling Load Case)

UN3 CASE

UN3 Event: No Diversion, 1000 Yr.Flood

Horiz Sliding Factor of Safety:	$FS_{HorizSliding.UN3} = 1.22$
Horiz Sliding Factor of Safety Check:	$FS_{HorizSliding.UN3.Check}$ = "Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !"
Sliding Factor of Safety:	$FS_{InclinedlSlidingUN3} = 3.2$
Sliding Factor of Safety Check:	$FS_{InclinedSliding.UN3.check}$ = "OKAY "
Eccentricity:	$e_{UN3} = 0.80\,m$
Eccentricity Check:	$e_{check.UN3}$ = "Okay"
Bearing Pressure At Heel on Inclined Plane:	$\sigma_{heel.UN3} = 124.9 \cdot \frac{kN}{m^2}$
Bearing Pressure At Heel Check:	$\sigma_{heel.UN3.check}$ = "Okay"
Bearing Pressure At Toe on Inclined Plane:	$\sigma_{toe.UN3} = 185.5 \cdot \frac{kN}{m^2}$
Bearing Pressure At Toe Check:	$\sigma_{toe.UN3.check}$ = "Okay"
Flotation Factor of Safety	$FS_{Flotation.UN3} = 2.4$
Flotation Factor of Safety Check:	$FS_{Flotation.UN3.check}$ = "OKAY "
Overturning Resultant Ratio	$Ratio_{Overturning.UN3} = 0.49$
Overturning Stability Check	$Ratio_{Overturning.UN3.check}$ = "Okay"

UN4 DESIGN CASE



This load case is the Construction / Maintenance / Single Gate Bay De-watered Load Case. One vertical lift gate is open, while the other has been removed for maintenance, and bulkheads in place to dewater one gate bay at a time. Calculation highlighted in Orange where calculation which differ from Load Case UN1 procedures.

ACCEPTANCE PARAMETERS

Required Factor of Safety for Sliding: $FS_{req.UN4.sl} := 1.3$ (Without Cohesion) (Section 8.1, Design Criteria)

Resultant Within Middle Third of Base: $e \le \frac{L_b}{6} \wedge e \ge \frac{-L_b}{6}$

Allowable Rock Bearing Pressure: $\sigma_{allow.UN4} := 1470.0 \cdot \frac{kN}{m^2}$ (Section 5.2, Design Criteria)

Required Factor of Safety for Flotation: $FS_{req.UN.flt} = 1.3$

Overturning Min Required Resultant Ratio: $\frac{X_{R.UN}}{Horizontal\_Width\_of\_Base} > 0.33$

INPUT PARAMETERS

UN4 CASE

Headwater Elevation: $HW_{UN4} := 1215.80m$

Tailwater Elevation: $TW_{UN4} := 1211.10m$

(Water Elevations based on Diversion Structure 2D Hydraulic Model Results. See page 7 and Section 8.2, Design Criteria)

Crest Water Elevation, EL.1215.81 $CrestW_{UN4} := 2.87 \cdot m$

Chute Block Water Elevation EL.1208.78 $ChuteW_{UN4} := 1.28 \cdot m$ $TW_{UN4} := TOC_{fce} + ChuteW_{UN4} = 1208.8\,m$

Bottom of Key (Footing Heel) Elevation: $BOF_{elev} = 1204.00\,m$

Apron Slab Top of Concrete Elevation at Edge of Slab: $TOC_{as} = 1210.00\,m$

Fixed Crest Top of Concrete Elevation at Downstream Face: $TOC_{fce} = 1207.50\,m$

Fixed Crest Top of Concrete Elevation at Center of Footing: $TOC_{fcc} = 1211.50\,m$

VERTICAL LIFT GATE

Lift Gate Position per Hydraulic Criteria $poss_{UN4} := 0$

poss = 1 if gate is closed
0 if gate is open

DEAD LOAD SUMMATION:

$$Gate_{R.UN4} := \frac{1}{2} + 4.5 \cdot \frac{m}{20 \cdot m} = 0.73$$

Monolith Reaction for Wheel Gate
UN4 - Maintenance one DI channel de-watered, while another DI channel open to tailwater pool

$$\Sigma V_{DL.UN4} := D_{conc} + Gate_{R.UN4} D_{Gate} = 52603.3 \cdot kN$$

$$\Sigma M_{DL.UN4} := D_{conc} \cdot X_{conc.loc} + Gate_{R.UN4} \cdot D_{Gate} \cdot X_{gate} = 652674.7 \cdot kN \cdot m$$

Dead Load of Vertical Lift Gate: $D_{Gate.UN4} := \frac{D_{Gate} \cdot 4.5 \cdot m \cdot 2}{20 \cdot m} = 261.0 \cdot kN$

Source: Drawing Q-202 dated 03-31-2017
Gate on Sill

Distance from Toe to COG of Gate: $X_{gate.UN4} := X_{pgs} = 9.75\,m$

Distance from Base to Centroid of Vertical Lift Gate: $Y_{gate.UN4} := 7.0m$

Distance from base to halfway between the bottom of the headwall and the top of the Fixed Crest.

DEAD LOAD SUMMATION:

$$\Sigma V_{DL.UN4} := D_{conc} + D_{Gate.UN4} = 52443.8 \cdot kN$$

$$\Sigma M_{DL.UN4} := D_{conc} \cdot X_{conc.loc} + D_{Gate.UN4} \cdot X_{gate.UN4} = 651119.6 \cdot kN \cdot m$$

UN4 CASE

LATERAL WATER LOADS

HEADWATER (DRIVING):

Water Depth on Pier at Heel: $D_{hwp.UN4} := HW_{UN4} - TOC_{as} = 5.80\,m$

Water Load Unit Width on Pier: $W_{hwp.UN4} := w_{pn} = 4.00\,m$

Total Horizontal Water Load on Pier:

$$H_{hwp.UN4} := \frac{-\left(\gamma_w \cdot D_{hwp.UN4}^{\;2}\right)}{2} \cdot W_{hwp.UN4} = -660.0 \cdot kN$$

Apply Total Pier Water Load at:

$$H_{hwp.UN4.loc} := \frac{D_{hwp.UN4}}{3} + \left(TOC_{as} - BOF_{toe}\right) = 6.43\,m$$

Water Depth Above Fixed Crest at Gate: $D_{hwg.UN4} := HW_{UN4} - TOC_{fcc} = 4.3\,m$

Water Load Unit Width on Gate: $W_{hwg.UN4} := 2 \cdot \frac{20}{2} m = 20.00\,m$

Apply Load to Gate?: $poss_{UN4} = 0$

poss = 1 if gate is closed
0 if gate is open

Total Horizontal Water Load on Gate:

$$H_{hwg.UN4} := \frac{-\left(\gamma_w \cdot D_{hwg.UN4}^{\;2}\right)}{2} \cdot W_{hwg.UN4} = -1813.9 \cdot kN$$

Apply Total Gate Water Load at:

$$H_{hwg.UN4.loc} := \frac{D_{hwg.UN4}}{3} + \left(TOC_{fcc} - BOF_{toe}\right) = 7.43\,m$$

Water Depth at Heel: $D_{hwf.UN4} := HW_{UN4} - BOF_{elev} = 11.80\,m$

Water Load Unit With on Footing: $W_{hw.UN4} := W_b$

Water Load at Bottom of Footing:

$$H_{hwf.UN4.1} := -\left(\gamma_w \cdot D_{hwf.UN4}\right) \cdot W_{hw.UN4} = -1504.9 \frac{1}{m} \cdot kN$$

Water Load at Top of Footing:

$$H_{hwf.UN4.2} := -\left(\gamma_w \cdot D_{hwg.UN4}\right) \cdot W_{hw.UN4} = -548.4 \frac{1}{m} \cdot kN$$

Total Horizontal Water Load on Footing:

$$H_{hwf.UN4} := \frac{\left(H_{hwf.UN4.1} + H_{hwf.UN4.2}\right) \cdot \left(D_{hwf.UN4} - D_{hwg.UN4}\right)}{2} = -7699.6 \cdot kN$$

Apply Total Footing Water Load at:

$$H_{hwf.UN4.loc} := \frac{\left[H_{hwf.UN4.2} \cdot \frac{\left(TOC_{fcc} - BOF_{elev}\right)^2}{2} + \frac{\left(H_{hwf.UN4.1} - H_{hwf.UN4.2}\right)}{2} \cdot \frac{\left(TOC_{fcc} - BOF_{elev}\right)^2}{3}\right]}{\frac{\left(H_{hwf.UN4.2} + H_{hwf.UN4.1}\right) \cdot \left(TOC_{fcc} - BOF_{elev}\right)}{2}} - \left(BOF_{toe} - BOF_{elev}\right) = 1.67\,m$$

Converting horizontal force resultant from HEEL calculation to Point-O@TOE

UN4 CASE

LATERAL WATER LOADS (cont.)

TAILWATER (RESISTING):

Water Depth at toe: $D_{tw.UN4} := TW_{UN4} - BOF_{elev} = 4.78\,m$

Water Load Unit Width: $W_{twf.UN4} := W_b$

Total Horizontal Tailwater Load on Footing under Gate Openings, i.e., excluding Pier

Resisting Water on Rear Face of Monolith, i.e., bottom of heel elevation

$$COND_{UN4} := poss_{UN4} = 0 \wedge TW_{UN4} \geq TOC_{fcc}$$

$$H_{twf.UN4} := \begin{cases} \dfrac{\gamma_w \cdot D_{tw.UN4}^{\,2}}{2} \cdot \left(W_{twf.UN4}\right) & \text{if } poss_{UN4} = 1 \\ \dfrac{\gamma_w \cdot D_{tw.UN4}^{\,2}}{2} \cdot \left(W_{twf.UN4}\right) & \text{if } poss_{UN4} = 0 \wedge TW_{UN4} \leq TOC_{fcc} \\ \gamma_w \cdot \left[\dfrac{D_{tw.UN4}}{2} + \dfrac{\left(TW_{UN4} - TOC_{fcc}\right)}{2}\right] \cdot \left(TOC_{fcc} - BOF_{elev}\right) \cdot \left(W_{twf.UN4} - w_{pdg}\right) & \text{if } COND_{UN4} \end{cases} = 1456.9 \cdot kN$$

Apply Footing Tailwater Load within Gate Openings at:

$$H_{twf.UN4.loc} := \begin{cases} \dfrac{D_{tw.UN4}}{3} - \left(BOF_{toe} - BOF_{elev}\right) & \text{if } poss_{UN4} = 1 \\ \dfrac{D_{tw.UN4}}{3} - \left(BOF_{toe} - BOF_{elev}\right) & \text{if } poss_{UN4} = 0 \wedge TW_{UN4} \leq TOC_{fcc} \\ \dfrac{\left(TOC_{fcc} - BOF_{elev}\right)^2 \cdot \left[\dfrac{D_{tw.UN4}}{2} + \dfrac{\left(\left(TOC_{fcc} - BOF_{elev}\right)\right)}{6}\right]}{\left(TOC_{fcc} - BOF_{elev}\right)\left[\left(TW_{UN4} - TOC_{fcc}\right) + \dfrac{\left(TOC_{fcc} - BOF_{elev}\right)}{2}\right]} - \left(BOF_{toe} - BOF_{elev}\right) & \text{if } COND_{UN4} \end{cases} = 0.09 \cdot m$$

Total Horizontal Tailwater Load on Pier: $Bulkhead_{width} := 2 \cdot 4.5m$

Load on de-watered bulkhead at Stilling Basin end, from width of Monolith up to half of DI Channel

$$H_{twp.UN4} := \frac{\gamma_w \cdot D_{tw.UN4}^{\,2}}{2} \cdot \left(w_{pdg} + Bulkhead_{width}\right) = 1456.9 \cdot kN$$

Apply Horizontal Tailwater Load on Pier at:

$$H_{twp.UN4.loc} := \frac{D_{tw.UN4}}{3} - \left(BOF_{toe} - BOF_{elev}\right) = 0.09 \cdot m$$

$$\Sigma H_{Water.UN4} := H_{hwp.UN4} + H_{hwg.UN4} + H_{hwf.UN4} + H_{twf.UN4} + H_{twp.UN4} = -7259.7 \cdot kN$$

$$\Sigma M_{HWater.UN4} := H_{hwp.UN4} \cdot H_{hwp.UN4.loc} + H_{hwg.UN4} \cdot H_{hwg.UN4.loc} + H_{hwf.UN4} \cdot H_{hwf.UN4.loc} \cdots + H_{twf.UN4} \cdot H_{twf.UN4.loc} + H_{twp.UN4} \cdot H_{twp.UN4.loc} = -30297.9 \cdot kN \cdot m$$

VERTICAL WATER LOADS

UN4 CASE

HEADWATER:

Water Depth on top of fixed crest: $d_{hw.UN4} := HW_{UN4} - TOC_{as} = 5.80\,m$

Subtract Pier Volume:

$$S_{pn.UN4} := \left[\frac{(A_{pnt} - A_{pnb})}{h_{pn}}\right] = 1.00 \cdot \frac{m^2}{m}$$

$$V_{pn.UN4} := \frac{\left[(S_{pn.UN4} \cdot d_{hw.UN4} + A_{pnb}) + A_{pnb}\right]}{2} \cdot d_{hw.UN4} = 129.5 \cdot m^3$$

Weight of Water (H1) on Approach Slab: $H_{1.UN4} := (W_{hw.UN4} \cdot d_{hw.UN4} \cdot L_{as} - V_{pn.UN4}) \cdot \gamma_w = 3315.4 \cdot kN$

Horiz. Moment Arm for H1 (from toe): $H_{1.UN4.loc} := L_b - \frac{L_{as}}{2} = 21.10\,m$

Cross-sectional Area of
Headwater Above Fixed Crest: $A_{fc.hw.UN4} := 29.10m^2$

(From Bluebeam Measurement, Bound by Energy Line through Crest Water Elevation Crest and Chute Block Water Elevation Chute as defined above)

Volume of water Above Fixed Crest: $V_{fc.hw.UN4} := \left[A_{fc.hw.UN4} \cdot (W_{hw.UN4} - w_{pn})\right] = 261.9 \cdot m^3$

Weight of Water (H2) on Fixed Crest: $H_{2.UN4} := (V_{fc.hw.UN4}) \cdot \frac{\gamma_w}{2} = 1284.6 \cdot kN$ *Divide by 2 since one one side of pier is de-watered*

Horiz. Moment Arm for H2 (from toe): $H_{2.UN4.loc} := 14.412 \cdot m = 14.41\,m$ (From Bluebeam Measurement)

TAILWATER:

Slope of Crest from
D/S of Gate to edge of Stilling Basin: $S_{f.UN4} := S_{f.U1} = 0.500$

Height of Tailwater Above Stilling Basin: $y_{UN4} := TW_{UN4} - TOC_{fce} = 1.3\,m$

Cross Sectional Area of Tailwater
Above Sloped Portion of Crest: $A_{tw.UN4} := 23.86 \cdot m \cdot m = 23.9\,m^2$

(From Bluebeam Measurement, Bound by Energy Line through Crest Water Elevation CrestW and Chute Block Water Elevation ChuteW as defined above)

Weight of Water (H3)
Above Slope Portion of Crest: $H_{3.UN4} := \left[A_{tw.UN4} \cdot (W_{twf.UN4} - w_{pdg})\right] \cdot \gamma_w$ $H_{3.UN4} = 2106.6 \cdot kN$

Horiz. Moment Arm for H3 (from Toe): $H_{3.UN4.loc} := 5.780 \cdot m$ (From Bluebeam Measurement)

UPLIFT AT INCLINED SLIDING PLANE

Uplift pressure at Headwater:

$$U_{HW.UN4} := D_{hwf.UN4} \cdot \gamma_w = 115.76 \cdot \frac{kN}{m^2}$$

Uplift pressure at D/S end of Stilling Basin:

$$U_{TW.UN4} := D_{tw.UN4} \cdot \gamma_w = 46.9 \cdot \frac{kN}{m^2}$$

Length from U/S Face of Gate Structure to Toe of Block: effective drain, Lsb = 0*m

$L_{overall} = 24.20\,m$ $\quad L_{sb} = 0$

Length of Seepage per Line of Creep

$L_{seepage} = 27.1\,m$

Difference between Uplift pressure at Headwater and Uplift Pressure at Toe of Stilling Basin:

$$U_{diffUN4} := U_{HW.UN4} - U_{TW.UN4} = 68.9 \cdot \frac{kN}{m^2}$$

Slope of difference between Uplift pressure at Headwater and Uplift Pressure at Toe of Stilling Basin:

$$U_{slopeUN4} := \frac{U_{diffUN4} - Key_d \cdot \gamma_w}{L_{overall}} = 2.24 \cdot \frac{kN}{m^2 \cdot m}$$

$$U_{seepageslopeUN4} := \frac{U_{diffUN4} - Key_d \cdot \gamma_w}{L_{seepage}}$$

Tailwater Pressure at toe of Gate Structure:

$$U_{press.toe.gsUN4} := U_{TW.UN4} + L_{sb} \cdot U_{slopeUN4} = 46.9 \cdot \frac{kN}{m^2}$$

$$U_{pore.toe.UN4} := U_{TW.UN4} + U_{seepageslopeUN4} \cdot L_{sb} = 46.9 \cdot \frac{kN}{m^2}$$

$$U_{pore.F.UN4} := U_{pore.toe.UN4} + U_{seepageslopeUN4} \cdot L_{FG} = 49.9 \cdot \frac{kN}{2}$$

$$U_{pore.E.UN4} := U_{pore.F.UN4} - \left(BOF_{base} - BOF_{toe}\right) \cdot \gamma_w + U_{seepageslopeUN4} \cdot L_{EF} = 41.9 \cdot \frac{kN}{m^2}$$

$$U_{pore.D.UN4} := U_{pore.E.UN4} + U_{seepageslopeUN4} \cdot L_{DE} = 78.3 \cdot \frac{kN}{m^2}$$

$$U_{pore.C.UN4} := U_{pore.D.UN4} + \left(BOF_{base} - BOF_{elev}\right) \cdot \gamma_w + U_{seepageslopeUN4} \cdot L_{CD} = 113.8 \cdot \frac{kN}{m^2}$$

Uniform uplift due to Tailwater: (rectangular portion)

$$U_{A.UN4} := U_{press.toe.gsUN4} \cdot L_b \cdot W_b \cdot -1 = -14752.2 \cdot kN$$

Moment Arm for Uplift UA from Toe of Gate Structure:

$$L_{A.UN4} := \frac{L_b}{2} = 12.10\,m$$

Uplift - Linear Decrease from HW to TW: (triangular portion)

$$U_{B.UN4} := \frac{1}{2} \cdot \left(U_{HW.UN4} - U_{press.toe.gsUN4}\right) \cdot L_b \cdot W_b \cdot -1 = -10832.7 \cdot kN$$

Moment Arm for Uplift UB from Toe of Gate Structure:

$$L_{B.UN4} := \frac{2}{3} \cdot L_b = 16.13\,m$$

Total Resultant Uplift force:

$$U_{UN4} := U_{A.UN4} + U_{B.UN4} = -25584.8 \cdot kN$$

Resultant Location from Toe:

$$U_{UN4.loc} := \frac{U_{A.UN4} \cdot L_{A.UN4} + U_{B.UN4} \cdot L_{B.UN4}}{U_{A.UN4} + U_{B.UN4}} = 13.81\,m$$

$$\Sigma V_{water.UN4} := H_{1.UN4} + H_{2.UN4} + H_{3.UN4} + U_{UN4} = -18878.1 \cdot kN$$

$$\Sigma M_{Vwater.UN4} := H_{1.UN4} \cdot H_{1.UN4.loc} + H_{2.UN4} \cdot H_{2.UN4.loc} + H_{3.UN4} \cdot H_{3.UN4.loc} + U_{UN4} \cdot U_{UN4.loc} = -252621.9 \cdot kN \cdot m$$

Uplift as per Line of Creep Method (Flotation and Overturning)

UN4 CASE

$Uplift_{BC.UN4} := \frac{-1}{2} \cdot W_b \cdot (U_{HW.UN4} + U_{pore.C.UN4}) \cdot L_{BC} = -1491.9 \cdot kN$

$Uplift_{CD.UN4} := 0$

$Uplift_{DE.UN4} := \frac{-1}{2} \cdot W_b \cdot (U_{pore.D.UN4} + U_{pore.E.UN4}) \cdot L_{DE} = -14226.1 \cdot kN$

$Uplift_{EF.UN4} := \frac{-1}{2} \cdot W_b \cdot (U_{pore.E.UN4} + U_{pore.F.UN4}) \cdot L_{EF} = -1997.9 \cdot kN$

$Uplift_{FG.UN4} := \frac{-1}{2} \cdot W_b \cdot (U_{pore.F.UN4} + U_{pore.toe.UN4}) \cdot L_{FG} = -943.6 \cdot kN$

$Uplift_{pore.UN4} := Uplift_{BC.UN4} + Uplift_{DE.UN4} + Uplift_{EF.UN4} + Uplift_{FG.UN4} = -18659.5 \cdot kN$

$$Uplift_{FG.UN4.loc} := \frac{L_{FG}}{3} \cdot \frac{(2 \cdot U_{pore.F.UN4} + U_{pore.toe.UN4})}{(U_{pore.F.UN4} + U_{pore.toe.UN4})} = 0.76\,m$$

$$Uplift_{EF.UN4.loc} := \frac{L_{EF}}{3} \cdot \frac{(2 \cdot U_{pore.E.UN4} + U_{pore.F.UN4})}{(U_{pore.E.UN4} + U_{pore.F.UN4})} + L_{FG} = 3.13\,m$$

$$Uplift_{DE.UN4.loc} := \frac{L_{DE}}{3} \cdot \frac{(2 \cdot U_{pore.D.UN4} + U_{pore.E.UN4})}{(U_{pore.D.UN4} + U_{pore.E.UN4})} + L_{FG} + X_{EF} = 14.52\,m$$

$$Uplift_{BC.UN4.loc} := \frac{L_{BC}}{3} \cdot \frac{(2 \cdot U_{HW.UN4} + U_{pore.C.UN4})}{(U_{HW.UN4} + U_{pore.C.UN4})} + L_{FG} + X_{EF} + L_{DE} = 23.21\,m$$

SOIL LOADS

UN4 CASE

Equivalent Fluid Pressure (EFP): (CFEM 24.1)

At rest lateral pressure coefficient: $K_o = 0.66$

At-rest Soil Pressure to Heel, EM1110--2-2502 Section 3-7

Lateral Driving Force (Headwater Side)

Depth of Fill at Heel: $t_{hf.UN4} := TOC_{as} - BOF_{elev} = 6.00\,m$

At-Rest Soil Load: $E1_{drive.UN4} := \frac{K_o \cdot t_{hf.UN4}^{\,2}}{2} \cdot (\gamma_r - \gamma_w) \cdot W_b \cdot -1 = -1876.9 \cdot kN$

Acting at: $E1_{drive.loc.UN4} := \frac{t_{hf.UN4}}{3} - (BOF_{toe} - BOF_{elev}) = 0.50\,m$

Lateral Resisting Force (Tailwater Side)

Depth of Fill at Toe: $t_{tf.UN4} := TOC_{fce} - BOF_{toe} = 2.00\,m$

At-Rest Soil Load: $E2_{resistUN4} := \frac{K_o \cdot t_{tf.UN4}^{\,2}}{2} \cdot (\gamma_r - \gamma_w) \cdot W_b = 208.5 \cdot kN$ $\quad E2_{resistUN4} := 0$

Acting at: $E2_{resistlocUN4} := \frac{t_{tf.UN4}}{3} = 0.67\,m$

(Expansion Joint to Stilling Basin, No Sediment in Gap)

$\Sigma H_{soil.UN4} := E1_{drive.UN4} + E2_{resistUN4} = -1876.9 \cdot kN$

$\Sigma M_{soil.UN4} := E1_{drive.UN4} \cdot E1_{drive.loc.UN4} + E2_{resistUN4} \cdot E2_{resistlocUN4} = -938.4 \cdot kN \cdot m$

ICE / IMPACT LOADS (CONSERVATIVELY ASSUME NO ICE LOADING ON DOWNSTREAM SIDE)

ICE / IMPACT LOADS NOT APPLIED TO THIS LOAD CASE

Static Impact Loading on Structure: $I_{S.UN4} := 0.0 \frac{kN}{m}$ (Section 7.7, Design Criteria)

Static Impact load on Gates: $I_{G.UN4} := 0.0 \frac{kN}{m}$ (Section 7.7, Design Criteria)

Impact Loading Unit Width on Structure: $W_{S.UN4} := 4.00m$

Impact Loading Unit Width on Gates: $W_{G.UN4} := 2 \cdot \frac{20.00}{2} m = 20.00\,m$

Total Impact Load on Structure: $I_{UN4} := (I_{S.UN4} \cdot W_{S.UN4} + I_{G.UN4} \cdot W_{G.UN4}) \cdot -1 = 0 \cdot kN$

Apply Ice load at: $I_{UN4.loc} := (HW_{UN4} - BOF_{toe} - 0.30m) = 10.00\,m$

$\Sigma H_{I.UN4} := I_{UN4} = 0 \cdot kN$

$\Sigma M_{I.UN4} := I_{UN4} \cdot I_{UN4.loc} = 0 \cdot kN \cdot m$

SEISMIC LOAD (Not Applicable to this Load Case)

SUMMARY OF LOADS

	Loads	Moment Arm
UN4 CASE		
Dead Load of Concrete Structure:	$D_{conc} = 52182.8 \cdot kN$	$X_{conc.loc} = 12.43\,m$
Dead Load of Gate:	$D_{Gate.UN4} = 261.0 \cdot kN$	$X_{gate.UN4} = 9.75\,m$
Headwater Lateral Load on Pier:	$H_{hwp.UN4} = -660.0 \cdot kN$	$H_{hwp.UN4.loc} = 6.43\,m$
Headwater Lateral Load on Gate:	$H_{hwg.UN4} = -1813.9 \cdot kN$	$H_{hwg.UN4.loc} = 7.43\,m$
Headwater Lateral Load on Footing:	$H_{hwf.UN4} = -7699.6 \cdot kN$	$H_{hwf.UN4.loc} = 1.67\,m$
Tailwater Lateral Load on Footing:	$H_{twf.UN4} = 1456.9 \cdot kN$	$H_{twf.UN4.loc} = 0.09\,m$
Tailwater Lateral Load on Pier:	$H_{twp.UN4} = 1456.9 \cdot kN$	$H_{twp.UN4.loc} = 0.09\,m$
Water Weight (HW) on Apron Slab:	$H_{1.UN4} = 3315.4 \cdot kN$	$H_{1.UN4.loc} = 21.10\,m$
Water Weight (HW) on Fixed Crest:	$H_{2.UN4} = 1284.6 \cdot kN$	$H_{2.UN4.loc} = 14.41\,m$
Water Weight (TW) on Fixed Crest:	$H_{3.UN4} = 2106.6 \cdot kN$	$H_{3.UN4.loc} = 5.78\,m$
Uplift:	$U_{UN4} = -25584.8 \cdot kN$	$U_{UN4.loc} = 13.81\,m$
Upstream (driving) Lateral Soil Load:	$E1_{drive.UN4} = -1876.9 \cdot kN$	$E1_{drive.loc.UN4} = 0.50\,m$
Downstream (resisting) Lateral Soil Load:	$E2_{resistUN4} = 0 \cdot kN$	$E2_{resistlocUN4} = 0.67\,m$
Ice / Impact Load:	$I_{UN4} = 0.0 \cdot kN$	$I_{UN4.loc} = 10.00\,m$

STABILITY ASSESSMENT (SLIDNG, OVERTURNING AND BEARING): UN4 CASE

CHECK SLIDING ALONG HORIZONTAL PLANE THRU TOE,
IGNORING BEDROCK MOBILIZED BY STRUCTURAL HEEL KEY, OR VOID BEHIND KEY

Sum of Vertical Forces:

$\Sigma V_{UN4} := \Sigma V_{DL.UN4} + \Sigma V_{water.UN4} = 33565.7 \cdot kN$

Sum of Horizontal Forces:

$\Sigma H_{UN4} := \Sigma H_{Water.UN4} + \Sigma H_{soil.UN4} + \Sigma H_{I.UN4} = -9136.5 \cdot kN$

Sliding Factor of Safety:

$$FS_{HorizSliding.UN4} := \frac{\left(\tan_{\phi} \cdot \Sigma V_{UN4}\right)}{\left|\Sigma H_{UN4}\right|} = 1.79$$

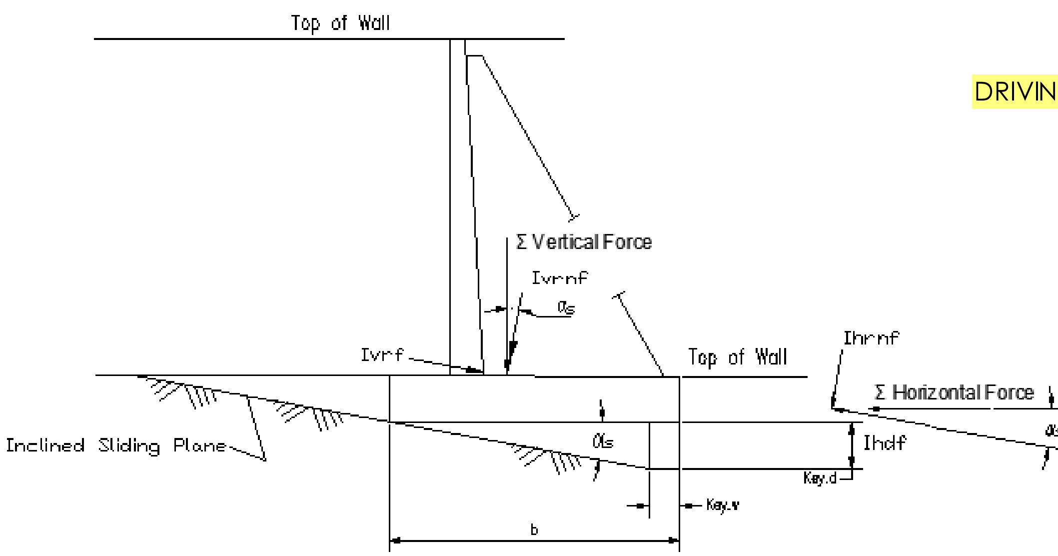
$FS_{HorizSliding.UN4.Check} :=$ | "OKAY" if $FS_{HorizSliding.UN4} \geq FS_{req.UN4.sl}$
| "Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !" otherwise

$FS_{HorizSliding.UN4.Check} =$ "OKAY"

CHECK SLIDING ALONG INCLINED SLIDING PLANE FROM HEEL KEY TO TOE,
WITH BEDROCK MASS MOBILIZED BY REINFOCREDE CONCRETE KEY)

RESISTING SIDE

DRIVING SIDE



TOE

HEEL

Ivrf=Inclined Resisting Force
Ivrnf=Inclined Resisting Normal Force
Ihrnf=Inclined Resisting Normal Force
Ihdf=Inclined Driving Force

$$\alpha s := \operatorname{atan}\left(\frac{BOF_{toe} - BOF_{elev}}{L_b - Key_l}\right) = 0.13$$

as degrees= $\alpha s \cdot \left(\frac{180}{\pi}\right) = 7.63$

Resolve $\Sigma Vert_{UN4}$ & $\Sigma Horiz_{UN4}$

$$\Sigma V_{InclinedUN4} := \cos(\alpha s) \cdot \left(\Sigma V_{UN4} + V_{rs}\right) + \sin(\alpha s) \cdot \left|\Sigma H_{UN4}\right| = 47583.4 \cdot kN$$

$$\Sigma H_{InclinedUN4} := \cos(\alpha s) \cdot \left|\Sigma H_{UN4}\right| - \sin(\alpha s) \cdot \left(\Sigma V_{UN4} + V_{rs}\right) = 2845.3 \cdot kN$$

(With properly engineered reinforced concrete Key, horizontal sliding plane thru Toe is protected, critical sliding plane is relocated to the INCLINED SLIDING PLANE FROM HEEL KEY To TOE, Bedrock Mass above this examing plane is mobilized by reinforced concrete key and combined into Structural Wedge.)

Inclined Sliding Plane Length $L_{incline} = 24.2\,m$

Safety Factor for Sliding Inclined Failure Plane

$$FS_{InclinedlSlidingUN4} := \frac{\Sigma V_{InclinedUN4} \cdot \tan\left(\phi_{rock} \cdot \frac{\pi}{180}\right)}{\left|\Sigma H_{InclinedUN4}\right|} = 8.16$$

$FS_{InclinedSliding.UN4.check} :=$ | "OKAY " if $FS_{InclinedlSlidingUN4} > FS_{req.UN4.sl}$ = "OKAY "
| "Revise Structure"" otherwise

$FS_{InclinedSliding.UN4.check} =$ "OKAY "

UN4 CASE

CHECK ECCENTRICITY ON INCLINED PLANE

Sum of the Moments:

$$\Sigma M_{rs.UN4} := \Sigma M_{DL.UN4} + \Sigma M_{HWater.UN4} + \Sigma M_{Vwater.UN4} + \Sigma M_{I.UN4} + \Sigma M_{soil.UN4} + V_{rs} \cdot L_{rs} = 551797 \cdot kN \cdot m$$

Eccentricity:

$$e_{UN4} := \frac{L_{incline}}{2} - \frac{\Sigma M_{rs.UN4}}{\Sigma V_{InclinedUN4}} = 0.53\,m$$

Eccentricity Check:

$$e_{check.UN4} := \begin{cases} \text{"Okay"} & \text{if } |e_{UN4}| \le Kern \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$$e_{check.UN4} = \text{"Okay"}$$

Foundation Bearing Pressures on Inclined Plane:

Bearing Pressure at Heel:

$$\sigma_{heel.UN4} := \frac{\Sigma V_{InclinedUN4}}{\frac{A_b}{\cos(\alpha s)}} - \frac{\Sigma V_{UN4} \cdot e_{UN4}}{\frac{S_b}{\cos(\alpha s)^2}} = 136.2 \cdot \frac{kN}{m^2}$$

$$\sigma_{heel.UN4.check} := \left(\begin{cases} \text{"Okay"} & \text{if } \sigma_{heel.UN4} \le \sigma_{allow.UN4} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} \right)$$

$$\sigma_{heel.UN4.check} = \text{"Okay"}$$

Bearing Pressure at Toe:

$$\sigma_{toe.UN4} := \frac{\Sigma V_{InclinedUN4}}{\frac{A_b}{\cos(\alpha s)}} + \frac{\Sigma V_{InclinedUN4} \cdot e_{UN4}}{\frac{S_b}{\cos(\alpha s)^2}} = 169.3 \cdot \frac{kN}{m^2}$$

$$\sigma_{toe.UN4.check} := \begin{cases} \text{"Okay"} & \text{if } \sigma_{heel.UN4} \le \sigma_{allow.UN4} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$$\sigma_{toe.UN4.check} = \text{"Okay"}$$

CHECK FLOTATION

$$Uplift_{sliding.UN4} := U_{UN4} = -25584.8 \cdot kN$$

$$Uplift_{pore.UN4} = -18659.5 \cdot kN$$

$$\left(Uplift_{UN4}\right) := \min\left(Uplift_{pore.UN4}, Uplift_{sliding.UN4}\right)$$

(For conservative, taking maximum values)

$$FS_{Flotation.UN4} := \frac{D_{conc} + D_{Gate} + H_{1.UN4} + H_{2.UN4} + H_{3.UN4}}{|Uplift_{UN4}|} = 2.3$$

$$FS_{Flotation.UN4.check} := \begin{cases} \text{"OKAY "} & \text{if } FS_{Flotation.UN4} > FS_{req.UN.flt} \\ \text{"Revise Structure""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

MONOLITH OVERTURNING STABILITY ANALYSIS

UN4 CASE

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.

Assumptions are made in order to compute overturning stability of indetermine forces on monolith with key;

(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.

(b) The horizontal resisting force acting on the key, P.key, is that required for static equilibrium

(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1 $Ratio_{overturning.allow.Unusual} = 0.333$

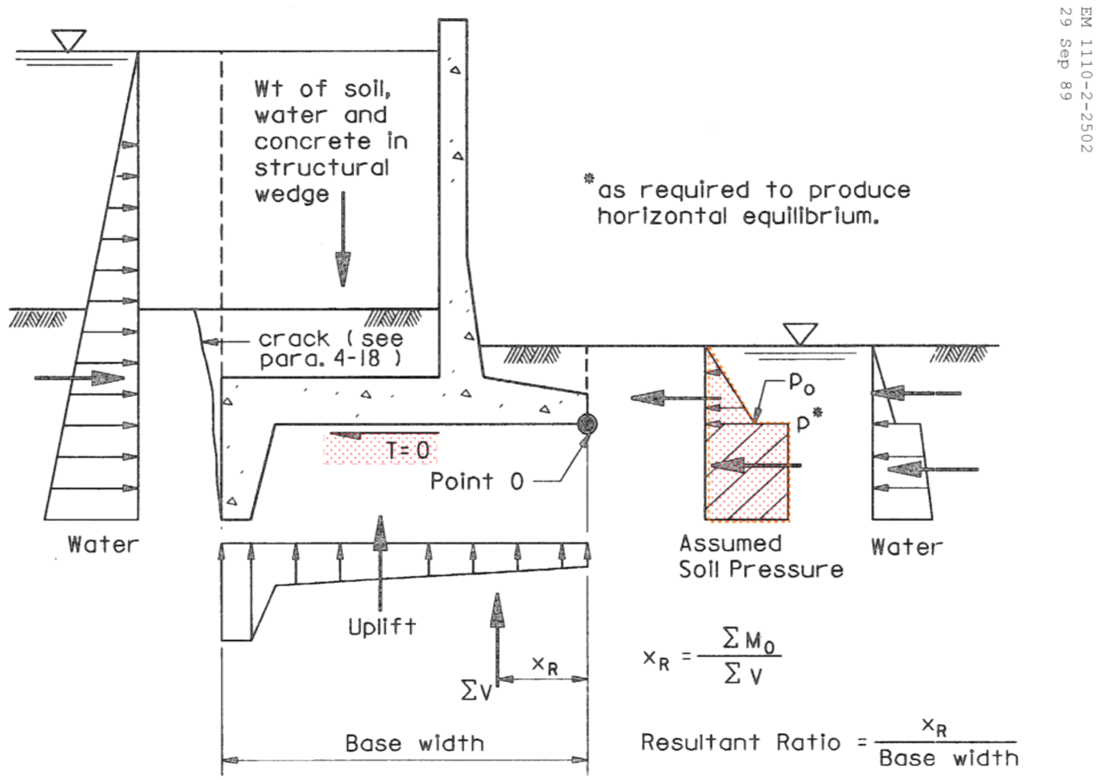


Figure 4-5. Forces for overturning analysis for wall with horizontal base and key

All Vertical Loads Applicable to Overturning Stability Analysis

Total Concrete Dead Loads:	$D_{conc} = 52182.8 \cdot kN$	at:	$X_{conc.loc} = 12.4\,m$
Dead Load of Gate:	$D_{Gate} = 580.0 \cdot kN$		$X_{gate} = 9.75\,m$
Water Weight (HW) on Apron Slab:	$H_{1.UN4} = 3315.4 \cdot kN$		$H_{1.UN4.loc} = 21.10\,m$
Water Weight (HW) on Fixed Crest:	$H_{2.UN4} = 1284.6 \cdot kN$		$H_{2.UN4.loc} = 14.41\,m$
Water Weight (TW) on Fixed Crest:	$H_{3.UN4} = 2106.6 \cdot kN$		$H_{3.UN4.loc} = 5.78\,m$

Uplift Force from Sliding Analysis. Line of Creep Method applied at presumed inclined sliding line, and subtraction gravity effect to Base of Concrete by Archimedes Principle

$$U_{UN4.loc.sliding} := \frac{U_{A.UN4} \cdot L_{A.UN4} + U_{B.UN4} \cdot L_{B.UN4} - A_{rs} \cdot w_{as} \cdot \gamma_w \cdot L_{rs}}{U_{A.UN4} + U_{B.UN4} - A_{rs} \cdot w_{as} \cdot \gamma_w} = 13.84\,m$$

$$U_{UN4.sliding} := U_{UN4} + A_{rs} \cdot w_{as} \cdot \gamma_w = -19690.4 \cdot kN$$

UN4 CASE

Uplift for Overturning Analysis, Line of Creep Method. Pore pressure at base of Concrete $\quad Uplift_{pore.UN4} = -18659.5 \cdot kN$

$$Uplift_{pore.UN4.loc} := \frac{Uplift_{BC.UN4} \cdot Uplift_{BC.UN4.loc} + Uplift_{DE.UN4} \cdot Uplift_{DE.UN4.loc} + Uplift_{EF.UN4} \cdot Uplift_{EF.UN4.loc} + Uplift_{FG.UN4} \cdot Uplift_{FG.UN4.loc}}{Uplift_{pore.UN4}}$$

$Uplift_{pore.UN4.loc} = 13.3\,m$

Sum of All Water Load for Overturning Analysis $\quad \Sigma V_{water.UN4.OT} := H_{1.UN4} + H_{2.UN4} + H_{3.UN4} + Uplift_{pore.UN4} = -11952.9 \cdot kN$

All Lateral Loads Applicable to Overturning Stability Analysis

Apply Load to Gate?: $\quad poss_{UN4} = 0 \quad$ poss = 1 if gate is closed
0 if gate is open

Headwater Lateral Load on Pier: $\quad H_{hwp.UN4} = -660.0 \cdot kN \quad H_{hwp.UN4.loc} = 6.43\,m$

Headwater Lateral Load on Gate: $\quad H_{hwg.UN4} = -1813.9 \cdot kN \quad H_{hwg.UN4.loc} = 7.43\,m$

Headwater Lateral Load on Footing: $\quad H_{hwf.UN4} = -7699.6 \cdot kN \quad H_{hwf.UN4.loc} = 1.67\,m$

Total Horizontal Tailwater Load on Pier: $\quad H_{twp.UN4} = 1456.9 \cdot kN \quad H_{twp.UN4.loc} = 0.09\,m$

Total Horizontal Tailwater Load on Footing under Gate Openings, i.e., excluding Pier $\quad H_{twf.UN4} = 1456.9 \cdot kN \quad H_{twf.UN4.loc} = 0.09\,m$

Resisting Water on Rear Face of Monolith, i.e., bottom of heel elevation: *(Point O @ TOE: BOFtoe = EL.1205.5)*

Ice / Impact Load: $\quad I_{UN4} = 0.0 \cdot kN \quad$ at: $\quad I_{UN4.loc} = 10.00\,m$

Depth of Fill at Heel Side for Overturning Analysis: $\quad t_{hf.UN4} := TOC_{as} - BOF_{toe} = 4.50\,m$

Driving Soil Load for overturning: $\quad E1_{drive.UN4} := \dfrac{K_o \cdot t_{hf.UN4}^{\,2}}{2} \cdot (\gamma_r - \gamma_w) \cdot W_b \cdot -1 = -1055.7 \cdot kN$

Acting at: $\quad E1_{drive.loc.UN4} := \dfrac{t_{hf.UN4}}{3} = 1.50\,m$

Downstream (resisting) Lateral Soil Load as required to produce horizontal equilibrium:

$$E2_{resistUN4} := -1 \cdot \left(H_{hwp.UN4} + H_{hwg.UN4} + H_{hwf.UN4} + H_{twp.UN4} + H_{twf.UN4} + I_{UN4} + E1_{drive.UN4}\right)$$

$E2_{resistUN4} = 8315.4 \cdot kN$

Assumed Resisting Bedrock at middle of Key, passive soil pressure or lateral bearing contract joint at end of Monolith 3A3B $\quad E2_{resistlocUN4} := E2_{resistlocU1} = 0.67\,m$

Overturning moment by Dead Loads about Point O @ Toe $\quad \Sigma M_{DL.UN4} = 651119.6 \cdot kN \cdot m$

Overturning moment by Vertical Water Loads and Uplift, about Point O @ Toe

$$\Sigma M_{Vwater.UN4.OT} := H_{1.UN4} \cdot H_{1.UN4.loc} + H_{2.UN4} \cdot H_{2.UN4.loc} + H_{3.UN4} \cdot H_{3.UN4.loc} + Uplift_{pore.UN4} \cdot Uplift_{pore.UN4.loc} = -147507.1 \cdot kN \cdot m$$

Overturning moment by Lateral Hydrostatic Forces of Headwater Pool and Tailwater Pool,about Point O @ Toe

$\Sigma M_{HWater.UN4} = -30297.9 \cdot kN \cdot m$

Overturning Moment by Impact/Ice Load, about Point O@ Toe

$\Sigma M_{I.UN4} = 0$

Overturning moment by Lateral Soil Forces about Point O @ Toe

$\Sigma M_{soil.UN4} := E1_{drive.UN4} \cdot E1_{drive.loc.UN4} + E2_{resistUN4} \cdot E2_{resistlocUN4} = 3960 \cdot kN \cdot m$

Sum of the Overturning Moments about Point O @ Toe:

$$\Sigma M_{UN4.OT} := \Sigma M_{DL.UN4} + \Sigma M_{HWater.UN4} + \Sigma M_{Vwater.UN4.OT} + \Sigma M_{I.UN4} + \Sigma M_{soil.UN4} = 477275 \cdot kN \cdot m$$

Sum of Vertical Forces:

$$\Sigma V_{UN4.OT} := \Sigma V_{DL.UN4} + \Sigma V_{water.UN4.OT} = 40491.0 \cdot kN$$

Distance X_R: EM 1110-2-2502 Eq.4-1

$$X_{R.UN4} := \frac{\Sigma M_{UN4.OT}}{\Sigma V_{UN4.OT}} = 11.8 m$$

Overturning Resultant Ratio

$$Ratio_{Overturning.UN4} := \frac{X_{R.UN4}}{L_b} = 0.49$$

EM 1110-2-2502

Table 4-1

Retaining Wall Stability Criteria

Loading Condition	Sliding Factor of Safety, FS	Shear Strength Test Required: Soil Foundation	Shear Strength Test Required: Rock Foundation[3]	Overturning Criteria Minimum Base Area in Compression: Soil Foundation	Overturning Criteria Minimum Base Area in Compression: Rock Foundation
Usual	1.5	(Q &/or S)[2,1]	Direct shear	100%[4]	75%[4]
Unusual	1.33	(Q &/or S)[2,1]	Direct shear	75%[4]	50%[4]
Earthquake	1.1	(Q)	Direct shear	Resultant within base	Resultant within base

Overturning Stability Check

$$Ratio_{Overturning.UN4.check} := \begin{cases} \text{"Okay"} & \text{if } Ratio_{Overturning.UN4} \ge Ratio_{overturning.allow.Unusual} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$Ratio_{Overturning.UN4.check} = \text{"Okay"}$

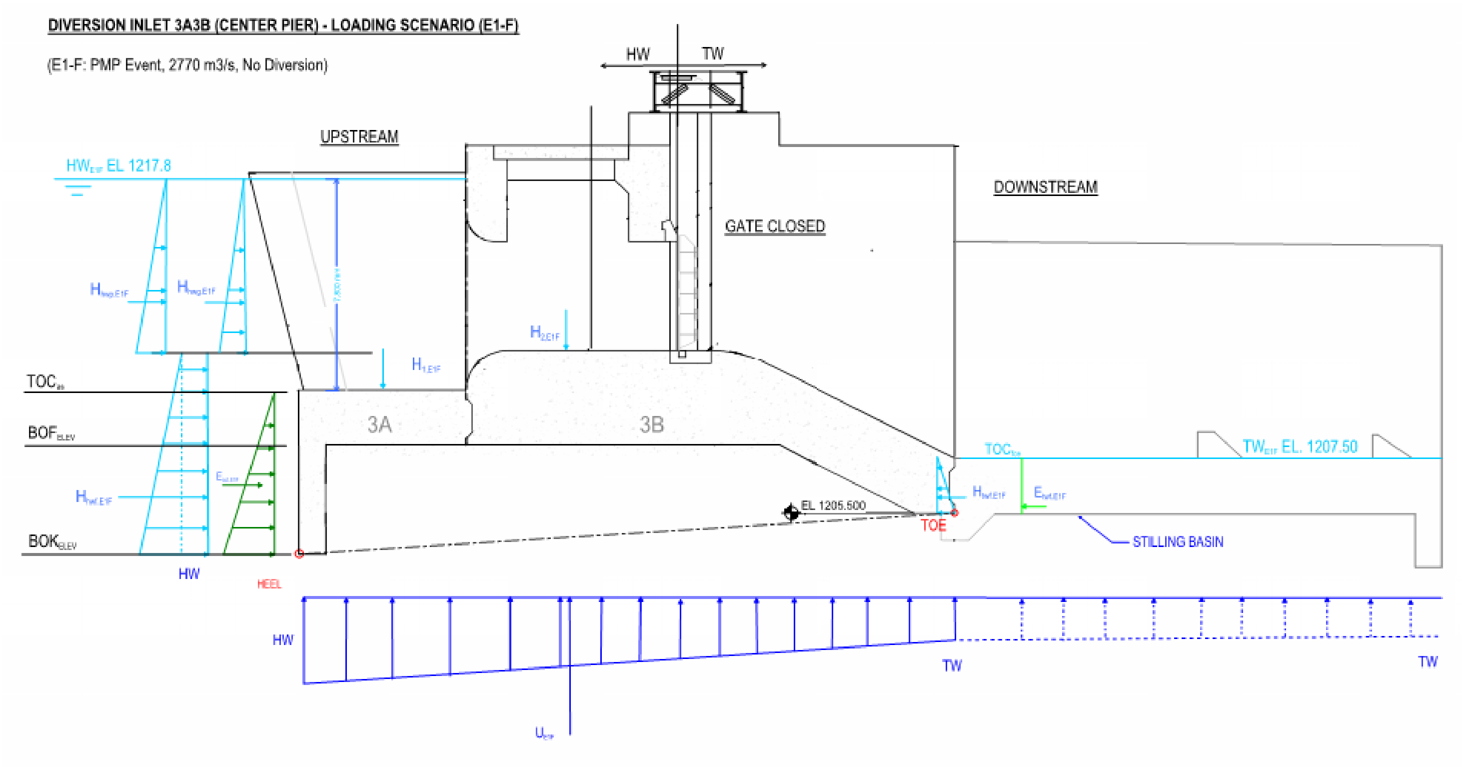
Summary of Extreme Flood Results (Only Report Controlling Load Case)

UN4 CASE

UN4 Event: Construction / Maintenance

Horiz Sliding Factor of Safety:	$FS_{HorizSliding.UN4} = 1.79$
Horiz Sliding Factor of Safety Check:	$FS_{HorizSliding.UN4.Check} = \text{"OKAY"}$
Sliding Factor of Safety:	$FS_{InclinedISlidingUN4} = 8.2$
Sliding Factor of Safety Check:	$FS_{InclinedSliding.UN4.check} = \text{"OKAY "}$
Eccentricity:	$e_{UN4} = 0.53\,m$
Eccentricity Check:	$e_{check.UN4} = \text{"Okay"}$
Bearing Pressure At Heel on Inclined Plane:	$\sigma_{heel.UN4} = 136.2 \cdot \frac{kN}{m^2}$
Bearing Pressure At Heel Check:	$\sigma_{heel.UN4.check} = \text{"Okay"}$
Bearing Pressure At Toe on Inclined Plane:	$\sigma_{toe.UN4} = 169.3 \cdot \frac{kN}{m^2}$
Bearing Pressure At Toe Check:	$\sigma_{toe.UN4.check} = \text{"Okay"}$
Flotation Factor of Safety	$FS_{Flotation.UN4} = 2.3$
Flotation Factor of Safety Check:	$FS_{Flotation.UN4.check} = \text{"OKAY "}$
Overturning Resultant Ratio	$Ratio_{Overturning.UN4} = 0.49$
Overturning Stability Check	$Ratio_{Overturning.UN4.check} = \text{"Okay"}$

E1 DESIGN CASE



ACCEPTANCE PARAMETERS

Required Factor of Safety for Sliding: $FS_{req.E1.sl} := 1.1$ (Without Cohesion) (Section 8.1, Design Criteria)

Resultant Within Middle Half of Base: $e \le \frac{L_b}{4} \wedge e \ge \frac{-L_b}{4}$

Allowable Rock Bearing Pressure: $\sigma_{allow.E1} := 1740.0 \cdot \frac{kN}{m^2}$ (Section 5.2, Design Criteria)

Required Factor of Safety for Flotation: $FS_{req.E.flt} := 1.1$

Overturning Min Required Resultant Ratio: $\frac{X_{R.E}}{Horizontal\_Width\_of\_Base} > 0.167$ (Min.50% Base in Compression)

INPUT PARAMETERS

E1 CASE

Headwater Elevation: $HW_{E1} := 1217.80m$

Tailwater Elevation: $TW_{E1} := 1207.50m$

(Water Elevations based on Diversion Structure 2D Hydraulic Model Results. See page 7 and Section 8.2, Design Criteria)

Crest Water Elevation (No Diversion)

Chute Block Water Elevation (No Diversion)

Bottom of Key (Footing Heel) Elevation: $BOF_{elev} = 1204.00\,m$

Apron Slab Top of Concrete Elevation at Edge of Slab: $TOC_{as} = 1210.00\,m$

Fixed Crest Top of Concrete Elevation at Downstream Face: $TOC_{fce} = 1207.50\,m$

Fixed Crest Top of Concrete Elevation at Center of Footing: $TOC_{fcc} = 1211.50\,m$

VERTICAL LIFT GATE

Lift Gate Position per Hydraulic Criteria: $poss_{E1} := 1$

poss = 1 if gate is closed
0 if gate is open

DEAD LOAD SUMMATION:

$$Gate_{R.E1} := \begin{cases} 1 & \text{if } poss_{E1} = 0 \\ 0.45 & \text{otherwise} \end{cases} = 0.45$$

Monolith Reaction for Wheel Gate

$$\Sigma V_{DL.E1} := D_{conc} + Gate_{R.E1}\, D_{Gate} = 52443.8\cdot kN$$

$$\Sigma M_{DL.E1} := D_{conc}\cdot X_{conc.loc} + Gate_{R.E1}\cdot D_{Gate}\cdot X_{gate} = 651119.6\cdot kN\cdot m$$

LATERAL WATER LOADS

E1 CASE

HEADWATER (DRIVING):

Water Depth on Pier at Heel: $D_{hwp.E1} := HW_{E1} - TOC_{as} = 7.80\,m$

Water Load Unit Width on Pier: $w_{hwp.E1} := w_{pn} = 4.00\,m$

Total Horizontal Water Load on Pier: $H_{hwp.E1} := \dfrac{-\left(\gamma_w \cdot D_{hwp.E1}^{\;2}\right)}{2} \cdot w_{hwp.E1} = -1193.7 \cdot kN$

Apply Total Pier Water Load at: $H_{hwp.E1.loc} := \dfrac{D_{hwp.E1}}{3} + \left(TOC_{as} - BOF_{toe}\right) = 7.10\,m$

Point O @ TOE: BOFtoe = EL.1205.5

Water Depth Above Fixed Crest at Gate: $D_{hwg.E1} := HW_{E1} - TOC_{fcc} = 6.3\,m$

Water Load Unit Width on Gate $w_{hwg.E1} := 2 \cdot \dfrac{20.00}{2}\,m = 20.00\,m$

Apply Load to Gate?: $poss_{E1} = 1$

poss = 1 if gate is closed
0 if gate is open

Total Horizontal Water Load on Gate: $H_{hwg.E1} := \dfrac{-\left(\gamma_w \cdot D_{hwg.E1}^{\;2}\right)}{2} \cdot w_{hwg.E1} \cdot poss_{E1} = -3893.6 \cdot kN$

Apply Total Gate Water Load at: $H_{hwg.E1.loc} := \dfrac{D_{hwg.E1}}{3} + \left(TOC_{fcc} - BOF_{toe}\right) = 8.10\,m$

Water Depth at Heel: $D_{hwf.E1} := HW_{E1} - BOF_{elev} = 13.80\,m$

Water Load Unit With on Footing: $w_{hw.E1} := w_b$

Water Load at Bottom of Footing: $H_{hwf.E1.1} := -\left(\gamma_w \cdot D_{hwf.E1}\right) \cdot w_{hw.E1} = -1759.9 \dfrac{1}{m} \cdot kN$

Water Load at Top of Footing: $H_{hwf.E1.2} := -\left(\gamma_w \cdot D_{hwg.E1}\right) \cdot w_{hw.E1} = -803.4 \dfrac{1}{m} \cdot kN$

Total Horizontal Water Load on Footing: $H_{hwf.E1} := \dfrac{\left(H_{hwf.E1.1} + H_{hwf.E1.2}\right) \cdot \left(D_{hwf.E1} - D_{hwg.E1}\right)}{2} = -9612.6 \cdot kN$

Apply Total Footing Water Load at:

$$H_{hwf.E1.loc} := \frac{\left[H_{hwf.E1.2} \cdot \dfrac{\left(TOC_{fcc} - BOF_{elev}\right)^2}{2} + \dfrac{\left(H_{hwf.E1.1} - H_{hwf.E1.2}\right)}{2} \cdot \dfrac{\left(TOC_{fcc} - BOF_{elev}\right)^2}{3}\right]}{\dfrac{\left(H_{hwf.E1.2} + H_{hwf.E1.1}\right) \cdot \left(TOC_{fcc} - BOF_{elev}\right)}{2}} - \left(BOF_{toe} - BOF_{elev}\right) = 1.78\,m$$

Converting horizontal force resultant from HEEL calculation to Point-O@TOE

LATERAL WATER LOADS (cont.)

E1 CASE

TAILWATER (RESISTING):

Water Depth at toe: $D_{tw.E1} := TW_{E1} - BOF_{elev} = 3.50\,m$

Water Load Unit Width: $W_{twf.E1} := W_b$

Total Horizontal Tailwater Load on Footing under Gate Openings, i.e., excluding Pier

Resisting Water on Rear Face of Monolith, i.e., bottom of heel elevation:

$COND_{E1} := poss_{E1} = 0 \wedge TW_{E1} \ge TOC_{fcc}$

$$H_{twf.E1} := \begin{cases} \dfrac{\gamma_w \cdot D_{tw.E1}^{\;2}}{2} \cdot \left(W_{twf.E1} - w_{pdg}\right) & \text{if } poss_{E1} = 1 \\ \dfrac{\gamma_w \cdot D_{tw.E1}^{\;2}}{2} \cdot \left(W_{twf.E1} - w_{pdg}\right) & \text{if } poss_{E1} = 0 \wedge TW_{E1} \le TOC_{fcc} \\ \gamma_w \cdot \left[\dfrac{D_{tw.E1}}{2} + \dfrac{\left(TW_{E1} - TOC_{fcc}\right)}{2}\right] \cdot \left(TOC_{fcc} - BOF_{elev}\right) \cdot \left(W_{twf.E1} - w_{pdg}\right) & \text{if } COND_{E1} \end{cases} = 540.8 \cdot kN$$

Apply Footing Tailwater Load within Gate Openings at:

$$H_{twf.E1.loc} := \begin{cases} \dfrac{D_{tw.E1}}{3} - \left(BOF_{toe} - BOF_{elev}\right) & \text{if } poss_{E1} = 1 \\ \dfrac{D_{tw.E1}}{3} - \left(BOF_{toe} - BOF_{elev}\right) & \text{if } poss_{E1} = 0 \wedge TW_{E1} \le TOC_{fcc} \\ \dfrac{\left(TOC_{fcc} - BOF_{elev}\right)^2 \cdot \left[\dfrac{\left(TW_{E1} - TOC_{fcc}\right)}{2} + \dfrac{\left(\left(TOC_{fcc} - BOF_{elev}\right)\right)}{6}\right]}{\left(TOC_{fcc} - BOF_{elev}\right)\left[\left(TW_{E1} - TOC_{fcc}\right) + \dfrac{\left(TOC_{fcc} - BOF_{elev}\right)}{2}\right]} - \left(BOF_{toe} - BOF_{elev}\right) & \text{if } COND_{E1} \end{cases} = -0.33 \cdot m$$

Total Horizontal Tailwater Load on Pier:

$$H_{twp.E1} := \frac{\gamma_w \cdot D_{tw.E1}^{\;2}}{2} \cdot w_{pdg} = 240.3 \cdot kN$$

Apply Horizontal Tailwater Load on Pier at:

$$H_{twp.E1.loc} := \frac{D_{tw.E1}}{3} - \left(BOF_{toe} - BOF_{elev}\right) = -0.33 \cdot m$$

$$\Sigma H_{Water.E1} := H_{hwp.E1} + H_{hwg.E1} + H_{hwf.E1} + H_{twf.E1} + H_{twp.E1} = -13918.7 \cdot kN$$

$$\Sigma M_{HWater.E1} := H_{hwp.E1} \cdot H_{hwp.E1.loc} + H_{hwg.E1} \cdot H_{hwg.E1.loc} + H_{hwf.E1} \cdot H_{hwf.E1.loc} \cdots + H_{twf.E1} \cdot H_{twf.E1.loc} + H_{twp.E1} \cdot H_{twp.E1.loc} = -57418.4 \cdot kN \cdot m$$

VERTICAL WATER LOADS

E1 CASE

HEADWATER:

Water Depth on top of fixed crest: $d_{hw.E1} := HW_{E1} - TOC_{as} = 7.80\,m$

Subtract Pier Volume:

$$S_{pn.E1} := \left[\frac{(A_{pnt} - A_{pnb})}{h_{pn}}\right] = 1.00 \cdot \frac{m^2}{m}$$

$$V_{pn.E1} := \frac{\left[(S_{pn.E1} \cdot d_{hw.E1} + A_{pnb}) + A_{pnb}\right]}{2} \cdot d_{hw.E1} = 182 \cdot m^3$$

Weight of Water (H1) on Approach Slab: $H_{1.E1} := (W_{hw.E1} \cdot d_{hw.E1} \cdot L_{as} - V_{pn.E1}) \cdot \gamma_w = 4382.2 \cdot kN$

Horiz. Moment Arm for H1 (from toe): $H_{1.E1.loc} := L_b - \frac{L_{as}}{2} = 21.10\,m$

Cross-sectional Area of Headwater Above Fixed Crest: $A_{fc.hw.E1} := 47.55m^2$ From Bluebeam Measurement

Volume of water Above Fixed Crest: $V_{fc.hw.E1} := \left[A_{fc.hw.E1} \cdot (W_{hw.E1} - w_{pn})\right] = 427.9 \cdot m^3$

Weight of Water (H2) on Fixed Crest: $H_{2.E1} := (V_{fc.hw.E1}) \cdot \gamma_w = 4198.2 \cdot kN$

Horiz. Moment Arm for H2 (from toe): $H_{2.E1.loc} := X_{pug} = 14.25\,m$

TAILWATER:

Slope of Crest from D/S of Gate to edge of Stilling Basin: $S_{f.E1} := \frac{(TOC_{fcc} - TOC_{fce})}{8.00m} = 0.500$

Height of Tailwater Above Stilling Basin:

$$y_{E1} := \begin{cases} (TW_{E1} - TOC_{fce}) & \text{if } TW_{E1} \le TOC_{fcc} \\ (TOC_{fcc} - TOC_{fce}) & \text{otherwise} \end{cases}$$

$y_{E1} = 0.00\,m$

Horizontal Distance of Tailwater Above Sloped Portion of Crest: $x_{E1} := \frac{y_{E1}}{S_{f.E1}} = 0.00\,m$

Cross Sectional Area of Tailwater Above Sloped Portion of Crest: $A_{tw.E1} := \frac{(x_{E1} \cdot y_{E1})}{2} = 0\,m^2$

$= 0.00m^2$ if TW_{E1} is less than or equal to TOC_{fce}

Weight of Water (H3) Above Slope Portion of Crest:

$$H_{3.E1} := \begin{cases} (0.0kN) & \text{if } TW_{E1} \le TOC_{fce} \\ \left[A_{tw.E1} \cdot (W_{twf.E1} - w_{pdg})\right] \cdot \gamma_w & \text{if } TOC_{fcc} \ge TW_{E1} > TOC_{fce} \\ \left[A_{tw.E1} + Dist_{gate} \cdot (TW_{E1} - TOC_{fcc})\right] \cdot (W_{twf.E1} - w_{pdg}) \cdot \gamma_w & \text{if } TW_{E1} > TOC_{fcc} \end{cases}$$

Horiz. Moment Arm for H3 (from toe): $H_{3.E1} = 0.0 \cdot kN$

$$H_{3.E1.loc} := \begin{cases} (0.00m) & \text{if } TW_{E1} \le TOC_{fce} \\ \left(\frac{1}{3} \cdot x_{E1}\right) & \text{if } TOC_{fcc} \ge TW_{E1} > TOC_{fce} \\ \dfrac{\left[\frac{1}{2} \cdot x_{E1} \cdot y_{E1} \cdot \left(\frac{1}{3}\right) x_{E1} + (TW_{E1} - TOC_{fcc}) \cdot Dist_{gate} \cdot \left(\frac{Dist_{gate}}{2}\right)\right]}{\left(\frac{1}{2} x_{E1} \cdot y_{E1}\right) + (TW_{E1} - TOC_{fcc}) \cdot Dist_{gate}} & \text{if } TW_{E1} > TOC_{fcc} \end{cases}$$

$H_{3.E1.loc} = 0.00\,m$

UPLIFT AT INCLINED SLIDING PLANE

E1 CASE

Uplift pressure at Headwater: $U_{HW.E1} := D_{hwf.E1} \cdot \gamma_w = 135.38 \cdot \frac{kN}{m^2}$

Uplift pressure at D/S end of Stilling Basin: $U_{TW.E1} := D_{tw.E1} \cdot \gamma_w = 34.3 \cdot \frac{kN}{m^2}$

Length from U/S Face of Gate Structure to Toe of Block: effective drain, Lsb = 0*m $L_{overall} = 24.20\,m$ $L_{sb} = 0$

Length of Seepage per Line of Creep $L_{seepage} = 27.1\,m$

Difference between Uplift pressure at Headwater and Uplift Pressure at Toe of Stilling Basin: $U_{diffE1} := U_{HW.E1} - U_{TW.E1} = 101 \cdot \frac{kN}{m^2}$

Slope of difference between Uplift pressure at Headwater and Uplift Pressure at Toe of Stilling Basin: $U_{slopeE1} := \frac{U_{diffE1} - Key_d \cdot \gamma_w}{L_{overall}} = 3.57 \cdot \frac{kN}{m^2 \cdot m}$

$U_{seepageslopeE1} := \frac{U_{diffE1} - Key_d \cdot \gamma_w}{L_{seepage}}$

Tailwater Pressure at toe of Gate Structure: $U_{press.toe.gsE1} := U_{TW.E1} + L_{sb} \cdot U_{slopeE1} = 34.3 \cdot \frac{kN}{m^2}$

$$U_{pore.toe.E1} := U_{TW.E1} + U_{seepageslopeE1} \cdot L_{sb} = 34.3 \cdot \frac{kN}{m^2}$$

$$U_{pore.F.E1} := U_{pore.toe.E1} + U_{seepageslopeE1} \cdot L_{FG} = 39.1 \cdot \frac{kN}{m^2}$$

$$U_{pore.E.E1} := U_{pore.F.E1} - \left(BOF_{base} - BOF_{toe}\right) \cdot \gamma_w + U_{seepageslopeE1} \cdot L_{EF} = 35.1 \cdot \frac{kN}{m^2}$$

$$U_{pore.D.E1} := U_{pore.E.E1} + U_{seepageslopeE1} \cdot L_{DE} = 93.1 \cdot \frac{kN}{m^2}$$

$$U_{pore.C.E1} := U_{pore.D.E1} + \left(BOF_{base} - BOF_{elev}\right) \cdot \gamma_w + U_{seepageslopeE1} \cdot L_{CD} = 132.2 \cdot \frac{kN}{m^2}$$

Uniform uplift due to Tailwater: (rectangular portion) $U_{A.E1} := U_{press.toe.gsE1} \cdot L_b \cdot W_b \cdot -1 = -10801.8 \cdot kN$

Moment Arm for Uplift UA from Toe of Gate Structure: $L_{A.E1} := \frac{L_b}{2} = 12.10\,m$

Uplift - Linear Decrease from HW to TW: (triangular portion) $U_{B.E1} := \frac{1}{2} \cdot \left(U_{HW.E1} - U_{press.toe.gsE1}\right) \cdot L_b \cdot W_b \cdot -1 = -15894.1 \cdot kN$

Moment Arm for Uplift UB from Toe of Gate Structure: $L_{B.E1} := \frac{2}{3} \cdot L_b = 16.13\,m$

Total Resultant Uplift force: $U_{E1} := U_{A.E1} + U_{B.E1} = -26695.9 \cdot kN$

Resultant Location from Toe: $U_{E1.loc} := \frac{U_{A.E1} \cdot L_{A.E1} + U_{B.E1} \cdot L_{B.E1}}{U_{A.E1} + U_{B.E1}} = 14.50\,m$

$$\Sigma V_{water.E1} := H_{1.E1} + H_{2.E1} + H_{3.E1} + U_{E1} = -18115.5 \cdot kN$$

$$\Sigma M_{Vwater.E1} := H_{1.E1} \cdot H_{1.E1.loc} + H_{2.E1} \cdot H_{2.E1.loc} + H_{3.E1} \cdot H_{3.E1.loc} + U_{E1} \cdot U_{E1.loc} = -234837.6 \cdot kN \cdot m$$

Uplift as per Line of Creep Method (Flotation and Overturning) — E1 CASE

$$Uplift_{BC.E1} := \frac{-1}{2} \cdot W_b \cdot \left(U_{HW.E1} + U_{pore.C.E1}\right) \cdot L_{BC} = -1739.2 \cdot kN$$

$$Uplift_{CD.E1} := 0$$

$$Uplift_{DE.E1} := \frac{-1}{2} \cdot W_b \cdot \left(U_{pore.D.E1} + U_{pore.E.E1}\right) \cdot L_{DE} = -15176.5 \cdot kN$$

$$Uplift_{EF.E1} := \frac{-1}{2} \cdot W_b \cdot \left(U_{pore.E.E1} + U_{pore.F.E1}\right) \cdot L_{EF} = -1615.2 \cdot kN$$

$$Uplift_{FG.E1} := \frac{-1}{2} \cdot W_b \cdot \left(U_{pore.F.E1} + U_{pore.toe.E1}\right) \cdot L_{FG} = -716.1 \cdot kN$$

$$Uplift_{pore.E1} := Uplift_{BC.E1} + Uplift_{DE.E1} + Uplift_{EF.E1} + Uplift_{FG.E1} = -19247 \cdot kN$$

$$Uplift_{FG.E1.loc} := \frac{L_{FG}}{3} \cdot \frac{\left(2 \cdot U_{pore.F.E1} + U_{pore.toe.E1}\right)}{\left(U_{pore.F.E1} + U_{pore.toe.E1}\right)} = 0.77\,m$$

$$Uplift_{EF.E1.loc} := \frac{L_{EF}}{3} \cdot \frac{\left(2 \cdot U_{pore.E.E1} + U_{pore.F.E1}\right)}{\left(U_{pore.E.E1} + U_{pore.F.E1}\right)} + L_{FG} = 3.14\,m$$

$$Uplift_{DE.E1.loc} := \frac{L_{DE}}{3} \cdot \frac{\left(2 \cdot U_{pore.D.E1} + U_{pore.E.E1}\right)}{\left(U_{pore.D.E1} + U_{pore.E.E1}\right)} + L_{FG} + X_{EF} = 14.97\,m$$

$$Uplift_{BC.E1.loc} := \frac{L_{BC}}{3} \cdot \frac{\left(2 \cdot U_{HW.E1} + U_{pore.C.E1}\right)}{\left(U_{HW.E1} + U_{pore.C.E1}\right)} + L_{FG} + X_{EF} + L_{DE} = 23.21\,m$$

E1 CASE

SOIL LOADS

(CFEM 24.1)

Equivalent Fluid Pressure (EFP):

At rest lateral pressure coefficient: $K_o = 0.66$

At-rest Soil Pressure to Heel, EM1110--2-2502 Section 3-7

Lateral Driving Force (Headwater Side)

Depth of Fill at Heel: $t_{hf.E1} := TOC_{as} - BOF_{elev} = 6.00\,m$

At-Rest Soil Load: $E1_{drive.E1} := \frac{K_o \cdot t_{hf.E1}^{\,2}}{2} \cdot (\gamma_r - \gamma_w) \cdot W_b \cdot -1 = -1876.9 \cdot kN$

Acting at: $E1_{drive.loc.E1} := \frac{t_{hf.E1}}{3} - (BOF_{toe} - BOF_{elev}) = 0.50\,m$

Lateral Resisting Force (Tailwater Side)

Depth of Fill at Toe: $t_{tf.E1} := TOC_{fce} - BOF_{toe} = 2.00\,m$

At-Rest Soil Load: $E2_{resistE1} := \frac{K_o \cdot t_{tf.E1}^{\,2}}{2} \cdot (\gamma_r - \gamma_w) \cdot W_b = 208.5 \cdot kN$

$E2_{resistE1} := 0$

Acting at: $E2_{resistlocE1} := \frac{t_{tf.E1}}{3} = 0.67\,m$

(Expansion Joint to Stilling Basin, No Sediment in Gap)

$\Sigma H_{soil.E1} := E1_{drive.E1} + E2_{resistE1} = -1876.9 \cdot kN$

$\Sigma M_{soil.E1} := E1_{drive.E1} \cdot E1_{drive.loc.E1} + E2_{resistE1} \cdot E2_{resistlocE1} = -938.4 \cdot kN \cdot m$

ICE / IMPACT LOADS (CONSERVATIVELY ASSUME NO ICE LOADING ON DOWNSTREAM SIDE)

ICE / IMPACT LOADS NOT APPLIED TO THIS LOAD CASE

Static Impact Loading on Structure: $I_{S.E1} := 0.0 \frac{kN}{m}$ (Section 7.7, Design Criteria)

Static Impact load on Gates: $I_{G.E1} := 0.0 \frac{kN}{m}$ (Section 7.7, Design Criteria)

Impact Loading Unit Width on Structure: $W_{S.E1} := 4.00 m$

Impact Loading Unit Width on Gates: $W_{G.E1} := 2 \cdot \frac{20.00}{2} m = 20.00\,m$

Total Impact Load on Structure: $I_{E1} := (I_{S.E1} \cdot W_{S.E1} + I_{G.E1} \cdot W_{G.E1}) \cdot -1 = 0 \cdot kN$

Apply Ice load at: $I_{E1.loc} := (HW_{E1} - BOF_{toe} - 0.30m) = 12.00\,m$

$\Sigma H_{I.E1} := I_{E1} = 0 \cdot kN$

$\Sigma M_{I.E1} := I_{E1} \cdot I_{E1.loc} = 0 \cdot kN \cdot m$

SEISMIC LOAD (Not Applicable to this Load Case)

SUMMARY OF LOADS

E1 CASE

	Loads	Moment Arm
Dead Load of Concrete Structure:	$D_{conc} = 52182.8 \cdot kN$	$X_{conc.loc} = 12.43\,m$
Dead Load of Gate:	$D_{Gate} = 580.0 \cdot kN$	$X_{gate} = 9.75\,m$
Headwater Lateral Load on Pier:	$H_{hwp.E1} = -1193.7 \cdot kN$	$H_{hwp.E1.loc} = 7.10\,m$
Headwater Lateral Load on Gate:	$H_{hwg.E1} = -3893.6 \cdot kN$	$H_{hwg.E1.loc} = 8.10\,m$
Headwater Lateral Load on Footing:	$H_{hwf.E1} = -9612.6 \cdot kN$	$H_{hwf.E1.loc} = 1.78\,m$
Tailwater Lateral Load:	$H_{twf.E1} = 540.8 \cdot kN$	$H_{twf.E1.loc} = -0.33\,m$
Tailwater Lateral Load on Pier:	$H_{twp.E1} = 240.3 \cdot kN$	$H_{twp.E1.loc} = -0.33\,m$
Water Weight (HW) on Apron Slab:	$H_{1.E1} = 4382.2 \cdot kN$	$H_{1.E1.loc} = 21.10\,m$
Water Weight (HW) on Fixed Crest:	$H_{2.E1} = 4198.2 \cdot kN$	$H_{2.E1.loc} = 14.25\,m$
Water Weight (TW) on Fixed Crest:	$H_{3.E1} = 0.0 \cdot kN$	$H_{3.E1.loc} = 0.00\,m$
Uplift:	$U_{E1} = -26695.9 \cdot kN$	$U_{E1.loc} = 14.50\,m$
Upstream (driving) Lateral Soil Load:	$E1_{drive.E1} = -1876.9 \cdot kN$	$E1_{drive.loc.E1} = 0.50\,m$
Downstream (resisting) Lateral Soil Load:	$E2_{resistE1} = 0 \cdot kN$	$E2_{resistlocE1} = 0.67\,m$
Ice / Impact Load:	$I_{E1} = 0.0 \cdot kN$	$I_{E1.loc} = 12.00\,m$

STABILITY ASSESSMENT (SLIDNG, OVERTURNING AND BEARING):

E1 CASE

CHECK SLIDING ALONG HORIZONTAL PLANE THRU TOE,
IGNORING BEDROCK MOBILIZED BY STRUCTURAL HEEL KEY , OR VOID BEHIND KEY

Sum of Vertical Forces:

$\Sigma V_{E1} := \Sigma V_{DL.E1} + \Sigma V_{water.E1} = 34328.3 \cdot kN$

Sum of Horizontal Forces:

$\Sigma H_{E1} := \Sigma H_{Water.E1} + \Sigma H_{soil.E1} + \Sigma H_{I.E1} = -15795.6 \cdot kN$

Sliding Factor of Safety:

$$FS_{HorizSliding.E1} := \frac{\left(\tan_{\phi} \cdot \Sigma V_{E1}\right)}{\left|\Sigma H_{E1}\right|} = 1.06$$

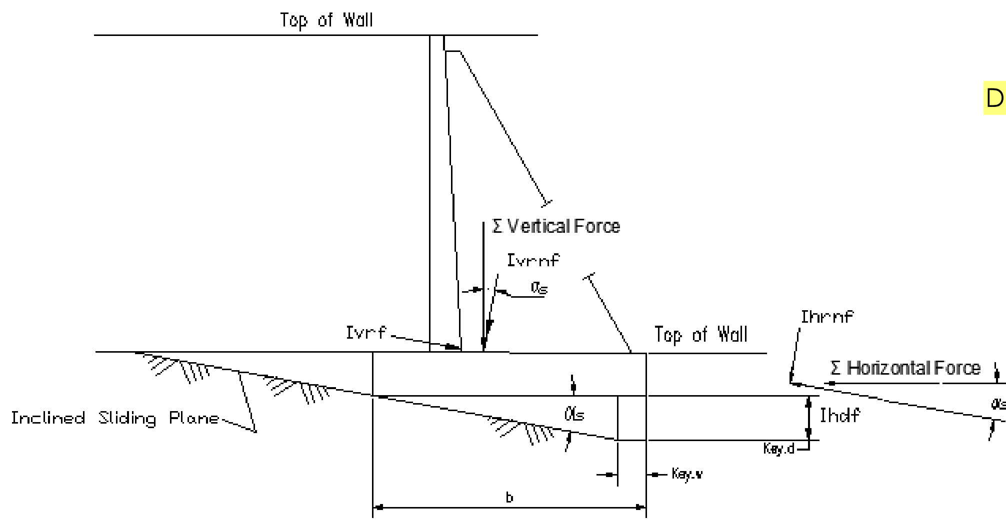
$FS_{HorizSliding.E1.Check} :=$ "OKAY" if $FS_{HorizSliding.E1} \geq FS_{req.E1.sl}$
"Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !" otherwise

$FS_{HorizSliding.E1.Check}$ = "Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !"

CHECK SLIDING ALONG INCLINED SLIDING PLANE FROM HEEL KEY TO TOE,
WITH BEDROCK MASS MOBILIZED BY REINFOCREDE CONCRETE KEY)

RESISTING SIDE

DRIVING SIDE



Ivrf=Inclined Resisting Force
Ivrnf=Inclined Resisting Normal Force
Ihrnf=Inclined Resisting Normal Force
Ihdf=Inclined Driving Force

HEEL

TOE

$$\alpha s := \operatorname{atan}\left(\frac{BOF_{toe} - BOF_{elev}}{L_b - Key_l}\right) = 0.13$$

as degrees= $\alpha s \cdot \left(\frac{180}{\pi}\right) = 7.63$

Resolve $\Sigma Vert_{E1}$ & $\Sigma Horiz_{E1}$

$$\Sigma V_{InclinedE1} := \cos(\alpha s) \cdot \left(\Sigma V_{E1} + V_{rs}\right) + \sin(\alpha s) \cdot \left|\Sigma H_{E1}\right| = 49223.2 \cdot kN$$

$$\Sigma H_{InclinedE1} := \cos(\alpha s) \cdot \left|\Sigma H_{E1}\right| - \sin(\alpha s) \cdot \left(\Sigma V_{E1} + V_{rs}\right) = 9344.2 \cdot kN$$

(With properly engineered reinforced concrete Key, horizontal sliding plane thru Toe is protected, critical sliding plane is relocated to the INCLINED SLIDING PLANE FROM HEEL KEY To TOE, Bedrock Mass above this examing plane is mobilized by reinforced concrete key and combined into Structural Wedge.)

Safety Factor for Sliding
Inclined Failure Plane

$$FS_{InclinedlSlidingE1} := \frac{\Sigma V_{InclinedE1} \cdot \tan\left(\phi_{rock} \cdot \frac{\pi}{180}\right)}{\left|\Sigma H_{InclinedE1}\right|} = 2.57$$

$FS_{InclinedSliding.check.E1} :=$ "OKAY " if $FS_{InclinedlSlidingE1} > FS_{req.E1.sl}$ = "OKAY "
"Revise Structure"" otherwise

$FS_{InclinedSliding.check.E1}$ = "OKAY "

E1 CASE

CHECK ECCENTRICITY ON INCLINED PLANE

Sum of the Moments:

$$\Sigma M_{rs.E1} := \Sigma M_{DL.E1} + \Sigma M_{HWater.E1} + \Sigma M_{Vwater.E1} + \Sigma M_{I.E1} + \Sigma M_{soil.E1} + V_{rs} \cdot L_{rs} = 542461 \cdot kN \cdot m$$

Eccentricity:

$$e_{E1} := \frac{L_{incline}}{2} - \frac{\Sigma M_{rs.E1}}{\Sigma V_{InclinedE1}} = 1.10\,m$$

Eccentricity Check:

$$e_{check.E1} := \begin{cases} \text{"Okay"} & \text{if } \left|e_{E1}\right| \le Ecc_{midhalf} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$e_{check.E1} = \text{"Okay"}$

Foundation Bearing Pressures on Inclined Plane:

Bearing Pressure at Heel:

$$\sigma_{heel.E1} := \frac{\Sigma V_{InclinedE1}}{\frac{A_b}{\cos(\alpha s)}} - \frac{\Sigma V_{E1} \cdot e_{E1}}{\frac{S_b}{\cos(\alpha s)^2}} = 125.8 \cdot \frac{kN}{m^2}$$

$$\sigma_{heel.E1.check} := \left(\begin{cases} \text{"Okay"} & \text{if } \sigma_{heel.E1} \le \sigma_{allow.E1} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} \right)$$

$\sigma_{heel.E1.check} = \text{"Okay"}$

Bearing Pressure at Toe:

$$\sigma_{toe.E1} := \frac{\Sigma V_{InclinedE1}}{\frac{A_b}{\cos(\alpha s)}} + \frac{\Sigma V_{InclinedE1} \cdot e_{E1}}{\frac{S_b}{\cos(\alpha s)^2}} = 197.1 \cdot \frac{kN}{m^2}$$

$$\sigma_{toe.E1.check} := \begin{cases} \text{"Okay"} & \text{if } \sigma_{toe.E1} \le \sigma_{allow.E1} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$\sigma_{toe.E1.check} = \text{"Okay"}$

CHECK FLOTATION

$$Uplift_{sliding.E1} := U_{E1} = -26695.9 \cdot kN$$

$$Uplift_{pore.E1} = -19247 \cdot kN$$

$$\left(Uplift_{E1}\right) := \min\left(Uplift_{pore.E1}, Uplift_{sliding.E1}\right)$$

(For conservative, taking maximum values)

$$FS_{Flotation.E1} := \frac{D_{conc} + D_{Gate} + H_{1.E1} + H_{2.E1} + H_{3.E1}}{\left|Uplift_{E1}\right|} = 2.3$$

$$FS_{Flotation.E1.check} := \begin{cases} \text{"OKAY "} & \text{if } FS_{Flotation.E1} > FS_{req.E.flt} \\ \text{"Revise Structure""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

MONOLITH OVERTURNING STABILITY ANALYSIS

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.
Assumptions are made in order to compute overturning stability of indetermine forces on monolith with key;
(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.
(b) The horizontal resisting force acting on the key, P.key, is that required for static equilibrium
(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1 $Ratio_{overturning.allow.Extreme} := 0.167$ Resultant within Middle Half

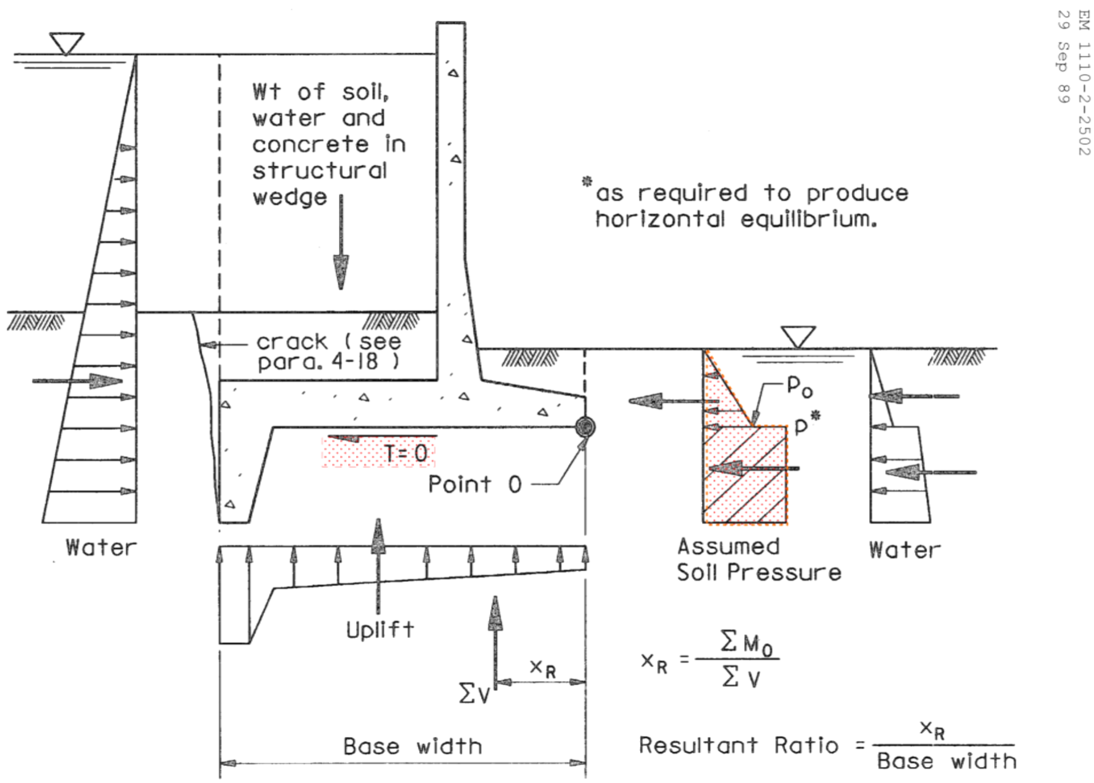


Figure 4-5. Forces for overturning analysis for wall with horizontal base and key

All Vertical Loads Applicable to Overturning Stability Analysis

Total Concrete Dead Loads:	$D_{conc} = 52182.8 \cdot kN$	at:	$X_{conc.loc} = 12.4\,m$
Dead Load of Gate:	$D_{Gate} = 580.0 \cdot kN$		$X_{gate} = 9.75\,m$
Water Weight (HW) on Apron Slab:	$H_{1.E1} = 4382.2 \cdot kN$		$H_{1.E1.loc} = 21.10\,m$
Water Weight (HW) on Fixed Crest:	$H_{2.E1} = 4198.2 \cdot kN$		$H_{2.E1.loc} = 14.25\,m$
Water Weight (TW) on Fixed Crest:	$H_{3.E1} = 0.0 \cdot kN$		$H_{3.E1.loc} = 0.00\,m$

Uplift Force from Sliding Analysis. Line of Creep Method applied at presumed inclined sliding line, Hand subtraction gravity effect to Base of Concrete by Archimedes Principle

$$U_{E1.loc.sliding} := \frac{U_{A.E1} \cdot L_{A.E1} + U_{B.E1} \cdot L_{B.E1} - A_{rs} \cdot w_{as} \cdot \gamma_w \cdot L_{rs}}{U_{A.E1} + U_{B.E1} - A_{rs} \cdot w_{as} \cdot \gamma_w} = 14.40\,m$$

$$U_{E1.sliding} := U_{E1} + A_{rs} \cdot w_{as} \cdot \gamma_w = -20801.4 \cdot kN$$

E1 CASE

Uplift for Overturning Analysis, Line of Creep Method. Pore pressure at base of Concrete

$Uplift_{pore.E1} = -19247 \cdot kN$

$$Uplift_{pore.E1.loc} := \frac{Uplift_{BC.E1} \cdot Uplift_{BC.E1.loc} + Uplift_{DE.E1} \cdot Uplift_{DE.E1.loc} + Uplift_{EF.E1} \cdot Uplift_{EF.E1.loc} + Uplift_{FG.E1} \cdot Uplift_{FG.E1.loc}}{Uplift_{pore.E1}}$$

$Uplift_{pore.E1.loc} = 14.2\,m$

Sum of All Water Load for Overturning Analysis

$\Sigma V_{water.E1.OT} := H_{1.E1} + H_{2.E1} + H_{3.E1} + Uplift_{pore.E1} = -10666.6 \cdot kN$

All Lateral Loads Applicable to Overturning Stability Analysis

Apply Load to Gate?: $poss_{E1} = 1$

poss = 1 if gate is closed
0 if gate is open

Headwater Lateral Load on Pier: $H_{hwp.E1} = -1193.7 \cdot kN$ $H_{hwp.E1.loc} = 7.10\,m$

Headwater Lateral Load on Gate: $H_{hwg.E1} = -3893.6 \cdot kN$ $H_{hwg.E1.loc} = 8.10\,m$

Headwater Lateral Load on Footing: $H_{hwf.E1} = -9612.6 \cdot kN$ $H_{hwf.E1.loc} = 1.78\,m$

Total Horizontal Tailwater Load on Pier: $H_{twp.E1} = 240.3 \cdot kN$ $H_{twp.E1.loc} = -0.33\,m$

Total Horizontal Tailwater Load on Footing under Gate Openings, i.e., excluding Pier: $H_{twf.E1} = 540.8 \cdot kN$ $H_{twf.E1.loc} = -0.33\,m$

Resisting Water on Rear Face of Monolith, i.e., bottom of heel elevation:

(Point O @ TOE: BOFtoe = EL.1205.5)

Ice / Impact Load: $I_{E1} = 0.0 \cdot kN$ at: $I_{E1.loc} = 12.00\,m$

Depth of Fill at Heel Side for Overturning Analysis:

$t_{hf.E1} := TOC_{as} - BOF_{toe} = 4.50\,m$

Driving Soil Load for overturning:

$$E1_{drive.E1} := \frac{K_o \cdot t_{hf.E1}^{\,2}}{2} \cdot (\gamma_r - \gamma_w) \cdot W_b \cdot -1 = -1055.7 \cdot kN$$

Acting at:

$$E1_{drive.loc.E1} := \frac{t_{hf.E1}}{3} = 1.50\,m$$

Downstream (resisting) Lateral Soil Load as required to produce horizontal equilibrium:

$$E2_{resistE1} := -1 \cdot \left(H_{hwp.E1} + H_{hwg.E1} + H_{hwf.E1} + H_{twp.E1} + H_{twf.E1} + I_{E1} + E1_{drive.E1}\right)$$

$E2_{resistE1} = 14974.5 \cdot kN$

Assumed Resisting Bedrock at middle of Key, passive soil pressure or lateral bearing contract joint at end of Monolith 3A3B

$E2_{resistlocE1} := E2_{resistlocU1} = 0.67\,m$

Overturning moment by Dead Loads about Point O @ Toe

$\Sigma M_{DL.E1} = 651119.6 \cdot kN \cdot m$

Overturning moment by Vertical Water Loads and Uplift, about Point O @ Toe

$$\Sigma M_{Vwater.E1.OT} := H_{1.E1} \cdot H_{1.E1.loc} + H_{2.E1} \cdot H_{2.E1.loc} + H_{3.E1} \cdot H_{3.E1.loc} + Uplift_{pore.E1} \cdot Uplift_{pore.E1.loc} = -120975.8 \cdot kN \cdot m$$

E1 CASE

Overturning moment by Lateral Hydrostatic Forces of Headwater Pool and Tailwater Pool,about Point O @ Toe

$\Sigma M_{HWater.E1} = -57418.4 \cdot kN \cdot m$

Overturning Moment by Impact/Ice Load, about Point O@ Toe

$\Sigma M_{I.E1} = 0$

Overturning moment by Lateral Soil Forces about Point O @ Toe

$\Sigma M_{soil.E1} := E1_{drive.E1} \cdot E1_{drive.loc.E1} + E2_{resistE1} \cdot E2_{resistlocE1} = 8399.4 \cdot kN \cdot m$

Sum of the Overturning Moments about Point O @ Toe:

$$\Sigma M_{E1.OT} := \Sigma M_{DL.E1} + \Sigma M_{HWater.E1} + \Sigma M_{Vwater.E1.OT} + \Sigma M_{I.E1} + \Sigma M_{soil.E1} = 481125 \cdot kN \cdot m$$

Sum of Vertical Forces:

$$\Sigma V_{E1.OT} := \Sigma V_{DL.E1} + \Sigma V_{water.E1.OT} = 41777.2 \cdot kN$$

Distance X_R: EM 1110-2-2502 Eq.4-1

$$X_{R.E1} := \frac{\Sigma M_{E1.OT}}{\Sigma V_{E1.OT}} = 11.5 m$$

Overturning Resultant Ratio

$$Ratio_{Overturning.E1} := \frac{X_{R.E1}}{L_b} = 0.48$$

EM 1110-2-2502

Table 4-1

Retaining Wall Stability Criteria

Loading Condition	Sliding Factor of Safety, FS	Shear Strength Test Required: Soil Foundation	Shear Strength Test Required: Rock Foundation[3]	Overturning Criteria Minimum Base Area in Compression: Soil Foundation	Overturning Criteria Minimum Base Area in Compression: Rock Foundation
Usual	1.5	(Q &/or S)[2,1]	Direct shear	100%[4]	75%[4]
Unusual	1.33	(Q &/or S)[2,1]	Direct shear	75%[4]	50%[4]
Earthquake	1.1	(Q)	Direct shear	Resultant within base	Resultant within base

Overturning Stability Check

$$Ratio_{Overturning.E1.check} := \begin{cases} \text{"Okay"} & \text{if } Ratio_{Overturning.E1} \ge Ratio_{overturning.allow.Extreme} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$$Ratio_{Overturning.E1.check} = \text{"Okay"}$$

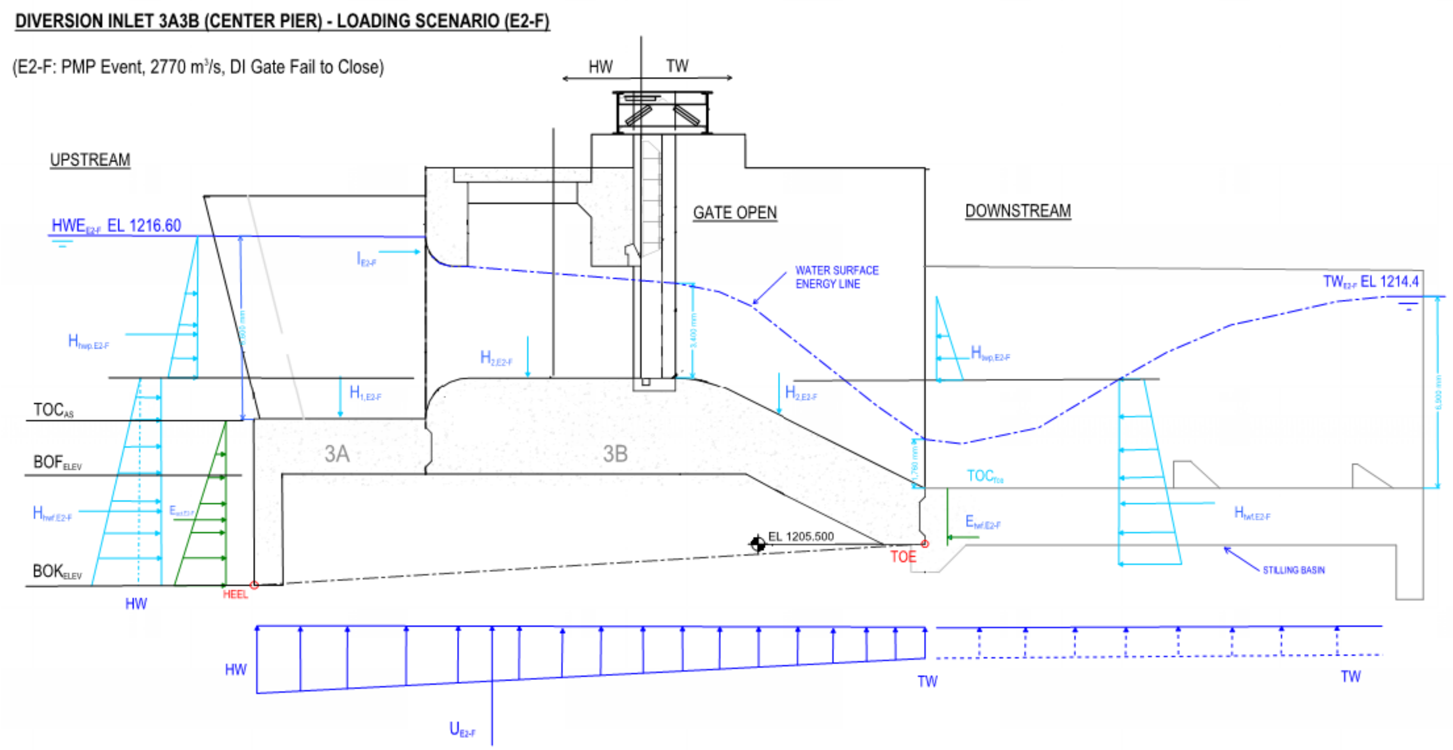
Summary of Extreme Flood Results (Only Report Controlling Load Case)

E1 CASE

E1 Event: PMF without Diversion

Horiz Sliding Factor of Safety:	$FS_{HorizSliding.E1} = 1.06$
Horiz Sliding Factor of Safety Check:	$FS_{HorizSliding.E1.Check}$ = "Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !"
Sliding Factor of Safety:	$FS_{InclinedlSlidingE1} = 2.6$
Sliding Factor of Safety Check:	$FS_{InclinedSliding.check.E1}$ = "OKAY "
Eccentricity:	$e_{E1} = 1.10\,m$
Eccentricity Check:	$e_{check.E1}$ = "Okay"
Bearing Pressure At Heel on Inclined Plane:	$\sigma_{heel.E1} = 125.8 \cdot \frac{kN}{m^2}$
Bearing Pressure At Heel Check:	$\sigma_{heel.E1.check}$ = "Okay"
Bearing Pressure At Toe on Inclined Plane:	$\sigma_{toe.E1} = 197.1 \cdot \frac{kN}{m^2}$
Bearing Pressure At Toe Check:	$\sigma_{toe.E1.check}$ = "Okay"
Flotation Factor of Safety	$FS_{Flotation.E1} = 2.3$
Flotation Factor of Safety Check:	$FS_{Flotation.E1.check}$ = "OKAY "
Overturning Resultant Ratio	$Ratio_{Overturning.E1} = 0.48$
Overturning Stability Check	$Ratio_{Overturning.E1.check}$ = "Okay"

E2 DESIGN CASE



ACCEPTANCE PARAMETERS

Required Factor of Safety for Sliding:	$FS_{req.E2.sl} := 1.1$	(Without Cohesion) (Section 8.1, Design Criteria)
Resultant Within Middle Half of Base:	$e \le \frac{L_b}{4} \wedge e \ge \frac{-L_b}{4}$	
Allowable Rock Bearing Pressure:	$\sigma_{allow.E2} := 1740.0 \cdot \frac{kN}{m^2}$	(Section 5.2, Design Criteria)
Required Factor of Safety for Flotation:	$FS_{req.E.flt} = 1.1$	
Overturning Min Required Resultant Ratio:	$\frac{X_{R.E}}{Horizontal\_Width\_of\_Base} > 0.167$	

INPUT PARAMETERS **E2 CASE**

Headwater Elevation: $HW_{E2} := 1216.60m$

Tailwater Elevation: $TW_{E2} := 1214.40m$

(Water Elevations based on Diversion Structure 2D Hydraulic Model Results. See page 7 and Section 8.2, Design Criteria)

Crest Water Elevation, EL.1214.90 $CrestW_{E2} := 3.4 \cdot m$

Chute Block Water Elevation EL.1209.26 $ChuteW_{E2} := 1.76 \cdot m$ $TW_{E2} := TOC_{fce} + ChuteW_{E2} = 1209.3\,m$

Bottom of Key (Footing Heel) Elevation: $BOF_{elev} = 1204.00\,m$

Apron Slab Top of Concrete Elevation at Edge of Slab: $TOC_{as} = 1210.00\,m$

Fixed Crest Top of Concrete Elevation at Downstream Face: $TOC_{fce} = 1207.50\,m$

Fixed Crest Top of Concrete Elevation at Center of Footing: $TOC_{fcc} = 1211.50\,m$

VERTICAL LIFT GATE

Lift Gate Position per Hydraulic Criteria $poss_{E2} := 0$

poss = 1 if gate is closed
0 if gate is open

DEAD LOAD SUMMATION:

$$Gate_{R.E2} := \begin{cases} 1 & \text{if } poss_{E2} = 0 \\ 0.45 & \text{otherwise} \end{cases}$$

Monolith Reaction for Wheel Gate

$$\Sigma V_{DL.E2} := D_{conc} + Gate_{R.E2} D_{Gate} = 52762.8 \cdot kN$$

$$\Sigma M_{DL.E2} := D_{conc} \cdot X_{conc.loc} + Gate_{R.E2} \cdot D_{Gate} \cdot X_{gate} = 654229.9 \cdot kN \cdot m$$

LATERAL WATER LOADS

E2 CASE

HEADWATER (DRIVING):

Water Depth on Pier at Heel: $D_{hwp.E2} := HW_{E2} - TOC_{as} = 6.60\,m$

Water Load Unit Width on Pier: $W_{hwp.E2} := w_{pn} = 4.00\,m$

Total Horizontal Water Load on Pier: $H_{hwp.E2} := \frac{-\left(\gamma_w \cdot D_{hwp.E2}{}^2\right)}{2} \cdot W_{hwp.E2} = -854.6 \cdot kN$

Apply Total Pier Water Load at: $H_{hwp.E2.loc} := \frac{D_{hwp.E2}}{3} + \left(TOC_{as} - BOF_{toe}\right) = 6.70\,m$

Water Depth Above Fixed Crest at Gate: $D_{hwg.E2} := HW_{E2} - TOC_{fcc} = 5.1\,m$

Water Load Unit Width on Gate $W_{hwg.E2} := 2 \cdot 10.00m = 20.00\,m$

Apply Load to Gate?: $poss_{E2} = 0$

poss = 1 if gate is closed
0 if gate is open

Total Horizontal Water Load on Gate: $H_{hwg.E2} := \frac{-\left(\gamma_w \cdot D_{hwg.E2}{}^2\right)}{2} \cdot W_{hwg.E2} \cdot poss_{E2} = 0 \cdot kN$

Apply Total Gate Water Load at: $H_{hwg.E2.loc} := \frac{D_{hwg.E2}}{3} + \left(TOC_{fcc} - BOF_{toe}\right) = 7.70\,m$

Water Depth at Heel: $D_{hwf.E2} := HW_{E2} - BOF_{elev} = 12.60\,m$

Water Load Unit With on Footing: $W_{hw.E2} := W_b$

Water Load at Bottom of Footing: $H_{hwf.E2.1} := -\left(\gamma_w \cdot D_{hwf.E2}\right) \cdot W_{hw.E2} = -1606.9 \frac{1}{m} \cdot kN$

Water Load at Top of Footing: $H_{hwf.E2.2} := -\left(\gamma_w \cdot D_{hwg.E2}\right) \cdot W_{hw.E2} = -650.4 \frac{1}{m} \cdot kN$

Total Horizontal Water Load on Footing: $H_{hwf.E2} := \frac{\left(H_{hwf.E2.1} + H_{hwf.E2.2}\right) \cdot \left(D_{hwf.E2} - D_{hwg.E2}\right)}{2} = -8464.8 \cdot kN$

Apply Total Footing Water Load at:

$$H_{hwf.E2.loc} := \frac{\left[H_{hwf.E2.2} \cdot \frac{\left(TOC_{fcc} - BOF_{elev}\right)^2}{2} + \frac{\left(H_{hwf.E2.1} - H_{hwf.E2.2}\right)}{2} \cdot \frac{\left(TOC_{fcc} - BOF_{elev}\right)^2}{3}\right]}{\frac{\left(H_{hwf.E2.2} + H_{hwf.E2.1}\right) \cdot \left(TOC_{fcc} - BOF_{elev}\right)}{2}} - \left(BOF_{toe} - BOF_{elev}\right) = 1.72\,m$$

Converting horizontal force resultant from HEEL calculation to Point-O@TOE

LATERAL WATER LOADS (cont.)

E2 CASE

TAILWATER (RESISTING):

Water Depth at toe: $D_{tw.E2} := TW_{E2} - BOF_{elev} = 5.26\,m$

Water Load Unit Width: $W_{twf.E2} := W_b$

Total Horizontal Tailwater Load on Footing under Gate Openings, i.e., excluding Pier

Resisting Water on Rear Face of Monolith, i.e., bottom of heel elevation:

$COND_{E2} := poss_{E2} = 0 \wedge TW_{E2} \geq TOC_{fcc}$

$$H_{twf.E2} := \begin{cases} \dfrac{\gamma_w \cdot D_{tw.E2}^{\,2}}{2} \cdot \left(W_{twf.E2} - w_{pdg}\right) & \text{if } poss_{E2} = 1 \\ \dfrac{\gamma_w \cdot D_{tw.E2}^{\,2}}{2} \cdot \left(W_{twf.E2} - w_{pdg}\right) & \text{if } poss_{E2} = 0 \wedge TW_{E2} \leq TOC_{fcc} \\ \gamma_w \cdot \left[\dfrac{D_{tw.E2}}{2} + \dfrac{\left(TW_{E2} - TOC_{fcc}\right)}{2}\right] \cdot \left(TOC_{fcc} - BOF_{elev}\right) \cdot \left(W_{twf.E2} - w_{pdg}\right) & \text{if } COND_{E2} \end{cases} = 1221.4 \cdot kN$$

Apply Footing Tailwater Load within Gate Openings at:

$$H_{twf.E2.loc} := \begin{cases} \dfrac{D_{tw.E2}}{3} - \left(BOF_{toe} - BOF_{elev}\right) & \text{if } poss_{E2} = 1 \\ \dfrac{D_{tw.E2}}{3} - \left(BOF_{toe} - BOF_{elev}\right) & \text{if } poss_{E2} = 0 \wedge TW_{E2} \leq TOC_{fcc} \\ \dfrac{\gamma_w \cdot \left[\left(TW_{E2} - TOC_{fcc}\right) \cdot \dfrac{\left(TOC_{fcc} - BOF_{elev}\right)^2}{2} + \dfrac{\left(TOC_{fcc} - BOF_{elev}\right)^3}{6}\right] \cdot W_{twf.E2}}{\gamma_w \left[\left(TW_{E2} - TOC_{fcc}\right) \cdot \left(TOC_{fcc} - BOF_{elev}\right) + \dfrac{\left(TOC_{fcc} - BOF_{elev}\right)^2}{2}\right] \cdot W_{twf.E2}} - \left(BOF_{toe} - BOF_{elev}\right) & \text{if } COND_{E2} \end{cases} = 0.25 \cdot m$$

Total Horizontal Tailwater Load on Pier:

$$H_{twp.E2} := \frac{\gamma_w \cdot D_{tw.E2}^{\,2}}{2} \cdot w_{pdg} = 542.8 \cdot kN$$

Apply Horizontal Tailwater Load on Pier at:

$$H_{twp.E2.loc} := \frac{D_{tw.E2}}{3} - \left(BOF_{toe} - BOF_{elev}\right) = 0.25 \cdot m$$

$$\Sigma H_{Water.E2} := H_{hwp.E2} + H_{hwg.E2} + H_{hwf.E2} + H_{twf.E2} + H_{twp.E2} = -7555.2 \cdot kN$$

$$\Sigma M_{HWater.E2} := H_{hwp.E2} \cdot H_{hwp.E2.loc} + H_{hwg.E2} \cdot H_{hwg.E2.loc} + H_{hwf.E2} \cdot H_{hwf.E2.loc} \cdots + H_{twf.E2} \cdot H_{twf.E2.loc} + H_{twp.E2} \cdot H_{twp.E2.loc} = -19841.5 \cdot kN \cdot m$$

VERTICAL WATER LOADS

E2 CASE

HEADWATER:

Water Depth on top of fixed crest: $d_{hw.E2} := HW_{E2} - TOC_{as} = 6.60\,m$

Subtract Pier Volume:

$$S_{pn.E2} := \left[\frac{\left(A_{pnt} - A_{pnb}\right)}{h_{pn}}\right] = 1.00 \cdot \frac{m^2}{m}$$

$$V_{pn.E2} := \frac{\left[\left(S_{pn.E2} \cdot d_{hw.E2} + A_{pnb}\right) + A_{pnb}\right]}{2} \cdot d_{hw.E2} = 150 \cdot m^3$$

Weight of Water (H1) on Approach Slab: $H_{1.E2} := \left(W_{hw.E2} \cdot d_{hw.E2} \cdot L_{as} - V_{pn.E2}\right) \cdot \gamma_w = 3746.9 \cdot kN$

Horiz. Moment Arm for H1 (from toe): $H_{1.E2.loc} := L_b - \frac{L_{as}}{2} = 21.10\,m$

Cross-sectional Area of
Headwater Above Fixed Crest: $A_{fc.hw.E2} := 30.44 m^2$

(From Bluebeam Measurement, Bound by Energy Line through Crest Water Elevation Crest and Chute Block Water Elevation Chute as defined above)

Volume of water Above Fixed Crest: $V_{fc.hw.E2} := \left[A_{fc.hw.E2} \cdot \left(W_{hw.E2} - w_{pn}\right)\right] = 274 \cdot m^3$

Weight of Water (H2) on Fixed Crest: $H_{2.E2} := \left(V_{fc.hw.E2}\right) \cdot \gamma_w = 2687.5 \cdot kN$

Horiz. Moment Arm for H2 (from toe): $H_{2.E2.loc} := 14.339 \cdot m = 14.34\,m$

TAILWATER:

Slope of Crest from
D/S of Gate to edge of Stilling Basin: $S_{f.E2} := S_{f.U1} = 0.500$

Height of Tailwater Above Stilling Basin: $y_{E2} := TW_{E2} - TOC_{fce} = 1.8\,m$

Cross Sectional Area of Tailwater
Above Sloped Portion of Crest: $A_{tw.E2} := 29.22 \cdot m \cdot m = 29.2\,m^2$ (From Bluebeam Measurement)

(From Bluebeam Measurement, Bound by Energy Line through Crest Water Elevation CrestW and Chute Block Water Elevation ChuteW as defined above)

Weight of Water (H3)
Above Slope Portion of Crest: $H_{3.E2} := \left[A_{tw.E2} \cdot \left(W_{twf.E2} - w_{pdg}\right)\right] \cdot \gamma_w$ $H_{3.E2} = 2579.8 \cdot kN$

Horiz. Moment Arm for H3 (from Toe): $H_{3.E2.loc} := 5.689 \cdot m$ (From Bluebeam Measurement)

UPLIFT AT INCLINED SLIDING PLANE

E2 CASE

Uplift pressure at Headwater: $U_{HW.E2} := D_{hwf.E2} \cdot \gamma_w = 123.61 \cdot \frac{kN}{m^2}$

Uplift pressure at D/S end of Stilling Basin: $U_{TW.E2} := D_{tw.E2} \cdot \gamma_w = 51.6 \cdot \frac{kN}{m^2}$

Length from U/S Face of Gate Structure to Toe of Block: effective drain, Lsb = 0*m $L_{overall} = 24.20\,m$ $L_{sb} = 0$

Length of Seepage per Line of Creep $L_{seepage} = 27.1\,m$

Difference between Uplift pressure at Headwater and Uplift Pressure at Toe of Stilling Basin: $U_{diffE2} := U_{HW.E2} - U_{TW.E2} = 72 \cdot \frac{kN}{m^2}$

Slope of difference between Uplift pressure at Headwater and Uplift Pressure at Toe of Stilling Basin: $U_{slopeE2} := \frac{U_{diffE2} - Key_d \cdot \gamma_w}{L_{overall}} = 2.37 \cdot \frac{kN}{m^2 \cdot m}$

$$U_{seepageslopeE2} := \frac{U_{diffE2} - Key_d \cdot \gamma_w}{L_{seepage}}$$

Tailwater Pressure at toe of Gate Structure: $U_{press.toe.gsE2} := U_{TW.E2} + L_{sb} \cdot U_{slopeE2} = 51.6 \cdot \frac{kN}{m^2}$

$$U_{pore.toe.E2} := U_{TW.E2} + U_{seepageslopeE2} \cdot L_{sb} = 51.6 \cdot \frac{kN}{m^2}$$

$$U_{pore.F.E2} := U_{pore.toe.E2} + U_{seepageslopeE2} \cdot L_{FG} = 54.8 \cdot \frac{kN}{m^2}$$

$$U_{pore.E.E2} := U_{pore.F.E2} - \left(BOF_{base} - BOF_{toe}\right) \cdot \gamma_w + U_{seepageslopeE2} \cdot L_{EF} = 47.1 \cdot \frac{kN}{m^2}$$

$$U_{pore.D.E2} := U_{pore.E.E2} + U_{seepageslopeE2} \cdot L_{DE} = 85.6 \cdot \frac{kN}{m^2}$$

$$U_{pore.C.E2} := U_{pore.D.E2} + \left(BOF_{base} - BOF_{elev}\right) \cdot \gamma_w + U_{seepageslopeE2} \cdot L_{CD} = 121.5 \cdot \frac{kN}{m^2}$$

Uniform uplift due to Tailwater: (rectangular portion) $U_{A.E2} := U_{press.toe.gsE2} \cdot L_b \cdot W_b \cdot -1 = -16233.5 \cdot kN$

Moment Arm for Uplift UA from Toe of Gate Structure: $L_{A.E2} := \frac{L_b}{2} = 12.10\,m$

Uplift - Linear Decrease from HW to TW: (triangular portion) $U_{B.E2} := \frac{1}{2} \cdot \left(U_{HW.E2} - U_{press.toe.gsE2}\right) \cdot L_b \cdot W_b \cdot -1 = -11326.4 \cdot kN$

Moment Arm for Uplift UB from Toe of Gate Structure: $L_{B.E2} := \frac{2}{3} \cdot L_b = 16.13\,m$

Total Resultant Uplift force: $U_{E2} := U_{A.E2} + U_{B.E2} = -27560 \cdot kN$

Resultant Location from Toe: $U_{E2.loc} := \frac{U_{A.E2} \cdot L_{A.E2} + U_{B.E2} \cdot L_{B.E2}}{U_{A.E2} + U_{B.E2}} = 13.76\,m$

$$\Sigma V_{water.E2} := H_{1.E2} + H_{2.E2} + H_{3.E2} + U_{E2} = -18545.8 \cdot kN$$

$$\Sigma M_{Vwater.E2} := H_{1.E2} \cdot H_{1.E2.loc} + H_{2.E2} \cdot H_{2.E2.loc} + H_{3.E2} \cdot H_{3.E2.loc} + U_{E2} \cdot U_{E2.loc} = -246887.3 \cdot kN \cdot m$$

Uplift as per Line of Creep Method (Flotation and Overturning)

E2 CASE

$$Uplift_{BC.E2} := \frac{-1}{2} \cdot W_b \cdot \left(U_{HW.E2} + U_{pore.C.E2}\right) \cdot L_{BC} = -1593.1 \cdot kN$$

$$Uplift_{CD.E2} := 0$$

$$Uplift_{DE.E2} := \frac{-1}{2} \cdot W_b \cdot \left(U_{pore.D.E2} + U_{pore.E.E2}\right) \cdot L_{DE} = -15724.3 \cdot kN$$

$$Uplift_{EF.E2} := \frac{-1}{2} \cdot W_b \cdot \left(U_{pore.E.E2} + U_{pore.F.E2}\right) \cdot L_{EF} = -2219 \cdot kN$$

$$Uplift_{FG.E2} := \frac{-1}{2} \cdot W_b \cdot \left(U_{pore.F.E2} + U_{pore.toe.E2}\right) \cdot L_{FG} = -1037.1 \cdot kN$$

$$Uplift_{pore.E2} := Uplift_{BC.E2} + Uplift_{DE.E2} + Uplift_{EF.E2} + Uplift_{FG.E2} = -20573.6 \cdot kN$$

$$Uplift_{FG.E2.loc} := \frac{L_{FG}}{3} \cdot \frac{\left(2 \cdot U_{pore.F.E2} + U_{pore.toe.E2}\right)}{\left(U_{pore.F.E2} + U_{pore.toe.E2}\right)} = 0.76\,m$$

$$Uplift_{EF.E2.loc} := \frac{L_{EF}}{3} \cdot \frac{\left(2 \cdot U_{pore.E.E2} + U_{pore.F.E2}\right)}{\left(U_{pore.E.E2} + U_{pore.F.E2}\right)} + L_{FG} = 3.13\,m$$

$$Uplift_{DE.E2.loc} := \frac{L_{DE}}{3} \cdot \frac{\left(2 \cdot U_{pore.D.E2} + U_{pore.E.E2}\right)}{\left(U_{pore.D.E2} + U_{pore.E.E2}\right)} + L_{FG} + X_{EF} = 14.48\,m$$

$$Uplift_{BC.E2.loc} := \frac{L_{BC}}{3} \cdot \frac{\left(2 \cdot U_{HW.E2} + U_{pore.C.E2}\right)}{\left(U_{HW.E2} + U_{pore.C.E2}\right)} + L_{FG} + X_{EF} + L_{DE} = 23.21\,m$$

E2 CASE

SOIL LOADS

Equivalent Fluid Pressure (EFP):

(CFEM 24.1)

At rest lateral pressure coefficient: $K_o = 0.66$

At-rest Soil Pressure to Heel, EM1110--2-2502 Section 3-7

Lateral Driving Force (Headwater Side)

Depth of Fill at Heel: $t_{hf.E2} := TOC_{as} - BOF_{elev} = 6.00\,m$

At-Rest Soil Load: $E2_{drive.E2} := \frac{K_o \cdot t_{hf.E2}^{2}}{2} \cdot (\gamma_r - \gamma_w) \cdot W_b \cdot -1 = -1876.9 \cdot kN$

Acting at: $E2_{drive.loc.E2} := \frac{t_{hf.E2}}{3} - (BOF_{toe} - BOF_{elev}) = 0.50\,m$

Lateral Resisting Force (Tailwater Side)

Depth of Fill at Toe: $t_{tf.E2} := TOC_{fce} - BOF_{toe} = 2.00\,m$

At-Rest Soil Load: $E2_{resistE2} := \frac{K_o \cdot t_{tf.E2}^{2}}{2} \cdot (\gamma_r - \gamma_w) \cdot W_b = 208.5 \cdot kN$ $\quad E2_{resistE2} := 0$

Acting at: $E2_{resistlocE2} := \frac{t_{tf.E2}}{3} = 0.67\,m$

(Expansion Joint to Stilling Basin, No Sediment in Gap)

$\Sigma H_{soil.E2} := E2_{drive.E2} + E2_{resistE2} = -1876.9 \cdot kN$

$\Sigma M_{soil.E2} := E2_{drive.E2} \cdot E2_{drive.loc.E2} + E2_{resistE2} \cdot E2_{resistlocE2} = -938.4 \cdot kN \cdot m$

ICE / IMPACT LOADS (CONSERVATIVELY ASSUME NO ICE LOADING ON DOWNSTREAM SIDE)

Static Impact Loading on Structure: $I_{S.E2} := 150.0 \frac{kN}{m}$ (Section 7.7, Design Criteria)

Static Impact load on Gates: $I_{G.E2} := 75 \frac{kN}{m}$ (Section 7.7, Design Criteria)

Impact Loading Unit Width on Structure: $W_{S.E2} := 4.00m$

Impact Loading Unit Width on Gates: $W_{G.E2} := 2 \cdot \frac{20.00}{2} m = 20.00\,m$

Total Impact Load on Structure: $I_{E2} := (I_{S.E2} \cdot W_{S.E2} + I_{G.E2} \cdot W_{G.E2}) \cdot -1 = -2100 \cdot kN$

Apply Ice load at: $I_{E2.loc} := (HW_{E2} - BOF_{toe} - 0.30m) = 10.80\,m$

$\Sigma H_{I.E2} := I_{E2} = -2100 \cdot kN$

$\Sigma M_{I.E2} := I_{E2} \cdot I_{E2.loc} = -22680 \cdot kN \cdot m$

SEISMIC LOAD (Not Applicable to this Load Case)

SUMMARY OF LOADS

E2 CASE

	Loads	Moment Arm
Dead Load of Concrete Structure:	$D_{conc} = 52182.8 \cdot kN$	$X_{conc.loc} = 12.43\,m$
Dead Load of Gate:	$D_{Gate} = 580.0 \cdot kN$	$X_{gate} = 9.75\,m$
Headwater Lateral Load on Pier:	$H_{hwp.E2} = -854.6 \cdot kN$	$H_{hwp.E2.loc} = 6.70\,m$
Headwater Lateral Load on Gate:	$H_{hwg.E2} = 0.0 \cdot kN$	$H_{hwg.E2.loc} = 7.70\,m$
Headwater Lateral Load on Footing:	$H_{hwf.E2} = -8464.8 \cdot kN$	$H_{hwf.E2.loc} = 1.72\,m$
Tailwater Lateral Load:	$H_{twf.E2} = 1221.4 \cdot kN$	$H_{twf.E2.loc} = 0.25\,m$
Tailwater Lateral Load on Pier:	$H_{twp.E2} = 542.8 \cdot kN$	$H_{twp.E2.loc} = 0.25\,m$
Water Weight (HW) on Apron Slab:	$H_{1.E2} = 3746.9 \cdot kN$	$H_{1.E2.loc} = 21.10\,m$
Water Weight (HW) on Fixed Crest:	$H_{2.E2} = 2687.5 \cdot kN$	$H_{2.E2.loc} = 14.34\,m$
Water Weight (TW) on Fixed Crest:	$H_{3.E2} = 2579.8 \cdot kN$	$H_{3.E2.loc} = 5.69\,m$
Uplift:	$U_{E2} = -27560.0 \cdot kN$	$U_{E2.loc} = 13.76\,m$
Upstream (driving) Lateral Soil Load:	$E2_{drive.E2} = -1876.9 \cdot kN$	$E2_{drive.loc.E2} = 0.50\,m$
Downstream (resisting) Lateral Soil Load:	$E2_{resistE2} = 0 \cdot kN$	$E2_{resistlocE2} = 0.67\,m$
Ice / Impact Load:	$I_{E2} = -2100.0 \cdot kN$	$I_{E2.loc} = 10.80\,m$

STABILITY ASSESSMENT (SLIDNG, OVERTURNING AND BEARING):

E2 CASE

CHECK SLIDING ALONG HORIZONTAL PLANE THRU TOE,
IGNORING BEDROCK MOBILIZED BY STRUCTURAL HEEL KEY , OR VOID BEHIND KEY

Sum of Vertical Forces:

$\Sigma V_{E2} := \Sigma V_{DL.E2} + \Sigma V_{water.E2} = 34217.1 \cdot kN$

Sum of Horizontal Forces:

$\Sigma H_{E2} := \Sigma H_{Water.E2} + \Sigma H_{soil.E2} + \Sigma H_{I.E2} = -11532.1 \cdot kN$

Sliding Factor of Safety:

$$FS_{HorizSliding.E2} := \frac{\left(\tan_{\phi} \cdot \Sigma V_{E2}\right)}{\left|\Sigma H_{E2}\right|} = 1.45$$

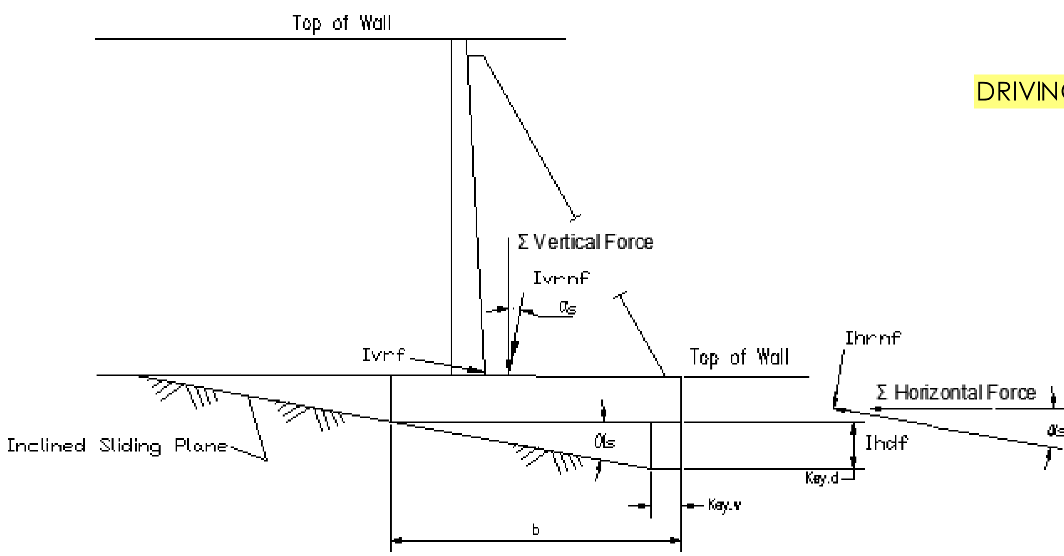
$FS_{HorizSliding.E2.Check} :=$ | "OKAY" if $FS_{HorizSliding.E2} \geq FS_{req.E2.sl}$
| "Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !" otherwise

$FS_{HorizSliding.E2.Check} =$ "OKAY"

CHECK SLIDING ALONG INCLINED SLIDING PLANE FROM HEEL KEY TO TOE,
WITH BEDROCK MASS MOBILIZED BY REINFOCREDE CONCRETE KEY)

RESISTING SIDE

DRIVING SIDE



TOE

HEEL

Ivrf=Inclined Resisting Force
Ivrnf=Inclined Resisting Normal Force
Ihrnf=Inclined Resisting Normal Force
Ihdf=Inclined Driving Force

$$\alpha s := \operatorname{atan}\left(\frac{BOF_{toe} - BOF_{elev}}{L_b - Key_l}\right) = 0.13$$

as degrees= $\alpha s \cdot \left(\frac{180}{\pi}\right) = 7.63$

Resolve $\Sigma Vert_{E2}$ & $\Sigma Horiz_{E2}$

$$\Sigma V_{InclinedE2} := \cos(\alpha s) \cdot \left(\Sigma V_{E2} + V_{rs}\right) + \sin(\alpha s) \cdot \left|\Sigma H_{E2}\right| = 48547.0 \cdot kN$$

$$\Sigma H_{InclinedE2} := \cos(\alpha s) \cdot \left|\Sigma H_{E2}\right| - \sin(\alpha s) \cdot \left(\Sigma V_{E2} + V_{rs}\right) = 5133.2 \cdot kN$$

(With properly engineered reinforced concrete Key, horizontal sliding plane thru Toe is protected, critical sliding plane is relocated to the INCLINED SLIDING PLANE FROM HEEL KEY To TOE, Bedrock Mass above this examing plane is mobilized by reinforced concrete key and combined into Structural Wedge.)

Safety Factor for Sliding
Inclined Failure Plane

$$FS_{InclinedlSlidingE2} := \frac{\Sigma V_{InclinedE2} \cdot \tan\left(\phi_{rock} \cdot \frac{\pi}{180}\right)}{\left|\Sigma H_{InclinedE2}\right|} = 4.61$$

$FS_{InclinedSliding.check.E2} :=$ | "OKAY " if $FS_{InclinedlSlidingE2} > FS_{req.E2.sl}$ = "OKAY "
| "Revise Structure"" otherwise

$FS_{InclinedSliding.check.E2} =$ "OKAY "

CHECK ECCENTRICITY ON INCLINED PLANE

E2 CASE

Sum of the Moments:

$$\Sigma M_{rs.E2} := \Sigma M_{DL.E2} + \Sigma M_{HWater.E2} + \Sigma M_{Vwater.E2} + \Sigma M_{I.E2} + \Sigma M_{soil.E2} + V_{rs} \cdot L_{rs} = 548419 \cdot kN \cdot m$$

Eccentricity:

$$e_{E2} := \frac{L_{incline}}{2} - \frac{\Sigma M_{rs.E2}}{\Sigma V_{InclinedE2}} = 0.83\,m$$

Eccentricity Check:

$$e_{check.E2} := \begin{cases} \text{"Okay"} & \text{if } \left|e_{E2}\right| \le Ecc_{midhalf} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$e_{check.E2} = \text{"Okay"}$

Foundation Bearing Pressures on Inclined Plane:

Bearing Pressure at Heel:

$$\sigma_{heel.E2} := \frac{\Sigma V_{InclinedE2}}{\frac{A_b}{\cos(\alpha s)}} - \frac{\Sigma V_{E2} \cdot e_{E2}}{\frac{S_b}{\cos(\alpha s)^2}} = 131.1 \cdot \frac{kN}{m^2}$$

$$\sigma_{heel.E2.check} := \left(\begin{cases} \text{"Okay"} & \text{if } \sigma_{heel.E2} \le \sigma_{allow.E2} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} \right)$$

$\sigma_{heel.E2.check} = \text{"Okay"}$

Bearing Pressure at Toe:

$$\sigma_{toe.E2} := \frac{\Sigma V_{InclinedE2}}{\frac{A_b}{\cos(\alpha s)}} + \frac{\Sigma V_{InclinedE2} \cdot e_{E2}}{\frac{S_b}{\cos(\alpha s)^2}} = 184 \cdot \frac{kN}{m^2}$$

$$\sigma_{toe.E2.check} := \begin{cases} \text{"Okay"} & \text{if } \sigma_{toe.E2} \le \sigma_{allow.E2} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$\sigma_{toe.E2.check} = \text{"Okay"}$

CHECK FLOTATION

$$Uplift_{sliding.E2} := U_{E2} = -27560 \cdot kN$$

$$Uplift_{pore.E2} = -20573.6 \cdot kN$$

$$\left(Uplift_{E2}\right) := \min\left(Uplift_{pore.E2}, Uplift_{sliding.E2}\right)$$

(For conservative, taking maximum values)

$$FS_{Flotation.E2} := \frac{D_{conc} + D_{Gate} + H_{1.E2} + H_{2.E2} + H_{3.E2}}{\left|Uplift_{E2}\right|} = 2.24$$

$$FS_{Flotation.E2.check} := \begin{cases} \text{"OKAY "} & \text{if } FS_{Flotation.E2} > FS_{req.E.flt} \\ \text{"Revise Structure""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

MONOLITH OVERTURNING STABILITY ANALYSIS

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.
Assumptions are made in order to compute overturning stability of indetermine forces on monolith with key;
(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.
(b) The horizontal resisting force acting on the key, P.key, is that required for static equilibrium
(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1 $Ratio_{overturning.allow.Extreme} = 0.167$

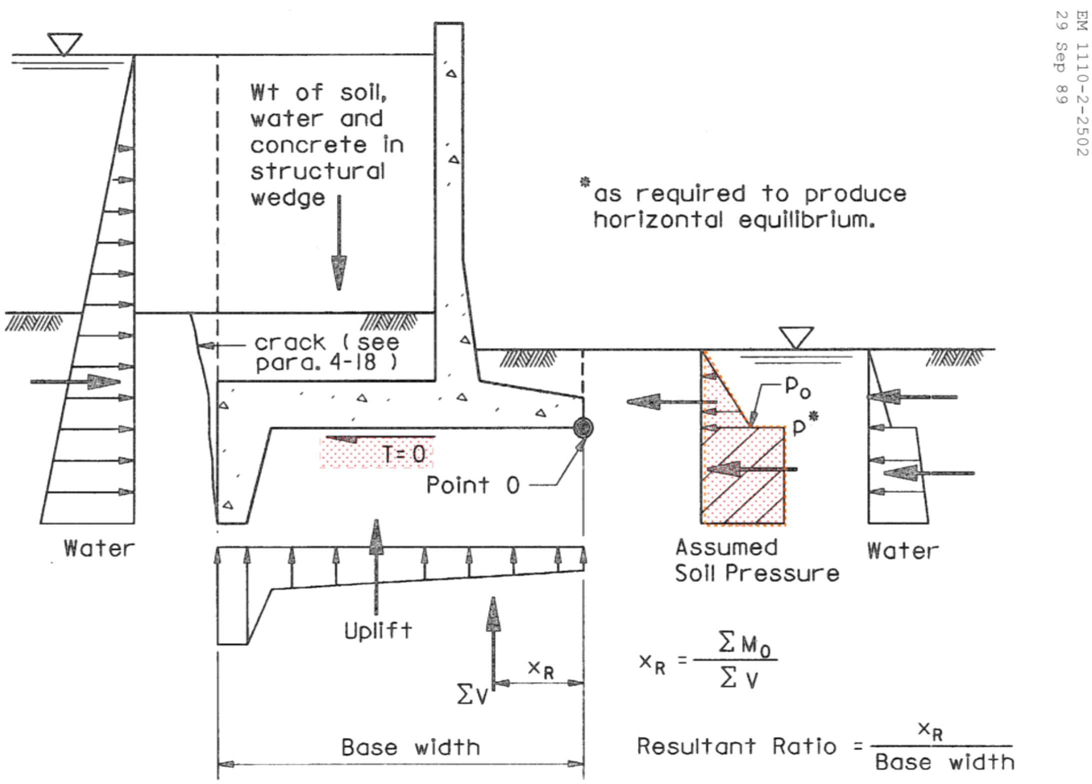


Figure 4-5. Forces for overturning analysis for wall with horizontal base and key

All Vertical Loads Applicable to Overturning Stability Analysis

Total Concrete Dead Loads:	$D_{conc} = 52182.8 \cdot kN$	at:	$X_{conc.loc} = 12.4\,m$
Dead Load of Gate:	$D_{Gate} = 580.0 \cdot kN$		$X_{gate} = 9.75\,m$
Water Weight (HW) on Apron Slab:	$H_{1.E2} = 3746.9 \cdot kN$		$H_{1.E2.loc} = 21.10\,m$
Water Weight (HW) on Fixed Crest:	$H_{2.E2} = 2687.5 \cdot kN$		$H_{2.E2.loc} = 14.34\,m$
Water Weight (TW) on Fixed Crest:	$H_{3.E2} = 2579.8 \cdot kN$		$H_{3.E2.loc} = 5.69\,m$

Uplift Force from Sliding Analysis. Line of Creep Method applied at presumed inclined sliding line, and subtraction gravity effect to Base of Concrete by Archimedes Principle

$$U_{E2.loc.sliding} := \frac{U_{A.E2} \cdot L_{A.E2} + U_{B.E2} \cdot L_{B.E2} - A_{rs} \cdot w_{as} \cdot \gamma_w \cdot L_{rs}}{U_{A.E2} + U_{B.E2} - A_{rs} \cdot w_{as} \cdot \gamma_w} = 13.79\,m$$

$$U_{E2.sliding} := U_{E2} + A_{rs} \cdot w_{as} \cdot \gamma_w = -21665.6 \cdot kN$$

E2 CASE

Uplift for Overturning Analysis, Line of Creep Method. Pore pressure at base of Concrete

$Uplift_{pore.E1} = -19247 \cdot kN$

$$Uplift_{pore.E2.loc} := \frac{Uplift_{BC.E2} \cdot Uplift_{BC.E2.loc} + Uplift_{DE.E2} \cdot Uplift_{DE.E2.loc} + Uplift_{EF.E2} \cdot Uplift_{EF.E2.loc} + Uplift_{FG.E2} \cdot Uplift_{FG.E2.loc}}{Uplift_{pore.E2}}$$

$Uplift_{pore.E2.loc} = 13.2\,m$

Sum of All Water Load for Overturning Analysis

$\Sigma V_{water.E2.OT} := H_{1.E2} + H_{2.E2} + H_{3.E2} + Uplift_{pore.E2} = -11559.4 \cdot kN$

<u>All Lateral Loads Applicable to Overturning Stability Analysis</u>

Apply Load to Gate?: $poss_{E2} = 0$ — poss = 1 if gate is closed, 0 if gate is open

Headwater Lateral Load on Pier: $H_{hwp.E2} = -854.6 \cdot kN$ — $H_{hwp.E2.loc} = 6.70\,m$

Headwater Lateral Load on Gate: $H_{hwg.E2} = 0.0 \cdot kN$ — $H_{hwg.E2.loc} = 7.70\,m$

Headwater Lateral Load on Footing: $H_{hwf.E2} = -8464.8 \cdot kN$ — $H_{hwf.E2.loc} = 1.72\,m$

Total Horizontal Tailwater Load on Pier: $H_{twp.E2} = 542.8 \cdot kN$ — $H_{twp.E2.loc} = 0.25\,m$

Total Horizontal Tailwater Load on Footing under Gate Openings, i.e., excluding Pier: $H_{twf.E2} = 1221.4 \cdot kN$ — $H_{twf.E2.loc} = 0.25\,m$

Resisting Water on Rear Face of Monolith, i.e., bottom of heel elevation: *(Point O @ TOE: BOFtoe = EL.1205.5)*

Ice / Impact Load: $I_{E2} = -2100.0 \cdot kN$ at: $I_{E2.loc} = 10.80\,m$

Depth of Fill at Heel Side for Overturning Analysis:

$t_{hf.E1} := TOC_{as} - BOF_{toe} = 4.50\,m$

Driving Soil Load for overturning:

$$E1_{drive.E2} := \frac{K_o \cdot t_{hf.E2}^{\,2}}{2} \cdot (\gamma_r - \gamma_w) \cdot W_b \cdot -1 = -1055.7 \cdot kN$$

Acting at:

$$E1_{drive.loc.E2} := \frac{t_{hf.E2}}{3} = 1.50\,m$$

Downstream (resisting) Lateral Soil Load as required to produce horizontal equilibrium:

$$E2_{resistE2} := -1 \cdot \left(H_{hwp.E2} + H_{hwg.E2} + H_{hwf.E2} + H_{twp.E2} + H_{twf.E2} + I_{E2} + E1_{drive.E2}\right)$$

$E2_{resistE2} = 10711 \cdot kN$

Assumed Resisting Bedrock at middle of Key, passive soil pressure or lateral bearing contract joint at end of Monolith 3A3B

$E2_{resistlocE2} := E2_{resistlocU1} = -0.75\,m$

Overturning moment by Dead Loads about Point O @ Toe

$\Sigma M_{DL.E2} = 654229.9 \cdot kN \cdot m$

Overturning moment by Vertical Water Loads and Uplift, about Point O @ Toe

$$\Sigma M_{Vwater.E2.OT} := H_{1.E2} \cdot H_{1.E2.loc} + H_{2.E2} \cdot H_{2.E2.loc} + H_{3.E2} \cdot H_{3.E2.loc} + Uplift_{pore.E2} \cdot Uplift_{pore.E2.loc} = -140143.4 \cdot kN \cdot m$$

Overturning moment by Lateral Hydrostatic Forces of Headwater Pool and Tailwater Pool,about Point O @ Toe

$\Sigma M_{HWater.E1} = -57418.4 \cdot kN \cdot m$

Overturning Moment by Impact/Ice Load, about Point O@ Toe

$\Sigma M_{I.E2} = -22680 \cdot kN \cdot m$

Overturning moment by Lateral Soil Forces about Point O @ Toe

$\Sigma M_{soil.E2} := E1_{drive.E2} \cdot E1_{drive.loc.E2} \cdots + E2_{resistE2} \cdot E2_{resistlocE2} = -9616.8 \cdot kN \cdot m$

Sum of the Overturning Moments about Point O @ Toe:

$$\Sigma M_{E2.OT} := \Sigma M_{DL.E2} + \Sigma M_{HWater.E2} + \Sigma M_{Vwater.E2.OT} + \Sigma M_{I.E2} + \Sigma M_{soil.E2} = 461948 \cdot kN \cdot m$$

Sum of Vertical Forces:

$$\Sigma V_{E2.OT} := \Sigma V_{DL.E2} + \Sigma V_{water.E2.OT} = 41203.5 \cdot kN$$

Distance X_R: EM 1110-2-2502 Eq.4-1

$$X_{R.E2} := \frac{\Sigma M_{E2.OT}}{\Sigma V_{E2.OT}} = 11.2 m$$

Overturning Resultant Ratio

$$Ratio_{Overturning.E2} := \frac{X_{R.E2}}{L_b} = 0.46$$

EM 1110-2-2502

Table 4-1

Retaining Wall Stability Criteria

Loading Condition	Sliding Factor of Safety, FS	Shear Strength Test Required: Soil Foundation	Shear Strength Test Required: Rock Foundation[3]	Overturning Criteria Minimum Base Area in Compression: Soil Foundation	Overturning Criteria Minimum Base Area in Compression: Rock Foundation
Usual	1.5	(Q &/or S)[2,1]	Direct shear	100%[4]	75%[4]
Unusual	1.33	(Q &/or S)[2,1]	Direct shear	75%[4]	50%[4]
Earthquake	1.1	(Q)	Direct shear	Resultant within base	Resultant within base

Overturning Stability Check

$$Ratio_{Overturning.E2.check} := \begin{cases} \text{"Okay"} & \text{if } Ratio_{Overturning.E2} \ge Ratio_{overturning.allow.Extreme} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$$Ratio_{Overturning.E2.check} = \text{"Okay"}$$

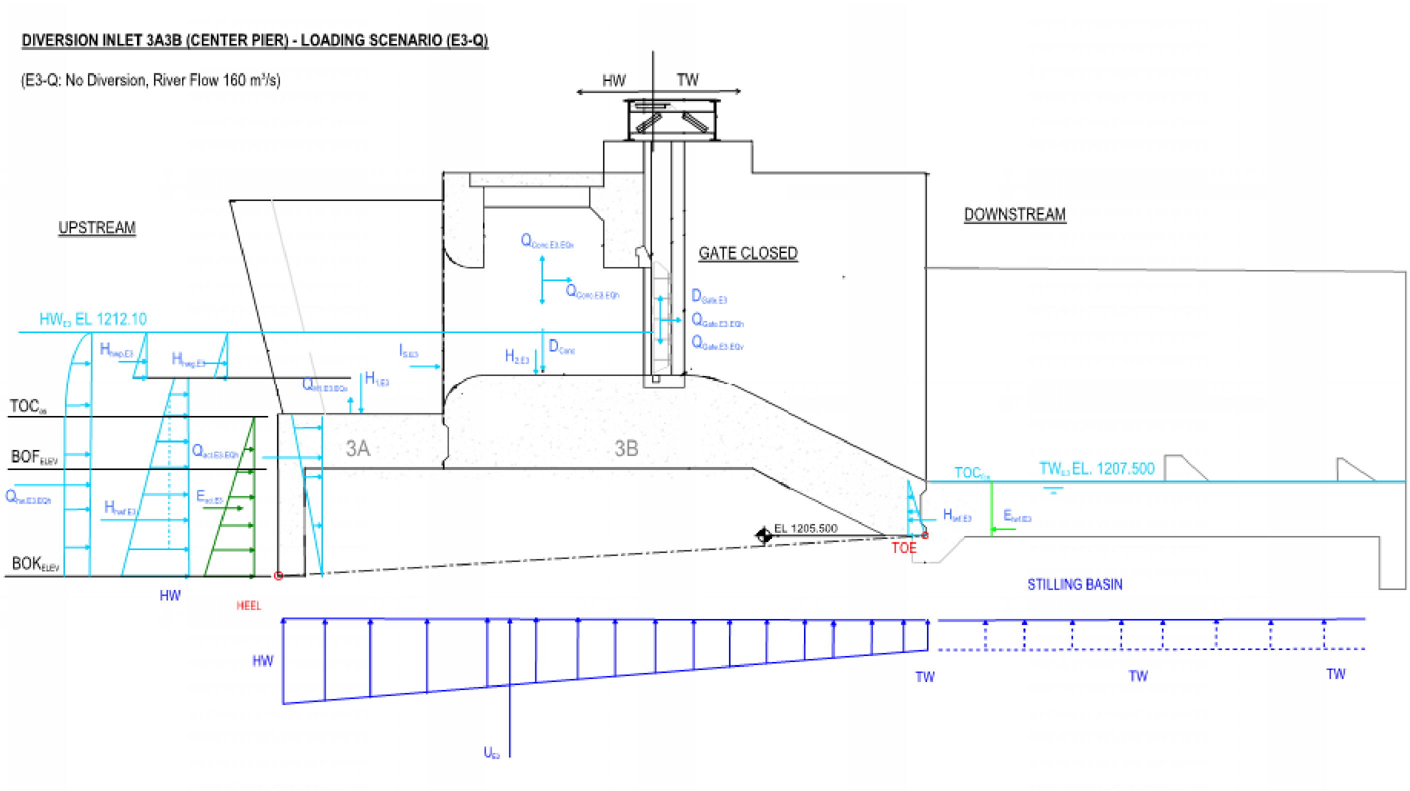
Summary of Extreme Flood Results (Only Report Controlling Load Case)

E2 CASE

E2 Event: PMF with Diversion

Horiz Sliding Factor of Safety:	$FS_{HorizSliding.E2} = 1.45$
Horiz Sliding Factor of Safety Check:	$FS_{HorizSliding.E2.Check} = \text{"OKAY"}$
Sliding Factor of Safety:	$FS_{InclinedlSlidingE2} = 4.6$
Sliding Factor of Safety Check:	$FS_{InclinedSliding.check.E2} = \text{"OKAY "}$
Eccentricity:	$e_{E2} = 0.83\,m$
Eccentricity Check:	$e_{check.E2} = \text{"Okay"}$
Bearing Pressure At Heel on Inclined Plane:	$\sigma_{heel.E2} = 131.1 \cdot \frac{kN}{m^2}$
Bearing Pressure At Heel Check:	$\sigma_{heel.E2.check} = \text{"Okay"}$
Bearing Pressure At Toe on Inclined Plane:	$\sigma_{toe.E2} = 184.0 \cdot \frac{kN}{m^2}$
Bearing Pressure At Toe Check:	$\sigma_{toe.E2.check} = \text{"Okay"}$
Flotation Factor of Safety	$FS_{Flotation.E2} = 2.2$
Flotation Factor of Safety Check:	$FS_{Flotation.E2.check} = \text{"OKAY "}$
Overturning Resultant Ratio	$Ratio_{Overturning.E2} = 0.46$
Overturning Stability Check	$Ratio_{Overturning.E2.check} = \text{"Okay"}$

E3 DESIGN CASE



E3 Case: U1 CASE PLUS SEISMIC

ACCEPTANCE PARAMETERS

Required Factor of Safety for Sliding: $FS_{req.E3.sl} := 1.0$ (Without Cohesion) (Section 8.1, Design Criteria)

Resultant Within Middle Half of Base: $e \le \frac{L_b}{4} \wedge e \ge \frac{-L_b}{4}$

Allowable Rock Bearing Pressure: $\sigma_{allow.E3} := 1740.0 \cdot \frac{kN}{m^2}$ (Section 5.2, Design Criteria)

Required Factor of Safety for Flotation: $FS_{req.E.flt} = 1.1$

Overturning Min Required Resultant Ratio: $\frac{X_{R.E}}{Horizontal\_Width\_of\_Base} > 0.167$

INPUT PARAMETERS

E3 CASE

Headwater Elevation: $HW_{E3} := 1212.10m$

Tailwater Elevation: $TW_{E3} := 1207.50m$

(Water Elevations based on Diversion Structure 2D Hydraulic Model Results. See page 7 and Section 8.2, Design Criteria)

Crest Water Elevation (No Diversion)

Chute Block Water Elevation (No Diversion)

Bottom of Footing Elevation: $BOF_{elev} = 1204.00\,m$

Apron Slab Top of Concrete Elevation at Edge of Slab: $TOC_{as} = 1210.00\,m$

Fixed Crest Top of Concrete Elevation at Downstream Face: $TOC_{fce} = 1207.50\,m$

Fixed Crest Top of Concrete Elevation at Center of Footing: $TOC_{fcc} = 1211.50\,m$

SEISMIC LOAD E3: EDGM Post-Seismic Assessment of Usual Load U1 Event (3 Load Cases)

Seismic Case $Q_{E3.1}$ - 100% Horizontal Seismic Force, No Vertical **E3.1 CASE**

Horizontal Seismic Coefficient: $K_{h.E3.1} := \frac{-2}{3} \cdot 0.26 = -0.17$

Vertical Seismic Coefficient: $K_{v.E3.1} := 0. \frac{-2}{3} \cdot 0.56 \cdot 0.26 = 0$

HORIZONTAL SEISMIC LOADS	Loads	Moment Arm
Horizontal Seismic Component of Concrete Structure:	$Q_{conc.E3.EQh.1} := D_{conc} \cdot K_{h.E3.1} = -9045 \cdot kN$	$Y_{conc.loc} = 6.21\,m$
Horizontal Seismic Component of Vertical Lift Gate:	$Q_{Gate.E3.EQh.1} := D_{Gate} \cdot K_{h.E3.1} = -100.5 \cdot kN$	$Y_{gate} = 8.00\,m$
Horizontal Seismic Component of Headwater on Pier: (Section 7.9, Design Criteria)	$Q_{hwp.E3.EQh.1} := \left(\frac{7}{12}\right) \cdot K_{h.E3.1} \cdot \gamma_w \cdot \left(D_{hwp.U1}\right)^2 \cdot W_{hwp.U1} = -17.5 \cdot kN$	$Y_{HWp.E3} := 0.4 \cdot D_{hwp.U1} + \left(TOC_{as} - BOF_{toe}\right) = 5.34\,m$
Horizontal Seismic Component of Headwater on Gate: (Section 7.9, Design Criteria)	$Q_{hwg.E3.EQh.1} := \left(\frac{7}{12}\right) \cdot K_{h.E3.1} \cdot \gamma_w \cdot \left(D_{hwg.U1}\right)^2 \cdot W_{hwg.U1} \cdot poss_{U1} = -7.1 \cdot kN$	$Y_{HWg.E3} := 0.4 \cdot D_{hwg.U1} + \left(TOC_{fcc} - BOF_{toe}\right) = 6.24\,m$
Horizontal Seismic Component of Headwater on Footing: (Section 7.9, Design Criteria)	$Q_{hwf.E3.EQh.1} := \left(\frac{7}{12}\right) \cdot K_{h.E3.1} \cdot \gamma_w \cdot \left(D_{hwf.U1}\right)^2 \cdot W_{hw.U1} = -846 \cdot kN$	$Y_{HWf.E3} := 0.4 \cdot \left(TOC_{fcc} - BOF_{toe}\right) = 2.40\,m$
Horizontal Seismic Component of Active Soil: (Section 5-5, USACE EM_1110-2-2100)	$Q_{act.E3.EQh.1} := \gamma_r \cdot \left(TOC_{as} - BOF_{elev}\right)^2 \cdot K_{h.E3.1} \cdot W_{hw.U1} = -1784.6 \cdot kN$	$Y_{E.act.E3} := 0.63 \cdot \left(TOC_{as} - BOF_{toe}\right) = 2.84\,m$

VERTICAL SEISMIC LOADS	Loads	Moment Arm
Vertical Component of Concrete Structure:	$Q_{conc.E3.EQv.1} := D_{conc} \cdot K_{v.E3.1} = 0 \cdot kN$	$X_{conc.loc} = 12.43\,m$
Vertical Component of Vertical Lift Gate:	$Q_{Gate.E3.EQv.1} := D_{Gate} \cdot K_{v.E3.1} = 0 \cdot kN$	$X_{gate} = 9.75\,m$
Vertical Seismic Component of Headwater over Apron Slab: (Section 7.9, Design Criteria)	$Q_{H1.E3.EQv.1} := K_{v.E3.1} \cdot H_{1.U1} = 0 \cdot kN$	$H_{1.U1.loc} = 21.10\,m$
Vertical Seismic Component of Headwater over Fixed Crest Slab: (Section 7.9, Design Criteria)	$Q_{H2.E3.EQv.1} := K_{v.E3.1} \cdot H_{2.U1} = 0 \cdot kN$	$H_{2.U1.loc} = 14.25\,m$

$$\Sigma H_{Q.E3.EQh.1} := Q_{conc.E3.EQh.1} + Q_{Gate.E3.EQh.1} + Q_{hwp.E3.EQh.1} + Q_{hwg.E3.EQh.1} + Q_{hwf.E3.EQh.1} + Q_{act.E3.EQh.1} = -11800.9 \cdot kN$$

$$\Sigma V_{Q.E3.EQv.1} := Q_{conc.E3.EQv.1} + Q_{Gate.E3.EQv.1} + Q_{H1.E3.EQv.1} + Q_{H2.E3.EQv.1} = 0.0 \cdot kN$$

$$\Sigma M_{Q.E3.1} := Q_{conc.E3.EQh.1} \cdot Y_{conc.loc} + Q_{Gate.E3.EQh.1} \cdot Y_{gate} + Q_{hwp.E3.EQh.1} \cdot Y_{HWp.E3} + Q_{hwg.E3.EQh.1} \cdot Y_{HWg.E3} \cdots = -64212.5 \cdot kN \cdot m$$
$$+ Q_{hwf.E3.EQh.1} \cdot Y_{HWf.E3} + Q_{act.E3.EQh.1} \cdot Y_{E.act.E3} + Q_{conc.E3.EQv.1} \cdot X_{conc.loc} + Q_{Gate.E3.EQv.1} \cdot X_{gate} \cdots$$
$$+ Q_{H1.E3.EQv.1} \cdot H_{1.U1.loc} + Q_{H2.E3.EQv.1} \cdot H_{2.U1.loc}$$

STABILITY ASSESSMENT:

E3.1 CASE

Seismic Case $Q_{E3.1}$: 100% Horizontal Seismic Force, No Vertical

Sum of Vertical Forces:

$\Sigma V_{E3.1} := \Sigma V_{U1} + \Sigma V_{Q.E3.EQv.1} = 36221.9 \cdot kN$

Sum of Horizontal Forces:

$\Sigma H_{E3.1} := \Sigma H_{U1} + \Sigma H_{Q.E3.EQh.1} = -19070.6 \cdot kN$

$\Sigma V_{U1} = 36221.9 \cdot kN$

Sliding Factor of Safety:

$$FS_{HorizSliding.E3.1} := \frac{\tan_{\phi} \cdot \Sigma V_{E3.1}}{\left|\Sigma H_{E3.1}\right|} = 0.93$$

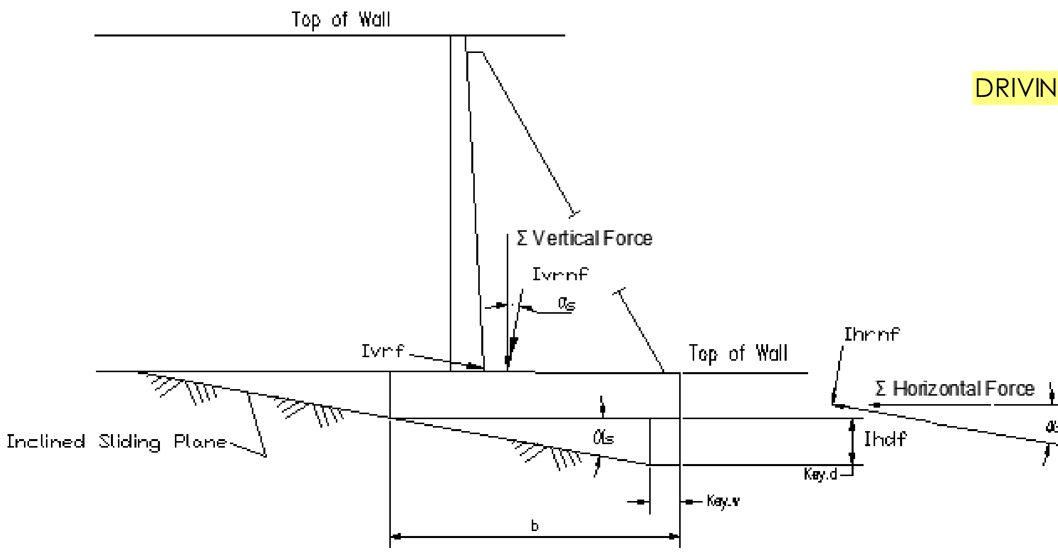
$FS_{HorizSliding.E3.1.Check} :=$ "OKAY" if $FS_{HorizSliding.E3.1} \geq FS_{req.E3.sl}$
"Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !" otherwise

$FS_{HorizSliding.E3.1.Check}$ = "Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !"

CHECK **SLIDING** ALONG INCLINED SLIDING PLANE FROM HEEL KEY TO TOE,
WITH BEDROCK MASS MOBILIZED BY REINFOCREDE CONCRETE KEY

RESISTING SIDE

DRIVING SIDE



TOE

HEEL

Ivrf=Inclined Resisting Force
Ivrnf=Inclined Resisting Normal Force
Ihrnf=Inclined Resisting Normal Force
Ihdf=Inclined Driving Force

$$\alpha s := \operatorname{atan}\left(\frac{BOF_{toe} - BOF_{elev}}{L_b - Key_l}\right) = 0.13 \qquad \text{as degrees=} \quad \alpha s \cdot \left(\frac{180}{\pi}\right) = 7.63$$

Resolve $\Sigma Vert_{E3.1}$ & $\Sigma Horiz_{E3.1}$

$$\Sigma V_{InclinedE3.1} := \cos(\alpha s) \cdot \left(\Sigma V_{E3.1} + V_{rs}\right) + \sin(\alpha s) \cdot \left|\Sigma H_{E3.1}\right| = 51534.8 \cdot kN$$

$$\Sigma H_{InclinedE3.1} := \cos(\alpha s) \cdot \left|\Sigma H_{E3.1}\right| - \sin(\alpha s) \cdot \left(\Sigma V_{E3.1} + V_{rs}\right) = 12338.9 \cdot kN$$

(With properly engineered reinforced concrete Key, horizontal sliding plane thru Toe is protected, critical sliding plane is relocated to the INCLINED SLIDING PLANE FROM HEEL KEY To TOE, Bedrock Mass above this examing plane is mobilized by reinforced concrete key and combined into Structural Wedge.)

Safety Factor for Sliding
Inclined Failure Plane

$$FS_{InclinedlSlidingE3.1} := \frac{\Sigma V_{InclinedE3.1} \cdot \tan\left(\phi_{rock} \cdot \frac{\pi}{180}\right)}{\left|\Sigma H_{InclinedE3.1}\right|} = 2.04$$

$FS_{Sliding.E3.1.InclinedCheck} :=$ "OKAY " if $FS_{InclinedlSlidingE3.1} > FS_{req.E3.sl}$ = "OKAY "
"Revise Structure"" otherwise

$FS_{Sliding.E3.1.InclinedCheck}$ = "OKAY "

E3.1 CASE

CHECK ECCENTRICITY ON INCLINED PLANE

Seismic Case $Q_{E3.1}$: 100% Horizontal Seismic Force, No Vertical

Sum of the moments:

$$\Sigma M_{rs.E3.1} := \Sigma M_{DL.U1} + \Sigma M_{HWater.U1} + \Sigma M_{Vwater.U1} + \Sigma M_{I.U1} + \Sigma M_{soil.U1} + \Sigma M_{Q.E3.1} + V_{rs} \cdot L_{rs} = 538784 \cdot kN \cdot m$$

Eccentricity:

$$e_{E3.1} := \frac{L_{incline}}{2} - \frac{\Sigma M_{rs.E3.1}}{\Sigma V_{InclinedE3.1}} = 1.67\,m$$

Eccentricity Check:

$$e_{check.E3.1} := \begin{cases} \text{"Okay"} & \text{if } \left|e_{E3.1}\right| \le Ecc_{midhalf} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$e_{check.E3.1} = \text{"Okay"}$

Foundation Bearing Pressures on Inclined Plane:

Bearing Pressure at Heel:

$$\sigma_{heel.E3.1} := \begin{cases} 0 & \text{if } \left|e_{E3.1}\right| \ge Ecc_{midhalf} \\ \left(\dfrac{\Sigma V_{InclinedE3.1}}{\dfrac{A_b}{\cos(\alpha s)}} - \dfrac{\Sigma V_{InclinedE3.1} \cdot e_{E3.1}}{\dfrac{S_b}{\cos(\alpha s)^2}} \right) & \text{otherwise} \end{cases} = 95.8 \cdot \frac{kN}{m^2}$$

$$\sigma_{heel.E3.1.check} := \left(\begin{cases} \text{"Okay"} & \text{if } \sigma_{heel.E3.1} \le \sigma_{allow.E3} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} \right)$$

$\sigma_{heel.E3.1.check} = \text{"Okay"}$

Bearing Pressure at Toe:

$$\sigma_{toe.E3.1} := \begin{cases} \left[\dfrac{4}{3} \cdot \left(\dfrac{\dfrac{\Sigma V_{InclinedE3.1}}{W_b}}{L_{incline} - 2 \cdot e_{E3.1}} \right) \right] & \text{if } e_{E3.1} \ge Ecc_{midhalf} \\ \left[\dfrac{\Sigma V_{InclinedE3.1}}{\dfrac{A_b}{\cos(\alpha s)}} + \dfrac{\left(\Sigma V_{InclinedE3.1} \cdot e_{E3.1}\right)}{\dfrac{S_b}{\cos(\alpha s)^2}} \right] & \text{otherwise} \end{cases} = 228.9 \cdot \frac{kN}{m^2}$$

$$\sigma_{toe.E3.1.check} := \begin{cases} \text{"Okay"} & \text{if } \sigma_{toe.E3.1} \le \sigma_{allow.E3} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$\sigma_{toe.E3.1.check} = \text{"Okay"}$

Foundation Flotation Checks:

$$FS_{Flotation.E3.1} := \frac{D_{conc} + D_{Gate} + H_{1.U1} + H_{2.U1} + H_{3.U1} - \left|\Sigma V_{Q.E3.EQv.1}\right|}{\left|Uplift_{U1}\right|} = 3$$

$$Flotation_{E3.1.check} := \begin{cases} \text{"Okay"} & \text{if } FS_{Flotation.E3.1} \ge FS_{req.E.flt} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$Flotation_{E3.1.check} = \text{"Okay"}$

MONOLITH OVERTURNING STABILITY ANALYSIS

E3.1 CASE

Seismic Case $Q_{E3.1}$: 100% Horizontal Seismic Force, No Vertical

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.

Assumptions are made in order to compute overturning stability of indetermine forces on monolith with key;

(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.

(b) The horizontal resisting force acting on the key, P.key, is that required for static equilibrium

(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1

$Ratio_{overturning.allow.Extreme} := 0.167$

Resultant within Middle Half

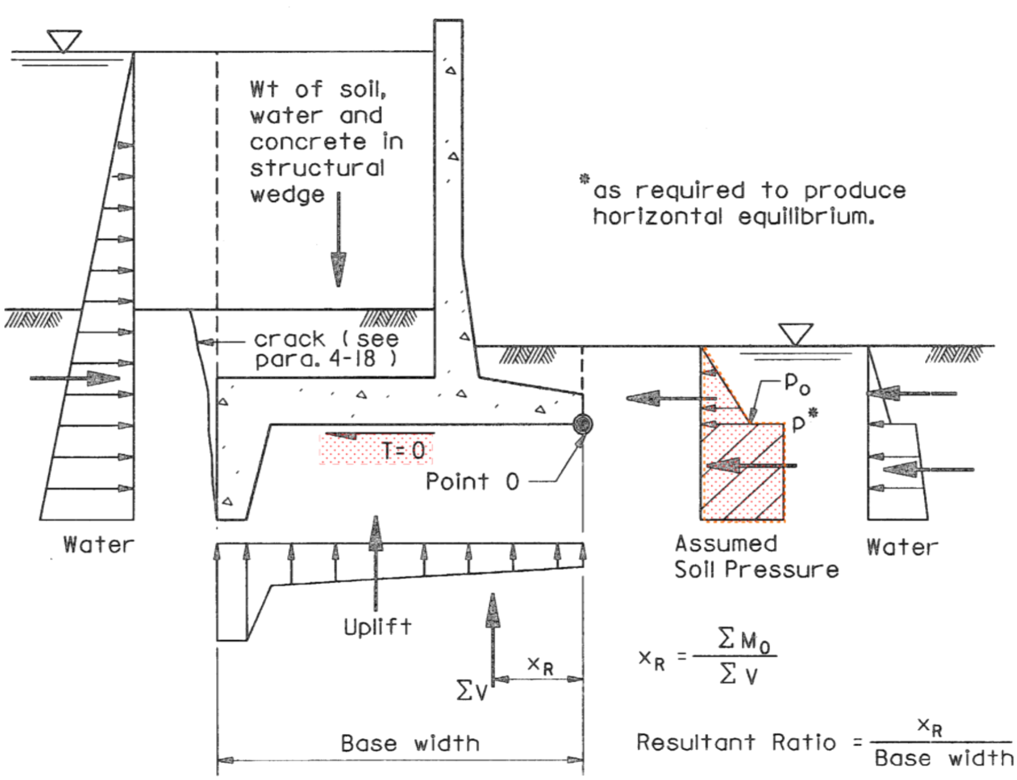


Figure 4-5. Forces for overturning analysis for wall with horizontal base and key

All Vertical Loads Applicable to Overturning Stability Analysis

Total Concrete Dead Loads:	$D_{conc} = 52182.8 \cdot kN$	at:	$X_{conc.loc} = 12.43\,m$
Dead Load of Gate:	$D_{Gate} = 580.0 \cdot kN$		$X_{gate} = 9.75\,m$
Water Weight (HW) on Apron Slab:	$H_{1.U1} = 1238.5 \cdot kN$		$H_{1.U1.loc} = 21.10\,m$
Water Weight (HW) on Fixed Crest:	$H_{2.U1} = 439.7 \cdot kN$		$H_{2.U1.loc} = 14.25\,m$
Water Weight (TW) on Fixed Crest:	$H_{3.U1} = 0.0 \cdot kN$		$H_{3.U1.loc} = 0.00\,m$
Vertical Seismic Component of Concrete Structure:	$Q_{conc.E3.EQv.1} = 0$	at:	$X_{conc.loc} = 12.43\,m$
Vertical Seismic Component of Vertical Lift Gate:	$Q_{Gate.E3.EQv.1} = 0$		$X_{gate} = 9.75\,m$
Vertical Seismic Component of Headwater over Apron Slab:	$Q_{H1.E3.EQv.1} = 0$		$H_{1.U1.loc} = 21.10\,m$
Vertical Seismic Component of Headwater over Fixed Crest Slab:	$Q_{H2.E3.EQv.1} = 0$		$H_{2.U1.loc} = 14.25\,m$

E3.1 CASE

Uplift for Overturning Analysis, Line of Creep Method. Pore pressure at base of Concrete, first calculation to presumed inclined straight line from Heel to Toe, thereafter by Archimedes Principle.

$$U_{E3.1.loc.sliding} := \frac{U_{A.U1} \cdot L_{A.U1} + U_{B.U1} \cdot L_{B.U1} - A_{rs} \cdot w_{as} \cdot \gamma_w \cdot L_{rs}}{U_{A.U1} + U_{B.U1} - A_{rs} \cdot w_{as} \cdot \gamma_w} = 13.76\,m$$

$$U_{E3.1.sliding} := U_{U1} + A_{rs} \cdot w_{as} \cdot \gamma_w = -12005.7 \cdot kN$$

Uplift for Overturning Analysis, Line of Creep Method. Pore pressure at base of Concrete $\quad Uplift_{pore.U1} = -11398 \cdot kN$

$$Uplift_{pore.E3.1.loc} := \frac{Uplift_{BC.U1} \cdot Uplift_{BC.U1.loc} + Uplift_{DE.U1} \cdot Uplift_{DE.U1.loc} + Uplift_{EF.U1} \cdot Uplift_{EF.U1.loc} + Uplift_{FG.U1} \cdot Uplift_{FG.U1.loc}}{Uplift_{pore.U1}}$$

$$Uplift_{pore.E3.1.loc} = 13.1\,m$$

Sum of All Water Load for Overturning Analysis $\quad \Sigma V_{water.E3.1.OT} := H_{1.U1} + H_{2.U1} + H_{3.U1} + Uplift_{pore.U1} = -9719.8 \cdot kN$

<u>All Lateral Loads Applicable to Overturning Stability Analysis</u>

Apply Load to Gate?: $\quad poss_{U1} = 1 \quad$ poss = 1 if gate is closed; 0 if gate is open

Headwater Lateral Load on Pier: $\quad H_{hwp.U1} = -86.5 \cdot kN \quad$ at: $\quad H_{hwp.U1.loc} = 5.20\,m$

Headwater Lateral Load on Gate: $\quad H_{hwg.U1} = -35.3 \cdot kN \quad H_{hwg.U1.loc} = 6.20\,m$

Headwater Lateral Load on Footing: $\quad H_{hwf.U1} = -4160.7 \cdot kN \quad H_{hwf.U1.loc} = 1.17\,m$

Total Horizontal Tailwater Load on Pier: $\quad H_{twp.U1} = 240.3 \cdot kN \quad H_{twp.U1.loc} = -0.33\,m$

Total Horizontal Tailwater Load on Footing under Gate Openings, i.e., excluding Pier $\quad H_{twf.U1} = 540.8 \cdot kN \quad H_{twf.U1.loc} = -0.33\,m$

Resisting Water on Rear Face of Monolith, i.e., bottom of heel elevation:

(Point O @ TOE: BOFtoe = EL.1205.5)

Horizontal Seismic Component of Concrete Structure: $\quad Q_{conc.E3.EQh.1} = -9045 \cdot kN \quad$ AT $\quad Y_{conc.loc} = 6.21\,m$

Horizontal Seismic Component of Vertical Lift Gate: $\quad Q_{Gate.E3.EQh.1} = -100.5 \cdot kN \quad Y_{gate} = 8.00\,m$

Horizontal Seismic Component of Headwater on Pier: $\quad Q_{hwp.E3.EQh.1} = -17.5 \cdot kN \quad Y_{HWp.E3} = 5.3\,m$

Horizontal Seismic Component of Headwater on Gate: $\quad Q_{hwg.E3.EQh.1} = -7.1 \cdot kN \quad Y_{HWg.E3} = 6.2\,m$

Horizontal Seismic Component of Headwater on Footing: $\quad Q_{hwf.E3.EQh.1} = -846 \cdot kN \quad Y_{HWf.E3} = 2.4\,m$

Horizontal Seismic Component of Active Soil: (Section 5-5, USACE EM_1110-2-2100) $\quad Q_{act.E3.EQh.1} = -1784.6 \cdot kN \quad Y_{E.act.E3} = 2.8\,m$

Ice / Impact Load: $\quad I_{U1} = -2100.0 \cdot kN \quad$ at: $\quad I_{U1.loc} = 6.30\,m$

Depth of Fill at Heel Side for Overturning Analysis (neglecting resistance by driving below Point O): $\quad t_{hf.E3.1} := TOC_{as} - BOF_{toe} = 4.50\,m$

Driving Soil Load for overturning:

$$E1_{drive.E3.1} := \frac{K_o \cdot t_{hf.U1}^{\,2}}{2} \cdot \left(\gamma_r - \gamma_w\right) \cdot W_b \cdot -1 = -1055.7 \cdot kN$$

Acting at:

$$E1_{drive.loc.E3.1} := \frac{t_{hf.E3.1}}{3} = 1.50\,m$$

Downstream (resisting) Lateral Soil Load as required to produce horizontal equilibrium:

$$E2_{resistE3.1} := -1\cdot\left(H_{hwp.U1} + H_{hwg.U1} + H_{hwf.U1} + H_{twp.U1} + H_{twf.U1} + I_{U1} + E1_{drive.U1}\right) = 6657.1\cdot kN$$

Assumed Resisting Bedrock at middle of Key, passive soil pressure or lateral bearing contract joint at end of Monolith 3A3B

$$E2_{resistlocE3.1} := E2_{resistlocU1} = -0.75\,m$$

Overturning moment by Dead Loads about Point O @ Toe

$$\Sigma M_{DL.U1} = 651119.6\cdot kN\cdot m$$

Overturning moment by Vertical Water Loads and Uplift, about Point O @ Toe

$$\Sigma M_{Vwater.U1} = -212822.7\cdot kN\cdot m$$

Overturning moment by Lateral Hydrostatic Forces of Headwater Pool and Tailwater Pool,about Point O @ Toe

$$\Sigma M_{HWater.U1} = -5807.3\cdot kN\cdot m$$

Overturning Moment by Impact/Ice Load, about Point O@ Toe

$$\Sigma M_{I.U1} = -13230\cdot kN\cdot m$$

Overturning moment by Lateral Soil Forces about Point O @ Toe

$$\Sigma M_{soil.E3.1} := E1_{drive.E3.1}\cdot E1_{drive.loc.E3.1} + E2_{resistE3.1}\cdot E2_{resistlocE3.1} = -6576.4\cdot kN\cdot m$$

Sum of the Overturning Moments about Point O @ Toe:

$$\Sigma M_{E3.1.OT} := \Sigma M_{DL.U1} + \Sigma M_{HWater.U1} + \Sigma M_{Vwater.U1.OT} + \Sigma M_{I.U1} + \Sigma M_{soil.E3.1} + \Sigma M_{Q.E3.1} = 444279\cdot kN\cdot m$$

Sum of Vertical Forces:

$$\Sigma V_{E3.1.OT} := \Sigma V_{DL.U1} + \Sigma V_{water.U1.OT} + \left|\Sigma V_{Q.E3.EQv.1}\right| = 42724.0\cdot kN$$

Distance X_R: EM 1110-2-2502 Eq.4-1

$$X_{R.E3.1} := \frac{\Sigma M_{E3.1.OT}}{\Sigma V_{E3.1.OT}} = 10.4\,m$$

Overturning Resultant Ratio

$$Ratio_{Overturning.E3.1} := \frac{X_{R.E3.1}}{L_b} = 0.43$$

EM 1110-2-2502

Table 4-1

Retaining Wall Stability Criteria

Loading Condition	Sliding Factor of Safety, FS	Shear Strength Test Required: Soil Foundation	Shear Strength Test Required: Rock Foundation[3]	Overturning Criteria Minimum Base Area in Compression: Soil Foundation	Overturning Criteria Minimum Base Area in Compression: Rock Foundation
Usual	1.5	(Q &/or S)[2,1]	Direct shear	100%[4]	75%[4]
Unusual	1.33	(Q &/or S)[2,1]	Direct shear	75%[4]	50%[4]
Earthquake	1.1	(Q)	Direct shear	Resultant within base	Resultant within base

Overturning Stability Check

$$Ratio_{Overturning.E3.1.check} := \begin{cases} \text{"Okay"} & \text{if } Ratio_{Overturning.E3.1} \ge Ratio_{overturning.allow.Extreme} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$$Ratio_{Overturning.E3.1.check} = \text{"Okay"}$$

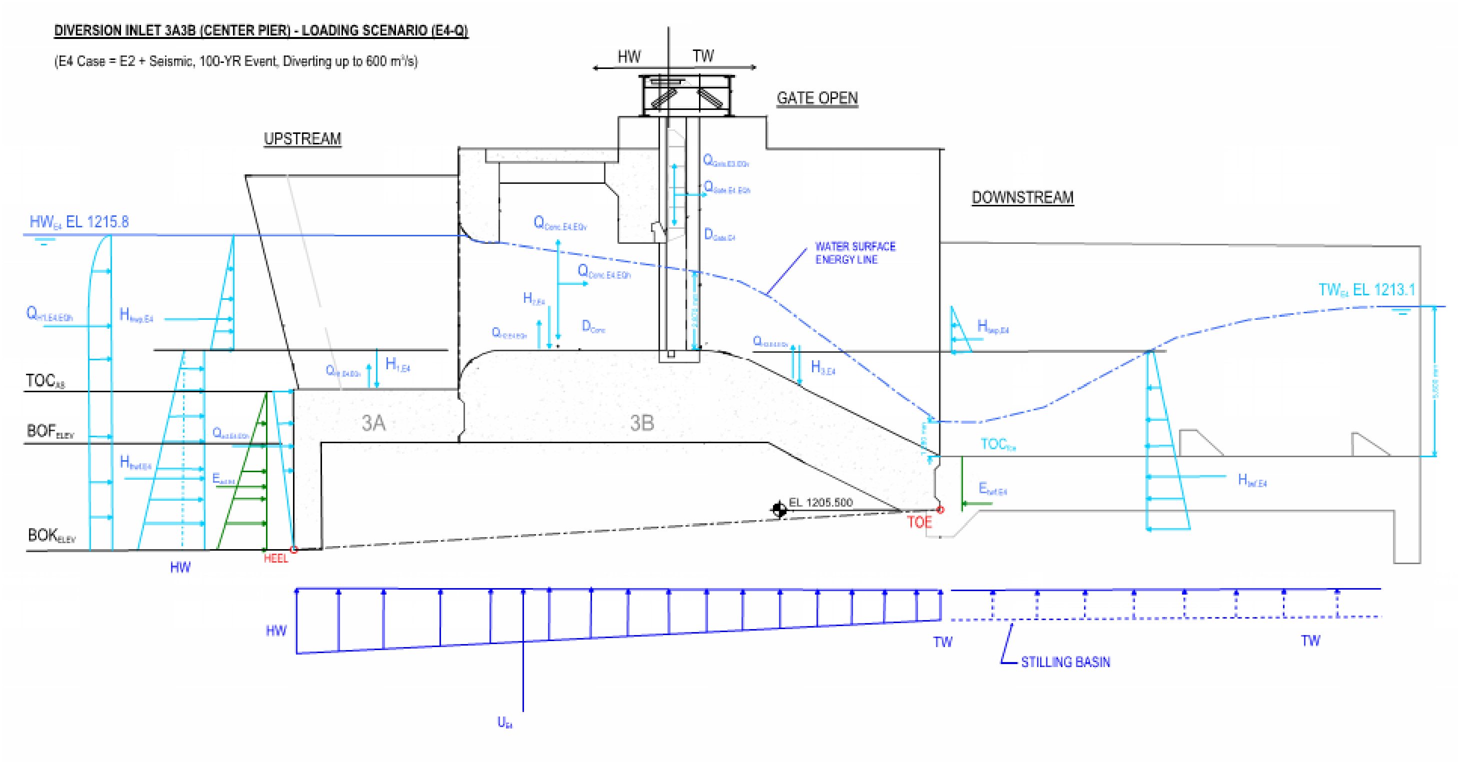
Summary of Seismic Results (Only Report Controlling Load Case)

E3.1 CASE

Seismic Case $Q_{E3.1}$: 100% Horizontal Seismic Force, No Vertical

Horiz Sliding Factor of Safety:	$FS_{HorizSliding.E3.1} = 0.93$
Horiz Sliding Factor of Safety Check:	$FS_{HorizSliding.E3.1.Check}$ = "Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !"
Sliding Factor of Safety:	$FS_{InclinedlSlidingE3.1} = 2$
Sliding Factor of Safety Check:	$FS_{Sliding.E3.1.InclinedCheck}$ = "OKAY "
Eccentricity:	$e_{E3.1} = 1.67\,m$
Eccentricity Check:	$e_{check.E3.1}$ = "Okay"
Bearing Pressure At Heel on Inclined Plane:	$\sigma_{heel.E3.1} = 95.8\cdot\frac{kN}{m^2}$
Bearing Pressure At Heel Check:	$\sigma_{heel.E3.1.check}$ = "Okay"
Bearing Pressure At Toe on Inclined Plane:	$\sigma_{toe.E3.1} = 228.9\cdot\frac{kN}{m^2}$
Bearing Pressure At Toe Check:	$\sigma_{toe.E3.1.check}$ = "Okay"
Flotation Factor of Safety	$FS_{Flotation.E3.1} = 3$
Flotation Factor of Safety Check:	$Flotation_{E3.1.check}$ = "Okay"
Overturning Resultant Ratio	$Ratio_{Overturning.E3.1} = 0.43$
Overturning Stability Check	$Ratio_{Overturning.E3.1.check}$ = "Okay"

E4 DESIGN CASE



E4 Case: U2 CASE PLUS SEISMIC

ACCEPTANCE PARAMETERS

Required Factor of Safety for Sliding: $FS_{req.E4.sl} := 1.0$ (Without Cohesion) (Section 8.1, Design Criteria)

Resultant Within Middle Half of Base: $e \le \frac{L_b}{4} \wedge e \ge \frac{-L_b}{4}$

Allowable Rock Bearing Pressure: $\sigma_{allow.E4} := 1740 \cdot \frac{kN}{m^2}$ (Section 5.2, Design Criteria)

Required Factor of Safety for Flotation: $FS_{req.E.flt} = 1.1$

Overturning Min Required Resultant Ratio: $\frac{X_{R.E}}{Horizontal\_Width\_of\_Base} > 0.167$

INPUT PARAMETERS **E4 CASE**

Headwater Elevation: $HW_{E4} := 1215.80m$

Tailwater Elevation: $TW_{E4} := 1213.1m$

(Water Elevations based on Diversion Structure 2D Hydraulic Model Results. See page 7 and Section 8.2, Design Criteria)

Crest Water Elevation, EL.1215.81 $CrestW_{E4} := 2.87 \cdot m$

Chute Block Water Elevation EL.1208.78 $ChuteW_{E4} := 1.28 \cdot m$

$TW_{E4} := TOC_{fce} + ChuteW_{E4} = 1208.8\,m$

Bottom of Footing Elevation: $BOF_{elev} = 1204.00\,m$

Apron Slab Top of Concrete Elevation at Edge of Slab: $TOC_{as} = 1210.00\,m$

Fixed Crest Top of Concrete Elevation at Downstream Face: $TOC_{fce} = 1207.50\,m$

Fixed Crest Top of Concrete Elevation at Center of Footing: $TOC_{fcc} = 1211.50\,m$

SEISMIC LOAD E4: EDGM Post-Seismic Assessment of Usual Load U2 Event (3 Load Cases)

Seismic Case $Q_{E4.1}$ - 100% Horizontal Seismic Force, No Vertical **E4.1 CASE**

Horizontal Seismic Coefficient: $K_{h.E4.1} := \frac{-2}{3} \cdot 0.26 = -0.17$

Vertical Seismic Coefficient: $K_{v.E4.1} := 0 \frac{-2}{3} \cdot 0.56 \cdot 0.26 = 0$

HORIZONTAL SEISMIC LOADS	Loads	Moment Arm
Horizontal Seismic Component of Concrete Structure:	$Q_{conc.E4.EQh.1} := D_{conc} \cdot K_{h.E4.1} = -9045 \cdot kN$	$Y_{conc.loc} = 6.21\,m$
Horizontal Seismic Component of Vertical Lift Gate:	$Q_{Gate.E4.EQh.1} := D_{Gate} \cdot K_{h.E4.1} = -100.5 \cdot kN$	$Y_{gate} = 8.00\,m$
Horizontal Seismic Component of Headwater on Pier: (Section 7.9, Design Criteria)	$Q_{hwp.E4.EQh.1} := \left(\frac{7}{12}\right) \cdot K_{h.E4.1} \cdot \gamma_w \cdot \left(D_{hwp.U2}\right)^2 \cdot W_{hwp.U2} = -133.9 \cdot kN$	$Y_{HWp.E4} := 0.4 \cdot D_{hwp.U2} + \left(TOC_{as} - BOF_{toe}\right) = 6.82\,m$
Horizontal Seismic Component of Headwater on Gate: (Section 7.9, Design Criteria)	$Q_{hwg.E4.EQh.1} := \left(\frac{7}{12}\right) \cdot K_{h.E4.1} \cdot \gamma_w \cdot \left(D_{hwg.U2}\right)^2 \cdot W_{hwg.U2} \cdot poss_{U2} = 0 \cdot kN$	$Y_{HWg.E4} := 0.4 \cdot D_{hwg.U2} + \left(TOC_{fcc} - BOF_{toe}\right) = 7.72\,m$
Horizontal Seismic Component of Headwater on Footing: (Section 7.9, Design Criteria)	$Q_{hwf.E4.EQh.1} := \left(\frac{7}{12}\right) \cdot K_{h.E4.1} \cdot \gamma_w \cdot \left(D_{hwf.U2}\right)^2 \cdot W_{hw.U2} = -1798.5 \cdot kN$	$Y_{HWf.E4} := 0.4 \cdot \left(TOC_{fcc} - BOF_{toe}\right) = 2.40\,m$
Horizontal Seismic Component of Active Soil: (Section 5-5, USACE EM_1110-2-2100)	$Q_{act.E4.EQh.1} := \gamma_r \cdot \left(TOC_{as} - BOF_{elev}\right)^2 \cdot K_{h.E4.1} \cdot W_{hw.U2} = -1784.6 \cdot kN$	$Y_{E.act.E4} := 0.63 \cdot \left(TOC_{as} - BOF_{toe}\right) = 2.84\,m$

VERTICAL SEISMIC LOADS	Loads	Moment Arm
Vertical Component of Concrete Structure:	$Q_{conc.E4.EQv.1} := D_{conc} \cdot K_{v.E4.1} = 0 \cdot kN$	$X_{conc.loc} = 12.43\,m$
Vertical Component of Vertical Lift Gate:	$Q_{Gate.E4.EQv.1} := D_{Gate} \cdot K_{v.E4.1} = 0 \cdot kN$	$X_{gate} = 9.75\,m$
Vertical Seismic Component of Headwater over Apron Slab: (Section 7.9, Design Criteria)	$Q_{H1.E4.EQv.1} := K_{v.E4.1} \cdot H_{1.U2} = 0 \cdot kN$	$H_{1.U2.loc} = 21.10\,m$
Vertical Seismic Component of Headwater over Fixed Crest Slab: (Section 7.9, Design Criteria)	$Q_{H2.E4.EQv.1} := K_{v.E4.1} \cdot H_{2.U2} = 0 \cdot kN$	$H_{2.U2.loc} = 14.41\,m$

$$\Sigma H_{Q.E4.EQh.1} := Q_{conc.E4.EQh.1} + Q_{Gate.E4.EQh.1} + Q_{hwp.E4.EQh.1} + Q_{hwg.E4.EQh.1} + Q_{hwf.E4.EQh.1} + Q_{act.E4.EQh.1} = -12862.6 \cdot kN$$

$$\Sigma V_{Q.E4.EQv.1} := Q_{conc.E4.EQv.1} + Q_{Gate.E4.EQv.1} + Q_{H1.E4.EQv.1} + Q_{H2.E4.EQv.1} = 0.0 \cdot kN$$

$$\begin{aligned}\Sigma M_{Q.E4.1} := {} & Q_{conc.E4.EQh.1} \cdot Y_{conc.loc} + Q_{Gate.E4.EQh.1} \cdot Y_{gate} + Q_{hwp.E4.EQh.1} \cdot Y_{HWp.E4} + Q_{hwg.E4.EQh.1} \cdot Y_{HWg.E4} \cdots = -67274.4 \cdot kN \cdot m \\ & + Q_{hwf.E4.EQh.1} \cdot Y_{HWf.E4} + Q_{act.E4.EQh.1} \cdot Y_{E.act.E4} + Q_{conc.E4.EQv.1} \cdot X_{conc.loc} + Q_{Gate.E4.EQv.1} \cdot X_{gate} \cdots \\ & + Q_{H1.E4.EQv.1} \cdot H_{1.U2.loc} + Q_{H2.E4.EQv.1} \cdot H_{2.U2.loc}\end{aligned}$$

STABILITY ASSESSMENT:

E4.1 CASE

Seismic Case $Q_{E4.1}$: 100% Horizontal Seismic Force, No Vertical

Sum of Vertical Forces:

$\Sigma V_{E4.1} := \Sigma V_{U2} + \Sigma V_{Q.E4.EQv.1} = 35159.3 \cdot kN$

Sum of Horizontal Forces:

$\Sigma H_{E4.1} := \Sigma H_{U2} + \Sigma H_{Q.E4.EQh.1} = -23545.5 \cdot kN$

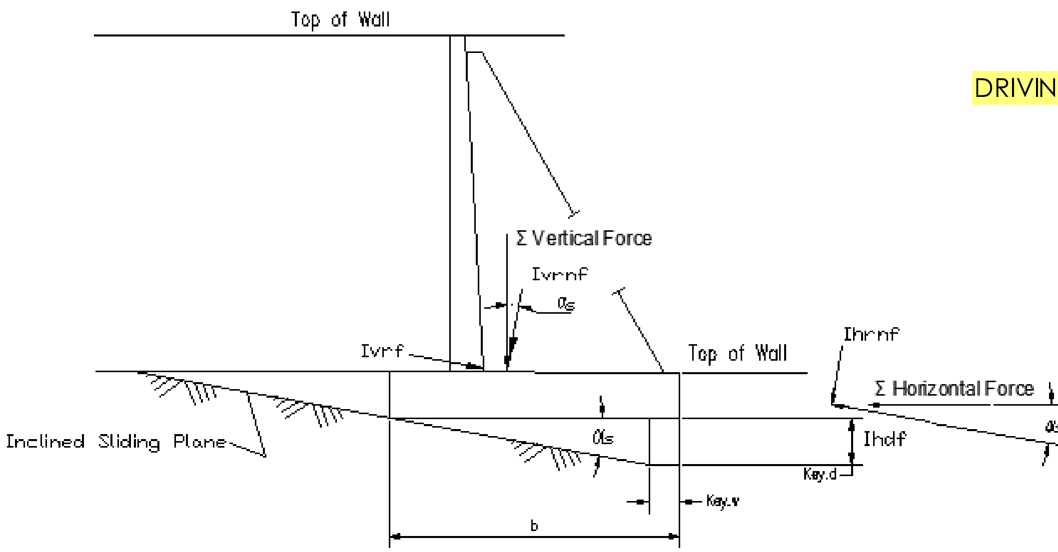
Sliding Factor of Safety:

$$FS_{HorizSliding.E4.1} := \frac{\tan_{\phi} \cdot \Sigma V_{E4.1}}{\left|\Sigma H_{E4.1}\right|} = 0.73$$

$FS_{HorizSliding.E4.1.Check} :=$ | "OKAY" if $FS_{HorizSliding.E4.1} \geq FS_{req.E4.sl}$
"Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !" otherwise

$FS_{HorizSliding.E4.1.Check} =$ "Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !"

CHECK **SLIDING** ALONG INCLINED SLIDING PLANE FROM HEEL KEY TO TOE,
WITH BEDROCK MASS MOBILIZED BY REINFOCREDE CONCRETE KEY



Ivrf=Inclined Resisting Force
Ivrnf=Inclined Resisting Normal Force
Ihrnf=Inclined Resisting Normal Force
Ihdf=Inclined Driving Force

Incline angle: $\alpha s = 0.13$ as degrees= $\alpha s \cdot \left(\frac{180}{\pi}\right) = 7.63$

Resolve $\Sigma Vert_{E4.1}$ & $\Sigma Horiz_{E4.1}$

$$\Sigma V_{InclinedE4.1} := \cos(\alpha s) \cdot \left(\Sigma V_{E4.1} + V_{rs}\right) + \sin(\alpha s) \cdot \left|\Sigma H_{E4.1}\right| = 51075.6 \cdot kN$$

$$\Sigma H_{InclinedE4.1} := \cos(\alpha s) \cdot \left|\Sigma H_{E4.1}\right| - \sin(\alpha s) \cdot \left(\Sigma V_{E4.1} + V_{rs}\right) = 16915.3 \cdot kN$$

(With properly engineered reinforced concrete Key, horizontal sliding plane thru Toe is protected, critical sliding plane is relocated to the INCLINED SLIDING PLANE FROM HEEL KEY To TOE, Bedrock Mass above this examing plane is mobilized by reinforced concrete key and combined into Structural Wedge.)

Safety Factor for Sliding
Inclined Failure Plane

$$FS_{InclinedISlidingE4.1} := \frac{\Sigma V_{InclinedE4.1} \cdot \tan\left(\phi_{rock} \cdot \frac{\pi}{180}\right)}{\left|\Sigma H_{InclinedE4.1}\right|} = 1.47$$

$FS_{Sliding.E4.1.InclinedCheck} :=$ | "OKAY " if $FS_{InclinedISlidingE4.1} > FS_{req.E4.sl}$ = "OKAY "
"Revise Structure"" otherwise

$FS_{Sliding.E4.1.InclinedCheck} =$ "OKAY "

E4.1 CASE

CHECK ECCENTRICITY ON INCLINED PLANE

Seismic Case $Q_{E4.1}$: 100% Horizontal Seismic Force, No Vertical

Sum of the moments:

$$\Sigma M_{rs.E4.1} := \Sigma M_{DL.U2} + \Sigma M_{HWater.U2} + \Sigma M_{Vwater.U2} + \Sigma M_{I.U2} + \Sigma M_{soil.U2} + \Sigma M_{Q.E4.1} + V_{rs} \cdot L_{rs} = 498440 \cdot kN \cdot m$$

Eccentricity:

$$e_{E4.1} := \frac{L_{incline}}{2} - \frac{\Sigma M_{rs.E4.1}}{\Sigma V_{InclinedE4.1}} = 2.36\,m$$

Eccentricity Check:

$$e_{check.E4.1} := \begin{cases} \text{"Okay"} & \text{if } \left|e_{E4.1}\right| \le Ecc_{midhalf} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$$e_{check.E4.1} = \text{"Okay"}$$

Foundation Bearing Pressures on Inclined Plane:

Bearing Pressure at Heel:

$$\sigma_{heel.E4.1} := \begin{cases} 0 & \text{if } \left|e_{E4.1}\right| \ge Ecc_{midhalf} \\ \left(\dfrac{\Sigma V_{InclinedE4.1}}{\dfrac{A_b}{\cos(\alpha s)}} - \dfrac{\Sigma V_{InclinedE4.1} \cdot e_{E4.1}}{\dfrac{S_b}{\cos(\alpha s)^2}} \right) & \text{otherwise} \end{cases} = 67.4 \cdot \frac{kN}{m^2}$$

$$\sigma_{heel.E4.1.check} := \left(\begin{cases} \text{"Okay"} & \text{if } \sigma_{heel.E4.1} \le \sigma_{allow.E4} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} \right)$$

$$\sigma_{heel.E4.1.check} = \text{"Okay"}$$

Bearing Pressure at Toe:

$$\sigma_{toe.E4.1} := \begin{cases} \left[\dfrac{4}{3} \cdot \left(\dfrac{\dfrac{\Sigma V_{InclinedE4.1}}{W_b}}{L_{incline} - 2 \cdot e_{E4.1}} \right) \right] & \text{if } \left|e_{E4.1}\right| \ge Ecc_{midhalf} \\ \left[\dfrac{\Sigma V_{InclinedE4.1}}{\dfrac{A_b}{\cos(\alpha s)}} + \dfrac{\left(\Sigma V_{InclinedE4.1} \cdot e_{E4.1}\right)}{\dfrac{S_b}{\cos(\alpha s)^2}} \right] & \text{otherwise} \end{cases} = 254.4 \cdot \frac{kN}{m^2}$$

$$\sigma_{toe.E4.1.check} := \begin{cases} \text{"Okay"} & \text{if } \sigma_{toe.E4.1} \le \sigma_{allow.E4} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$$\sigma_{toe.E4.1.check} = \text{"Okay"}$$

Foundation Flotation Checks:

$$FS_{Flotation.E4.1} := \frac{D_{conc} + D_{Gate} + H_{1.U2} + H_{2.U2} + H_{3.U2} - \left|\Sigma V_{Q.E4.EQv.1}\right|}{\left|Uplift_{U2}\right|} = 2.4$$

$$Flotation_{E4.1.check} := \begin{cases} \text{"Okay"} & \text{if } FS_{Flotation.E4.1} \ge FS_{req.E.flt} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$$Flotation_{E4.1.check} = \text{"Okay"}$$

MONOLITH OVERTURNING STABILITY ANALYSIS

E4.1 CASE

Seismic Case $Q_{E3.1}$: 100% Horizontal Seismic Force, No Vertical

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.
Assumptions are made in order to compute overturning stability of indetermine forces on monolith with key;
(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.
(b) The horizontal resisting force acting on the key, P.key, is that required for static equilibrium
(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1 $Ratio_{overturning.allow.Extreme} = 0.167$ Resultant within Base

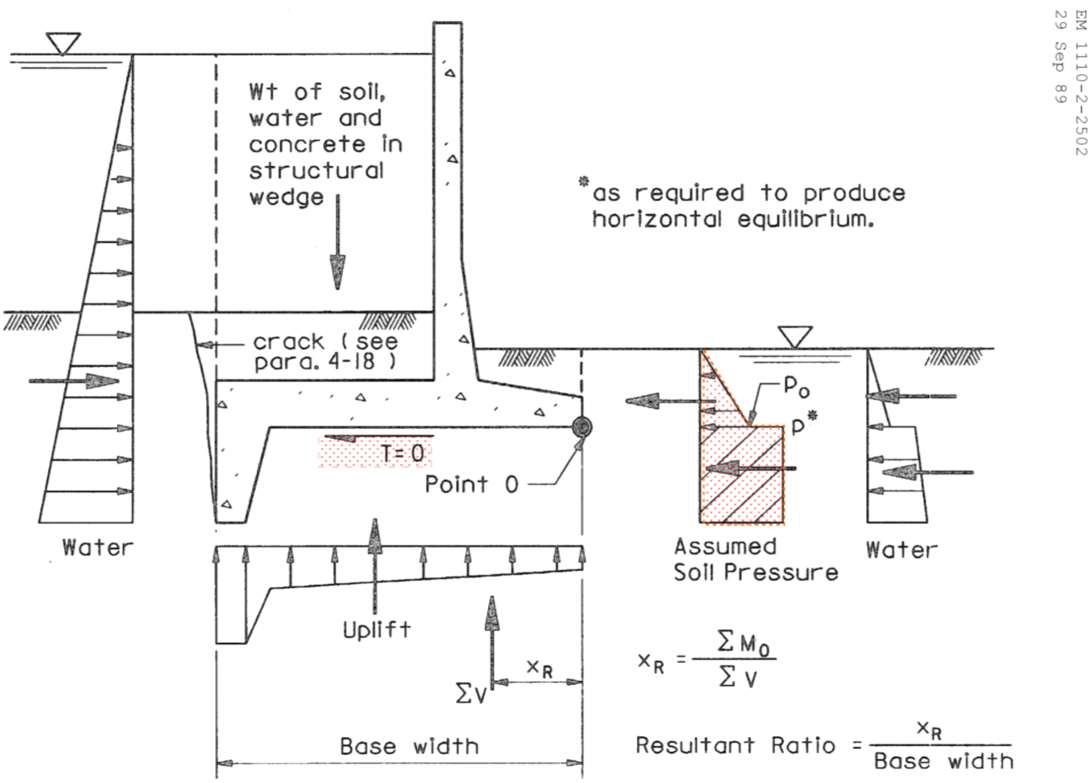


Figure 4-5. Forces for overturning analysis for wall with horizontal base and key

All Vertical Loads Applicable to Overturning Stability Analysis

Total Concrete Dead Loads:	$D_{conc} = 52182.8 \cdot kN$	at:	$X_{conc.loc} = 12.43\,m$
Dead Load of Gate:	$D_{Gate} = 580.0 \cdot kN$		$X_{gate} = 9.75\,m$
Water Weight (HW) on Apron Slab:	$H_{1.U2} = 3320.9 \cdot kN$		$H_{1.U2.loc} = 21.10\,m$
Water Weight (HW) on Fixed Crest:	$H_{2.U2} = 2569.2 \cdot kN$		$H_{2.U2.loc} = 14.41\,m$
Water Weight (TW) on Fixed Crest:	$H_{3.U2} = 2106.6 \cdot kN$		$H_{3.U2.loc} = 5.78\,m$
Vertical Seismic Component of Concrete Structure:	$Q_{conc.E4.EQv.1} = 0$	at:	$X_{conc.loc} = 12.43\,m$
Vertical Seismic Component of Vertical Lift Gate:	$Q_{Gate.E4.EQv.1} = 0$		$X_{gate} = 9.75\,m$
Vertical Seismic Component of Headwater over Apron Slab:	$Q_{H1.E4.EQv.1} = 0$		$H_{1.U2.loc} = 21.10\,m$
Vertical Seismic Component of Headwater over Fixed Crest Slab:	$Q_{H2.E4.EQv.1} = 0$		$H_{2.U2.loc} = 14.41\,m$

E4.1 CASE

Uplift for Overturning Analysis, Line of Creep Method. Pore pressure at base of Concrete, first calculation to presumed inclined straight line from Heel to Toe, thereafter by Archimedes Principle.

$$U_{E4.1.loc.sliding} := \frac{U_{A.U2} \cdot L_{A.U2} + U_{B.U2} \cdot L_{B.U2} - A_{rs} \cdot w_{as} \cdot \gamma_w \cdot L_{rs}}{U_{A.U2} + U_{B.U2} - A_{rs} \cdot w_{as} \cdot \gamma_w} = 13.84\,m$$

$$U_{E4.1.sliding} := U_{U2} + A_{rs} \cdot w_{as} \cdot \gamma_w = -19705.8 \cdot kN$$

Uplift for Overturning Analysis, Line of Creep Method. Pore pressure at base of Concrete $\quad Uplift_{pore.U1} = -11398 \cdot kN$

$$Uplift_{pore.E4.1.loc} := \frac{Uplift_{BC.U2} \cdot Uplift_{BC.U2.loc} + Uplift_{DE.U2} \cdot Uplift_{DE.U2.loc} + Uplift_{EF.U2} \cdot Uplift_{EF.U2.loc} + Uplift_{FG.U2} \cdot Uplift_{FG.U2.loc}}{Uplift_{pore.U2}}$$

$$Uplift_{pore.E4.1.loc} = 13.3\,m$$

Sum of All Water Load for Overturning Analysis $\quad \Sigma V_{water.E4.1.OT} := H_{1.U1} + H_{2.U1} + H_{3.U1} + Uplift_{pore.U2} = -16995.1 \cdot kN$

All Lateral Loads Applicable to Overturning Stability Analysis

Apply Load to Gate?: $\quad poss_{U1} = 1 \quad$ poss = 1 if gate is closed, 0 if gate is open

Headwater Lateral Load on Pier: $\quad H_{hwp.U2} = -662.3 \cdot kN \quad$ at: $\quad H_{hwp.U2.loc} = 6.44\,m$

Headwater Lateral Load on Gate: $\quad H_{hwg.U2} = 0.0 \cdot kN \quad H_{hwg.U2.loc} = 7.44\,m$

Headwater Lateral Load on Footing: $\quad H_{hwf.U2} = -7709.2 \cdot kN \quad H_{hwf.U2.loc} = 1.67\,m$

Total Horizontal Tailwater Load on Pier: $\quad H_{twp.U2} = 448.3 \cdot kN \quad H_{twp.U2.loc} = 0.09\,m$

Total Horizontal Tailwater Load on Footing under Gate Openings, i.e., excluding Pier $\quad H_{twf.U2} = 1008.6 \cdot kN \quad H_{twf.U2.loc} = 0.09\,m$

Resisting Water on Rear Face of Monolith, i.e., bottom of heel elevation: $\quad$ *(Point O @ TOE: BOFtoe = EL.1205.5)*

Horizontal Seismic Component of Concrete Structure: $\quad Q_{conc.E4.EQh.1} = -9045 \cdot kN \quad$ AT $\quad Y_{conc.loc} = 6.21\,m$

Horizontal Seismic Component of Vertical Lift Gate: $\quad Q_{Gate.E4.EQh.1} = -100.5 \cdot kN \quad Y_{gate} = 8.00\,m$

Horizontal Seismic Component of Headwater on Pier: $\quad Q_{hwp.E4.EQh.1} = -133.9 \cdot kN \quad Y_{HWp.E4} = 6.8\,m$

Horizontal Seismic Component of Headwater on Gate: $\quad Q_{hwg.E4.EQh.1} = 0 \quad Y_{HWg.E4} = 7.7\,m$

Horizontal Seismic Component of Headwater on Footing: $\quad Q_{hwf.E4.EQh.1} = -1798.5 \cdot kN \quad Y_{HWf.E4} = 2.4\,m$

Horizontal Seismic Component of Active Soil: (Section 5-5, USACE EM_1110-2-2100) $\quad Q_{act.E4.EQh.1} = -1784.6 \cdot kN \quad Y_{E.act.E4} = 2.8\,m$

Ice / Impact Load: $\quad I_{U2} = -2100.0 \cdot kN \quad$ at: $\quad I_{U2.loc} = 10.01\,m$

Depth of Fill at Heel Side for Overturning Analysis (neglecting resistance by driving below Point O): $\quad t_{hf.E4.1} := TOC_{as} - BOF_{toe} = 4.50\,m$

Driving Soil Load for overturning: $\quad E1_{drive.E4.1} := \frac{K_o \cdot t_{hf.U2}^{\ 2}}{2} \cdot (\gamma_r - \gamma_w) \cdot W_b \cdot -1 = -1055.7 \cdot kN$

Acting at: $\quad E1_{drive.loc.E4.1} := \frac{t_{hf.E4.1}}{3} = 1.50\,m$

E4.1 CASE

Downstream (resisting) Lateral Soil Load as required to produce horizontal equilibrium:

$$E2_{resistE4.1} := -1 \cdot \left(H_{hwp.U2} + H_{hwg.U2} + H_{hwf.U2} + H_{twp.U2} + H_{twf.U2} + I_{U2} + E1_{drive.U2}\right) = 10070.3 \cdot kN$$

Assumed Resisting Bedrock at middle of Key, passive soil pressure or lateral bearing contract joint at end of Monolith 3A3B

$$E2_{resistlocE4.1} := E2_{resistlocU2} = -0.75\,m$$

Overturning moment by Dead Loads about Point O @ Toe

$$\Sigma M_{DL.U2} = 654229.9 \cdot kN \cdot m$$

Overturning moment by Vertical Water Loads and Uplift, about Point O @ Toe

$$\Sigma M_{Vwater.U2} = -234242.4 \cdot kN \cdot m$$

Overturning moment by Lateral Hydrostatic Forces of Headwater Pool and Tailwater Pool,about Point O @ Toe

$$\Sigma M_{HWater.U2} = -16989.2 \cdot kN \cdot m$$

Overturning Moment by Impact/Ice Load, about Point O@ Toe

$$\Sigma M_{I.U2} = -21021 \cdot kN \cdot m$$

Overturning moment by Lateral Soil Forces about Point O @ Toe

$$\Sigma M_{soil.E4.1} := E1_{drive.E4.1} \cdot E1_{drive.loc.E4.1} \ldots + E2_{resistE4.1} \cdot E2_{resistlocE4.1} = -9136.3 \cdot kN \cdot m$$

Sum of the Overturning Moments about Point O @ Toe:

$$\Sigma M_{E4.1.OT} := \Sigma M_{DL.U2} + \Sigma M_{HWater.U2} + \Sigma M_{Vwater.U2.OT} + \Sigma M_{I.U2} + \Sigma M_{soil.E4.1} + \Sigma M_{Q.E4.1} = 410713 \cdot kN \cdot m$$

Sum of Vertical Forces:

$$\Sigma V_{E4.1.OT} := \Sigma V_{DL.U2} + \Sigma V_{water.U2.OT} + \left|\Sigma V_{Q.E4.EQv.1}\right| = 42086.2 \cdot kN$$

Distance X_R: EM 1110-2-2502 Eq.4-1

$$X_{R.E4.1} := \frac{\Sigma M_{E4.1.OT}}{\Sigma V_{E4.1.OT}} = 9.8\,m$$

Overturning Resultant Ratio

$$Ratio_{Overturning.E4.1} := \frac{X_{R.E4.1}}{L_b} = 0.40$$

EM 1110-2-2502

Table 4-1

Retaining Wall Stability Criteria

Loading Condition	Sliding Factor of Safety, FS	Shear Strength Test Required: Soil Foundation	Shear Strength Test Required: Rock Foundation[3]	Overturning Criteria Minimum Base Area in Compression: Soil Foundation	Overturning Criteria Minimum Base Area in Compression: Rock Foundation
Usual	1.5	(Q &/or S)[2,1]	Direct shear	100%[4]	75%[4]
Unusual	1.33	(Q &/or S)[2,1]	Direct shear	75%[4]	50%[4]
Earthquake	1.1	(Q)	Direct shear	Resultant within base	Resultant within base

Overturning Stability Check

$$Ratio_{Overturning.E4.1.check} := \begin{cases} \text{"Okay"} & \text{if } Ratio_{Overturning.E4.1} \ge Ratio_{overturning.allow.Extreme} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$$Ratio_{Overturning.E4.1.check} = \text{"Okay"}$$

Summary of Seismic Results (Only Report Controlling Load Case)

E4.1 CASE

Seismic Case $Q_{E4.1}$: 100% Horizontal Seismic Force, No Vertical

Horiz Sliding Factor of Safety:	$FS_{HorizSliding.E4.1} = 0.73$
Horiz Sliding Factor of Safety Check:	$FS_{HorizSliding.E4.1.Check}$ = "Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !"
Sliding Factor of Safety:	$FS_{InclinedlSlidingE4.1} = 1.5$
Sliding Factor of Safety Check:	$FS_{Sliding.E4.1.InclinedCheck}$ = "OKAY "
Eccentricity:	$e_{E4.1} = 2.36\,m$
Eccentricity Check:	$e_{check.E4.1}$ = "Okay"
Bearing Pressure At Heel on Inclined Plane:	$\sigma_{heel.E4.1} = 67.4 \cdot \frac{kN}{m^2}$
Bearing Pressure At Heel Check:	$\sigma_{heel.E4.1.check}$ = "Okay"
Bearing Pressure At Toe on Inclined Plane:	$\sigma_{toe.E4.1} = 254.4 \cdot \frac{kN}{m^2}$
Bearing Pressure At Toe Check:	$\sigma_{toe.E4.1.check}$ = "Okay"
Flotation Factor of Safety	$FS_{Flotation.E4.1} = 2.4$
Flotation Factor of Safety Check:	$Flotation_{E4.1.check}$ = "Okay"
Overturning Resultant Ratio	$Ratio_{Overturning.E4.1} = 0.40$
Overturning Stability Check	$Ratio_{Overturning.E4.1.check}$ = "Okay"

SEISMIC LOAD E3: EDGM Post-Seismic Assessment of Usual Load U1 Event (3 Load Cases)

Seismic Case $Q_{E3.2}$ - 100% Horizontal Seismic Force, 30% Vertical **E3.2 CASE**

Horizontal Seismic Coefficient: $K_{h.E3.2} := \frac{-2}{3} \cdot 0.26 = -0.17$

Vertical Seismic Coefficient: $K_{v.E3.2} := 0.3 \cdot \frac{-2}{3} \cdot 0.56 \cdot 0.26 = -0.03$

HORIZONTAL SEISMIC LOADS	Loads	Moment Arm
Horizontal Seismic Component of Concrete Structure:	$Q_{conc.E3.EQh.2} := D_{conc} \cdot K_{h.E3.2} = -9045 \cdot kN$	$Y_{conc.loc} = 6.21\,m$
Horizontal Seismic Component of Vertical Lift Gate:	$Q_{Gate.E3.EQh.2} := D_{Gate} \cdot K_{h.E3.2} = -100.5 \cdot kN$	$Y_{gate} = 8.00\,m$
Horizontal Seismic Component of Headwater on Pier: (Section 7.9, Design Criteria)	$Q_{hwp.E3.EQh.2} := \left(\frac{7}{12}\right) \cdot K_{h.E3.2} \cdot \gamma_w \cdot \left(D_{hwp.U1}\right)^2 \cdot W_{hwp.U1} = -17.5 \cdot kN$	$Y_{HWp.E3} = 5.34\,m$
Horizontal Seismic Component of Headwater on Gate: (Section 7.9, Design Criteria)	$Q_{hwg.E3.EQh.2} := \left(\frac{7}{12}\right) \cdot K_{h.E3.2} \cdot \gamma_w \cdot \left(D_{hwg.U1}\right)^2 \cdot W_{hwg.U1} \cdot poss_{U1} = -7.1 \cdot kN$	$Y_{HWg.E3} = 6.24\,m$
Horizontal Seismic Component of Headwater on Footing: (Section 7.9, Design Criteria)	$Q_{hwf.E3.EQh.2} := \left(\frac{7}{12}\right) \cdot K_{h.E3.2} \cdot \gamma_w \cdot \left(D_{hwf.U1}\right)^2 \cdot W_{hw.U1} = -846 \cdot kN$	$Y_{HWf.E3} = 2.40\,m$
Horizontal Seismic Component of Active Soil: (Section 5-5, USACE EM_1110-2-2100)	$Q_{act.E3.EQh.2} := \gamma_r \cdot \left(TOC_{as} - BOF_{elev}\right)^2 \cdot K_{h.E3.2} \cdot W_{hw.U1} = -1784.6 \cdot kN$	$Y_{E.act.E3} = 2.84\,m$

VERTICAL SEISMIC LOADS	Loads	Moment Arm
Vertical Component of Concrete Structure:	$Q_{conc.E3.EQv.2} := D_{conc} \cdot K_{v.E3.2} = -1519.6 \cdot kN$	$X_{conc.loc} = 12.43\,m$
Vertical Component of Vertical Lift Gate:	$Q_{Gate.E3.EQv.2} := D_{Gate} \cdot K_{v.E3.2} = -16.9 \cdot kN$	$X_{gate} = 9.75\,m$
Vertical Seismic Component of Headwater over Apron Slab: (Section 7.9, Design Criteria)	$Q_{H1.E3.EQv.2} := K_{v.E3.2} \cdot H_{1.U1} = -36.1 \cdot kN$	$H_{1.U1.loc} = 21.10\,m$
Vertical Seismic Component of Headwater over Fixed Crest Slab: (Section 7.9, Design Criteria)	$Q_{H2.E3.EQv.2} := K_{v.E3.2} \cdot H_{2.U1} = -12.8 \cdot kN$	$H_{2.U1.loc} = 14.25\,m$

$$\Sigma H_{Q.E3.EQh.2} := Q_{conc.E3.EQh.2} + Q_{Gate.E3.EQh.2} + Q_{hwp.E3.EQh.2} + Q_{hwg.E3.EQh.2} + Q_{hwf.E3.EQh.2} + Q_{act.E3.EQh.2} = -11800.9 \cdot kN$$

$$\Sigma V_{Q.E3.EQv.2} := Q_{conc.E3.EQv.2} + Q_{Gate.E3.EQv.2} + Q_{H1.E3.EQv.2} + Q_{H2.E3.EQv.2} = -1585.3 \cdot kN$$

$$\begin{aligned}\Sigma M_{Q.E3.2} := {} & Q_{conc.E3.EQh.2} \cdot Y_{conc.loc} + Q_{Gate.E3.EQh.2} \cdot Y_{gate} + Q_{hwp.E3.EQh.2} \cdot Y_{HWp.E3} + Q_{hwg.E3.EQh.2} \cdot Y_{HWg.E3} \cdots = -84207.1 \cdot kN \cdot m \\ & + Q_{hwf.E3.EQh.2} \cdot Y_{HWf.E3} + Q_{act.E3.EQh.2} \cdot Y_{E.act.E3} + Q_{conc.E3.EQv.2} \cdot X_{conc.loc} + Q_{Gate.E3.EQv.2} \cdot X_{gate} \cdots \\ & + Q_{H1.E3.EQv.2} \cdot H_{1.U1.loc} + Q_{H2.E3.EQv.2} \cdot H_{2.U1.loc}\end{aligned}$$

E3.2 CASE

STABILITY ASSESSMENT:

CHECK **SLIDING** ALONG HORIZONTAL PLANE THRU TOE,
IGNORING BEDROCK MOBILIZED BY STRUCTURAL HEEL KEY, OR VOID BEHIND KEY

Sum of Vertical Forces:

$\Sigma V_{E3.2} := \Sigma V_{U1} + \Sigma V_{Q.E3.EQv.2} = 34636.6 \cdot kN$

Sum of Horizontal Forces:

$\Sigma H_{E3.2} := \Sigma H_{U1} + \Sigma H_{Q.E3.EQh.2} = -19070.6 \cdot kN$

Sliding Factor of Safety:

$$FS_{HorizSliding.E3.2} := \frac{\tan_{\phi} \cdot \Sigma V_{E3.2}}{\left|\Sigma H_{E3.2}\right|} = 0.89$$

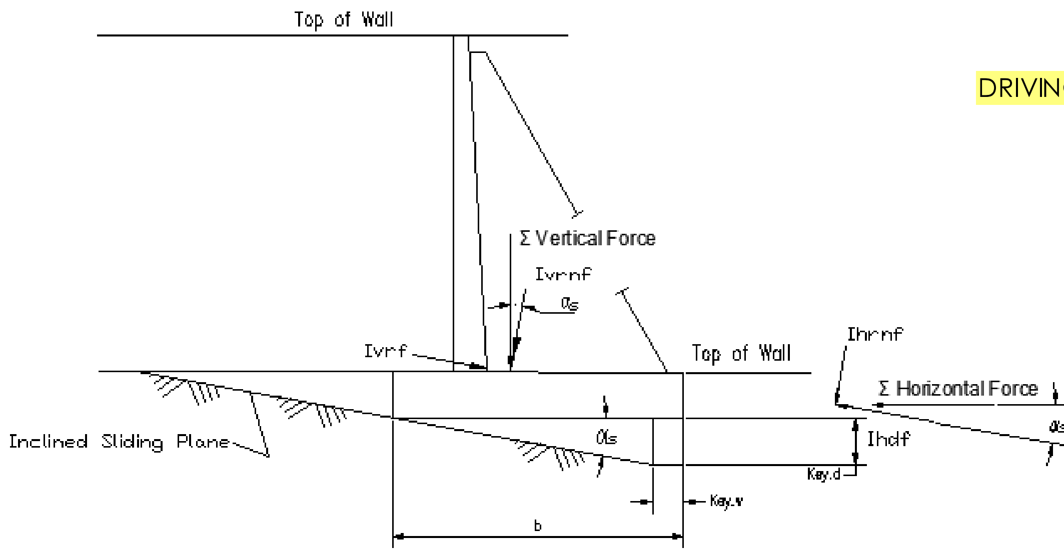
$$FS_{HorizSliding.E3.2.Check} := \begin{cases} \text{"OKAY"} & \text{if } FS_{HorizSliding.E3.2} \geq FS_{req.E3.sl} \\ \text{"Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !"} & \text{otherwise} \end{cases}$$

$FS_{HorizSliding.E3.2.Check} =$ "Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !"

CHECK **SLIDING** ALONG INCLINED SLIDING PLANE FROM HEEL KEY TO TOE,
WITH BEDROCK MASS MOBILIZED BY REINFOCREDE CONCRETE KEY)

RESISTING SIDE

DRIVING SIDE



TOE

HEEL

Ivrf=Inclined Resisting Force
Ivrnf=Inclined Resisting Normal Force
Ihrnf=Inclined Resisting Normal Force
Ihdf=Inclined Driving Force

Incline angle: $\alpha s = 0.13$ $\quad \alpha s \cdot \left(\frac{180}{\pi}\right) = 7.63$

Resolve $\Sigma Vert_{E3.2}$ & $\Sigma Horiz_{E3.2}$

$$\Sigma V_{InclinedE3.2} := \cos(\alpha s) \cdot \left(\Sigma V_{E3.2} + V_{rs}\right) + \sin(\alpha s) \cdot \left|\Sigma H_{E3.2}\right| = 49963.5 \cdot kN$$

$$\Sigma H_{InclinedE3.2} := \cos(\alpha s) \cdot \left|\Sigma H_{E3.2}\right| - \sin(\alpha s) \cdot \left(\Sigma V_{E3.2} + V_{rs}\right) = 12549.3 \cdot kN$$

(With properly engineered reinforced concrete Key, horizontal sliding plane thru Toe is protected, critical sliding plane is relocated to the INCLINED SLIDING PLANE FROM HEEL KEY To TOE, Bedrock Mass above this examing plane is mobilized by reinforced concrete key and combined into Structural Wedge.)

Safety Factor for Sliding
Inclined Failure Plane

$$FS_{InclinedlSlidingE3.2} := \frac{\Sigma V_{InclinedE3.2} \cdot \tan\left(\phi_{rock} \cdot \frac{\pi}{180}\right)}{\left|\Sigma H_{InclinedE3.2}\right|} = 1.94$$

$$FS_{Sliding.E3.2.InclinedCheck} := \begin{cases} \text{"OKAY "} & \text{if } FS_{InclinedlSlidingE3.2} > FS_{req.E3.sl} \\ \text{"Revise Structure""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

$FS_{Sliding.E3.2.InclinedCheck} =$ "OKAY "

CHECK ECCENTRICITY ON INCLINED PLANE

E3.2 CASE

Seismic Case $Q_{E3.2}$: 100% Horizontal Seismic Force, 30% Vertical

Sum of the moments:

$$\Sigma M_{rs.E3.2} := \Sigma M_{DL.U1} + \Sigma M_{HWater.U1} + \Sigma M_{Vwater.U1} + \Sigma M_{I.U1} + \Sigma M_{soil.U1} + \Sigma M_{Q.E3.2} + V_{rs} \cdot L_{rs} = 518789 \cdot kN \cdot m$$

Eccentricity:

$$e_{E3.2} := \frac{L_{incline}}{2} - \frac{\Sigma M_{rs.E3.2}}{\Sigma V_{InclinedE3.2}} = 1.74\,m$$

Eccentricity Check:

$$e_{check.E3.2} := \begin{cases} \text{"Okay"} & \text{if } \left|e_{E3.2}\right| \le Ecc_{midhalf} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$e_{check.E3.2} = \text{"Okay"}$

Foundation Bearing Pressures on Inclined Plane:

Bearing Pressure at Heel:

$$\sigma_{heel.E3.2} := \begin{cases} 0 & \text{if } \left|e_{E3.2}\right| \ge Ecc_{midhalf} \\ \left(\dfrac{\Sigma V_{InclinedE3.2}}{\dfrac{A_b}{\cos(\alpha s)}} - \dfrac{\Sigma V_{InclinedE3.2} \cdot e_{E3.2}}{\dfrac{S_b}{\cos(\alpha s)^2}} \right) & \text{otherwise} \end{cases} = 90.1 \cdot \frac{kN}{m^2}$$

$$\sigma_{heel.E3.2.check} := \left(\begin{cases} \text{"Okay"} & \text{if } \sigma_{heel.E3.2} \le \sigma_{allow.E3} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} \right)$$

$\sigma_{heel.E3.2.check} = \text{"Okay"}$

Bearing Pressure at Toe:

$$\sigma_{toe.E3.2} := \begin{cases} \left[\dfrac{4}{3} \cdot \left[\dfrac{\left(\dfrac{\Sigma V_{InclinedE3.2}}{W_b} \right)}{L_{incline} - 2 \cdot e_{E3.2}} \right] \right] & \text{if } e_{E3.2} \ge Ecc_{midhalf} \\ \left[\dfrac{\Sigma V_{InclinedE3.2}}{\dfrac{A_b}{\cos(\alpha s)}} + \dfrac{\left(\Sigma V_{InclinedE3.2} \cdot e_{E3.2}\right)}{\dfrac{S_b}{\cos(\alpha s)^2}} \right] & \text{otherwise} \end{cases} = 224.7 \cdot \frac{kN}{m^2}$$

$$\sigma_{toe.E3.2.check} := \begin{cases} \text{"Okay"} & \text{if } \sigma_{toe.E3.2} \le \sigma_{allow.E3} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$\sigma_{toe.E3.2.check} = \text{"Okay"}$

Foundation Flotation Checks:

$$FS_{Flotation.E3.2} := \frac{D_{conc} + D_{Gate} + H_{1.U1} + H_{2.U1} + H_{3.U1} - \left|\Sigma V_{Q.E3.EQv.2}\right|}{\left|Uplift_{U1}\right|} = 3$$

$$Flotation_{E3.2.check} := \begin{cases} \text{"Okay"} & \text{if } FS_{Flotation.E3.2} \ge FS_{req.E.flt} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$Flotation_{E3.1.check} = \text{"Okay"}$

MONOLITH OVERTURNING STABILITY ANALYSIS

Seismic Case $Q_{E3.2}$: 100% Horizontal Seismic Force, 30% Vertical

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.

Assumptions are made in order to compute overturning stability of indetermine forces on monolith with key;

(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.

(b) The horizontal resisting force acting on the key, P.key, is that required for static equilibrium

(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1 $Ratio_{overturning.allow.Extreme} := 0.167$ Resultant within Middle Half

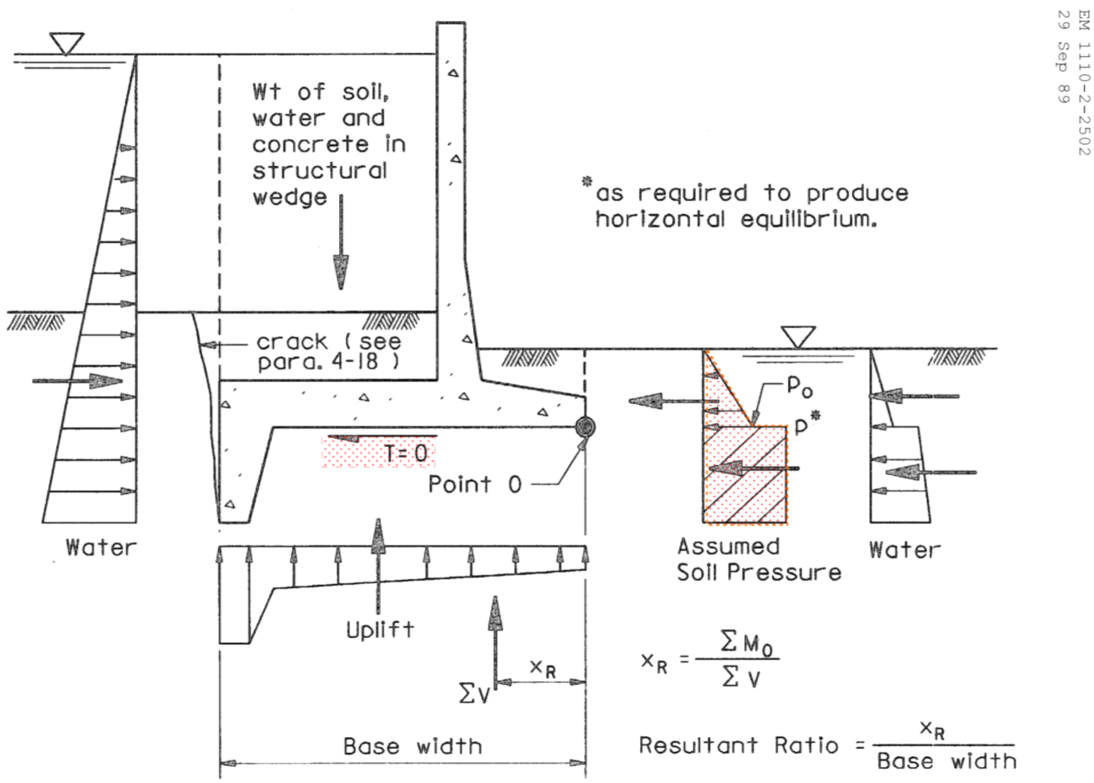


Figure 4-5. Forces for overturning analysis for wall with horizontal base and key

All Vertical Loads Applicable to Overturning Stability Analysis

Total Concrete Dead Loads:	$D_{conc} = 52182.8 \cdot kN$	at:	$X_{conc.loc} = 12.43\,m$
Dead Load of Gate:	$D_{Gate} = 580.0 \cdot kN$		$X_{gate} = 9.75\,m$
Water Weight (HW) on Apron Slab:	$H_{1.U1} = 1238.5 \cdot kN$		$H_{1.U1.loc} = 21.10\,m$
Water Weight (HW) on Fixed Crest:	$H_{2.U1} = 439.7 \cdot kN$		$H_{2.U1.loc} = 14.25\,m$
Water Weight (TW) on Fixed Crest:	$H_{3.U1} = 0.0 \cdot kN$		$H_{3.U1.loc} = 0.00\,m$

Vertical Seismic Component of Concrete Structure:	$Q_{conc.E3.EQv.2} = -1519.6 \cdot kN$	at:	$X_{conc.loc} = 12.43\,m$
Vertical Seismic Component of Vertical Lift Gate:	$Q_{Gate.E3.EQv.2} = -16.9 \cdot kN$		$X_{gate} = 9.75\,m$
Vertical Seismic Component of Headwater over Apron Slab:	$Q_{H1.E3.EQv.2} = -36.1 \cdot kN$		$H_{1.U1.loc} = 21.10\,m$
Vertical Seismic Component of Headwater over Fixed Crest Slab:	$Q_{H2.E3.EQv.2} = -12.8 \cdot kN$		$H_{2.U1.loc} = 14.25\,m$

E3.2 CASE

Uplift for Overturning Analysis, Line of Creep Method. Pore pressure at base of Concrete, first calculation to presumed inclined straight line from Heel to Toe, thereafter by Archimedes Principle.

$$U_{E3.2.loc.sliding} := \frac{U_{A.U1} \cdot L_{A.U1} + U_{B.U1} \cdot L_{B.U1} - A_{rs} \cdot w_{as} \cdot \gamma_w \cdot L_{rs}}{U_{A.U1} + U_{B.U1} - A_{rs} \cdot w_{as} \cdot \gamma_w} = 13.76\,m$$

$$U_{E3.2.sliding} := U_{U1} + A_{rs} \cdot w_{as} \cdot \gamma_w = -12005.7 \cdot kN$$

Uplift for Overturning Analysis, Line of Creep Method. Pore pressure at base of Concrete $\quad Uplift_{pore.U1} = -11398 \cdot kN$

$$Uplift_{pore.E3.2.loc} := \frac{Uplift_{BC.U1} \cdot Uplift_{BC.U1.loc} + Uplift_{DE.U1} \cdot Uplift_{DE.U1.loc} + Uplift_{EF.U1} \cdot Uplift_{EF.U1.loc} + Uplift_{FG.U1} \cdot Uplift_{FG.U1.loc}}{Uplift_{pore.U1}}$$

$$Uplift_{pore.E3.2.loc} = 13.1\,m$$

Sum of All Water Load for Overturning Analysis $\quad \Sigma V_{water.E3.2.OT} := H_{1.U1} + H_{2.U1} + H_{3.U1} + Uplift_{pore.U1} = -9719.8 \cdot kN$

All Lateral Loads Applicable to Overturning Stability Analysis

Apply Load to Gate?:	$poss_{U1} = 1$		poss = 1 if gate is closed 0 if gate is open
Headwater Lateral Load on Pier:	$H_{hwp.U1} = -86.5 \cdot kN$	at:	$H_{hwp.U1.loc} = 5.20\,m$
Headwater Lateral Load on Gate:	$H_{hwg.U1} = -35.3 \cdot kN$		$H_{hwg.U1.loc} = 6.20\,m$
Headwater Lateral Load on Footing:	$H_{hwf.U1} = -4160.7 \cdot kN$		$H_{hwf.U1.loc} = 1.17\,m$
Total Horizontal Tailwater Load on Pier:	$H_{twp.U1} = 240.3 \cdot kN$		$H_{twp.U1.loc} = -0.33\,m$
Total Horizontal Tailwater Load on Footing under Gate Openings, i.e., excluding Pier	$H_{twf.U1} = 540.8 \cdot kN$		$H_{twf.U1.loc} = -0.33\,m$
Resisting Water on Rear Face of Monolith, i.e., bottom of heel elevation:			*(Point O @ TOE: BOFtoe = EL.1205.5)*
Horizontal Seismic Component of Concrete Structure:	$Q_{conc.E3.EQh.2} = -9045 \cdot kN$	AT	$Y_{conc.loc} = 6.21\,m$
Horizontal Seismic Component of Vertical Lift Gate:	$Q_{Gate.E3.EQh.2} = -100.5 \cdot kN$		$Y_{gate} = 8.00\,m$
Horizontal Seismic Component of Headwater on Pier:	$Q_{hwp.E3.EQh.2} = -17.5 \cdot kN$		$Y_{HWp.E3} = 5.3\,m$
Horizontal Seismic Component of Headwater on Gate:	$Q_{hwg.E3.EQh.2} = -7.1 \cdot kN$		$Y_{HWg.E3} = 6.2\,m$
Horizontal Seismic Component of Headwater on Footing:	$Q_{hwf.E3.EQh.2} = -846 \cdot kN$		$Y_{HWf.E3} = 2.4\,m$
Horizontal Seismic Component of Active Soil: (Section 5-5, USACE EM_1110-2-2100)	$Q_{act.E3.EQh.2} = -1784.6 \cdot kN$		$Y_{E.act.E3} = 2.8\,m$
Ice / Impact Load:	$I_{U1} = -2100.0 \cdot kN$	at:	$I_{U1.loc} = 6.30\,m$

Depth of Fill at Heel Side for Overturning Analysis (neglecting resistance by driving below Point O): $\quad t_{hf.E3.2} := TOC_{as} - BOF_{toe} = 4.50\,m$

Driving Soil Load for overturning:

$$E1_{drive.E3.2} := \frac{K_o \cdot t_{hf.U1}^{\,2}}{2} \cdot \left(\gamma_r - \gamma_w\right) \cdot W_b \cdot -1 = -1055.7 \cdot kN$$

Acting at:

$$E1_{drive.loc.E3.2} := \frac{t_{hf.E3.2}}{3} = 1.50\,m$$

Downstream (resisting) Lateral Soil Load as required to produce horizontal equilibrium:

$$E2_{resistE3.2} := -1\cdot\left(H_{hwp.U1} + H_{hwg.U1} + H_{hwf.U1} + H_{twp.U1} + H_{twf.U1} + I_{U1} + E1_{drive.U1}\right) = 6657.1\cdot kN$$

Assumed Resisting Bedrock at middle of Key, passive soil pressure or lateral bearing contract joint at end of Monolith 3A3B

$$E2_{resistlocE3.2} := E2_{resistlocU1} = -0.75\,m$$

Overturning moment by Dead Loads about Point O @ Toe

$$\Sigma M_{DL.U1} = 651119.6\cdot kN\cdot m$$

Overturning moment by Vertical Water Loads and Uplift, about Point O @ Toe

$$\Sigma M_{Vwater.U1} = -212822.7\cdot kN\cdot m$$

Overturning moment by Lateral Hydrostatic Forces of Headwater Pool and Tailwater Pool,about Point O @ Toe

$$\Sigma M_{HWater.U1} = -5807.3\cdot kN\cdot m$$

Overturning Moment by Impact/Ice Load, about Point O@ Toe

$$\Sigma M_{I.U1} = -13230\cdot kN\cdot m$$

Overturning moment by Lateral Soil Forces about Point O @ Toe

$$\Sigma M_{soil.E3.2} := E1_{drive.E3.3}\cdot E1_{drive.loc.E3.3} \cdots + E2_{resistE3.2}\cdot E2_{resistlocE3.2} = -6576.4\cdot kN\cdot m$$

Sum of the Overturning Moments about Point O @ Toe:

$$\Sigma M_{E3.2.OT} := \Sigma M_{DL.U1} + \Sigma M_{HWater.U1} + \Sigma M_{Vwater.U1.OT} + \Sigma M_{I.U1} + \Sigma M_{soil.E3.2} + \Sigma M_{Q.E3.2} = 424284\cdot kN\cdot m$$

Sum of Vertical Forces:

$$\Sigma V_{E3.2.OT} := \Sigma V_{DL.U1} + \Sigma V_{water.U1.OT} + \left|\Sigma V_{Q.E3.EQv.2}\right| = 44309.4\cdot kN$$

Distance X_R: EM 1110-2-2502 Eq.4-1

$$X_{R.E3.2} := \frac{\Sigma M_{E3.2.OT}}{\Sigma V_{E3.2.OT}} = 9.6\,m$$

Overturning Resultant Ratio

$$Ratio_{Overturning.E3.2} := \frac{X_{R.E3.2}}{L_b} = 0.4$$

EM 1110-2-2502

Table 4-1

Retaining Wall Stability Criteria

Loading Condition	Sliding Factor of Safety, FS	Shear Strength Test Required: Soil Foundation	Shear Strength Test Required: Rock Foundation[3]	Overturning Criteria Minimum Base Area in Compression: Soil Foundation	Overturning Criteria Minimum Base Area in Compression: Rock Foundation
Usual	1.5	(Q &/or S)[2,1]	Direct shear	100%[4]	75%[4]
Unusual	1.33	(Q &/or S)[2,1]	Direct shear	75%[4]	50%[4]
Earthquake	1.1	(Q)	Direct shear	Resultant within base	Resultant within base

Overturning Stability Check

$$Ratio_{Overturning.E3.2.check} := \begin{cases} \text{"Okay"} & \text{if } Ratio_{Overturning.E3.2} \ge Ratio_{overturning.allow.Extreme} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$$Ratio_{Overturning.E3.2.check} = \text{"Okay"}$$

Summary of Seismic Results (Only Report Controlling Load Case)

E3.2 CASE

Seismic Case $Q_{E3.2}$: 100% Horizontal Seismic Force, 30% Vertical

Horiz Sliding Factor of Safety: $FS_{HorizSliding.E3.2} = 0.89$

Horiz Sliding Factor of Safety Check: $FS_{HorizSliding.E3.2.Check} =$ "Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !"

Sliding Factor of Safety: $FS_{InclinedlSlidingE3.2} = 1.9$

Sliding Factor of Safety Check: $FS_{Sliding.E3.2.InclinedCheck} =$ "OKAY "

Eccentricity: $e_{E3.2} = 1.74\,m$

Eccentricity Check: $e_{check.E3.2} =$ "Okay"

Bearing Pressure At Heel on Inclined Plane: $\sigma_{heel.E3.2} = 90.1 \cdot \frac{kN}{m^2}$

Bearing Pressure At Heel Check: $\sigma_{heel.E3.2.check} =$ "Okay"

Bearing Pressure At Toe on Inclined Plane: $\sigma_{toe.E3.2} = 224.7 \cdot \frac{kN}{m^2}$

Bearing Pressure At Toe Check: $\sigma_{toe.E3.2.check} =$ "Okay"

Flotation Factor of Safety: $FS_{Flotation.E3.2} = 3$

Flotation Factor of Safety Check: $Flotation_{E3.2.check} =$ "Okay"

Overturning Resultant Ratio: $Ratio_{Overturning.E3.2} = 0.40$

Overturning Stability Check: $Ratio_{Overturning.E3.2.check} =$ "Okay"

SEISMIC LOAD E4: EDGM Post-Seismic Assessment of Usual Load U2 Event (3 Load Cases)

Seismic Case $Q_{E4.2}$ - 100% Horizontal Seismic Force, 30% Vertical **E4.2 CASE**

Horizontal Seismic Coefficient: $K_{h.E4.2} := \frac{-2}{3} \cdot 0.26 = -0.17$

Vertical Seismic Coefficient: $K_{v.E4.2} := 0.3 \frac{-2}{3} \cdot 0.56 \cdot 0.26 = -0.03$

HORIZONTAL SEISMIC LOADS — **Loads** — **Moment Arm**

Horizontal Seismic Component of Concrete Structure: $Q_{conc.E4.EQh.2} := D_{conc} \cdot K_{h.E4.2} = -9045 \cdot kN$ — $Y_{conc.loc} = 6.21\, m$

Horizontal Seismic Component of Vertical Lift Gate: $Q_{Gate.E4.EQh.2} := D_{Gate} \cdot K_{h.E4.2} = -100.5 \cdot kN$ — $Y_{gate} = 8.00\, m$

Horizontal Seismic Component of Headwater on Pier: (Section 7.9, Design Criteria)

$$Q_{hwp.E4.EQh.2} := \left(\frac{7}{12}\right) \cdot K_{h.E4.2} \cdot \gamma_w \cdot \left(D_{hwp.U2}\right)^2 \cdot W_{hwp.U2} = -133.9 \cdot kN$$

$Y_{HWp.E4} = 6.82\, m$

Horizontal Seismic Component of Headwater on Gate: (Section 7.9, Design Criteria)

$$Q_{hwg.E4.EQh.2} := \left(\frac{7}{12}\right) \cdot K_{h.E4.2} \cdot \gamma_w \cdot \left(D_{hwg.U2}\right)^2 \cdot W_{hwg.U2} \cdot poss_{U2} = 0 \cdot kN$$

$Y_{HWg.E4} = 7.72\, m$

Horizontal Seismic Component of Headwater on Footing: (Section 7.9, Design Criteria)

$$Q_{hwf.E4.EQh.2} := \left(\frac{7}{12}\right) \cdot K_{h.E4.2} \cdot \gamma_w \cdot \left(D_{hwf.U2}\right)^2 \cdot W_{hw.U2} = -1798.5 \cdot kN$$

$Y_{HWf.E4} = 2.40\, m$

Horizontal Seismic Component of Active Soil: (Section 5-5, USACE EM_1110-2-2100)

$$Q_{act.E4.EQh.2} := \gamma_r \cdot \left(TOC_{as} - BOF_{elev}\right)^2 \cdot K_{h.E4.2} \cdot W_{hw.U2} = -1784.6 \cdot kN$$

$Y_{E.act.E4} = 2.84\, m$

VERTICAL SEISMIC LOADS — **Loads** — **Moment Arm**

Vertical Component of Concrete Structure: $Q_{conc.E4.EQv.2} := D_{conc} \cdot K_{v.E4.2} = -1519.6 \cdot kN$ — $X_{conc.loc} = 12.43\, m$

Vertical Component of Vertical Lift Gate: $Q_{Gate.E4.EQv.2} := D_{Gate} \cdot K_{v.E4.2} = -16.9 \cdot kN$ — $X_{gate} = 9.75\, m$

Vertical Seismic Component of Headwater over Apron Slab: (Section 7.9, Design Criteria) $Q_{H1.E4.EQv.2} := K_{v.E4.2} \cdot H_{1.U2} = -96.7 \cdot kN$ — $H_{1.U2.loc} = 21.10\, m$

Vertical Seismic Component of Headwater over Fixed Crest Slab: (Section 7.9, Design Criteria) $Q_{H2.E4.EQv.2} := K_{v.E4.2} \cdot H_{2.U2} = -74.8 \cdot kN$ — $H_{2.U2.loc} = 14.41\, m$

$$\Sigma H_{Q.E4.EQh.2} := Q_{conc.E4.EQh.2} + Q_{Gate.E4.EQh.2} + Q_{hwp.E4.EQh.2} + Q_{hwg.E4.EQh.2} + Q_{hwf.E4.EQh.2} + Q_{act.E4.EQh.2} = -12862.6 \cdot kN$$

$$\Sigma V_{Q.E4.EQv.2} := Q_{conc.E4.EQv.2} + Q_{Gate.E4.EQv.2} + Q_{H1.E4.EQv.2} + Q_{H2.E4.EQv.2} = -1708.0 \cdot kN$$

$$\Sigma M_{Q.E4.2} := Q_{conc.E4.EQh.2} \cdot Y_{conc.loc} + Q_{Gate.E4.EQh.2} \cdot Y_{gate} + Q_{hwp.E4.EQh.2} \cdot Y_{HWp.E4} + Q_{hwg.E4.EQh.2} \cdot Y_{HWg.E4} \cdots + Q_{hwf.E4.EQh.2} \cdot Y_{HWf.E4} + Q_{act.E4.EQh.2} \cdot Y_{E.act.E4} + Q_{conc.E4.EQv.2} \cdot X_{conc.loc} + Q_{Gate.E4.EQv.2} \cdot X_{gate} \cdots + Q_{H1.E4.EQv.2} \cdot H_{1.U2.loc} + Q_{H2.E4.EQv.2} \cdot H_{2.U2.loc} = -89444.3 \cdot kN \cdot m$$

E4.2 CASE

STABILITY ASSESSMENT: Seismic Case $Q_{E4.2}$: 100% Horizontal Seismic Force, 30% Vertical

CHECK SLIDING ALONG HORIZONTAL PLANE THRU TOE,
IGNORING BEDROCK MOBILIZED BY STRUCTURAL HEEL KEY , OR VOID BEHIND KEY

Sum of Vertical Forces:

$\Sigma V_{E4.2} := \Sigma V_{U2} + \Sigma V_{Q.E4.EQv.2} = 33451.3 \cdot kN$

Sum of Horizontal Forces:

$\Sigma H_{E4.2} := \Sigma H_{U2} + \Sigma H_{Q.E4.EQh.2} = -23545.5 \cdot kN$

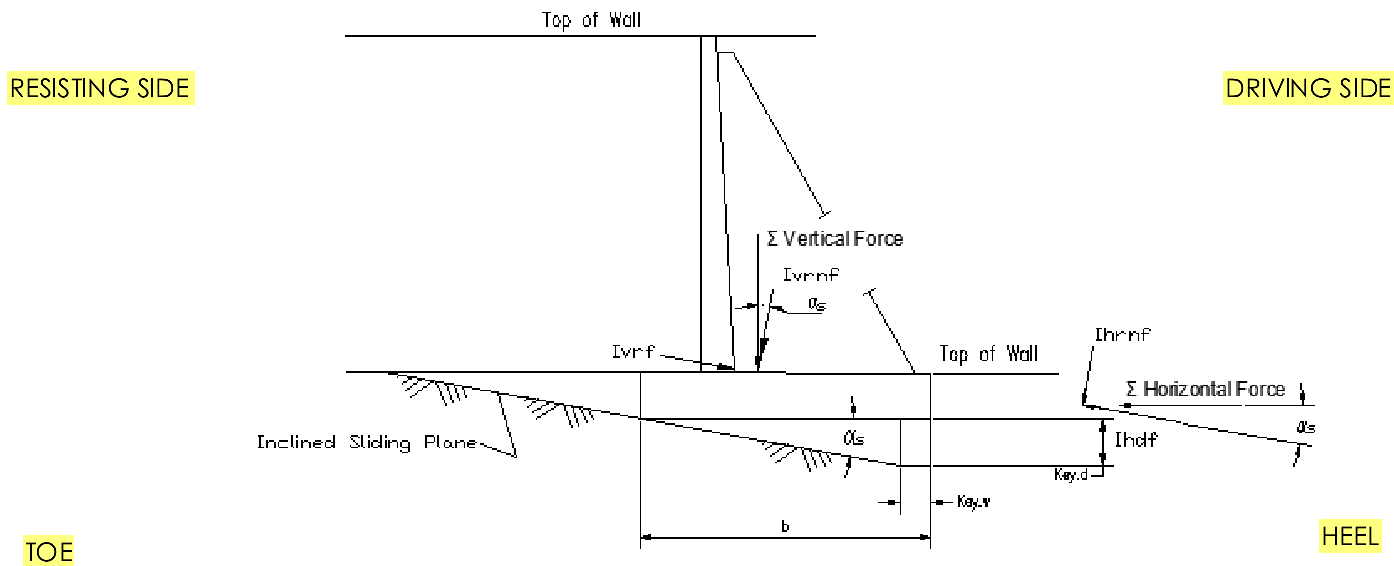
Sliding Factor of Safety:

$$FS_{HorizSliding.E4.2} := \frac{\tan_{\phi} \cdot \Sigma V_{E4.2}}{\left|\Sigma H_{E4.2}\right|} = 0.69$$

$$FS_{HorizSliding.E4.2.Check} := \begin{cases} \text{"OKAY"} & \text{if } FS_{HorizSliding.E4.2} \geq FS_{req.E4.sl} \\ \text{"Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !"} & \text{otherwise} \end{cases}$$

$FS_{HorizSliding.E4.2.Check}$ = "Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !"

CHECK SLIDING ALONG INCLINED SLIDING PLANE FROM HEEL KEY TO TOE,
WITH BEDROCK MASS MOBILIZED BY REINFOCREDE CONCRETE KEY)



Ivrf=Inclined Resisting Force
Ivrnf=Inclined Resisting Normal Force
Ihrnf=Inclined Resisting Normal Force
Ihdf=Inclined Driving Force

Incline angle: $\alpha s = 0.13$ $\qquad \alpha s \cdot \left(\frac{180}{\pi}\right) = 7.63$

Resolve $\Sigma Vert_{E4.2}$ & $\Sigma Horiz_{E4.2}$

$$\Sigma V_{InclinedE4.2} := \cos(\alpha s) \cdot \left(\Sigma V_{E4.2} + V_{rs}\right) + \sin(\alpha s) \cdot \left|\Sigma H_{E4.2}\right| = 49382.7 \cdot kN$$

$$\Sigma H_{InclinedE4.2} := \cos(\alpha s) \cdot \left|\Sigma H_{E4.2}\right| - \sin(\alpha s) \cdot \left(\Sigma V_{E4.2} + V_{rs}\right) = 17142.0 \cdot kN$$

(With properly engineered reinforced concrete Key, horizontal sliding plane thru Toe is protected, critical sliding plane is relocated to the INCLINED SLIDING PLANE FROM HEEL KEY To TOE, Bedrock Mass above this examing plane is mobilized by reinforced concrete key and combined into Structural Wedge.)

Safety Factor for Sliding
Inclined Failure Plane

$$FS_{InclinedlSlidingE4.2} := \frac{\Sigma V_{InclinedE4.2} \cdot \tan\left(\phi_{rock} \cdot \frac{\pi}{180}\right)}{\left|\Sigma H_{InclinedE4.2}\right|} = 1.41$$

$$FS_{Sliding.E4.2.InclinedCheck} := \begin{cases} \text{"OKAY "} & \text{if } FS_{InclinedlSlidingE4.2} > FS_{req.E4.sl} \\ \text{"Revise Structure""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

$FS_{Sliding.E4.2.InclinedCheck}$ = "OKAY "

E4.2 CASE

CHECK ECCENTRICITY ON INCLINED PLANE

Seismic Case $Q_{E4.2}$: 100% Horizontal Seismic Force, 30% Vertical

Sum of the moments:

$$\Sigma M_{rs.E4.2} := \Sigma M_{DL.U2} + \Sigma M_{HWater.U2} + \Sigma M_{Vwater.U2} + \Sigma M_{I.U2} + \Sigma M_{soil.U2} + \Sigma M_{Q.E4.2} + V_{rs} \cdot L_{rs} = 476270 \cdot kN \cdot m$$

Eccentricity:

$$e_{E4.2} := \frac{L_{incline}}{2} - \frac{\Sigma M_{rs.E4.2}}{\Sigma V_{InclinedE4.2}} = 2.48\,m$$

Eccentricity Check:

$$e_{check.E4.2} := \begin{cases} \text{"Okay"} & \text{if } \left|e_{E4.2}\right| \le Ecc_{midhalf} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$e_{check.E4.2} = \text{"Okay"}$

Foundation Bearing Pressures on Inclined Plane:

Bearing Pressure at Heel:

$$\sigma_{heel.E4.2} := \begin{cases} 0 & \text{if } \left|e_{E4.2}\right| \ge Ecc_{midhalf} \\ \left(\dfrac{\Sigma V_{InclinedE4.2}}{\dfrac{A_b}{\cos(\alpha s)}} - \dfrac{\Sigma V_{InclinedE4.2} \cdot e_{E4.2}}{\dfrac{S_b}{\cos(\alpha s)^2}}\right) & \text{otherwise} \end{cases} = 60.8 \cdot \frac{kN}{m^2}$$

$$\sigma_{heel.E4.2.check} := \left(\begin{cases} \text{"Okay"} & \text{if } \sigma_{heel.E4.2} \le \sigma_{allow.E4} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}\right)$$

$\sigma_{heel.E4.2.check} = \text{"Okay"}$

Bearing Pressure at Toe:

$$\sigma_{toe.E4.2} := \begin{cases} \left[\dfrac{4}{3} \cdot \left(\dfrac{\dfrac{\Sigma V_{InclinedE4.2}}{W_b}}{L_{incline} - 2 \cdot e_{E4.2}}\right)\right] & \text{if } \left|e_{E4.2}\right| \ge Ecc_{midhalf} \\ \left[\dfrac{\Sigma V_{InclinedE4.2}}{\dfrac{A_b}{\cos(\alpha s)}} + \dfrac{\left(\Sigma V_{InclinedE4.2} \cdot e_{E4.2}\right)}{\dfrac{S_b}{\cos(\alpha s)^2}}\right] & \text{otherwise} \end{cases} = 250.3 \cdot \frac{kN}{m^2}$$

$$\sigma_{toe.E4.2.check} := \begin{cases} \text{"Okay"} & \text{if } \sigma_{toe.E4.2} \le \sigma_{allow.E4} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$\sigma_{toe.E4.2.check} = \text{"Okay"}$

Foundation Flotation Checks:

$$FS_{Flotation.E4.2} := \frac{D_{conc} + D_{Gate} + H_{1.U2} + H_{2.U2} + H_{3.U2} - \left|\Sigma V_{Q.E4.EQv.2}\right|}{\left|Uplift_{U2}\right|} = 2.3$$

$$Flotation_{E4.2.check} := \begin{cases} \text{"Okay"} & \text{if } FS_{Flotation.E4.2} \ge FS_{req.E.flt} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$Flotation_{E3.1.check} = \text{"Okay"}$

E4.2 CASE

MONOLITH OVERTURNING STABILITY ANALYSIS

Seismic Case $Q_{E4.2}$: 100% Horizontal Seismic Force, 30% Vertical

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.
Assumptions are made in order to compute overturning stability of indetermine forces on monolith with key;
(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.
(b) The horizontal resisting force acting on the key, P.key, is that required for static equilibrium
(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1 $Ratio_{overturning.allow.Extreme} = 0.167$

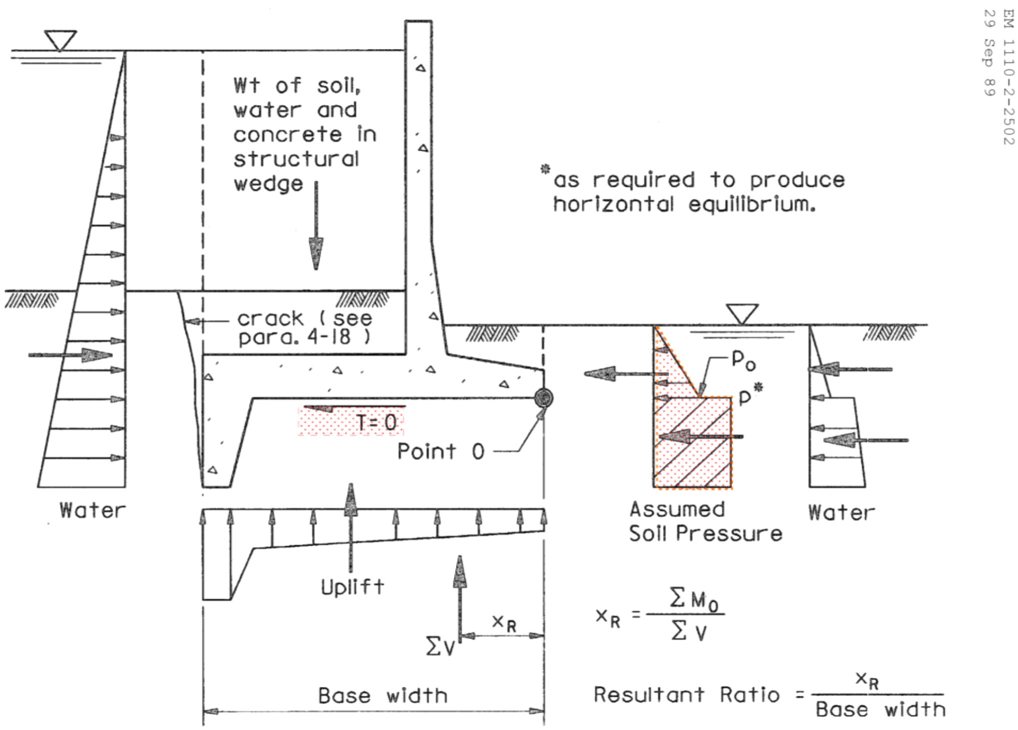


Figure 4-5. Forces for overturning analysis for wall with horizontal base and key

All Vertical Loads Applicable to Overturning Stability Analysis

Total Concrete Dead Loads:	$D_{conc} = 52182.8 \cdot kN$	at:	$X_{conc.loc} = 12.43\ m$
Dead Load of Gate:	$D_{Gate} = 580.0 \cdot kN$		$X_{gate} = 9.75\ m$
Water Weight (HW) on Apron Slab:	$H_{1.U2} = 3320.9 \cdot kN$		$H_{1.U2.loc} = 21.10\ m$
Water Weight (HW) on Fixed Crest:	$H_{2.U2} = 2569.2 \cdot kN$		$H_{2.U2.loc} = 14.41\ m$
Water Weight (TW) on Fixed Crest:	$H_{3.U2} = 2106.6 \cdot kN$		$H_{3.U2.loc} = 5.78\ m$

Vertical Seismic Component of Concrete Structure:	$Q_{conc.E4.EQv.2} = -1519.6 \cdot kN$	at:	$X_{conc.loc} = 12.43\ m$
Vertical Seismic Component of Vertical Lift Gate:	$Q_{Gate.E4.EQv.2} = -16.9 \cdot kN$		$X_{gate} = 9.75\ m$
Vertical Seismic Component of Headwater over Apron Slab:	$Q_{H1.E4.EQv.2} = -96.7 \cdot kN$		$H_{1.U2.loc} = 21.10\ m$
Vertical Seismic Component of Headwater over Fixed Crest Slab:	$Q_{H2.E4.EQv.2} = -74.8 \cdot kN$		$H_{2.U2.loc} = 14.41\ m$

Uplift for Overturning Analysis, Line of Creep Method. Pore pressure at base of Concrete, first calculation to presumed inclined straight line from Heel to Toe, thereafter by Archimedes Principle.

E4.2CASE

$$U_{E4.2.loc.sliding} := \frac{U_{A.U2} \cdot L_{A.U2} + U_{B.U2} \cdot L_{B.U2} - A_{rs} \cdot w_{as} \cdot \gamma_w \cdot L_{rs}}{U_{A.U2} + U_{B.U2} - A_{rs} \cdot w_{as} \cdot \gamma_w} = 13.84\,m$$

$$U_{E4.2.sliding} := U_{U2} + A_{rs} \cdot w_{as} \cdot \gamma_w = -19705.8 \cdot kN$$

Uplift for Overturning Analysis, Line of Creep Method. Pore pressure at base of Concrete

$$Uplift_{pore.U2} = -18673.3 \cdot kN$$

$$Uplift_{pore.E4.2.loc} := \frac{Uplift_{BC.U2} \cdot Uplift_{BC.U2.loc} + Uplift_{DE.U2} \cdot Uplift_{DE.U2.loc} + Uplift_{EF.U2} \cdot Uplift_{EF.U2.loc} + Uplift_{FG.U2} \cdot Uplift_{FG.U2.loc}}{Uplift_{pore.U2}}$$

$$Uplift_{pore.E4.2.loc} = 13.3\,m$$

Sum of All Water Load for Overturning Analysis

$$\Sigma V_{water.E4.2.OT} := H_{1.U1} + H_{2.U1} + H_{3.U1} + Uplift_{pore.U2} = -16995.1 \cdot kN$$

All Lateral Loads Applicable to Overturning Stability Analysis

Apply Load to Gate?: $poss_{U1} = 1$ — poss = 1 if gate is closed, 0 if gate is open

Headwater Lateral Load on Pier: $H_{hwp.U2} = -662.3 \cdot kN$ at: $H_{hwp.U2.loc} = 6.44\,m$

Headwater Lateral Load on Gate: $H_{hwg.U2} = 0.0 \cdot kN$ $H_{hwg.U2.loc} = 7.44\,m$

Headwater Lateral Load on Footing: $H_{hwf.U2} = -7709.2 \cdot kN$ $H_{hwf.U2.loc} = 1.67\,m$

Total Horizontal Tailwater Load on Pier: $H_{twp.U2} = 448.3 \cdot kN$ $H_{twp.U2.loc} = 0.09\,m$

Total Horizontal Tailwater Load on Footing under Gate Openings, i.e., excluding Pier: $H_{twf.U2} = 1008.6 \cdot kN$ $H_{twf.U2.loc} = 0.09\,m$

Resisting Water on Rear Face of Monolith, i.e., bottom of heel elevation: *(Point O @ TOE: BOFtoe = EL.1205.5)*

Horizontal Seismic Component of Concrete Structure: $Q_{conc.E4.EQh.2} = -9045 \cdot kN$ AT $Y_{conc.loc} = 6.21\,m$

Horizontal Seismic Component of Vertical Lift Gate: $Q_{Gate.E4.EQh.2} = -100.5 \cdot kN$ $Y_{gate} = 8.00\,m$

Horizontal Seismic Component of Headwater on Pier: $Q_{hwp.E4.EQh.2} = -133.9 \cdot kN$ $Y_{HWp.E4} = 6.8\,m$

Horizontal Seismic Component of Headwater on Gate: $Q_{hwg.E4.EQh.2} = 0$ $Y_{HWg.E4} = 7.7\,m$

Horizontal Seismic Component of Headwater on Footing: $Q_{hwf.E4.EQh.2} = -1798.5 \cdot kN$ $Y_{HWf.E4} = 2.4\,m$

Horizontal Seismic Component of Active Soil: (Section 5-5, USACE EM_1110-2-2100) $Q_{act.E4.EQh.2} = -1784.6 \cdot kN$ $Y_{E.act.E4} = 2.8\,m$

Ice / Impact Load: $I_{U2} = -2100.0 \cdot kN$ at: $I_{U2.loc} = 10.01\,m$

Depth of Fill at Heel Side for Overturning Analysis (neglecting resistance by driving below Point O):

$$t_{hf.E4.2} := TOC_{as} - BOF_{toe} = 4.50\,m$$

Driving Soil Load for overturning:

$$E1_{drive.E4.2} := \frac{K_o \cdot t_{hf.U2}^{\,2}}{2} \cdot \left(\gamma_r - \gamma_w\right) \cdot W_b \cdot -1 = -1055.7 \cdot kN$$

Acting at:

$$E1_{drive.loc.E4.2} := \frac{t_{hf.E4.2}}{3} = 1.50\,m$$

Downstream (resisting) Lateral Soil Load as required to produce horizontal equilibrium:

$$E2_{resistE4.2} := -1 \cdot \left(H_{hwp.U2} + H_{hwg.U2} + H_{hwf.U2} + H_{twp.U2} + H_{twf.U2} + I_{U2} + E1_{drive.U2}\right) = 10070.3 \cdot kN$$

Assumed Resisting Bedrock at middle of Key, passive soil pressure or lateral bearing contract joint at end of Monolith 3A3B

$$E2_{resistlocE4.2} := E2_{resistlocU2} = -0.75\,m$$

Overturning moment by Dead Loads about Point O @ Toe

$$\Sigma M_{DL.U2} = 654229.9 \cdot kN \cdot m$$

Overturning moment by Vertical Water Loads and Uplift, about Point O @ Toe

$$\Sigma M_{Vwater.U2} = -234242.4 \cdot kN \cdot m$$

Overturning moment by Lateral Hydrostatic Forces of Headwater Pool and Tailwater Pool,about Point O @ Toe

$$\Sigma M_{HWater.U2} = -16989.2 \cdot kN \cdot m$$

Overturning Moment by Impact/Ice Load, about Point O@ Toe

$$\Sigma M_{I.U2} = -21021 \cdot kN \cdot m$$

Overturning moment by Lateral Soil Forces about Point O @ Toe

$$\Sigma M_{soil.E4.2} := E1_{drive.E4.2} \cdot E1_{drive.loc.E4.2} \cdots + E2_{resistE4.2} \cdot E2_{resistlocE4.2} = -9136.3 \cdot kN \cdot m$$

Sum of the Overturning Moments about Point O @ Toe:

$$\Sigma M_{E4.2.OT} := \Sigma M_{DL.U2} + \Sigma M_{HWater.U2} + \Sigma M_{Vwater.U2.OT} + \Sigma M_{I.U2} + \Sigma M_{soil.E4.2} + \Sigma M_{Q.E4.2} = 388543 \cdot kN \cdot m$$

Sum of Vertical Forces:

$$\Sigma V_{E4.2.OT} := \Sigma V_{DL.U2} + \Sigma V_{water.U2.OT} + \left|\Sigma V_{Q.E4.EQv.2}\right| = 43794.2 \cdot kN$$

Distance X_R: EM 1110-2-2502 Eq.4-1

$$X_{R.E4.2} := \frac{\Sigma M_{E4.2.OT}}{\Sigma V_{E4.2.OT}} = 8.9\,m$$

Overturning Resultant Ratio

$$Ratio_{Overturning.E4.2} := \frac{X_{R.E4.2}}{L_b} = 0.37$$

EM 1110-2-2502

Table 4-1

Retaining Wall Stability Criteria

Loading Condition	Sliding Factor of Safety, FS	Shear Strength Test Required: Soil Foundation	Shear Strength Test Required: Rock Foundation[3]	Overturning Criteria Minimum Base Area in Compression: Soil Foundation	Overturning Criteria Minimum Base Area in Compression: Rock Foundation
Usual	1.5	(Q &/or S)[2,1]	Direct shear	100%[4]	75%[4]
Unusual	1.33	(Q &/or S)[2,1]	Direct shear	75%[4]	50%[4]
Earthquake	1.1	(Q)	Direct shear	Resultant within base	Resultant within base

Overturning Stability Check

$$Ratio_{Overturning.E4.2.check} := \begin{cases} \text{"Okay"} & \text{if } Ratio_{Overturning.E4.2} \geq Ratio_{overturning.allow.Extreme} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$$Ratio_{Overturning.E4.2.check} = \text{"Okay"}$$

Summary of Seismic Results (Only Report Controlling Load Case)

E4.2 CASE

Seismic Case $Q_{E4.2}$: 100% Horizontal Seismic Force, 30% Vertical

Horiz Sliding Factor of Safety: $FS_{HorizSliding.E4.2} = 0.69$

Horiz Sliding Factor of Safety Check: $FS_{HorizSliding.E4.2.Check}$ = "Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !"

Sliding Factor of Safety: $FS_{InclinedlSlidingE4.2} = 1.4$

Sliding Factor of Safety Check: $FS_{Sliding.E4.2.InclinedCheck}$ = "OKAY "

Eccentricity: $e_{E4.2} = 2.48\,m$

Eccentricity Check: $e_{check.E4.2}$ = "Okay"

Bearing Pressure At Heel on Inclined Plane: $\sigma_{heel.E4.2} = 60.8 \cdot \frac{kN}{m^2}$

Bearing Pressure At Heel Check: $\sigma_{heel.E4.2.check}$ = "Okay"

Bearing Pressure At Toe on Inclined Plane: $\sigma_{toe.E4.2} = 250.3 \cdot \frac{kN}{m^2}$

Bearing Pressure At Toe Check: $\sigma_{toe.E4.2.check}$ = "Okay"

Flotation Factor of Safety: $FS_{Flotation.E4.2} = 2.3$

Flotation Factor of Safety Check: $Flotation_{E4.2.check}$ = "Okay"

Overturning Resultant Ratio: $Ratio_{Overturning.E4.2} = 0.37$

Overturning Stability Check: $Ratio_{Overturning.E4.2.check}$ = "Okay"

SEISMIC LOAD E3: EDGM Post-Seismic Assessment of Usual Load U1 Event (3 Load Cases)

E3.3 CASE

Seismic Case $Q_{E3.3}$ - 30% Horizontal Seismic Force, 100% Vertical

Horizontal Seismic Coefficient: $K_{h.E3.3} := 0.3 \cdot \frac{-2}{3} \cdot 0.26 = -0.05$

Vertical Seismic Coefficient: $K_{v.E3.3} := 1 \cdot \frac{-2}{3} \cdot 0.56 \cdot 0.26 = -0.10$

HORIZONTAL SEISMIC LOADS	**Loads**	**Moment Arm**
Horizontal Seismic Component of Concrete Structure:	$Q_{conc.E3.EQh.3} := D_{conc} \cdot K_{h.E3.3} = -2713.5 \cdot kN$	$Y_{conc.loc} = 6.21\,m$
Horizontal Seismic Component of Vertical Lift Gate:	$Q_{Gate.E3.EQh.3} := D_{Gate} \cdot K_{h.E3.3} = -30.2 \cdot kN$	$Y_{gate} = 8.00\,m$
Horizontal Seismic Component of Headwater on Pier: (Section 7.9, Design Criteria)	$Q_{hwp.E3.EQh.3} := \left(\frac{7}{12}\right) \cdot K_{h.E3.3} \cdot \gamma_w \cdot \left(D_{hwp.U1}\right)^2 \cdot W_{hwp.U1} = -5.2 \cdot kN$	$Y_{HWp.E3} = 5.34\,m$
Horizontal Seismic Component of Headwater on Gate: (Section 7.9, Design Criteria)	$Q_{hwg.E3.EQh.3} := \left(\frac{7}{12}\right) \cdot K_{h.E3.3} \cdot \gamma_w \cdot \left(D_{hwg.U1}\right)^2 \cdot W_{hwg.U1} \cdot poss_{U1} = -2.1 \cdot kN$	$Y_{HWg.E3} = 6.24\,m$
Horizontal Seismic Component of Headwater on Footing: (Section 7.9, Design Criteria)	$Q_{hwf.E3.EQh.3} := \left(\frac{7}{12}\right) \cdot K_{h.E3.3} \cdot \gamma_w \cdot \left(D_{hwf.U1}\right)^2 \cdot W_{hw.U1} = -253.8 \cdot kN$	$Y_{HWf.E3} = 2.40\,m$
Horizontal Seismic Component of Active Soil: (Section 5-5, USACE EM_1110-2-2100)	$Q_{act.E3.EQh.3} := \gamma_r \cdot \left(TOC_{as} - BOF_{elev}\right)^2 \cdot K_{h.E3.3} \cdot W_{hw.U1} = -535.4 \cdot kN$	$Y_{E.act.E3} = 2.84\,m$

VERTICAL SEISMIC LOADS	**Loads**	**Moment Arm**
Vertical Component of Concrete Structure:	$Q_{conc.E3.EQv.3} := D_{conc} \cdot K_{v.E3.3} = -5065.2 \cdot kN$	$X_{conc.loc} = 12.43\,m$
Vertical Component of Lift Gate:	$Q_{Gate.E3.EQv.3} := D_{Gate} \cdot K_{v.E3.3} = -56.3 \cdot kN$	$X_{gate} = 9.75\,m$
Vertical Seismic Component of Headwater over Apron Slab: (Section 7.9, Design Criteria)	$Q_{H1.E3.EQv.3} := K_{v.E3.3} \cdot H_{1.U1} = -120.2 \cdot kN$	$H_{1.U1.loc} = 21.10\,m$
Vertical Seismic Component of Headwater over Fixed Crest Slab: (Section 7.9, Design Criteria)	$Q_{H2.E3.EQv.3} := K_{v.E3.3} \cdot H_{2.U1} = -42.7 \cdot kN$	$H_{2.U1.loc} = 14.25\,m$

$$\Sigma H_{Q.E3.EQh.3} := Q_{conc.E3.EQh.3} + Q_{Gate.E3.EQh.3} + Q_{hwp.E3.EQh.3} + Q_{hwg.E3.EQh.3} + Q_{hwf.E3.EQh.3} + Q_{act.E3.EQh.3} = -3540.3 \cdot kN$$

$$\Sigma V_{Q.E3.EQv.3} := Q_{conc.E3.EQv.3} + Q_{Gate.E3.EQv.3} + Q_{H1.E3.EQv.3} + Q_{H2.E3.EQv.3} = -5284.4 \cdot kN$$

$$\begin{aligned}\Sigma M_{Q.E3.3} := {} & Q_{conc.E3.EQh.3} \cdot Y_{conc.loc} + Q_{Gate.E3.EQh.3} \cdot Y_{gate} + Q_{hwp.E3.EQh.3} \cdot Y_{HWp.E3} + Q_{hwg.E3.EQh.3} \cdot Y_{HWg.E3} \cdots = -85912.5 \cdot kN \cdot m \\ & + Q_{hwf.E3.EQh.3} \cdot Y_{HWf.E3} + Q_{act.E3.EQh.3} \cdot Y_{E.act.E3} + Q_{conc.E3.EQv.3} \cdot X_{conc.loc} + Q_{Gate.E3.EQv.3} \cdot X_{gate} \cdots \\ & + Q_{H1.E3.EQv.3} \cdot H_{1.U1.loc} + Q_{H2.E3.EQv.3} \cdot H_{2.U1.loc}\end{aligned}$$

STABILITY ASSESSMENT:

Seismic Case $Q_{E3.3}$ - 30% Horizontal Seismic Force, 100% Vertical

E3.3 CASE

CHECK SLIDING ALONG HORIZONTAL PLANE THRU TOE,
IGNORING BEDROCK MOBILIZED BY STRUCTURAL HEEL KEY , OR VOID BEHIND KEY

Sum of Vertical Forces:

$\Sigma V_{E3.3} := \Sigma V_{U1} + \Sigma V_{Q.E3.EQv.3} = 30937.5 \cdot kN$

Sum of Horizontal Forces:

$\Sigma H_{E3.3} := \Sigma H_{U1} + \Sigma H_{Q.E3.EQh.3} = -10810 \cdot kN$

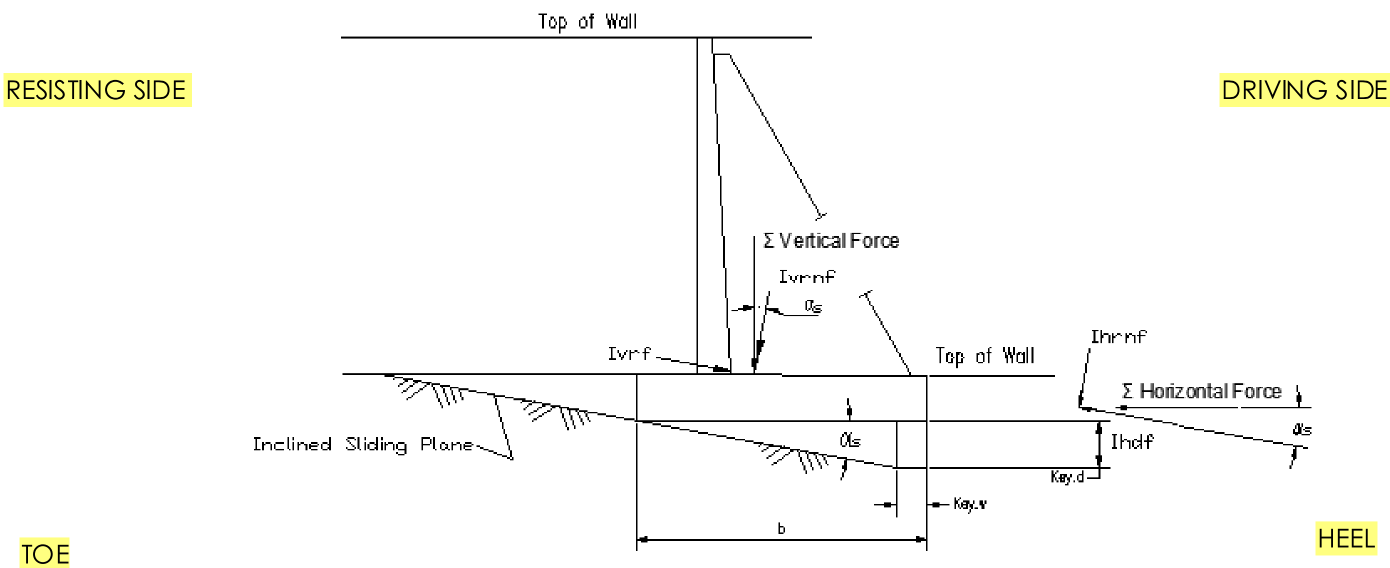
Sliding Factor of Safety:

$$FS_{HorizSliding.E3.3} := \frac{\tan_{\phi} \cdot \Sigma V_{E3.3}}{\left|\Sigma H_{E3.3}\right|} = 1.40$$

$$FS_{HorizSliding.E3.3.Check} := \begin{cases} \text{"OKAY"} & \text{if } FS_{HorizSliding.E3.3} \geq FS_{req.E3.sl} \\ \text{"Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !"} & \text{otherwise} \end{cases}$$

$FS_{HorizSliding.E3.3.Check} = \text{"OKAY"}$

CHECK SLIDING ALONG INCLINED SLIDING PLANE FROM HEEL KEY TO TOE,
WITH BEDROCK MASS MOBILIZED BY REINFOCREDE CONCRETE KEY)



Ivrf=Inclined Resisting Force
Ivrnf=Inclined Resisting Normal Force
Ihrnf=Inclined Resisting Normal Force
Ihdf=Inclined Driving Force

Incline angle: $\alpha s = 0.13$ $\qquad \alpha s \cdot \left(\frac{180}{\pi}\right) = 7.63$

Resolve $\Sigma Vert_{E3.3}$ & $\Sigma Horiz_{E3.3}$

$\Sigma V_{InclinedE3.3} := \cos(\alpha s) \cdot \left(\Sigma V_{E3.3} + V_{rs}\right) + \sin(\alpha s) \cdot \left|\Sigma H_{E3.3}\right| = 45200.6 \cdot kN$

$\Sigma H_{InclinedE3.3} := \cos(\alpha s) \cdot \left|\Sigma H_{E3.3}\right| - \sin(\alpha s) \cdot \left(\Sigma V_{E3.3} + V_{rs}\right) = 4852.8 \cdot kN$

(With properly engineered reinforced concrete Key, horizontal sliding plane thru Toe is protected, critical sliding plane is relocated to the INCLINED SLIDING PLANE FROM HEEL KEY To TOE, Bedrock Mass above this examing plane is mobilized by reinforced concrete key and combined into Structural Wedge.)

Safety Factor for Sliding
Inclined Failure Plane

$$FS_{InclinedISlidingE3.3} := \frac{\Sigma V_{InclinedE3.3} \cdot \tan\left(\phi_{rock} \cdot \frac{\pi}{180}\right)}{\left|\Sigma H_{InclinedE3.3}\right|} = 4.54$$

$$FS_{Sliding.E3.3.InclinedCheck} := \begin{cases} \text{"OKAY "} & \text{if } FS_{InclinedISlidingE3.3} > FS_{req.E3.sl} \\ \text{"Revise Structure""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

$FS_{Sliding.E3.3.InclinedCheck} = \text{"OKAY "}$

CHECK ECCENTRICITY ON INCLINED PLANE

E3.3 CASE

Seismic Case $Q_{E3.3}$ - 30% Horizontal Seismic Force, 100% Vertical

Sum of the moments:

$$\Sigma M_{rs.E3.3} := \Sigma M_{DL.U1} + \Sigma M_{HWater.U1} + \Sigma M_{Vwater.U1} + \Sigma M_{I.U1} + \Sigma M_{soil.U1} + \Sigma M_{Q.E3.3} + V_{rs} \cdot L_{rs} = 517084 \cdot kN \cdot m$$

Eccentricity:

$$e_{E3.3} := \frac{L_{incline}}{2} - \frac{\Sigma M_{rs.E3.3}}{\Sigma V_{InclinedE3.3}} = 0.68\,m$$

Eccentricity Check:

$$e_{check.E3.3} := \begin{cases} \text{"Okay"} & \text{if } e_{E3.3} \le Ecc_{midhalf} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$$e_{check.E3.3} = \text{"Okay"}$$

Foundation Bearing Pressures on Inclined Plane:

Bearing Pressure at Heel:

$$\sigma_{heel.E3.3} := \begin{cases} 0 & \text{if } \left|e_{E3.3}\right| \ge Ecc_{midhalf} \\ \left(\dfrac{\Sigma V_{InclinedE3.3}}{\dfrac{A_b}{\cos(\alpha s)}} - \dfrac{\Sigma V_{InclinedE3.3} \cdot e_{E3.3}}{\dfrac{S_b}{\cos(\alpha s)^2}} \right) & \text{otherwise} \end{cases} = 118.5 \cdot \frac{kN}{m^2}$$

$$\sigma_{heel.E3.3.check} := \left(\begin{cases} \text{"Okay"} & \text{if } \sigma_{heel.E3.3} \le \sigma_{allow.E3} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} \right)$$

$$\sigma_{heel.E3.3.check} = \text{"Okay"}$$

Bearing Pressure at Toe:

$$\sigma_{toe.E3.3} := \begin{cases} \left[\dfrac{4}{3} \cdot \left(\dfrac{\dfrac{\Sigma V_{InclinedE3.3}}{W_b}}{L_{incline} - 2 \cdot e_{E3.3}} \right) \right] & \text{if } e_{E3.3} \ge Ecc_{midhalf} \\ \left[\dfrac{\Sigma V_{InclinedE3.3}}{\dfrac{A_b}{\cos(\alpha s)}} + \dfrac{\left(\Sigma V_{InclinedE3.3} \cdot e_{E3.3}\right)}{\dfrac{S_b}{\cos(\alpha s)^2}} \right] & \text{otherwise} \end{cases} = 166.3 \cdot \frac{kN}{m^2}$$

$$\sigma_{toe.E3.3.check} := \begin{cases} \text{"Okay"} & \text{if } \sigma_{toe.E3.3} \le \sigma_{allow.E3} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$$\sigma_{toe.E3.3.check} = \text{"Okay"}$$

Foundation Flotation Checks:

$$FS_{Flotation.E3.3} := \frac{\left(D_{conc} + D_{Gate} + H_{1.U1} + H_{2.U1} + H_{3.U1}\right) - \left|\Sigma V_{Q.E3.EQv.3}\right|}{\left|Uplift_{U1}\right|} = 2.7$$

$$Flotation_{E3.3.check} := \begin{cases} \text{"Okay"} & \text{if } FS_{Flotation.E3.3} \ge FS_{req.E.flt} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$$Flotation_{E3.3.check} = \text{"Okay"}$$

E3.3 CASE

MONOLITH OVERTURNING STABILITY ANALYSIS

Seismic Case $Q_{E3.3}$ - 30% Horizontal Seismic Force, 100% Vertical

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.
Assumptions are made in order to compute overturning stability of indetermine forces on monolith with key;
(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.
(b) The horizontal resisting force acting on the key, P.key, is that required for static equilibrium
(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1

$Ratio_{overturning.allow.Extreme} = 0.167$

Resultant within Middle Half

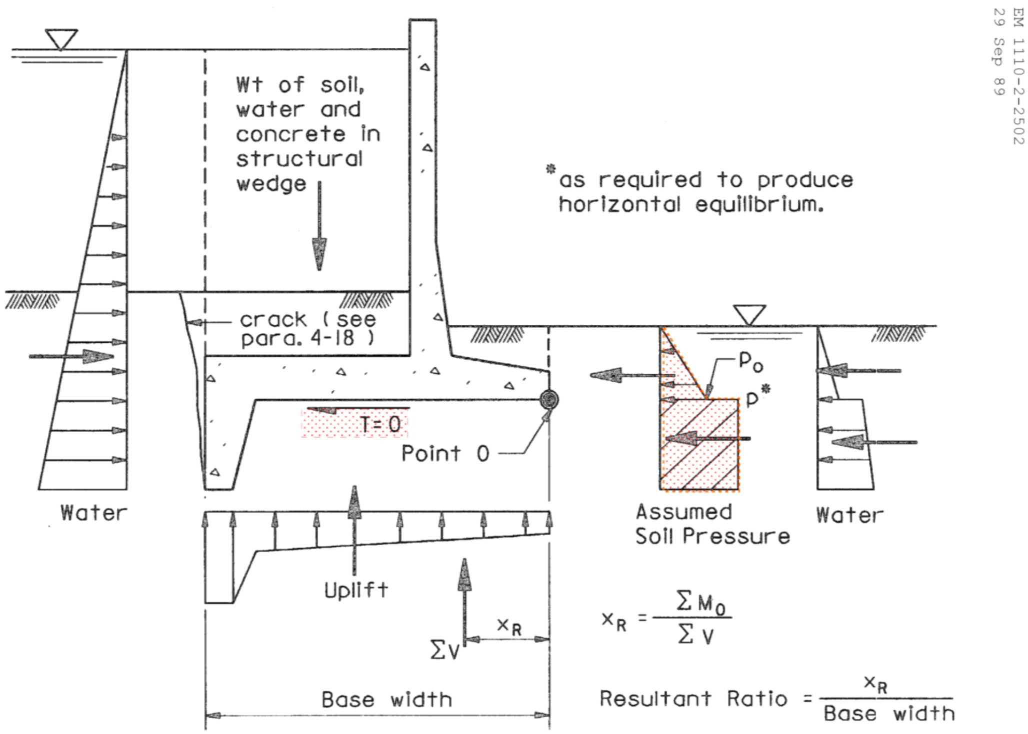


Figure 4-5. Forces for overturning analysis for wall with horizontal base and key

All Vertical Loads Applicable to Overturning Stability Analysis

		at:	
Total Concrete Dead Loads:	$D_{conc} = 52182.8 \cdot kN$		$X_{conc.loc} = 12.43\,m$
Dead Load of Gate:	$D_{Gate} = 580.0 \cdot kN$		$X_{gate} = 9.75\,m$
Water Weight (HW) on Apron Slab:	$H_{1.U1} = 1238.5 \cdot kN$		$H_{1.U1.loc} = 21.10\,m$
Water Weight (HW) on Fixed Crest:	$H_{2.U1} = 439.7 \cdot kN$		$H_{2.U1.loc} = 14.25\,m$
Water Weight (TW) on Fixed Crest:	$H_{3.U1} = 0.0 \cdot kN$		$H_{3.U1.loc} = 0.00\,m$

		at:	
Vertical Seismic Component of Concrete Structure:	$Q_{conc.E3.EQv.3} = -5065.2 \cdot kN$		$X_{conc.loc} = 12.43\,m$
Vertical Seismic Component of Vertical Lift Gate:	$Q_{Gate.E3.EQv.3} = -56.3 \cdot kN$		$X_{gate} = 9.75\,m$
Vertical Seismic Component of Headwater over Apron Slab:	$Q_{H1.E3.EQv.3} = -120.2 \cdot kN$		$H_{1.U1.loc} = 21.10\,m$
Vertical Seismic Component of Headwater over Fixed Crest Slab:	$Q_{H2.E3.EQv.3} = -42.7 \cdot kN$		$H_{2.U1.loc} = 14.25\,m$

Uplift for Overturning Analysis, Line of Creep Method. Pore pressure at base of Concrete, first calculation to presumed inclined straight line from Heel to Toe, thereafter by Archimedes Principle.

E3.3 CASE

$$U_{E3.3.loc.sliding} := \frac{U_{A.U1} \cdot L_{A.U1} + U_{B.U1} \cdot L_{B.U1} - A_{rs} \cdot w_{as} \cdot \gamma_w \cdot L_{rs}}{U_{A.U1} + U_{B.U1} - A_{rs} \cdot w_{as} \cdot \gamma_w} = 13.76\,m$$

$$U_{E3.3.sliding} := U_{U1} + A_{rs} \cdot w_{as} \cdot \gamma_w = -12005.7 \cdot kN$$

Uplift for Overturning Analysis, Line of Creep Method. Pore pressure at base of Concrete

$$Uplift_{pore.U1} = -11398 \cdot kN$$

$$Uplift_{pore.E3.3.loc} := \frac{Uplift_{BC.U1} \cdot Uplift_{BC.U1.loc} + Uplift_{DE.U1} \cdot Uplift_{DE.U1.loc} + Uplift_{EF.U1} \cdot Uplift_{EF.U1.loc} + Uplift_{FG.U1} \cdot Uplift_{FG.U1.loc}}{Uplift_{pore.U1}}$$

$$Uplift_{pore.E3.3.loc} = 13.1\,m$$

Sum of All Water Load for Overturning Analysis

$$\Sigma V_{water.E3.3.OT} := H_{1.U1} + H_{2.U1} + H_{3.U1} + Uplift_{pore.U1} = -9719.8 \cdot kN$$

<u>All Lateral Loads Applicable to Overturning Stability Analysis</u>

Apply Load to Gate?:	$poss_{U1} = 1$		poss = 1 if gate is closed 0 if gate is open
Headwater Lateral Load on Pier:	$H_{hwp.U1} = -86.5 \cdot kN$	at:	$H_{hwp.U1.loc} = 5.20\,m$
Headwater Lateral Load on Gate:	$H_{hwg.U1} = -35.3 \cdot kN$		$H_{hwg.U1.loc} = 6.20\,m$
Headwater Lateral Load on Footing:	$H_{hwf.U1} = -4160.7 \cdot kN$		$H_{hwf.U1.loc} = 1.17\,m$
Total Horizontal Tailwater Load on Pier:	$H_{twp.U1} = 240.3 \cdot kN$		$H_{twp.U1.loc} = -0.33\,m$
Total Horizontal Tailwater Load on Footing under Gate Openings, i.e., excluding Pier	$H_{twf.U1} = 540.8 \cdot kN$		$H_{twf.U1.loc} = -0.33\,m$
Resisting Water on Rear Face of Monolith, i.e., bottom of heel elevation:			*(Point O @ TOE: BOFtoe = EL.1205.5)*
Horizontal Seismic Component of Concrete Structure:	$Q_{conc.E3.EQh.3} = -2713.5 \cdot kN$	AT	$Y_{conc.loc} = 6.21\,m$
Horizontal Seismic Component of Vertical Lift Gate:	$Q_{Gate.E3.EQh.3} = -30.2 \cdot kN$		$Y_{gate} = 8.00\,m$
Horizontal Seismic Component of Headwater on Pier:	$Q_{hwp.E3.EQh.3} = -5.2 \cdot kN$		$Y_{HWp.E3} = 5.3\,m$
Horizontal Seismic Component of Headwater on Gate:	$Q_{hwg.E3.EQh.3} = -2.1 \cdot kN$		$Y_{HWg.E3} = 6.2\,m$
Horizontal Seismic Component of Headwater on Footing:	$Q_{hwf.E3.EQh.3} = -253.8 \cdot kN$		$Y_{HWf.E3} = 2.4\,m$
Horizontal Seismic Component of Active Soil: (Section 5-5, USACE EM_1110-2-2100)	$Q_{act.E3.EQh.3} = -535.4 \cdot kN$		$Y_{E.act.E3} = 2.8\,m$
Ice / Impact Load:	$I_{U1} = -2100.0 \cdot kN$	at:	$I_{U1.loc} = 6.30\,m$

Depth of Fill at Heel Side for Overturning Analysis (neglecting resistance by driving below Point O):

$$t_{hf.E3.3} := TOC_{as} - BOF_{toe} = 4.50\,m$$

Driving Soil Load for overturning:

$$E1_{drive.E3.3} := \frac{K_o \cdot t_{hf.U1}^{\,2}}{2} \cdot (\gamma_r - \gamma_w) \cdot W_b \cdot -1 = -1055.7 \cdot kN$$

Acting at:

$$E1_{drive.loc.E3.3} := \frac{t_{hf.E3.3}}{3} = 1.50\,m$$

E3.3 CASE

Downstream (resisting) Lateral Soil Load as required to produce horizontal equilibrium:

$$E2_{resistE3.3} := -1\cdot\left(H_{hwp.U1} + H_{hwg.U1} + H_{hwf.U1} + H_{twp.U1} + H_{twf.U1} + I_{U1} + E1_{drive.U1}\right) = 6657.1\cdot kN$$

Assumed Resisting Bedrock at middle of Key,passive soil pressure or lateral bearing contract joint at end of Monolith 3A3B

$$E2_{resistlocE3.3} := E2_{resistlocU1} = -0.75\,m$$

Overturning moment by Dead Loads about Point O @ Toe

$$\Sigma M_{DL.U1} = 651119.6\cdot kN\cdot m$$

Overturning moment by Vertical Water Loads and Uplift, about Point O @ Toe

$$\Sigma M_{Vwater.U1} = -212822.7\cdot kN\cdot m$$

Overturning moment by Lateral Hydrostatic Forces of Headwater Pool and Tailwater Pool,about Point O @ Toe

$$\Sigma M_{HWater.U1} = -5807.3\cdot kN\cdot m$$

Overturning Moment by Impact/Ice Load, about Point O@ Toe

$$\Sigma M_{I.U1} = -13230\cdot kN\cdot m$$

Overturning moment by Lateral Soil Forces about Point O @ Toe

$$\Sigma M_{soil.E3.3} := E1_{drive.E3.3}\cdot E1_{drive.loc.E3.3} \cdots + E2_{resistE3.3}\cdot E2_{resistlocE3.3} = -6576.4\cdot kN\cdot m$$

Sum of the Overturning Moments about Point O @ Toe:

$$\Sigma M_{E3.3.OT} := \Sigma M_{DL.U1} + \Sigma M_{HWater.U1} + \Sigma M_{Vwater.U1.OT} + \Sigma M_{I.U1} + \Sigma M_{soil.E3.3} + \Sigma M_{Q.E3.3} = 422579\cdot kN\cdot m$$

Sum of Vertical Forces:

$$\Sigma V_{E3.3.OT} := \Sigma V_{DL.U1} + \Sigma V_{water.U1.OT} + \left|\Sigma V_{Q.E3.EQv.3}\right| = 48008.5\cdot kN$$

Distance X_R: EM 1110-2-2502 Eq.4-1

$$X_{R.E3.3} := \frac{\Sigma M_{E3.3.OT}}{\Sigma V_{E3.3.OT}} = 8.8\,m$$

Overturning Resultant Ratio

$$Ratio_{Overturning.E3.3} := \frac{X_{R.E3.3}}{L_b} = 0.36$$

EM 1110-2-2502

Table 4-1

Retaining Wall Stability Criteria

Loading Condition	Sliding Factor of Safety, FS	Shear Strength Test Required: Soil Foundation	Shear Strength Test Required: Rock Foundation[3]	Overturning Criteria Minimum Base Area in Compression: Soil Foundation	Overturning Criteria Minimum Base Area in Compression: Rock Foundation
Usual	1.5	(Q &/or S)[2,1]	Direct shear	100%[4]	75%[4]
Unusual	1.33	(Q &/or S)[2,1]	Direct shear	75%[4]	50%[4]
Earthquake	1.1	(Q)	Direct shear	Resultant within base	Resultant within base

Overturning Stability Check

$$Ratio_{Overturning.E3.3.check} := \begin{cases} \text{"Okay"} & \text{if } Ratio_{Overturning.E3.3} \geq Ratio_{overturning.allow.Extreme} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$$Ratio_{Overturning.E3.3.check} = \text{"Okay"}$$

Summary of Seismic Results (Only Report Controlling Load Case)

E3.3 CASE

Seismic Case $Q_{E3.3}$ - 30% Horizontal Seismic Force, 100% Vertical

Horiz Sliding Factor of Safety:	$FS_{HorizSliding.E3.3} = 1.40$
Horiz Sliding Factor of Safety Check:	$FS_{HorizSliding.E3.3.Check} =$ "OKAY"
Sliding Factor of Safety:	$FS_{InclinedlSlidingE3.3} = 4.5$
Sliding Factor of Safety Check:	$FS_{Sliding.E3.3.InclinedCheck} =$ "OKAY "
Eccentricity:	$e_{E3.3} = 0.68\,m$
Eccentricity Check:	$e_{check.E3.3} =$ "Okay"
Bearing Pressure At Heel on Inclined Plane:	$\sigma_{heel.E3.3} = 118.5 \cdot \frac{kN}{m^2}$
Bearing Pressure At Heel Check:	$\sigma_{heel.E3.3.check} =$ "Okay"
Bearing Pressure At Toe on Inclined Plane:	$\sigma_{toe.E3.3} = 166.3 \cdot \frac{kN}{m^2}$
Bearing Pressure At Toe Check:	$\sigma_{toe.E3.3.check} =$ "Okay"
Flotation Factor of Safety	$FS_{Flotation.E3.3} = 2.7$
Flotation Factor of Safety Check:	$Flotation_{E3.3.check} =$ "Okay"
Overturning Resultant Ratio	$Ratio_{Overturning.E3.3} = 0.36$
Overturning Stability Check	$Ratio_{Overturning.E3.3.check} =$ "Okay"

SEISMIC LOAD E4: EDGM Post-Seismic Assessment of Usual Load U2 Event (3 Load Cases)

Seismic Case $Q_{E4.3}$ - 30% Horizontal Seismic Force, 100% Vertical **E4.3 CASE**

Horizontal Seismic Coefficient: $K_{h.E4.3} := 0.3 \cdot \frac{-2}{3} \cdot 0.26 = -0.05$

Vertical Seismic Coefficient: $K_{v.E4.3} := 1 \cdot \frac{-2}{3} \cdot 0.56 \cdot 0.26 = -0.10$

HORIZONTAL SEISMIC LOADS	Loads	Moment Arm
Horizontal Seismic Component of Concrete Structure:	$Q_{conc.E4.EQh.3} := D_{conc} \cdot K_{h.E4.3} = -2713.5 \cdot kN$	$Y_{conc.loc} = 6.21\,m$
Horizontal Seismic Component of Vertical Lift Gate:	$Q_{Gate.E4.EQh.3} := D_{Gate} \cdot K_{h.E4.3} = -30.2 \cdot kN$	$Y_{gate} = 8.00\,m$
Horizontal Seismic Component of Headwater on Pier: (Section 7.9, Design Criteria)	$Q_{hwp.E4.EQh.3} := \left(\frac{7}{12}\right) \cdot K_{h.E4.3} \cdot \gamma_w \cdot \left(D_{hwp.U2}\right)^2 \cdot W_{hwp.U2} = -40.2 \cdot kN$	$Y_{HWp.E4} = 6.82\,m$
Horizontal Seismic Component of Headwater on Gate: (Section 7.9, Design Criteria)	$Q_{hwg.E4.EQh.3} := \left(\frac{7}{12}\right) \cdot K_{h.E4.3} \cdot \gamma_w \cdot \left(D_{hwg.U2}\right)^2 \cdot W_{hwg.U2} \cdot poss_{U2} = 0 \cdot kN$	$Y_{HWg.E4} = 7.72\,m$
Horizontal Seismic Component of Headwater on Footing: (Section 7.9, Design Criteria)	$Q_{hwf.E4.EQh.3} := \left(\frac{7}{12}\right) \cdot K_{h.E4.3} \cdot \gamma_w \cdot \left(D_{hwf.U2}\right)^2 \cdot W_{hw.U2} = -539.6 \cdot kN$	$Y_{HWf.E4} = 2.40\,m$
Horizontal Seismic Component of Active Soil: (Section 5-5, USACE EM_1110-2-2100)	$Q_{act.E4.EQh.3} := \gamma_r \cdot \left(TOC_{as} - BOF_{elev}\right)^2 \cdot K_{h.E4.3} \cdot W_{hw.U2} = -535.4 \cdot kN$	$Y_{E.act.E4} = 2.84\,m$

VERTICAL SEISMIC LOADS	Loads	Moment Arm
Vertical Component of Concrete Structure:	$Q_{conc.E4.EQv.3} := D_{conc} \cdot K_{v.E4.3} = -5065.2 \cdot kN$	$X_{conc.loc} = 12.43\,m$
Vertical Component of Lift Gate:	$Q_{Gate.E4.EQv.3} := D_{Gate} \cdot K_{v.E4.3} = -56.3 \cdot kN$	$X_{gate} = 9.75\,m$
Vertical Seismic Component of Headwater over Apron Slab: (Section 7.9, Design Criteria)	$Q_{H1.E4.EQv.3} := K_{v.E4.3} \cdot H_{1.U2} = -322.3 \cdot kN$	$H_{1.U2.loc} = 21.10\,m$
Vertical Seismic Component of Headwater over Fixed Crest Slab: (Section 7.9, Design Criteria)	$Q_{H2.E4.EQv.3} := K_{v.E4.3} \cdot H_{2.U2} = -249.4 \cdot kN$	$H_{2.U2.loc} = 14.41\,m$

$$\Sigma H_{Q.E4.EQh.3} := Q_{conc.E4.EQh.3} + Q_{Gate.E4.EQh.3} + Q_{hwp.E4.EQh.3} + Q_{hwg.E4.EQh.3} + Q_{hwf.E4.EQh.3} + Q_{act.E4.EQh.3} = -3858.8 \cdot kN$$

$$\Sigma V_{Q.E4.EQv.3} := Q_{conc.E4.EQv.3} + Q_{Gate.E4.EQv.3} + Q_{H1.E4.EQv.3} + Q_{H2.E4.EQv.3} = -5693.2 \cdot kN$$

$$\begin{aligned}\Sigma M_{Q.E4.3} := {} & Q_{conc.E4.EQh.3} \cdot Y_{conc.loc} + Q_{Gate.E4.EQh.3} \cdot Y_{gate} + Q_{hwp.E4.EQh.3} \cdot Y_{HWp.E4} + Q_{hwg.E4.EQh.3} \cdot Y_{HWg.E4} \cdots = -94081.9 \cdot kN \cdot m \\ & + Q_{hwf.E4.EQh.3} \cdot Y_{HWf.E4} + Q_{act.E4.EQh.3} \cdot Y_{E.act.E4} + Q_{conc.E4.EQv.3} \cdot X_{conc.loc} + Q_{Gate.E4.EQv.3} \cdot X_{gate} \cdots \\ & + Q_{H1.E4.EQv.3} \cdot H_{1.U2.loc} + Q_{H2.E4.EQv.3} \cdot H_{2.U2.loc}\end{aligned}$$

STABILITY ASSESSMENT:

E4.3 CASE

Seismic Case $Q_{E4.3}$ - 30% Horizontal Seismic Force, 100% Vertical

CHECK SLIDING ALONG HORIZONTAL PLANE THRU TOE,
IGNORING BEDROCK MOBILIZED BY STRUCTURAL HEEL KEY, OR VOID BEHIND KEY

Sum of Vertical Forces:

$\Sigma V_{E4.3} := \Sigma V_{U2} + \Sigma V_{Q.E4.EQv.3} = 29466.0 \cdot kN$

Sum of Horizontal Forces:

$\Sigma H_{E4.3} := \Sigma H_{U2} + \Sigma H_{Q.E4.EQh.3} = -14541.7 \cdot kN$

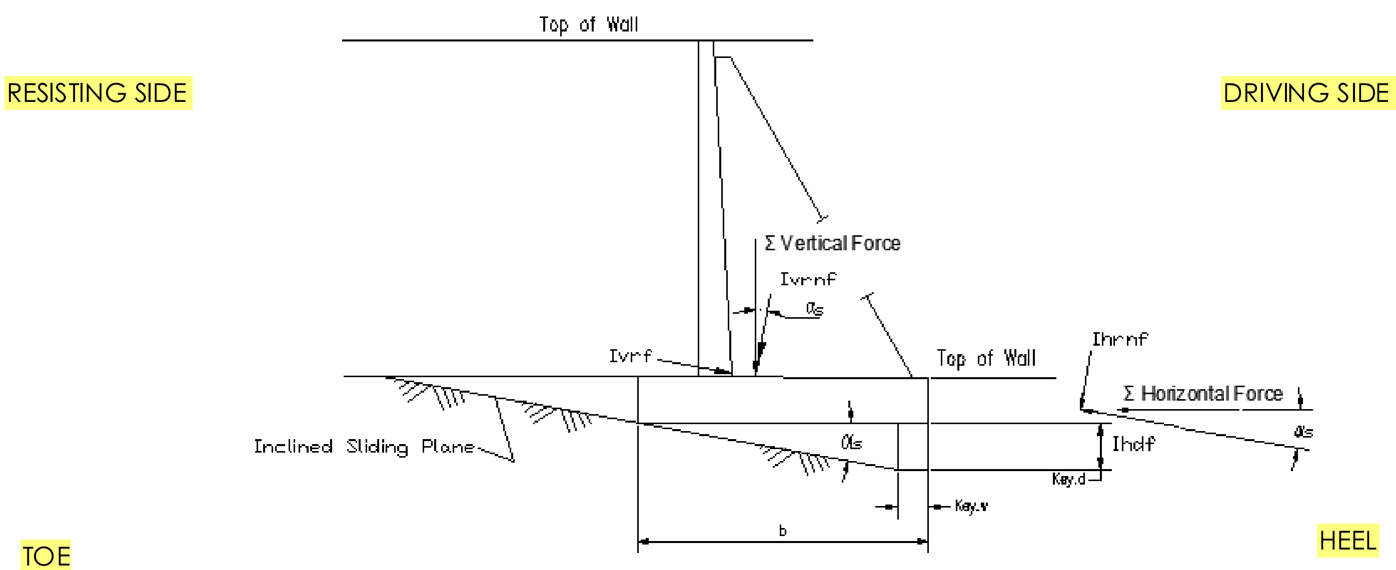
Sliding Factor of Safety:

$$FS_{HorizSliding.E4.3} := \frac{\tan_{\phi} \cdot \Sigma V_{E4.3}}{\left|\Sigma H_{E4.3}\right|} = 0.99$$

$FS_{HorizSliding.E4.3.Check} :=$ "OKAY" if $FS_{HorizSliding.E4.3} \geq FS_{req.E4.sl}$
"Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !" otherwise

$FS_{HorizSliding.E4.3.Check} =$ "Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !"

CHECK SLIDING ALONG INCLINED SLIDING PLANE FROM HEEL KEY TO TOE,
WITH BEDROCK MASS MOBILIZED BY REINFOCREDE CONCRETE KEY)



Ivrf=Inclined Resisting Force
Ivrnf=Inclined Resisting Normal Force
Ihrnf=Inclined Resisting Normal Force
Ihdf=Inclined Driving Force

Incline angle: $\alpha s = 0.13$ $\quad \alpha s \cdot \left(\frac{180}{\pi}\right) = 7.63$

Resolve $\Sigma Vert_{E4.3}$ & $\Sigma Horiz_{E4.3}$

$\Sigma V_{InclinedE4.3} := \cos(\alpha s) \cdot \left(\Sigma V_{E4.3} + V_{rs}\right) + \sin(\alpha s) \cdot \left|\Sigma H_{E4.3}\right| = 44237.5 \cdot kN$

$\Sigma H_{InclinedE4.3} := \cos(\alpha s) \cdot \left|\Sigma H_{E4.3}\right| - \sin(\alpha s) \cdot \left(\Sigma V_{E4.3} + V_{rs}\right) = 8746.8 \cdot kN$

(With properly engineered reinforced concrete Key, horizontal sliding plane thru Toe is protected, critical sliding plane is relocated to the INCLINED SLIDING PLANE FROM HEEL KEY To TOE, Bedrock Mass above this examing plane is mobilized by reinforced concrete key and combined into Structural Wedge.)

Safety Factor for Sliding
Inclined Failure Plane

$$FS_{InclinedlSlidingE4.3} := \frac{\Sigma V_{InclinedE4.3} \cdot \tan\left(\phi_{rock} \cdot \frac{\pi}{180}\right)}{\left|\Sigma H_{InclinedE4.3}\right|} = 2.47$$

$FS_{Sliding.E4.3.InclinedCheck} :=$ "OKAY " if $FS_{InclinedlSlidingE4.3} > FS_{req.E3.sl}$ = "OKAY "
"Revise Structure"" otherwise

$FS_{Sliding.E4.3.InclinedCheck} =$ "OKAY "

CHECK ECCENTRICITY

E4.3 CASE

Seismic Case $Q_{E4.3}$ - 30% Horizontal Seismic Force, 100% Vertical

Sum of the moments:

$$\Sigma M_{rs.E4.3} := \Sigma M_{DL.U2} + \Sigma M_{HWater.U2} + \Sigma M_{Vwater.U2} + \Sigma M_{I.U2} + \Sigma M_{soil.U2} + \Sigma M_{Q.E4.3} + V_{rs} \cdot L_{rs} = 471632 \cdot kN \cdot m$$

Eccentricity:

$$e_{E4.3} := \frac{L_{incline}}{2} - \frac{\Sigma M_{rs.E4.3}}{\Sigma V_{InclinedE4.3}} = 1.46\,m$$

Eccentricity Check:

$$e_{check.E4.3} := \begin{cases} \text{"Okay"} & \text{if } e_{E4.3} \le Ecc_{midhalf} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$$e_{check.E4.3} = \text{"Okay"}$$

Foundation Bearing Pressures on Inclined Plane:

Bearing Pressure at Heel:

$$\sigma_{heel.E4.3} := \begin{cases} 0 & \text{if } \left|e_{E4.3}\right| \ge Ecc_{midhalf} \\ \left(\frac{\Sigma V_{InclinedE4.3}}{\frac{A_b}{\cos(\alpha s)}} - \frac{\Sigma V_{InclinedE4.3} \cdot e_{E4.3}}{\frac{S_b}{\cos(\alpha s)^2}} \right) & \text{otherwise} \end{cases} = 89.3 \cdot \frac{kN}{m^2}$$

$$\sigma_{heel.E4.3.check} := \left(\begin{cases} \text{"Okay"} & \text{if } \sigma_{heel.E4.3} \le \sigma_{allow.E4} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} \right)$$

$$\sigma_{heel.E4.3.check} = \text{"Okay"}$$

Bearing Pressure at Toe:

$$\sigma_{toe.E4.3} := \begin{cases} \left[\frac{4}{3} \cdot \left(\frac{\frac{\Sigma V_{InclinedE4.3}}{W_b}}{L_{incline} - 2 \cdot e_{E4.3}} \right) \right] & \text{if } \left|e_{E4.3}\right| \ge Ecc_{midhalf} \\ \left[\frac{\Sigma V_{InclinedE4.3}}{\frac{A_b}{\cos(\alpha s)}} + \frac{\left(\Sigma V_{InclinedE4.3} \cdot e_{E4.3}\right)}{\frac{S_b}{\cos(\alpha s)^2}} \right] & \text{otherwise} \end{cases} = 189.4 \cdot \frac{kN}{m^2}$$

$$\sigma_{toe.E4.3.check} := \begin{cases} \text{"Okay"} & \text{if } \sigma_{toe.E4.3} \le \sigma_{allow.E4} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$$\sigma_{toe.E4.3.check} = \text{"Okay"}$$

Foundation Flotation Checks:

$$FS_{Flotation.E4.3} := \frac{\left(D_{conc} + D_{Gate} + H_{1.U2} + H_{2.U2} + H_{3.U2}\right) - \left|\Sigma V_{Q.E4.EQv.3}\right|}{\left|Uplift_{U2}\right|} = 2.2$$

$$Flotation_{E4.3.check} := \begin{cases} \text{"Okay"} & \text{if } FS_{Flotation.E4.3} \ge FS_{req.E.flt} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$$Flotation_{E4.3.check} = \text{"Okay"}$$

MONOLITH OVERTURNING STABILITY ANALYSIS

E4.3 CASE

Seismic Case $Q_{E4.3}$ - 30% Horizontal Seismic Force, 100% Vertical

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.
Assumptions are made in order to compute overturning stability of indetermine forces on monolith with key;
(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.
(b) The horizontal resisting force acting on the key, P.key, is that required for static equilibrium
(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1 $Ratio_{overturning.allow.Extreme} = 0.167$ Resultant within Middle Half

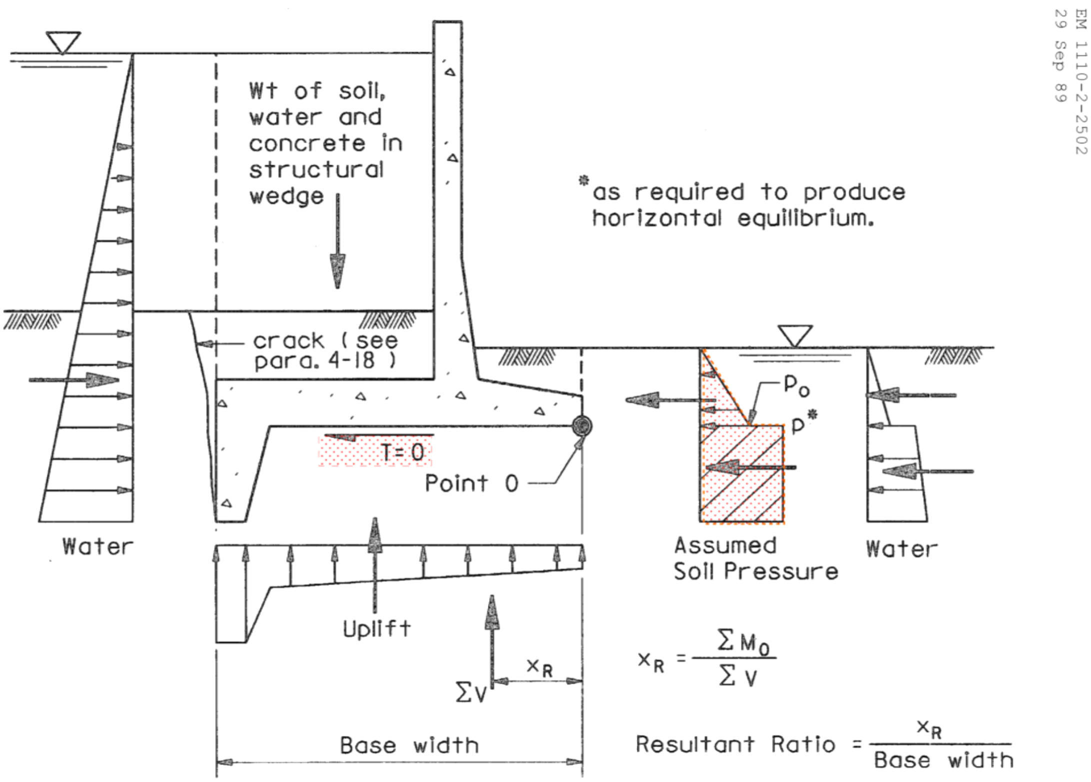


Figure 4-5. Forces for overturning analysis for wall with horizontal base and key

All Vertical Loads Applicable to Overturning Stability Analysis

Total Concrete Dead Loads:	$D_{conc} = 52182.8 \cdot kN$	at:	$X_{conc.loc} = 12.43\,m$
Dead Load of Gate:	$D_{Gate} = 580.0 \cdot kN$		$X_{gate} = 9.75\,m$
Water Weight (HW) on Apron Slab:	$H_{1.U2} = 3320.9 \cdot kN$		$H_{1.U2.loc} = 21.10\,m$
Water Weight (HW) on Fixed Crest:	$H_{2.U2} = 2569.2 \cdot kN$		$H_{2.U2.loc} = 14.41\,m$
Water Weight (TW) on Fixed Crest:	$H_{3.U2} = 2106.6 \cdot kN$		$H_{3.U2.loc} = 5.78\,m$
Vertical Seismic Component of Concrete Structure:	$Q_{conc.E4.EQv.3} = -5065.2 \cdot kN$	at:	$X_{conc.loc} = 12.43\,m$
Vertical Seismic Component of Vertical Lift Gate:	$Q_{Gate.E4.EQv.3} = -56.3 \cdot kN$		$X_{gate} = 9.75\,m$
Vertical Seismic Component of Headwater over Apron Slab:	$Q_{H1.E4.EQv.3} = -322.3 \cdot kN$		$H_{1.U2.loc} = 21.10\,m$
Vertical Seismic Component of Headwater over Fixed Crest Slab:	$Q_{H2.E4.EQv.3} = -249.4 \cdot kN$		$H_{2.U2.loc} = 14.41\,m$

E4.3 CASE

Uplift for Overturning Analysis, Line of Creep Method. Pore pressure at base of Concrete, first calculation to presumed inclined straight line from Heel to Toe, thereafter by Archimedes Principle.

$$U_{E4.3.loc.sliding} := \frac{U_{A.U2} \cdot L_{A.U2} + U_{B.U2} \cdot L_{B.U2} - A_{rs} \cdot w_{as} \cdot \gamma_w \cdot L_{rs}}{U_{A.U2} + U_{B.U2} - A_{rs} \cdot w_{as} \cdot \gamma_w} = 13.84\,m$$

$$U_{E4.3.sliding} := U_{U2} + A_{rs} \cdot w_{as} \cdot \gamma_w = -19705.8 \cdot kN$$

Uplift for Overturning Analysis, Line of Creep Method. Pore pressure at base of Concrete

$Uplift_{pore.U2} = -18673.3 \cdot kN$

$$Uplift_{pore.E4.3.loc} := \frac{Uplift_{BC.U2} \cdot Uplift_{BC.U2.loc} + Uplift_{DE.U2} \cdot Uplift_{DE.U2.loc} + Uplift_{EF.U2} \cdot Uplift_{EF.U2.loc} + Uplift_{FG.U2} \cdot Uplift_{FG.U2.loc}}{Uplift_{pore.U2}}$$

$Uplift_{pore.E4.3.loc} = 13.3\,m$

Sum of All Water Load for Overturning Analysis

$\Sigma V_{water.E4.3.OT} := H_{1.U1} + H_{2.U1} + H_{3.U1} + Uplift_{pore.U2} = -16995.1 \cdot kN$

All Lateral Loads Applicable to Overturning Stability Analysis

Apply Load to Gate?:	$poss_{U1} = 1$		poss = 1 if gate is closed 0 if gate is open
Headwater Lateral Load on Pier:	$H_{hwp.U2} = -662.3 \cdot kN$	at:	$H_{hwp.U2.loc} = 6.44\,m$
Headwater Lateral Load on Gate:	$H_{hwg.U2} = 0.0 \cdot kN$		$H_{hwg.U2.loc} = 7.44\,m$
Headwater Lateral Load on Footing:	$H_{hwf.U2} = -7709.2 \cdot kN$		$H_{hwf.U2.loc} = 1.67\,m$
Total Horizontal Tailwater Load on Pier:	$H_{twp.U2} = 448.3 \cdot kN$		$H_{twp.U2.loc} = 0.09\,m$
Total Horizontal Tailwater Load on Footing under Gate Openings, i.e., excluding Pier	$H_{twf.U2} = 1008.6 \cdot kN$		$H_{twf.U2.loc} = 0.09\,m$

Resisting Water on Rear Face of Monolith, i.e., bottom of heel elevation: *(Point O @ TOE: BOFtoe = EL.1205.5)*

Horizontal Seismic Component of Concrete Structure:	$Q_{conc.E4.EQh.3} = -2713.5 \cdot kN$	AT	$Y_{conc.loc} = 6.21\,m$
Horizontal Seismic Component of Vertical Lift Gate:	$Q_{Gate.E4.EQh.3} = -30.2 \cdot kN$		$Y_{gate} = 8.00\,m$
Horizontal Seismic Component of Headwater on Pier:	$Q_{hwp.E4.EQh.3} = -40.2 \cdot kN$		$Y_{HWp.E4} = 6.8\,m$
Horizontal Seismic Component of Headwater on Gate:	$Q_{hwg.E4.EQh.3} = 0$		$Y_{HWg.E4} = 7.7\,m$
Horizontal Seismic Component of Headwater on Footing:	$Q_{hwf.E4.EQh.3} = -539.6 \cdot kN$		$Y_{HWf.E4} = 2.4\,m$
Horizontal Seismic Component of Active Soil: (Section 5-5, USACE EM_1110-2-2100)	$Q_{act.E4.EQh.3} = -535.4 \cdot kN$		$Y_{E.act.E4} = 2.8\,m$
Ice / Impact Load:	$I_{U2} = -2100.0 \cdot kN$	at:	$I_{U2.loc} = 10.01\,m$

Depth of Fill at Heel Side for Overturning Analysis (neglecting resistance by driving below Point O):

$t_{hf.E4.3} := TOC_{as} - BOF_{toe} = 4.50\,m$

Driving Soil Load for overturning:

$$E1_{drive.E4.3} := \frac{K_o \cdot t_{hf.U2}^{\;2}}{2} \cdot (\gamma_r - \gamma_w) \cdot W_b \cdot -1 = -1055.7 \cdot kN$$

Acting at:

$$E1_{drive.loc.E4.3} := \frac{t_{hf.E4.3}}{3} = 1.50\,m$$

Downstream (resisting) Lateral Soil Load as required to produce horizontal equilibrium:

$$E2_{resistE4.3} := -1\cdot\left(H_{hwp.U2} + H_{hwg.U2} + H_{hwf.U2} + H_{twp.U2} + H_{twf.U2} + I_{U2} + E1_{drive.U2}\right) = 10070.3\cdot kN$$

Assumed Resisting Bedrock at middle of Key, passive soil pressure or lateral bearing contract joint at end of Monolith 3A3B

$$E2_{resistlocE4.3} := E2_{resistlocU2} = -0.75\,m$$

Overturning moment by Dead Loads about Point O @ Toe

$$\Sigma M_{DL.U2} = 654229.9\cdot kN\cdot m$$

Overturning moment by Vertical Water Loads and Uplift, about Point O @ Toe

$$\Sigma M_{Vwater.U2} = -234242.4\cdot kN\cdot m$$

Overturning moment by Lateral Hydrostatic Forces of Headwater Pool and Tailwater Pool,about Point O @ Toe

$$\Sigma M_{HWater.U2} = -16989.2\cdot kN\cdot m$$

Overturning Moment by Impact/Ice Load, about Point O@ Toe

$$\Sigma M_{I.U2} = -21021\cdot kN\cdot m$$

Overturning moment by Lateral Soil Forces about Point O @ Toe

$$\Sigma M_{soil.E4.3} := E1_{drive.E4.3}\cdot E1_{drive.loc.E4.3} \cdots + E2_{resistE4.3}\cdot E2_{resistlocE4.3} = -9136.3\cdot kN\cdot m$$

Sum of the Overturning Moments about Point O @ Toe:

$$\Sigma M_{E4.3.OT} := \Sigma M_{DL.U2} + \Sigma M_{HWater.U2} + \Sigma M_{Vwater.U2.OT} + \Sigma M_{I.U2} + \Sigma M_{soil.E4.3} + \Sigma M_{Q.E4.3} = 383906\cdot kN\cdot m$$

Sum of Vertical Forces:

$$\Sigma V_{E4.3.OT} := \Sigma V_{DL.U2} + \Sigma V_{water.U2.OT} + \left|\Sigma V_{Q.E4.EQv.3}\right| = 47779.5\cdot kN$$

Distance X_R: EM 1110-2-2502 Eq.4-1

$$X_{R.E4.3} := \frac{\Sigma M_{E4.3.OT}}{\Sigma V_{E4.3.OT}} = 8\,m$$

Overturning Resultant Ratio

$$Ratio_{Overturning.E4.3} := \frac{X_{R.E4.3}}{L_b} = 0.33$$

EM 1110-2-2502

Table 4-1

Retaining Wall Stability Criteria

Loading Condition	Sliding Factor of Safety, FS	Shear Strength Test Required: Soil Foundation	Shear Strength Test Required: Rock Foundation[3]	Overturning Criteria Minimum Base Area in Compression: Soil Foundation	Overturning Criteria Minimum Base Area in Compression: Rock Foundation
Usual	1.5	(Q &/or S)[2,1]	Direct shear	100%[4]	75%[4]
Unusual	1.33	(Q &/or S)[2,1]	Direct shear	75%[4]	50%[4]
Earthquake	1.1	(Q)	Direct shear	Resultant within base	Resultant within base

Overturning Stability Check

$$Ratio_{Overturning.E4.3.check} := \begin{cases} \text{"Okay"} & \text{if } Ratio_{Overturning.E4.3} \ge Ratio_{overturning.allow.Extreme} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$$Ratio_{Overturning.E4.3.check} = \text{"Okay"}$$

E4.3 CASE

Summary of Seismic Results (Only Report Controlling Load Case)

Seismic Case $Q_{E4.3}$ - 30% Horizontal Seismic Force, 100% Vertical

Horiz Sliding Factor of Safety: $FS_{HorizSliding.E4.3} = 0.99$

Horiz Sliding Factor of Safety Check:

$FS_{HorizSliding.E4.3.Check}$ = "Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !"

Sliding Factor of Safety: $FS_{InclinedlSlidingE4.3} = 2.5$

Sliding Factor of Safety Check: $FS_{Sliding.E4.3.InclinedCheck}$ = "OKAY "

Eccentricity: $e_{E4.3} = 1.46\,m$

Eccentricity Check: $e_{check.E4.3}$ = "Okay"

Bearing Pressure At Heel on Inclined Plane: $\sigma_{heel.E4.3} = 89.3 \cdot \frac{kN}{m^2}$

Bearing Pressure At Heel Check: $\sigma_{heel.E4.3.check}$ = "Okay"

Bearing Pressure At Toe on Inclined Plane: $\sigma_{toe.E4.3} = 189.4 \cdot \frac{kN}{m^2}$

Bearing Pressure At Toe Check: $\sigma_{toe.E4.3.check}$ = "Okay"

Flotation Factor of Safety: $FS_{Flotation.E4.3} = 2.2$

Flotation Factor of Safety Check: $Flotation_{E4.3.check}$ = "Okay"

Overturning Resultant Ratio: $Ratio_{Overturning.E4.3} = 0.33$

Overturning Stability Check: $Ratio_{Overturning.E4.3.check}$ = "Okay"

Summary of Seismic Results (Controlling Load Cases)

$FS_{InclinedISlidingE3} := \min\left(FS_{InclinedISlidingE3.1}, FS_{InclinedISlidingE3.2}, FS_{InclinedISlidingE3.3}\right) = 1.94$

$FS_{InclinedISlidingE4} := \min\left(FS_{InclinedISlidingE4.1}, FS_{InclinedISlidingE4.2}, FS_{InclinedISlidingE4.3}\right) = 1.41$

$\sigma_{heel.E3} := \min\left(\sigma_{heel.E3.1}, \sigma_{heel.E3.2}, \sigma_{heel.E3.3}\right) = 90.1 \cdot \frac{kN}{2}$

$\sigma_{heel.E4} := \min\left(\sigma_{heel.E4.1}, \sigma_{heel.E4.2}, \sigma_{heel.E4.3}\right) = 60.8 \cdot \frac{kN}{m^2}$

$\sigma_{toe.E3} := \max\left(\sigma_{toe.E3.1}, \sigma_{toe.E3.2}, \sigma_{toe.E3.3}\right) = 228.9 \cdot \frac{kN}{2}$

$\sigma_{toe.E4} := \max\left(\sigma_{toe.E4.1}, \sigma_{toe.E4.2}, \sigma_{toe.E4.3}\right) = 254.4 \cdot \frac{kN}{m^2}$

$FS_{Flotation.E3} := \min\left(FS_{Flotation.E3.1}, FS_{Flotation.E3.2}, FS_{Flotation.E3.3}\right) = 2.7$

$FS_{Flotation.E4} := \min\left(FS_{Flotation.E4.1}, FS_{Flotation.E4.2}, FS_{Flotation.E4.3}\right) = 2.2$

$Ratio_{Overturning.E3} := \min\left(Ratio_{Overturning.E3.1}, Ratio_{Overturning.E3.1}, Ratio_{Overturning.E3.3}\right) = 0.36$

$Ratio_{Overturning.E4} := \min\left(Ratio_{Overturning.E4.1}, Ratio_{Overturning.E4.1}, Ratio_{Overturning.E4.3}\right) = 0.33$

$Ratio_{InComp} := 3 \cdot Ratio_{Overturning.E4} = 1.00$

Calculation Section IV

DI-2A/2B and DI-4A/4B Gate Blocks Stability Calculations

Project Number: 110773396

Project Title: SR1 Project

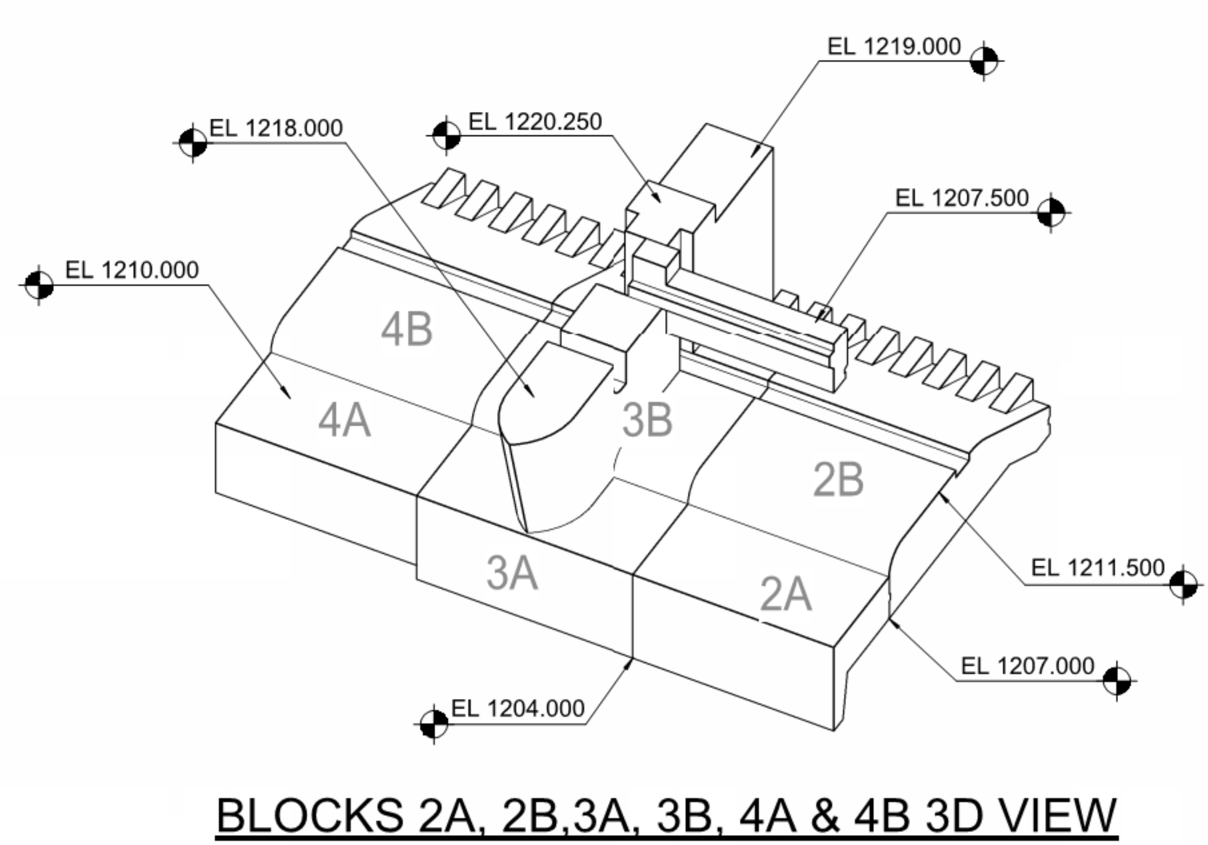
Client: Alberta Transportation

Engineer: Dave Crawford Date: 2018/12/14

Checker: Sean Xiao Date: 2019/01/09

Sliding Stability, Bearing Capacity and Overturning Stability Analysis for: Diversion Inlet Gate Blocks 2A2B / 4A4B

Structure Isometric:



DIVERSION INLET - MONOLITHS (2A+2B; 4A+4B) - GATE BLOCKS

REGION COLOR CONVENTION User Input Calculation Highlights Results

DIVERSION INLET DEIMENSIONAL INPUT PARAMETERS

BASE SECTION PROPERTIES

Base Length: $L_b := 24.20m$ Kern $:= \frac{L_b}{6} = 4.03\,m$

Stilling Basin Length: Lsb=0
when Drain effective at End of Block $L_{sb} := 0m$ $Ecc_{midhalf} := \frac{L_b}{4} = 6.1\,m$ (Dwg. S-330)

Base Width: $W_b := 12.00m$

Area of Base: $A_b := L_b \cdot W_b = 290.4\,m^2$

Section Modulus of Base: $S_b := \frac{W_b \cdot L_b^2}{6} = 1171.3\,m^3$

PIER, ABUTMENT, BREAST WALL AND HEADWALL: Not Applicable to Gate Blocks 2A4A and 4A4B

FOOTINGS (BOF_{base} EL = 1207.0)

Bottom of Key (Footing Heel) Elevation: $BOF_{elev} := 1204.00m$ <=========== *(Critical Design Parameter)*

Apron Slab Top of Concrete
Elevation at Edge of Slab: $TOC_{as} := 1210.00m$

Fixed Crest Top of Concrete
Elevation at Downstream Face: $TOC_{fce} := 1207.50m$ (TOC Elevation of DI Stilling Basin)

Fixed Crest Top of Concrete
Elevation at Center of Footing: $TOC_{fcc} := 1211.50m$

Bottom of Footing Elevation @ Toe: $BOF_{toe} := 1205.50m$ <========== *(Critical Design Parameter)*

(Point O @ TOE: BOFtoe = EL.1205.5)

Footing Concrete Base Elevation
(typ,, Except Heel Key and Toe): $BOF_{base} := 1207.0 \cdot m$

Fixed Crest Footing Elevation Area: $A_{fc} := 68.5m^2$ (From Bluebeam Area Measurement)

Fixed Crest Footing Width: $w_{fc} := 12.00m$

Total Fixed Crest Footing Volume: $V_{fc} := A_{fc} \cdot w_{fc} = 822.0 \cdot m^3$

Apron Slab Footing Width: $w_{as} := 12.00m$

Length of Apron Slab Footing: $L_{as} := 6.20m$

Apron Slab Elevation Area: $A_{as} := L_{as} \cdot \left(TOC_{as} - BOF_{base}\right) = 18.6\,m^2$

Total Apron Slab Footing Volume: $V_{as} := A_{as} \cdot w_{as} = 223.2 \cdot m^3$

Shear Key Depth from Toe
(below Toe EL): $Key_d := BOF_{toe} - BOF_{elev} = 1.5\,m$

Shear Key Width: $Key_w := 1m$

Shear Key Length $Key_l := 12m$

Total Shear Key Volume: $V_{key} := \left(Key_d + BOF_{base} - BOF_{toe}\right) \cdot Key_w \cdot Key_l = 36.0 \cdot m^3$

FOUNDATION PARAMETERS

Granular Fill Internal Angle of Friction: $\phi := 34 \cdot \frac{\pi}{180} = 0.593$ (Section 5.3, Design Criteria)

Friction Angle at Base Concrete / Rock Interface: $\phi_{rock} := 26$ (Section 5.2, Design Criteria)

Base Friction Coefficient: $\tan_{\phi} := \tan\left(\phi_{rock} \frac{\pi}{180}\right) = 0.488$ radians

Line-of-Seepage Parameters $L_{AB} := 0$ (Assuming Cracking for Overturning)

Seepage Line:
A-B-C-D-E-F-G-End of Stilling Basin

$L_{BC} := 1 \cdot m$

$L_{CD} := 3.04 \cdot m$

$L_{DE} := 18.203 \cdot m$

$L_{EF} := 3.353 \cdot m$ $X_{EF} := 3.0 \cdot m$

$L_{FG} := 1.5 \cdot m$

$L_{sb} = 0$

MATERIAL PROPERTIES

Unit Weight of Concrete: $\gamma_c := 23.5 \frac{kN}{m^3}$ (Section 7.1, Design Criteria)

Unit Weight of Rock Fill: $\gamma_r := 22.0 \frac{kN}{m^3}$ (Section 5.3, Design Criteria)

Rip Rap Backfill, Refer Dwg. C-214 $\phi_{backfill} := \left(20 \frac{\pi}{180}\right) = 0.3$ radians

Unit Weight of Water: $\gamma_w := 9.81 \frac{kN}{m^3}$ (Section 7.2, Design Criteria)

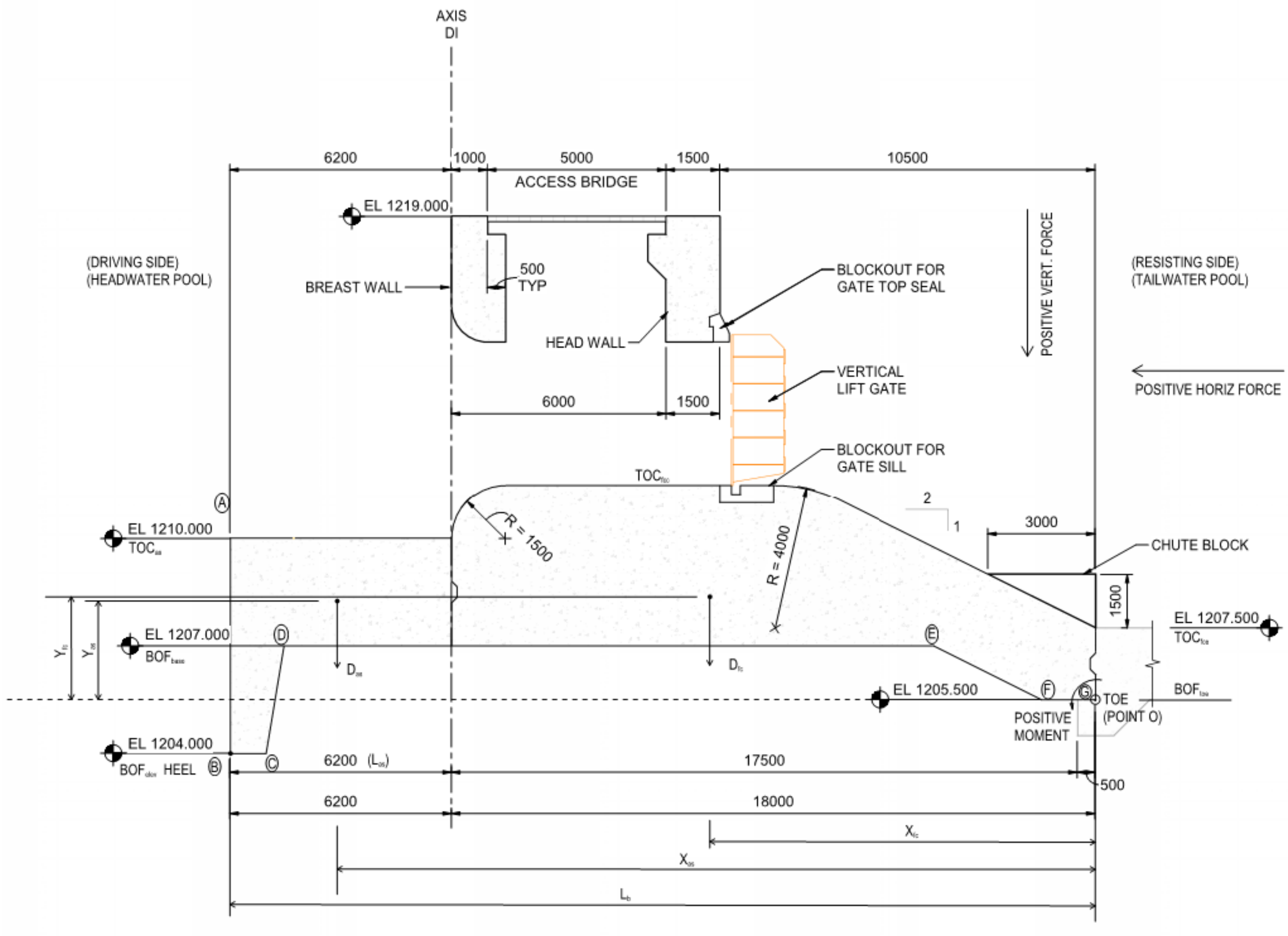
CONCRETE DEAD LOADS

Fixed Crest Footing: $D_{fc} := V_{fc} \cdot \gamma_c = 19317 \cdot kN$

Apron Slab Footing: $D_{as} := V_{as} \cdot \gamma_c = 5245.2 \cdot kN$

Concrete key: $D_{key} := V_{key} \cdot \gamma_c = 846 \cdot kN$

Total Concrete Dead Loads: $D_{conc} := D_{fc} + D_{as} + D_{key} = 25408.2 \cdot kN$



VARIABLES AND SIGN CONVENTION

MOMENT ARM FROM TOE TO CENTROID OF COMPONENT

Dist. from Toe to COG of Fixed Crest: $X_{fc} := 9.948\text{m}$ (From Bluebeam Measurements)

Dist. from Toe to COG of Apron Slab: $X_{as} := 21.10\text{m}$

Dist. from Toe to COG of Heel Key: $X_{key} := \left(L_b - \frac{Key_w}{2}\right) = 23.7\,\text{m}$

MOMENT ARM FROM BASE OF FOOTING TO CENTROID OF COMPONENT

Dist. from Base to COG of Fixed Crest: $Y_{fc} := 3.35\text{m}$ (From Bluebeam Measurements)

Dist. from Base to COG of Apron Slab: $Y_{as} := 3.0\text{m}$

Dist. from Base to COG of Heel Key: $Y_{key} := \frac{BOF_{base} + BOF_{elev}}{2} - BOF_{toe} = 0.00\,\text{m}$

Distance From Toe to COG of Concrete Dead Loads:

$$X_{conc.loc} := \frac{X_{fc} \cdot D_{fc} + X_{as} \cdot D_{as} + X_{key} \cdot D_{key}}{D_{conc}} = 12.71\,\text{m}$$

Distance Above Base to COG of Concrete Dead Loads:

$$Y_{conc.loc} := \frac{Y_{fc} \cdot D_{fc} + Y_{as} \cdot D_{as} + Y_{key} \cdot D_{key}}{D_{conc}} = 3.2\,\text{m}$$

Gate Block similar to Center Pier, without loading from Pier, Gate Slot, Deck, Breast Wall, Headwall)

VERTICAL LIFT GATE

(Lift Gate See Drawing Q-202 dated 03-31-2017.
Gate supported on Center Pier and Abutment when Open, partially sit on Monolith-2A2B when Gate is closed. Loading depends on individual Load Case)

Dead Load of Vertical Lift Gate: $D_{Gate} := 580 \cdot \frac{2}{2} kN$

Distance from Toe to COG of Gate: $X_{gate} := 8.75 \cdot m$

Distance from Base to Centroid of Vertical Lift Gate: $Y_{gate} := \left[\left(TOC_{fcc} - BOF_{toe} \right) + \frac{1215.5 \cdot m - TOC_{fcc}}{2} \right] = 8\,m$

(Distance from base to halfway between the bottom of the headwall and the top of the Fixed Crest.)

Lift Gate Position per Hydraulic Criteria $poss_{U1} := 1$ (poss = 1 if gate is Closed; = 0 if gate is Open)

(When Gate is Closed, it sits on Sill, tributary weight 2/20m = 60% of Unit Assembly ; when Gate is Open, simply supported on Center Pier, No load on Gate Block)

DEAD LOAD SUMMATION:

$$Gate_{R.U1} := \begin{cases} 0 & \text{if } poss_{U1} = 0 \\ 0.60 & \text{otherwise} \end{cases}$$

(Monolith Reaction for Lift Gate)

$$\Sigma V_{DL.U1} := D_{conc} + Gate_{R.U1} D_{Gate} = 25756.2 \cdot kN$$

$$\Sigma M_{DL.U1} := D_{conc} \cdot X_{conc.loc} + Gate_{R.U1} \cdot D_{Gate} \cdot X_{gate} = 325934.4 \cdot kN \cdot m$$

ROCK SECTION MOBILIZED FOR INCLINDED SLIDING FAILURE

Area of Rock Section Mobilized: $A_{rs} := 46.9 m^2$

(From Bluebeam Measurement)

Rock Mass Mobilized: $V_{rs} := A_{rs} \cdot \gamma_r \cdot W_b = 12381.6 \cdot kN$

(Pore pressure taken along assumed inclined sliding plane)

Distance from Toe to COG of Rock Section: $L_{rs} := 13.81 m$ (From Bluebeam Measurement)

Diversion Structure 2D Hydraulic Model Results

Tabular Summary of Diversion Structure 2D Hydraulic Model Results

Applicable or Relevant Scenarios: Diversion Inlet (DI) - Gate Structure

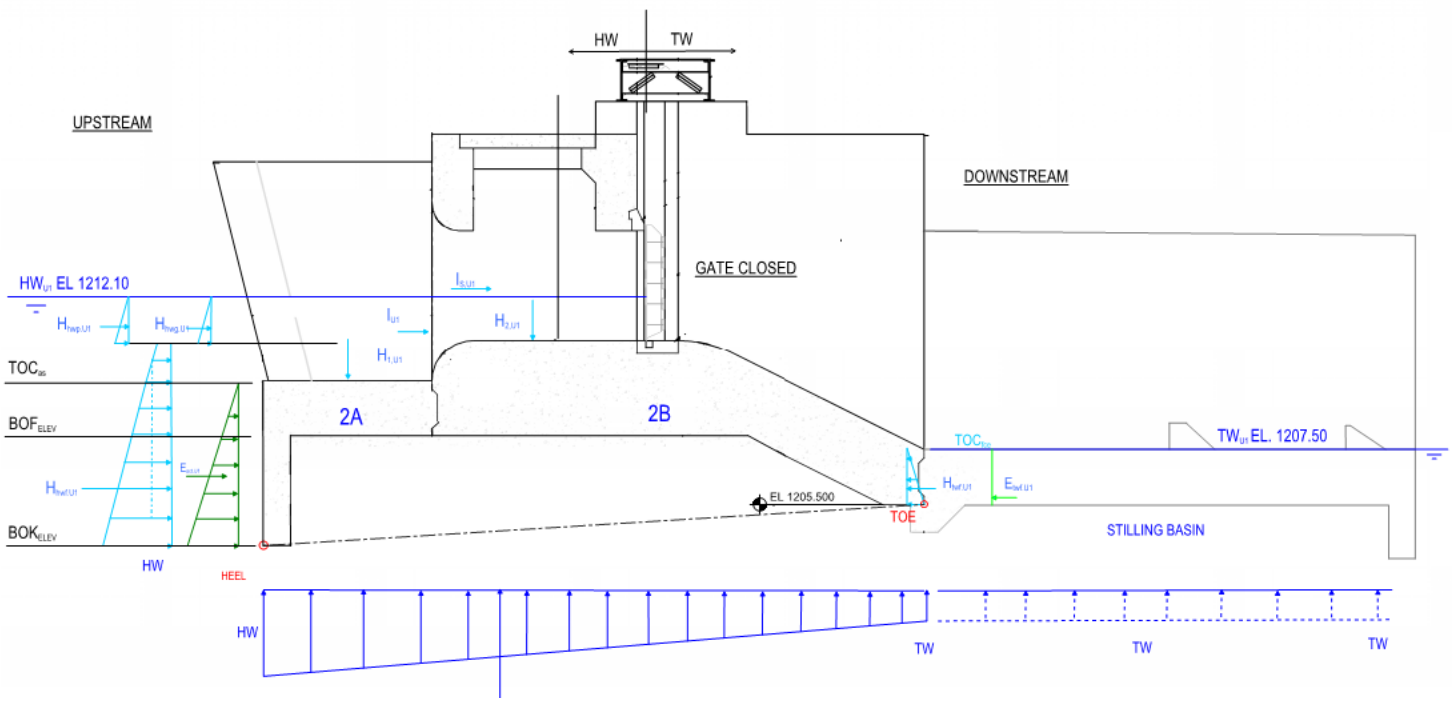
Prepared: 17 October 2018

Water Surface Over DI Gate Bay - Gate Open

Scenario	Total Inflow (m^3/s)	Service Spillway Discharge (m^3/s)			Diversion Inlet Discharge (m^3/s)			Auxiliary Spillway Discharge (m^3/s)	Head water (m)	Service Spillway Tailwater (m)	Diversion Inlet Tailwater (m)*	Notes		Headwater at breast wall (m)	Critical depth at D/S radius (m)	Depth at Basin Toe (m)	Diversion Inlet Tailwater at end of basin (m)*
		Left Gate	Right Gate	Total	Left Gate	Right Gate	Total										
160 m^3/s, No Diversion **(U1, E3-Q)**	160	91	69	160	n/a	n/a	0	n/a	1212.1	1211.8	n/a	Diversion Inlet gates closed and Service Spillway gates fully open		DI Gates Closed	n/a	n/a	n/a
100-yr Event, No Diversion **(UN2)?** Use or 2013 event?	765	400	370	770	n/a	n/a	0	n/a	1214.5	1213.6	n/a	Diversion Inlet gates closed and Service Spillway gates fully open	May delete as 2013 event may control	DI Gates Closed	n/a	n/a	n/a
100-yr Event, Diverting up to 600 m^3/s **(U2, E4-Q)**	765	140	27	167	296	305	601	n/a	1215.8	1211.9	1213.1	Diversion Inlet gates open. Service Spillway left crest gate at EL 1213.4 m and right crest gate at EL 1215.0 m		d = 4.31 EL 1215.81	y_c = 2.87 EL = 1214.37	toe submerged d_{toe} = 1.28 EL = 1208.78	d_{tw} = 5.6 EL = 1213.1
100-yr Event, Diversion Inlet Maintenance **(UN4)**	765	474	23	497	0	274	274	n/a	1215.8	1212.7	1211.0	Left DI gate closed and right DI gate open; and Service Spillway gates fully open		d = 4.30 EL 1215.8	y_c = 2.67 EL 1214.17	d_{toe} = 1.16 EL 1208.66	d_{tw} = 3.5 EL 1211.0
100-yr Event, DI Gates Fail to Close (Not Critical Load Case)	765	309	219	529	123	116	238	n/a	1213.6	1213.2	1210.7	Diversion Inlet gates open and Service Spillway gates fully open.	May delete as not critical load case	n/a			
2013 Event, No Diversion **(UN2)** Auxiliary Spillway at point of overtopping	1240	648	597	1245	n/a	n/a	0	n/a	1216.2	1214.0	n/a	Diversion Inlet gates closed and Service Spillway gates fully open. AS at point of overtopping	2013 Design flood controls over 100-year flood? But DI gates are open during peak passage.	DI Gates Closed	n/a	n/a	n/a
2013 Event, Diverting up to 600 m^3/s **(UN1)**	1240	498	137	634	307	303	610	n/a	1215.8	1213.1	1213.1	Diversion Inlet gates open; Service Spillway left crest gate at EL 1210.0 m and right crest gate at EL 1213.5 m	TOR 2013 design flood requirement	d = 4.3 EL 1215.8	y_c = 2.87 EL 1214.37	toe submerged d_{toe} = 1.28 EL 1208.78	d_{tw} = 5.6 EL 1213.1
1000-yr Event, No Diversion **(UN3)** Auxiliary Spillway cover eroded	1930	759	708	1467	n/a	n/a	0	463	1217.0	1214.7	n/a	Diversion Inlet gates closed and Service Spillway gates fully open. Auxiliary Spillway cover layer eroded	But are DI gates open during peak passage????	DI Gates Closed	n/a	n/a	n/a
1000-yr Event, Diverting up to 600 m3/s, **(UN3a)?** Auxiliary Spillway cover eroded	1930			0			0					Diversion Inlet gates **regulating** and Service Spillway gates fully open. Auxiliary Spillway cover layer eroded	Is this the requirement for 1000-year event?	d = 4.31 EL 1215.81	y_c = 2.87 EL 1214.37	toe submerged d_{toe} = 1.28 EL 1208.78	d_{tw} = 5.6 EL 1213.1
1000-yr Event, DI Gates Fail to close, **(UN3a)?** Auxiliary Spillway cover eroded	1930	631	492	1124	341	337	677	129	1215.8	1214.0	1213.5	Diversion Inlet gates open and Service Spillway gates fully open. Auxiliary Spillway cover layer eroded	Not realistic - compounding probabilities	n/a			
Diversion Structure IDF Event, 1/3 Between 1000-yr and PMF, No Diversion. AS cover eroded.	2210	812	758	1570	n/a	n/a	0	640	1217.3	1214.9	n/a	Diversion Inlet gates closed and Service Spillway gates fully open. Auxiliary Spillway cover layer eroded	Regulatory requirement for SS and AS, not pertinent to DI.	DI Gates Closed	n/a	n/a	n/a
Diversion Structure IDF Event, 1/3 Between 1000-yr and PMF, DI Gates Fail to Close. AS cover eroded	2210	684	532	1215	375	371	746	249	1216.1	1214.2	1213.8	Diversion Inlet gates open and Service Spillway gates fully open. Auxiliary Spillway cover layer eroded	Not realistic - compounding probabilities	n/a			
PMF Event, No Diversion **(E1-F)** AS cover eroded.	2770	911	854	1765	n/a	n/a	0	1001	1217.8	1215.3	n/a	Diversion Inlet gates closed and Service Spillway gates fully open. Auxiliary Spillway cover layer eroded	But are DI gates open during peak passage????	DI Gates Closed	n/a	n/a	n/a
PMF Event, Diverting up to 600 m^3/s **(E2-F)?** AS cover eroded.	2770			0			0					Diversion Inlet gates **regulating** and Service Spillway gates fully open. Auxiliary Spillway cover layer eroded	This is the regulatory requirement for PMF at extreme hazard	d = 4.31 EL 1215.81	y_c = 2.87 EL 1214.37	toe submerged d_{toe} = 1.28 EL 1208.78	d_{tw} = 5.6 EL 1213.1
PMF Event, DI Gates Fail to Close **(E2-F) Determines Diversion Channel max capacity ???**	2770	783	593	1376	435	434	869	521	1216.6	1214.5	1214.4	Diversion Inlet gates open and Service Spillway gates fully open. Auxiliary Spillway cover layer eroded	Not realistic - compounding probabilities	d = 5.1 EL 1216.6	y_c = 3.4 EL 1214.9	toe submerged d_{toe} = 1.76 EL 1209.26	d_{tw} = 6.9 EL 1214.4

U1 DESIGN CASE

DIVERSION INLET GATE BLOCK (2A2B) - LOADING SCENARIO (U1, E3-Q) (U1, E3-Q: No Diversion, River Flow 160 m³/s)



ACCEPTANCE PARAMETERS

Required Factor of Safety for Sliding: $FS_{req.U1.sl} := 1.5$ (Without Cohesion) (Section 8.1, Design Criteria)

Resultant Within Middle Third of Base: $e \le \frac{L_b}{6} \wedge e \ge \frac{-L_b}{6}$ (100% Base in Compression, Design Criteria)

Allowable Rock Bearing Pressure: $\sigma_{allow.U1} := 1270 \cdot \frac{kN}{m^2}$ (Section 5.2, Design Criteria)

Required Factor of Safety for Flotation: $FS_{req.U.flt} := 1.5$

Overturning Min Required Resultant Ratio: $\frac{X_{R.U}}{Horizontal\_Width\_of\_Base} > 0.333$

(100% Base in Compression, Resultant within Middle Third)

INPUT PARAMETERS

Headwater Elevation: $HW_{U1} := 1212.10m$

Tailwater Elevation: $TW_{U1} := 1207.50m$

(Water Elevations based on Diversion Structure 2D Hydraulic Model Results. See page 6 and Section 8.2, Design Criteria)

Crest Water Elevation (No Diversion)

Chute Block Water Elevation (No Diversion)

Bottom of Key (Footing Heel) Elevation: $BOF_{elev} = 1204\,m$ <============= *(Critical Design Parameter)*

Apron Slab Top of Concrete Elevation at Edge of Slab: $TOC_{as} = 1210\,m$

Fixed Crest Top of Concrete Elevation at Downstream Face: $TOC_{fce} = 1207.5\,m$

Fixed Crest Top of Concrete Elevation at Center of Footing: $TOC_{fcc} = 1211.5\,m$

Bottom of Footing Elevation @ Toe: $BOF_{toe} = 1205.5\,m$ <============= *(Critical Design Parameter)*
(Point O @ TOE: BOFtoe = EL.1205.5)

LATERAL WATER LOADS

U1 CASE

HEADWATER (DRIVING): *(Point O @ TOE: BOFtoe = EL.1205.5)*

Water Depth Above Fixed Crest at Gate: $D_{hwg.U1} := HW_{U1} - TOC_{fcc} = 0.6\,m$

Water Load Unit Width on Gate $W_{hwg.U1} := 0 = 0.00$ (Gate supported by Abut and Center Pier)

Apply Load to Gate?: $poss_{U1} = 1$ poss = 1 if gate is closed
0 if gate is open

Total Horizontal Water Load on Gate: $H_{hwg.U1} := \frac{-\left(\gamma_w \cdot D_{hwg.U1}^{\,2}\right)}{2} \cdot W_{hwg.U1} \cdot poss_{U1} = 0 \cdot kN$

Apply Total Gate Water Load at: $H_{hwg.U1.loc} := \frac{D_{hwg.U1}}{3} + \left(TOC_{fcc} - BOF_{toe}\right) = 6.20\,m$

Water Depth at Heel: $D_{hwf.U1} := HW_{U1} - BOF_{elev} = 8.10\,m$

Water Load Unit With on Footing: $W_{hw.U1} := W_b = 12.00\,m$

Water Load at Bottom of Footing: $H_{hwf.U1.1} := -\left(\gamma_w \cdot D_{hwf.U1}\right) \cdot W_{hw.U1} = -953.5\,\frac{1}{m} \cdot kN$

Water Load at Top of Footing: $H_{hwf.U1.2} := -\left(\gamma_w \cdot D_{hwg.U1}\right) \cdot W_{hw.U1} = -70.6\,\frac{1}{m} \cdot kN$

Total Horizontal Water Load on Footing:

$$H_{hwf.U1} := \frac{\left(H_{hwf.U1.1} + H_{hwf.U1.2}\right) \cdot \left(D_{hwf.U1} - D_{hwg.U1}\right)}{2} = -3840.6 \cdot kN$$

Apply Total Footing Water Load at:

$$H_{hwf.U1.loc} := \frac{H_{hwf.U1.2} \cdot \frac{\left(TOC_{fcc} - BOF_{elev}\right)^2}{2} + \frac{\left(H_{hwf.U1.1} - H_{hwf.U1.2}\right)}{2} \cdot \frac{\left(TOC_{fcc} - BOF_{elev}\right)^2}{3}}{\frac{\left(H_{hwf.U1.2} + H_{hwf.U1.1}\right) \cdot \left(TOC_{fcc} - BOF_{elev}\right)}{2}} - \left(BOF_{toe} - BOF_{elev}\right) = 1.17\,m$$

(Converting horizontal force resultant from HEEL calculation to Point-O@TOE)

LATERAL WATER LOADS (cont.)

TAILWATER (RESISTING):

Water Depth at toe: $D_{tw.U1} := TW_{U1} - BOF_{elev} = 3.50\,m$

Water Load Unit Width: $W_{twf.U1} := W_b = 12.00\,m$

Total Horizontal Tailwater Load on Footing under Gate Openings, i.e., excluding Pier

Resisting Water on Rear Face of Monolith, i.e., bottom of heel elevation:

$$COND_{U1} := poss_{U1} = 0 \wedge TW_{U1} \geq TOC_{fcc}$$

$$H_{twf.U1} := \begin{cases} \dfrac{\gamma_w \cdot D_{tw.U1}^{\;2}}{2} \cdot W_{twf.U1} & \text{if } poss_{U1} = 1 \\ \dfrac{\gamma_w \cdot D_{tw.U1}^{\;2}}{2} \cdot W_{twf.U1} & \text{if } poss_{U1} = 0 \wedge TW_{U1} \leq TOC_{fcc} \\ \gamma_w \cdot \left[\dfrac{D_{tw.U1}}{2} + \dfrac{\left(TW_{U1} - TOC_{fcc}\right)}{2} \right] \cdot \left(TOC_{fcc} - BOF_{elev}\right) \cdot W_{twf.U1} & \text{if } COND_{U1} \end{cases} = 721.0 \cdot kN$$

Apply Footing Tailwater Load within Gate Openings at:

$$H_{twf.U1.loc} := \begin{cases} \dfrac{D_{tw.U1}}{3} - \left(BOF_{toe} - BOF_{elev}\right) & \text{if } poss_{U1} = 1 \\ \dfrac{D_{tw.U1}}{3} - \left(BOF_{toe} - BOF_{elev}\right) & \text{if } poss_{U1} = 0 \wedge TW_{U1} \leq TOC_{fcc} \\ \dfrac{\left(TOC_{fcc} - BOF_{elev}\right)^2 \cdot \left[\dfrac{\left(TW_{U1} - TOC_{fcc}\right)}{2} + \dfrac{\left(\left(TOC_{fcc} - BOF_{elev}\right)\right)}{6} \right]}{\left(TOC_{fcc} - BOF_{elev}\right)\left[\left(TW_{U1} - TOC_{fcc}\right) + \dfrac{\left(TOC_{fcc} - BOF_{elev}\right)}{2}\right]} - \left(BOF_{toe} - BOF_{elev}\right) & \text{if } COND_{U1} \end{cases} = -0.33 \cdot m$$

$$\Sigma H_{Water.U1} := H_{hwg.U1} + H_{hwf.U1} + H_{twf.U1} = -3119.6 \cdot kN$$

$$\Sigma M_{HWater.U1} := H_{hwg.U1} \cdot H_{hwg.U1.loc} + H_{hwf.U1} \cdot H_{hwf.U1.loc} \cdots + H_{twf.U1} \cdot H_{twf.U1.loc} = -4743.1 \cdot kN \cdot m$$

VERTICAL WATER LOADS

U1 CASE

HEADWATER:

Water Depth on top of fixed crest: $d_{hw.U1} := HW_{U1} - TOC_{as} = 2.10\,m$

Weight of Water (H1) on Approach Slab: $H_{1.U1} := \left(W_{hw.U1} \cdot d_{hw.U1} \cdot L_{as}\right) \cdot \gamma_w = 1532.7 \cdot kN$

Horiz. Moment Arm for H1 (from toe): $H_{1.U1.loc} := L_b - \frac{L_{as}}{2} = 21.10\,m$

Distance from Gate to Toe: $Dist_{gate} := 10.2 \cdot m$

Cross-sectional Area of Headwater Above Fixed Crest: $A_{fc.hw.U1} := 4.98m^2$ (From Bluebeam Measurement)

Volume of water Above Fixed Crest: $V_{fc.hw.U1} := \left[A_{fc.hw.U1} \cdot \left(W_{hw.U1}\right)\right] = 59.8 \cdot m^3$

Weight of Water (H2) on Fixed Crest: $H_{2.U1} := V_{fc.hw.U1} \cdot \gamma_w = 586.2 \cdot kN$

Horiz. Moment Arm for H2 (from toe): $H_{2.U1.loc} := 14.25 \cdot m$

TAILWATER:

Slope of Crest from D/S of Gate to edge of Stilling Basin: $S_{f.U1} := \frac{\left(TOC_{fcc} - TOC_{fce}\right)}{8.00m} = 0.500$

Height of Tailwater Above Stilling Basin:

$$y_{U1} := \begin{vmatrix} \left(TW_{U1} - TOC_{fce}\right) & \text{if } TW_{U1} \le TOC_{fcc} \\ \left(TOC_{fcc} - TOC_{fce}\right) & \text{otherwise} \end{vmatrix} \qquad y_{U1} = 0.00\,m$$

Horizontal Distance of Tailwater Above Sloped Portion of Crest: $x_{U1} := \frac{y_{U1}}{S_{f.U1}} = 0.00\,m$

Cross Sectional Area of Tailwater Above Sloped Portion of Crest: $A_{tw.U1} := \frac{x_{U1} \cdot y_{U1}}{2} = 0\,m^2$

$= 0.00m^2$ if TW_{U1} is less than or equal to TOC_{fce}

Weight of Water (H3) Above Slope Portion of Crest:

$$H_{3.U1} := \begin{vmatrix} (0.0kN) & \text{if } TW_{U1} \le TOC_{fce} \\ \left(A_{tw.U1} \cdot W_{twf.U1}\right) \cdot \gamma_w & \text{if } TOC_{fcc} \ge TW_{U1} > TOC_{fce} \\ \left[A_{tw.U1} + Dist_{gate} \cdot \left(TW_{U1} - TOC_{fcc}\right)\right] \cdot \left(W_{twf.U1}\right) \cdot \gamma_w & \text{if } TW_{U1} > TOC_{fcc} \end{vmatrix}$$

$H_{3.U1} = 0.0 \cdot kN$

Horiz. Moment Arm for H3 (from Toe):

$$H_{3.U1.loc} := \begin{vmatrix} (0.00m) & \text{if } TW_{U1} \le TOC_{fce} \\ \left(\frac{1}{3} \cdot x_{U1}\right) & \text{if } TOC_{fcc} \ge TW_{U1} > TOC_{fce} \\ \dfrac{\left[\frac{1}{2} \cdot x_{U1} \cdot y_{U1} \cdot \left(\frac{1}{3}\right) x_{U1} + \left(TW_{U1} - TOC_{fcc}\right) \cdot Dist_{gate} \cdot \left(\frac{Dist_{gate}}{2}\right)\right]}{\left(\frac{1}{2} x_{U1} \cdot y_{U1}\right) + \left(TW_{U1} - TOC_{fcc}\right) \cdot Dist_{gate}} & \text{if } TW_{U1} > TOC_{fcc} \end{vmatrix}$$

$H_{3.U1.loc} = 0.00\,m$

UPLIFT AT INCLINED SLIDING PLANE

U1 CASE

Uplift pressure at Headwater: $U_{HW.U1} := D_{hwf.U1} \cdot \gamma_w = 79.46 \cdot \frac{kN}{m^2}$

Uplift pressure at D/S end of Stilling Basin: $U_{TW.U1} := D_{tw.U1} \cdot \gamma_w = 34.3 \cdot \frac{kN}{m^2}$

Length from U/S Face of Gate Structure to Toe Point(Effective Drain at end of Monolith) $L_{overall} := L_b + L_{sb} = 24.20\ m$ $\quad L_{sb} = 0$

Length of Seepage per Line of Creep $L_{seepage} := L_{BC} + L_{CD} + L_{DE} + L_{EF} + L_{FG} + L_{sb} = 27.1\ m$

Difference between Uplift pressure at Headwater and Uplift Pressure at Toe of Stilling Basin: $U_{diffU1} := U_{HW.U1} - U_{TW.U1} = 45.1 \cdot \frac{kN}{m^2}$

Slope of difference between Uplift pressure at Headwater and Uplift Pressure at Toe of Stilling Basin: $U_{slopeU1} := \frac{U_{diffU1} - Key_d \cdot \gamma_w}{L_{overall}} = 1.26 \cdot \frac{kN}{m^2 \cdot m}$ $\quad Key_d = 1.5\ m$

$$U_{seepageslopeU1} := \frac{U_{diffU1} - Key_d \cdot \gamma_w}{L_{seepage}}$$

Pore Pressure at Base of Gate Structure: $U_{press.toe.gsU1} := U_{TW.U1} + L_{sb} \cdot U_{slopeU1} = 34.3 \cdot \frac{kN}{m^2}$

$$U_{pore.toe.U1} := U_{TW.U1} + U_{seepageslopeU1} \cdot L_{sb} = 34.3 \cdot \frac{kN}{m^2}$$

$$U_{pore.F.U1} := U_{pore.toe.U1} + U_{seepageslopeU1} \cdot L_{FG} = 36 \cdot \frac{kN}{m^2}$$

$$U_{pore.E.U1} := U_{pore.F.U1} - \left(BOF_{base} - BOF_{toe}\right) \cdot \gamma_w + U_{seepageslopeU1} \cdot L_{EF} = 25.1 \cdot \frac{kN}{m^2}$$

$$U_{pore.D.U1} := U_{pore.E.U1} + U_{seepageslopeU1} \cdot L_{DE} = 45.5 \cdot \frac{kN}{m^2}$$

$$U_{pore.C.U1} := U_{pore.D.U1} + \left(BOF_{base} - BOF_{elev}\right) \cdot \gamma_w + U_{seepageslopeU1} \cdot L_{CD} = 78.3 \cdot \frac{kN}{m^2}$$

Uniform uplift due to Tailwater: (rectangular portion) $U_{A.U1} := U_{press.toe.gsU1} \cdot L_b \cdot W_b \cdot -1 = -9970.9 \cdot kN$

Moment Arm for Uplift UA from Toe of Gate Structure: $L_{A.U1} := \frac{L_b}{2} = 12.10\ m$

Uplift - Linear Decrease from HW to TW: (triangular portion) $U_{B.U1} := \frac{1}{2} \cdot \left(U_{HW.U1} - U_{press.toe.gsU1}\right) \cdot L_b \cdot W_b \cdot -1 = -6552.3 \cdot kN$

Moment Arm for Uplift UB from Toe of Gate Structure: $L_{B.U1} := \frac{2}{3} \cdot L_b = 16.13\ m$

Total Resultant Uplift force for Sliding Analysis: $U_{U1} := U_{A.U1} + U_{B.U1} = -16523.2 \cdot kN$

Resultant Location from Toe: $U_{U1.loc} := \frac{U_{A.U1} \cdot L_{A.U1} + U_{B.U1} \cdot L_{B.U1}}{U_{A.U1} + U_{B.U1}} = 13.70\ m$

$\Sigma V_{water.U1} := H_{1.U1} + H_{2.U1} + H_{3.U1} + U_{U1} = -14404.2 \cdot kN$

$\Sigma M_{Vwater.U1} := H_{1.U1} \cdot H_{1.U1.loc} + H_{2.U1} \cdot H_{2.U1.loc} + H_{3.U1} \cdot H_{3.U1.loc} + U_{U1} \cdot U_{U1.loc} = -185663.8 \cdot kN \cdot m$

Uplift as per Line of Creep Method
(Flotation and Overturning)

$$Uplift_{BC.U1} := \frac{-1}{2} \cdot W_b \cdot \left(U_{HW.U1} + U_{pore.C.U1}\right) \cdot L_{BC} = -946797.9\,N$$

$$Uplift_{CD.U1} := 0$$

$$Uplift_{DE.U1} := \frac{-1}{2} \cdot W_b \cdot \left(U_{pore.D.U1} + U_{pore.E.U1}\right) \cdot L_{DE} = -7706800.5\,N$$

$$Uplift_{EF.U1} := \frac{-1}{2} \cdot W_b \cdot \left(U_{pore.E.U1} + U_{pore.F.U1}\right) \cdot L_{EF} = -1228912.9\,N$$

$$Uplift_{FG.U1} := \frac{-1}{2} \cdot W_b \cdot \left(U_{pore.F.U1} + U_{pore.toe.U1}\right) \cdot L_{FG} = -633181.6\,N$$

$$Uplift_{pore.U1} := Uplift_{BC.U1} + Uplift_{DE.U1} + Uplift_{EF.U1} + Uplift_{FG.U1} = -10515.7 \cdot kN$$

$$Uplift_{FG.U1.loc} := \frac{L_{FG}}{3} \cdot \frac{\left(2 \cdot U_{pore.F.U1} + U_{pore.toe.U1}\right)}{\left(U_{pore.F.U1} + U_{pore.toe.U1}\right)} = 0.76\,m$$

$$Uplift_{EF.U1.loc} := \frac{L_{EF}}{3} \cdot \frac{\left(2 \cdot U_{pore.E.U1} + U_{pore.F.U1}\right)}{\left(U_{pore.E.U1} + U_{pore.F.U1}\right)} + L_{FG} = 3.08\,m$$

$$Uplift_{DE.U1.loc} := \frac{L_{DE}}{3} \cdot \frac{\left(2 \cdot U_{pore.D.U1} + U_{pore.E.U1}\right)}{\left(U_{pore.D.U1} + U_{pore.E.U1}\right)} + L_{FG} + X_{EF} = 14.48\,m$$

$$Uplift_{BC.U1.loc} := \frac{L_{BC}}{3} \cdot \frac{\left(2 \cdot U_{HW.U1} + U_{pore.C.U1}\right)}{\left(U_{HW.U1} + U_{pore.C.U1}\right)} + L_{FG} + X_{EF} + L_{DE} = 23.20\,m$$

U1 CASE

SOIL LOADS

Equivalent Fluid Pressure (EFP):

At rest lateral pressure coefficient: $K_o := 1 - \sin(\phi_{backfill}) = 0.66$ (CFEM 24.1)

Lateral Driving Force (Headwater Side)

(At-rest Soil Pressure to Heel, EM1110--2-2502 Section 3-7)

Depth of Fill at Heel: $t_{hf.U1} := TOC_{as} - BOF_{elev} = 6.00\,m$

Soil Load: $E1_{drive.U1} := \frac{K_o \cdot t_{hf.U1}^2}{2} \cdot (\gamma_r - \gamma_w) \cdot W_b \cdot -1 = -1732.5 \cdot kN$

Acting at: $E1_{drive.loc.U1} := \frac{t_{hf.U1}}{3} - (BOF_{toe} - BOF_{elev}) = 0.50\,m$

Lateral Resisting Force (Tailwater Side)

Depth of Fill at Toe: $t_{tf.U1} := TOC_{fce} - BOF_{toe} = 2.00\,m$ (EM1110--2-2502 Fig.4-11)

At-Rest Soil Load: $E2_{resistU1} := \frac{K_o \cdot t_{tf.U1}^2}{2} \cdot (\gamma_r - \gamma_w) \cdot W_b = 192.5 \cdot kN$ $E2_{resistU1} := 0$

Acting at: $E2_{resistlocU1} := \frac{t_{tf.U1}}{3} = 0.67\,m$ (Expansion Joint to Stilling Basin, No Sediment in Gap)

$\Sigma H_{soil.U1} := E1_{drive.U1} + E2_{resistU1} = -1732.5 \cdot kN$

$\Sigma M_{soil.U1} := E1_{drive.U1} \cdot E1_{drive.loc.U1} + E2_{resistU1} \cdot E2_{resistlocU1} = -866.2 \cdot kN \cdot m$

ICE / IMPACT LOADS (CONSERVATIVELY ASSUME NO ICE LOADING ON DOWNSTREAM SIDE)

Static Impact Loading on Structure: $I_{S.U1} := 150.0 \frac{kN}{m}$ (Section 7.7, Design Criteria)

Static Impact load on Gates: $I_{G.U1} := 75 \frac{kN}{m}$ (Section 7.7, Design Criteria)

Impact Loading Unit Width on Structure: $W_{S.U1} := 0.00m$

Impact Loading Unit Width on Gates: $W_{G.U1} := 0m = 0.00$

(Gate supported by Abut and Pier. Ice/Impact Loads do not apply to Gate Block)

Total Impact Load on Structure: $I_{U1} := (I_{S.U1} \cdot W_{S.U1} + I_{G.U1} \cdot W_{G.U1}) \cdot -1 = 0 \cdot kN$

Apply Ice load at: $I_{U1.loc} := (HW_{U1} - BOF_{toe} - 0.30m) = 6.30\,m$

$\Sigma H_{I.U1} := I_{U1} = 0 \cdot kN$

$\Sigma M_{I.U1} := I_{U1} \cdot I_{U1.loc} = 0 \cdot kN \cdot m$

SEISMIC LOAD (Not Applicable to this Load Case)

U1 CASE

SUMMARY OF LOADS

	Loads	Moment Arm
Dead Load of Concrete Structure:	$D_{conc} = 25408.2 \cdot kN$	$X_{conc.loc} = 12.71\,m$
Dead Load of Gate:	$D_{Gate} = 580.0 \cdot kN$	$X_{gate} = 8.75\,m$
Headwater Lateral Load on Gate:	$H_{hwg.U1} = 0.0 \cdot kN$	$H_{hwg.U1.loc} = 6.20\,m$
Headwater Lateral Load on Footing:	$H_{hwf.U1} = -3840.6 \cdot kN$	$H_{hwf.U1.loc} = 1.17\,m$
Tailwater Lateral Load:	$H_{twf.U1} = 721.0 \cdot kN$	$H_{twf.U1.loc} = -0.33\,m$
Water Weight (HW) on Apron Slab:	$H_{1.U1} = 1532.7 \cdot kN$	$H_{1.U1.loc} = 21.10\,m$
Water Weight (HW) on Fixed Crest:	$H_{2.U1} = 586.2 \cdot kN$	$H_{2.U1.loc} = 14.25\,m$
Water Weight (TW) on Fixed Crest:	$H_{3.U1} = 0.0 \cdot kN$	$H_{3.U1.loc} = 0.00\,m$
Uplift:	$U_{U1} = -16523.2 \cdot kN$	$U_{U1.loc} = 13.70\,m$
Upstream (driving) Lateral Soil Load:	$E1_{drive.U1} = -1732.5 \cdot kN$	$E1_{drive.loc.U1} = 0.50\,m$
Downstream (resisting) Lateral Soil Load:	$E2_{resistU1} = 0 \cdot kN$	$E2_{resistlocU1} = 0.67\,m$
Ice / Impact Load:	$I_{U1} = 0.0 \cdot kN$	$I_{U1.loc} = 6.30\,m$

CASE

STABILITY ASSESSMENT (SLIDNG, BEARING, FLOTATION AND OVERTURNING):

CHECK SLIDING ALONG HORIZONTAL PLANE THRU TOE,
IGNORING BEDROCK MOBILIZED BY STRUCTURAL HEEL KEY, OR VOID BEHIND KEY

Sum of Vertical Forces:

$\Sigma V_{U1} := \Sigma V_{DL.U1} + \Sigma V_{water.U1} = 11352.0 \cdot kN$

Sum of Horizontal Forces:

$\Sigma H_{U1} := \Sigma H_{Water.U1} + \Sigma H_{soil.U1} + \Sigma H_{I.U1} = -4852.1 \cdot kN$

Sliding Factor of Safety:

$$FS_{HorizSliding.U1} := \frac{\tan_{\phi} \cdot \Sigma V_{U1}}{\left|\Sigma H_{U1}\right|} = 1.14$$

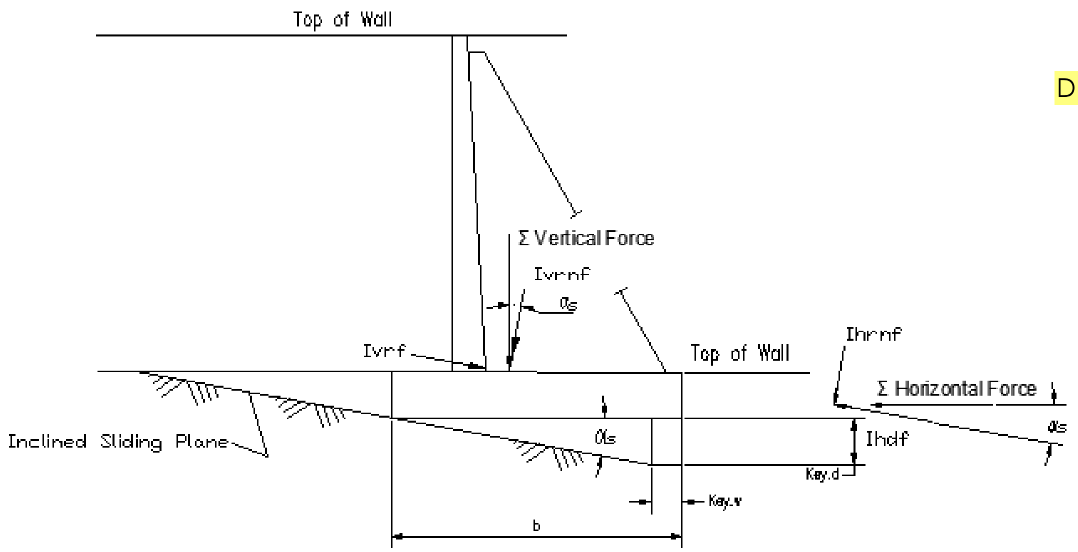
$FS_{HorizSliding.U1.Check} :=$ | "OKAY" if $FS_{HorizSliding.U1} \geq FS_{req.U1.sl}$
| "Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !" otherwise

$FS_{HorizSliding.U1.Check}$ = "Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !"

CHECK SLIDING ALONG INCLINED SLIDING PLANE FROM HEEL KEY TO TOE,
WITH BEDROCK MASS MOBILIZED BY REINFOCREDE CONCRETE KEY)

RESISTING SIDE

DRIVING SIDE



TOE

HEEL

Ivrf=Inclined Resisting Force
Ivrnf=Inclined Resisting Normal Force
Ihrnf=Inclined Resisting Normal Force
Ihdf=Inclined Driving Force

$$\alpha s := \operatorname{atan}\left(\frac{BOF_{toe} - BOF_{elev}}{L_b - Key_l}\right) = 0.12$$

as degrees= $\alpha s \cdot \left(\frac{180}{\pi}\right) = 7.01$

Resolve $\Sigma Vert_{U1}$ & $\Sigma Horiz_{U1}$

$$\Sigma V_{InclinedU1} := \cos(\alpha s) \cdot \left(\Sigma V_{U1} + V_{rs}\right) + \sin(\alpha s) \cdot \left|\Sigma H_{U1}\right| = 24148.3 \cdot kN$$

$$\Sigma H_{InclinedU1} := \cos(\alpha s) \cdot \left|\Sigma H_{U1}\right| - \sin(\alpha s) \cdot \left(\Sigma V_{U1} + V_{rs}\right) = 1919.5 \cdot kN$$

(With properly engineered reinforced concrete Key, horizontal sliding plane thru Toe is protected, critical sliding plane is relocated to the INCLINED SLIDING PLANE FROM HEEL KEY To TOE, Bedrock Mass above this examing plane is mobilized by reinforced concrete key and combined into Structural Wedge.)

Inclined Sliding Plane Length

$$L_{incline} := \left[L_b^{\,2} + \left(BOF_{toe} - BOF_{elev}\right)^2\right]^{0.5} = 24.25\, m$$

Safety Factor for Sliding
Inclined Failure Plane

$$FS_{InclinedISlidingU1} := \frac{\Sigma V_{InclinedU1} \cdot \tan\left(\phi_{rock} \cdot \frac{\pi}{180}\right)}{\left|\Sigma H_{InclinedU1}\right|} = 6.14$$

$FS_{InclinedSliding.check.U1} :=$ | "OKAY " if $FS_{InclinedISlidingU1} > FS_{req.U1.sl}$ = "OKAY "
| "Revise Structure"" otherwise

$FS_{InclinedSliding.check.U1}$ = "OKAY "

U1 CASE

CHECK ECCENTRICITY ON INCLINED PLANE

Sum of the Moments:

$$\Sigma M_{rs.U1} := \Sigma M_{DL.U1} + \Sigma M_{HWater.U1} + \Sigma M_{Vwater.U1} + \Sigma M_{I.U1} + \Sigma M_{soil.U1} + V_{rs} \cdot L_{rs} = 305651 \cdot kN \cdot m$$

Eccentricity:

$$e_{U1} := \frac{L_{incline}}{2} - \frac{\Sigma M_{rs.U1}}{\Sigma V_{InclinedU1}} = -0.53\,m$$

Eccentricity Check:

$$e_{check.U1} := \begin{cases} \text{"Okay"} & \text{if } \left|e_{U1}\right| \le Kern \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$e_{check.U1} = \text{"Okay"}$

Foundation Bearing Pressures on Inclined Plane :

Bearing Pressure at Heel:

$$\sigma_{heel.U1} := \frac{\Sigma V_{InclinedU1}}{\frac{A_b}{\cos(\alpha s)}} - \frac{\Sigma V_{InclinedU1} \cdot e_{U1}}{\frac{S_b}{\cos(\alpha s)^2}} = 93.4 \cdot \frac{kN}{m^2}$$

$$\sigma_{heel.U1.check} := \left(\begin{cases} \text{"Okay"} & \text{if } \sigma_{heel.U1} \le \sigma_{allow.U1} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} \right)$$

$\sigma_{heel.U1.check} = \text{"Okay"}$

Bearing Pressure at Toe:

$$\sigma_{toe.U1} := \frac{\Sigma V_{InclinedU1}}{A_b} + \frac{\Sigma V_{InclinedU1} \cdot e_{U1}}{S_b} = 72.1 \cdot \frac{kN}{m^2}$$

$$\sigma_{toe.U1.check} := \begin{cases} \text{"Okay"} & \text{if } \sigma_{toe.U1} \le \sigma_{allow.U1} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$\sigma_{toe.U1.check} = \text{"Okay"}$

CHECK FLOTATION

$$Uplift_{sliding.U1} := U_{U1} = -16523.2 \cdot kN$$

$$Uplift_{pore.U1} = -10515.7 \cdot kN$$

$$\left(Uplift_{U1}\right) := \min\left(Uplift_{pore.U1}, Uplift_{sliding.U1}\right)$$

(For conservative, taking maximum values)

$$FS_{Flotation.U1} := \frac{D_{conc} + D_{Gate} + H_{1.U1} + H_{2.U1} + H_{3.U1}}{\left|Uplift_{U1}\right|} = 1.7$$

$$FS_{Flotation.U1.check} := \begin{cases} \text{"OKAY "} & \text{if } FS_{Flotation.U1} > FS_{req.U.flt} \\ \text{"Revise Structure""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

U1 CASE

MONOLITH OVERTURNING STABILITY ANALYSIS

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.
Assumptions are made in order to compute overturning stability of indetermine forces on monolith with key;
(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.
(b) The horizontal resisting force acting on the key, P.key, is that required for static equilibrium
(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1 $Ratio_{overturning.allow.Usual} := 0.333$ (Resultant within Middle Third)

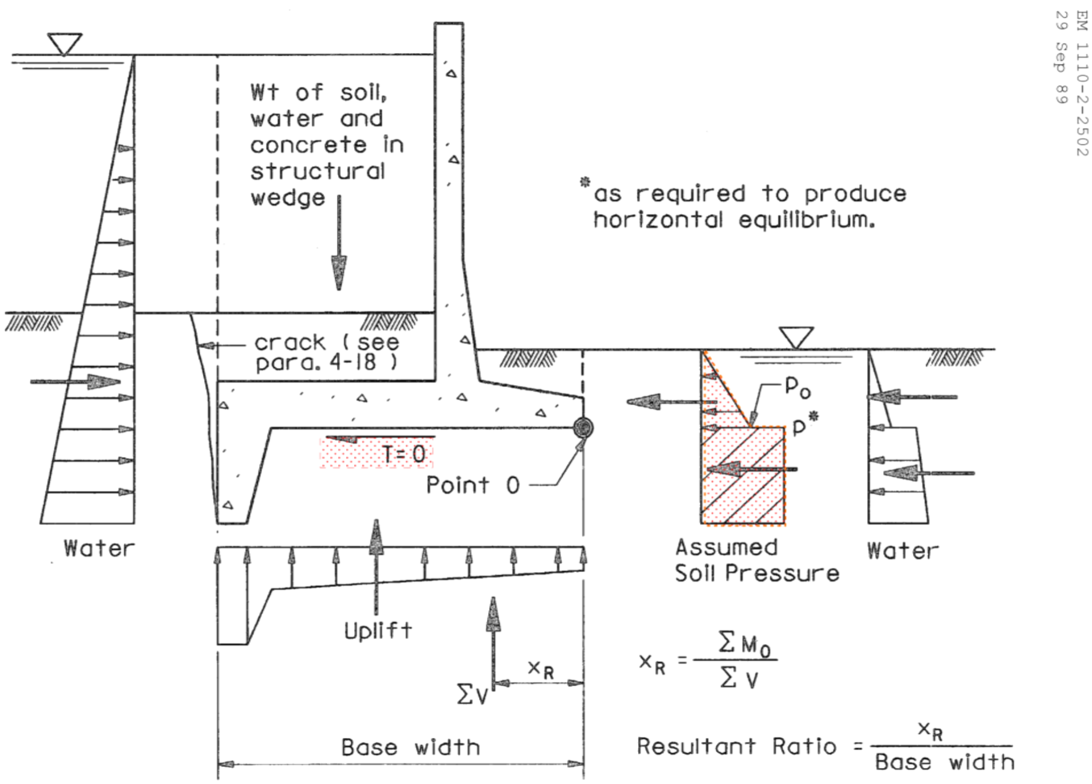


Figure 4-5. Forces for overturning analysis for wall with horizontal base and key

All Vertical Loads Applicable to Overturning Stability Analysis

Total Concrete Dead Loads:	$D_{conc} = 25408.2 \cdot kN$	at:	$X_{conc.loc} = 12.7\,m$
Dead Load of Gate:	$D_{Gate} = 580.0 \cdot kN$		$X_{gate} = 8.75\,m$
Water Weight (HW) on Apron Slab:	$H_{1.U1} = 1532.7 \cdot kN$		$H_{1.U1.loc} = 21.10\,m$
Water Weight (HW) on Fixed Crest:	$H_{2.U1} = 586.2 \cdot kN$		$H_{2.U1.loc} = 14.25\,m$
Water Weight (TW) on Fixed Crest:	$H_{3.U1} = 0.0 \cdot kN$		$H_{3.U1.loc} = 0.00\,m$

Uplift Force from Sliding Analysis. Line of Creep Method applied at presumed inclined sliding line, and subtraction gravity effect to Base of Concrete by Archimedes Principle

$$U_{U1.loc.sliding} := \frac{U_{A.U1} \cdot L_{A.U1} + U_{B.U1} \cdot L_{B.U1} - A_{rs} \cdot w_{as} \cdot \gamma_w \cdot L_{rs}}{U_{A.U1} + U_{B.U1} - A_{rs} \cdot w_{as} \cdot \gamma_w} = 13.73\,m$$

$$U_{U1.sliding} := U_{U1} + A_{rs} \cdot w_{as} \cdot \gamma_w = -11002.1 \cdot kN$$

U1 CASE

Uplift for Overturning Analysis, Line of Creep Method. Pore pressure at base of Concrete

$Uplift_{pore.U1} = -10515.7 \cdot kN$

$$Uplift_{pore.U1.loc} := \frac{\left(\begin{array}{l} Uplift_{BC.U1} \cdot Uplift_{BC.U1.loc} + Uplift_{DE.U1} \cdot Uplift_{DE.U1.loc} \cdots \\ + Uplift_{EF.U1} \cdot Uplift_{EF.U1.loc} + Uplift_{FG.U1} \cdot Uplift_{FG.U1.loc} \end{array}\right)}{Uplift_{pore.U1}} = 13.1\,m$$

Sum of All Water Load for Overturning Analysis $\Sigma V_{water.U1.OT} := H_{1.U1} + H_{2.U1} + H_{3.U1} + Uplift_{pore.U1} = -8396.7 \cdot kN$

All Lateral Loads Applicable to Overturning Stability Analysis

Apply Load to Gate?: $poss_{U1} = 1$ poss = 1 if gate is closed
0 if gate is open

Headwater Lateral Load on Gate: $H_{hwg.U1} = 0.0 \cdot kN$ $H_{hwg.U1.loc} = 6.20\,m$

Headwater Lateral Load on Footing: $H_{hwf.U1} = -3840.6 \cdot kN$ $H_{hwf.U1.loc} = 1.17\,m$

Total Horizontal Tailwater Load on Footing under Gate Openings, i.e., excluding Pier $H_{twf.U1} = 721.0 \cdot kN$ $H_{twf.U1.loc} = -0.33\,m$

(Point O @ TOE: BOFtoe = EL.1205.5)

Resisting Water on Rear Face of Monolith, i.e., bottom of heel elevation:

Ice / Impact Load: $I_{U1} = 0.0 \cdot kN$ at: $I_{U1.loc} = 6.30\,m$

Depth of Fill at Heel Side for Overturning Analysis: $t_{hf.U1} := TOC_{as} - BOF_{toe} = 4.50\,m$

Driving Soil Load for overturning: $$E1_{drive.U1} := \frac{K_o \cdot t_{hf.U1}^{\,2}}{2} \cdot \left(\gamma_r - \gamma_w\right) \cdot W_b \cdot -1 = -974.5 \cdot kN$$

Acting at: $$E1_{drive.loc.U1} := \frac{t_{hf.U1}}{3} = 1.50\,m$$

Downstream (resisting) Lateral Soil Load as required to produce horizontal equilibrium: $E2_{resist.U1} := -1 \cdot \left(H_{hwg.U1} + H_{hwf.U1} + H_{twf.U1} + I_{U1} + E1_{drive.U1}\right) = 4094.1 \cdot kN$

Assumed Resisting Bedrock at middle of Key, passive soil pressure or lateral bearing on contract joint at end of Monolith 3A3B $$E2_{resist.loc.U1} := \frac{-\left(BOF_{toe} - BOF_{elev}\right)}{2} = -0.75\,m$$

Overturning moment by Dead Loads about Point O @ Toe $\Sigma M_{DL.U1} = 325934.4 \cdot kN \cdot m$

Overturning moment by Vertical Water Loads and Uplift, about Point O @ Toe

$$\Sigma M_{Vwater.U1.OT} := H_{1.U1} \cdot H_{1.U1.loc} + H_{2.U1} \cdot H_{2.U1.loc} + H_{3.U1} \cdot H_{3.U1.loc} + Uplift_{pore.U1} \cdot Uplift_{pore.U1.loc} = -97128.1 \cdot kN \cdot m$$

Overturning moment by Lateral Hydrostatic Forces of Headwater Pool and Tailwater Pool, about Point O @ Toe $\Sigma M_{HWater.U1} = -4743.1 \cdot kN \cdot m$

Overturning Moment by Impact/Ice Load, about Point O@ Toe $\Sigma M_{I.U1} = 0 \cdot kN \cdot m$

Overturning moment by Lateral Soil Forces
about Point O @ Toe

$$\Sigma M_{soil.U1} := E1_{drive.U1} \cdot E1_{drive.loc.U1} + E2_{resistU1} \cdot E2_{resistlocU1} = -4532.4 \cdot kN \cdot m$$

Sum of the Overturning Moments about Point O @ Toe:

$$\Sigma M_{U1.OT} := \Sigma M_{DL.U1} + \Sigma M_{HWater.U1} + \Sigma M_{Vwater.U1.OT} + \Sigma M_{I.U1} + \Sigma M_{soil.U1} = 219531 \cdot kN \cdot m$$

Sum of Vertical Forces:

$$\Sigma V_{U1.OT} := \Sigma V_{DL.U1} + \Sigma V_{water.U1.OT} = 17359.5 \cdot kN$$

Distance X_R: EM 1110-2-2502 Eq.4-1

$$X_{R.U1} := \frac{\Sigma M_{U1.OT}}{\Sigma V_{U1.OT}} = 12.6\,m$$

Overturning Resultant Ratio

$$Ratio_{Overturning.U1} := \frac{X_{R.U1}}{L_b} = 0.52$$

EM 1110-2-2502

Table 4-1

Retaining Wall Stability Criteria

Loading Condition	Sliding Factor of Safety, FS	Shear Strength Test Required: Soil Foundation	Shear Strength Test Required: Rock Foundation[3]	Overturning Criteria Minimum Base Area in Compression: Soil Foundation	Overturning Criteria Minimum Base Area in Compression: Rock Foundation
Usual	1.5	(Q &/or S)[2,1]	Direct shear	100%[4]	75%[4]
Unusual	1.33	(Q &/or S)[2,1]	Direct shear	75%[4]	50%[4]
Earthquake	1.1	(Q)	Direct shear	Resultant within base	Resultant within base

Overturning Stability Check

$$Ratio_{Overturning.U1.check} := \begin{cases} \text{"Okay"} & \text{if } Ratio_{Overturning.U1} \geq Ratio_{overturning.allow.Usual} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$$Ratio_{Overturning.U1.check} = \text{"Okay"}$$

Summary of Extreme Flood Results (Only Report Controlling Load Case)

U1 CASE

U1 Event: Normal Operation

Horiz Sliding Factor of Safety: $FS_{HorizSliding.U1} = 1.14$

Horiz Sliding Factor of Safety Check: $FS_{HorizSliding.U1.Check}$ = "Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !"

Sliding Factor of Safety: $FS_{InclinedlSlidingU1} = 6.1$

Sliding Factor of Safety Check: $FS_{InclinedSliding.check.U1}$ = "OKAY "

Eccentricity: $e_{U1} = -0.53\,m$

Eccentricity Check: $e_{check.U1}$ = "Okay"

Bearing Pressure At Heel: $\sigma_{heel.U1} = 93.4 \cdot \frac{kN}{m^2}$

Bearing Pressure At Heel Check: $\sigma_{heel.U1.check}$ = "Okay"

Bearing Pressure At Heel: $\sigma_{toe.U1} = 72.1 \cdot \frac{kN}{m^2}$

Bearing Pressure At Toe Check: $\sigma_{toe.U1.check}$ = "Okay"

Flotation Factor of Safety $FS_{Flotation.U1} = 1.7$

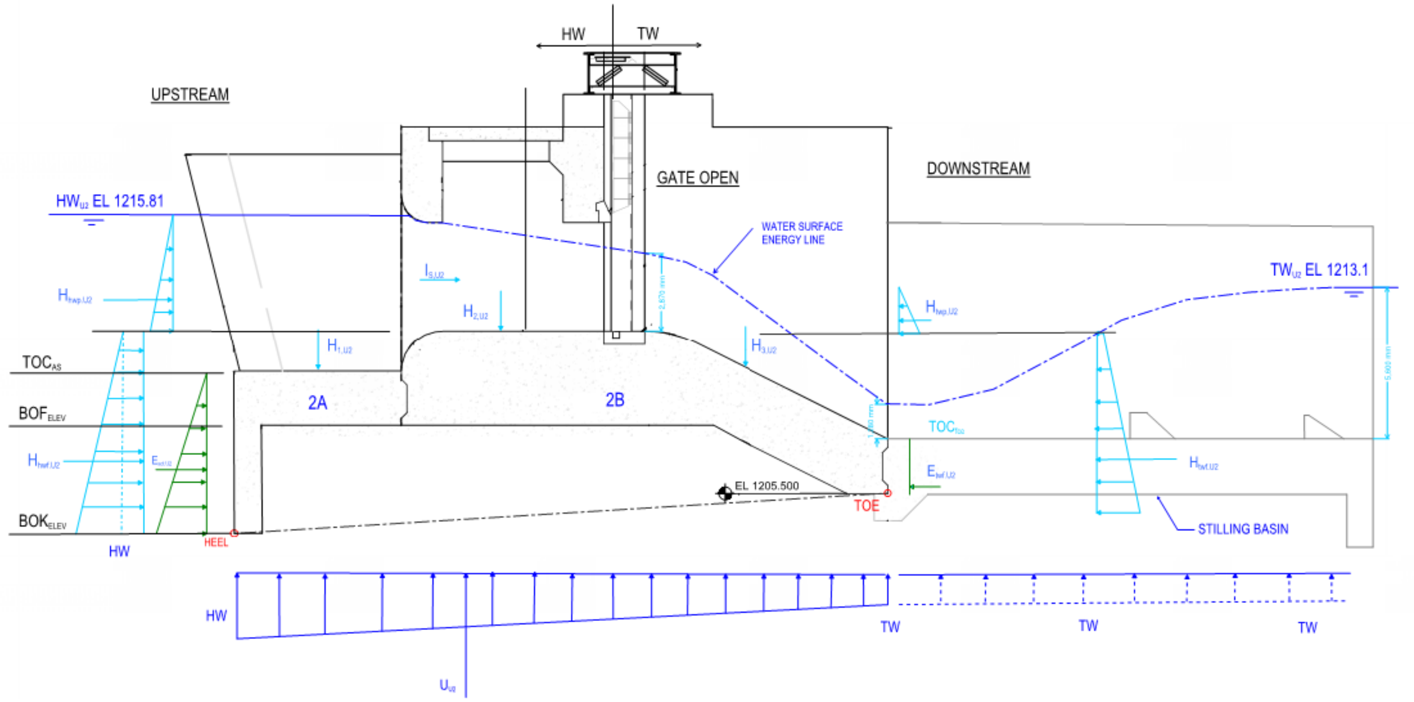
Flotation Factor of Safety Check: $FS_{Flotation.U1.check}$ = "OKAY "

Overturning Resultant Ratio $Ratio_{Overturning.U1} = 0.52$

Overturning Stability Check $Ratio_{Overturning.U1.check}$ = "Okay"

U2 DESIGN CASE

DIVERSION INLET GATE BLOCK (2A2B) - LOADING SCENARIO (U2, E4-Q) (U2, E4-Q: 100-YR Event, Diverting up to 600 m³/s)



ACCEPTANCE PARAMETERS

Required Factor of Safety for Sliding: $FS_{req.U2.sl} := 1.5$ (Without Cohesion) (Section 8.1, Design Criteria)

Resultant Within Middle Third of Base: $e \le \frac{L_b}{6} \wedge e \ge \frac{-L_b}{6}$ (100% Base in Compression, Design Criteria)

Allowable Rock Bearing Pressure: $\sigma_{allow.U2} := 1270.0 \cdot \frac{kN}{m^2}$ (Section 5.2, Design Criteria)

Required Factor of Safety for Flotation: $FS_{req.U.flt} = 1.5$

Overturning Min Required Resultant Ratio: $\frac{X_{R.U}}{Horizontal\_Width\_of\_Base} > 0.333$

(100% Base in Compression, Resultant within Middle Third)

INPUT PARAMETERS

Headwater Elevation: $HW_{U2} := 1215.80m$

Tailwater Elevation: $TW_{U2} := 1213.10m$

(Water Elevations based on Diversion Structure 2D Hydraulic Model Results. See page 6 and Section 8.2, Design Criteria)

Crest Water Elevation, EL.1215.81 $CrestW_{U2} := 2.87 \cdot m$

Chute Block Water Elevation EL.1208.78 $ChuteW_{U2} := 1.28 \cdot m$ $TW_{U2} := TOC_{fce} + ChuteW_{U2} = 1208.8\,m$

Bottom of Key (Footing Heel) Elevation: $BOF_{elev} = 1204.00\,m$

Apron Slab Top of Concrete Elevation at Edge of Slab: $TOC_{as} = 1210.00\,m$

Fixed Crest Top of Concrete Elevation at Downstream Face: $TOC_{fce} = 1207.50\,m$

Fixed Crest Top of Concrete Elevation at Center of Footing: $TOC_{fcc} = 1211.50\,m$

Lift Gate Position per Hydraulic Criteria $poss_{U2} := 0$ poss = 1 if gate is closed
0 if gate is open

$$Gate_{R.U2} := \begin{cases} 0 & \text{if } poss_{U2} = 0 \\ 0.60 & \text{otherwise} \end{cases}$$

$$\Sigma V_{DL.U2} := D_{conc} + Gate_{R.U2} D_{Gate} = 25408.2 \cdot kN$$

$$\Sigma M_{DL.U2} := D_{conc} \cdot X_{conc.loc} + Gate_{R.U2} \cdot D_{Gate} \cdot X_{gate} = 322889.4 \cdot kN \cdot m$$

LATERAL WATER LOADS

U2 CASE

HEADWATER (DRIVING): *Point O @ TOE: BOFtoe = EL.1205.5*

Water Depth Above Fixed Crest at Gate: $D_{hwg.U2} := HW_{U2} - TOC_{fcc} = 4.3\,m$

Water Load Unit Width on Gate $W_{hwg.U2} := 0 = 0.00$

Apply Load to Gate?: $poss_{U2} = 0$

poss = 1 if gate is closed
0 if gate is open

Total Horizontal Water Load on Gate: $H_{hwg.U2} := \frac{-\gamma_w \cdot D_{hwg.U2}^2}{2} \cdot W_{hwg.U2} \cdot poss_{U2} = 0 \cdot kN$

Apply Total Gate Water Load at: $H_{hwg.U2.loc} := \frac{D_{hwg.U2}}{3} + \left(TOC_{fcc} - BOF_{toe}\right) = 7.43\,m$

Water Depth at Heel: $D_{hwf.U2} := HW_{U2} - BOF_{elev} = 11.80\,m$

Water Load Unit With on Footing: $W_{hw.U2} := W_b$

Water Load at Bottom of Footing: $H_{hwf.U2.1} := -\left(\gamma_w \cdot D_{hwf.U2}\right) \cdot W_{hw.U2} = -1389.1\,\frac{1}{m} \cdot kN$

Water Load at Top of Footing: $H_{hwf.U2.2} := -\left(\gamma_w \cdot D_{hwg.U2}\right) \cdot W_{hw.U2} = -506.2\,\frac{1}{m} \cdot kN$

Total Horizontal Water Load on Footing:

$$H_{hwf.U2} := \frac{\left(H_{hwf.U2.1} + H_{hwf.U2.2}\right) \cdot \left(D_{hwf.U2} - D_{hwg.U2}\right)}{2} = -7107.3 \cdot kN$$

Apply Total Footing Water Load at:

$$H_{hwf.U2.loc} := \frac{\left[H_{hwf.U2.2} \cdot \frac{\left(TOC_{fcc} - BOF_{elev}\right)^2}{2} + \frac{\left(H_{hwf.U2.1} - H_{hwf.U2.2}\right)}{2} \cdot \frac{\left(TOC_{fcc} - BOF_{elev}\right)^2}{3}\right]}{\left[\frac{\left(H_{hwf.U2.2} + H_{hwf.U2.1}\right) \cdot \left(TOC_{fcc} - BOF_{elev}\right)}{2}\right]} - \left(BOF_{toe} - BOF_{elev}\right) = 1.67\,m$$

(Converting horizontal force resultant from HEEL calculation to Point-O@TOE)

U2 CASE

LATERAL WATER LOADS (cont.)

TAILWATER (RESISTING):

Water Depth at toe: $D_{tw.U2} := TW_{U2} - BOF_{elev} = 4.78\,m$

Water Load Unit Width: $W_{twf.U2} := W_b$

Total Horizontal Tailwater Load on Footing under Gate Openings, i.e., excluding Pier

Resisting Water on Rear Face of Monolith, i.e., bottom of heel elevation:

$$H_{twf.U2} := \begin{cases} \dfrac{\gamma_w \cdot D_{tw.U2}^{\;2}}{2} \cdot W_{twf.U2} & \text{if } poss_{U2} = 1 \\[2ex] \dfrac{\gamma_w \cdot D_{tw.U2}^{\;2}}{2} \cdot W_{twf.U2} & \text{if } poss_{U2} = 0 \wedge TW_{U2} \le TOC_{fcc} \\[2ex] \gamma_w \cdot \left[\dfrac{D_{tw.U2}}{2} + \dfrac{(TW_{U2} - TOC_{fcc})}{2}\right] \cdot (TOC_{fcc} - BOF_{elev}) \cdot W_{twf.U2} & \text{if } poss_{U2} = 0 \wedge TW_{U2} \ge TOC_{fcc} \end{cases} = 1344.9 \cdot kN$$

Apply Footing Tailwater Load within Gate Openings at:

$$COND_{U2} := poss_{U2} = 0 \wedge TW_{U2} \ge TOC_{fcc}$$

$$H_{twf.U2.loc} := \begin{cases} \dfrac{D_{tw.U2}}{3} - (BOF_{toe} - BOF_{elev}) & \text{if } poss_{U2} = 1 \\[2ex] \dfrac{D_{tw.U2}}{3} - (BOF_{toe} - BOF_{elev}) & \text{if } poss_{U2} = 0 \wedge TW_{U2} \le TOC_{fcc} \\[2ex] \dfrac{(TOC_{fcc} - BOF_{elev})^2 \cdot \left[\dfrac{(TW_{U2} - TOC_{fcc})}{2} + \dfrac{((TOC_{fcc} - BOF_{elev}))}{6}\right]}{(TOC_{fcc} - BOF_{elev})\left[(TW_{U2} - TOC_{fcc}) + \dfrac{(TOC_{fcc} - BOF_{elev})}{2}\right]} - (BOF_{toe} - BOF_{elev}) & \text{if } COND_{U2} \end{cases} = 0.09 \cdot m$$

$$\Sigma H_{Water.U2} := H_{hwg.U2} + H_{hwf.U2} + H_{twf.U2} = -5762.5 \cdot kN$$

$$\Sigma M_{HWater.U2} := H_{hwg.U2} \cdot H_{hwg.U2.loc} + H_{hwf.U2} \cdot H_{hwf.U2.loc} \cdots + H_{twf.U2} \cdot H_{twf.U2.loc} = -11727.4 \cdot kN \cdot m$$

VERTICAL WATER LOADS

U2 CASE

HEADWATER:

Water Depth on top of fixed crest: $d_{hw.U2} := HW_{U2} - TOC_{as} = 5.80\,m$

Weight of Water (H1) on Approach Slab: $H_{1.U2} := \left(W_{hw.U2} \cdot d_{hw.U2} \cdot L_{as}\right) \cdot \gamma_w = 4233.2 \cdot kN$

Horiz. Moment Arm for H1 (from toe): $H_{1.U2.loc} := L_b - \dfrac{L_{as}}{2} = 21.10\,m$

Distance from Gate to Toe: $Dist_{gate} = 10.2\,m$

Cross-sectional Area of Headwater Above Fixed Crest: $A_{fc.hw.U2} := 29.10m^2$

(From Bluebeam Measurement, Bound by Energy Line through Crest Water Elevation CrestW and Chute Block Water Elevation ChuteW as defined above)

Volume of water Above Fixed Crest: $V_{fc.hw.U2} := \left(A_{fc.hw.U2} \cdot W_{hw.U2}\right) = 349.2 \cdot m^3$

Weight of Water (H2) on Fixed Crest: $H_{2.U2} := V_{fc.hw.U2} \cdot \gamma_w = 3425.7 \cdot kN$

Horiz. Moment Arm for H2 (from toe): $H_{2.U2.loc} := 14.25 \cdot m$ (From Bluebeam Measurement)

TAILWATER:

Slope of Crest from D/S of Gate to edge of Stilling Basin: $S_{f.U2} := S_{f.U1} = 0.500$

Height of Tailwater Above Stilling Basin: $y_{U2} := TW_{U2} - TOC_{fce} = 1.3\,m$

Cross Sectional Area of Tailwater Above Sloped Portion of Crest: $A_{tw.U2} := 23.86 \cdot m \cdot m = 23.9\,m^2$

(From Bluebeam Measurement, Bound by Energy Line through Crest Water Elevation CrestW and Chute Block Water Elevation ChuteW as defined above)

Weight of Water (H3) Above Slope Portion of Crest: $H_{3.U2} := \left(A_{tw.U2} \cdot W_{twf.U2}\right) \cdot \gamma_w$ $H_{3.U2} = 2808.8 \cdot kN$

Horiz. Moment Arm for H3 (from Toe): $H_{3.U2.loc} := 5.78 \cdot m$ (From Bluebeam Measurement)

UPLIFT AT INCLINED SLIDING PLANE

U2 CASE

Uplift pressure at Headwater: $U_{HW.U2} := D_{hwf.U2} \cdot \gamma_w = 115.76 \cdot \frac{kN}{m^2}$

Uplift pressure at D/S end of Stilling Basin: $U_{TW.U2} := D_{tw.U2} \cdot \gamma_w = 46.9 \cdot \frac{kN}{m^2}$

Length from U/S Face of Gate Structure to Toe Point(Effective Drain at end of Monolith) $L_{overall} = 24.20\,m$ $L_{sb} = 0$

Length of Seepage per Line of Creep $L_{seepage} = 27.1\,m$

Difference between Uplift pressure at Headwater and Uplift Pressure at Toe of Stilling Basin: $U_{diffU2} := U_{HW.U2} - U_{TW.U2} = 68.9 \cdot \frac{kN}{m^2}$

Slope of difference between Uplift pressure at Headwater and Uplift Pressure at Toe of Stilling Basin: $U_{slopeU2} := \frac{U_{diffU2} - Key_d \cdot \gamma_w}{L_{overall}} = 2.24 \cdot \frac{kN}{m^2 \cdot m}$

$$U_{seepageslopeU2} := \frac{U_{diffU2} - Key_d \cdot \gamma_w}{L_{seepage}}$$

Pore Pressure at Base of Gate Structure: $U_{press.toe.gsU2} := U_{TW.U2} + L_{sb} \cdot U_{slopeU2} = 46.9 \cdot \frac{kN}{m^2}$

$$U_{pore.toe.U2} := U_{TW.U2} + U_{seepageslopeU2} \cdot L_{sb} = 46.9 \cdot \frac{kN}{m^2}$$

$$U_{pore.F.U2} := U_{pore.toe.U2} + U_{seepageslopeU2} \cdot L_{FG} = 49.9 \cdot \frac{kN}{2}$$

$$U_{pore.E.U2} := U_{pore.F.U2} - \left(BOF_{base} - BOF_{toe}\right) \cdot \gamma_w + U_{seepageslopeU2} \cdot L_{EF} = 41.9 \cdot \frac{kN}{m^2}$$

$$U_{pore.D.U2} := U_{pore.E.U2} + U_{seepageslopeU2} \cdot L_{DE} = 78.3 \cdot \frac{kN}{m^2}$$

$$U_{pore.C.U2} := U_{pore.D.U2} + \left(BOF_{base} - BOF_{elev}\right) \cdot \gamma_w + U_{seepageslopeU2} \cdot L_{CD} = 113.8 \cdot \frac{kN}{m^2}$$

Uniform uplift due to Tailwater: (rectangular portion) $U_{A.U2} := U_{press.toe.gsU2} \cdot L_b \cdot W_b \cdot -1 = -13617.4 \cdot kN$

Moment Arm for Uplift UA from Toe of Gate Structure: $L_{A.U2} := \frac{L_b}{2} = 12.10\,m$

Uplift - Linear Decrease from HW to TW: (triangular portion) $U_{B.U2} := \frac{1}{2} \cdot \left(U_{HW.U2} - U_{press.toe.gsU2}\right) \cdot L_b \cdot W_b \cdot -1 = -9999.4 \cdot kN$

Moment Arm for Uplift UB from Toe of Gate Structure: $L_{B.U2} := \frac{2}{3} \cdot L_b = 16.13\,m$

Total Resultant Uplift force: $U_{U2} := U_{A.U2} + U_{B.U2} = -23616.8 \cdot kN$

Resultant Location from Toe: $U_{U2.loc} := \frac{U_{A.U2} \cdot L_{A.U2} + U_{B.U2} \cdot L_{B.U2}}{U_{A.U2} + U_{B.U2}} = 13.81\,m$

U2 CASE

$\Sigma V_{water.U2} := H_{1.U2} + H_{2.U2} + H_{3.U2} + U_{U2} = -13149.1 \cdot kN$

$\Sigma M_{Vwater.U2} := H_{1.U2} \cdot H_{1.U2.loc} + H_{2.U2} \cdot H_{2.U2.loc} + H_{3.U2} \cdot H_{3.U2.loc} + U_{U2} \cdot U_{U2.loc} = -171722.3 \cdot kN \cdot m$

Uplift as per Line of Creep Method
(Flotation and Overturning)

$$Uplift_{BC.U2} := \frac{-1}{2} \cdot W_b \cdot \left(U_{HW.U2} + U_{pore.C.U2}\right) \cdot L_{BC} = -1377105\ N$$

$$Uplift_{CD.U2} := 0$$

$$Uplift_{DE.U2} := \frac{-1}{2} \cdot W_b \cdot \left(U_{pore.D.U2} + U_{pore.E.U2}\right) \cdot L_{DE} = -13120312\ N$$

$$Uplift_{EF.U2} := \frac{-1}{2} \cdot W_b \cdot \left(U_{pore.E.U2} + U_{pore.F.U2}\right) \cdot L_{EF} = -1846129\ N$$

$$Uplift_{FG.U2} := \frac{-1}{2} \cdot W_b \cdot \left(U_{pore.F.U2} + U_{pore.toe.U2}\right) \cdot L_{FG} = -871032.1\ N$$

$$Uplift_{pore.U2} := Uplift_{BC.U2} + Uplift_{DE.U2} + Uplift_{EF.U2} + Uplift_{FG.U2} = -17214.6 \cdot kN$$

$$Uplift_{FG.U2.loc} := \frac{L_{FG}}{3} \cdot \frac{\left(2 \cdot U_{pore.F.U2} + U_{pore.toe.U2}\right)}{\left(U_{pore.F.U2} + U_{pore.toe.U2}\right)} = 0.76\ m$$

$$Uplift_{EF.U2.loc} := \frac{L_{EF}}{3} \cdot \frac{\left(2 \cdot U_{pore.E.U2} + U_{pore.F.U2}\right)}{\left(U_{pore.E.U2} + U_{pore.F.U2}\right)} + L_{FG} = 3.13\ m$$

$$Uplift_{DE.U2.loc} := \frac{L_{DE}}{3} \cdot \frac{\left(2 \cdot U_{pore.D.U2} + U_{pore.E.U2}\right)}{\left(U_{pore.D.U2} + U_{pore.E.U2}\right)} + L_{FG} + X_{EF} = 14.52\ m$$

$$Uplift_{BC.U2.loc} := \frac{L_{BC}}{3} \cdot \frac{\left(2 \cdot U_{HW.U2} + U_{pore.C.U2}\right)}{\left(U_{HW.U2} + U_{pore.C.U2}\right)} + L_{FG} + X_{EF} + L_{DE} = 23.20\ m$$

U2 CASE

SOIL LOADS

Equivalent Fluid Pressure (EFP): (CFEM 24.1)

At rest lateral pressure coefficient: $K_o = 0.66$

At-rest Soil Pressure to Heel, EM1110--2-2502 Section 3-7

Lateral Driving Force (Headwater Side)

Depth of Fill at Heel: $t_{hf.U2} := TOC_{as} - BOF_{elev} = 6.00\,m$

At-Rest Soil Load: $E1_{drive.U2} := \frac{K_o \cdot t_{hf.U2}^{\,2}}{2} \cdot (\gamma_r - \gamma_w) \cdot W_b \cdot -1 = -1732.5 \cdot kN$

Acting at: $E1_{drive.loc.U2} := \frac{t_{hf.U2}}{3} - (BOF_{toe} - BOF_{elev}) = 0.50\,m$

Lateral Resisting Force (Tailwater Side)

Depth of Fill at Toe: $t_{tf.U2} := TOC_{fce} - BOF_{elev} = 3.50\,m$

At-Rest Soil Load: $E2_{resistU2} := \frac{K_o \cdot t_{tf.U2}^{\,2}}{2} \cdot (\gamma_r - \gamma_w) \cdot W_b = 589.5 \cdot kN$ $E2_{resistU2} := 0$

Acting at: $E2_{resistlocU2} := \frac{t_{tf.U2}}{3} = 1.17\,m$ (Expansion Joint to Stilling Basin, No Sediment in Gap)

$\Sigma H_{soil.U2} := E1_{drive.U2} + E2_{resistU2} = -1732.5 \cdot kN$

$\Sigma M_{soil.U2} := E1_{drive.U2} \cdot E1_{drive.loc.U2} + E2_{resistU2} \cdot E2_{resistlocU2} = -866.2 \cdot kN \cdot m$

ICE / IMPACT LOADS (CONSERVATIVELY ASSUME NO ICE LOADING ON DOWNSTREAM SIDE)

Static Impact Loading on Structure: $I_{S.U2} := 150.0 \frac{kN}{m}$ (Section 7.7, Design Criteria)

Static Impact load on Gates: $I_{G.U2} := 75 \frac{kN}{m}$ (Section 7.7, Design Criteria)

Impact Loading Unit Width on Structure: $W_{S.U2} := 0.00m$

Impact Loading Unit Width on Gates: $W_{G.U2} := 0m = 0.00$

Total Impact Load on Structure: $I_{U2} := (I_{S.U2} \cdot W_{S.U2} + I_{G.U2} \cdot W_{G.U2}) \cdot -1 = 0 \cdot kN$

Apply Ice load at: $I_{U2.loc} := (HW_{U2} - BOF_{elev} - 0.30m) = 11.50\,m$

$\Sigma H_{I.U2} := I_{U2} = 0 \cdot kN$

$\Sigma M_{I.U2} := I_{U2} \cdot I_{U2.loc} = 0 \cdot kN \cdot m$

SEISMIC LOAD (Not Applicable to this Load Case)

U2 CASE

SUMMARY OF LOADS

	Loads	Moment Arm
Dead Load of Concrete Structure:	$D_{conc} = 25408.2 \cdot kN$	$X_{conc.loc} = 12.71\ m$
Dead Load of Gate:	$D_{Gate} = 580.0 \cdot kN$	$X_{gate} = 8.75\ m$
Headwater Lateral Load on Gate:	$H_{hwg.U2} = 0.0 \cdot kN$	$H_{hwg.U2.loc} = 7.43\ m$
Headwater Lateral Load on Footing:	$H_{hwf.U2} = -7107.3 \cdot kN$	$H_{hwf.U2.loc} = 1.67\ m$
Tailwater Lateral Load:	$H_{twf.U2} = 1344.9 \cdot kN$	$H_{twf.U2.loc} = 0.09\ m$
Water Weight (HW) on Apron Slab:	$H_{1.U2} = 4233.2 \cdot kN$	$H_{1.U2.loc} = 21.10\ m$
Water Weight (HW) on Fixed Crest:	$H_{2.U2} = 3425.7 \cdot kN$	$H_{2.U2.loc} = 14.25\ m$
Water Weight (TW) on Fixed Crest:	$H_{3.U2} = 2808.8 \cdot kN$	$H_{3.U2.loc} = 5.78\ m$
Uplift:	$U_{U2} = -23616.8 \cdot kN$	$U_{U2.loc} = 13.81\ m$
Upstream (driving) Lateral Soil Load:	$E1_{drive.U2} = -1732.5 \cdot kN$	$E1_{drive.loc.U2} = 0.50\ m$
Downstream (resisting) Lateral Soil Load:	$E2_{resistU2} = 0 \cdot kN$	$E2_{resistlocU2} = 1.17\ m$
Ice / Impact Load:	$I_{U2} = 0.0 \cdot kN$	$I_{U2.loc} = 11.50\ m$

STABILITY ASSESSMENT (SLIDNG, OVERTURNING AND BEARING):

U2 CASE

CHECK SLIDING ALONG HORIZONTAL PLANE THRU TOE,
IGNORING BEDROCK MOBILIZED BY STRUCTURAL HEEL KEY , OR VOID BEHIND KEY

Sum of Vertical Forces:

$\Sigma V_{U2} := \Sigma V_{DL.U2} + \Sigma V_{water.U2} = 12259.1 \cdot kN$

Sum of Horizontal Forces:

$\Sigma H_{U2} := \Sigma H_{Water.U2} + \Sigma H_{soil.U2} + \Sigma H_{I.U2} = -7495 \cdot kN$

Sliding Factor of Safety:

$$FS_{HorizSliding.U2} := \frac{\tan_{\phi} \cdot \Sigma V_{U2}}{|\Sigma H_{U2}|} = 0.80$$

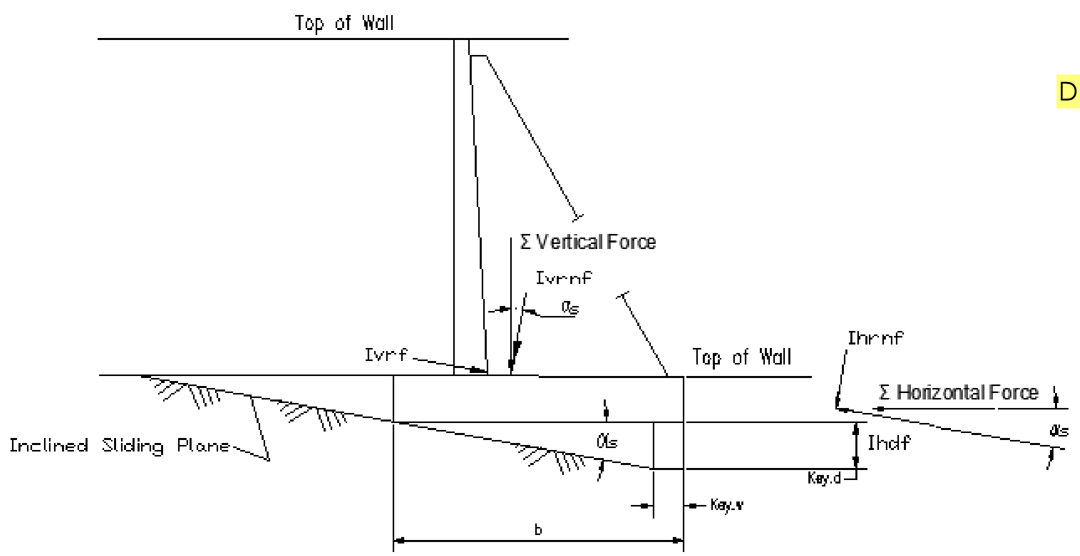
$$FS_{HorizSliding.U2.Check} := \begin{cases} \text{"OKAY"} & \text{if } FS_{HorizSliding.U2} \geq FS_{req.U2.sl} \\ \text{"Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !"} & \text{otherwise} \end{cases}$$

$FS_{HorizSliding.U2.Check} =$ "Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !"

CHECK SLIDING ALONG INCLINED SLIDING PLANE FROM HEEL KEY TO TOE,
WITH BEDROCK MASS MOBILIZED BY REINFOCREDE CONCRETE KEY)

RESISTING SIDE

DRIVING SIDE



TOE

Ivrf=Inclined Resisting Force
Ivrnf=Inclined Resisting Normal Force
Ihrnf=Inclined Resisting Normal Force
Ihdf=Inclined Driving Force

HEEL

$$\alpha s := \operatorname{atan}\left(\frac{BOF_{toe} - BOF_{elev}}{L_b - Key_l}\right) = 0.12 \qquad \text{as degrees=} \qquad \alpha s \cdot \left(\frac{180}{\pi}\right) = 7.01$$

Resolve $\Sigma Vert_{U2}$ & $\Sigma Horiz_{U2}$

$$\Sigma V_{InclinedU2} := \cos(\alpha s) \cdot \left(\Sigma V_{U2} + V_{rs}\right) + \sin(\alpha s) \cdot |\Sigma H_{U2}| = 25371.2 \cdot kN$$

$$\Sigma H_{InclinedU2} := \cos(\alpha s) \cdot |\Sigma H_{U2}| - \sin(\alpha s) \cdot \left(\Sigma V_{U2} + V_{rs}\right) = 4432.0 \cdot kN$$

(With properly engineered reinforced concrete Key, horizontal sliding plane thru Toe is protected, critical sliding plane is relocated to the INCLINED SLIDING PLANE FROM HEEL KEY To TOE, Bedrock Mass above this examing plane is mobilized by reinforced concrete key and combined into Structural Wedge.)

Inclined Sliding Plane Length $\qquad L_{incline} = 24.2\,m$

Safety Factor for Sliding
Inclined Failure Plane

$$FS_{InclinedlSlidingU2} := \frac{\Sigma V_{InclinedU1} \cdot \tan\left(\phi_{rock} \cdot \frac{\pi}{180}\right)}{|\Sigma H_{InclinedU2}|} = 2.66$$

$$FS_{InclinedSliding.check.U2} := \begin{cases} \text{"OKAY "} & \text{if } FS_{InclinedlSlidingU2} > FS_{req.U2.sl} \\ \text{"Revise Structure""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

$FS_{InclinedSliding.check.U2} =$ "OKAY "

CHECK ECCENTRICITY ON INCLINED PLANE

Sum of the Moments:

$$\Sigma M_{rs.U2} := \Sigma M_{DL.U2} + \Sigma M_{HWater.U2} + \Sigma M_{Vwater.U2} + \Sigma M_{I.U2} + \Sigma M_{soil.U2} + V_{rs} \cdot L_{rs} = 309563 \cdot kN \cdot m$$

Eccentricity:

$$e_{U2} := \frac{L_{incline}}{2} - \frac{\Sigma M_{rs.U2}}{\Sigma V_{InclinedU2}} = -0.08\,m$$

Eccentricity Check:

$$e_{check.U2} := \begin{cases} \text{"Okay"} & \text{if } |e_{U2}| \le Kern \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$$e_{check.U2} = \text{"Okay"}$$

Foundation Bearing Pressures on Inclined Plane :

Bearing Pressure at Heel:

$$\sigma_{heel.U2} := \frac{\Sigma V_{InclinedU2}}{\frac{A_b}{\cos(\alpha s)}} - \frac{\Sigma V_{InclinedU2} \cdot e_{U2}}{\frac{S_b}{\cos(\alpha s)^2}} = 88.4 \cdot \frac{kN}{m^2}$$

$$\sigma_{heel.U2.check} := \left(\begin{cases} \text{"Okay"} & \text{if } \sigma_{heel.U2} \le \sigma_{allow.U2} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} \right)$$

$$\sigma_{heel.U2.check} = \text{"Okay"}$$

Bearing Pressure at Toe:

$$\sigma_{toe.U2} := \frac{\Sigma V_{InclinedU2}}{\frac{A_b}{\cos(\alpha s)}} + \frac{\Sigma V_{InclinedU2} \cdot e_{U2}}{\frac{S_b}{\cos(\alpha s)^2}} = 85 \cdot \frac{kN}{m^2}$$

$$\sigma_{toe.U2.check} := \begin{cases} \text{"Okay"} & \text{if } \sigma_{toe.U2} \le \sigma_{allow.U2} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$$\sigma_{toe.U2.check} = \text{"Okay"}$$

CHECK FLOTATION

$$Uplift_{sliding.U2} := U_{U2} = -23616.8 \cdot kN$$

$$Uplift_{pore.U2} = -17214.6 \cdot kN$$

$$\left(Uplift_{U2}\right) := \min\left(Uplift_{pore.U2}, Uplift_{sliding.U2}\right)$$

(For conservative, taking maximum values)

$$FS_{Flotation.U2} := \frac{D_{conc} + D_{Gate} + H_{1.U2} + H_{2.U2} + H_{3.U2}}{|Uplift_{U2}|} = 1.5$$

$$FS_{Flotation.U2.check} := \begin{cases} \text{"OKAY "} & \text{if } FS_{Flotation.U2} > FS_{req.U.flt} \\ \text{"Revise Structure""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

MONOLITH OVERTURNING STABILITY ANALYSIS

U2 CASE

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.

Assumptions are made in order to compute overturning stability of indetermine forces on monolith with key;

(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.

(b) The horizontal resisting force acting on the key, P.key, is that required for static equilibrium

(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1 $Ratio_{overturning.allow.Usual} = 0.33$ (Resultant within Middle Third)

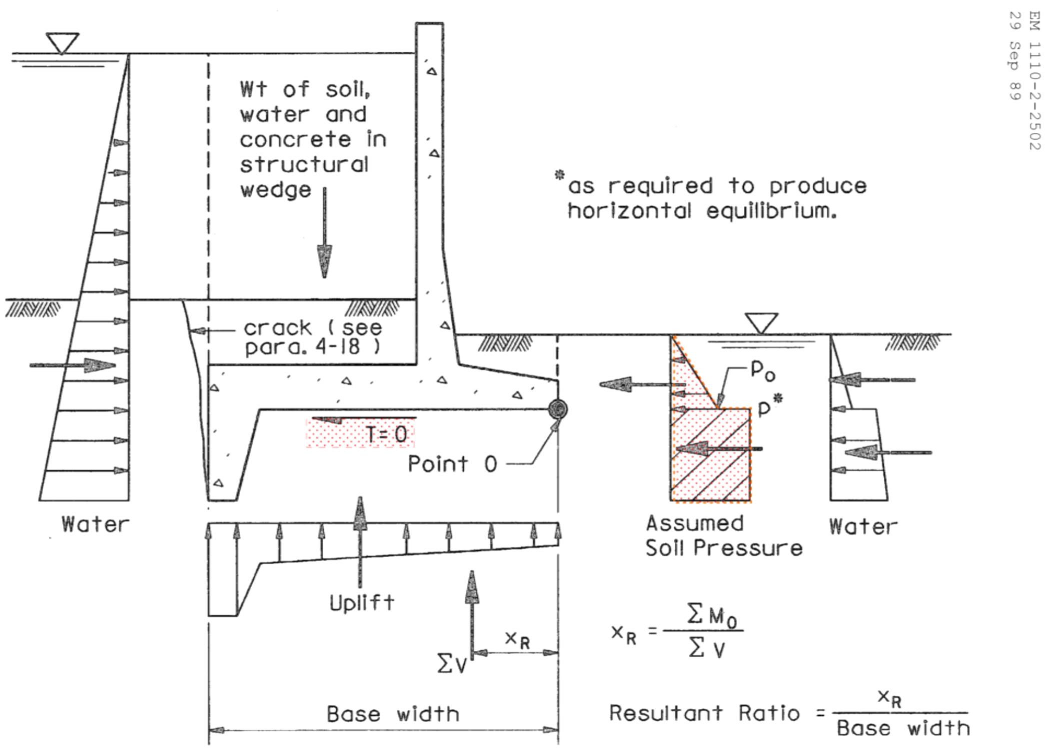


Figure 4-5. Forces for overturning analysis for wall with horizontal base and key

All Vertical Loads Applicable to Overturning Stability Analysis

Total Concrete Dead Loads:	$D_{conc} = 25408.2 \cdot kN$	at:	$X_{conc.loc} = 12.7\,m$
Dead Load of Gate:	$D_{Gate} = 580.0 \cdot kN$		$X_{gate} = 8.75\,m$
Water Weight (HW) on Apron Slab:	$H_{1.U2} = 4233.2 \cdot kN$		$H_{1.U2.loc} = 21.10\,m$
Water Weight (HW) on Fixed Crest:	$H_{2.U2} = 3425.7 \cdot kN$		$H_{2.U2.loc} = 14.25\,m$
Water Weight (TW) on Fixed Crest:	$H_{3.U2} = 2808.8 \cdot kN$		$H_{3.U2.loc} = 5.78\,m$

Uplift Force from Sliding Analysis. Line of Creep Method applied at presumed inclined sliding line, and subtraction gravity effect to Base of Concrete by Archimedes Principle

$$U_{U2.loc.sliding} := \frac{U_{A.U2} \cdot L_{A.U2} + U_{B.U2} \cdot L_{B.U2} - A_{rs} \cdot w_{as} \cdot \gamma_w \cdot L_{rs}}{U_{A.U2} + U_{B.U2} - A_{rs} \cdot w_{as} \cdot \gamma_w} = 13.81\,m$$

$$U_{U2.sliding} := U_{U2} + A_{rs} \cdot w_{as} \cdot \gamma_w = -18095.7 \cdot kN$$

U2 CASE

Uplift for Overturning Analysis, Line of Creep Method. Pore pressure at base of Concrete

$Uplift_{pore.U2} = -17214.6 \cdot kN$

$$Uplift_{pore.U2.loc} := \frac{\left(Uplift_{BC.U2} \cdot Uplift_{BC.U2.loc} + Uplift_{DE.U2} \cdot Uplift_{DE.U2.loc} + Uplift_{EF.U2} \cdot Uplift_{EF.U2.loc} + Uplift_{FG.U2} \cdot Uplift_{FG.U2.loc}\right)}{Uplift_{pore.U2}}$$

$Uplift_{pore.U2.loc} = 13.3\,m$

Sum of All Water Load for Overturning Analysis

$\Sigma V_{water.U2.OT} := H_{1.U2} + H_{2.U2} + H_{3.U2} + Uplift_{pore.U2} = -6746.9 \cdot kN$

All Lateral Loads Applicable to Overturning Stability Analysis

Apply Load to Gate?: $poss_{U2} = 0$ — poss = 1 if gate is closed; 0 if gate is open

Headwater Lateral Load on Gate: $H_{hwg.U2} = 0.0 \cdot kN$ $H_{hwg.U2.loc} = 7.43\,m$

Headwater Lateral Load on Footing: $H_{hwf.U2} = -7107.3 \cdot kN$ $H_{hwf.U2.loc} = 1.67\,m$

Total Horizontal Tailwater Load on Footing under Gate Openings, i.e., excluding Pier: $H_{twf.U2} = 1344.9 \cdot kN$ $H_{twf.U2.loc} = 0.09\,m$

Resisting Water on Rear Face of Monolith, i.e., bottom of heel elevation: *(Point O @ TOE: BOFtoe = EL.1205.5)*

Ice / Impact Load: $I_{U2} = 0.0 \cdot kN$ at: $I_{U2.loc} = 11.50\,m$

Depth of Fill at Heel Side for Overturning Analysis: $t_{hf.U2} := TOC_{as} - BOF_{toe} = 4.50\,m$

Driving Soil Load for overturning: $E1_{drive.U2} := \frac{K_o \cdot t_{hf.U2}^{\,2}}{2} \cdot \left(\gamma_r - \gamma_w\right) \cdot W_b \cdot -1 = -974.5 \cdot kN$

Acting at: $E1_{drive.loc.U2} := \frac{t_{hf.U2}}{3} = 1.50\,m$

Downstream (resisting) Lateral Soil Load as required to produce horizontal equilibrium: $E2_{resist.U2} := -1 \cdot \left(H_{hwg.U2} + H_{hwf.U2} + H_{twf.U2} + I_{U2} + E1_{drive.U2}\right) = 6737 \cdot kN$

Assumed Resisting Bedrock at middle of Key, passive soil pressure or lateral bearing on contract joint at end of Monolith 3A3B: $E2_{resistlocU2} := E2_{resistlocU1} = -0.75\,m$

Overturning moment by Dead Loads about Point O @ Toe: $\Sigma M_{DL.U2} = 322889.4 \cdot kN \cdot m$

Overturning moment by Vertical Water Loads and Uplift, about Point O @ Toe

$$\Sigma M_{Vwater.U2.OT} := H_{1.U2} \cdot H_{1.U2.loc} + H_{2.U2} \cdot H_{2.U2.loc} + H_{3.U2} \cdot H_{3.U2.loc} + Uplift_{pore.U2} \cdot Uplift_{pore.U2.loc} = -74527.9 \cdot kN \cdot m$$

Overturning moment by Lateral Hydrostatic Forces of Headwater Pool and Tailwater Pool,about Point O @ Toe: $\Sigma M_{HWater.U2} = -11727.4 \cdot kN \cdot m$

Overturning Moment by Impact/Ice Load, about Point O@ Toe: $\Sigma M_{I.U2} = 0 \cdot kN \cdot m$

Overturning moment by Lateral Soil Forces
about Point O @ Toe

$$\Sigma M_{soil.U2} := E1_{drive.U2} \cdot E1_{drive.loc.U2} + E2_{resistU2} \cdot E2_{resistlocU2} = -6514.5 \cdot kN \cdot m$$

Sum of the Overturning Moments about Point O @ Toe:

$$\Sigma M_{U2.OT} := \Sigma M_{DL.U2} + \Sigma M_{HWater.U2} + \Sigma M_{Vwater.U2.OT} + \Sigma M_{I.U2} + \Sigma M_{soil.U2} = 230120 \cdot kN \cdot m$$

Sum of Vertical Forces:

$$\Sigma V_{U2.OT} := \Sigma V_{DL.U2} + \Sigma V_{water.U2.OT} = 18661.3 \cdot kN$$

$$\Sigma M_{Vwater.U2} = -171722331.3\,J$$

Distance X_R: EM 1110-2-2502 Eq.4-1

$$X_{R.U2} := \frac{\Sigma M_{U2.OT}}{\Sigma V_{U2.OT}} = 12.3\,m$$

Overturning Resultant Ratio

$$Ratio_{Overturning.U2} := \frac{X_{R.U2}}{L_b} = 0.51$$

EM 1110-2-2502

Table 4-1

Retaining Wall Stability Criteria

Loading Condition	Sliding Factor of Safety, FS	Shear Strength Test Required: Soil Foundation	Shear Strength Test Required: Rock Foundation[3]	Overturning Criteria Minimum Base Area in Compression: Soil Foundation	Overturning Criteria Minimum Base Area in Compression: Rock Foundation
Usual	1.5	(Q &/or S)[2,1]	Direct shear	100%[4]	75%[4]
Unusual	1.33	(Q &/or S)[2,1]	Direct shear	75%[4]	50%[4]
Earthquake	1.1	(Q)	Direct shear	Resultant within base	Resultant within base

Overturning Stability Check

$$Ratio_{Overturning.U2.check} := \begin{cases} \text{"Okay"} & \text{if } Ratio_{Overturning.U2} \geq Ratio_{overturning.allow.Usual} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$$Ratio_{Overturning.U2.check} = \text{"Okay"}$$

Summary of Extreme Flood Results (Only Report Controlling Load Case)

U2 CASE

U2 Event: Diversion Operation, 100 Yr.Flood

Horiz Sliding Factor of Safety: $FS_{HorizSliding.U2} = 0.80$

Horiz Sliding Factor of Safety Check: $FS_{HorizSliding.U2.Check}$ = "Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !"

Sliding Factor of Safety: $FS_{InclinedlSlidingU2} = 2.7$

Sliding Factor of Safety Check: $FS_{InclinedSliding.check.U2}$ = "OKAY "

Eccentricity: $e_{U2} = -0.08\,m$

Eccentricity Check: $e_{check.U2}$ = "Okay"

Bearing Pressure At Heel: $\sigma_{heel.U2} = 88.4 \cdot \frac{kN}{m^2}$

Bearing Pressure At Heel Check: $\sigma_{heel.U2.check}$ = "Okay"

Bearing Pressure At Heel: $\sigma_{toe.U2} = 85.0 \cdot \frac{kN}{m^2}$

Bearing Pressure At Toe Check: $\sigma_{toe.U2.check}$ = "Okay"

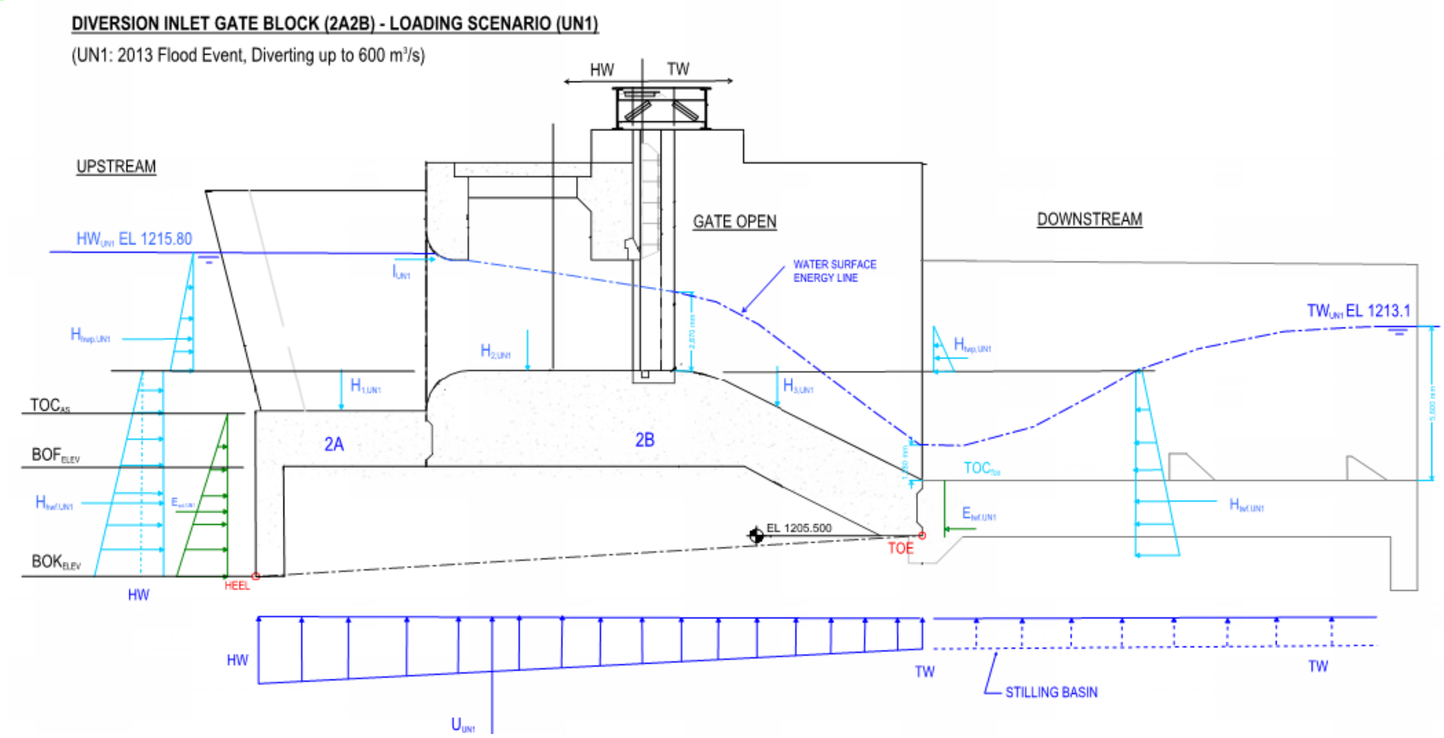
Flotation Factor of Safety $FS_{Flotation.U2} = 1.54$

Flotation Factor of Safety Check: $FS_{Flotation.U2.check}$ = "OKAY "

Overturning Resultant Ratio $Ratio_{Overturning.U2} = 0.51$

Overturning Stability Check $Ratio_{Overturning.U2.check}$ = "Okay"

UN1 DESIGN CASE



ACCEPTANCE PARAMETERS

Required Factor of Safety for Sliding: $FS_{req.UN1.sl} := 1.3$ (Without Cohesion) (Section 8.1, Design Criteria)

Resultant Within Middle Third of Base: $e \le \frac{L_b}{6} \wedge e \ge \frac{-L_b}{6}$ (100% Base in Compression, Design Criteria)

Allowable Rock Bearing Pressure: $\sigma_{allow.UN1} := 1470.0 \cdot \frac{kN}{m^2}$ (Section 5.2, Design Criteria)

Required Factor of Safety for Flotation: $FS_{req.UN.flt} := 1.3$

Overturning Min Required Resultant Ratio: $\frac{X_{R.UN}}{Horizontal\_Width\_of\_Base} > 0.333$

(100% Base in Compression, Resultant within Middle Third)

INPUT PARAMETERS

(Water Elevations based on Diversion Structure 2D Hydraulic Model Results. See page 6 and Section 8.2, Design Criteria)

Headwater Elevation: $HW_{UN1} := 1215.80m$

Tailwater Elevation: $TW_{UN1} := 1213.10m$

Crest Water Elevation, EL.1215.81 $CrestW_{UN1} := 2.87 \cdot m$

Chute Block Water Elevation EL.1208.78 $ChuteW_{UN1} := 1.28 \cdot m$ $TW_{UN1} := TOC_{fce} + ChuteW_{UN1} = 1208.8\,m$

Bottom of Key (Footing Heel) Elevation: $BOF_{elev} = 1204.00\,m$

Apron Slab Top of Concrete Elevation at Edge of Slab: $TOC_{as} = 1210.00\,m$

Fixed Crest Top of Concrete Elevation at Downstream Face: $TOC_{fce} = 1207.50\,m$

Fixed Crest Top of Concrete Elevation at Center of Footing: $TOC_{fcc} = 1211.50\,m$

Lift Gate Position per Hydraulic Criteria $poss_{UN1} := 0$ poss = 1 if gate is closed
0 if gate is open

$$Gate_{R.UN1} := \begin{cases} 0 & \text{if } poss_{UN1} = 0 \\ 0.60 & \text{otherwise} \end{cases}$$

$\Sigma V_{DL.UN1} := D_{conc} + Gate_{R.UN1} D_{Gate} = 25408.2 \cdot kN$

$\Sigma M_{DL.UN1} := D_{conc} \cdot X_{conc.loc} + Gate_{R.UN1} \cdot D_{Gate} \cdot X_{gate} = 322889.4 \cdot kN \cdot m$

LATERAL WATER LOADS

UN1 CASE

HEADWATER (DRIVING):

Point O @ TOE: BOFtoe = EL.1205.5

Water Depth Above Fixed Crest at Gate: $D_{hwg.UN1} := HW_{UN1} - TOC_{fcc} = 4.3\,m$

Water Load Unit Width on Gate $W_{hwg.UN1} := 0 = 0.00$

Apply Load to Gate?: $poss_{UN1} := 0$

poss = 1 if gate is closed
0 if gate is open

Total Horizontal Water Load on Gate: $H_{hwg.UN1} := \frac{-\left(\gamma_w \cdot D_{hwg.UN1}{}^2\right)}{2} \cdot W_{hwg.UN1} \cdot poss_{UN1} = 0 \cdot kN$

Apply Total Gate Water Load at: $H_{hwg.UN1.loc} := \frac{D_{hwg.UN1}}{3} + \left(TOC_{fcc} - BOF_{toe}\right) = 7.43\,m$

Water Depth at Heel: $D_{hwf.UN1} := HW_{UN1} - BOF_{elev} = 11.80\,m$

Water Load Unit With on Footing: $W_{hw.UN1} := W_b$

Water Load at Bottom of Footing: $H_{hwf.UN1.1} := -\left(\gamma_w \cdot D_{hwf.UN1}\right) \cdot W_{hw.UN1} = -1389.1\,\frac{1}{m} \cdot kN$

Water Load at Top of Footing: $H_{hwf.UN1.2} := -\left(\gamma_w \cdot D_{hwg.UN1}\right) \cdot W_{hw.UN1} = -506.2\,\frac{1}{m} \cdot kN$

Total Horizontal Water Load on Footing:

$$H_{hwf.UN1} := \frac{\left(H_{hwf.UN1.1} + H_{hwf.UN1.2}\right) \cdot \left(D_{hwf.UN1} - D_{hwg.UN1}\right)}{2} = -7107.3 \cdot kN$$

Apply Total Footing Water Load at:

$$H_{hwf.UN1.loc} := \frac{H_{hwf.UN1.2} \cdot \frac{\left(TOC_{fcc} - BOF_{elev}\right)^2}{2} + \frac{\left(H_{hwf.UN1.1} - H_{hwf.UN1.2}\right)}{2} \cdot \frac{\left(TOC_{fcc} - BOF_{elev}\right)^2}{3}}{\frac{\left(H_{hwf.UN1.2} + H_{hwf.UN1.1}\right) \cdot \left(TOC_{fcc} - BOF_{elev}\right)}{2}} - \left(BOF_{toe} - BOF_{elev}\right) = 1.67\,m$$

(Converting horizontal force resultant from HEEL calculation to Point-O@TOE)

UN1 CASE

LATERAL WATER LOADS (cont.)

TAILWATER (RESISTING):

Water Depth at toe: $D_{tw.UN1} := TW_{UN1} - BOF_{elev} = 4.78\,m$

Water Load Unit Width: $W_{twf.UN1} := W_b$

Total Horizontal Tailwater Load on Footing under Gate Openings, i.e., excluding Pier

Resisting Water on Rear Face of Monolith, i.e., bottom of heel elevation:

$$H_{twf.UN1} := \begin{cases} \dfrac{\gamma_w \cdot D_{tw.UN1}^{\,2}}{2} \cdot \left(W_{twf.UN1}\right) & \text{if } poss_{UN1} = 1 \\ \dfrac{\gamma_w \cdot D_{tw.UN1}^{\,2}}{2} \cdot \left(W_{twf.UN1}\right) & \text{if } poss_{UN1} = 0 \wedge TW_{UN1} \le TOC_{fcc} \\ \gamma_w \cdot \left[\dfrac{D_{tw.UN1}}{2} + \dfrac{\left(TW_{UN1} - TOC_{fcc}\right)}{2}\right] \cdot \left(TOC_{fcc} - BOF_{elev}\right) \cdot W_{twf.UN1} & \text{if } poss_{UN1} = 0 \wedge TW_{UN1} \ge TOC_{fcc} \end{cases} = 1344.9 \cdot kN$$

Apply Footing Tailwater Load within Gate Openings at:

$$H_{twf.UN1.loc} := \begin{cases} \dfrac{D_{tw.UN1}}{3} - \left(BOF_{toe} - BOF_{elev}\right) & \text{if } poss_{UN1} = 1 \\ \dfrac{D_{tw.UN1}}{3} - \left(BOF_{toe} - BOF_{elev}\right) & \text{if } poss_{UN1} = 0 \wedge TW_{UN1} \le TOC_{fcc} \\ \dfrac{\left(TOC_{fcc} - BOF_{elev}\right)^2 \cdot \left[\dfrac{\left(TW_{UN1} - TOC_{fcc}\right)}{2} + \dfrac{\left(\left(TOC_{fcc} - BOF_{elev}\right)\right)}{6}\right]}{\left(TOC_{fcc} - BOF_{elev}\right)\left[\left(TW_{UN1} - TOC_{fcc}\right) + \dfrac{\left(TOC_{fcc} - BOF_{elev}\right)}{2}\right]} & \text{if } poss_{UN1} = 0 \wedge TW_{UN1} \ge TOC_{fcc} \end{cases} = 0.09 \cdot m$$

$$\Sigma H_{Water.UN1} := H_{hwg.UN1} + H_{hwf.UN1} + H_{twf.UN1} = -5762.5 \cdot kN$$

$$\Sigma M_{HWater.UN1} := H_{hwg.UN1} \cdot H_{hwg.UN1.loc} + H_{hwf.UN1} \cdot H_{hwf.UN1.loc} \cdots + H_{twf.UN1} \cdot H_{twf.UN1.loc} = -11727.4 \cdot kN \cdot m$$

VERTICAL WATER LOADS

UN1 CASE

HEADWATER:

Water Depth on top of fixed crest: $d_{hw.UN1} := HW_{UN1} - TOC_{as} = 5.80\,m$

Weight of Water (H1) on Approach Slab: $H_{1.UN1} := \left(W_{hw.UN1} \cdot d_{hw.UN1} \cdot L_{as}\right) \cdot \gamma_w = 4233.2 \cdot kN$

Horiz. Moment Arm for H1 (from toe): $H_{1.UN1.loc} := L_b - \frac{L_{as}}{2} = 21.10\,m$

Distance from Gate to Toe: $Dist_{gate} = 10.2\,m$

Cross-sectional Area of Headwater Above Fixed Crest: $A_{fc.hw.UN1} := 29.10m^2$

(From Bluebeam Measurement, Bound by Energy Line through Crest Water Elevation CrestW and Chute Block Water Elevation ChuteW as defined above)

Volume of water Above Fixed Crest: $V_{fc.hw.UN1} := \left(A_{fc.hw.UN1} \cdot W_{hw.UN1}\right) = 349.2 \cdot m^3$

Weight of Water (H2) on Fixed Crest: $H_{2.UN1} := V_{fc.hw.UN1} \cdot \gamma_w = 3425.7 \cdot kN$

Horiz. Moment Arm for H2 (from toe): $H_{2.UN1.loc} := 14.25 \cdot m$

(From Bluebeam Measurement)

TAILWATER:

Slope of Crest from D/S of Gate to edge of Stilling Basin: $S_{f.UN1} := S_{f.U1} = 0.500$

Height of Tailwater Above Stilling Basin: $y_{UN1} := TW_{UN1} - TOC_{fce} = 1.3\,m$

Cross Sectional Area of Tailwater Above Sloped Portion of Crest: $A_{tw.UN1} := 23.86 \cdot m \cdot m = 23.9\,m^2$

(From Bluebeam Measurement, Bound by Energy Line through Crest Water Elevation CrestW and Chute Block Water Elevation ChuteW as defined above)

Weight of Water (H3) Above Slope Portion of Crest: $H_{3.UN1} := \left(A_{tw.U2} \cdot W_{twf.U2}\right) \cdot \gamma_w$ $\quad H_{3.UN1} = 2808.8 \cdot kN$

Horiz. Moment Arm for H3 (from Toe): $H_{3.UN1.loc} := 5.78 \cdot m$ (From Bluebeam Measurement)

UPLIFT AT INCLINED SLIDING PLANE

UN1 CASE

Uplift pressure at Headwater: $U_{HW.UN1} := D_{hwf.UN1} \cdot \gamma_w = 115.76 \cdot \frac{kN}{m^2}$

Uplift pressure at D/S end of Stilling Basin: $U_{TW.UN1} := D_{tw.UN1} \cdot \gamma_w = 46.9 \cdot \frac{kN}{m^2}$

Length from U/S Face of Gate Structure to Toe Point(Effective Drain at end of Monolith) $L_{overall} = 24.20\ m$ $L_{sb} = 0$

Length of Seepage per Line of Creep $L_{seepage} = 27.1\ m$

Difference between Uplift pressure at Headwater and Uplift Pressure at Toe of Stilling Basin: $U_{diffUN1} := U_{HW.UN1} - U_{TW.UN1} = 68.9 \cdot \frac{kN}{m^2}$

Slope of difference between Uplift pressure at Headwater and Uplift Pressure at Toe of Stilling Basin: $U_{slopeUN1} := \frac{U_{diffUN1} - Key_d \cdot \gamma_w}{L_{overall}} = 2.24 \cdot \frac{kN}{m^2 \cdot m}$

$$U_{seepageslopeUN1} := \frac{U_{diffUN1} - Key_d \cdot \gamma_w}{L_{seepage}}$$

Tailwater Pressure at toe of Gate Structure: $U_{press.toe.gsUN1} := U_{TW.UN1} + L_{sb} \cdot U_{slopeUN1} = 46.9 \cdot \frac{kN}{m^2}$

$$U_{pore.toe.UN1} := U_{TW.UN1} + U_{seepageslopeUN1} \cdot L_{sb} = 46.9 \cdot \frac{kN}{m^2}$$

$$U_{pore.F.UN1} := U_{pore.toe.UN1} + U_{seepageslopeUN1} \cdot L_{FG} = 49.9 \cdot \frac{kN}{m^2}$$

$$U_{pore.E.UN1} := U_{pore.F.UN1} - \left(BOF_{base} - BOF_{toe}\right) \cdot \gamma_w + U_{seepageslopeUN1} \cdot L_{EF} = 41.9 \cdot \frac{kN}{m^2}$$

$$U_{pore.D.UN1} := U_{pore.E.UN1} + U_{seepageslopeUN1} \cdot L_{DE} = 78.3 \cdot \frac{kN}{m^2}$$

$$U_{pore.C.UN1} := U_{pore.D.UN1} + \left(BOF_{base} - BOF_{elev}\right) \cdot \gamma_w + U_{seepageslopeUN1} \cdot L_{CD} = 113.8 \cdot \frac{kN}{m^2}$$

Uniform uplift due to Tailwater: (rectangular portion) $U_{A.UN1} := U_{press.toe.gsUN1} \cdot L_b \cdot W_b \cdot -1 = -13617.4 \cdot kN$

Moment Arm for Uplift UA from Toe of Gate Structure: $L_{A.UN1} := \frac{L_b}{2} = 12.10\ m$

Uplift - Linear Decrease from HW to TW: (triangular portion) $U_{B.UN1} := \frac{1}{2} \cdot \left(U_{HW.UN1} - U_{press.toe.gsUN1}\right) \cdot L_b \cdot W_b \cdot -1 = -9999.4 \cdot kN$

Moment Arm for Uplift UB from Toe of Gate Structure: $L_{B.UN1} := \frac{2}{3} \cdot L_b = 16.13\ m$

Total Resultant Uplift force: $U_{UN1} := U_{A.UN1} + U_{B.UN1} = -23616.8 \cdot kN$

Resultant Location from Toe: $U_{UN1.loc} := \frac{U_{A.UN1} \cdot L_{A.UN1} + U_{B.UN1} \cdot L_{B.UN1}}{U_{A.UN1} + U_{B.UN1}} = 13.81\ m$

$\Sigma V_{water.UN1} := H_{1.UN1} + H_{2.UN1} + H_{3.UN1} + U_{UN1} = -13149.1 \cdot kN$

$\Sigma M_{Vwater.UN1} := H_{1.UN1} \cdot H_{1.UN1.loc} + H_{2.UN1} \cdot H_{2.UN1.loc} + H_{3.UN1} \cdot H_{3.UN1.loc} + U_{UN1} \cdot U_{UN1.loc} = -171722.3 \cdot kN \cdot m$

Uplift as per Line of Creep Method
(Flotation and Overturning)

$$Uplift_{BC.UN1} := \frac{-1}{2} \cdot W_b \cdot \left(U_{HW.UN1} + U_{pore.C.UN1}\right) \cdot L_{BC} = -1377105\,N$$

$$Uplift_{CD.UN1} := 0$$

$$Uplift_{DE.UN1} := \frac{-1}{2} \cdot W_b \cdot \left(U_{pore.D.UN1} + U_{pore.E.UN1}\right) \cdot L_{DE} = -13120312\,N$$

$$Uplift_{EF.UN1} := \frac{-1}{2} \cdot W_b \cdot \left(U_{pore.E.UN1} + U_{pore.F.UN1}\right) \cdot L_{EF} = -1846129\,N$$

$$Uplift_{FG.UN1} := \frac{-1}{2} \cdot W_b \cdot \left(U_{pore.F.UN1} + U_{pore.toe.UN1}\right) \cdot L_{FG} = -871032.1\,N$$

$$Uplift_{pore.UN1} := Uplift_{BC.UN1} + Uplift_{DE.UN1} + Uplift_{EF.UN1} + Uplift_{FG.UN1} = -17214.6 \cdot kN$$

$$Uplift_{FG.UN1.loc} := \frac{L_{FG}}{3} \cdot \frac{\left(2 \cdot U_{pore.F.UN1} + U_{pore.toe.UN1}\right)}{\left(U_{pore.F.UN1} + U_{pore.toe.UN1}\right)} = 0.76\,m$$

$$Uplift_{EF.UN1.loc} := \frac{L_{EF}}{3} \cdot \frac{\left(2 \cdot U_{pore.E.UN1} + U_{pore.F.UN1}\right)}{\left(U_{pore.E.UN1} + U_{pore.F.UN1}\right)} + L_{FG} = 3.13\,m$$

$$Uplift_{DE.UN1.loc} := \frac{L_{DE}}{3} \cdot \frac{\left(2 \cdot U_{pore.D.UN1} + U_{pore.E.UN1}\right)}{\left(U_{pore.D.UN1} + U_{pore.E.UN1}\right)} + L_{FG} + X_{EF} = 14.52\,m$$

$$Uplift_{BC.UN1.loc} := \frac{L_{BC}}{3} \cdot \frac{\left(2 \cdot U_{HW.UN1} + U_{pore.C.UN1}\right)}{\left(U_{HW.UN1} + U_{pore.C.UN1}\right)} + L_{FG} + X_{EF} + L_{DE} = 23.20\,m$$

UN1 CASE

SOIL LOADS

Equivalent Fluid Pressure (EFP):

(CFEM 24.1)

At rest lateral pressure coefficient: $K_o = 0.66$

At-rest Soil Pressure to Heel, EM1110--2-2502 Section 3-7

Lateral Driving Force (Headwater Side)

Depth of Fill at Heel: $t_{hf.UN1} := TOC_{as} - BOF_{elev} = 6.00\,m$

At-Rest Soil Load: $E1_{drive.UN1} := \frac{K_o \cdot t_{hf.UN1}^{\,2}}{2} \cdot \left(\gamma_r - \gamma_w\right) \cdot W_b \cdot -1 = -1732.5 \cdot kN$

Acting at: $E1_{drive.loc.UN1} := \frac{t_{hf.UN1}}{3} - \left(BOF_{toe} - BOF_{elev}\right) = 0.50\,m$

Lateral Resisting Force (Tailwater Side)

Depth of Fill at Toe: $t_{tf.UN1} := TOC_{fce} - BOF_{elev} = 3.50\,m$

At-Rest Soil Load: $E2_{resistUN1} := \frac{K_o \cdot t_{tf.UN1}^{\,2}}{2} \cdot \left(\gamma_r - \gamma_w\right) \cdot W_b = 589.5 \cdot kN$ $E2_{resistUN1} := 0$

Acting at: $E2_{resistlocUN1} := \frac{t_{tf.UN1}}{3} = 1.17\,m$

(Expansion Joint to Stilling Basin, No Sediment in Gap)

$\Sigma H_{soil.UN1} := E1_{drive.UN1} + E2_{resistUN1} = -1732.5 \cdot kN$

$\Sigma M_{soil.UN1} := E1_{drive.UN1} \cdot E1_{drive.loc.UN1} + E2_{resistUN1} \cdot E2_{resistlocUN1} = -866.2 \cdot kN \cdot m$

ICE / IMPACT LOADS (CONSERVATIVELY ASSUME NO ICE LOADING ON DOWNSTREAM SIDE)

Static Impact Loading on Structure: $I_{S.UN1} := 150.0 \frac{kN}{m}$ (Section 7.7, Design Criteria)

Static Impact load on Gates: $I_{G.UN1} := 75 \frac{kN}{m}$ (Section 7.7, Design Criteria)

Impact Loading Unit Width on Structure: $W_{S.UN1} := 0m$

Impact Loading Unit Width on Gates: $W_{G.UN1} := 0m = 0.00$

Total Impact Load on Structure: $I_{UN1} := \left(I_{S.UN1} \cdot W_{S.UN1} + I_{G.UN1} \cdot W_{G.UN1}\right) \cdot -1 = 0 \cdot kN$

Apply Ice load at: $I_{UN1.loc} := \left(HW_{UN1} - BOF_{elev} - 0.30m\right) = 11.50\,m$

$\Sigma H_{I.UN1} := I_{UN1} = 0 \cdot kN$

$\Sigma M_{I.UN1} := I_{UN1} \cdot I_{UN1.loc} = 0 \cdot kN \cdot m$

SEISMIC LOAD (Not Applicable to this Load Case)

UN1 CASE

SUMMARY OF LOADS

	Loads	Moment Arm
Dead Load of Concrete Structure:	$D_{conc} = 25408.2 \cdot kN$	$X_{conc.loc} = 12.71\ m$
Dead Load of Gate:	$D_{Gate} = 580.0 \cdot kN$	$X_{gate} = 8.75\ m$
Headwater Lateral Load on Gate:	$H_{hwg.UN1} = 0.0 \cdot kN$	$H_{hwg.UN1.loc} = 7.43\ m$
Headwater Lateral Load on Footing:	$H_{hwf.UN1} = -7107.3 \cdot kN$	$H_{hwf.UN1.loc} = 1.67\ m$
Tailwater Lateral Load:	$H_{twf.UN1} = 1344.9 \cdot kN$	$H_{twf.UN1.loc} = 0.09\ m$
Water Weight (HW) on Apron Slab:	$H_{1.UN1} = 4233.2 \cdot kN$	$H_{1.UN1.loc} = 21.10\ m$
Water Weight (HW) on Fixed Crest:	$H_{2.UN1} = 3425.7 \cdot kN$	$H_{2.UN1.loc} = 14.25\ m$
Water Weight (TW) on Fixed Crest:	$H_{3.UN1} = 2808.8 \cdot kN$	$H_{3.UN1.loc} = 5.78\ m$
Uplift:	$U_{UN1} = -23616.8 \cdot kN$	$U_{UN1.loc} = 13.81\ m$
Upstream (driving) Lateral Soil Load:	$E1_{drive.UN1} = -1732.5 \cdot kN$	$E1_{drive.loc.UN1} = 0.50\ m$
Downstream (resisting) Lateral Soil Load:	$E2_{resistUN1} = 0 \cdot kN$	$E2_{resistlocUN1} = 1.17\ m$
Ice / Impact Load:	$I_{UN1} = 0.0 \cdot kN$	$I_{UN1.loc} = 11.50\ m$

UN1 CASE

STABILITY ASSESSMENT (SLIDNG, OVERTURNING AND BEARING):

CHECK SLIDING ALONG HORIZONTAL PLANE THRU TOE,
IGNORING BEDROCK MOBILIZED BY STRUCTURAL HEEL KEY, OR VOID BEHIND KEY

Sum of Vertical Forces:

$\Sigma V_{UN1} := \Sigma V_{DL.UN1} + \Sigma V_{water.UN1} = 12259.1 \cdot kN$

Sum of Horizontal Forces:

$\Sigma H_{UN1} := \Sigma H_{Water.UN1} + \Sigma H_{soil.UN1} + \Sigma H_{I.UN1} = -7495 \cdot kN$

Sliding Factor of Safety:

$$FS_{HorizSliding.UN1} := \frac{\tan_{\phi} \cdot \Sigma V_{UN1}}{\left|\Sigma H_{UN1}\right|} = 0.80$$

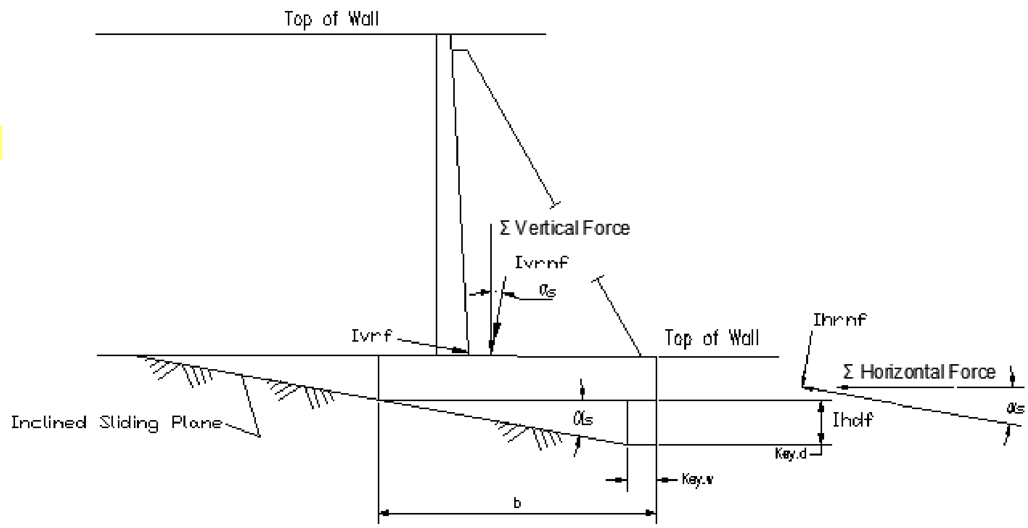
$FS_{HorizSliding.UN1.Check} :=$ | "OKAY" if $FS_{HorizSliding.UN1} \geq FS_{req.UN1.sl}$
"Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !" otherwise

$FS_{HorizSliding.UN1.Check} =$ "Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !"

CHECK SLIDING ALONG INCLINED SLIDING PLANE FROM HEEL KEY TO TOE,
WITH BEDROCK MASS MOBILIZED BY REINFOCREDE CONCRETE KEY)

RESISTING SIDE

DRIVING SIDE



Ivrf=Inclined Resisting Force
Ivrnf=Inclined Resisting Normal Force
Ihrnf=Inclined Resisting Normal Force
Ihdf=Inclined Driving Force

TOE

HEEL

$$\alpha s := \operatorname{atan}\left(\frac{BOF_{toe} - BOF_{elev}}{L_b - Key_l}\right) = 0.12$$

as degrees= $\alpha s \cdot \left(\frac{180}{\pi}\right) = 7.01$

Resolve $\Sigma Vert_{UN1}$ & $\Sigma Horiz_{UN1}$

$$\Sigma V_{InclinedUN1} := \cos(\alpha s) \cdot \left(\Sigma V_{UN1} + V_{rs}\right) + \sin(\alpha s) \cdot \left|\Sigma H_{UN1}\right| = 25371.2 \cdot kN$$

$$\Sigma H_{InclinedUN1} := \cos(\alpha s) \cdot \left|\Sigma H_{UN1}\right| - \sin(\alpha s) \cdot \left(\Sigma V_{UN1} + V_{rs}\right) = 4432.0 \cdot kN$$

(With properly engineered reinforced concrete Key, horizontal sliding plane thru Toe is protected, critical sliding plane is relocated to the INCLINED SLIDING PLANE FROM HEEL KEY To TOE, Bedrock Mass above this examing plane is mobilized by reinforced concrete key and combined into Structural Wedge.)

Inclined Sliding Plane Length $L_{incline} = 24.2 m$

Safety Factor for Sliding
Inclined Failure Plane

$$FS_{InclinedlSlidingUN1} := \frac{\Sigma V_{InclinedUN1} \cdot \tan\left(\phi_{rock} \cdot \frac{\pi}{180}\right)}{\left|\Sigma H_{InclinedUN1}\right|} = 2.79$$

$FS_{InclinedSliding.UN1.check} :=$ | "OKAY " if $FS_{InclinedlSlidingUN1} > FS_{req.U1.sl}$ = "OKAY "
"Revise Structure"" otherwise

$FS_{InclinedSliding.UN1.check} =$ "OKAY "

CHECK ECCENTRICITY ON INCLINED PLANE

UN1 CASE

Sum of the Moments:

$$\Sigma M_{rs.UN1} := \Sigma M_{DL.UN1} + \Sigma M_{HWater.UN1} + \Sigma M_{Vwater.UN1} + \Sigma M_{I.UN1} + \Sigma M_{soil.UN1} + V_{rs} \cdot L_{rs} = 309563 \cdot kN \cdot m$$

Eccentricity:

$$e_{UN1} := \frac{L_{incline}}{2} - \frac{\Sigma M_{rs.UN1}}{\Sigma V_{InclinedUN1}} = -0.08\,m$$

Eccentricity Check:

$$e_{check.UN1} := \begin{cases} \text{"Okay"} & \text{if } |e_{UN1}| \le Kern \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$e_{check.UN1} = \text{"Okay"}$

Foundation Bearing Pressures on Inclined Plane:

Bearing Pressure at Heel:

$$\sigma_{heel.UN1} := \frac{\Sigma V_{InclinedUN1}}{\frac{A_b}{\cos(\alpha s)}} - \frac{\Sigma V_{InclinedUN1} \cdot e_{UN1}}{\frac{S_b}{\cos(\alpha s)^2}} = 88.4 \cdot \frac{kN}{m^2}$$

$$\sigma_{heel.UN1.check} := \left(\begin{cases} \text{"Okay"} & \text{if } \sigma_{heel.UN1} \le \sigma_{allow.UN1} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} \right)$$

$\sigma_{heel.UN1.check} = \text{"Okay"}$

Bearing Pressure at Toe:

$$\sigma_{toe.UN1} := \frac{\Sigma V_{InclinedUN1}}{\frac{A_b}{\cos(\alpha s)}} + \frac{\Sigma V_{InclinedUN1} \cdot e_{UN1}}{\frac{S_b}{\cos(\alpha s)^2}} = 85 \cdot \frac{kN}{m^2}$$

$$\sigma_{toe.UN1.check} := \begin{cases} \text{"Okay"} & \text{if } \sigma_{toe.UN1} \le \sigma_{allow.UN1} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$\sigma_{toe.UN1.check} = \text{"Okay"}$

CHECK FLOTATION

$$Uplift_{sliding.UN1} := U_{UN1} = -23616.8 \cdot kN$$

$$Uplift_{pore.UN1} = -17214.6 \cdot kN$$

$$\left(Uplift_{UN1}\right) := \min\left(Uplift_{pore.UN1}, Uplift_{sliding.UN1}\right)$$

(For conservative, taking maximum values)

$$FS_{Flotation.UN1} := \frac{D_{conc} + D_{Gate} + H_{1.UN1} + H_{2.UN1} + H_{3.UN1}}{|Uplift_{UN1}|} = 1.54$$

$$FS_{Flotation.UN1.check} := \begin{cases} \text{"OKAY "} & \text{if } FS_{Flotation.UN1} > FS_{req.UN.flt} \\ \text{"Revise Structure""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

UN1 CASE

MONOLITH OVERTURNING STABILITY ANALYSIS

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.
Assumptions are made in order to compute overturning stability of indetermine forces on monolith with key;
(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.
(b) The horizontal resisting force acting on the key, P.key, is that required for static equilibrium
(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1 $Ratio_{overturning.allow.Unusual} := 0.333$ (Resultant within Middle Third)

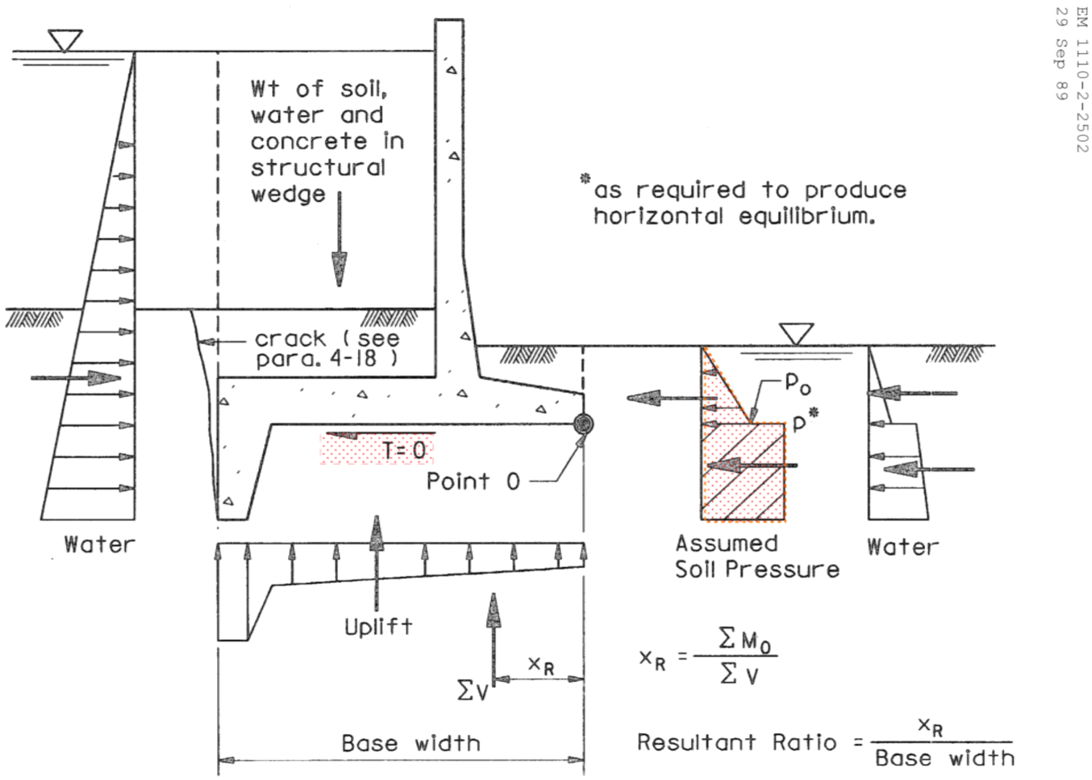


Figure 4-5. Forces for overturning analysis for wall with horizontal base and key

All Vertical Loads Applicable to Overturning Stability Analysis

Total Concrete Dead Loads:	$D_{conc} = 25408.2 \cdot kN$	at:	$X_{conc.loc} = 12.7\,m$
Dead Load of Gate:	$D_{Gate} = 580.0 \cdot kN$		$X_{gate} = 8.75\,m$
Water Weight (HW) on Apron Slab:	$H_{1.UN1} = 4233.2 \cdot kN$		$H_{1.UN1.loc} = 21.10\,m$
Water Weight (HW) on Fixed Crest:	$H_{2.UN1} = 3425.7 \cdot kN$		$H_{2.UN1.loc} = 14.25\,m$
Water Weight (TW) on Fixed Crest:	$H_{3.UN1} = 2808.8 \cdot kN$		$H_{3.UN1.loc} = 5.78\,m$

Uplift Force from Sliding Analysis. Line of Creep Method applied at presumed inclined sliding line, and subtraction gravity effect to Base of Concrete by Archimedes Principle

$$U_{UN1.loc.sliding} := \frac{U_{A.UN1} \cdot L_{A.UN1} + U_{B.UN1} \cdot L_{B.UN1} - A_{rs} \cdot w_{as} \cdot \gamma_w \cdot L_{rs}}{U_{A.UN1} + U_{B.UN1} - A_{rs} \cdot w_{as} \cdot \gamma_w} = 13.81\,m$$

$$U_{UN1.sliding} := U_{UN1} + A_{rs} \cdot w_{as} \cdot \gamma_w = -18095.7 \cdot kN$$

Uplift for Overturning Analysis, Line of Creep Method. Pore pressure at base of Concrete

UN1 CASE

$Uplift_{pore.UN1} = -17214.6 \cdot kN$

$$Uplift_{pore.UN1.loc} := \frac{Uplift_{BC.UN1} \cdot Uplift_{BC.UN1.loc} + Uplift_{DE.UN1} \cdot Uplift_{DE.UN1.loc} \cdots + Uplift_{EF.UN1} \cdot Uplift_{EF.UN1.loc} + Uplift_{FG.UN1} \cdot Uplift_{FG.UN1.loc}}{Uplift_{pore.U2}} = 13.3\,m$$

Sum of All Water Load for Overturning Analysis

$$\Sigma V_{water.UN1.OT} := H_{1.UN1} + H_{2.UN1} + H_{3.UN1} + Uplift_{pore.UN1} = -6746.9 \cdot kN$$

All Lateral Loads Applicable to Overturning Stability Analysis

Apply Load to Gate?: $poss_{UN1} = 0$ — poss = 1 if gate is closed, 0 if gate is open

Headwater Lateral Load on Gate: $H_{hwg.UN1} = 0.0 \cdot kN$ — $H_{hwg.UN1.loc} = 7.43\,m$

Headwater Lateral Load on Footing: $H_{hwf.UN1} = -7107.3 \cdot kN$ — $H_{hwf.UN1.loc} = 1.67\,m$

Total Horizontal Tailwater Load on Footing under Gate Openings, i.e., excluding Pier: $H_{twf.UN1} = 1344.9 \cdot kN$ — $H_{twf.UN1.loc} = 0.09\,m$

Resisting Water on Rear Face of Monolith, i.e., bottom of heel elevation: *(Point O @ TOE: BOFtoe = EL.1205.5)*

Ice / Impact Load: $I_{UN1} = 0.0 \cdot kN$ at: $I_{UN1.loc} = 11.50\,m$

Depth of Fill at Heel Side for Overturning Analysis: $t_{hf.UN1} := TOC_{as} - BOF_{toe} = 4.50\,m$

Driving Soil Load for overturning:

$$E1_{drive.UN1} := \frac{K_o \cdot t_{hf.UN1}^{\;2}}{2} \cdot (\gamma_r - \gamma_w) \cdot W_b \cdot -1 = -974.5 \cdot kN$$

Acting at:

$$E1_{drive.loc.UN1} := \frac{t_{hf.UN1}}{3} = 1.50\,m$$

Downstream (resisting) Lateral Soil Load as required to produce horizontal equilibrium:

$$E2_{resistUN1} := -1 \cdot (H_{hwg.UN1} + H_{hwf.UN1} + H_{twf.UN1} + I_{UN1} + E1_{drive.UN1})$$

$E2_{resistUN1} = 6737 \cdot kN$

Assumed Resisting Bedrock at middle of Key, passive soil pressure or lateral bearing on contract joint at end of Monolith 3A3B: $E2_{resistlocUN1} := E2_{resistlocU1} = -0.75\,m$

Overturning moment by Dead Loads about Point O @ Toe: $\Sigma M_{DL.UN1} = 322889.4 \cdot kN \cdot m$

Overturning moment by Vertical Water Loads and Uplift, about Point O @ Toe

$$\Sigma M_{Vwater.UN1.OT} := H_{1.UN1} \cdot H_{1.UN1.loc} + H_{2.UN1} \cdot H_{2.UN1.loc} + H_{3.UN1} \cdot H_{3.UN1.loc} + Uplift_{pore.UN1} \cdot Uplift_{pore.UN1.loc} = -74527.9 \cdot kN \cdot m$$

Overturning moment by Lateral Hydrostatic Forces of Headwater Pool and Tailwater Pool,about Point O @ Toe: $\Sigma M_{HWater.UN1} = -11727.4 \cdot kN \cdot m$

Overturning Moment by Impact/Ice Load, about Point O@ Toe: $\Sigma M_{I.UN1} = 0 \cdot kN \cdot m$

Overturning moment by Lateral Soil Forces
about Point O @ Toe

$\Sigma M_{soil.UN1} := E1_{drive.UN1} \cdot E1_{drive.loc.UN1} + E2_{resistUN1} \cdot E2_{resistlocUN1} = -6514.5 \cdot kN \cdot m$

Sum of the Overturning Moments about Point O @ Toe:

$\Sigma M_{UN1.OT} := \Sigma M_{DL.UN1} + \Sigma M_{HWater.UN1} + \Sigma M_{Vwater.UN1.OT} + \Sigma M_{I.UN1} + \Sigma M_{soil.UN1} = 230120 \cdot kN \cdot m$

Sum of Vertical Forces: $\Sigma V_{UN1.OT} := \Sigma V_{DL.UN1} + \Sigma V_{water.UN1.OT} = 18661.3 \cdot kN$

Distance X_R: EM 1110-2-2502 Eq.4-1 $X_{R.UN1} := \dfrac{\Sigma M_{UN1.OT}}{\Sigma V_{UN1.OT}} = 12.3\,m$

Overturning Resultant Ratio $Ratio_{Overturning.UN1} := \dfrac{X_{R.UN1}}{L_b} = 0.51$

EM 1110-2-2502

Table 4-1

Retaining Wall Stability Criteria

Loading Condition	Sliding Factor of Safety, FS	Shear Strength Test Required: Soil Foundation	Shear Strength Test Required: Rock Foundation[3]	Overturning Criteria Minimum Base Area in Compression: Soil Foundation	Overturning Criteria Minimum Base Area in Compression: Rock Foundation
Usual	1.5	(Q &/or S)[2,1]	Direct shear	100%[4]	75%[4]
Unusual	1.33	(Q &/or S)[2,1]	Direct shear	75%[4]	50%[4]
Earthquake	1.1	(Q)	Direct shear	Resultant within base	Resultant within base

Overturning Stability Check

$Ratio_{Overturning.UN1.check} := \begin{cases} \text{"Okay"} & \text{if } Ratio_{Overturning.UN1} \geq Ratio_{overturning.allow.Unusual} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$

$Ratio_{Overturning.UN1.check} = \text{"Okay"}$

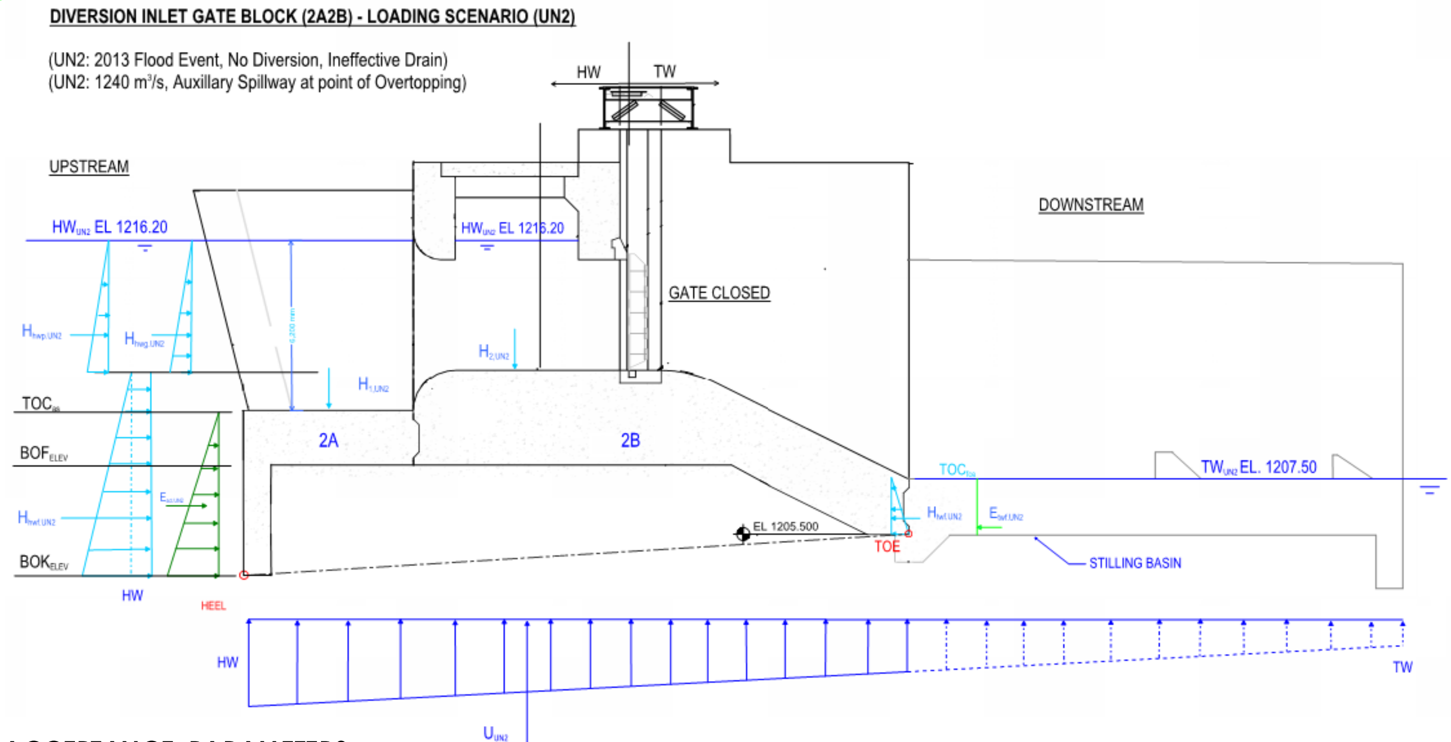
Summary of Extreme Flood Results (Only Report Controlling Load Case)

UN1 CASE

UN1 Event: Diversion Operation, 2013 Flood

Horiz Sliding Factor of Safety:	$FS_{HorizSliding.UN1} = 0.80$
Horiz Sliding Factor of Safety Check:	$FS_{HorizSliding.UN1.Check} =$ "Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !"
Sliding Factor of Safety:	$FS_{InclinedlSlidingUN1} = 2.8$
Sliding Factor of Safety Check:	$FS_{InclinedSliding.UN1.check} =$ "OKAY "
Eccentricity:	$e_{UN1} = -0.08\,m$
Eccentricity Check:	$e_{check.UN1} =$ "Okay"
Bearing Pressure At Heel:	$\sigma_{heel.UN1} = 88.4\cdot\frac{kN}{m^2}$
Bearing Pressure At Heel Check:	$\sigma_{heel.UN1.check} =$ "Okay"
Bearing Pressure At Heel:	$\sigma_{toe.UN1} = 85.0\cdot\frac{kN}{m^2}$
Bearing Pressure At Toe Check:	$\sigma_{toe.UN1.check} =$ "Okay"
Flotation Factor of Safety	$FS_{Flotation.UN1} = 1.54$
Flotation Factor of Safety Check:	$FS_{Flotation.UN1.check} =$ "OKAY "
Overturning Resultant Ratio	$Ratio_{Overturning.UN1} = 0.51$
Overturning Stability Check	$Ratio_{Overturning.UN1.check} =$ "Okay"

UN2 DESIGN CASE



ACCEPTANCE PARAMETERS

Required Factor of Safety for Sliding: $FS_{req.UN2.sl} := 1.3$ (Without Cohesion) (Section 8.1, Design Criteria)

Resultant Within Middle Third of Base: $e \le \frac{L_b}{6} \wedge e \ge \frac{-L_b}{6}$

Allowable Rock Bearing Pressure: $\sigma_{allow.UN2} := 1470 \cdot \frac{kN}{m^2}$ (Section 5.2, Design Criteria)

Required Factor of Safety for Flotation: $FS_{req.UN.flt} = 1.3$

Overturning Min Required Resultant Ratio: $\frac{X_{R.UN}}{\text{Horizontal\_Width\_of\_Base}} > 0.333$

(100% Base in Compression, Resultant within Middle Third)

INPUT PARAMETERS

Headwater Elevation: $HW_{UN2} := 1216.20m$

Tailwater Elevation: $TW_{UN2} := 1207.50m$

(Water Elevations based on Diversion Structure 2D Hydraulic Model Results. See page 6 and Section 8.2, Design Criteria)

Crest Water Elevation (No Diversion)

Chute Block Water Elevation (No Diversion)

Bottom of Key (Footing Heel) Elevation: $BOF_{elev} = 1204.00\,m$

Apron Slab Top of Concrete Elevation at Edge of Slab: $TOC_{as} = 1210.00\,m$

Fixed Crest Top of Concrete Elevation at Downstream Face: $TOC_{fce} = 1207.50\,m$

Fixed Crest Top of Concrete Elevation at Center of Footing: $TOC_{fcc} = 1211.50\,m$

Lift Gate Position per Hydraulic Criteria $poss_{UN2} := 1$ poss = 1 if gate is closed
0 if gate is open

$$Gate_{R.UN2} := \begin{cases} 0 & \text{if } poss_{UN2} = 0 \\ 0.60 & \text{otherwise} \end{cases}$$

$$\Sigma V_{DL.UN2} := D_{conc} + Gate_{R.UN2} D_{Gate} = 25756.2 \cdot kN$$

$$\Sigma M_{DL.UN2} := D_{conc} \cdot X_{conc.loc} + Gate_{R.UN2} \cdot D_{Gate} \cdot X_{gate} = 325934.4 \cdot kN \cdot m$$

LATERAL WATER LOADS

UN2 CASE

HEADWATER (DRIVING): *Point O @ TOE: BOFtoe = EL.1205.5*

Water Depth Above Fixed Crest at Gate: $D_{hwg.UN2} := HW_{UN2} - TOC_{fcc} = 4.7\ m$

Water Load Unit Width on Gate $W_{hwg.UN2} := 0 = 0.00$

Apply Load to Gate?: $poss_{UN2} = 1$

poss = 1 if gate is closed
0 if gate is open

Total Horizontal Water Load on Gate: $H_{hwg.UN2} := \frac{-\left(\gamma_w \cdot D_{hwg.UN2}{}^2\right)}{2} \cdot W_{hwg.UN2} \cdot poss_{UN2} = 0 \cdot kN$

Apply Total Gate Water Load at: $H_{hwg.UN2.loc} := \frac{D_{hwg.UN2}}{3} + \left(TOC_{fcc} - BOF_{toe}\right) = 7.57\ m$

Water Depth at Heel: $D_{hwf.UN2} := HW_{UN2} - BOF_{elev} = 12.20\ m$

Water Load Unit With on Footing: $W_{hw.UN2} := W_b$

Water Load at Bottom of Footing: $H_{hwf.UN2.1} := -\left(\gamma_w \cdot D_{hwf.UN2}\right) \cdot W_{hw.UN2} = -1436.2 \frac{1}{m} \cdot kN$

Water Load at Top of Footing: $H_{hwf.UN2.2} := -\left(\gamma_w \cdot D_{hwg.UN2}\right) \cdot W_{hw.UN2} = -553.3 \frac{1}{m} \cdot kN$

Total Horizontal Water Load on Footing:

$$H_{hwf.UN2} := \frac{\left(H_{hwf.UN2.1} + H_{hwf.UN2.2}\right) \cdot \left(D_{hwf.UN2} - D_{hwg.UN2}\right)}{2} = -7460.5 \cdot kN$$

Apply Total Footing Water Load at:

$$H_{hwf.UN2.loc} := \frac{\left[H_{hwf.UN2.2} \cdot \frac{\left(TOC_{fcc} - BOF_{elev}\right)^2}{2} + \frac{\left(H_{hwf.UN2.1} - H_{hwf.UN2.2}\right)}{2} \cdot \frac{\left(TOC_{fcc} - BOF_{elev}\right)^2}{3}\right]}{\left[\frac{\left(H_{hwf.UN2.2} + H_{hwf.UN2.1}\right) \cdot \left(TOC_{fcc} - BOF_{elev}\right)}{2}\right]} - \left(BOF_{toe} - BOF_{elev}\right) = 1.70\ m$$

(Converting horizontal force resultant from HEEL calculation to Point-O@TOE)

LATERAL WATER LOADS (cont.)

UN2 CASE

TAILWATER (RESISTING):

Water Depth at toe: $D_{tw.UN2} := TW_{UN2} - BOF_{elev} = 3.50\,m$

Water Load Unit Width: $W_{twf.UN2} := W_b$

Total Horizontal Tailwater Load on Footing under Gate Openings, i.e., excluding Pier

Resisting Water on Rear Face of Monolith, i.e., bottom of heel elevation:

$$COND_{UN2} := poss_{UN2} = 0 \wedge TW_{UN2} \geq TOC_{fcc}$$

$$H_{twf.UN2} := \begin{cases} \dfrac{\gamma_w \cdot D_{tw.UN2}^{\;2}}{2} \cdot \left(W_{twf.UN2}\right) & \text{if } \; poss_{UN2} = 1 \\ \dfrac{\gamma_w \cdot D_{tw.UN2}^{\;2}}{2} \cdot \left(W_{twf.UN2}\right) & \text{if } \; poss_{UN2} = 0 \wedge TW_{UN2} \leq TOC_{fcc} \\ \gamma_w \cdot \left[\dfrac{D_{tw.UN2}}{2} + \dfrac{\left(TW_{UN2} - TOC_{fcc}\right)}{2}\right] \cdot \left(TOC_{fcc} - BOF_{elev}\right) \cdot W_{twf.UN2} & \text{if } \; COND_{UN2} \end{cases} = 721.0 \cdot kN$$

Apply Footing Tailwater Load within Gate Openings at:

$$H_{twf.UN2.loc} := \begin{cases} \dfrac{D_{tw.UN2}}{3} - \left(BOF_{toe} - BOF_{elev}\right) & \text{if } \; poss_{UN2} = 1 \\ \dfrac{D_{tw.UN2}}{3} - \left(BOF_{toe} - BOF_{elev}\right) & \text{if } \; poss_{UN2} = 0 \wedge TW_{UN2} \leq TOC_{fcc} \\ \dfrac{\left(TOC_{fcc} - BOF_{elev}\right)^2 \cdot \left[\dfrac{\left(TW_{UN2} - TOC_{fcc}\right)}{2} + \dfrac{\left(TOC_{fcc} - BOF_{elev}\right)}{6}\right]}{\left(TOC_{fcc} - BOF_{elev}\right)\left[\left(TW_{UN2} - TOC_{fcc}\right) + \dfrac{\left(TOC_{fcc} - BOF_{elev}\right)}{2}\right]} - \left(BOF_{toe} - BOF_{elev}\right) & \text{if } \; COND_{UN2} \end{cases} = -0.33 \cdot m$$

$$\Sigma H_{Water.UN2} := H_{hwg.UN2} + H_{hwf.UN2} + H_{twf.UN2} = -6739.5 \cdot kN$$

$$\Sigma M_{HWater.UN2} := H_{hwg.UN2} \cdot H_{hwg.UN2.loc} + H_{hwf.UN2} \cdot H_{hwf.UN2.loc} \cdots + H_{twf.UN2} \cdot H_{twf.UN2.loc} = -12887.9 \cdot kN \cdot m$$

VERTICAL WATER LOADS

UN2 CASE

HEADWATER:

Water Depth on top of fixed crest: $d_{hw.UN2} := HW_{UN2} - TOC_{as} = 6.20\,m$

Weight of Water (H1) on Approach Slab: $H_{1.UN2} := \left(W_{hw.UN2} \cdot d_{hw.UN2} \cdot L_{as}\right) \cdot \gamma_w = 4525.2 \cdot kN$

Horiz. Moment Arm for H1 (from toe): $H_{1.UN2.loc} := L_b - \dfrac{L_{as}}{2} = 21.10\,m$

Cross-sectional Area of Headwater Above Fixed Crest: $A_{fc.hw.UN2} := 35.85m^2$ (From Bluebeam Measurement)

Volume of water Above Fixed Crest: $V_{fc.hw.UN2} := \left(A_{fc.hw.UN2} \cdot W_{hw.UN2}\right) = 430.2 \cdot m^3$

Weight of Water (H2) on Fixed Crest: $H_{2.UN2} := V_{fc.hw.UN2} \cdot \gamma_w = 4220.3 \cdot kN$

Horiz. Moment Arm for H2 (from toe): $H_{2.UN2.loc} := 14.25 \cdot m$

TAILWATER:

Slope of Crest from D/S of Gate to edge of Stilling Basin: $S_{f.UN2} := \dfrac{\left(TOC_{fcc} - TOC_{fce}\right)}{8.00m} = 0.500$

Height of Tailwater Above Stilling Basin:

$$y_{UN2} := \begin{cases} \left(TW_{UN2} - TOC_{fce}\right) & \text{if } TW_{UN2} \le TOC_{fcc} \\ \left(TOC_{fcc} - TOC_{fce}\right) & \text{otherwise} \end{cases}$$

$y_{UN2} = 0.00\,m$

Horizontal Distance of Tailwater Above Sloped Portion of Crest: $x_{UN2} := \dfrac{y_{UN2}}{S_{f.UN2}} = 0.00\,m$

Cross Sectional Area of Tailwater Above Sloped Portion of Crest: $A_{tw.UN2} := \dfrac{x_{UN2} \cdot y_{UN2}}{2} = 0\,m^2$

$= 0.00m^2$ if TW_{UN2} is less than or equal to TOC_{fce}

Weight of Water (H3) Above Slope Portion of Crest:

$$H_{3.UN2} := \begin{cases} (0.0kN) & \text{if } TW_{UN2} \le TOC_{fce} \\ \left(A_{tw.UN2} \cdot W_{twf.UN2}\right) \cdot \gamma_w & \text{if } TOC_{fcc} \ge TW_{UN2} > TOC_{fce} \\ \left[A_{tw.UN2} + Dist_{gate} \cdot \left(TW_{UN2} - TOC_{fcc}\right)\right] \cdot W_{twf.UN2} \cdot \gamma_w & \text{if } TW_{UN2} > TOC_{fcc} \end{cases}$$

$H_{3.UN2} = 0.0 \cdot kN$

Horiz. Moment Arm for H3 (from toe):

$$H_{3.UN2.loc} := \begin{cases} (0.00m) & \text{if } TW_{UN2} \le TOC_{fce} \\ \left(\dfrac{1}{3} \cdot x_{UN2}\right) & \text{if } TOC_{fcc} \ge TW_{UN2} > TOC_{fce} \\ \dfrac{\left[\dfrac{1}{2} \cdot x_{UN2} \cdot y_{UN2} \cdot \left(\dfrac{1}{3}\right) x_{UN2} + \left(TW_{UN2} - TOC_{fcc}\right) \cdot Dist_{gate} \cdot \left(\dfrac{Dist_{gate}}{2}\right)\right]}{\left(\dfrac{1}{2} x_{UN2} \cdot y_{UN2}\right) + \left(TW_{UN2} - TOC_{fcc}\right) \cdot Dist_{gate}} & \text{if } TW_{UN2} > TOC_{fcc} \end{cases}$$

$H_{3.UN2.loc} = 0.00\,m$

UPLIFT AT INCLINED SLIDING PLANE

UN2 CASE

Uplift pressure at Headwater: $U_{HW.UN2} := D_{hwf.UN2} \cdot \gamma_w = 119.68 \cdot \frac{kN}{m^2}$

Uplift pressure at D/S end of Stilling Basin: $U_{TW.UN2} := D_{tw.UN2} \cdot \gamma_w = 34.3 \cdot \frac{kN}{m^2}$

Length from U/S Face of Gate Structure to Toe Point(Effective Drain at end of Monolith: $L_{sb.UN2} := 18 \cdot m + 2 \cdot 2 \cdot m$ $L_{overall.UN2} := L_b + L_{sb.UN2} = 46.20\,m$

Length of Seepage per Line of Creep (UN2: Ineffective Drain) $L_{seepage.UN2} := L_{BC} + L_{CD} + L_{DE} + L_{EF} + L_{FG} + L_{sb.UN2} = 49.1\,m$

Difference between Uplift pressure at Headwater and Uplift Pressure at Toe of Stilling Basin: $U_{diffUN2} := U_{HW.UN2} - U_{TW.UN2} = 85.3 \cdot \frac{kN}{m^2}$

Slope of difference between Uplift pressure at Headwater and Uplift Pressure at Toe of Stilling Basin: $U_{slopeUN2} := \frac{U_{diffUN2} - Key_d \cdot \gamma_w}{L_{overall.UN2}} = 1.53 \cdot \frac{kN}{m^2 \cdot m}$

$$U_{seepageslopeUN2} := \frac{U_{diffUN2} - Key_d \cdot \gamma_w}{L_{seepage.UN2}}$$

Tailwater Pressure at toe of Gate Structure: $U_{press.toe.gsUN2} := U_{TW.UN2} + U_{slopeUN2} \cdot L_{sb.UN2} = 68 \cdot \frac{kN}{m^2}$

$$U_{pore.toe.UN2} := U_{TW.UN2} + U_{seepageslopeUN2} \cdot L_{sb.UN2} = 66 \cdot \frac{kN}{m^2}$$

$$U_{pore.F.UN2} := U_{pore.toe.UN2} + U_{seepageslopeUN2} \cdot L_{FG} = 68.1 \cdot \frac{kN}{m^2}$$

$$U_{pore.E.UN2} := U_{pore.F.UN2} - \left(BOF_{base} - BOF_{toe}\right) \cdot \gamma_w + U_{seepageslopeUN2} \cdot L_{EF} = 58.3 \cdot \frac{kN}{m^2}$$

$$U_{pore.D.UN2} := U_{pore.E.UN2} + U_{seepageslopeUN2} \cdot L_{DE} = 84.4 \cdot \frac{kN}{m^2}$$

$$U_{pore.C.UN2} := U_{pore.D.UN2} + \left(BOF_{base} - BOF_{elev}\right) \cdot \gamma_w + U_{seepageslopeUN2} \cdot L_{CD} = 118.2 \cdot \frac{kN}{m^2}$$

Uniform uplift due to Tailwater: (rectangular portion) $U_{A.UN2} := U_{press.toe.gsUN2} \cdot L_b \cdot W_b \cdot -1 = -19738.3 \cdot kN$

Moment Arm for Uplift UA from Toe of Gate Structure: $L_{A.UN2} := \frac{L_b}{2} = 12.10\,m$

Uplift - Linear Decrease from HW to TW: (triangular portion) $U_{B.UN2} := \frac{1}{2} \cdot \left(U_{HW.UN2} - U_{press.toe.gsUN2}\right) \cdot L_b \cdot W_b \cdot -1 = -7508.7 \cdot kN$

Moment Arm for Uplift UB from Toe of Gate Structure: $L_{B.UN2} := \frac{2}{3} \cdot L_b = 16.13\,m$

Total Resultant Uplift force: $U_{UN2} := U_{A.UN2} + U_{B.UN2} = -27247 \cdot kN$

Resultant Location from Toe: $U_{UN2.loc} := \frac{U_{A.UN2} \cdot L_{A.UN2} + U_{B.UN2} \cdot L_{B.UN2}}{U_{A.UN2} + U_{B.UN2}} = 13.21\,m$

$$\Sigma V_{water.UN2} := H_{1.UN2} + H_{2.UN2} + H_{3.UN2} + U_{UN2} = -18501.5 \cdot kN$$

$$\Sigma M_{Vwater.UN2} := H_{1.UN2} \cdot H_{1.UN2.loc} + H_{2.UN2} \cdot H_{2.UN2.loc} + H_{3.UN2} \cdot H_{3.UN2.loc} + U_{UN2} \cdot U_{UN2.loc} = -204353.8 \cdot kN \cdot m$$

Uplift as per Line of Creep Method
(Flotation and Overturning)

$$Uplift_{BC.UN2} := \frac{-1}{2} \cdot W_b \cdot \left(U_{HW.UN2} + U_{pore.C.UN2}\right) \cdot L_{BC} = -1427552.1\,N$$

$$Uplift_{CD.UN2} := 0$$

$$Uplift_{DE.UN2} := \frac{-1}{2} \cdot W_b \cdot \left(U_{pore.D.UN2} + U_{pore.E.UN2}\right) \cdot L_{DE} = -15584528.4\,N$$

$$Uplift_{EF.UN2} := \frac{-1}{2} \cdot W_b \cdot \left(U_{pore.E.UN2} + U_{pore.F.UN2}\right) \cdot L_{EF} = -2542822.3\,N$$

$$Uplift_{FG.UN2} := \frac{-1}{2} \cdot W_b \cdot \left(U_{pore.F.UN2} + U_{pore.toe.UN2}\right) \cdot L_{FG} = -1207157.5\,N$$

$$Uplift_{pore.UN2} := Uplift_{BC.UN2} + Uplift_{DE.UN2} + Uplift_{EF.UN2} + Uplift_{FG.UN2} = -20762.1 \cdot kN$$

$$Uplift_{FG.UN2.loc} := \frac{L_{FG}}{3} \cdot \frac{\left(2 \cdot U_{pore.F.UN2} + U_{pore.toe.UN2}\right)}{\left(U_{pore.F.UN2} + U_{pore.toe.UN2}\right)} = 0.75\,m$$

$$Uplift_{EF.UN2.loc} := \frac{L_{EF}}{3} \cdot \frac{\left(2 \cdot U_{pore.E.UN2} + U_{pore.F.UN2}\right)}{\left(U_{pore.E.UN2} + U_{pore.F.UN2}\right)} + L_{FG} = 3.13\,m$$

$$Uplift_{DE.UN2.loc} := \frac{L_{DE}}{3} \cdot \frac{\left(2 \cdot U_{pore.D.UN2} + U_{pore.E.UN2}\right)}{\left(U_{pore.D.UN2} + U_{pore.E.UN2}\right)} + L_{FG} + X_{EF} = 14.16\,m$$

$$Uplift_{BC.UN2.loc} := \frac{L_{BC}}{3} \cdot \frac{\left(2 \cdot U_{HW.UN2} + U_{pore.C.UN2}\right)}{\left(U_{HW.UN2} + U_{pore.C.UN2}\right)} + L_{FG} + X_{EF} + L_{DE} = 23.20\,m$$

UN2 CASE

SOIL LOADS

Equivalent Fluid Pressure (EFP): (CFEM 24.1)

At rest lateral pressure coefficient: $K_o = 0.66$

At-rest Soil Pressure to Heel, EM1110--2-2502 Section 3-7

Lateral Driving Force (Headwater Side)

Depth of Fill at Heel: $t_{hf.UN2} := TOC_{as} - BOF_{elev} = 6.00\,m$

At-Rest Soil Load: $E1_{drive.UN2} := \frac{K_o \cdot t_{hf.UN2}^2}{2} \cdot (\gamma_r - \gamma_w) \cdot W_b \cdot -1 = -1732.5 \cdot kN$

Acting at: $E1_{drive.loc.UN2} := \frac{t_{hf.UN2}}{3} - (BOF_{toe} - BOF_{elev}) = 0.50\,m$

Lateral Resisting Force (Tailwater Side)

Depth of Fill at Toe: $t_{tf.UN2} := TOC_{fce} - BOF_{elev} = 3.50\,m$

At-Rest Soil Load: $E2_{resistUN2} := \frac{K_o \cdot t_{tf.UN2}^2}{2} \cdot (\gamma_r - \gamma_w) \cdot W_b = 589.5 \cdot kN$

$E2_{resistUN2} := 0$

Acting at: $E2_{resistlocUN2} := \frac{t_{tf.UN2}}{3} = 1.17\,m$

(Expansion Joint to Stilling Basin, No Sediment in Gap)

$\Sigma H_{soil.UN2} := E1_{drive.UN2} + E2_{resistUN2} = -1732.5 \cdot kN$

$\Sigma M_{soil.UN2} := E1_{drive.UN2} \cdot E1_{drive.loc.UN2} + E2_{resistUN2} \cdot E2_{resistlocUN2} = -866.2 \cdot kN \cdot m$

ICE / IMPACT LOADS (CONSERVATIVELY ASSUME NO ICE LOADING ON DOWNSTREAM SIDE)

ICE / IMPACT LOADS NOT APPLIED TO THIS LOAD CASE

Static Impact Loading on Structure: $I_{S.UN2} := 0.0 \frac{kN}{m}$ (Section 7.7, Design Criteria)

Static Impact load on Gates: $I_{G.UN2} := 0.0 \frac{kN}{m}$ (Section 7.7, Design Criteria)

Impact Loading Unit Width on Structure: $W_{S.UN2} := 0m$

Impact Loading Unit Width on Gates: $W_{G.UN2} := 0m = 0.00$

Total Impact Load on Structure: $I_{UN2} := (I_{S.UN2} \cdot W_{S.UN2} + I_{G.UN2} \cdot W_{G.UN2}) \cdot -1 = 0 \cdot kN$

Apply Ice load at: $I_{UN2.loc} := (HW_{UN2} - BOF_{elev} - 0.30m) = 11.90\,m$

$\Sigma H_{I.UN2} := I_{UN2} = 0 \cdot kN$

$\Sigma M_{I.UN2} := I_{UN2} \cdot I_{UN2.loc} = 0 \cdot kN \cdot m$

SEISMIC LOAD (Not Applicable to this Load Case)

UN2 CASE

SUMMARY OF LOADS

	Loads	Moment Arm
Dead Load of Concrete Structure:	$D_{conc} = 25408.2 \cdot kN$	$X_{conc.loc} = 12.71\ m$
Dead Load of Gate:	$D_{Gate} = 580.0 \cdot kN$	$X_{gate} = 8.75\ m$
Headwater Lateral Load on Gate:	$H_{hwg.UN2} = 0.0 \cdot kN$	$H_{hwg.UN2.loc} = 7.57\ m$
Headwater Lateral Load on Footing:	$H_{hwf.UN2} = -7460.5 \cdot kN$	$H_{hwf.UN2.loc} = 1.70\ m$
Tailwater Lateral Load:	$H_{twf.UN2} = 721.0 \cdot kN$	$H_{twf.UN2.loc} = -0.33\ m$
Water Weight (HW) on Apron Slab:	$H_{1.UN2} = 4525.2 \cdot kN$	$H_{1.UN2.loc} = 21.10\ m$
Water Weight (HW) on Fixed Crest:	$H_{2.UN2} = 4220.3 \cdot kN$	$H_{2.UN2.loc} = 14.25\ m$
Water Weight (TW) on Fixed Crest:	$H_{3.UN2} = 0.0 \cdot kN$	$H_{3.UN2.loc} = 0.00\ m$
Uplift:	$U_{UN2} = -27247.0 \cdot kN$	$U_{UN2.loc} = 13.21\ m$
Upstream (driving) Lateral Soil Load:	$E1_{drive.UN2} = -1732.5 \cdot kN$	$E1_{drive.loc.UN2} = 0.50\ m$
Downstream (resisting) Lateral Soil Load:	$E2_{resistUN2} = 0 \cdot kN$	$E2_{resistlocUN2} = 1.17\ m$
Ice / Impact Load:	$I_{UN2} = 0.0 \cdot kN$	$I_{UN2.loc} = 11.90\ m$

STABILITY ASSESSMENT (SLIDNG, OVERTURNING AND BEARING): UN2 CASE

CHECK SLIDING ALONG HORIZONTAL PLANE THRU TOE,
IGNORING BEDROCK MOBILIZED BY STRUCTURAL HEEL KEY, OR VOID BEHIND KEY

Sum of Vertical Forces:

$\Sigma V_{UN2} := \Sigma V_{DL.UN2} + \Sigma V_{water.UN2} = 7254.7 \cdot kN$

Sum of Horizontal Forces:

$\Sigma H_{UN2} := \Sigma H_{Water.UN2} + \Sigma H_{soil.UN2} + \Sigma H_{I.UN2} = -8472 \cdot kN$

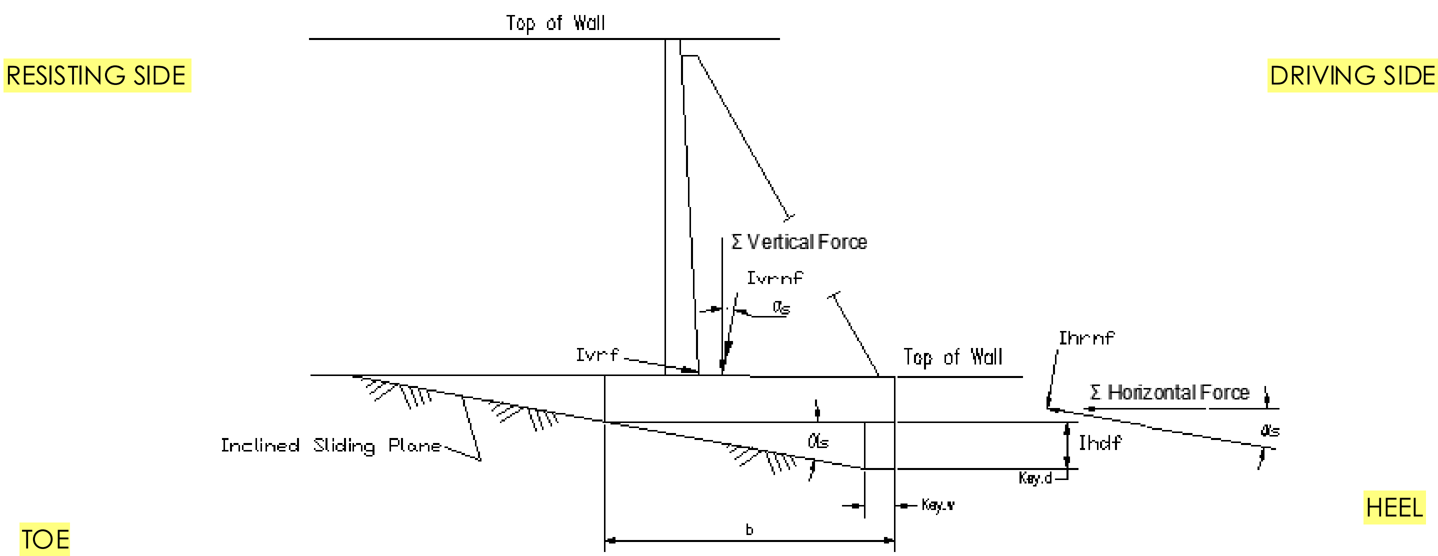
Sliding Factor of Safety:

$$FS_{HorizSliding.UN2} := \frac{\tan_{\phi} \cdot \Sigma V_{UN2}}{\left|\Sigma H_{UN2}\right|} = 0.42$$

$$FS_{HorizSliding.UN2.Check} := \begin{vmatrix} \text{"OKAY"} \quad \text{if} \quad FS_{HorizSliding.UN2} \ge FS_{req.UN2.sl} \\ \text{"Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !"} \quad \text{otherwise} \end{vmatrix}$$

$FS_{HorizSliding.UN2.Check} =$ "Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !"

CHECK SLIDING ALONG INCLINED SLIDING PLANE FROM HEEL KEY TO TOE,
WITH BEDROCK MASS MOBILIZED BY REINFOCREDE CONCRETE KEY)



Ivrf=Inclined Resisting Force
Ivrnf=Inclined Resisting Normal Force
Ihrnf=Inclined Resisting Normal Force
Ihdf=Inclined Driving Force

$$\alpha s := \operatorname{atan}\left(\frac{BOF_{toe} - BOF_{elev}}{L_b - Key_l}\right) = 0.12 \qquad \text{as degrees=} \quad \alpha s \cdot \left(\frac{180}{\pi}\right) = 7.01$$

Resolve $\Sigma Vert_{UN2}$ & $\Sigma Horiz_{UN2}$

$$\Sigma V_{InclinedUN2} := \cos(\alpha s) \cdot \left(\Sigma V_{UN2} + V_{rs}\right) + \sin(\alpha s) \cdot \left|\Sigma H_{UN2}\right| = 20523.3 \cdot kN$$

$$\Sigma H_{InclinedUN2} := \cos(\alpha s) \cdot \left|\Sigma H_{UN2}\right| - \sin(\alpha s) \cdot \left(\Sigma V_{UN2} + V_{rs}\right) = 6012.4 \cdot kN$$

(With properly engineered reinforced concrete Key, horizontal sliding plane thru Toe is protected, critical sliding plane is relocated to the INCLINED SLIDING PLANE FROM HEEL KEY To TOE, Bedrock Mass above this examing plane is mobilized by reinforced concrete key and combined into Structural Wedge.)

Inclined Sliding Plane Length $\quad L_{incline} = 24.2\,m$

Safety Factor for Sliding
Inclined Failure Plane

$$FS_{InclinedlSlidingUN2} := \frac{\Sigma V_{InclinedUN2} \cdot \tan\left(\phi_{rock} \cdot \frac{\pi}{180}\right)}{\left|\Sigma H_{InclinedUN2}\right|} = 1.66$$

$$FS_{InclinedSliding.UN2.check} := \begin{vmatrix} \text{"OKAY "} \quad \text{if} \quad FS_{InclinedlSlidingUN2} > FS_{req.UN2.sl} \\ \text{"Revise Structure""} \quad \text{otherwise} \end{vmatrix} = \text{"OKAY "}$$

$FS_{InclinedSliding.UN2.check} =$ "OKAY "

CHECK ECCENTRICITY ON INCLINED PLANE

UN2 CASE

Sum of the Moments:

$$\Sigma M_{rs.UN2} := \Sigma M_{DL.UN2} + \Sigma M_{HWater.UN2} + \Sigma M_{Vwater.UN2} + \Sigma M_{I.UN2} + \Sigma M_{soil.UN2} + V_{rs} \cdot L_{rs} = 278816 \cdot kN \cdot m$$

Eccentricity:

$$e_{UN2} := \frac{L_{incline}}{2} - \frac{\Sigma M_{rs.UN2}}{\Sigma V_{InclinedUN2}} = -1.46\,m$$

Eccentricity Check:

$$e_{check.UN2} := \begin{cases} \text{"Okay"} & \text{if } |e_{UN2}| \le Kern \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$e_{check.UN2} = \text{"Okay"}$

Foundation Bearing Pressures on Inclined Plane:

Bearing Pressure at Heel:

$$\sigma_{heel.UN2} := \frac{\Sigma V_{InclinedUN2}}{\frac{A_b}{\cos(\alpha s)}} - \frac{\Sigma V_{InclinedUN2} \cdot e_{UN2}}{\frac{S_b}{\cos(\alpha s)^2}} = 95.4 \cdot \frac{kN}{m^2}$$

$$\sigma_{heel.UN2.check} := \left(\begin{cases} \text{"Okay"} & \text{if } \sigma_{heel.UN2} \le \sigma_{allow.UN2} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} \right)$$

$\sigma_{heel.UN2.check} = \text{"Okay"}$

Bearing Pressure at Toe:

$$\sigma_{toe.UN2} := \frac{\Sigma V_{InclinedUN2}}{\frac{A_b}{\cos(\alpha s)}} + \frac{\Sigma V_{InclinedUN2} \cdot e_{UN2}}{\frac{S_b}{\cos(\alpha s)^2}} = 44.9 \cdot \frac{kN}{m^2}$$

$$\sigma_{toe.UN2.check} := \begin{cases} \text{"Okay"} & \text{if } \sigma_{toe.UN2} \le \sigma_{allow.UN2} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$\sigma_{toe.UN2.check} = \text{"Okay"}$

CHECK FLOTATION

$Uplift_{sliding.UN2} := U_{UN2} = -27247 \cdot kN$

$Uplift_{pore.UN2} = -20762.1 \cdot kN$

$(Uplift_{UN2}) := \min(Uplift_{pore.UN2}, Uplift_{sliding.UN2})$ (For conservative, taking maximum values)

$$FS_{Flotation.UN2} := \frac{D_{conc} + D_{Gate} + H_{1.UN2} + H_{2.UN2} + H_{3.UN2}}{|Uplift_{UN2}|} = 1.3$$

$$FS_{Flotation.UN2.check} := \begin{cases} \text{"OKAY "} & \text{if } round(FS_{Flotation.UN2}, 1) \ge FS_{req.UN.flt} \\ \text{"Revise Structure""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

MONOLITH OVERTURNING STABILITY ANALYSIS

UN2 CASE

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.

Assumptions are made in order to compute overturning stability of indetermine forces on monolith with key;

(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.

(b) The horizontal resisting force acting on the key, P.key, is that required for static equilibrium

(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1 $Ratio_{overturning.allow.Unusual} := 0.333$ (Resultant within Middle Third)

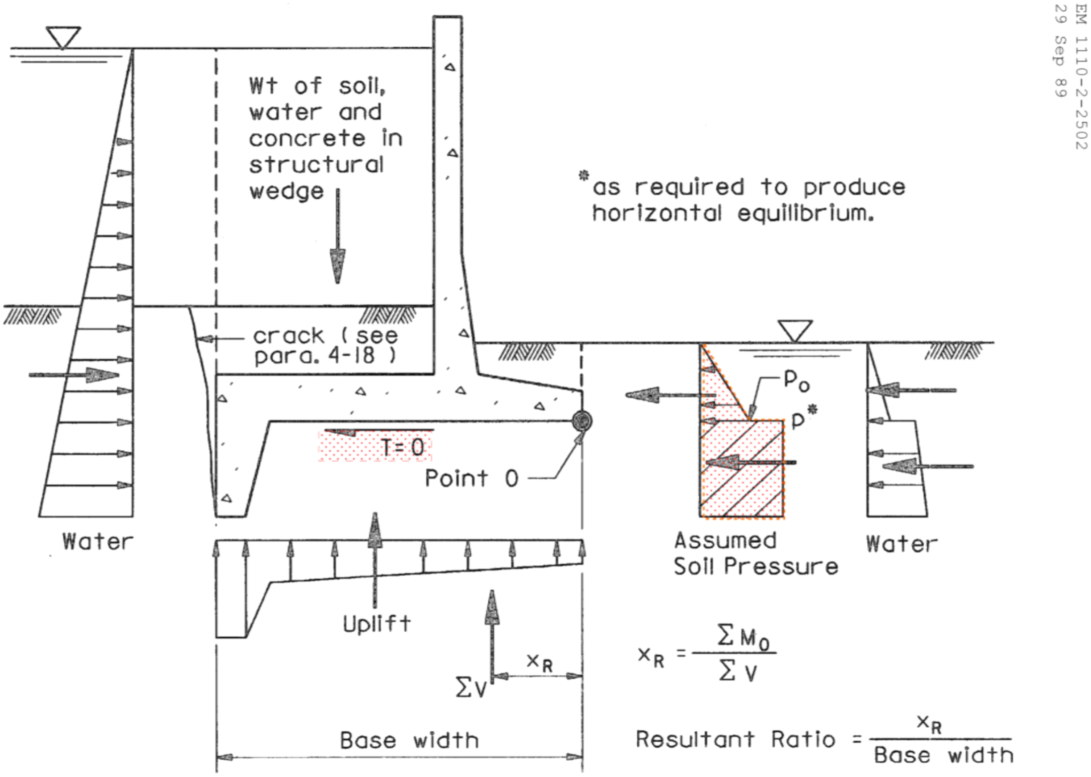


Figure 4-5. Forces for overturning analysis for wall with horizontal base and key

All Vertical Loads Applicable to Overturning Stability Analysis

Total Concrete Dead Loads:	$D_{conc} = 25408.2 \cdot kN$	at:	$X_{conc.loc} = 12.7\,m$
Dead Load of Gate:	$D_{Gate} = 580.0 \cdot kN$		$X_{gate} = 8.75\,m$
Water Weight (HW) on Apron Slab:	$H_{1.UN2} = 4525.2 \cdot kN$		$H_{1.UN2.loc} = 21.10\,m$
Water Weight (HW) on Fixed Crest:	$H_{2.UN2} = 4220.3 \cdot kN$		$H_{2.UN2.loc} = 14.25\,m$
Water Weight (TW) on Fixed Crest:	$H_{3.UN2} = 0.0 \cdot kN$		$H_{3.UN2.loc} = 0.00\,m$

Uplift Force from Sliding Analysis. Line of Creep Method applied at presumed inclined sliding line, and subtraction gravity effect to Base of Concrete by Archimedes Principle

$$U_{UN2.loc.sliding} := \frac{U_{A.UN2} \cdot L_{A.UN2} + U_{B.UN2} \cdot L_{B.UN2} - A_{rs} \cdot w_{as} \cdot \gamma_w \cdot L_{rs}}{U_{A.UN2} + U_{B.UN2} - A_{rs} \cdot w_{as} \cdot \gamma_w} = 13.31\,m$$

$$U_{UN2.sliding} := U_{UN2} + A_{rs} \cdot w_{as} \cdot \gamma_w = -21725.9 \cdot kN$$

UN2 CASE

Uplift for Overturning Analysis, Line of Creep Method. Pore pressure at base of Concrete

$Uplift_{pore.UN2} = -20762.1 \cdot kN$

$$Uplift_{pore.UN2.loc} := \frac{Uplift_{BC.UN2} \cdot Uplift_{BC.UN2.loc} + Uplift_{DE.UN2} \cdot Uplift_{DE.UN2.loc} \cdots + Uplift_{EF.UN2} \cdot Uplift_{EF.UN2.loc} + Uplift_{FG.UN2} \cdot Uplift_{FG.UN2.loc}}{Uplift_{pore.UN2}} = 12.7\, m$$

Sum of All Water Load for Overturning Analysis

$$\Sigma V_{water.UN2.OT} := H_{1.UN2} + H_{2.UN2} + H_{3.UN2} + Uplift_{pore.UN2} = -12016.6 \cdot kN$$

<u>All Lateral Loads Applicable to Overturning Stability Analysis</u>

Apply Load to Gate?: $poss_{UN2} = 1$ poss = 1 if gate is closed
0 if gate is open

Headwater Lateral Load on Gate: $H_{hwg.UN2} = 0.0 \cdot kN$ $H_{hwg.UN2.loc} = 7.57\, m$

Headwater Lateral Load on Footing: $H_{hwf.UN2} = -7460.5 \cdot kN$ $H_{hwf.UN2.loc} = 1.70\, m$

Total Horizontal Tailwater Load on Footing under Gate Openings, i.e., excluding Pier $H_{twf.UN2} = 721.0 \cdot kN$ $H_{twf.UN2.loc} = -0.33\, m$

Resisting Water on Rear Face of Monolith, i.e., bottom of heel elevation: *(Point O @ TOE: BOFtoe = EL.1205.5)*

Ice / Impact Load: $I_{UN2} = 0.0 \cdot kN$ at: $I_{UN2.loc} = 11.90\, m$

Depth of Fill at Heel Side for Overturning Analysis: $t_{hf.UN2} := TOC_{as} - BOF_{toe} = 4.50\, m$

Driving Soil Load for overtuming:

$$E1_{drive.UN2} := \frac{K_o \cdot t_{hf.UN2}^{\;2}}{2} \cdot \left(\gamma_r - \gamma_w\right) \cdot W_b \cdot -1 = -974.5 \cdot kN$$

Acting at:

$$E1_{drive.loc.UN2} := \frac{t_{hf.UN2}}{3} = 1.50\, m$$

Downstream (resisting) Lateral Soil Load as required to produce horizontal equilibrium:

$$E2_{resistUN2} := -1 \cdot \left(H_{hwg.UN2} + H_{hwf.UN2} + H_{twf.UN2} + I_{UN2} + E1_{drive.UN2}\right)$$

$E2_{resistUN2} = 7714 \cdot kN$

Assumed Resisting Bedrock at middle of Key, passive soil pressure or lateral bearing on contract joint at end of Monolith 3A3B $E2_{resistlocUN2} := E2_{resistlocU1} = -0.75\, m$

Overturning moment by Dead Loads about Point O @ Toe $\Sigma M_{DL.UN2} = 325934.4 \cdot kN \cdot m$

Overturning moment by Vertical Water Loads and Uplift, about Point O @ Toe

$$\Sigma M_{Vwater.UN2.OT} := H_{1.UN2} \cdot H_{1.UN2.loc} + H_{2.UN2} \cdot H_{2.UN2.loc} + H_{3.UN2} \cdot H_{3.UN2.loc} + Uplift_{pore.UN2} \cdot Uplift_{pore.UN2.loc} = -107031.9 \cdot kN \cdot m$$

Overturning moment by Lateral Hydrostatic Forces of Headwater Pool and Tailwater Pool,about Point O @ Toe $\Sigma M_{HWater.UN2} = -12887.9 \cdot kN \cdot m$

Overturning Moment by Impact/Ice Load, about Point O@ Toe $\Sigma M_{I.UN2} = 0$

Overturning moment by Lateral Soil Forces
about Point O @ Toe

$$\Sigma M_{soil.UN2} := E1_{drive.UN2} \cdot E1_{drive.loc.UN2} + E2_{resistUN2} \cdot E2_{resistlocUN2} = -7247.3 \cdot kN \cdot m$$

Sum of the Overturning Moments about Point O @ Toe:

$$\Sigma M_{UN2.OT} := \Sigma M_{DL.UN2} + \Sigma M_{HWater.UN2} + \Sigma M_{Vwater.UN2.OT} + \Sigma M_{I.UN2} + \Sigma M_{soil.UN2} = 198767 \cdot kN \cdot m$$

Sum of Vertical Forces:

$$\Sigma V_{UN2.OT} := \Sigma V_{DL.UN2} + \Sigma V_{water.UN2.OT} = 13739.6 \cdot kN$$

Distance X_R: EM 1110-2-2502 Eq.4-1

$$X_{R.UN2} := \frac{\Sigma M_{UN2.OT}}{\Sigma V_{UN2.OT}} = 14.5\,m$$

Overturning Resultant Ratio

$$Ratio_{Overturning.UN2} := \frac{X_{R.UN2}}{L_b} = 0.6$$

EM 1110-2-2502

Table 4-1

Retaining Wall Stability Criteria

Loading Condition	Sliding Factor of Safety, FS	Shear Strength Test Required: Soil Foundation	Shear Strength Test Required: Rock Foundation[3]	Overturning Criteria Minimum Base Area in Compression: Soil Foundation	Overturning Criteria Minimum Base Area in Compression: Rock Foundation
Usual	1.5	(Q &/or S)[2,1]	Direct shear	100%[4]	75%[4]
Unusual	1.33	(Q &/or S)[2,1]	Direct shear	75%[4]	50%[4]
Earthquake	1.1	(Q)	Direct shear	Resultant within base	Resultant within base

Overturning Stability Check

$$Ratio_{Overturning.UN2.check} := \begin{cases} \text{"Okay"} & \text{if } Ratio_{Overturning.UN2} \geq Ratio_{overturning.allow.Unusual} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$$Ratio_{Overturning.UN1.check} = \text{"Okay"}$$

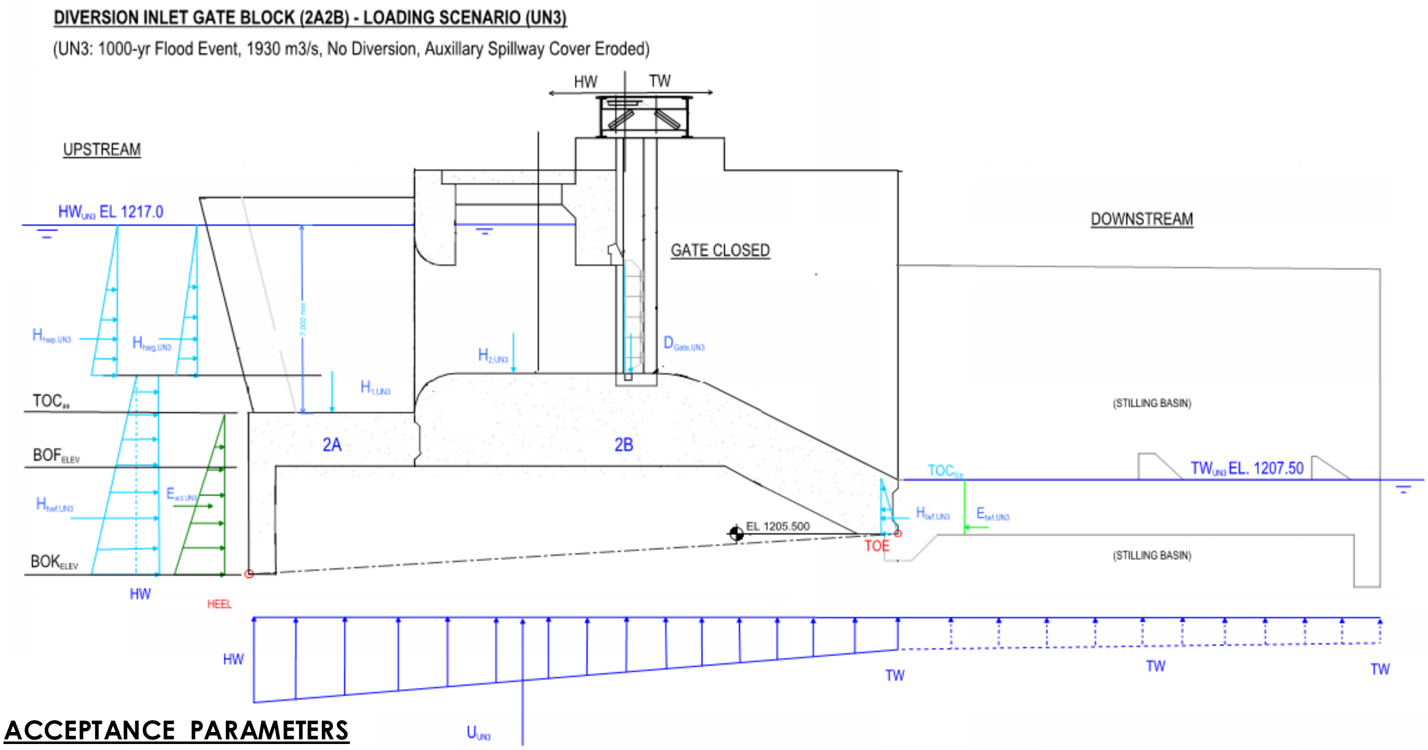
UN2 CASE

Summary of Extreme Flood Results (Only Report Controlling Load Case)

UN2 Event: No Diversion, 2013 Flood

Horiz Sliding Factor of Safety:	$FS_{HorizSliding.UN2} = 0.42$
Horiz Sliding Factor of Safety Check:	$FS_{HorizSliding.UN2.Check}$ = "Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !"
Sliding Factor of Safety:	$FS_{InclinedlSlidingUN2} = 1.7$
Sliding Factor of Safety Check:	$FS_{InclinedSliding.UN2.check}$ = "OKAY "
Eccentricity:	$e_{UN2} = -1.46\,m$
Eccentricity Check:	$e_{check.UN2}$ = "Okay"
Bearing Pressure At Heel:	$\sigma_{heel.UN2} = 95.4 \cdot \frac{kN}{m^2}$
Bearing Pressure At Heel Check:	$\sigma_{heel.UN2.check}$ = "Okay"
Bearing Pressure At Heel:	$\sigma_{toe.UN2} = 44.9 \cdot \frac{kN}{m^2}$
Bearing Pressure At Toe Check:	$\sigma_{toe.UN2.check}$ = "Okay"
Flotation Factor of Safety	$FS_{Flotation.UN2} = 1.3$
Flotation Factor of Safety Check:	$FS_{Flotation.UN2.check}$ = "OKAY "
Overturning Resultant Ratio	$Ratio_{Overturning.UN2} = 0.60$
Overturning Stability Check	$Ratio_{Overturning.UN2.check}$ = "Okay"

UN3 DESIGN CASE



ACCEPTANCE PARAMETERS

Required Factor of Safety for Sliding: $FS_{req.UN3.sl} := 1.3$ (Without Cohesion) (Section 8.1, Design Criteria)

Resultant Within Middle Third of Base: $e \le \frac{L_b}{6} \wedge e \ge \frac{-L_b}{6}$

Allowable Rock Bearing Pressure: $\sigma_{allow.UN3} := 1470.0 \cdot \frac{kN}{m^2}$ (Section 5.2, Design Criteria)

Required Factor of Safety for Flotation: $FS_{rea.UN.flt} = 1.3$

Overturning Min Required Resultant Ratio: $\frac{X_{R.UN}}{Horizontal\_Width\_of\_Base} > 0.333$

(100% Base in Compression, Resultant within Middle Third)

INPUT PARAMETERS

Headwater Elevation: $HW_{UN3} := 1217.00m$

Tailwater Elevation: $TW_{UN3} := 1207.50m$

(Water Elevations based on Diversion Structure 2D Hydraulic Model Results. See page 6 and Section 8.2, Design Criteria)

Crest Water Elevation (No Diversion)

Chute Block Water Elevation (No Diversion)

Bottom of Key (Footing Heel) Elevation: $BOF_{elev} = 1204.00\,m$

Apron Slab Top of Concrete Elevation at Edge of Slab: $TOC_{as} = 1210.00\,m$

Fixed Crest Top of Concrete Elevation at Downstream Face: $TOC_{fce} = 1207.50\,m$

Fixed Crest Top of Concrete Elevation at Center of Footing: $TOC_{fcc} = 1211.50\,m$

Lift Gate Position per Hydraulic Criteria $poss_{UN3} := 1$ poss = 1 if gate is closed
0 if gate is open

$$Gate_{R.UN3} := \begin{cases} 0 & \text{if } poss_{UN3} = 0 \\ 0.60 & \text{otherwise} \end{cases}$$

$$\Sigma V_{DL.UN3} := D_{conc} + Gate_{R.UN3} D_{Gate} = 25756.2 \cdot kN$$

$$\Sigma M_{DL.UN3} := D_{conc} \cdot X_{conc.loc} + Gate_{R.UN3} \cdot D_{Gate} \cdot X_{gate} = 325934.4 \cdot kN \cdot m$$

LATERAL WATER LOADS

UN3 CASE

HEADWATER (DRIVING): *Point O @ TOE: BOFtoe = EL.1205.5*

Water Depth Above Fixed Crest at Gate: $D_{hwg.UN3} := HW_{UN3} - TOC_{fcc} = 5.5\,m$

Water Load Unit Width on Gate $W_{hwg.UN3} := 0 = 0.00$

Apply Load to Gate?: $poss_{UN3} = 1$

poss = 1 if gate is closed
0 if gate is open

Total Horizontal Water Load on Gate: $H_{hwg.UN3} := \frac{-\left(\gamma_w \cdot D_{hwg.UN3}^{\;2}\right)}{2} \cdot W_{hwg.UN3} \cdot poss_{UN3} = 0 \cdot kN$

Apply Total Gate Water Load at: $H_{hwg.UN3.loc} := \frac{D_{hwg.UN3}}{3} + \left(TOC_{fcc} - BOF_{toe}\right) = 7.83\,m$

Water Depth at Heel: $D_{hwf.UN3} := HW_{UN3} - BOF_{elev} = 13.00\,m$

Water Load Unit With on Footing: $W_{hw.UN3} := W_b$

Water Load at Bottom of Footing: $H_{hwf.UN3.1} := -\left(\gamma_w \cdot D_{hwf.UN3}\right) \cdot W_{hw.UN3} = -1530.4\,\frac{1}{m} \cdot kN$

Water Load at Top of Footing: $H_{hwf.UN3.2} := -\left(\gamma_w \cdot D_{hwg.UN3}\right) \cdot W_{hw.UN3} = -647.5\,\frac{1}{m} \cdot kN$

Total Horizontal Water Load on Footing: $H_{hwf.UN3} := \frac{\left(H_{hwf.UN3.1} + H_{hwf.UN3.2}\right) \cdot \left(D_{hwf.UN3} - D_{hwg.UN3}\right)}{2} = -8166.8 \cdot kN$

Apply Total Footing Water Load at:

$$H_{hwf.UN3.loc} := \frac{\left[H_{hwf.UN3.2} \cdot \frac{\left(TOC_{fcc} - BOF_{elev}\right)^2}{2} + \frac{\left(H_{hwf.UN3.1} - H_{hwf.UN3.2}\right)}{2} \cdot \frac{\left(TOC_{fcc} - BOF_{elev}\right)^2}{3}\right]}{\frac{\left(H_{hwf.UN3.2} + H_{hwf.UN3.1}\right) \cdot \left(TOC_{fcc} - BOF_{elev}\right)}{2}} - \left(BOF_{toe} - BOF_{elev}\right) = 1.74\,m$$

Converting horizontal force resultant from HEEL calculation to Point-O@TOE

LATERAL WATER LOADS (cont.)

UN3 CASE

TAILWATER (RESISTING):

Water Depth at toe: $D_{tw.UN3} := TW_{UN3} - BOF_{elev} = 3.50\,m$

Water Load Unit Width: $W_{twf.UN3} := W_b$

Total Horizontal Tailwater Load on Footing under Gate Openings, i.e., excluding Pier

Resisting Water on Rear Face of Monolith, i.e., bottom of heel elevation:

$COND_{UN3} := poss_{UN3} = 0 \wedge TW_{UN3} \geq TOC_{fcc}$

$$H_{twf.UN3} := \begin{cases} \dfrac{\gamma_w \cdot D_{tw.UN3}^2}{2} \cdot (W_{twf.UN3}) & \text{if } poss_{UN3} = 1 \\ \dfrac{\gamma_w \cdot D_{tw.UN3}^2}{2} \cdot (W_{twf.UN3}) & \text{if } poss_{UN3} = 0 \wedge TW_{UN3} \leq TOC_{fcc} \\ \gamma_w \cdot \left[\dfrac{D_{tw.UN3}}{2} + \dfrac{(TW_{UN3} - TOC_{fcc})}{2}\right] \cdot (TOC_{fcc} - BOF_{elev}) \cdot (W_{twf.UN3}) & \text{if } COND_{UN3} \end{cases} = 721.0 \cdot kN$$

Apply Footing Tailwater Load within Gate Openings at:

$$H_{twf.UN3.loc} := \begin{cases} \dfrac{D_{tw.UN3}}{3} - (BOF_{toe} - BOF_{elev}) & \text{if } poss_{UN3} = 1 \\ \dfrac{D_{tw.UN3}}{3} - (BOF_{toe} - BOF_{elev}) & \text{if } poss_{UN3} = 0 \wedge TW_{UN3} \leq TOC_{fcc} \\ \dfrac{(TOC_{fcc} - BOF_{elev})^2 \cdot \left[\dfrac{(TW_{UN3} - TOC_{fcc})}{2} + \dfrac{(TOC_{fcc} - BOF_{elev})}{6}\right]}{(TOC_{fcc} - BOF_{elev})\left[(TW_{UN3} - TOC_{fcc}) + \dfrac{(TOC_{fcc} - BOF_{elev})}{2}\right]} - (BOF_{toe} - BOF_{elev}) & \text{if } COND_{UN3} \end{cases} = -0.33 \cdot m$$

$\Sigma H_{Water.UN3} := H_{hwg.UN3} + H_{hwf.UN3} + H_{twf.UN3} = -7445.8 \cdot kN$

$$\Sigma M_{HWater.UN3} := H_{hwg.UN3} \cdot H_{hwg.UN3.loc} + H_{hwf.UN3} \cdot H_{hwf.UN3.loc} \cdots + H_{twf.UN3} \cdot H_{twf.UN3.loc} = -14477.1 \cdot kN \cdot m$$

VERTICAL WATER LOADS

UN3 CASE

HEADWATER:

Water Depth on top of fixed crest: $d_{hw.UN3} := HW_{UN3} - TOC_{as} = 7.00\,m$

Weight of Water (H1) on Approach Slab: $H_{1.UN3} := \left(W_{hw.UN3} \cdot d_{hw.UN3} \cdot L_{as}\right) \cdot \gamma_w = 5109 \cdot kN$

Horiz. Moment Arm for H1 (from toe): $H_{1.UN3.loc} := L_b - \dfrac{L_{as}}{2} = 21.10\,m$

Cross-sectional Area of Headwater Above Fixed Crest: $A_{fc.hw.UN3} := 41.71m^2$ (From Bluebeam Measurement)

Volume of water Above Fixed Crest: $V_{fc.hw.UN3} := \left(A_{fc.hw.UN3} \cdot W_{hw.UN3}\right) = 500.5 \cdot m^3$

Weight of Water (H2) on Fixed Crest: $H_{2.UN3} := V_{fc.hw.UN3} \cdot \gamma_w = 4910.1 \cdot kN$

Horiz. Moment Arm for H2 (from toe): $H_{2.UN3.loc} := 14.25 \cdot m$

TAILWATER:

Slope of Crest from D/S of Gate to edge of Stilling Basin: $S_{f.UN3} := \dfrac{\left(TOC_{fcc} - TOC_{fce}\right)}{8.00m} = 0.500$

Height of Tailwater Above Stilling Basin:

$$y_{UN3} := \begin{cases} \left(TW_{UN3} - TOC_{fce}\right) & \text{if } TW_{UN3} \le TOC_{fcc} \\ \left(TOC_{fcc} - TOC_{fce}\right) & \text{otherwise} \end{cases}$$

$y_{UN3} = 0.00\,m$

Horizontal Distance of Tailwater Above Sloped Portion of Crest: $x_{UN3} := \dfrac{y_{UN3}}{S_{f.UN3}} = 0.00\,m$

Cross Sectional Area of Tailwater Above Sloped Portion of Crest: $A_{tw.UN3} := \dfrac{x_{UN3} \cdot y_{UN3}}{2} = 0\,m^2$

$= 0.00m^2$ if TW_{UN3} is less than or equal to TOC_{fce}

Weight of Water (H3) Above Slope Portion of Crest:

$$H_{3.UN3} := \begin{cases} (0.0kN) & \text{if } TW_{UN3} \le TOC_{fce} \\ \left(A_{tw.UN3} \cdot W_{twf.UN3}\right) \cdot \gamma_w & \text{if } TOC_{fcc} \ge TW_{UN3} > TOC_{fce} \\ \left[A_{tw.UN3} + Dist_{gate} \cdot \left(TW_{UN3} - TOC_{fcc}\right)\right] \cdot W_{twf.UN3} \cdot \gamma_w & \text{if } TW_{UN3} > TOC_{fcc} \end{cases}$$

$H_{3.UN3} = 0.0 \cdot kN$

Horiz. Moment Arm for H3 (from toe):

$$H_{3.UN3.loc} := \begin{cases} (0.00m) & \text{if } TW_{UN3} \le TOC_{fce} \\ \left(\frac{1}{3} \cdot x_{UN3}\right) & \text{if } TOC_{fcc} \ge TW_{UN3} > TOC_{fce} \\ \dfrac{\left[\frac{1}{2} \cdot x_{UN3} \cdot y_{UN3} \cdot \left(\frac{1}{3}\right) x_{UN3} + \left(TW_{UN3} - TOC_{fcc}\right) \cdot Dist_{gate} \cdot \left(\frac{Dist_{gate}}{2}\right)\right]}{\left(\frac{1}{2} \cdot x_{UN3} \cdot y_{UN3}\right) + \left(TW_{UN3} - TOC_{fcc}\right) \cdot Dist_{gate}} & \text{if } TW_{UN3} > TOC_{fcc} \end{cases}$$

$H_{3.UN3.loc} = 0.00\,m$

UPLIFT AT INCLINED SLIDING PLANE

UN3 CASE

Uplift pressure at Headwater: $U_{HW.UN3} := D_{hwf.UN3} \cdot \gamma_w = 127.53 \cdot \frac{kN}{m^2}$

Uplift pressure at D/S end of Stilling Basin: $U_{TW.UN3} := D_{tw.UN3} \cdot \gamma_w = 34.3 \cdot \frac{kN}{m^2}$

Length from U/S Face of Gate Structure to Toe Point(Effective Drain at end of Monolith) $L_{overall} = 24.20\,m$ $L_{sb} = 0$

Length of Seepage per Line of Creep $L_{seepage} = 27.1\,m$

Difference between Uplift pressure at Headwater and Uplift Pressure at Toe of Stilling Basin: $U_{diffUN3} := U_{HW.UN3} - U_{TW.UN3} = 93.2 \cdot \frac{kN}{m^2}$

Slope of difference between Uplift pressure at Headwater and Uplift Pressure at Toe of Stilling Basin: $U_{slopeUN3} := \frac{U_{diffUN3} - Key_d \cdot \gamma_w}{L_{overall}} = 3.24 \cdot \frac{kN}{m^2 \cdot m}$

$$U_{seepageslopeUN3} := \frac{U_{diffUN3} - Key_d \cdot \gamma_w}{L_{seepage}}$$

Tailwater Pressure at toe of Gate Structure: $U_{press.toe.gsUN3} := U_{TW.UN3} + L_{sb} \cdot U_{slopeUN3} = 34.3 \cdot \frac{kN}{m^2}$

$$U_{pore.toe.UN3} := U_{TW.UN3} + U_{seepageslopeUN3} \cdot L_{sb} = 34.3 \cdot \frac{kN}{m^2}$$

$$U_{pore.F.UN3} := U_{pore.toe.UN3} + U_{seepageslopeUN3} \cdot L_{FG} = 38.7 \cdot \frac{kN}{m^2}$$

$$U_{pore.E.UN3} := U_{pore.F.UN3} - \left(BOF_{base} - BOF_{toe}\right) \cdot \gamma_w + U_{seepageslopeUN3} \cdot L_{EF} = 33.7 \cdot \frac{kN}{m^2}$$

$$U_{pore.D.UN3} := U_{pore.E.UN3} + U_{seepageslopeUN3} \cdot L_{DE} = 86.4 \cdot \frac{kN}{m^2}$$

$$U_{pore.C.UN3} := U_{pore.D.UN3} + \left(BOF_{base} - BOF_{elev}\right) \cdot \gamma_w + U_{seepageslopeUN3} \cdot L_{CD} = 124.6 \cdot \frac{kN}{m^2}$$

Uniform uplift due to Tailwater: (rectangular portion) $U_{A.UN3} := U_{press.toe.gsUN3} \cdot L_b \cdot W_b \cdot -1 = -9970.9 \cdot kN$

Moment Arm for Uplift UA from Toe of Gate Structure: $L_{A.UN3} := \frac{L_b}{2} = 12.10\,m$

Uplift - Linear Decrease from HW to TW: (triangular portion) $U_{B.UN3} := \frac{1}{2} \cdot \left(U_{HW.UN3} - U_{press.toe.gsUN3}\right) \cdot L_b \cdot W_b \cdot -1 = -13531.9 \cdot kN$

Moment Arm for Uplift UB from Toe of Gate Structure: $L_{B.UN3} := \frac{2}{3} \cdot L_b = 16.13\,m$

Total Resultant Uplift force: $U_{UN3} := U_{A.UN3} + U_{B.UN3} = -23502.8 \cdot kN$

Resultant Location from Toe: $U_{UN3.loc} := \frac{U_{A.UN3} \cdot L_{A.UN3} + U_{B.UN3} \cdot L_{B.UN3}}{U_{A.UN3} + U_{B.UN3}} = 14.42\,m$

UN3 CASE

$$\Sigma V_{water.UN3} := H_{1.UN3} + H_{2.UN3} + H_{3.UN3} + U_{UN3} = -13483.6 \cdot kN$$

$$\Sigma M_{Vwater.UN3} := H_{1.UN3} \cdot H_{1.UN3.loc} + H_{2.UN3} \cdot H_{2.UN3.loc} + H_{3.UN3} \cdot H_{3.UN3.loc} + U_{UN3} \cdot U_{UN3.loc} = -161192.7 \cdot kN \cdot m$$

Uplift as per Line of Creep Method
(Flotation and Overturning)

$$Uplift_{BC.UN3} := \frac{-1}{2} \cdot W_b \cdot \left(U_{HW.UN3} + U_{pore.C.UN3}\right) \cdot L_{BC} = -1512981.8\,N$$

$$Uplift_{CD.UN3} := 0$$

$$Uplift_{DE.UN3} := \frac{-1}{2} \cdot W_b \cdot \left(U_{pore.D.UN3} + U_{pore.E.UN3}\right) \cdot L_{DE} = -13114323.8\,N$$

$$Uplift_{EF.UN3} := \frac{-1}{2} \cdot W_b \cdot \left(U_{pore.E.UN3} + U_{pore.F.UN3}\right) \cdot L_{EF} = -1455650.5\,N$$

$$Uplift_{FG.UN3} := \frac{-1}{2} \cdot W_b \cdot \left(U_{pore.F.UN3} + U_{pore.toe.UN3}\right) \cdot L_{FG} = -657131\,N$$

$$Uplift_{pore.UN3} := Uplift_{BC.UN3} + Uplift_{DE.UN3} + Uplift_{EF.UN3} + Uplift_{FG.UN3} = -16740.1 \cdot kN$$

$$Uplift_{FG.UN3.loc} := \frac{L_{FG}}{3} \cdot \frac{\left(2 \cdot U_{pore.F.UN3} + U_{pore.toe.UN3}\right)}{\left(U_{pore.F.UN3} + U_{pore.toe.UN3}\right)} = 0.76\,m$$

$$Uplift_{EF.UN3.loc} := \frac{L_{EF}}{3} \cdot \frac{\left(2 \cdot U_{pore.E.UN3} + U_{pore.F.UN3}\right)}{\left(U_{pore.E.UN3} + U_{pore.F.UN3}\right)} + L_{FG} = 3.14\,m$$

$$Uplift_{DE.UN3.loc} := \frac{L_{DE}}{3} \cdot \frac{\left(2 \cdot U_{pore.D.UN3} + U_{pore.E.UN3}\right)}{\left(U_{pore.D.UN3} + U_{pore.E.UN3}\right)} + L_{FG} + X_{EF} = 14.93\,m$$

$$Uplift_{BC.UN3.loc} := \frac{L_{BC}}{3} \cdot \frac{\left(2 \cdot U_{HW.UN3} + U_{pore.C.UN3}\right)}{\left(U_{HW.UN3} + U_{pore.C.UN3}\right)} + L_{FG} + X_{EF} + L_{DE} = 23.20\,m$$

UN3 CASE

SOIL LOADS

Equivalent Fluid Pressure (EFP): (CFEM 24.1)

At rest lateral pressure coefficient: $K_o = 0.66$

At-rest Soil Pressure to Heel, EM1110--2-2502 Section 3-7

Lateral Driving Force (Headwater Side)

Depth of Fill at Heel: $t_{hf.UN3} := TOC_{as} - BOF_{elev} = 6.00\,m$

At-Rest Soil Load: $E1_{drive.UN3} := \frac{K_o \cdot t_{hf.UN3}^{2}}{2} \cdot (\gamma_r - \gamma_w) \cdot W_b \cdot -1 = -1732.5 \cdot kN$

Acting at: $E1_{drive.loc.UN3} := \frac{t_{hf.UN3}}{3} - (BOF_{toe} - BOF_{elev}) = 0.50\,m$

Lateral Resisting Force (Tailwater Side)

Depth of Fill at Toe: $t_{tf.UN3} := TOC_{fce} - BOF_{elev} = 3.50\,m$

At-Rest Soil Load: $E2_{resistUN3} := \frac{K_o \cdot t_{tf.UN3}^{2}}{2} \cdot (\gamma_r - \gamma_w) \cdot W_b = 589.5 \cdot kN$ $\quad E2_{resistUN3} := 0$

Acting at: $E2_{resistlocUN3} := \frac{t_{tf.UN3}}{3} = 1.17\,m$

(Expansion Joint to Stilling Basin, No Sediment in Gap)

$\Sigma H_{soil.UN3} := E1_{drive.UN3} + E2_{resistUN3} = -1732.5 \cdot kN$

$\Sigma M_{soil.UN3} := E1_{drive.UN3} \cdot E1_{drive.loc.UN3} + E2_{resistUN3} \cdot E2_{resistlocUN3} = -866.2 \cdot kN \cdot m$

ICE / IMPACT LOADS (CONSERVATIVELY ASSUME NO ICE LOADING ON DOWNSTREAM SIDE)

ICE / IMPACT LOADS NOT APPLIED TO THIS LOAD CASE

Static Impact Loading on Structure: $I_{S.UN3} := 0.0 \frac{kN}{m}$ (Section 7.7, Design Criteria)

Static Impact load on Gates: $I_{G.UN3} := 0.0 \frac{kN}{m}$ (Section 7.7, Design Criteria)

Impact Loading Unit Width on Structure: $W_{S.UN3} := 0m$

Impact Loading Unit Width on Gates: $W_{G.UN3} := 0m = 0.00$

Total Impact Load on Structure: $I_{UN3} := (I_{S.UN3} \cdot W_{S.UN3} + I_{G.UN3} \cdot W_{G.UN3}) \cdot -1 = 0 \cdot kN$

Apply Ice load at: $I_{UN3.loc} := (HW_{UN3} - BOF_{elev} - 0.30m) = 12.70\,m$

$\Sigma H_{I.UN3} := I_{UN3} = 0 \cdot kN$

$\Sigma M_{I.UN3} := I_{UN3} \cdot I_{UN3.loc} = 0 \cdot kN \cdot m$

SEISMIC LOAD (Not Applicable to this Load Case)

UN3 CASE

SUMMARY OF LOADS

	Loads	Moment Arm
Dead Load of Concrete Structure:	$D_{conc} = 25408.2 \cdot kN$	$X_{conc.loc} = 12.71\,m$
Dead Load of Gate:	$D_{Gate} = 580.0 \cdot kN$	$X_{gate} = 8.75\,m$
Headwater Lateral Load on Gate:	$H_{hwg.UN3} = 0.0 \cdot kN$	$H_{hwg.UN3.loc} = 7.83\,m$
Headwater Lateral Load on Footing:	$H_{hwf.UN3} = -8166.8 \cdot kN$	$H_{hwf.UN3.loc} = 1.74\,m$
Tailwater Lateral Load:	$H_{twf.UN3} = 721.0 \cdot kN$	$H_{twf.UN3.loc} = -0.33\,m$
Water Weight (HW) on Apron Slab:	$H_{1.UN3} = 5109.0 \cdot kN$	$H_{1.UN3.loc} = 21.10\,m$
Water Weight (HW) on Fixed Crest:	$H_{2.UN3} = 4910.1 \cdot kN$	$H_{2.UN3.loc} = 14.25\,m$
Water Weight (TW) on Fixed Crest:	$H_{3.UN3} = 0.0 \cdot kN$	$H_{3.UN3.loc} = 0.00\,m$
Uplift:	$U_{UN3} = -23502.8 \cdot kN$	$U_{UN3.loc} = 14.42\,m$
Upstream (driving) Lateral Soil Load:	$E1_{drive.UN3} = -1732.5 \cdot kN$	$E1_{drive.loc.UN3} = 0.50\,m$
Downstream (resisting) Lateral Soil Load:	$E2_{resistUN3} = 0 \cdot kN$	$E2_{resistlocUN3} = 1.17\,m$
Ice / Impact Load:	$I_{UN3} = 0.0 \cdot kN$	$I_{UN3.loc} = 12.70\,m$

STABILITY ASSESSMENT (SLIDNG, OVERTURNING AND BEARING): UN3 CASE

CHECK SLIDING ALONG HORIZONTAL PLANE THRU TOE,
IGNORING BEDROCK MOBILIZED BY STRUCTURAL HEEL KEY , OR VOID BEHIND KEY

Sum of Vertical Forces:

$\Sigma V_{UN3} := \Sigma V_{DL.UN3} + \Sigma V_{water.UN3} = 12272.6 \cdot kN$

Sum of Horizontal Forces:

$\Sigma H_{UN3} := \Sigma H_{Water.UN3} + \Sigma H_{soil.UN3} + \Sigma H_{I.UN3} = -9178.3 \cdot kN$

Sliding Factor of Safety:

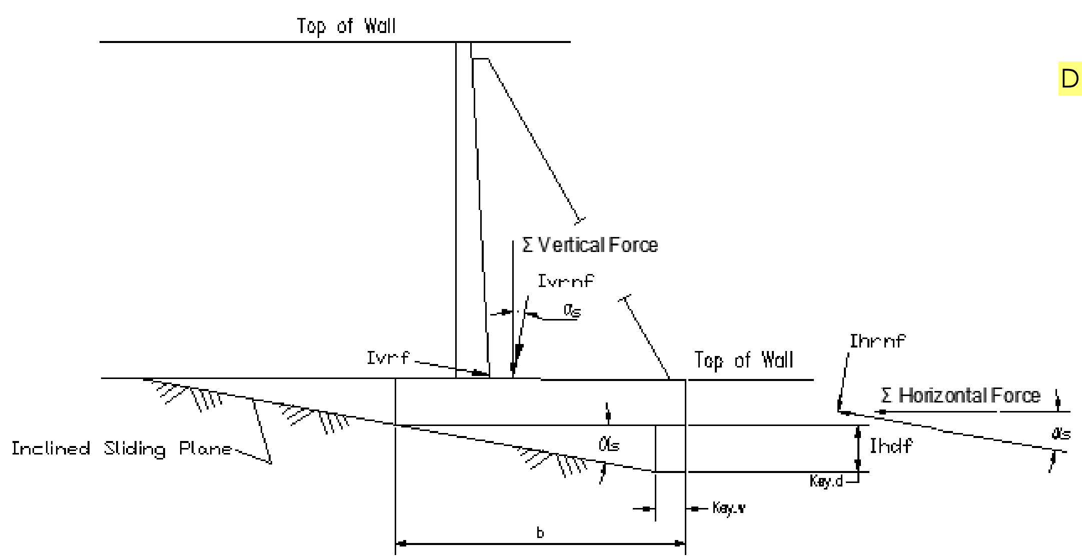
$$FS_{HorizSliding.UN3} := \frac{\left(\tan_{\phi} \cdot \Sigma V_{UN3}\right)}{\left|\Sigma H_{UN3}\right|} = 0.65$$

$$FS_{HorizSliding.UN3.Check} := \begin{cases} \text{"OKAY"} & \text{if } FS_{HorizSliding.UN3} \geq FS_{req.UN3.sl} \\ \text{"Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !"} & \text{otherwise} \end{cases}$$

$FS_{HorizSliding.UN3.Check} =$ "Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !"

CHECK SLIDING ALONG INCLINED SLIDING PLANE FROM HEEL KEY TO TOE,
WITH BEDROCK MASS MOBILIZED BY REINFOCREDE CONCRETE KEY)

RESISTING SIDE | DRIVING SIDE



TOE | HEEL

Ivrf=Inclined Resisting Force
Ivrnf=Inclined Resisting Normal Force
Ihrnf=Inclined Resisting Normal Force
Ihdf=Inclined Driving Force

$$\alpha s := \operatorname{atan}\left(\frac{BOF_{toe} - BOF_{elev}}{L_b - Key_l}\right) = 0.12 \qquad \text{as degrees=} \quad \alpha s \cdot \left(\frac{180}{\pi}\right) = 7.01$$

Resolve $\Sigma Vert_{UN3}$ & $\Sigma Horiz_{UN3}$

$$\Sigma V_{InclinedUN3} := \cos(\alpha s) \cdot \left(\Sigma V_{UN3} + V_{rs}\right) + \sin(\alpha s) \cdot \left|\Sigma H_{UN3}\right| = 25589.9 \cdot kN$$

$$\Sigma H_{InclinedUN3} := \cos(\alpha s) \cdot \left|\Sigma H_{UN3}\right| - \sin(\alpha s) \cdot \left(\Sigma V_{UN3} + V_{rs}\right) = 6101.1 \cdot kN$$

(With properly engineered reinforced concrete Key, horizontal sliding plane thru Toe is protected, critical sliding plane is relocated to the INCLINED SLIDING PLANE FROM HEEL KEY To TOE, Bedrock Mass above this examing plane is mobilized by reinforced concrete key and combined into Structural Wedge.)

Inclined Sliding Plane Length $\quad L_{incline} = 24.2\,m$

Safety Factor for Sliding
Inclined Failure Plane

$$FS_{InclinedISlidingUN3} := \frac{\Sigma V_{InclinedUN3} \cdot \tan\left(\phi_{rock} \cdot \frac{\pi}{180}\right)}{\left|\Sigma H_{InclinedUN3}\right|} = 2.05$$

$$FS_{InclinedSliding.UN3.check} := \begin{cases} \text{"OKAY "} & \text{if } FS_{InclinedISlidingUN3} > FS_{req.UN3.sl} \\ \text{"Revise Structure""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

$FS_{InclinedSliding.UN3.check} =$ "OKAY "

CHECK ECCENTRICITY ON INCLINED PLANE

UN3 CASE

Sum of the Moments:

$$\Sigma M_{rs.UN3} := \Sigma M_{DL.UN3} + \Sigma M_{HWater.UN3} + \Sigma M_{Vwater.UN3} + \Sigma M_{I.UN3} + \Sigma M_{soil.UN3} + V_{rs} \cdot L_{rs} = 320388 \cdot kN \cdot m$$

Eccentricity:

$$e_{UN3} := \frac{L_{incline}}{2} - \frac{\Sigma M_{rs.UN3}}{\Sigma V_{InclinedUN3}} = -0.40\,m$$

Eccentricity Check:

$$e_{check.UN3} := \begin{cases} \text{"Okay"} & \text{if } \left|e_{UN3}\right| \le Kern \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$$e_{check.UN3} = \text{"Okay"}$$

Foundation Bearing Pressures on Inclined Plane:

Bearing Pressure at Heel:

$$\sigma_{heel.UN3} := \frac{\Sigma V_{InclinedUN3}}{\frac{A_b}{\cos(\alpha s)}} - \frac{\Sigma V_{InclinedUN3} \cdot e_{UN3}}{\frac{S_b}{\cos(\alpha s)^2}} = 96 \cdot \frac{kN}{m^2}$$

$$\sigma_{heel.UN3.check} := \left(\begin{cases} \text{"Okay"} & \text{if } \sigma_{heel.UN3} \le \sigma_{allow.UN3} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} \right)$$

$$\sigma_{heel.UN3.check} = \text{"Okay"}$$

Bearing Pressure at Toe:

$$\sigma_{toe.UN3} := \frac{\Sigma V_{InclinedUN3}}{\frac{A_b}{\cos(\alpha s)}} + \frac{\Sigma V_{InclinedUN3} \cdot e_{UN3}}{\frac{S_b}{\cos(\alpha s)^2}} = 78.9 \cdot \frac{kN}{m^2}$$

$$\sigma_{toe.UN3.check} := \begin{cases} \text{"Okay"} & \text{if } \sigma_{toe.UN3} \le \sigma_{allow.UN3} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$$\sigma_{toe.UN3.check} = \text{"Okay"}$$

CHECK FLOTATION

$$Uplift_{sliding.UN3} := U_{UN3} = -23502.8 \cdot kN$$

$$Uplift_{pore.UN3} = -16740.1 \cdot kN$$

$$\left(Uplift_{UN3}\right) := \min\left(Uplift_{pore.UN3}, Uplift_{sliding.UN3}\right)$$

(For conservative, taking maximum values)

$$FS_{Flotation.UN3} := \frac{D_{conc} + D_{Gate} + H_{1.UN3} + H_{2.UN3} + H_{3.UN3}}{\left|Uplift_{UN3}\right|} = 1.5$$

$$FS_{Flotation.UN3.check} := \begin{cases} \text{"OKAY "} & \text{if } FS_{Flotation.UN3} > FS_{req.UN.flt} \\ \text{"Revise Structure""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

MONOLITH OVERTURNING STABILITY ANALYSIS

UN3 CASE

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.
Assumptions are made in order to compute overturning stability of indetermine forces on monolith with key;
(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.
(b) The horizontal resisting force acting on the key, P.key, is that required for static equilibrium
(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1

$Ratio_{overturning.allow.Unusual} = 0.333$ (Resultant within Middle Third)

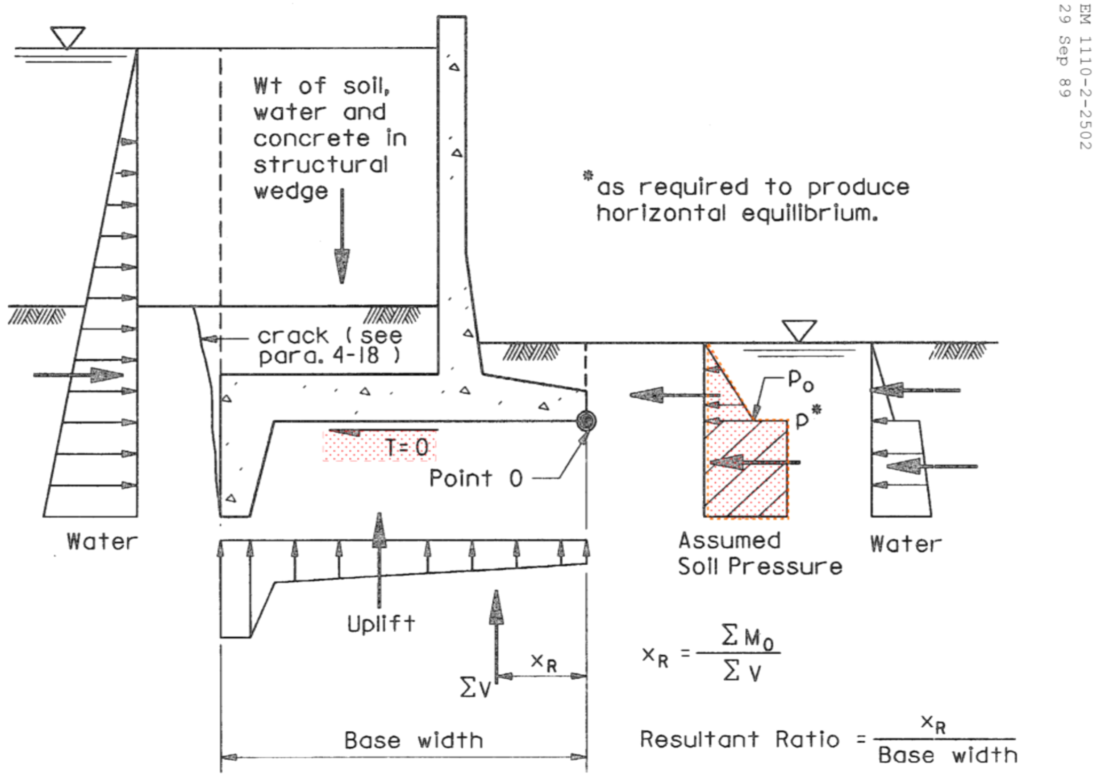


Figure 4-5. Forces for overturning analysis for wall with horizontal base and key

All Vertical Loads Applicable to Overturning Stability Analysis

Total Concrete Dead Loads:	$D_{conc} = 25408.2 \cdot kN$	at:	$X_{conc.loc} = 12.7\,m$
Dead Load of Gate:	$D_{Gate} = 580.0 \cdot kN$		$X_{gate} = 8.75\,m$
Water Weight (HW) on Apron Slab:	$H_{1.UN3} = 5109.0 \cdot kN$		$H_{1.UN3.loc} = 21.10\,m$
Water Weight (HW) on Fixed Crest:	$H_{2.UN3} = 4910.1 \cdot kN$		$H_{2.UN3.loc} = 14.25\,m$
Water Weight (TW) on Fixed Crest:	$H_{3.UN3} = 0.0 \cdot kN$		$H_{3.UN3.loc} = 0.00\,m$

Uplift Force from Sliding Analysis. Line of Creep Method applied at presumed inclined sliding line, and subtraction gravity effect to Base of Concrete by Archimedes Principle

$$U_{UN3.loc.sliding} := \frac{U_{A.UN3} \cdot L_{A.UN3} + U_{B.UN3} \cdot L_{B.UN3} - A_{rs} \cdot w_{as} \cdot \gamma_w \cdot L_{rs}}{U_{A.UN3} + U_{B.UN3} - A_{rs} \cdot w_{as} \cdot \gamma_w} = 14.31\ m$$

$$U_{UN3.sliding} := U_{UN3} + A_{rs} \cdot w_{as} \cdot \gamma_w = -17981.7 \cdot kN$$

UN3 CASE

Uplift for Overturning Analysis, Line of Creep Method. Pore pressure at base of Concrete

$$Uplift_{pore.UN3} = -16740.1 \cdot kN$$

$$Uplift_{pore.UN3.loc} := \frac{Uplift_{BC.UN3} \cdot Uplift_{BC.UN3.loc} + Uplift_{DE.UN3} \cdot Uplift_{DE.UN3.loc} \cdots + Uplift_{EF.UN3} \cdot Uplift_{EF.UN3.loc} + Uplift_{FG.UN3} \cdot Uplift_{FG.UN3.loc}}{Uplift_{pore.UN3}} = 14.1\,m$$

Sum of All Water Load for Overturning Analysis

$$\Sigma V_{water.UN3.OT} := H_{1.UN3} + H_{2.UN3} + H_{3.UN3} + Uplift_{pore.UN3} = -6720.9 \cdot kN$$

All Lateral Loads Applicable to Overturning Stability Analysis

Apply Load to Gate?: $poss_{UN3} = 1$ poss = 1 if gate is closed, 0 if gate is open

Headwater Lateral Load on Gate: $H_{hwg.UN3} = 0.0 \cdot kN$ $H_{hwg.UN3.loc} = 7.83\,m$

Headwater Lateral Load on Footing: $H_{hwf.UN3} = -8166.8 \cdot kN$ $H_{hwf.UN3.loc} = 1.74\,m$

Total Horizontal Tailwater Load on Footing under Gate Openings, i.e., excluding Pier: $H_{twf.UN3} = 721.0 \cdot kN$ $H_{twf.UN3.loc} = -0.33\,m$

Resisting Water on Rear Face of Monolith, i.e., bottom of heel elevation:

(Point O @ TOE: BOFtoe = EL.1205.5)

Ice / Impact Load: $I_{UN3} = 0.0 \cdot kN$ at: $I_{UN3.loc} = 12.70\,m$

Depth of Fill at Heel Side for Overturning Analysis: $t_{hf.UN3} := TOC_{as} - BOF_{toe} = 4.50\,m$

Driving Soil Load for overturning: $E1_{drive.UN3} := \frac{K_o \cdot t_{hf.UN3}^2}{2} \cdot (\gamma_r - \gamma_w) \cdot W_b \cdot -1 = -974.5 \cdot kN$

Acting at: $E1_{drive.loc.UN3} := \frac{t_{hf.UN3}}{3} = 1.50\,m$

Downstream (resisting) Lateral Soil Load as required to produce horizontal equilibrium:

$$E2_{resistUN3} := -1 \cdot (H_{hwg.UN3} + H_{hwf.UN3} + H_{twf.UN3} + I_{UN3} + E1_{drive.UN3})$$

$$E2_{resistUN3} = 8420.3 \cdot kN$$

Assumed Resisting Bedrock at middle of Key, passive soil pressure or lateral bearing on contract joint at end of Monolith 3A3B: $E2_{resistlocUN3} := E2_{resistlocU1} = -0.75\,m$

Overturning moment by Dead Loads about Point O @ Toe: $\Sigma M_{DL.UN1} = 322889.4 \cdot kN \cdot m$

Overturning moment by Vertical Water Loads and Uplift, about Point O @ Toe

$$\Sigma M_{Vwater.UN3.OT} := H_{1.UN3} \cdot H_{1.UN3.loc} + H_{2.UN3} \cdot H_{2.UN3.loc} + H_{3.UN1} \cdot H_{3.UN3.loc} + Uplift_{pore.UN3} \cdot Uplift_{pore.UN3.loc} = -58253.1 \cdot kN \cdot m$$

Overturning moment by Lateral Hydrostatic Forces of Headwater Pool and Tailwater Pool,about Point O @ Toe: $\Sigma M_{HWater.UN3} = -14477.1 \cdot kN \cdot m$

Overturning Moment by Impact/Ice Load, about Point O@ Toe: $\Sigma M_{I.UN3} = 0$

Overturning moment by Lateral Soil Forces
about Point O @ Toe

$$\Sigma M_{soil.UN3} := E1_{drive.UN3} \cdot E1_{drive.loc.UN3} + E2_{resistUN3} \cdot E2_{resistlocUN3} = -7777 \cdot kN \cdot m$$

Sum of the Overturning Moments about Point O @ Toe:

$$\Sigma M_{UN3.OT} := \Sigma M_{DL.UN3} + \Sigma M_{HWater.UN3} + \Sigma M_{Vwater.UN3.OT} + \Sigma M_{I.UN3} + \Sigma M_{soil.UN3} = 245427 \cdot kN \cdot m$$

Sum of Vertical Forces: $\Sigma V_{UN3.OT} := \Sigma V_{DL.UN3} + \Sigma V_{water.UN3.OT} = 19035.3 \cdot kN$

Distance X_R: EM 1110-2-2502 Eq.4-1 $X_{R.UN3} := \dfrac{\Sigma M_{UN3.OT}}{\Sigma V_{UN3.OT}} = 12.9\,m$

Overturning Resultant Ratio $Ratio_{Overturning.UN3} := \dfrac{X_{R.UN3}}{L_b} = 0.53$

EM 1110-2-2502

Table 4-1

Retaining Wall Stability Criteria

Loading Condition	Sliding Factor of Safety, FS	Shear Strength Test Required: Soil Foundation	Shear Strength Test Required: Rock Foundation[3]	Overturning Criteria Minimum Base Area in Compression: Soil Foundation	Overturning Criteria Minimum Base Area in Compression: Rock Foundation
Usual	1.5	(Q &/or S)[2,1]	Direct shear	100%[4]	75%[4]
Unusual	1.33	(Q &/or S)[2,1]	Direct shear	75%[4]	50%[4]
Earthquake	1.1	(Q)	Direct shear	Resultant within base	Resultant within base

Overturning Stability Check

$$Ratio_{Overturning.UN3.check} := \begin{cases} \text{"Okay"} & \text{if } Ratio_{Overturning.UN3} \ge Ratio_{overturning.allow.Unusual} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$Ratio_{Overturning.UN3.check} = \text{"Okay"}$

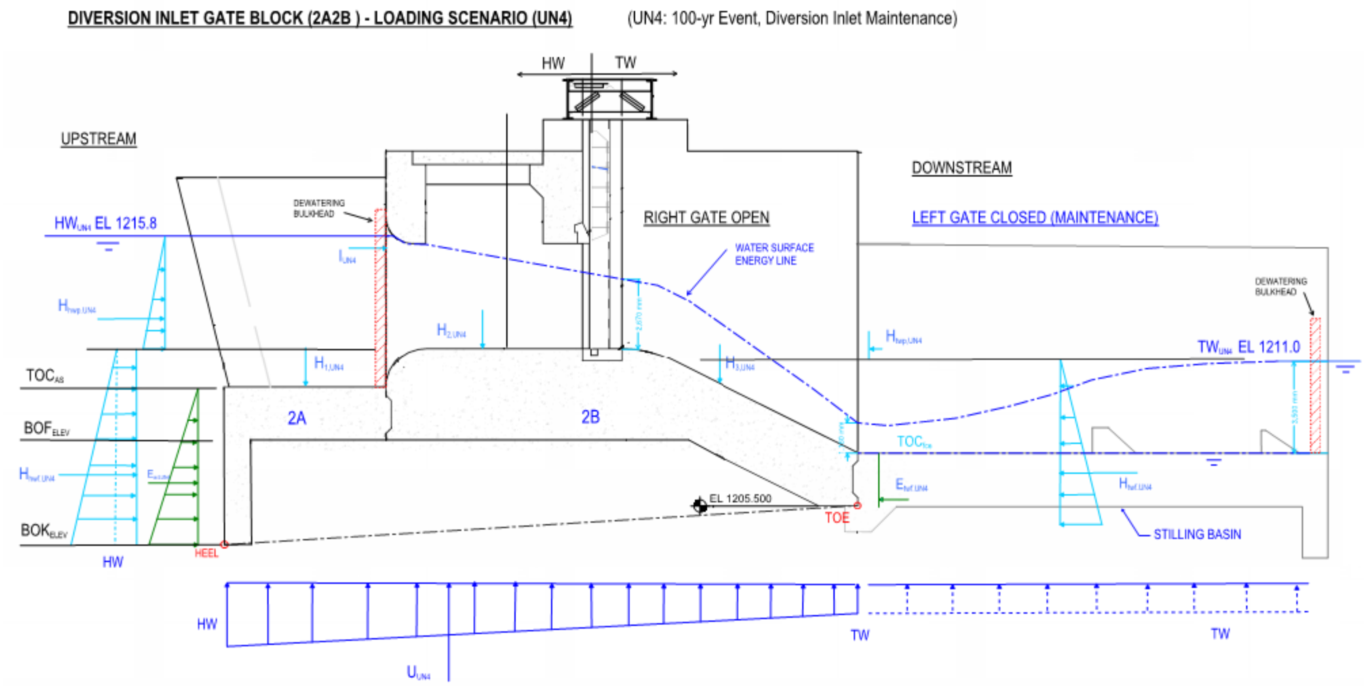
UN3 CASE

Summary of Extreme Flood Results (Only Report Controlling Load Case)

UN3 Event: No Diversion, 1000 Yr.Flood

Horiz Sliding Factor of Safety:	$FS_{HorizSliding.UN3} = 0.65$
Horiz Sliding Factor of Safety Check:	$FS_{HorizSliding.UN3.Check}$ = "Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !"
Sliding Factor of Safety:	$FS_{InclinedlSlidingUN3} = 2$
Sliding Factor of Safety Check:	$FS_{InclinedSliding.UN3.check}$ = "OKAY "
Eccentricity:	$e_{UN3} = -0.40\,m$
Eccentricity Check:	$e_{check.UN3}$ = "Okay"
Bearing Pressure At Heel:	$\sigma_{heel.UN3} = 96 \cdot \frac{kN}{m^2}$
Bearing Pressure At Heel Check:	$\sigma_{heel.UN3.check}$ = "Okay"
Bearing Pressure At Heel:	$\sigma_{toe.UN3} = 78.9 \cdot \frac{kN}{m^2}$
Bearing Pressure At Toe Check:	$\sigma_{toe.UN3.check}$ = "Okay"
Flotation Factor of Safety	$FS_{Flotation.UN3} = 1.5$
Flotation Factor of Safety Check:	$FS_{Flotation.UN3.check}$ = "OKAY "
Overturning Resultant Ratio	$Ratio_{Overturning.UN3} = 0.53$
Overturning Stability Check	$Ratio_{Overturning.UN3.check}$ = "Okay"

UN4 DESIGN CASE



This load case is the Construction / Maintenance / Single Gate Bay Dewatered Load Case. One vertical lift gate is open, while the other has been removed for maintenance, and bulkheads in place to dewater one gate bay at a time. Calculation highlighted in Orange where calculation which differ from Load Case UN1 procedures.

ACCEPTANCE PARAMETERS

Required Factor of Safety for Sliding: $FS_{req.UN4.sl} := 1.3$ (Without Cohesion) (Section 8.1, Design Criteria)

Resultant Within Middle Third of Base: $e \le \frac{L_b}{6} \wedge e \ge \frac{-L_b}{6}$

Allowable Rock Bearing Pressure: $\sigma_{allow.UN4} := 1470.0 \cdot \frac{kN}{m^2}$ (Section 5.2, Design Criteria)

Required Factor of Safety for Flotation: $FS_{req.UN.flt} = 1.3$

Overturning Min Required Resultant Ratio: $\frac{X_{R.UN}}{\text{Horizontal Width of Base}} > 0.333$

(100% Base in Compression, Resultant within Middle Third)

INPUT PARAMETERS

Headwater Elevation: $HW_{UN4} := 1215.80m$

Tailwater Elevation: $TW_{UN4} := 1211.10m$

(Water Elevations based on Diversion Structure 2D Hydraulic Model Results. See page 6 and Section 8.2, Design Criteria)

Crest Water Elevation, EL.1215.81 $CrestW_{UN4} := 2.87 \cdot m$

Chute Block Water Elevation EL.1208.78 $ChuteW_{UN4} := 1.28 \cdot m$ $TW_{UN4} := TOC_{fce} + ChuteW_{UN4} = 1208.8\,m$

Bottom of Key (Footing Heel) Elevation: $BOF_{elev} = 1204.00\,m$

Apron Slab Top of Concrete Elevation at Edge of Slab: $TOC_{as} = 1210.00\,m$

Fixed Crest Top of Concrete Elevation at Downstream Face: $TOC_{fce} = 1207.50\,m$

Fixed Crest Top of Concrete Elevation at Center of Footing: $TOC_{fcc} = 1211.50\,m$

UN4 CASE

Lift Gate Position per Hydraulic Criteria

$poss_{UN4} := 0$ poss = 1 if gate is closed
0 if gate is open

$Gate_{R.UN4} := 0.60 = 0.6$

Monolith Reaction for Lift Gate
UN4 - Maintenance one DI channel dewatered, while another DI channel open to tailwater pool

$\Sigma V_{DL.UN4} := D_{conc} + Gate_{R.UN4} D_{Gate} = 25756.2 \cdot kN$

$\Sigma M_{DL.UN4} := D_{conc} \cdot X_{conc.loc} + Gate_{R.UN4} \cdot D_{Gate} \cdot X_{gate} = 325934.4 \cdot kN \cdot m$

VERTICAL LIFT GATE

Dead Load of Vertical Lift Gate:

$D_{Gate.UN4} := \dfrac{D_{Gate} \cdot 4.5 \cdot m \cdot 2}{20 \cdot m} = 261.0 \cdot kN$

(Drawing Q-202 dated 03-31-2017, Gate on Sill)

Distance from Toe to COG of Gate:

$X_{gate.UN4} := 9.75 \cdot m$

Distance from Base to Centroid of Vertical Lift Gate:

$Y_{gate.UN4} := 7.0m$

Distance from base to halfway between the bottom of the headwall and the top of the Fixed Crest.

DEAD LOAD SUMMATION:

$\Sigma V_{DL.UN4} := D_{conc} + D_{Gate.UN4} = 25669.2 \cdot kN$

$\Sigma M_{DL.UN4} := D_{conc} \cdot X_{conc.loc} + D_{Gate.UN4} \cdot X_{gate.UN4} = 325434.2 \cdot kN \cdot m$

LATERAL WATER LOADS

HEADWATER (DRIVING):

Water Depth Above Fixed Crest at Gate: $D_{hwg.UN4} := HW_{UN4} - TOC_{fcc} = 4.3\,m$

Water Load Unit Width on Gate $W_{hwg.UN4} := 0 = 0.00$

Apply Load to Gate?: $poss_{UN4} = 0$

poss = 1 if gate is closed
0 if gate is open

Total Horizontal Water Load on Gate:

$H_{hwg.UN4} := \dfrac{-\left(\gamma_w \cdot D_{hwg.UN4}^{\;2}\right)}{2} \cdot W_{hwg.UN4} = 0 \cdot kN$

Apply Total Gate Water Load at:

$H_{hwg.UN4.loc} := \dfrac{D_{hwg.UN4}}{3} + \left(TOC_{fcc} - BOF_{toe}\right) = 7.43\,m$

Water Depth at Heel: $D_{hwf.UN4} := HW_{UN4} - BOF_{elev} = 11.80\,m$

Water Load Unit With on Footing: $W_{hw.UN4} := W_b$

Water Load at Bottom of Footing:

$H_{hwf.UN4.1} := -\left(\gamma_w \cdot D_{hwf.UN4}\right) \cdot W_{hw.UN4} = -1389.1 \dfrac{1}{m} \cdot kN$

Water Load at Top of Footing:
Total Horizontal Water Load on Footing:

$H_{hwf.UN4} := \dfrac{\left(H_{hwf.UN4.1} + H_{hwf.UN4.2}\right) \cdot \left(D_{hwf.UN4} - D_{hwg.UN4}\right)}{2} = -7107.3 \cdot kN \; UN4) \cdot W_{hw.UN4} = -506.2 \dfrac{1}{m} \cdot kN$

Apply Total Footing Water Load at:

$$H_{hwf.UN4.loc} := \frac{\left[H_{hwf.UN4.2} \cdot \dfrac{\left(TOC_{fcc} - BOF_{elev}\right)^2}{2} + \dfrac{\left(H_{hwf.UN4.1} - H_{hwf.UN4.2}\right)}{2} \cdot \dfrac{\left(TOC_{fcc} - BOF_{elev}\right)^2}{3}\right]}{\dfrac{\left(H_{hwf.UN4.2} + H_{hwf.UN4.1}\right) \cdot \left(TOC_{fcc} - BOF_{elev}\right)}{2}} - \left(BOF_{toe} - BOF_{elev}\right) = 1.67\,m$$

Converting horizontal force resultant from HEEL calculation to Point-O@TOE

LATERAL WATER LOADS (cont.)

UN4 CASE

TAILWATER (RESISTING):

Water Depth at toe: $D_{tw.UN4} := TW_{UN4} - BOF_{elev} = 4.78\,m$

Water Load Unit Width: $W_{twf.UN4} := W_b$

Total Horizontal Tailwater Load on Footing under Gate Openings, i.e., excluding Pier

Resisting Water on Rear Face of Monolith, i.e., bottom of heel elevation:

$COND_{UN4} := poss_{UN4} = 0 \wedge TW_{UN4} \geq TOC_{fcc}$

$$H_{twf.UN4} := \begin{cases} \frac{\gamma_w \cdot D_{tw.UN4}^2}{2} \cdot \left(W_{twf.UN4}\right) & \text{if } poss_{UN4} = 1 \\ \frac{\gamma_w \cdot D_{tw.UN4}^2}{2} \cdot \left(W_{twf.UN4}\right) & \text{if } poss_{UN4} = 0 \wedge TW_{UN4} \leq TOC_{fcc} \\ \gamma_w \cdot \left[\frac{D_{tw.UN4}}{2} + \frac{\left(TW_{UN4} - TOC_{fcc}\right)}{2}\right] \cdot \left(TOC_{fcc} - BOF_{elev}\right) \cdot \left(W_{twf.UN4}\right) & \text{if } COND_{UN4} \end{cases} = 1344.9 \cdot kN$$

Apply Footing Tailwater Load within Gate Openings at:

$$H_{twf.UN4.loc} := \begin{cases} \frac{D_{tw.UN4}}{3} - \left(BOF_{toe} - BOF_{elev}\right) & \text{if } poss_{UN4} = 1 \\ \frac{D_{tw.UN4}}{3} - \left(BOF_{toe} - BOF_{elev}\right) & \text{if } poss_{UN4} = 0 \wedge TW_{UN4} \leq TOC_{fcc} \\ \frac{\left(TOC_{fcc} - BOF_{elev}\right)^2 \cdot \left[\frac{D_{tw.UN4}}{2} + \frac{\left(\left(TOC_{fcc} - BOF_{elev}\right)\right)}{6}\right]}{\left(TOC_{fcc} - BOF_{elev}\right)\left[\left(TW_{UN4} - TOC_{fcc}\right) + \frac{\left(TOC_{fcc} - BOF_{elev}\right)}{2}\right]} - \left(BOF_{toe} - BOF_{elev}\right) & \text{if } COND_{UN4} \end{cases} = 0.09 \cdot m$$

$\Sigma H_{Water.UN4} := H_{hwg.UN4} + H_{hwf.UN4} + H_{twf.UN4} = -5762.5 \cdot kN$

$$\Sigma M_{HWater.UN4} := H_{hwg.UN4} \cdot H_{hwg.UN4.loc} + H_{hwf.UN4} \cdot H_{hwf.UN4.loc} \cdots + H_{twf.UN4} \cdot H_{twf.UN4.loc} = -11727.4 \cdot kN \cdot m$$

VERTICAL WATER LOADS

UN4 CASE

HEADWATER:

Water Depth on top of fixed crest: $d_{hw.UN4} := HW_{UN4} - TOC_{as} = 5.80\,m$

Weight of Water (H1) on Approach Slab: $H_{1.UN4} := \left(W_{hw.UN4} \cdot d_{hw.UN4} \cdot L_{as}\right) \cdot \gamma_w = 4233.2 \cdot kN$

Horiz. Moment Arm for H1 (from toe): $H_{1.UN4.loc} := L_b - \dfrac{L_{as}}{2} = 21.10\,m$

Cross-sectional Area of
Headwater Above Fixed Crest: $A_{fc.hw.UN4} := 29.10m^2$

(From Bluebeam Measurement, Bound by Energy Line through Crest Water Elevation CrestW and Chute Block Water Elevation ChuteW as defined above)

Volume of water Above Fixed Crest: $V_{fc.hw.UN4} := \left(A_{fc.hw.UN4} \cdot W_{hw.UN4}\right) = 349.2 \cdot m^3$

Weight of Water (H2) on Fixed Crest: $H_{2.UN4} := \left(V_{fc.hw.UN4}\right) \cdot \dfrac{\gamma_w}{2} = 1712.8 \cdot kN$

Divide by 2 since one one side of pier is dewatered

Horiz. Moment Arm for H2 (from toe): $H_{2.UN4.loc} := 14.25 \cdot m$ (From Bluebeam Measurement)

TAILWATER:

Slope of Crest from
D/S of Gate to edge of Stilling Basin: $S_{f.UN4} := S_{f.U1} = 0.500$

Height of Tailwater Above Stilling Basin: $y_{UN4} := TW_{UN4} - TOC_{fce} = 1.3\,m$

Cross Sectional Area of Tailwater
Above Sloped Portion of Crest: $A_{tw.UN4} := 23.86 \cdot m \cdot m = 23.9\,m^2$

(From Bluebeam Measurement, Bound by Energy Line through Crest Water Elevation CrestW and Chute Block Water Elevation ChuteW as defined above)

Weight of Water (H3)
Above Slope Portion of Crest: $H_{3.UN4} := \left(A_{tw.UN4} \cdot W_{twf.UN4}\right) \cdot \gamma_w$ $H_{3.UN4} = 2808.8 \cdot kN$

Horiz. Moment Arm for H3 (from Toe): $H_{3.UN4.loc} := 5.780 \cdot m$ (From Bluebeam Measurement)

UPLIFT AT INCLINED SLIDING PLANE

UN4 CASE

Uplift pressure at Headwater: $U_{HW.UN4} := D_{hwf.UN4} \cdot \gamma_w = 115.76 \cdot \frac{kN}{m^2}$

Uplift pressure at D/S end of Stilling Basin: $U_{TW.UN4} := D_{tw.UN4} \cdot \gamma_w = 46.9 \cdot \frac{kN}{m^2}$

Length from U/S Face of Gate Structure to Toe Point(Effective Drain at end of Monolith) $L_{overall} = 24.20\,m$ $L_{sb} = 0$

Length of Seepage per Line of Creep $L_{seepage} = 27.1\,m$

Difference between Uplift pressure at Headwater and Uplift Pressure at Toe of Stilling Basin: $U_{diffUN4} := U_{HW.UN4} - U_{TW.UN4} = 68.9 \cdot \frac{kN}{m^2}$

Slope of difference between Uplift pressure at Headwater and Uplift Pressure at Toe of Stilling Basin: $U_{slopeUN4} := \frac{U_{diffUN4} - Key_d \cdot \gamma_w}{L_{overall}} = 2.24 \cdot \frac{kN}{m^2 \cdot m}$

$$U_{seepageslopeUN4} := \frac{U_{diffUN4} - Key_d \cdot \gamma_w}{L_{seepage}}$$

Tailwater Pressure at toe of Gate Structure: $U_{press.toe.gsUN4} := U_{TW.UN4} + L_{sb} \cdot U_{slopeUN4} = 46.9 \cdot \frac{kN}{m^2}$

$$U_{pore.toe.UN4} := U_{TW.UN4} + U_{seepageslopeUN4} \cdot L_{sb} = 46.9 \cdot \frac{kN}{m^2}$$

$$U_{pore.F.UN4} := U_{pore.toe.UN4} + U_{seepageslopeUN4} \cdot L_{FG} = 49.9 \cdot \frac{kN}{2}$$

$$U_{pore.E.UN4} := U_{pore.F.UN4} - \left(BOF_{base} - BOF_{toe}\right) \cdot \gamma_w + U_{seepageslopeUN4} \cdot L_{EF} = 41.9 \cdot \frac{kN}{m^2}$$

$$U_{pore.D.UN4} := U_{pore.E.UN4} + U_{seepageslopeUN4} \cdot L_{DE} = 78.3 \cdot \frac{kN}{m^2}$$

$$U_{pore.C.UN4} := U_{pore.D.UN4} + \left(BOF_{base} - BOF_{elev}\right) \cdot \gamma_w + U_{seepageslopeUN4} \cdot L_{CD} = 113.8 \cdot \frac{kN}{m^2}$$

Uniform uplift due to Tailwater: (rectangular portion) $U_{A.UN4} := U_{press.toe.gsUN4} \cdot L_b \cdot W_b \cdot -1 = -13617.4 \cdot kN$

Moment Arm for Uplift UA from Toe of Gate Structure: $L_{A.UN4} := \frac{L_b}{2} = 12.10\,m$

Uplift - Linear Decrease from HW to TW: (triangular portion) $U_{B.UN4} := \frac{1}{2} \cdot \left(U_{HW.UN4} - U_{press.toe.gsUN4}\right) \cdot L_b \cdot W_b \cdot -1 = -9999.4 \cdot kN$

Moment Arm for Uplift UB from Toe of Gate Structure: $L_{B.UN4} := \frac{2}{3} \cdot L_b = 16.13\,m$

Total Resultant Uplift force: $U_{UN4} := U_{A.UN4} + U_{B.UN4} = -23616.8 \cdot kN$

Resultant Location from Toe: $U_{UN4.loc} := \frac{U_{A.UN4} \cdot L_{A.UN4} + U_{B.UN4} \cdot L_{B.UN4}}{U_{A.UN4} + U_{B.UN4}} = 13.81\,m$

UN4 CASE

$\Sigma V_{water.UN4} := H_{1.UN4} + H_{2.UN4} + H_{3.UN4} + U_{UN4} = -14861.9 \cdot kN$

$\Sigma M_{Vwater.UN4} := H_{1.UN4} \cdot H_{1.UN4.loc} + H_{2.UN4} \cdot H_{2.UN4.loc} + H_{3.UN4} \cdot H_{3.UN4.loc} + U_{UN4} \cdot U_{UN4.loc} = -196130.1 \cdot kN \cdot m$

Uplift as per Line of Creep Method
(Flotation and Overturning)

$$Uplift_{BC.UN4} := \frac{-1}{2} \cdot W_b \cdot \left(U_{HW.UN4} + U_{pore.C.UN4}\right) \cdot L_{BC} = -1377105\,N$$

$$Uplift_{CD.UN4} := 0$$

$$Uplift_{DE.UN4} := \frac{-1}{2} \cdot W_b \cdot \left(U_{pore.D.UN4} + U_{pore.E.UN4}\right) \cdot L_{DE} = -13120312\,N$$

$$Uplift_{EF.UN4} := \frac{-1}{2} \cdot W_b \cdot \left(U_{pore.E.UN4} + U_{pore.F.UN4}\right) \cdot L_{EF} = -1846129\,N$$

$$Uplift_{FG.UN4} := \frac{-1}{2} \cdot W_b \cdot \left(U_{pore.F.UN4} + U_{pore.toe.UN4}\right) \cdot L_{FG} = -871032.1\,N$$

$$Uplift_{pore.UN4} := Uplift_{BC.UN4} + Uplift_{DE.UN4} + Uplift_{EF.UN4} + Uplift_{FG.UN4} = -17214.6 \cdot kN$$

$$Uplift_{FG.UN4.loc} := \frac{L_{FG}}{3} \cdot \frac{\left(2 \cdot U_{pore.F.UN4} + U_{pore.toe.UN4}\right)}{\left(U_{pore.F.UN4} + U_{pore.toe.UN4}\right)} = 0.76\,m$$

$$Uplift_{EF.UN4.loc} := \frac{L_{EF}}{3} \cdot \frac{\left(2 \cdot U_{pore.E.UN4} + U_{pore.F.UN4}\right)}{\left(U_{pore.E.UN4} + U_{pore.F.UN4}\right)} + L_{FG} = 3.13\,m$$

$$Uplift_{DE.UN4.loc} := \frac{L_{DE}}{3} \cdot \frac{\left(2 \cdot U_{pore.D.UN4} + U_{pore.E.UN4}\right)}{\left(U_{pore.D.UN4} + U_{pore.E.UN4}\right)} + L_{FG} + X_{EF} = 14.52\,m$$

$$Uplift_{BC.UN4.loc} := \frac{L_{BC}}{3} \cdot \frac{\left(2 \cdot U_{HW.UN4} + U_{pore.C.UN4}\right)}{\left(U_{HW.UN4} + U_{pore.C.UN4}\right)} + L_{FG} + X_{EF} + L_{DE} = 23.20\,m$$

UN4 CASE

SOIL LOADS

Equivalent Fluid Pressure (EFP): (CFEM 24.1)

At rest lateral pressure coefficient: $K_o = 0.66$

At-rest Soil Pressure to Heel, EM1110--2-2502 Section 3-7

Lateral Driving Force (Headwater Side)

Depth of Fill at Heel: $t_{hf.UN4} := TOC_{as} - BOF_{elev} = 6.00\,m$

At-Rest Soil Load: $E1_{drive.UN4} := \frac{K_o \cdot t_{hf.UN4}^{\,2}}{2} \cdot (\gamma_r - \gamma_w) \cdot W_b \cdot -1 = -1732.5 \cdot kN$

Acting at: $E1_{drive.loc.UN4} := \frac{t_{hf.UN4}}{3} - (BOF_{toe} - BOF_{elev}) = 0.50\,m$

Lateral Resisting Force (Tailwater Side)

Depth of Fill at Toe: $t_{tf.UN4} := TOC_{fce} - BOF_{elev} = 3.50\,m$

At-Rest Soil Load: $E2_{resistUN4} := \frac{K_o \cdot t_{tf.UN4}^{\,2}}{2} \cdot (\gamma_r - \gamma_w) \cdot W_b = 589.5 \cdot kN$ $E2_{resistUN4} := 0$

Acting at: $E2_{resistlocUN4} := \frac{t_{tf.UN4}}{3} = 1.17\,m$ (Expansion Joint to Stilling Basin, No Sediment in Gap)

$\Sigma H_{soil.UN4} := E1_{drive.UN4} + E2_{resistUN4} = -1732.5 \cdot kN$

$\Sigma M_{soil.UN4} := E1_{drive.UN4} \cdot E1_{drive.loc.UN4} + E2_{resistUN4} \cdot E2_{resistlocUN4} = -866.2 \cdot kN \cdot m$

ICE / IMPACT LOADS (CONSERVATIVELY ASSUME NO ICE LOADING ON DOWNSTREAM SIDE)

ICE / IMPACT LOADS NOT APPLIED TO THIS LOAD CASE

Static Impact Loading on Structure: $I_{S.UN4} := 0.0 \frac{kN}{m}$ (Section 7.7, Design Criteria)

Static Impact load on Gates: $I_{G.UN4} := 0.0 \frac{kN}{m}$ (Section 7.7, Design Criteria)

Impact Loading Unit Width on Structure: $W_{S.UN4} := 0m$

Impact Loading Unit Width on Gates: $W_{G.UN4} := 0m = 0.00$

Total Impact Load on Structure: $I_{UN4} := (I_{S.UN4} \cdot W_{S.UN4} + I_{G.UN4} \cdot W_{G.UN4}) \cdot -1 = 0 \cdot kN$

Apply Ice load at: $I_{UN4.loc} := (HW_{UN4} - BOF_{elev} - 0.30m) = 11.50\,m$

$\Sigma H_{I.UN4} := I_{UN4} = 0 \cdot kN$

$\Sigma M_{I.UN4} := I_{UN4} \cdot I_{UN4.loc} = 0 \cdot kN \cdot m$

SEISMIC LOAD (Not Applicable to this Load Case)

UN4 CASE

SUMMARY OF LOADS

	Loads	Moment Arm
Dead Load of Concrete Structure:	$D_{conc} = 25408.2 \cdot kN$	$X_{conc.loc} = 12.71\,m$
Dead Load of Gate:	$D_{Gate.UN4} = 261.0 \cdot kN$	$X_{gate.UN4} = 9.75\,m$
Headwater Lateral Load on Gate:	$H_{hwg.UN4} = 0.0 \cdot kN$	$H_{hwg.UN4.loc} = 7.43\,m$
Headwater Lateral Load on Footing:	$H_{hwf.UN4} = -7107.3 \cdot kN$	$H_{hwf.UN4.loc} = 1.67\,m$
Tailwater Lateral Load on Footing:	$H_{twf.UN4} = 1344.9 \cdot kN$	$H_{twf.UN4.loc} = 0.09\,m$
Water Weight (HW) on Apron Slab:	$H_{1.UN4} = 4233.2 \cdot kN$	$H_{1.UN4.loc} = 21.10\,m$
Water Weight (HW) on Fixed Crest:	$H_{2.UN4} = 1712.8 \cdot kN$	$H_{2.UN4.loc} = 14.25\,m$
Water Weight (TW) on Fixed Crest:	$H_{3.UN4} = 2808.8 \cdot kN$	$H_{3.UN4.loc} = 5.78\,m$
Uplift:	$U_{UN4} = -23616.8 \cdot kN$	$U_{UN4.loc} = 13.81\,m$
Upstream (driving) Lateral Soil Load:	$E1_{drive.UN4} = -1732.5 \cdot kN$	$E1_{drive.loc.UN4} = 0.50\,m$
Downstream (resisting) Lateral Soil Load:	$E2_{resistUN4} = 0 \cdot kN$	$E2_{resistlocUN4} = 1.17\,m$
Ice / Impact Load:	$I_{UN4} = 0.0 \cdot kN$	$I_{UN4.loc} = 11.50\,m$

STABILITY ASSESSMENT (SLIDNG, OVERTURNING AND BEARING):

UN4 CASE

CHECK SLIDING ALONG HORIZONTAL PLANE THRU TOE,
IGNORING BEDROCK MOBILIZED BY STRUCTURAL HEEL KEY, OR VOID BEHIND KEY

Sum of Vertical Forces: $\Sigma V_{UN4} := \Sigma V_{DL.UN4} + \Sigma V_{water.UN4} = 10807.3 \cdot kN$

Sum of Horizontal Forces: $\Sigma H_{UN4} := \Sigma H_{Water.UN4} + \Sigma H_{soil.UN4} + \Sigma H_{I.UN4} = -7495 \cdot kN$

Sliding Factor of Safety: $FS_{HorizSliding.UN4} := \dfrac{(\tan_{\phi} \cdot \Sigma V_{UN4})}{|\Sigma H_{UN4}|} = 0.70$

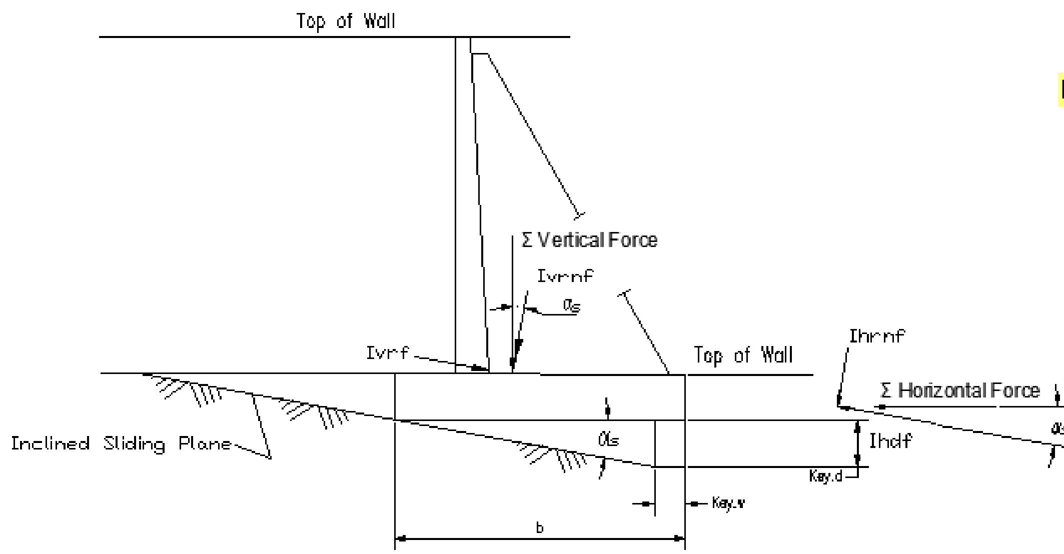
$FS_{HorizSliding.UN4.Check} :=$ | "OKAY" if $FS_{HorizSliding.UN4} \geq FS_{req.UN4.sl}$
"Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !" otherwise

$FS_{HorizSliding.UN4.Check}$ = "Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !"

CHECK SLIDING ALONG INCLINED SLIDING PLANE FROM HEEL KEY TO TOE,
WITH BEDROCK MASS MOBILIZED BY REINFOCREDE CONCRETE KEY)

RESISTING SIDE

DRIVING SIDE



TOE

Ivrf=Inclined Resisting Force
Ivrnf=Inclined Resisting Normal Force
Ihrnf=Inclined Resisting Normal Force
Ihdf=Inclined Driving Force

HEEL

$\alpha s := \operatorname{atan}\left(\dfrac{BOF_{toe} - BOF_{elev}}{L_b - Key_l}\right) = 0.12$ as degrees= $\alpha s \cdot \left(\dfrac{180}{\pi}\right) = 7.01$

Resolve $\Sigma Vert_{UN4}$ & $\Sigma Horiz_{UN4}$

$\Sigma V_{InclinedUN4} := \cos(\alpha s) \cdot (\Sigma V_{UN4} + V_{rs}) + \sin(\alpha s) \cdot |\Sigma H_{UN4}| = 23930.2 \cdot kN$

$\Sigma H_{InclinedUN4} := \cos(\alpha s) \cdot |\Sigma H_{UN4}| - \sin(\alpha s) \cdot (\Sigma V_{UN4} + V_{rs}) = 4609.2 \cdot kN$

(With properly engineered reinforced concrete Key, horizontal sliding plane thru Toe is protected, critical sliding plane is relocated to the INCLINED SLIDING PLANE FROM HEEL KEY To TOE, Bedrock Mass above this examing plane is mobilized by reinforced concrete key and combined into Structural Wedge.)

Inclined Sliding Plane Length $L_{incline} = 24.2\,m$

Safety Factor for Sliding Inclined Failure Plane

$FS_{InclinedlSlidingUN4} := \dfrac{\Sigma V_{InclinedUN4} \cdot \tan\left(\phi_{rock} \cdot \dfrac{\pi}{180}\right)}{|\Sigma H_{InclinedUN4}|} = 2.53$

$FS_{InclinedSliding.UN4.check} :=$ | "OKAY " if $FS_{InclinedlSlidingUN4} > FS_{req.UN4.sl}$ = "OKAY "
"Revise Structure"" otherwise

$FS_{InclinedSliding.UN4.check}$ = "OKAY "

CHECK ECCENTRICITY ON INCLINED PLANE

UN4 CASE

Sum of the Moments:

$$\Sigma M_{rs.UN4} := \Sigma M_{DL.UN4} + \Sigma M_{HWater.UN4} + \Sigma M_{Vwater.UN4} + \Sigma M_{I.UN4} + \Sigma M_{soil.UN4} + V_{rs} \cdot L_{rs} = 287700 \cdot kN \cdot m$$

Eccentricity:

$$e_{UN4} := \frac{L_{incline}}{2} - \frac{\Sigma M_{rs.UN4}}{\Sigma V_{InclinedUN4}} = 0.10\,m$$

Eccentricity Check:

$$e_{check.UN4} := \begin{cases} \text{"Okay"} & \text{if } \left|e_{UN4}\right| \le Kern \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$e_{check.UN4} = \text{"Okay"}$

Foundation Bearing Pressures on Inclined Plane:

Bearing Pressure at Heel:

$$\sigma_{heel.UN4} := \frac{\Sigma V_{InclinedUN4}}{\frac{A_b}{\cos(\alpha s)}} - \frac{\Sigma V_{UN4} \cdot e_{UN4}}{\frac{S_b}{\cos(\alpha s)^2}} = 80.9 \cdot \frac{kN}{m^2}$$

$$\sigma_{heel.UN4.check} := \left(\begin{cases} \text{"Okay"} & \text{if } \sigma_{heel.UN4} \le \sigma_{allow.UN4} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} \right)$$

$\sigma_{heel.UN4.check} = \text{"Okay"}$

Bearing Pressure at Toe:

$$\sigma_{toe.UN4} := \frac{\Sigma V_{InclinedUN4}}{\frac{A_b}{\cos(\alpha s)}} + \frac{\Sigma V_{InclinedUN4} \cdot e_{UN4}}{\frac{S_b}{\cos(\alpha s)^2}} = 83.8 \cdot \frac{kN}{m^2}$$

$$\sigma_{toe.UN4.check} := \begin{cases} \text{"Okay"} & \text{if } \sigma_{toe.UN4} \le \sigma_{allow.UN4} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$\sigma_{toe.UN4.check} = \text{"Okay"}$

CHECK FLOTATION

$$Uplift_{sliding.UN4} := U_{UN4} = -23616.8 \cdot kN$$

$$Uplift_{pore.UN4} = -17214.6 \cdot kN$$

$$\left(Uplift_{UN4}\right) := \min\left(Uplift_{pore.UN4}, Uplift_{sliding.UN4}\right)$$

(For conservative, taking maximum values)

$$FS_{Flotation.UN4} := \frac{D_{conc} + D_{Gate} + H_{1.UN4} + H_{2.UN4} + H_{3.UN4}}{\left|Uplift_{UN4}\right|} = 1.5$$

$$FS_{Flotation.UN4.check} := \begin{cases} \text{"OKAY "} & \text{if } FS_{Flotation.UN4} > FS_{req.UN.flt} \\ \text{"Revise Structure""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

MONOLITH OVERTURNING STABILITY ANALYSIS

UN4 CASE

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.

Assumptions are made in order to compute overturning stability of indetermine forces on monolith with key;

(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.

(b) The horizontal resisting force acting on the key, P.key, is that required for static equilibrium

(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1 $Ratio_{overturning.allow.Unusual} = 0.333$ (Resultant within Middle Third)

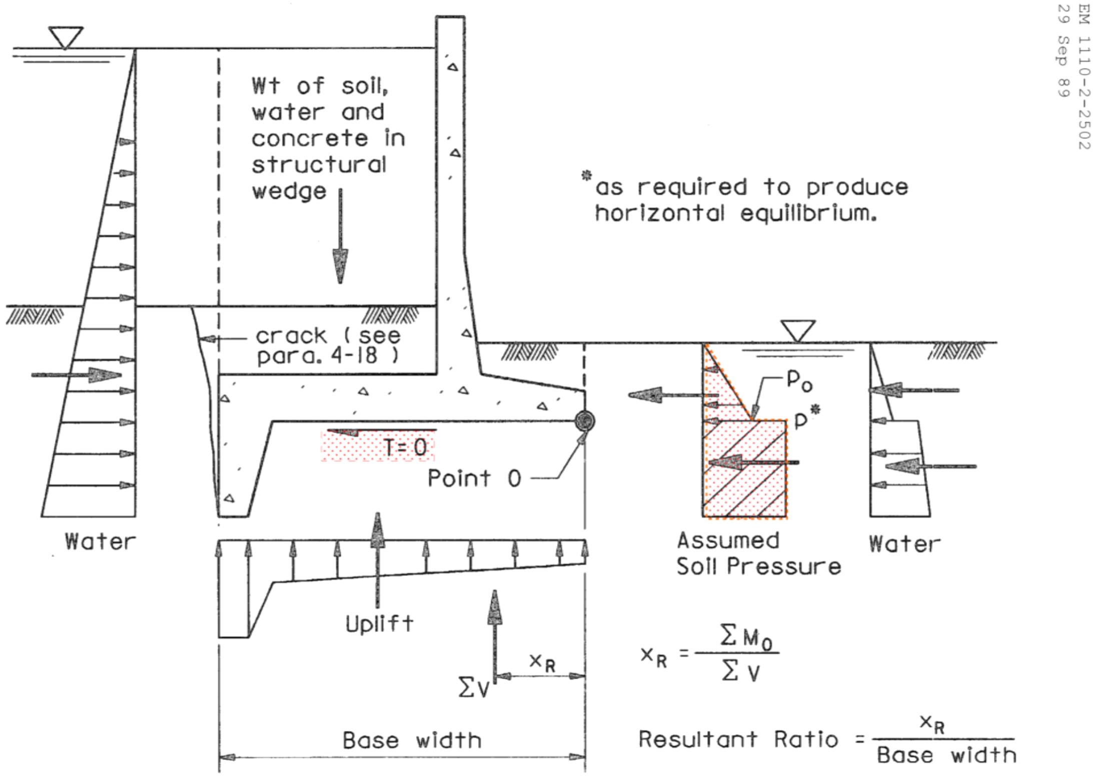


Figure 4-5. Forces for overturning analysis for wall with horizontal base and key

All Vertical Loads Applicable to Overturning Stability Analysis

Total Concrete Dead Loads:	$D_{conc} = 25408.2 \cdot kN$	at:	$X_{conc.loc} = 12.7\,m$
Dead Load of Gate:	$D_{Gate} = 580.0 \cdot kN$		$X_{gate} = 8.75\,m$
Water Weight (HW) on Apron Slab:	$H_{1.UN4} = 4233.2 \cdot kN$		$H_{1.UN4.loc} = 21.10\,m$
Water Weight (HW) on Fixed Crest:	$H_{2.UN4} = 1712.8 \cdot kN$		$H_{2.UN4.loc} = 14.25\,m$
Water Weight (TW) on Fixed Crest:	$H_{3.UN4} = 2808.8 \cdot kN$		$H_{3.UN4.loc} = 5.78\,m$

Uplift Force from Sliding Analysis. Line of Creep Method applied at presumed inclined sliding line, and subtraction gravity effect to Base of Concrete by Archimedes Principle

$$U_{UN4.loc.sliding} := \frac{U_{A.UN4} \cdot L_{A.UN4} + U_{B.UN4} \cdot L_{B.UN4} - A_{rs} \cdot w_{as} \cdot \gamma_w \cdot L_{rs}}{U_{A.UN4} + U_{B.UN4} - A_{rs} \cdot w_{as} \cdot \gamma_w} = 13.81\,m$$

$$U_{UN4.sliding} := U_{UN4} + A_{rs} \cdot w_{as} \cdot \gamma_w = -18095.7 \cdot kN$$

UN4 CASE

Uplift for Overturning Analysis, Line of Creep Method. Pore pressure at base of Concrete

$$Uplift_{pore.UN4} = -17214.6 \cdot kN$$

$$Uplift_{pore.UN4.loc} := \frac{Uplift_{BC.UN4} \cdot Uplift_{BC.UN4.loc} + Uplift_{DE.UN4} \cdot Uplift_{DE.UN4.loc} \cdots + Uplift_{EF.UN4} \cdot Uplift_{EF.UN4.loc} + Uplift_{FG.UN4} \cdot Uplift_{FG.UN4.loc}}{Uplift_{pore.UN4}} = 13.3\,m$$

Sum of All Water Load for Overturning Analysis

$$\Sigma V_{water.UN4.OT} := H_{1.UN4} + H_{2.UN4} + H_{3.UN4} + Uplift_{pore.UN4} = -8459.7 \cdot kN$$

<u>All Lateral Loads Applicable to Overturning Stability Analysis</u>

Apply Load to Gate?: $poss_{UN4} = 0$ poss = 1 if gate is closed, 0 if gate is open

Headwater Lateral Load on Gate: $H_{hwg.UN4} = 0.0 \cdot kN$ $H_{hwg.UN4.loc} = 7.43\,m$

Headwater Lateral Load on Footing: $H_{hwf.UN4} = -7107.3 \cdot kN$ $H_{hwf.UN4.loc} = 1.67\,m$

Total Horizontal Tailwater Load on Footing under Gate Openings, i.e., excluding Pier $H_{twf.UN4} = 1344.9 \cdot kN$ $H_{twf.UN4.loc} = 0.09\,m$

Resisting Water on Rear Face of Monolith, i.e., bottom of heel elevation: *(Point O @ TOE: BOFtoe = EL.1205.5)*

Ice / Impact Load: $I_{UN4} = 0.0 \cdot kN$ at: $I_{UN4.loc} = 11.50\,m$

Depth of Fill at Heel Side for Overturning Analysis: $t_{hf.UN4} := TOC_{as} - BOF_{toe} = 4.50\,m$

Driving Soil Load for overturning: $$E1_{drive.UN4} := \frac{K_o \cdot t_{hf.UN4}^{\,2}}{2} \cdot (\gamma_r - \gamma_w) \cdot W_b \cdot -1 = -974.5 \cdot kN$$

Acting at: $$E1_{drive.loc.UN4} := \frac{t_{hf.UN4}}{3} = 1.50\,m$$

Downstream (resisting) Lateral Soil Load as required to produce horizontal equilibrium:

$$E2_{resistUN4} := -1 \cdot \left(H_{hwg.UN4} + H_{hwf.UN4} + H_{twf.UN4} + I_{UN4} + E1_{drive.UN4}\right)$$

$$E2_{resistUN4} = 6737 \cdot kN$$

Assumed Resisting Bedrock at middle of Key, passive soil pressure or lateral bearing on contract joint at end of Monolith 3A3B $E2_{resistlocUN4} := E2_{resistlocU1} = -0.75\,m$

Overturning moment by Dead Loads about Point O @ Toe $\Sigma M_{DL.UN4} = 325434.2 \cdot kN \cdot m$

Overturning moment by Vertical Water Loads and Uplift, about Point O @ Toe

$$\Sigma M_{Vwater.UN4.OT} := H_{1.UN4} \cdot H_{1.UN4.loc} + H_{2.UN4} \cdot H_{2.UN4.loc} + H_{3.UN4} \cdot H_{3.UN4.loc} \cdots + Uplift_{pore.UN4} \cdot Uplift_{pore.UN4.loc} = -98935.7 \cdot kN \cdot m$$

Overturning moment by Lateral Hydrostatic Forces of Headwater Pool and Tailwater Pool,about Point O @ Toe $\Sigma M_{HWater.UN4} = -11727.4 \cdot kN \cdot m$

Overturning Moment by Impact/Ice Load, about Point O@ Toe $\Sigma M_{I.UN4} = 0$

Overturning moment by Lateral Soil Forces
about Point O @ Toe

$\Sigma M_{soil.UN4} := E1_{drive.UN4} \cdot E1_{drive.loc.UN4} + E2_{resistUN4} \cdot E2_{resistlocUN4} = -6514.5 \cdot kN \cdot m$

Sum of the Overturning Moments about Point O @ Toe:

$\Sigma M_{UN4.OT} := \Sigma M_{DL.UN4} + \Sigma M_{HWater.UN4} + \Sigma M_{Vwater.UN4.OT} + \Sigma M_{I.UN4} + \Sigma M_{soil.UN4} = 208257 \cdot kN \cdot m$

Sum of Vertical Forces: $\Sigma V_{UN4.OT} := \Sigma V_{DL.UN4} + \Sigma V_{water.UN4.OT} = 17209.5 \cdot kN$

Distance X_R: EM 1110-2-2502 Eq.4-1 $X_{R.UN4} := \dfrac{\Sigma M_{UN4.OT}}{\Sigma V_{UN4.OT}} = 12.1\, m$

Overturning Resultant Ratio $Ratio_{Overturning.UN4} := \dfrac{X_{R.UN4}}{L_b} = 0.5$

EM 1110-2-2502

Table 4-1

Retaining Wall Stability Criteria

Loading Condition	Sliding Factor of Safety, FS	Shear Strength Test Required: Soil Foundation	Shear Strength Test Required: Rock Foundation[3]	Overturning Criteria Minimum Base Area in Compression: Soil Foundation	Overturning Criteria Minimum Base Area in Compression: Rock Foundation
Usual	1.5	(Q &/or S)[2,1]	Direct shear	100%[4]	75%[4]
Unusual	1.33	(Q &/or S)[2,1]	Direct shear	75%[4]	50%[4]
Earthquake	1.1	(Q)	Direct shear	Resultant within base	Resultant within base

Overturning Stability Check

$Ratio_{Overturning.UN4.check} :=$ | "Okay" if $Ratio_{Overturning.UN4} \geq Ratio_{overturning.allow.Unusual}$
| "Revise Structure" otherwise

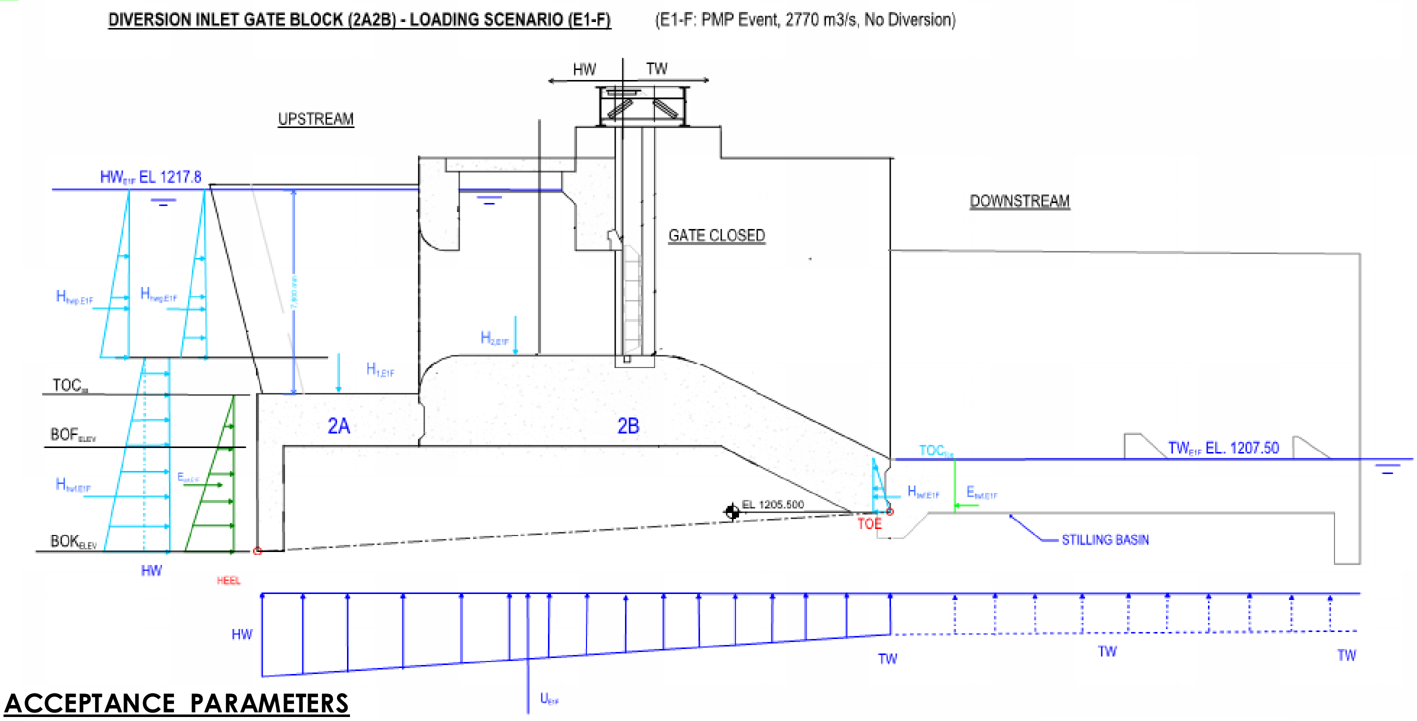
$Ratio_{Overturning.UN4.check} =$ "Okay"

Summary of Extreme Flood Results (Only Report Controlling Load Case)

UN4 Event: Construction / Maintenance

Horiz Sliding Factor of Safety:	$FS_{HorizSliding.UN4} = 0.70$
Horiz Sliding Factor of Safety Check:	$FS_{HorizSliding.UN4.Check}$ = "Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !"
Sliding Factor of Safety:	$FS_{InclinedISlidingUN4} = 2.5$
Sliding Factor of Safety Check:	$FS_{InclinedSliding.UN4.check}$ = "OKAY "
Eccentricity:	$e_{UN4} = 0.10\,m$
Eccentricity Check:	$e_{check.UN4}$ = "Okay"
Bearing Pressure At Heel:	$\sigma_{heel.UN4} = 80.9 \cdot \frac{kN}{m^2}$
Bearing Pressure At Heel Check:	$\sigma_{heel.UN4.check}$ = "Okay"
Bearing Pressure At Heel:	$\sigma_{toe.UN4} = 83.8 \cdot \frac{kN}{m^2}$
Bearing Pressure At Toe Check:	$\sigma_{toe.UN4.check}$ = "Okay"
Flotation Factor of Safety	$FS_{Flotation.UN4} = 1.5$
Flotation Factor of Safety Check:	$FS_{Flotation.UN4.check}$ = "OKAY "
Overturning Resultant Ratio	$Ratio_{Overturning.UN4} = 0.50$
Overturning Stability Check	$Ratio_{Overturning.UN4.check}$ = "Okay"

E1 DESIGN CASE



ACCEPTANCE PARAMETERS

Required Factor of Safety for Sliding: $FS_{req.E1.sl} := 1.1$ (Without Cohesion) (Section 8.1, Design Criteria)

Resultant Within Middle Half of Base: $e \le \frac{L_b}{4} \wedge e \ge \frac{-L_b}{4}$

Allowable Rock Bearing Pressure: $\sigma_{allow.E1} := 1740.0 \cdot \frac{kN}{m^2}$ (Section 5.2, Design Criteria)

Required Factor of Safety for Flotation: $FS_{req.E.flt} := 1.1$

Overturning Min Required Resultant Ratio: $\frac{X_{R.E}}{Horizontal\_Width\_of\_Base} > 0.167$

(75% Base in Compression, Resultant within Middle Half)

INPUT PARAMETERS

Headwater Elevation: $HW_{E1} := 1217.80m$

Tailwater Elevation: $TW_{E1} := 1207.50m$

(Water Elevations based on Diversion Structure 2D Hydraulic Model Results. See page 6 and Section 8.2, Design Criteria)

Crest Water Elevation (No Diversion)

Chute Block Water Elevation (No Diversion)

Bottom of Key (Footing Heel) Elevation: $BOF_{elev} = 1204.00\,m$

Apron Slab Top of Concrete Elevation at Edge of Slab: $TOC_{as} = 1210.00\,m$

Fixed Crest Top of Concrete Elevation at Downstream Face: $TOC_{fce} = 1207.50\,m$

Fixed Crest Top of Concrete Elevation at Center of Footing: $TOC_{fcc} = 1211.50\,m$

Lift Gate Position per Hydraulic Criteria $poss_{E1} := 1$ poss = 1 if gate is closed; 0 if gate is open

$$Gate_{R.E1} := \begin{cases} 0 & \text{if } poss_{E1} = 0 \\ 0.60 & \text{otherwise} \end{cases} = 0.6$$

$\Sigma V_{DL.E1} := D_{conc} + Gate_{R.E1} D_{Gate} = 25756.2 \cdot kN$

$\Sigma M_{DL.E1} := D_{conc} \cdot X_{conc.loc} + Gate_{R.E1} \cdot D_{Gate} \cdot X_{gate} = 325934.4 \cdot kN \cdot m$

LATERAL WATER LOADS

E1 CASE

HEADWATER (DRIVING):

Point O @ TOE: BOFtoe = EL.1205.5

Water Depth Above Fixed Crest at Gate: $D_{hwg.E1} := HW_{E1} - TOC_{fcc} = 6.3\,m$

Water Load Unit Width on Gate $W_{hwg.E1} := 0 = 0.00$

Apply Load to Gate?: $poss_{E1} = 1$

poss = 1 if gate is closed
0 if gate is open

Total Horizontal Water Load on Gate: $H_{hwg.E1} := \frac{-\left(\gamma_w \cdot D_{hwg.E1}{}^2\right)}{2} \cdot W_{hwg.E1} \cdot poss_{E1} = 0 \cdot kN$

Apply Total Gate Water Load at: $H_{hwg.E1.loc} := \frac{D_{hwg.E1}}{3} + \left(TOC_{fcc} - BOF_{toe}\right) = 8.10\,m$

Water Depth at Heel: $D_{hwf.E1} := HW_{E1} - BOF_{elev} = 13.80\,m$

Water Load Unit With on Footing: $W_{hw.E1} := W_b$

Water Load at Bottom of Footing: $H_{hwf.E1.1} := -\left(\gamma_w \cdot D_{hwf.E1}\right) \cdot W_{hw.E1} = -1624.5 \frac{1}{m} \cdot kN$

Water Load at Top of Footing: $H_{hwf.E1.2} := -\left(\gamma_w \cdot D_{hwg.E1}\right) \cdot W_{hw.E1} = -741.6 \frac{1}{m} \cdot kN$

Total Horizontal Water Load on Footing: $H_{hwf.E1} := \frac{\left(H_{hwf.E1.1} + H_{hwf.E1.2}\right) \cdot \left(D_{hwf.E1} - D_{hwg.E1}\right)}{2} = -8873.1 \cdot kN$

Apply Total Footing Water Load at:

$$H_{hwf.E1.loc} := \frac{\left[H_{hwf.E1.2} \cdot \frac{\left(TOC_{fcc} - BOF_{elev}\right)^2}{2} + \frac{\left(H_{hwf.E1.1} - H_{hwf.E1.2}\right)}{2} \cdot \frac{\left(TOC_{fcc} - BOF_{elev}\right)^2}{3}\right]}{\frac{\left(H_{hwf.E1.2} + H_{hwf.E1.1}\right) \cdot \left(TOC_{fcc} - BOF_{elev}\right)}{2}} - \left(BOF_{toe} - BOF_{elev}\right) = 1.78\,m$$

Converting horizontal force resultant from HEEL calculation to Point-O@TOE

E1 CASE

LATERAL WATER LOADS (cont.)

TAILWATER (RESISTING):

Water Depth at toe: $D_{tw.E1} := TW_{E1} - BOF_{elev} = 3.50\,m$

Water Load Unit Width: $W_{twf.E1} := W_b$

Total Horizontal Tailwater Load on Footing under Gate Openings, i.e., excluding Pier

Resisting Water on Rear Face of Monolith, i.e., bottom of heel elevation:

$$H_{twf.E1} := \begin{cases} \dfrac{\gamma_w \cdot D_{tw.E1}^{\,2}}{2} \cdot \left(W_{twf.E1}\right) & \text{if } poss_{E1} = 1 \\ \dfrac{\gamma_w \cdot D_{tw.E1}^{\,2}}{2} \cdot \left(W_{twf.E1}\right) & \text{if } poss_{E1} = 0 \wedge TW_{E1} \le TOC_{fcc} \\ \gamma_w \cdot \left[\dfrac{D_{tw.E1}}{2} + \dfrac{\left(TW_{E1} - TOC_{fcc}\right)}{2}\right] \cdot \left(TOC_{fcc} - BOF_{elev}\right) \cdot \left(W_{twf.E1}\right) & \text{if } poss_{E1} = 0 \wedge TW_{E1} \ge TOC_{fcc} \end{cases} = 721.0 \cdot kN$$

$$COND_{E1} := poss_{E1} = 0 \wedge TW_{E1} \ge TOC_{fcc}$$

Apply Footing Tailwater Load within Gate Openings at:

$$H_{twf.E1.loc} := \begin{cases} \dfrac{D_{tw.E1}}{3} - \left(BOF_{toe} - BOF_{elev}\right) & \text{if } poss_{E1} = 1 \\ \dfrac{D_{tw.E1}}{3} - \left(BOF_{toe} - BOF_{elev}\right) & \text{if } poss_{E1} = 0 \wedge TW_{E1} \le TOC_{fcc} \\ \dfrac{\left(TOC_{fcc} - BOF_{elev}\right)^2 \cdot \left[\dfrac{\left(TW_{E1} - TOC_{fcc}\right)}{2} + \dfrac{\left(\left(TOC_{fcc} - BOF_{elev}\right)\right)}{6}\right]}{\left(TOC_{fcc} - BOF_{elev}\right)\left[\left(TW_{E1} - TOC_{fcc}\right) + \dfrac{\left(TOC_{fcc} - BOF_{elev}\right)}{2}\right]} - \left(BOF_{toe} - BOF_{elev}\right) & \text{if } COND_{E1} \end{cases} = -0.33 \cdot m$$

$$\Sigma H_{Water.E1} := H_{hwg.E1} + H_{hwf.E1} + H_{twf.E1} = -8152.1 \cdot kN$$

$$\Sigma M_{HWater.E1} := H_{hwg.E1} \cdot H_{hwg.E1.loc} + H_{hwf.E1} \cdot H_{hwf.E1.loc} \cdots + H_{twf.E1} \cdot H_{twf.E1.loc} = -16066.3 \cdot kN \cdot m$$

VERTICAL WATER LOADS

E1 CASE

HEADWATER:

Water Depth on top of fixed crest: $d_{hw.E1} := HW_{E1} - TOC_{as} = 7.80\,m$

Weight of Water (H1) on Approach Slab: $H_{1.E1} := \left(W_{hw.E1} \cdot d_{hw.E1} \cdot L_{as}\right) \cdot \gamma_w = 5692.9 \cdot kN$

Horiz. Moment Arm for H1 (from toe): $H_{1.E1.loc} := L_b - \dfrac{L_{as}}{2} = 21.10\,m$

Cross-sectional Area of Headwater Above Fixed Crest: $A_{fc.hw.E1} := 47.55m^2$ From Bluebeam Measurement

Volume of water Above Fixed Crest: $V_{fc.hw.E1} := \left[A_{fc.hw.E1} \cdot \left(W_{hw.E1}\right)\right] = 570.6 \cdot m^3$

Weight of Water (H2) on Fixed Crest: $H_{2.E1} := \left(V_{fc.hw.E1}\right) \cdot \gamma_w = 5597.6 \cdot kN$

Horiz. Moment Arm for H2 (from toe): $H_{2.E1.loc} := 14.25 \cdot m$

TAILWATER:

Slope of Crest from D/S of Gate to edge of Stilling Basin: $S_{f.E1} := \dfrac{\left(TOC_{fcc} - TOC_{fce}\right)}{8.00m} = 0.500$

Height of Tailwater Above Stilling Basin:

$$y_{E1} := \begin{cases} \left(TW_{E1} - TOC_{fce}\right) & \text{if } TW_{E1} \le TOC_{fcc} \\ \left(TOC_{fcc} - TOC_{fce}\right) & \text{otherwise} \end{cases} \qquad y_{E1} = 0.00\,m$$

Horizontal Distance of Tailwater Above Sloped Portion of Crest: $x_{E1} := \dfrac{y_{E1}}{S_{f.E1}} = 0.00\,m$

Cross Sectional Area of Tailwater Above Sloped Portion of Crest: $A_{tw.E1} := \dfrac{\left(x_{E1} \cdot y_{E1}\right)}{2} = 0\,m^2$ $= 0.00m^2$ if TW_{E1} is less than or equal to TOC_{fce}

Weight of Water (H3) Above Slope Portion of Crest:

$$H_{3.E1} := \begin{cases} (0.0kN) & \text{if } TW_{E1} \le TOC_{fce} \\ \left(A_{tw.E1} \cdot W_{twf.E1}\right) \cdot \gamma_w & \text{if } TOC_{fcc} \ge TW_{E1} > TOC_{fce} \\ \left[A_{tw.E1} + Dist_{gate} \cdot \left(TW_{E1} - TOC_{fcc}\right)\right] \cdot W_{twf.E1} \cdot \gamma_w & \text{if } TW_{E1} > TOC_{fcc} \end{cases}$$

$H_{3.E1} = 0.0 \cdot kN$

Horiz. Moment Arm for H3 (from toe):

$$H_{3.E1.loc} := \begin{cases} (0.00m) & \text{if } TW_{E1} \le TOC_{fce} \\ \left(\dfrac{1}{3} \cdot x_{E1}\right) & \text{if } TOC_{fcc} \ge TW_{E1} > TOC_{fce} \\ \dfrac{\left[\dfrac{1}{2} \cdot x_{E1} \cdot y_{E1} \cdot \left(\dfrac{1}{3}\right) x_{E1} + \left(TW_{E1} - TOC_{fcc}\right) \cdot Dist_{gate} \cdot \left(\dfrac{Dist_{gate}}{2}\right)\right]}{\left(\dfrac{1}{2} x_{E1} \cdot y_{E1}\right) + \left(TW_{E1} - TOC_{fcc}\right) \cdot Dist_{gate}} & \text{if } TW_{E1} > TOC_{fcc} \end{cases}$$

$H_{3.E1.loc} = 0.00\,m$

UPLIFT AT INCLINED SLIDING PLANE

E1 CASE

Uplift pressure at Headwater: $U_{HW.E1} := D_{hwf.E1} \cdot \gamma_w = 135.38 \cdot \frac{kN}{m^2}$

Uplift pressure at D/S end of Stilling Basin: $U_{TW.E1} := D_{tw.E1} \cdot \gamma_w = 34.3 \cdot \frac{kN}{m^2}$

Length from U/S Face of Gate Structure to Toe Point(Effective Drain at end of Monolith) $L_{overall} = 24.20\,m$ $L_{sb} = 0$

Length of Seepage per Line of Creep $L_{seepage} = 27.1\,m$

Difference between Uplift pressure at Headwater and Uplift Pressure at Toe of Stilling Basin: $U_{diffE1} := U_{HW.E1} - U_{TW.E1} = 101 \cdot \frac{kN}{m^2}$

Slope of difference between Uplift pressure at Headwater and Uplift Pressure at Toe of Stilling Basin: $U_{slopeE1} := \frac{U_{diffE1} - Key_d \cdot \gamma_w}{L_{overall}} = 3.57 \cdot \frac{kN}{m^2 \cdot m}$

$$U_{seepageslopeE1} := \frac{U_{diffE1} - Key_d \cdot \gamma_w}{L_{seepage}}$$

Tailwater Pressure at toe of Gate Structure: $U_{press.toe.gsE1} := U_{TW.E1} + L_{sb} \cdot U_{slopeE1} = 34.3 \cdot \frac{kN}{m^2}$

$$U_{pore.toe.E1} := U_{TW.E1} + U_{seepageslopeE1} \cdot L_{sb} = 34.3 \cdot \frac{kN}{m^2}$$

$$U_{pore.F.E1} := U_{pore.toe.E1} + U_{seepageslopeE1} \cdot L_{FG} = 39.1 \cdot \frac{kN}{m^2}$$

$$U_{pore.E.E1} := U_{pore.F.E1} - \left(BOF_{base} - BOF_{toe}\right) \cdot \gamma_w + U_{seepageslopeE1} \cdot L_{EF} = 35.1 \cdot \frac{kN}{m^2}$$

$$U_{pore.D.E1} := U_{pore.E.E1} + U_{seepageslopeE1} \cdot L_{DE} = 93.1 \cdot \frac{kN}{m^2}$$

$$U_{pore.C.E1} := U_{pore.D.E1} + \left(BOF_{base} - BOF_{elev}\right) \cdot \gamma_w + U_{seepageslopeE1} \cdot L_{CD} = 132.2 \cdot \frac{kN}{m^2}$$

Uniform uplift due to Tailwater: (rectangular portion) $U_{A.E1} := U_{press.toe.gsE1} \cdot L_b \cdot W_b \cdot -1 = -9970.9 \cdot kN$

Moment Arm for Uplift UA from Toe of Gate Structure: $L_{A.E1} := \frac{L_b}{2} = 12.10\,m$

Uplift - Linear Decrease from HW to TW: (triangular portion) $U_{B.E1} := \frac{1}{2} \cdot \left(U_{HW.E1} - U_{press.toe.gsE1}\right) \cdot L_b \cdot W_b \cdot -1 = -14671.4 \cdot kN$

Moment Arm for Uplift UB from Toe of Gate Structure: $L_{B.E1} := \frac{2}{3} \cdot L_b = 16.13\,m$

Total Resultant Uplift force: $U_{E1} := U_{A.E1} + U_{B.E1} = -24642.3 \cdot kN$

Resultant Location from Toe: $U_{E1.loc} := \frac{U_{A.E1} \cdot L_{A.E1} + U_{B.E1} \cdot L_{B.E1}}{U_{A.E1} + U_{B.E1}} = 14.50\,m$

$$\Sigma V_{water.E1} := H_{1.E1} + H_{2.E1} + H_{3.E1} + U_{E1} = -13351.8 \cdot kN$$

$$\Sigma M_{Vwater.E1} := H_{1.E1} \cdot H_{1.E1.loc} + H_{2.E1} \cdot H_{2.E1.loc} + H_{3.E1} \cdot H_{3.E1.loc} + U_{E1} \cdot U_{E1.loc} = -157460.4 \cdot kN \cdot m$$

Uplift as per Line of Creep Method
(Flotation and Overturning)

$$Uplift_{BC.E1} := \frac{-1}{2} \cdot W_b \cdot \left(U_{HW.E1} + U_{pore.C.E1}\right) \cdot L_{BC} = -1605420\,N$$

$$Uplift_{CD.E1} := 0$$

$$Uplift_{DE.E1} := \frac{-1}{2} \cdot W_b \cdot \left(U_{pore.D.E1} + U_{pore.E.E1}\right) \cdot L_{DE} = -13997184.7\,N$$

$$Uplift_{EF.E1} := \frac{-1}{2} \cdot W_b \cdot \left(U_{pore.E.E1} + U_{pore.F.E1}\right) \cdot L_{EF} = -1492668.9\,N$$

$$Uplift_{FG.E1} := \frac{-1}{2} \cdot W_b \cdot \left(U_{pore.F.E1} + U_{pore.toe.E1}\right) \cdot L_{FG} = -661041.1\,N$$

$$Uplift_{pore.E1} := Uplift_{BC.E1} + Uplift_{DE.E1} + Uplift_{EF.E1} + Uplift_{FG.E1} = -17756.3 \cdot kN$$

$$Uplift_{FG.E1.loc} := \frac{L_{FG}}{3} \cdot \frac{\left(2 \cdot U_{pore.F.E1} + U_{pore.toe.E1}\right)}{\left(U_{pore.F.E1} + U_{pore.toe.E1}\right)} = 0.77\,m$$

$$Uplift_{EF.E1.loc} := \frac{L_{EF}}{3} \cdot \frac{\left(2 \cdot U_{pore.E.E1} + U_{pore.F.E1}\right)}{\left(U_{pore.E.E1} + U_{pore.F.E1}\right)} + L_{FG} = 3.15\,m$$

$$Uplift_{DE.E1.loc} := \frac{L_{DE}}{3} \cdot \frac{\left(2 \cdot U_{pore.D.E1} + U_{pore.E.E1}\right)}{\left(U_{pore.D.E1} + U_{pore.E.E1}\right)} + L_{FG} + X_{EF} = 14.97\,m$$

$$Uplift_{BC.E1.loc} := \frac{L_{BC}}{3} \cdot \frac{\left(2 \cdot U_{HW.E1} + U_{pore.C.E1}\right)}{\left(U_{HW.E1} + U_{pore.C.E1}\right)} + L_{FG} + X_{EF} + L_{DE} = 23.20\,m$$

E1 CASE

SOIL LOADS

(CFEM 24.1)

Equivalent Fluid Pressure (EFP):

At-rest Soil Pressure to Heel, EM1110--2-2502 Section 3-7

At rest lateral pressure coefficient: $K_o = 0.66$

Lateral Driving Force (Headwater Side)

Depth of Fill at Heel: $t_{hf.E1} := TOC_{as} - BOF_{elev} = 6.00\,m$

At-Rest Soil Load: $E1_{drive.E1} := \frac{K_o \cdot t_{hf.E1}^{\,2}}{2} \cdot (\gamma_r - \gamma_w) \cdot W_b \cdot -1 = -1732.5 \cdot kN$

Acting at: $E1_{drive.loc.E1} := \frac{t_{hf.E1}}{3} - (BOF_{toe} - BOF_{elev}) = 0.50\,m$

Lateral Resisting Force (Tailwater Side)

Depth of Fill at Toe: $t_{tf.E1} := TOC_{fce} - BOF_{elev} = 3.50\,m$

At-Rest Soil Load: $E2_{resistE1} := \frac{K_o \cdot t_{tf.E1}^{\,2}}{2} \cdot (\gamma_r - \gamma_w) \cdot W_b = 589.5 \cdot kN$

$E2_{resistE1} := 0$

Acting at: $E2_{resistlocE1} := \frac{t_{tf.E1}}{3} = 1.17\,m$

(Expansion Joint to Stilling Basin, No Sediment in Gap)

$\Sigma H_{soil.E1} := E1_{drive.E1} + E2_{resistE1} = -1732.5 \cdot kN$

$\Sigma M_{soil.E1} := E1_{drive.E1} \cdot E1_{drive.loc.E1} + E2_{resistE1} \cdot E2_{resistlocE1} = -866.2 \cdot kN \cdot m$

ICE / IMPACT LOADS (CONSERVATIVELY ASSUME NO ICE LOADING ON DOWNSTREAM SIDE)

ICE / IMPACT LOADS NOT APPLIED TO THIS LOAD CASE

Static Impact Loading on Structure: $I_{S.E1} := 0.0 \frac{kN}{m}$ (Section 7.7, Design Criteria)

Static Impact load on Gates: $I_{G.E1} := 0.0 \frac{kN}{m}$ (Section 7.7, Design Criteria)

Impact Loading Unit Width on Structure: $W_{S.E1} := 0m$

Impact Loading Unit Width on Gates: $W_{G.E1} := 0m = 0.00$

Total Impact Load on Structure: $I_{E1} := (I_{S.E1} \cdot W_{S.E1} + I_{G.E1} \cdot W_{G.E1}) \cdot -1 = 0 \cdot kN$

Apply Ice load at: $I_{E1.loc} := (HW_{E1} - BOF_{elev} - 0.30m) = 13.50\,m$

$\Sigma H_{I.E1} := I_{E1} = 0 \cdot kN$

$\Sigma M_{I.E1} := I_{E1} \cdot I_{E1.loc} = 0 \cdot kN \cdot m$

SEISMIC LOAD (Not Applicable to this Load Case)

E1 CASE

SUMMARY OF LOADS

	Loads	Moment Arm
Dead Load of Concrete Structure:	$D_{conc} = 25408.2 \cdot kN$	$X_{conc.loc} = 12.71\,m$
Dead Load of Gate:	$D_{Gate} = 580.0 \cdot kN$	$X_{gate} = 8.75\,m$
Headwater Lateral Load on Gate:	$H_{hwg.E1} = 0.0 \cdot kN$	$H_{hwg.E1.loc} = 8.10\,m$
Headwater Lateral Load on Footing:	$H_{hwf.E1} = -8873.1 \cdot kN$	$H_{hwf.E1.loc} = 1.78\,m$
Tailwater Lateral Load:	$H_{twf.E1} = 721.0 \cdot kN$	$H_{twf.E1.loc} = -0.33\,m$
Water Weight (HW) on Apron Slab:	$H_{1.E1} = 5692.9 \cdot kN$	$H_{1.E1.loc} = 21.10\,m$
Water Weight (HW) on Fixed Crest:	$H_{2.E1} = 5597.6 \cdot kN$	$H_{2.E1.loc} = 14.25\,m$
Water Weight (TW) on Fixed Crest:	$H_{3.E1} = 0.0 \cdot kN$	$H_{3.E1.loc} = 0.00\,m$
Uplift:	$U_{E1} = -24642.3 \cdot kN$	$U_{E1.loc} = 14.50\,m$
Upstream (driving) Lateral Soil Load:	$E1_{drive.E1} = -1732.5 \cdot kN$	$E1_{drive.loc.E1} = 0.50\,m$
Downstream (resisting) Lateral Soil Load:	$E2_{resistE1} = 0 \cdot kN$	$E2_{resistlocE1} = 1.17\,m$
Ice / Impact Load:	$I_{E1} = 0.0 \cdot kN$	$I_{E1.loc} = 13.50\,m$

STABILITY ASSESSMENT (SLIDNG, OVERTURNING AND BEARING): E1 CASE

CHECK SLIDING ALONG HORIZONTAL PLANE THRU TOE, IGNORING BEDROCK MOBILIZED BY STRUCTURAL HEEL KEY , OR VOID BEHIND KEY

Sum of Vertical Forces:

$\Sigma V_{E1} := \Sigma V_{DL.E1} + \Sigma V_{water.E1} = 12404.4 \cdot kN$

Sum of Horizontal Forces:

$\Sigma H_{E1} := \Sigma H_{Water.E1} + \Sigma H_{soil.E1} + \Sigma H_{I.E1} = -9884.6 \cdot kN$

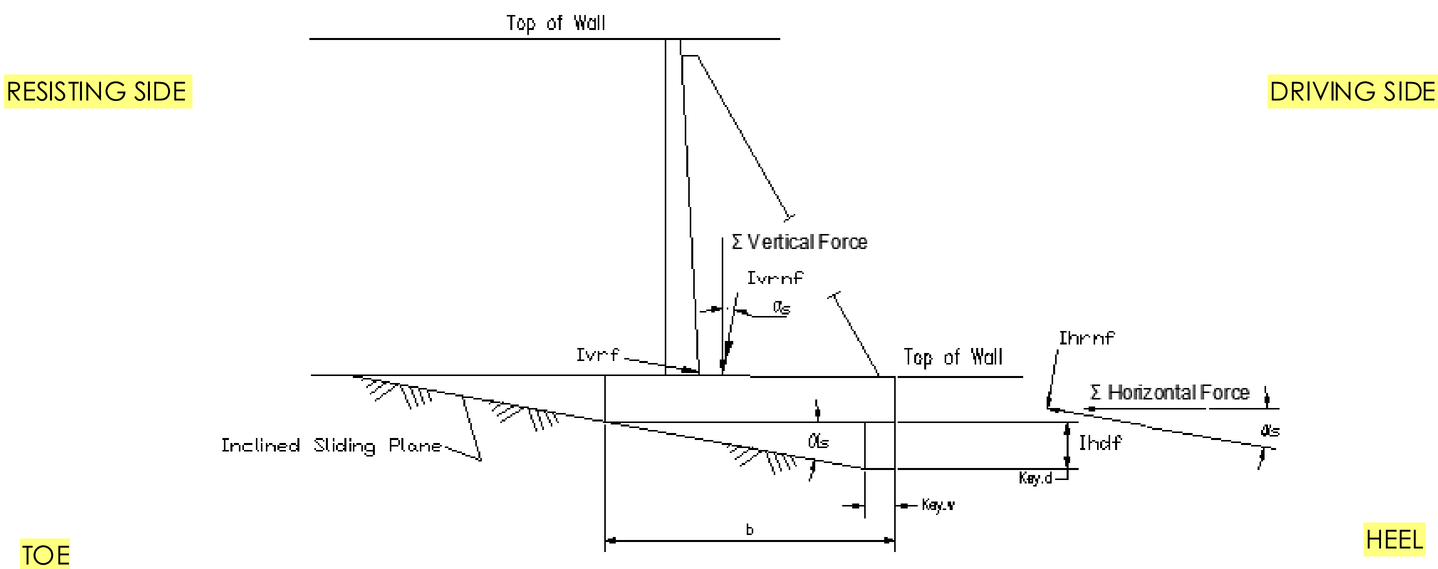
Sliding Factor of Safety:

$$FS_{HorizSliding.E1} := \frac{\left(\tan_{\phi} \cdot \Sigma V_{E1}\right)}{\left|\Sigma H_{E1}\right|} = 0.61$$

$FS_{HorizSliding.E1.Check} :=$ | "OKAY" if $FS_{HorizSliding.E1} \geq FS_{req.E1.sl}$
| "Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !" otherwise

$FS_{HorizSliding.E1.Check} =$ "Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !"

CHECK SLIDING ALONG INCLINED SLIDING PLANE FROM HEEL KEY TO TOE, WITH BEDROCK MASS MOBILIZED BY REINFOCREDE CONCRETE KEY)



Ivrf=Inclined Resisting Force
Ivrnf=Inclined Resisting Normal Force
Ihrnf=Inclined Resisting Normal Force
Ihdf=Inclined Driving Force

$$\alpha s := \operatorname{atan}\left(\frac{BOF_{toe} - BOF_{elev}}{L_b - Key_l}\right) = 0.12 \qquad \text{as degrees=} \quad \alpha s \cdot \left(\frac{180}{\pi}\right) = 7.01$$

Resolve $\Sigma Vert_{E1}$ & $\Sigma Horiz_{E1}$

$$\Sigma V_{InclinedE1} := \cos(\alpha s) \cdot \left(\Sigma V_{E1} + V_{rs}\right) + \sin(\alpha s) \cdot \left|\Sigma H_{E1}\right| = 25807.0 \cdot kN$$

$$\Sigma H_{InclinedE1} := \cos(\alpha s) \cdot \left|\Sigma H_{E1}\right| - \sin(\alpha s) \cdot \left(\Sigma V_{E1} + V_{rs}\right) = 6786.0 \cdot kN$$

(With properly engineered reinforced concrete Key, horizontal sliding plane thru Toe is protected, critical sliding plane is relocated to the INCLINED SLIDING PLANE FROM HEEL KEY To TOE, Bedrock Mass above this examing plane is mobilized by reinforced concrete key and combined into Structural Wedge.)

Inclined Sliding Plane Length $\qquad L_{incline} = 24.2\,m$

Safety Factor for Sliding Inclined Failure Plane

$$FS_{InclinedlSlidingE1} := \frac{\Sigma V_{InclinedE1} \cdot \tan\left(\phi_{rock} \cdot \frac{\pi}{180}\right)}{\left|\Sigma H_{InclinedE1}\right|} = 1.85$$

$FS_{InclinedSliding.check.E1} :=$ | "OKAY " if $FS_{InclinedlSlidingE1} > FS_{req.E1.sl}$ = "OKAY "
| "Revise Structure"" otherwise

$FS_{InclinedSliding.check.E1} =$ "OKAY "

CHECK ECCENTRICITY ON INCLINED PLANE

E1 CASE

Sum of the Moments:

$$\Sigma M_{rs.E1} := \Sigma M_{DL.E1} + \Sigma M_{HWater.E1} + \Sigma M_{Vwater.E1} + \Sigma M_{I.E1} + \Sigma M_{soil.E1} + V_{rs} \cdot L_{rs} = 322531 \cdot kN \cdot m$$

Eccentricity:

$$e_{E1} := \frac{L_{incline}}{2} - \frac{\Sigma M_{rs.E1}}{\Sigma V_{InclinedE1}} = -0.37\,m$$

Eccentricity Check:

$$e_{check.E1} := \begin{cases} \text{"Okay"} & \text{if } \left|e_{E1}\right| \le Ecc_{midhalf} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$e_{check.E1} = \text{"Okay"}$

Foundation Bearing Pressures on Inclined Plane:

Bearing Pressure at Heel:

$$\sigma_{heel.E1} := \frac{\Sigma V_{InclinedE1}}{\frac{A_b}{\cos(\alpha s)}} - \frac{\Sigma V_{E1} \cdot e_{E1}}{\frac{S_b}{\cos(\alpha s)^2}} = 92.1 \cdot \frac{kN}{m^2}$$

$$\sigma_{heel.E1.check} := \left(\begin{cases} \text{"Okay"} & \text{if } \sigma_{heel.E1} \le \sigma_{allow.E1} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} \right)$$

$\sigma_{heel.E1.check} = \text{"Okay"}$

Bearing Pressure at Toe:

$$\sigma_{toe.E1} := \frac{\Sigma V_{InclinedE1}}{\frac{A_b}{\cos(\alpha s)}} + \frac{\Sigma V_{InclinedE1} \cdot e_{E1}}{\frac{S_b}{\cos(\alpha s)^2}} = 80.1 \cdot \frac{kN}{m^2}$$

$$\sigma_{toe.E1.check} := \begin{cases} \text{"Okay"} & \text{if } \sigma_{toe.E1} \le \sigma_{allow.E1} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$\sigma_{toe.E1.check} = \text{"Okay"}$

CHECK FLOTATION

$$Uplift_{sliding.E1} := U_{E1} = -24642.3 \cdot kN$$

$$Uplift_{pore.E1} = -17756.3 \cdot kN$$

$$\left(Uplift_{E1}\right) := \min\left(Uplift_{pore.E1}, Uplift_{sliding.E1}\right)$$

(For conservative, taking maximum values)

$$FS_{Flotation.E1} := \frac{D_{conc} + D_{Gate} + H_{1.E1} + H_{2.E1} + H_{3.E1}}{\left|Uplift_{E1}\right|} = 1.51$$

$$FS_{Flotation.E1.check} := \begin{cases} \text{"OKAY "} & \text{if } FS_{Flotation.E1} > FS_{req.E.flt} \\ \text{"Revise Structure""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

MONOLITH OVERTURNING STABILITY ANALYSIS

E1 CASE

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.
Assumptions are made in order to compute overturning stability of indetermine forces on monolith with key;
(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.
(b) The horizontal resisting force acting on the key, P.key, is that required for static equilibrium
(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1

$Ratio_{overturning.allow.Extreme} := 0.167$

Resultant within Middle Half

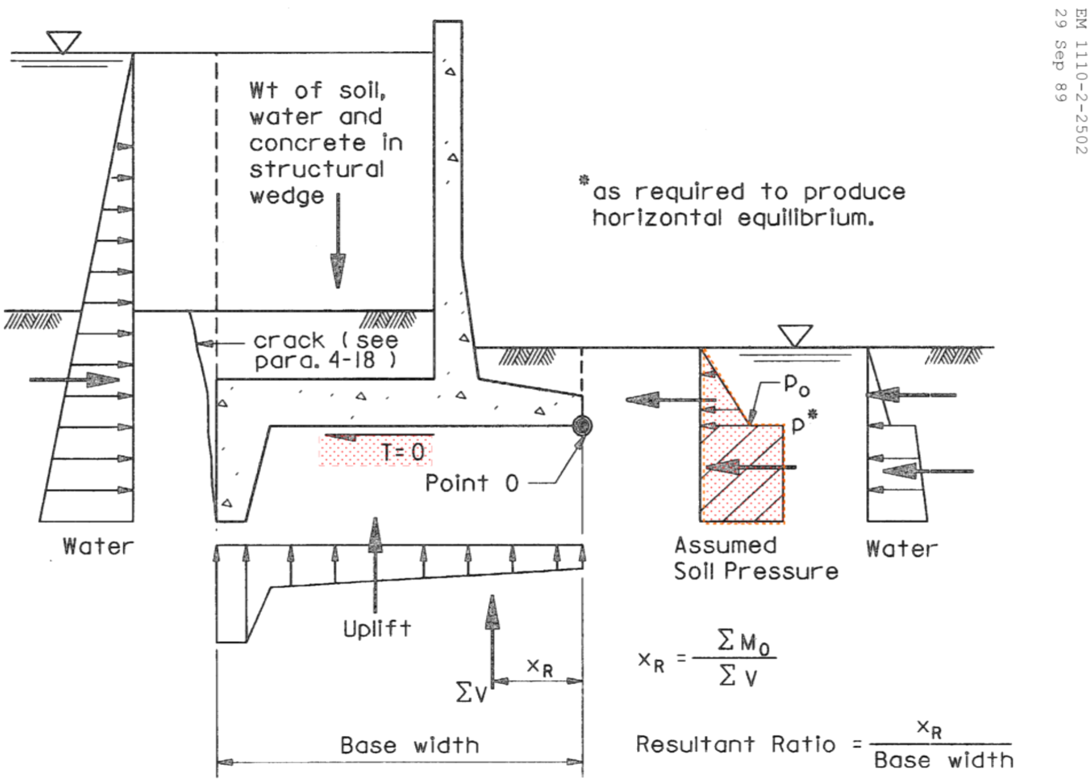


Figure 4-5. Forces for overturning analysis for wall with horizontal base and key

<u>All Vertical Loads Applicable to Overturning Stability Analysis</u>

Total Concrete Dead Loads:	$D_{conc} = 25408.2 \cdot kN$	at:	$X_{conc.loc} = 12.7\,m$
Dead Load of Gate:	$D_{Gate} = 580.0 \cdot kN$		$X_{gate} = 8.75\,m$
Water Weight (HW) on Apron Slab:	$H_{1.E1} = 5692.9 \cdot kN$		$H_{1.E1.loc} = 21.10\,m$
Water Weight (HW) on Fixed Crest:	$H_{2.E1} = 5597.6 \cdot kN$		$H_{2.E1.loc} = 14.25\,m$
Water Weight (TW) on Fixed Crest:	$H_{3.E1} = 0.0 \cdot kN$		$H_{3.E1.loc} = 0.00\,m$

Uplift Force from Sliding Analysis. Line of Creep Method applied at presumed inclined sliding line, and subtraction gravity effect to Base of Concrete by Archimedes Principle

$$U_{E1.loc.sliding} := \frac{U_{A.E1} \cdot L_{A.E1} + U_{B.E1} \cdot L_{B.E1} - A_{rs} \cdot w_{as} \cdot \gamma_w \cdot L_{rs}}{U_{A.E1} + U_{B.E1} - A_{rs} \cdot w_{as} \cdot \gamma_w} = 14.37\,m$$

$$U_{E1.sliding} := U_{E1} + A_{rs} \cdot w_{as} \cdot \gamma_w = -19121.3 \cdot kN$$

E1 CASE

Uplift for Overturning Analysis, Line of Creep Method. Pore pressure at base of Concrete

$$Uplift_{pore.E1} = -17756.3 \cdot kN$$

$$Uplift_{pore.E1.loc} := \frac{Uplift_{BC.E1} \cdot Uplift_{BC.E1.loc} + Uplift_{DE.E1} \cdot Uplift_{DE.E1.loc} \cdots + Uplift_{EF.E1} \cdot Uplift_{EF.E1.loc} + Uplift_{FG.E1} \cdot Uplift_{FG.E1.loc}}{Uplift_{pore.E1}} = 14.2\,m$$

Sum of All Water Load for Overturning Analysis

$$\Sigma V_{water.E1.OT} := H_{1.E1} + H_{2.E1} + H_{3.E1} + Uplift_{pore.E1} = -6465.8 \cdot kN$$

All Lateral Loads Applicable to Overturning Stability Analysis

Apply Load to Gate?: $poss_{E1} = 1$ poss = 1 if gate is closed, 0 if gate is open

Headwater Lateral Load on Gate: $H_{hwg.E1} = 0.0 \cdot kN$ $H_{hwg.E1.loc} = 8.10\,m$

Headwater Lateral Load on Footing: $H_{hwf.E1} = -8873.1 \cdot kN$ $H_{hwf.E1.loc} = 1.78\,m$

Total Horizontal Tailwater Load on Footing under Gate Openings, i.e., excluding Pier: $H_{twf.E1} = 721.0 \cdot kN$ $H_{twf.E1.loc} = -0.33\,m$

Resisting Water on Rear Face of Monolith, i.e., bottom of heel elevation: *(Point O @ TOE: BOFtoe = EL.1205.5)*

Ice / Impact Load: $I_{E1} = 0.0 \cdot kN$ at: $I_{E1.loc} = 13.50\,m$

Depth of Fill at Heel Side for Overturning Analysis: $t_{hf.E2} := TOC_{as} - BOF_{toe} = 4.50\,m$

Driving Soil Load for overturning: $$E1_{drive.E1} := \frac{K_o \cdot t_{hf.E1}^{\,2}}{2} \cdot (\gamma_r - \gamma_w) \cdot W_b \cdot -1 = -974.5 \cdot kN$$

Acting at: $$E1_{drive.loc.E1} := \frac{t_{hf.E1}}{3} = 1.50\,m$$

Downstream (resisting) Lateral Soil Load as required to produce horizontal equilibrium:

$$E2_{resistE1} := -1 \cdot (H_{hwg.E1} + H_{hwf.E1} + H_{twf.E1} + I_{E1} + E1_{drive.E1})$$

$$E2_{resistE1} = 9126.6 \cdot kN$$

Assumed Resisting Bedrock at middle of Key, passive soil pressure or lateral bearing on contract joint at end of Monolith 3A3B: $E2_{resistlocE1} := E2_{resistlocU1} = -0.75\,m$

Overturning moment by Dead Loads about Point O @ Toe: $\Sigma M_{DL.E1} = 325934.4 \cdot kN \cdot m$

Overturning moment by Vertical Water Loads and Uplift, about Point O @ Toe

$$\Sigma M_{Vwater.E1.OT} := H_{1.E1} \cdot H_{1.E1.loc} + H_{2.E1} \cdot H_{2.E1.loc} + H_{3.E1} \cdot H_{3.E1.loc} + Uplift_{pore.E1} \cdot Uplift_{pore.E1.loc} = -52169 \cdot kN \cdot m$$

Overturning moment by Lateral Hydrostatic Forces of Headwater Pool and Tailwater Pool,about Point O @ Toe: $\Sigma M_{HWater.E1} = -16066.3 \cdot kN \cdot m$

Overturning Moment by Impact/Ice Load, about Point O@ Toe: $\Sigma M_{I.E1} = 0$

Overturning moment by Lateral Soil Forces
about Point O @ Toe

$$\Sigma M_{soil.E1} := E1_{drive.E1} \cdot E1_{drive.loc.E1} + E2_{resistE1} \cdot E2_{resistlocE1} = -8306.8 \cdot kN \cdot m$$

Sum of the Overturning Moments about Point O @ Toe:

$$\Sigma M_{E1.OT} := \Sigma M_{DL.E1} + \Sigma M_{HWater.E1} + \Sigma M_{Vwater.E1.OT} + \Sigma M_{I.E1} + \Sigma M_{soil.E1} = 249392 \cdot kN \cdot m$$

Sum of Vertical Forces:

$$\Sigma V_{E1.OT} := \Sigma V_{DL.E1} + \Sigma V_{water.E1.OT} = 19290.4 \cdot kN$$

Distance X_R: EM 1110-2-2502 Eq.4-1

$$X_{R.E1} := \frac{\Sigma M_{E1.OT}}{\Sigma V_{E1.OT}} = 12.9\,m$$

Overturning Resultant Ratio

$$Ratio_{Overturning.E1} := \frac{X_{R.E1}}{L_b} = 0.53$$

EM 1110-2-2502

Table 4-1

Retaining Wall Stability Criteria

Loading Condition	Sliding Factor of Safety, FS	Shear Strength Test Required: Soil Foundation	Shear Strength Test Required: Rock Foundation[3]	Overturning Criteria Minimum Base Area in Compression: Soil Foundation	Overturning Criteria Minimum Base Area in Compression: Rock Foundation
Usual	1.5	(Q &/or S)[2,1]	Direct shear	100%[4]	75%[4]
Unusual	1.33	(Q &/or S)[2,1]	Direct shear	75%[4]	50%[4]
Earthquake	1.1	(Q)	Direct shear	Resultant within base	Resultant within base

Overturning Stability Check

$$Ratio_{Overturning.E1.check} := \begin{cases} \text{"Okay"} & \text{if } Ratio_{Overturning.E1} \geq Ratio_{overturning.allow.Extreme} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

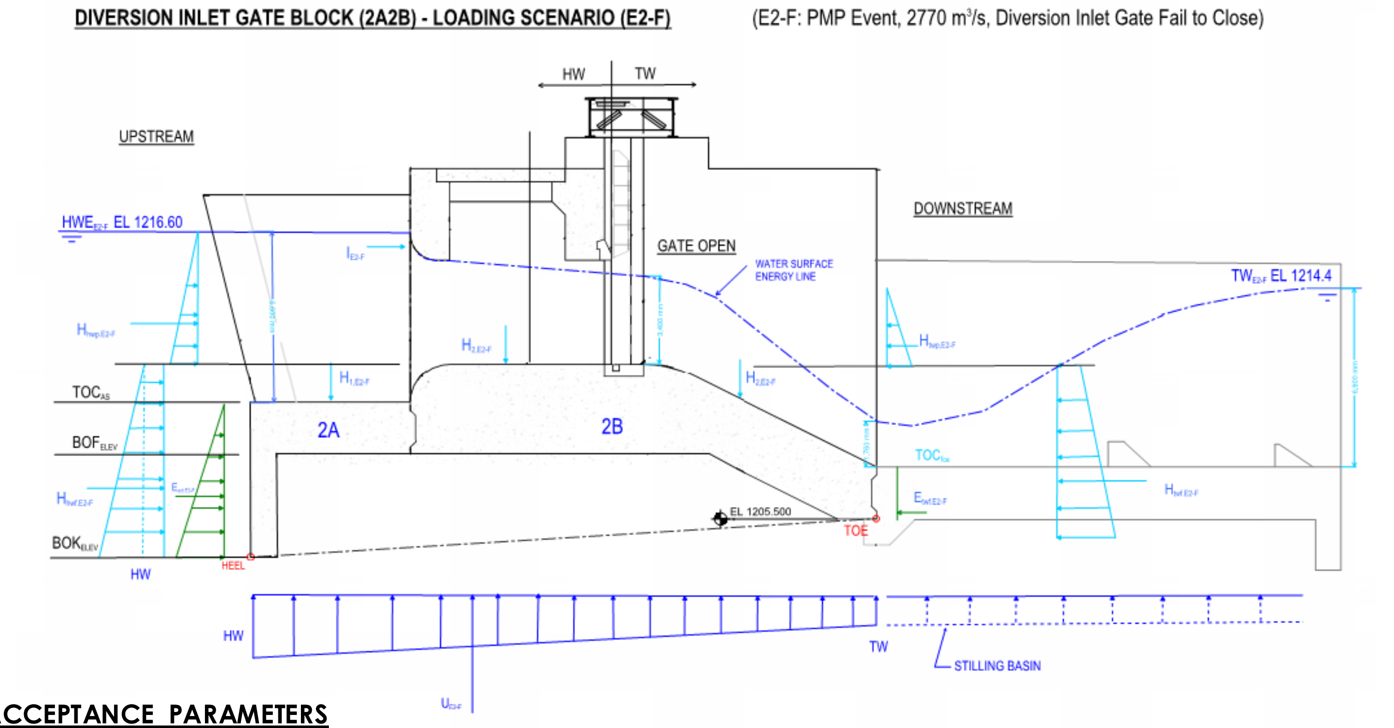
$$Ratio_{Overturning.E1.check} = \text{"Okay"}$$

Summary of Extreme Flood Results (Only Report Controlling Load Case)

E1 Event: PMF without Diversion

Horiz Sliding Factor of Safety:	$FS_{HorizSliding.E1} = 0.61$
Horiz Sliding Factor of Safety Check:	$FS_{HorizSliding.E1.Check}$ = "Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !"
Sliding Factor of Safety:	$FS_{InclinedlSlidingE1} = 1.9$
Sliding Factor of Safety Check:	$FS_{InclinedSliding.check.E1}$ = "OKAY "
Eccentricity:	$e_{E1} = -0.37\,m$
Eccentricity Check:	$e_{check.E1}$ = "Okay"
Bearing Pressure At Heel:	$\sigma_{heel.E1} = 92.1\cdot\frac{kN}{m^2}$
Bearing Pressure At Heel Check:	$\sigma_{heel.E1.check}$ = "Okay"
Bearing Pressure At Heel:	$\sigma_{toe.E1} = 80.1\cdot\frac{kN}{m^2}$
Bearing Pressure At Toe Check:	$\sigma_{toe.E1.check}$ = "Okay"
Flotation Factor of Safety	$FS_{Flotation.E1} = 1.5$
Flotation Factor of Safety Check:	$FS_{Flotation.E1.check}$ = "OKAY "
Overturning Resultant Ratio	$Ratio_{Overturning.E1} = 0.53$
Overturning Stability Check	$Ratio_{Overturning.E1.check}$ = "Okay"

E2 DESIGN CASE



ACCEPTANCE PARAMETERS

Required Factor of Safety for Sliding: $FS_{req.E2.sl} := 1.1$ (Without Cohesion) (Section 8.1, Design Criteria)

Resultant Within Middle Half of Base: $e \le \frac{L_b}{4} \wedge e \ge \frac{-L_b}{4}$

Allowable Rock Bearing Pressure: $\sigma_{allow.E2} := 1740.0 \cdot \frac{kN}{m^2}$ (Section 5.2, Design Criteria)

Required Factor of Safety for Flotation: $FS_{rea.E.flt} = 1.1$

Overturning Min Required Resultant Ratio: $\frac{X_{R.E}}{Horizontal\_Width\_of\_Base} > 0.167$

(75% Base in Compression, Resultant within Middle Half)

INPUT PARAMETERS

Headwater Elevation: $HW_{E2} := 1216.60m$

Tailwater Elevation: $TW_{E2} := 1214.10m$

(Water Elevations based on Diversion Structure 2D Hydraulic Model Results. See page 6 and Section 8.2, Design Criteria)

Crest Water Elevation, EL.1214.90 $CrestW_{E2} := 3.4 \cdot m$

Chute Block Water Elevation EL.1209.26 $ChuteW_{E2} := 1.76 \cdot m$ $\quad TW_{E2} := TOC_{fce} + ChuteW_{E2} = 1209.3\,m$

Bottom of Key (Footing Heel) Elevation: $BOF_{elev} = 1204.00\,m$

Apron Slab Top of Concrete Elevation at Edge of Slab: $TOC_{as} = 1210.00\,m$

Fixed Crest Top of Concrete Elevation at Downstream Face: $TOC_{fce} = 1207.50\,m$

Fixed Crest Top of Concrete Elevation at Center of Footing: $TOC_{fcc} = 1211.50\,m$

Lift Gate Position per Hydraulic Criteria $poss_{E2} := 0$ poss = 1 if gate is closed, 0 if gate is open

$$Gate_{R.E2} := \begin{cases} 0 & \text{if } poss_{E2} = 0 \\ 0.60 & \text{otherwise} \end{cases}$$

$$\Sigma V_{DL.E2} := D_{conc} + Gate_{R.E2} D_{Gate} = 25408.2 \cdot kN$$

$$\Sigma M_{DL.E2} := D_{conc} \cdot X_{conc.loc} + Gate_{R.E2} \cdot D_{Gate} \cdot X_{gate} = 322889.4 \cdot kN \cdot m$$

LATERAL WATER LOADS

E2 CASE

HEADWATER (DRIVING):

Water Depth Above Fixed Crest at Gate: $D_{hwg.E2} := HW_{E2} - TOC_{fcc} = 5.1\,m$

Water Load Unit Width on Gate $W_{hwg.E2} := 0m = 0.00$

Apply Load to Gate?: $poss_{E2} = 0$ poss = 1 if gate is closed
0 if gate is open

Total Horizontal Water Load on Gate: $H_{hwg.E2} := \frac{-\left(\gamma_w \cdot D_{hwg.E2}^{\;2}\right)}{2} \cdot W_{hwg.E2} \cdot poss_{E2} = 0 \cdot kN$

Apply Total Gate Water Load at: $H_{hwg.E2.loc} := \frac{D_{hwg.E2}}{3} + \left(TOC_{fcc} - BOF_{toe}\right) = 7.70\,m$

Water Depth at Heel: $D_{hwf.E2} := HW_{E2} - BOF_{elev} = 12.60\,m$

Water Load Unit With on Footing: $W_{hw.E2} := W_b$

Water Load at Bottom of Footing: $H_{hwf.E2.1} := -\left(\gamma_w \cdot D_{hwf.E2}\right) \cdot W_{hw.E2} = -1483.3\,\frac{1}{m} \cdot kN$

Water Load at Top of Footing: $H_{hwf.E2.2} := -\left(\gamma_w \cdot D_{hwg.E2}\right) \cdot W_{hw.E2} = -600.4\,\frac{1}{m} \cdot kN$

Total Horizontal Water Load on Footing:

$$H_{hwf.E2} := \frac{\left(H_{hwf.E2.1} + H_{hwf.E2.2}\right) \cdot \left(D_{hwf.E2} - D_{hwg.E2}\right)}{2} = -7813.7 \cdot kN$$

Apply Total Footing Water Load at:

$$H_{hwf.E2.loc} := \frac{\left[H_{hwf.E2.2} \cdot \frac{\left(TOC_{fcc} - BOF_{elev}\right)^2}{2} + \frac{\left(H_{hwf.E2.1} - H_{hwf.E2.2}\right)}{2} \cdot \frac{\left(TOC_{fcc} - BOF_{elev}\right)^2}{3}\right]}{\frac{\left(H_{hwf.E2.2} + H_{hwf.E2.1}\right) \cdot \left(TOC_{fcc} - BOF_{elev}\right)}{2}} - \left(BOF_{toe} - BOF_{elev}\right) = 1.72\,m$$

Converting horizontal force resultant from HEEL calculation to Point-O@TOE

LATERAL WATER LOADS (cont.)

E2 CASE

TAILWATER (RESISTING):

Water Depth at toe: $D_{tw.E2} := TW_{E2} - BOF_{elev} = 5.26\,m$

Water Load Unit Width: $W_{twf.E2} := W_b$

Total Horizontal Tailwater Load on Footing under Gate Openings, i.e., excluding Pier

Resisting Water on Rear Face of Monolith, i.e., bottom of heel elevation:

$COND_{E2} := poss_{E2} = 0 \wedge TW_{E2} \geq TOC_{fcc}$

$$H_{twf.E2} := \begin{cases} \dfrac{\gamma_w \cdot D_{tw.E2}^{\,2}}{2} \cdot \left(W_{twf.E2}\right) & \text{if } poss_{E2} = 1 \\ \dfrac{\gamma_w \cdot D_{tw.E2}^{\,2}}{2} \cdot \left(W_{twf.E2}\right) & \text{if } poss_{E2} = 0 \wedge TW_{E2} \leq TOC_{fcc} \\ \gamma_w \cdot \left[\dfrac{D_{tw.E2}}{2} + \dfrac{\left(TW_{E2} - TOC_{fcc}\right)}{2}\right] \cdot \left(TOC_{fcc} - BOF_{elev}\right) \cdot \left(W_{twf.E2}\right) & \text{if } COND_{E2} \end{cases} = 1628.5 \cdot kN$$

Apply Footing Tailwater Load within Gate Openings at:

$$H_{twf.E2.loc} := \begin{cases} \dfrac{D_{tw.E2}}{3} - \left(BOF_{toe} - BOF_{elev}\right) & \text{if } poss_{E2} = 1 \\ \dfrac{D_{tw.E2}}{3} - \left(BOF_{toe} - BOF_{elev}\right) & \text{if } poss_{E2} = 0 \wedge TW_{E2} \leq TOC_{fcc} \\ \dfrac{\gamma_w \cdot \left[\left(TW_{E2} - TOC_{fcc}\right) \cdot \dfrac{\left(TOC_{fcc} - BOF_{elev}\right)^2}{2} + \dfrac{\left(TOC_{fcc} - BOF_{elev}\right)^3}{6}\right] \cdot W_{twf.E2}}{\gamma_w \left[\left(TW_{E2} - TOC_{fcc}\right) \cdot \left(TOC_{fcc} - BOF_{elev}\right) + \dfrac{\left(TOC_{fcc} - BOF_{elev}\right)^2}{2}\right] \cdot W_{twf.E2}} - \left(BOF_{toe} - BOF_{elev}\right) & \text{if } COND_{E2} \end{cases} = 0.25 \cdot m$$

$\Sigma H_{Water.E2} := H_{hwg.E2} + H_{hwf.E2} + H_{twf.E2} = -6185.2 \cdot kN$

$$\Sigma M_{HWater.E2} := H_{hwg.E2} \cdot H_{hwg.E2.loc} + H_{hwf.E2} \cdot H_{hwf.E2.loc} \ldots + H_{twf.E2} \cdot H_{twf.E2.loc} = -13029.6 \cdot kN \cdot m$$

VERTICAL WATER LOADS

E2 CASE

HEADWATER:

Water Depth on top of fixed crest: $d_{hw.E2} := HW_{E2} - TOC_{as} = 6.60\,m$

Weight of Water (H1) on Approach Slab: $H_{1.E2} := \left(W_{hw.E2} \cdot d_{hw.E2} \cdot L_{as}\right) \cdot \gamma_w = 4817.1 \cdot kN$

Horiz. Moment Arm for H1 (from toe): $H_{1.E2.loc} := L_b - \frac{L_{as}}{2} = 21.10\,m$

Cross-sectional Area of
Headwater Above Fixed Crest: $A_{fc.hw.E2} := 30.44m^2$

(From Bluebeam Measurement, Bound by Energy Line through Crest Water Elevation CrestW and Chute Block Water Elevation ChuteW as defined above)

Volume of water Above Fixed Crest: $V_{fc.hw.E2} := \left[A_{fc.hw.E2} \cdot \left(W_{hw.E2}\right)\right] = 365.3 \cdot m^3$

Weight of Water (H2) on Fixed Crest: $H_{2.E2} := \left(V_{fc.hw.E2}\right) \cdot \gamma_w = 3583.4 \cdot kN$

Horiz. Moment Arm for H2 (from toe): $H_{2.E2.loc} := 14.25 \cdot m = 14.25\,m$

TAILWATER:

Slope of Crest from
D/S of Gate to edge of Stilling Basin: $S_{f.E2} := S_{f.U1} = 0.500$

Height of Tailwater Above Stilling Basin: $y_{E2} := TW_{E2} - TOC_{fce} = 1.8\,m$

Cross Sectional Area of Tailwater
Above Sloped Portion of Crest: $A_{tw.E2} := 29.22 \cdot m \cdot m = 29.2\,m^2$ (From Bluebeam Measurement)

(From Bluebeam Measurement, Bound by Energy Line through Crest Water Elevation CrestW and Chute Block Water Elevation ChuteW as defined above)

Weight of Water (H3)
Above Slope Portion of Crest: $H_{3.E2} := \left(A_{tw.E2} \cdot W_{twf.E2}\right) \cdot \gamma_w$ $H_{3.E2} = 3439.8 \cdot kN$

Horiz. Moment Arm for H3 (from Toe): $H_{3.E2.loc} := 5.689 \cdot m$ (From Bluebeam Measurement)

UPLIFT AT INCLINED SLIDING PLANE

E2 CASE

Uplift pressure at Headwater: $U_{HW.E2} := D_{hwf.E2} \cdot \gamma_w = 123.61 \cdot \frac{kN}{m^2}$

Uplift pressure at D/S end of Stilling Basin: $U_{TW.E2} := D_{tw.E2} \cdot \gamma_w = 51.6 \cdot \frac{kN}{m^2}$

Length from U/S Face of Gate Structure to Toe Point(Effective Drain at end of Monolith) $L_{overall} = 24.20\,m$ $L_{sb} = 0$

Length of Seepage per Line of Creep $L_{seepage} = 27.1\,m$

Difference between Uplift pressure at Headwater and Uplift Pressure at Toe of Stilling Basin: $U_{diffE2} := U_{HW.E2} - U_{TW.E2} = 72 \cdot \frac{kN}{m^2}$

Slope of difference between Uplift pressure at Headwater and Uplift Pressure at Toe of Stilling Basin: $U_{slopeE2} := \frac{U_{diffE2} - Key_d \cdot \gamma_w}{L_{overall}} = 2.37 \cdot \frac{kN}{m^2 \cdot m}$

$$U_{seepageslopeE2} := \frac{U_{diffE2} - Key_d \cdot \gamma_w}{L_{seepage}}$$

Tailwater Pressure at toe of Gate Structure: $U_{press.toe.gsE2} := U_{TW.E2} + L_{sb} \cdot U_{slopeE2} = 51.6 \cdot \frac{kN}{m^2}$

$$U_{pore.toe.E2} := U_{TW.E2} + U_{seepageslopeE2} \cdot L_{sb} = 51.6 \cdot \frac{kN}{m^2}$$

$$U_{pore.F.E2} := U_{pore.toe.E2} + U_{seepageslopeE2} \cdot L_{FG} = 54.8 \cdot \frac{kN}{m^2}$$

$$U_{pore.E.E2} := U_{pore.F.E2} - \left(BOF_{base} - BOF_{toe}\right) \cdot \gamma_w + U_{seepageslopeE2} \cdot L_{EF} = 47.1 \cdot \frac{kN}{m^2}$$

$$U_{pore.D.E2} := U_{pore.E.E2} + U_{seepageslopeE2} \cdot L_{DE} = 85.6 \cdot \frac{kN}{m^2}$$

$$U_{pore.C.E2} := U_{pore.D.E2} + \left(BOF_{base} - BOF_{elev}\right) \cdot \gamma_w + U_{seepageslopeE2} \cdot L_{CD} = 121.5 \cdot \frac{kN}{m^2}$$

Uniform uplift due to Tailwater: (rectangular portion) $U_{A.E2} := U_{press.toe.gsE2} \cdot L_b \cdot W_b \cdot -1 = -14984.8 \cdot kN$

Moment Arm for Uplift UA from Toe of Gate Structure: $L_{A.E2} := \frac{L_b}{2} = 12.10\,m$

Uplift - Linear Decrease from HW to TW: (triangular portion) $U_{B.E2} := \frac{1}{2} \cdot \left(U_{HW.E2} - U_{press.toe.gsE2}\right) \cdot L_b \cdot W_b \cdot -1 = -10455.2 \cdot kN$

Moment Arm for Uplift UB from Toe of Gate Structure: $L_{B.E2} := \frac{2}{3} \cdot L_b = 16.13\,m$

Total Resultant Uplift force: $U_{E2} := U_{A.E2} + U_{B.E2} = -25440 \cdot kN$

Resultant Location from Toe: $U_{E2.loc} := \frac{U_{A.E2} \cdot L_{A.E2} + U_{B.E2} \cdot L_{B.E2}}{U_{A.E2} + U_{B.E2}} = 13.76\,m$

E2 CASE

$$\Sigma V_{water.E2} := H_{1.E2} + H_{2.E2} + H_{3.E2} + U_{E2} = -13599.7 \cdot kN$$

$$\Sigma M_{Vwater.E2} := H_{1.E2} \cdot H_{1.E2.loc} + H_{2.E2} \cdot H_{2.E2.loc} + H_{3.E2} \cdot H_{3.E2.loc} + U_{E2} \cdot U_{E2.loc} = -177720.1 \cdot kN \cdot m$$

Uplift as per Line of Creep Method
(Flotation and Overturning)

$$Uplift_{BC.E2} := \frac{-1}{2} \cdot W_b \cdot \left(U_{HW.E2} + U_{pore.C.E2}\right) \cdot L_{BC} = -1470585.9\, N$$

$$Uplift_{CD.E2} := 0$$

$$Uplift_{DE.E2} := \frac{-1}{2} \cdot W_b \cdot \left(U_{pore.D.E2} + U_{pore.E.E2}\right) \cdot L_{DE} = -14502027.8\, N$$

$$Uplift_{EF.E2} := \frac{-1}{2} \cdot W_b \cdot \left(U_{pore.E.E2} + U_{pore.F.E2}\right) \cdot L_{EF} = -2050399.6\, N$$

$$Uplift_{FG.E2} := \frac{-1}{2} \cdot W_b \cdot \left(U_{pore.F.E2} + U_{pore.toe.E2}\right) \cdot L_{FG} = -957354.5\, N$$

$$Uplift_{pore.E2} := Uplift_{BC.E2} + Uplift_{DE.E2} + Uplift_{EF.E2} + Uplift_{FG.E2} = -18980.4 \cdot kN$$

$$Uplift_{FG.E2.loc} := \frac{L_{FG}}{3} \cdot \frac{\left(2 \cdot U_{pore.F.E2} + U_{pore.toe.E2}\right)}{\left(U_{pore.F.E2} + U_{pore.toe.E2}\right)} = 0.76\, m$$

$$Uplift_{EF.E2.loc} := \frac{L_{EF}}{3} \cdot \frac{\left(2 \cdot U_{pore.E.E2} + U_{pore.F.E2}\right)}{\left(U_{pore.E.E2} + U_{pore.F.E2}\right)} + L_{FG} = 3.13\, m$$

$$Uplift_{DE.E2.loc} := \frac{L_{DE}}{3} \cdot \frac{\left(2 \cdot U_{pore.D.E2} + U_{pore.E.E2}\right)}{\left(U_{pore.D.E2} + U_{pore.E.E2}\right)} + L_{FG} + X_{EF} = 14.48\, m$$

$$Uplift_{BC.E2.loc} := \frac{L_{BC}}{3} \cdot \frac{\left(2 \cdot U_{HW.E2} + U_{pore.C.E2}\right)}{\left(U_{HW.E2} + U_{pore.C.E2}\right)} + L_{FG} + X_{EF} + L_{DE} = 23.20\, m$$

E2 CASE

SOIL LOADS

Equivalent Fluid Pressure (EFP):

At rest lateral pressure coefficient: $K_o = 0.66$

(CFEM 24.1)

At-rest Soil Pressure to Heel, EM1110--2-2502 Section 3-7

Lateral Driving Force (Headwater Side)

Depth of Fill at Heel: $t_{hf.E2} := TOC_{as} - BOF_{elev} = 6.00\,m$

At-Rest Soil Load: $E2_{drive.E1} := \frac{K_o \cdot t_{hf.E2}^{2}}{2} \cdot (\gamma_r - \gamma_w) \cdot W_b \cdot -1 = -1732.5 \cdot kN$

Acting at: $E2_{drive.loc.E1} := \frac{t_{hf.E2}}{3} - (BOF_{toe} - BOF_{elev}) = 0.50\,m$

Lateral Resisting Force (Tailwater Side)

Depth of Fill at Toe: $t_{tf.E2} := TOC_{fce} - BOF_{elev} = 3.50\,m$

At-Rest Soil Load: $E2_{resistE2} := \frac{K_o \cdot t_{tf.E2}^{2}}{2} \cdot (\gamma_r - \gamma_w) \cdot W_b = 589.5 \cdot kN$

$E2_{resistE2} := 0$

Acting at: $E2_{resistlocE2} := \frac{t_{tf.E2}}{3} = 1.17\,m$

(Expansion Joint to Stilling Basin, No Sediment in Gap)

$\Sigma H_{soil.E2} := E2_{drive.E1} + E2_{resistE2} = -1732.5 \cdot kN$

$\Sigma M_{soil.E2} := E2_{drive.E1} \cdot E2_{drive.loc.E1} + E2_{resistE2} \cdot E2_{resistlocE2} = -866.2 \cdot kN \cdot m$

ICE / IMPACT LOADS (CONSERVATIVELY ASSUME NO ICE LOADING ON DOWNSTREAM SIDE)

Static Impact Loading on Structure: $I_{S.E2} := 150.0 \frac{kN}{m}$ (Section 7.7, Design Criteria)

Static Impact load on Gates: $I_{G.E2} := 75 \frac{kN}{m}$ (Section 7.7, Design Criteria)

Impact Loading Unit Width on Structure: $W_{S.E2} := 0m$

Impact Loading Unit Width on Gates: $W_{G.E2} := 0m = 0.00$

Total Impact Load on Structure: $I_{E2} := (I_{S.E2} \cdot W_{S.E2} + I_{G.E2} \cdot W_{G.E2}) \cdot -1 = 0 \cdot kN$

Apply Ice load at: $I_{E2.loc} := (HW_{E2} - BOF_{elev} - 0.30m) = 12.30\,m$

$\Sigma H_{I.E2} := I_{E2} = 0 \cdot kN$

$\Sigma M_{I.E2} := I_{E2} \cdot I_{E2.loc} = 0 \cdot kN \cdot m$

SEISMIC LOAD (Not Applicable to this Load Case)

E2 CASE

SUMMARY OF LOADS

	Loads	Moment Arm
Dead Load of Concrete Structure:	$D_{conc} = 25408.2 \cdot kN$	$X_{conc.loc} = 12.71\ m$
Dead Load of Gate:	$D_{Gate} = 580.0 \cdot kN$	$X_{gate} = 8.75\ m$
Headwater Lateral Load on Gate:	$H_{hwg.E2} = 0.0 \cdot kN$	$H_{hwg.E2.loc} = 7.70\ m$
Headwater Lateral Load on Footing:	$H_{hwf.E2} = -7813.7 \cdot kN$	$H_{hwf.E2.loc} = 1.72\ m$
Tailwater Lateral Load:	$H_{twf.E2} = 1628.5 \cdot kN$	$H_{twf.E2.loc} = 0.25\ m$
Water Weight (HW) on Apron Slab:	$H_{1.E2} = 4817.1 \cdot kN$	$H_{1.E2.loc} = 21.10\ m$
Water Weight (HW) on Fixed Crest:	$H_{2.E2} = 3583.4 \cdot kN$	$H_{2.E2.loc} = 14.25\ m$
Water Weight (TW) on Fixed Crest:	$H_{3.E2} = 3439.8 \cdot kN$	$H_{3.E2.loc} = 5.69\ m$
Uplift:	$U_{E2} = -25440.0 \cdot kN$	$U_{E2.loc} = 13.76\ m$
Upstream (driving) Lateral Soil Load:	$E2_{drive.E1} = -1732.5 \cdot kN$	$E2_{drive.loc.E1} = 0.50\ m$
Downstream (resisting) Lateral Soil Load:	$E2_{resistE2} = 0 \cdot kN$	$E2_{resistlocE2} = 1.17\ m$
Ice / Impact Load:	$I_{E2} = 0.0 \cdot kN$	$I_{E2.loc} = 12.30\ m$

STABILITY ASSESSMENT (SLIDNG, OVERTURNING AND BEARING): E2 CASE

CHECK SLIDING ALONG HORIZONTAL PLANE THRU TOE,
IGNORING BEDROCK MOBILIZED BY STRUCTURAL HEEL KEY , OR VOID BEHIND KEY

Sum of Vertical Forces: $\Sigma V_{E2} := \Sigma V_{DL.E2} + \Sigma V_{water.E2} = 11808.5 \cdot kN$

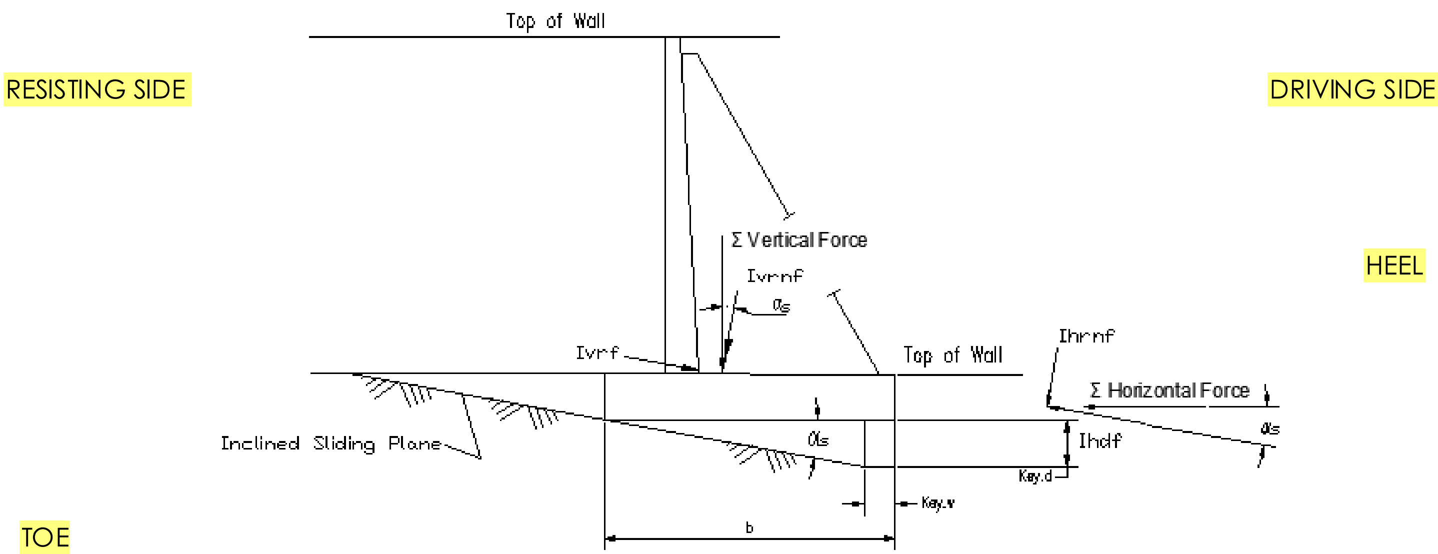
Sum of Horizontal Forces: $\Sigma H_{E2} := \Sigma H_{Water.E2} + \Sigma H_{soil.E2} + \Sigma H_{I.E2} = -7917.6 \cdot kN$

Sliding Factor of Safety: $FS_{HorizSliding.E2} := \dfrac{\left(\tan_{\phi} \cdot \Sigma V_{E2}\right)}{\left|\Sigma H_{E2}\right|} = 0.73$

$FS_{HorizSliding.E2.Check} :=$ | "OKAY" if $FS_{HorizSliding.E2} \geq FS_{req.E2.sl}$
"Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !" otherwise

$FS_{HorizSliding.E2.Check}$ = "Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !"

CHECK SLIDING ALONG INCLINED SLIDING PLANE FROM HEEL KEY TO TOE,
WITH BEDROCK MASS MOBILIZED BY REINFOCREDE CONCRETE KEY)



Ivrf=Inclined Resisting Force
Ivrnf=Inclined Resisting Normal Force
Ihrnf=Inclined Resisting Normal Force
Ihdf=Inclined Driving Force

$\alpha s := \operatorname{atan}\left(\dfrac{BOF_{toe} - BOF_{elev}}{L_b - Key_l}\right) = 0.12$ as degrees= $\alpha s \cdot \left(\dfrac{180}{\pi}\right) = 7.01$

Resolve $\Sigma Vert_{E2}$ & $\Sigma Horiz_{E2}$

$\Sigma V_{InclinedE2} := \cos(\alpha s) \cdot \left(\Sigma V_{E2} + V_{rs}\right) + \sin(\alpha s) \cdot \left|\Sigma H_{E2}\right| = 24975.5 \cdot kN$

$\Sigma H_{InclinedE2} := \cos(\alpha s) \cdot \left|\Sigma H_{E2}\right| - \sin(\alpha s) \cdot \left(\Sigma V_{E2} + V_{rs}\right) = 4906.5 \cdot kN$

(With properly engineered reinforced concrete Key, horizontal sliding plane thru Toe is protected, critical sliding plane is relocated to the INCLINED SLIDING PLANE FROM HEEL KEY To TOE, Bedrock Mass above this examing plane is mobilized by reinforced concrete key and combined into Structural Wedge.)

Inclined Sliding Plane Length $L_{incline} = 24.2 m$

Safety Factor for Sliding
Inclined Failure Plane

$FS_{InclinedlSlidingE2} := \dfrac{\Sigma V_{InclinedE2} \cdot \tan\left(\phi_{rock} \cdot \dfrac{\pi}{180}\right)}{\left|\Sigma H_{InclinedE2}\right|} = 2.48$

$FS_{InclinedSliding.check.E2} :=$ | "OKAY " if $FS_{InclinedlSlidingE2} > FS_{req.E2.sl}$ = "OKAY "
"Revise Structure"" otherwise

$FS_{InclinedSliding.check.E2}$ = "OKAY "

CHECK ECCENTRICITY ON INCLINED PLANE

E2 CASE

Sum of the Moments:

$$\Sigma M_{rs.E2} := \Sigma M_{DL.E2} + \Sigma M_{HWater.E2} + \Sigma M_{Vwater.E2} + \Sigma M_{I.E2} + \Sigma M_{soil.E2} + V_{rs} \cdot L_{rs} = 302263 \cdot kN \cdot m$$

Eccentricity:

$$e_{E2} := \frac{L_{incline}}{2} - \frac{\Sigma M_{rs.E2}}{\Sigma V_{InclinedE2}} = 0.02\,m$$

Eccentricity Check:

$$e_{check.E2} := \begin{cases} \text{"Okay"} & \text{if } \left|e_{E2}\right| \le Ecc_{midhalf} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$e_{check.E2} = \text{"Okay"}$

Foundation Bearing Pressures on Inclined Plane:

Bearing Pressure at Heel:

$$\sigma_{heel.E2} := \frac{\Sigma V_{InclinedE2}}{\dfrac{A_b}{\cos(\alpha s)}} - \frac{\Sigma V_{E2} \cdot e_{E2}}{\dfrac{S_b}{\cos(\alpha s)^2}} = 85.2 \cdot \frac{kN}{m^2}$$

$$\sigma_{heel.E2.check} := \left(\begin{cases} \text{"Okay"} & \text{if } \sigma_{heel.E2} \le \sigma_{allow.E2} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} \right)$$

$\sigma_{heel.E2.check} = \text{"Okay"}$

Bearing Pressure at Toe:

$$\sigma_{toe.E2} := \frac{\Sigma V_{InclinedE2}}{\dfrac{A_b}{\cos(\alpha s)}} + \frac{\Sigma V_{InclinedE2} \cdot e_{E2}}{\dfrac{S_b}{\cos(\alpha s)^2}} = 85.8 \cdot \frac{kN}{m^2}$$

$$\sigma_{toe.E2.check} := \begin{cases} \text{"Okay"} & \text{if } \sigma_{toe.E2} \le \sigma_{allow.E2} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$\sigma_{toe.E2.check} = \text{"Okay"}$

CHECK FLOTATION

$$Uplift_{sliding.E2} := U_{E2} = -25440 \cdot kN$$

$$Uplift_{pore.E2} = -18980.4 \cdot kN$$

$$\left(Uplift_{E2}\right) := \min\left(Uplift_{pore.E2}, Uplift_{sliding.E2}\right)$$

(For conservative, taking maximum values)

$$FS_{Flotation.E2} := \frac{D_{conc} + D_{Gate} + H_{1.E2} + H_{2.E2} + H_{3.E2}}{\left|Uplift_{E2}\right|} = 1.49$$

$$FS_{Flotation.E2.check} := \begin{cases} \text{"OKAY "} & \text{if } FS_{Flotation.E2} > FS_{req.E.flt} \\ \text{"Revise Structure""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

MONOLITH OVERTURNING STABILITY ANALYSIS

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.
Assumptions are made in order to compute overturning stability of indetermine forces on monolith with key;
(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.
(b) The horizontal resisting force acting on the key, P.key, is that required for static equilibrium
(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1 $Ratio_{overturning.allow.Extreme} = 0.167$ Resultant within Middle Half

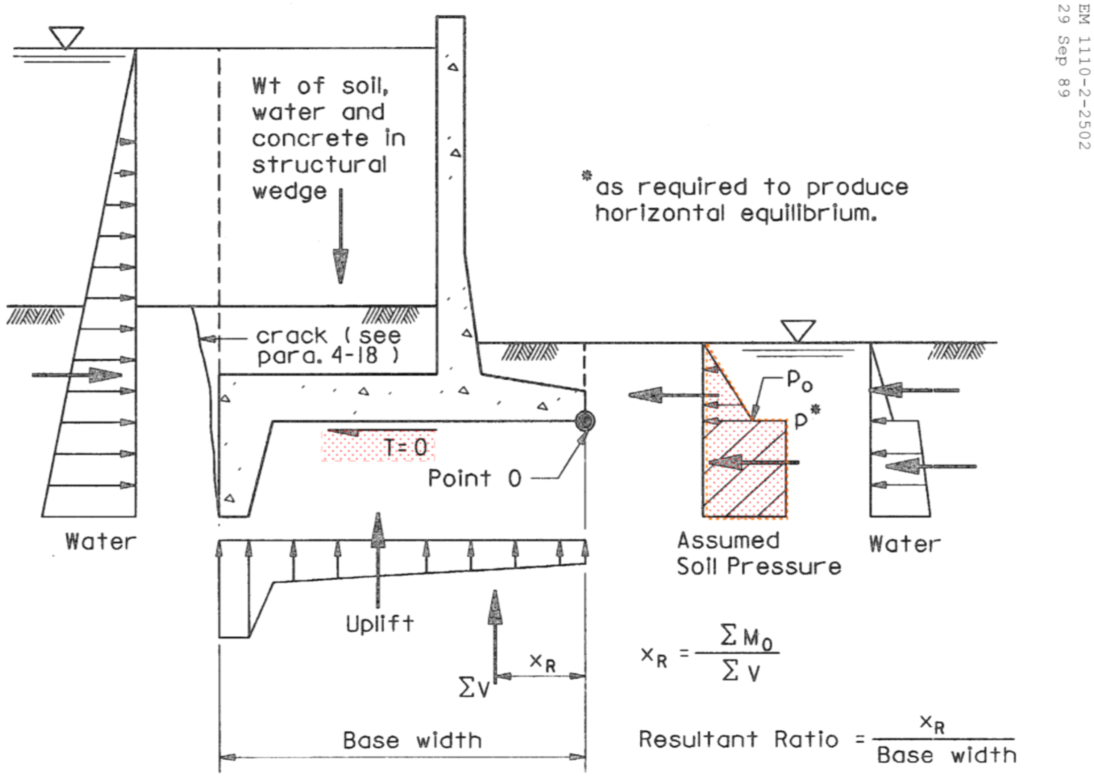


Figure 4-5. Forces for overturning analysis for wall with horizontal base and key

All Vertical Loads Applicable to Overturning Stability Analysis

Total Concrete Dead Loads:	$D_{conc} = 25408.2 \cdot kN$	at:	$X_{conc.loc} = 12.7\,m$
Dead Load of Gate:	$D_{Gate} = 580.0 \cdot kN$		$X_{gate} = 8.75\,m$
Water Weight (HW) on Apron Slab:	$H_{1.E2} = 4817.1 \cdot kN$		$H_{1.E2.loc} = 21.10\,m$
Water Weight (HW) on Fixed Crest:	$H_{2.E2} = 3583.4 \cdot kN$		$H_{2.E2.loc} = 14.25\,m$
Water Weight (TW) on Fixed Crest:	$H_{3.E2} = 3439.8 \cdot kN$		$H_{3.E2.loc} = 5.69\,m$

Uplift Force from Sliding Analysis. Line of Creep Method applied at presumed inclined sliding line, and subtraction gravity effect to Base of Concrete by Archimedes Principle

$$U_{E2.loc.sliding} := \frac{U_{A.E2} \cdot L_{A.E2} + U_{B.E2} \cdot L_{B.E2} - A_{rs} \cdot w_{as} \cdot \gamma_w \cdot L_{rs}}{U_{A.E2} + U_{B.E2} - A_{rs} \cdot w_{as} \cdot \gamma_w} = 13.77\,m$$

$$U_{E2.sliding} := U_{E2} + A_{rs} \cdot w_{as} \cdot \gamma_w = -19918.9 \cdot kN$$

E2 CASE

Uplift for Overturning Analysis, Line of Creep Method. Pore pressure at base of Concrete

$Uplift_{pore.E1} = -17756.3 \cdot kN$

$$Uplift_{pore.E2.loc} := \frac{Uplift_{BC.E2} \cdot Uplift_{BC.E2.loc} + Uplift_{DE.E2} \cdot Uplift_{DE.E2.loc} \cdots + Uplift_{EF.E2} \cdot Uplift_{EF.E2.loc} + Uplift_{FG.E2} \cdot Uplift_{FG.E2.loc}}{Uplift_{pore.E2}}$$

$Uplift_{pore.E2.loc} = 13.2 m$

Sum of All Water Load for Overturning Analysis

$\Sigma V_{water.E2.OT} := H_{1.E2} + H_{2.E2} + H_{3.E2} + Uplift_{pore.E2} = -7140.1 \cdot kN$

All Lateral Loads Applicable to Overturning Stability Analysis

Apply Load to Gate?: $poss_{E2} = 0$ — poss = 1 if gate is closed, 0 if gate is open

Headwater Lateral Load on Gate: $H_{hwg.E2} = 0.0 \cdot kN$ $H_{hwg.E2.loc} = 7.70 m$

Headwater Lateral Load on Footing: $H_{hwf.E2} = -7813.7 \cdot kN$ $H_{hwf.E2.loc} = 1.72 m$

Total Horizontal Tailwater Load on Footing under Gate Openings, i.e., excluding Pier: $H_{twf.E2} = 1628.5 \cdot kN$ $H_{twf.E2.loc} = 0.25 m$

Resisting Water on Rear Face of Monolith, i.e., bottom of heel elevation: *(Point O @ TOE: BOFtoe = EL.1205.5)*

Ice / Impact Load: $I_{E2} = 0.0 \cdot kN$ at: $I_{E2.loc} = 12.30 m$

Depth of Fill at Heel Side for Overturning Analysis: $t_{hf.E1} := TOC_{as} - BOF_{toe} = 4.50 m$

Driving Soil Load for overturning: $$E1_{drive.E2} := \frac{K_o \cdot t_{hf.E2}^{2}}{2} \cdot (\gamma_r - \gamma_w) \cdot W_b \cdot -1 = -974.5 \cdot kN$$

Acting at: $$E1_{drive.loc.E2} := \frac{t_{hf.E2}}{3} = 1.50 m$$

Downstream (resisting) Lateral Soil Load as required to produce horizontal equilibrium:

$E2_{resistE2} := -1 \cdot (H_{hwg.E2} + H_{hwf.E2} + H_{twf.E2} + I_{E2} + E1_{drive.E2})$

$E2_{resistE2} = 7159.7 \cdot kN$

Assumed Resisting Bedrock at middle of Key, passive soil pressure or lateral bearing on contract joint at end of Monolith 3A3B: $E2_{resistlocE2} := E2_{resistlocU1} = -0.75 m$

Overturning moment by Dead Loads about Point O @ Toe: $\Sigma M_{DL.E2} = 322889.4 \cdot kN \cdot m$

Overturning moment by Vertical Water Loads and Uplift, about Point O @ Toe

$\Sigma M_{Vwater.E2.OT} := H_{1.E2} \cdot H_{1.E2.loc} + H_{2.E2} \cdot H_{2.E2.loc} + H_{3.E2} \cdot H_{3.E2.loc} + Uplift_{pore.E2} \cdot Uplift_{pore.E2.loc} = -79005.6 \cdot kN \cdot m$

Overturning moment by Lateral Hydrostatic Forces of Headwater Pool and Tailwater Pool, about Point O @ Toe: $\Sigma M_{HWater.E1} = -16066.3 \cdot kN \cdot m$

Overturning Moment by Impact/Ice Load, about Point O@ Toe: $\Sigma M_{I.E2} = 0 \cdot kN \cdot m$

Overturning moment by Lateral Soil Forces
about Point O @ Toe

$$\Sigma M_{soil.E2} := E1_{drive.E2} \cdot E1_{drive.loc.E2} + E2_{resistE2} \cdot E2_{resistlocE2} = -6831.5 \cdot kN \cdot m$$

Sum of the Overturning Moments about Point O @ Toe:

$$\Sigma M_{E2.OT} := \Sigma M_{DL.E2} + \Sigma M_{HWater.E2} + \Sigma M_{Vwater.E2.OT} + \Sigma M_{I.E2} + \Sigma M_{soil.E2} = 224023 \cdot kN \cdot m$$

Sum of Vertical Forces:

$$\Sigma V_{E2.OT} := \Sigma V_{DL.E2} + \Sigma V_{water.E2.OT} = 18268.1 \cdot kN$$

Distance X_R: EM 1110-2-2502 Eq.4-1

$$X_{R.E2} := \frac{\Sigma M_{E2.OT}}{\Sigma V_{E2.OT}} = 12.3 m$$

Overturning Resultant Ratio

$$Ratio_{Overturning.E2} := \frac{X_{R.E2}}{L_b} = 0.51$$

EM 1110-2-2502

Table 4-1

Retaining Wall Stability Criteria

Loading Condition	Sliding Factor of Safety, FS	Shear Strength Test Required: Soil Foundation	Shear Strength Test Required: Rock Foundation[3]	Overturning Criteria Minimum Base Area in Compression: Soil Foundation	Overturning Criteria Minimum Base Area in Compression: Rock Foundation
Usual	1.5	(Q &/or S)[2,1]	Direct shear	100%[4]	75%[4]
Unusual	1.33	(Q &/or S)[2,1]	Direct shear	75%[4]	50%[4]
Earthquake	1.1	(Q)	Direct shear	Resultant within base	Resultant within base

Overturning Stability Check

$$Ratio_{Overturning.E2.check} := \begin{cases} \text{"Okay"} & \text{if } Ratio_{Overturning.E2} \geq Ratio_{overturning.allow.Extreme} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$$Ratio_{Overturning.E2.check} = \text{"Okay"}$$

E2 CASE

Summary of Extreme Flood Results (Only Report Controlling Load Case)

E2 Event: PMF with Diversion

Horiz Sliding Factor of Safety: $FS_{HorizSliding.E2} = 0.73$

Horiz Sliding Factor of Safety Check: $FS_{HorizSliding.E2.Check} =$ "Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !"

Sliding Factor of Safety: $FS_{InclinedlSlidingE2} = 2.5$

Sliding Factor of Safety Check: $FS_{InclinedSliding.check.E2} =$ "OKAY "

Eccentricity: $e_{E2} = 0.02\,m$

Eccentricity Check: $e_{check.E2} =$ "Okay"

Bearing Pressure At Heel: $\sigma_{heel.E2} = 85.2 \cdot \frac{kN}{m^2}$

Bearing Pressure At Heel Check: $\sigma_{heel.E2.check} =$ "Okay"

Bearing Pressure At Heel: $\sigma_{toe.E2} = 85.8 \cdot \frac{kN}{m^2}$

Bearing Pressure At Toe Check: $\sigma_{toe.E2.check} =$ "Okay"

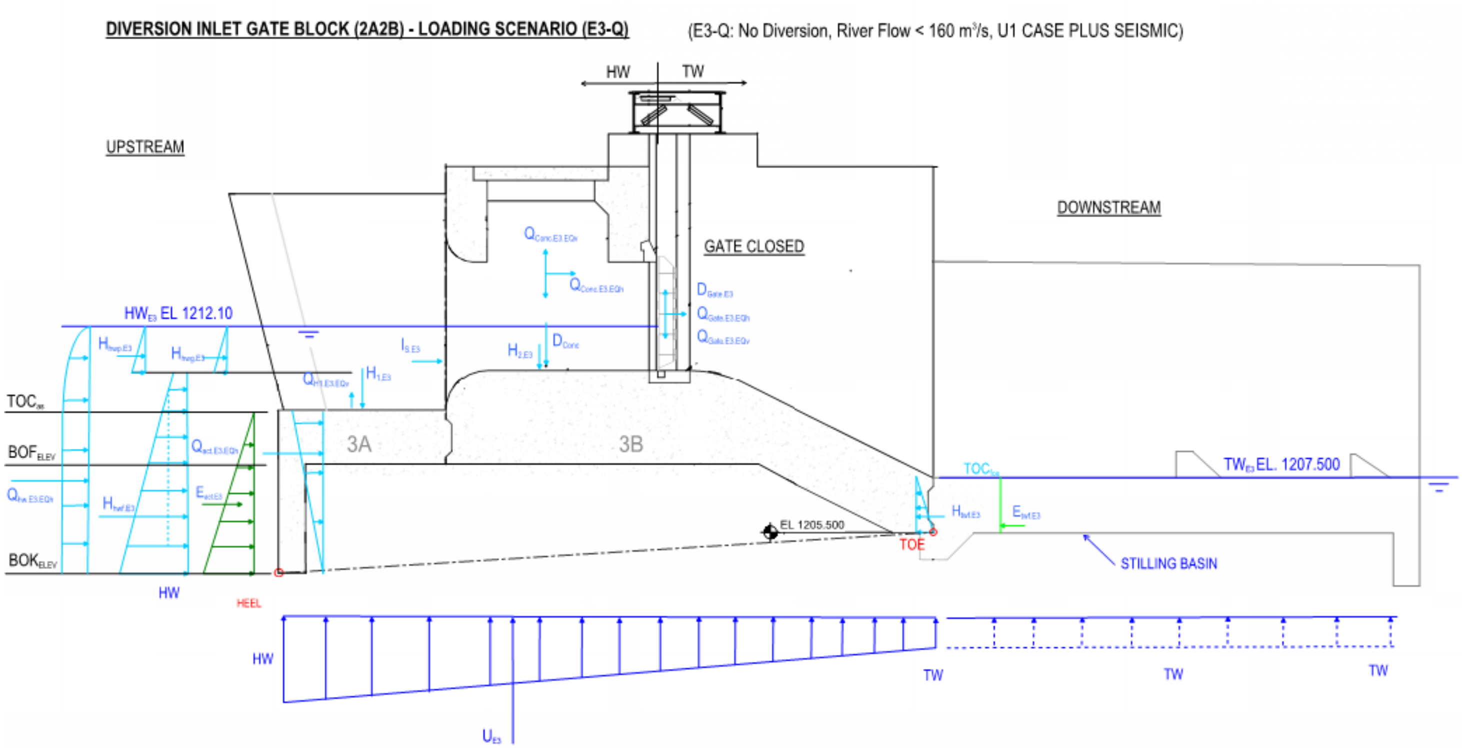
Flotation Factor of Safety $FS_{Flotation.E2} = 1.5$

Flotation Factor of Safety Check: $FS_{Flotation.E2.check} =$ "OKAY "

Overturning Resultant Ratio $Ratio_{Overturning.E2} = 0.51$

Overturning Stability Check $Ratio_{Overturning.E2.check} =$ "Okay"

E3 DESIGN CASE



E3 Case: U1 CASE PLUS SEISMIC

ACCEPTANCE PARAMETERS

Required Factor of Safety for Sliding:	$FS_{req.E3.sl} := 1.0$	(Without Cohesion) (Section 8.1, Design Criteria)
Resultant Within Middle Half of Base:	$e \le \frac{L_b}{4} \wedge e \ge \frac{-L_b}{4}$	
Allowable Rock Bearing Pressure:	$\sigma_{allow.E3} := 1740.0 \cdot \frac{kN}{m^2}$	(Section 5.2, Design Criteria)
Required Factor of Safety for Flotation:	$FS_{req.E.flt} = 1.1$	
Overturning Min Required Resultant Ratio:	$\frac{X_{R.E}}{Horizontal\_Width\_of\_Base} > 0.167$	

(75% Base in Compression, Resultant within Middle Half)

INPUT PARAMETERS

Headwater Elevation:	$HW_{E3} := 1212.10m$	(Water Elevations based on Diversion Structure 2D Hydraulic Model Results. See page 6 and Section 8.2, Design Criteria)
Tailwater Elevation:	$TW_{E3} := 1207.50m$	
Crest Water Elevation	(No Diversion)	
Chute Block Water Elevation	(No Diversion)	
Bottom of Footing Elevation:	$BOF_{elev} = 1204.00\,m$	
Apron Slab Top of Concrete Elevation at Edge of Slab:	$TOC_{as} = 1210.00\,m$	
Fixed Crest Top of Concrete Elevation at Downstream Face:	$TOC_{fce} = 1207.50\,m$	
Fixed Crest Top of Concrete Elevation at Center of Footing:	$TOC_{fcc} = 1211.50\,m$	

SEISMIC LOAD E3: EDGM Post-Seimic Assessment of Usual Load U1 Event (3 Load Cases)

Seismic Case $Q_{E3.1}$ - 100% Horizontal Seismic Force, No Vertical **E3.1 CASE**

Horizontal Seismic Coefficient: $K_{h.E3.1} := \frac{-2}{3} \cdot 0.26 = -0.17$

Vertical Seismic Coefficient: $K_{v.E3.1} := 0. \frac{-2}{3} \cdot 0.56 \cdot 0.26 = 0$

HORIZONTAL SEISMIC LOADS	Loads	Moment Arm
Horizontal Seismic Component of Concrete Structure:	$Q_{conc.E3.EQh.1} := D_{conc} \cdot K_{h.E3.1} = -4404.1 \cdot kN$	$Y_{conc.loc} = 3.17\,m$
Horizontal Seismic Component of Vertical Lift Gate:	$Q_{Gate.E3.EQh.1} := D_{Gate} \cdot K_{h.E3.1} = -100.5 \cdot kN$	$Y_{gate} = 8.00\,m$
Horizontal Seismic Component of Headwater on Gate: (Section 7.9, Design Criteria)	$Q_{hwg.E3.EQh.1} := \left(\frac{7}{12}\right) \cdot K_{h.E3.1} \cdot \gamma_w \cdot \left(D_{hwg.U1}\right)^2 \cdot W_{hwg.U1} \cdot poss_{U1} = 0 \cdot kN$	$Y_{HWg.E3} := 0.4 \cdot D_{hwg.U1} + \left(TOC_{fcc} - BOF_{elev}\right) = 7.74\,m$
Horizontal Seismic Component of Headwater on Footing: (Section 7.9, Design Criteria)	$Q_{hwf.E3.EQh.1} := \left(\frac{7}{12}\right) \cdot K_{h.E3.1} \cdot \gamma_w \cdot \left(D_{hwf.U1}\right)^2 \cdot W_{hw.U1} = -780.9 \cdot kN$	$Y_{HWf.E3} := 0.4 \cdot \left(TOC_{fcc} - BOF_{elev}\right) = 3.00\,m$
Horizontal Seismic Component of Active Soil: (Section 5-5, USACE EM_1110-2-2100)	$Q_{act.E3.EQh.1} := \gamma_r \cdot \left(TOC_{as} - BOF_{elev}\right)^2 \cdot K_{h.E3.1} \cdot W_{hw.U1} = -1647.4 \cdot kN$	$Y_{E.act.E3} := 0.63 \cdot \left(TOC_{as} - BOF_{elev}\right) = 3.78\,m$

VERTICAL SEISMIC LOADS	Loads	Moment Arm
Vertical Component of Concrete Structure:	$Q_{conc.E3.EQv.1} := D_{conc} \cdot K_{v.E3.1} = 0 \cdot kN$	$X_{conc.loc} = 12.71\,m$
Vertical Component of Vertical Lift Gate:	$Q_{Gate.E3.EQv.1} := D_{Gate} \cdot K_{v.E3.1} = 0 \cdot kN$	$X_{gate} = 8.75\,m$
Vertical Seismic Component of Headwater over Apron Slab: (Section 7.9, Design Criteria)	$Q_{H1.E3.EQv.1} := K_{v.E3.1} \cdot H_{1.U1} = 0 \cdot kN$	$H_{1.U1.loc} = 21.10\,m$
Vertical Seismic Component of Headwater over Fixed Crest Slab: (Section 7.9, Design Criteria)	$Q_{H2.E3.EQv.1} := K_{v.E3.1} \cdot H_{2.U1} = 0 \cdot kN$	$H_{2.U1.loc} = 14.25\,m$

$$\Sigma H_{Q.E3.EQh.1} := Q_{conc.E3.EQh.1} + Q_{Gate.E3.EQh.1} + Q_{hwg.E3.EQh.1} + Q_{hwf.E3.EQh.1} + Q_{act.E3.EQh.1} = -6932.9 \cdot kN$$

$$\Sigma V_{Q.E3.EQv.1} := Q_{conc.E3.EQv.1} + Q_{Gate.E3.EQv.1} + Q_{H1.E3.EQv.1} + Q_{H2.E3.EQv.1} = 0.0 \cdot kN$$

$$\Sigma M_{Q.E3.1} := Q_{conc.E3.EQh.1} \cdot Y_{conc.loc} + Q_{Gate.E3.EQh.1} \cdot Y_{gate} + Q_{hwg.E3.EQh.1} \cdot Y_{HWg.E3} \cdots + Q_{hwf.E3.EQh.1} \cdot Y_{HWf.E3} + Q_{act.E3.EQh.1} \cdot Y_{E.act.E3} + Q_{conc.E3.EQv.1} \cdot X_{conc.loc} + Q_{Gate.E3.EQv.1} \cdot X_{gate} \cdots + Q_{H1.E3.EQv.1} \cdot H_{1.U1.loc} + Q_{H2.E3.EQv.1} \cdot H_{2.U1.loc} = -23318.4 \cdot kN \cdot m$$

STABILITY ASSESSMENT:

E3.1 CASE

Seismic Case $Q_{E3.1}$: 100% Horizontal Seismic Force, No Vertical

CHECK **SLIDING** ALONG HORIZONTAL PLANE THRU TOE,
IGNORING BEDROCK MOBILIZED BY STRUCTURAL HEEL KEY, OR VOID BEHIND KEY

Sum of Vertical Forces: Sum of Horizontal Forces:

$\Sigma V_{E3.1} := \Sigma V_{U1} + \Sigma V_{Q.E3.EQv.1} = 11352.0 \cdot kN$ $\quad \Sigma H_{E3.1} := \Sigma H_{U1} + \Sigma H_{Q.E3.EQh.1} = -11785 \cdot kN$ $\quad \Sigma V_{U1} = 11351980.8\,N$

Sliding Factor of Safety: $FS_{HorizSliding.E3.1} := \dfrac{\tan_{\phi} \cdot \Sigma V_{E3.1}}{|\Sigma H_{E3.1}|} = 0.47$

$FS_{HorizSliding.E3.1.Check} := \begin{cases} \text{"OKAY"} & \text{if } FS_{HorizSliding.E3.1} \geq FS_{req.E3.sl} \\ \text{"Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !"} & \text{otherwise} \end{cases}$

$FS_{HorizSliding.E3.1.Check} =$ "Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !"

CHECK **SLIDING** ALONG INCLINED SLIDING PLANE FROM HEEL KEY TO TOE,
WITH BEDROCK MASS MOBILIZED BY REINFOCREDE CONCRETE KEY

$\alpha s := \operatorname{atan}\left(\dfrac{BOF_{toe} - BOF_{elev}}{L_b - Key_l}\right) = 0.12$ $\qquad$ as degrees= $\alpha s \cdot \left(\dfrac{180}{\pi}\right) = 7.01$

Resolve $\Sigma Vert_{E3.1}$ & $\Sigma Horiz_{E3.1}$

$\Sigma V_{InclinedE3.1} := \cos(\alpha s) \cdot \left(\Sigma V_{E3.1} + V_{rs}\right) + \sin(\alpha s) \cdot |\Sigma H_{E3.1}| = 24994.3 \cdot kN$

$\Sigma H_{InclinedE3.1} := \cos(\alpha s) \cdot |\Sigma H_{E3.1}| - \sin(\alpha s) \cdot \left(\Sigma V_{E3.1} + V_{rs}\right) = 8800.7 \cdot kN$

(With properly engineered reinforced concrete Key, horizontal sliding plane thru Toe is protected, critical sliding plane is relocated to the INCLINED SLIDING PLANE FROM HEEL KEY To TOE, Bedrock Mass above this examing plane is mobilized by reinforced concrete key and combined into Structural Wedge.)

Safety Factor for Sliding
Inclined Failure Plane

$FS_{InclinedlSlidingE3.1} := \dfrac{\Sigma V_{InclinedE3.1} \cdot \tan\left(\phi_{rock} \cdot \dfrac{\pi}{180}\right)}{|\Sigma H_{InclinedE3.1}|} = 1.39$

$FS_{Sliding.E3.1.InclinedCheck} := \begin{cases} \text{"OKAY "} & \text{if } FS_{InclinedlSlidingE3.1} > FS_{req.E3.sl} \\ \text{"Revise Structure""} & \text{otherwise} \end{cases} = \text{"OKAY "}$

$FS_{Sliding.E3.1.InclinedCheck} =$ "OKAY "

CHECK ECCENTRICITY ON INCLINED PLANE

E3.1 CASE

Seismic Case $Q_{E3.1}$: 100% Horizontal Seismic Force, No Vertical

Sum of the moments:

$$\Sigma M_{rs.E3.1} := \Sigma M_{DL.U1} + \Sigma M_{HWater.U1} + \Sigma M_{Vwater.U1} + \Sigma M_{I.U1} + \Sigma M_{soil.U1} + \Sigma M_{Q.E3.1} + V_{rs} \cdot L_{rs} = 282333 \cdot kN \cdot m$$

Eccentricity:

$$e_{E3.1} := \frac{L_{incline}}{2} - \frac{\Sigma M_{rs.E3.1}}{\Sigma V_{InclinedE3.1}} = 0.83\,m$$

Eccentricity Check:

$$e_{check.E3.1} := \begin{cases} \text{"Okay"} & \text{if } \left|e_{E3.1}\right| \le Ecc_{midhalf} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$e_{check.E3.1} = \text{"Okay"}$

Foundation Bearing Pressures on Inclined Plane:

Bearing Pressure at Heel:

$$\sigma_{heel.E3.1} := \begin{cases} 0 & \text{if } \left|e_{E3.1}\right| \ge Ecc_{midhalf} \\ \left(\dfrac{\Sigma V_{InclinedE3.1}}{\dfrac{A_b}{\cos(\alpha s)}} - \dfrac{\Sigma V_{InclinedE3.1} \cdot e_{E3.1}}{\dfrac{S_b}{\cos(\alpha s)^2}} \right) & \text{otherwise} \end{cases} = 68 \cdot \frac{kN}{m^2}$$

$$\sigma_{heel.E3.1.check} := \left(\begin{cases} \text{"Okay"} & \text{if } \sigma_{heel.E3.1} \le \sigma_{allow.E3} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} \right)$$

$\sigma_{heel.E3.1.check} = \text{"Okay"}$

Bearing Pressure at Toe:

$$\sigma_{toe.E3.1} := \begin{cases} \left[\dfrac{4}{3} \cdot \left(\dfrac{\dfrac{\Sigma V_{InclinedE3.1}}{W_b}}{L_{incline} - 2 \cdot e_{E3.1}} \right) \right] & \text{if } e_{E3.1} \ge Ecc_{midhalf} \\ \left[\dfrac{\Sigma V_{InclinedE3.1}}{\dfrac{A_b}{\cos(\alpha s)}} + \dfrac{\left(\Sigma V_{InclinedE3.1} \cdot e_{E3.1}\right)}{\dfrac{S_b}{\cos(\alpha s)^2}} \right] & \text{otherwise} \end{cases} = 102.8 \cdot \frac{kN}{m^2}$$

$$\sigma_{toe.E3.1.check} := \begin{cases} \text{"Okay"} & \text{if } \sigma_{toe.E3.1} \le \sigma_{allow.E3} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$\sigma_{toe.E3.1.check} = \text{"Okay"}$

Foundation Flotation Checks:

$$FS_{Flotation.E3.1} := \frac{D_{conc} + D_{Gate} + H_{1.U1} + H_{2.U1} + H_{3.U1} - \left|\Sigma V_{Q.E3.EQv.1}\right|}{\left|Uplift_{U1}\right|} = 1.7$$

$$Flotation_{E3.1.check} := \begin{cases} \text{"Okay"} & \text{if } FS_{Flotation.E3.1} \ge FS_{req.E.flt} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$Flotation_{E3.1.check} = \text{"Okay"}$

MONOLITH OVERTURNING STABILITY ANALYSIS

E3.1 CASE

Seismic Case $Q_{E3.1}$: 100% Horizontal Seismic Force, No Vertical

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.

Assumptions are made in order to compute overturning stability of indetermine forces on monolith with key;

(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.

(b) The horizontal resisting force acting on the key, P.key, is that required for static equilibrium

(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1 $Ratio_{overturning.allow.Extreme} := 0.167$ Resultant within Middle Half

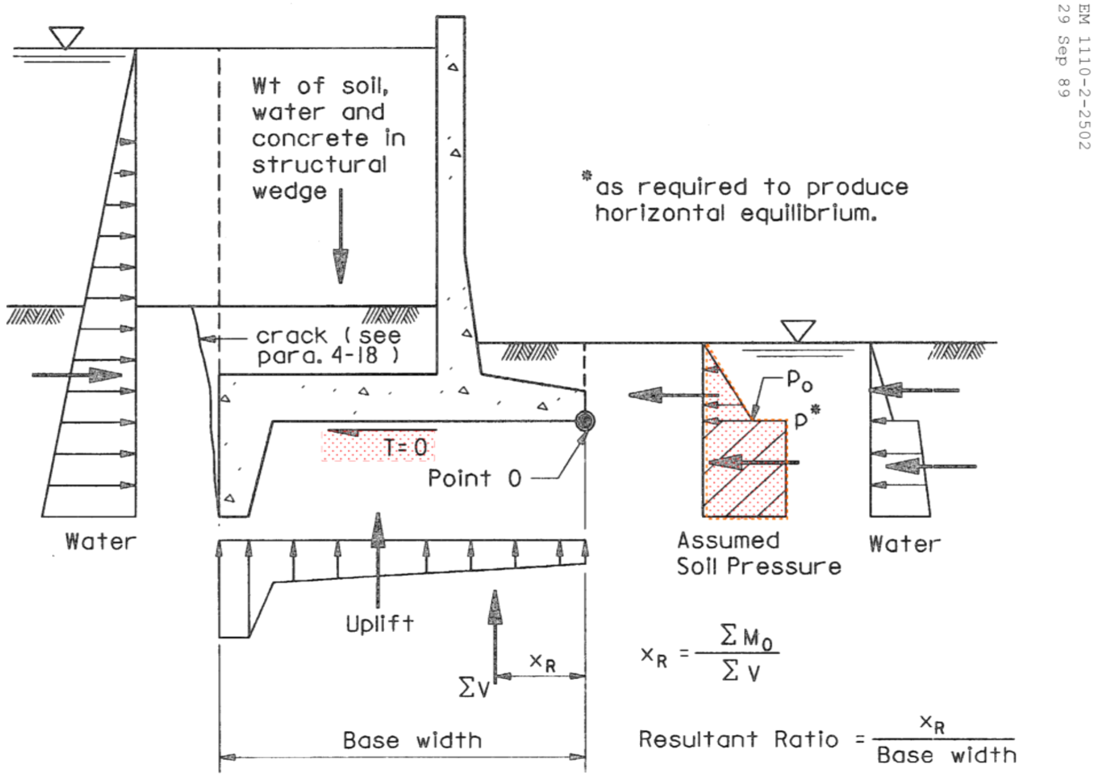


Figure 4-5. Forces for overturning analysis for wall with horizontal base and key

All Vertical Loads Applicable to Overturning Stability Analysis

Total Concrete Dead Loads:	$D_{conc} = 25408200\,N$	at:	$X_{conc.loc} = 12.71\,m$
Dead Load of Gate:	$D_{Gate} = 580.0\cdot kN$		$X_{gate} = 8.75\,m$
Water Weight (HW) on Apron Slab:	$H_{1.U1} = 1532.7\cdot kN$		$H_{1.U1.loc} = 21.10\,m$
Water Weight (HW) on Fixed Crest:	$H_{2.U1} = 586.2\cdot kN$		$H_{2.U1.loc} = 14.25\,m$
Water Weight (TW) on Fixed Crest:	$H_{3.U1} = 0.0\cdot kN$		$H_{3.U1.loc} = 0.00\,m$
Vertical Seismic Component of Concrete Structure:	$Q_{conc.E3.EQv.1} = 0$	at:	$X_{conc.loc} = 12.71\,m$
Vertical Seismic Component of Vertical Lift Gate:	$Q_{Gate.E3.EQv.1} = 0$		$X_{gate} = 8.75\,m$
Vertical Seismic Component of Headwater over Apron Slab:	$Q_{H1.E3.EQv.1} = 0$		$H_{1.U1.loc} = 21.10\,m$
Vertical Seismic Component of Headwater over Fixed Crest Slab:	$Q_{H2.E3.EQv.1} = 0$		$H_{2.U1.loc} = 14.25\,m$

Uplift for Overturning Analysis, Line of Creep Method. Pore pressure at base of Concrete, first calculation to presumed inclined straight line from Heel to Toe, thereafter by Archimedes Principle.

E3.1 CASE

$$U_{E3.1.loc.sliding} := \frac{U_{A.U1} \cdot L_{A.U1} + U_{B.U1} \cdot L_{B.U1} - A_{rs} \cdot w_{as} \cdot \gamma_w \cdot L_{rs}}{U_{A.U1} + U_{B.U1} - A_{rs} \cdot w_{as} \cdot \gamma_w} = 13.73\,m$$

$$U_{E3.1.sliding} := U_{U1} + A_{rs} \cdot w_{as} \cdot \gamma_w = -11002111.2\,N$$

Uplift for Overturning Analysis, Line of Creep Method. Pore pressure at base of Concrete

$Uplift_{pore.U1} = -10515.7 \cdot kN$

$$Uplift_{pore.E3.1.loc} := \frac{Uplift_{BC.U1} \cdot Uplift_{BC.U1.loc} + Uplift_{DE.U1} \cdot Uplift_{DE.U1.loc} + Uplift_{EF.U1} \cdot Uplift_{EF.U1.loc} + Uplift_{FG.U1} \cdot Uplift_{FG.U1.loc}}{Uplift_{pore.U1}}$$

$Uplift_{pore.E3.1.loc} = 13.1\,m$

Sum of All Water Load for Overturning Analysis

$$\Sigma V_{water.E3.1.OT} := H_{1.U1} + H_{2.U1} + H_{3.U1} + Uplift_{pore.U1} = -8396.7 \cdot kN$$

All Lateral Loads Applicable to Overturning Stability Analysis

Apply Load to Gate?:	$poss_{U1} = 1$		poss = 1 if gate is closed 0 if gate is open
Headwater Lateral Load on Gate:	$H_{hwg.U1} = 0.0 \cdot kN$		$H_{hwg.U1.loc} = 6.20\,m$
Headwater Lateral Load on Footing:	$H_{hwf.U1} = -3840.6 \cdot kN$		$H_{hwf.U1.loc} = 1.17\,m$
Total Horizontal Tailwater Load on Footing under Gate Openings, i.e., excluding Pier	$H_{twf.U1} = 721.0 \cdot kN$		$H_{twf.U1.loc} = -0.33\,m$
Resisting Water on Rear Face of Monolith, i.e., bottom of heel elevation:			*(Point O @ TOE: BOFtoe = EL.1205.5)*
Horizontal Seismic Component of Concrete Structure:	$Q_{conc.E3.EQh.1} = -4404.1 \cdot kN$	AT	$Y_{conc.loc} = 3.17\,m$
Horizontal Seismic Component of Vertical Lift Gate:	$Q_{Gate.E3.EQh.1} = -100.5 \cdot kN$		$Y_{gate} = 8.00\,m$
Horizontal Seismic Component of Headwater on Gate:	$Q_{hwg.E3.EQh.1} = 0$		$Y_{HWg.E3} = 7.7\,m$
Horizontal Seismic Component of Headwater on Footing:	$Q_{hwf.E3.EQh.1} = -780.9 \cdot kN$		$Y_{HWf.E3} = 3\,m$
Horizontal Seismic Component of Active Soil: (Section 5-5, USACE EM_1110-2-2100)	$Q_{act.E3.EQh.1} = -1647.4 \cdot kN$		$Y_{E.act.E3} = 3.8\,m$
Ice / Impact Load:	$I_{U1} = 0.0 \cdot kN$	at:	$I_{U1.loc} = 6.30\,m$

Depth of Fill at Heel Side for Overturning Analysis (neglecting resistance by driving below Point O):

$$t_{hf.E3.1} := TOC_{as} - BOF_{toe} = 4.50\,m$$

Driving Soil Load for overturning:

$$E1_{drive.E3.1} := \frac{K_o \cdot t_{hf.U1}^{\,2}}{2} \cdot (\gamma_r - \gamma_w) \cdot W_b \cdot -1 = -974.5 \cdot kN$$

Acting at:

$$E1_{drive.loc.E3.1} := \frac{t_{hf.E3.1}}{3} = 1.50\,m$$

Downstream (resisting) Lateral Soil Load
as required to produce horizontal equilibrium:

$$E2_{resistE3.1} := -1 \cdot \left(H_{hwg.U1} + H_{hwf.U1} + H_{twf.U1} + I_{U1} + E1_{drive.U1}\right)$$

$$E2_{resistE3.1} = 4094104.1\,N$$

Assumed Resisting Bedrock at middle of Key, passive soil pressure or lateral bearing contract joint at end of Monolith 3A3B

$$E2_{resistlocE3.1} := E2_{resistlocU1} = -0.75\,m$$

Overturning moment by Dead Loads about Point O @ Toe

$$\Sigma M_{DL.U1} = 325934.4 \cdot kN \cdot m$$

Overturning moment by Vertical Water Loads and Uplift, about Point O @ Toe

$$\Sigma M_{Vwater.U1} = -185663.8 \cdot kN \cdot m$$

Overturning moment by Lateral Hydrostatic Forces of Headwater Pool and Tailwater Pool,about Point O @ Toe

$$\Sigma M_{HWater.U1} = -4743.1 \cdot kN \cdot m$$

Overturning Moment by Impact/Ice Load, about Point O@ Toe

$$\Sigma M_{I.U1} = 0$$

Overturning moment by Lateral Soil Forces about Point O @ Toe

$$\Sigma M_{soil.E3.1} := E1_{drive.E3.1} \cdot E1_{drive.loc.E3.1} + E2_{resistE3.1} \cdot E2_{resistlocE3.1} = -4532.4 \cdot kN \cdot m$$

Sum of the Overturning Moments about Point O @ Toe:

$$\Sigma M_{E3.1.OT} := \Sigma M_{DL.U1} + \Sigma M_{HWater.U1} + \Sigma M_{Vwater.U1.OT} + \Sigma M_{I.U1} + \Sigma M_{soil.E3.1} + \Sigma M_{Q.E3.1} = 196212 \cdot kN \cdot m$$

Sum of Vertical Forces:

$$\Sigma V_{E3.1.OT} := \Sigma V_{DL.U1} + \Sigma V_{water.U1.OT} + \left|\Sigma V_{Q.E3.EQv.1}\right| = 17359.5 \cdot kN$$

Distance X_R: EM 1110-2-2502 Eq.4-1

$$X_{R.E3.1} := \frac{\Sigma M_{E3.1.OT}}{\Sigma V_{E3.1.OT}} = 11.3\,m$$

Overturning Resultant Ratio

$$Ratio_{Overturning.E3.1} := \frac{X_{R.E3.1}}{L_b} = 0.47$$

EM 1110-2-2502

Table 4-1

Retaining Wall Stability Criteria

Loading Condition	Sliding Factor of Safety, FS	Shear Strength Test Required: Soil Foundation	Shear Strength Test Required: Rock Foundation[3]	Overturning Criteria Minimum Base Area in Compression: Soil Foundation	Overturning Criteria Minimum Base Area in Compression: Rock Foundation
Usual	1.5	(Q &/or S)[2,1]	Direct shear	100%[4]	75%[4]
Unusual	1.33	(Q &/or S)[2,1]	Direct shear	75%[4]	50%[4]
Earthquake	1.1	(Q)	Direct shear	Resultant within base	Resultant within base

$$Ratio_{Overturning.E3.1.check} := \begin{cases} \text{"Okay"} & \text{if } Ratio_{Overturning.E3.1} \geq Ratio_{overturning.allow.Extreme} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

Overturning Stability Check

$$Ratio_{Overturning.E3.1.check} = \text{"Okay"}$$

E3.1 CASE

Summary of Seismic Results (Only Report Controlling Load Case)

Seismic Case $Q_{E3.1}$: 100% Horizontal Seismic Force, No Vertical

Horiz Sliding Factor of Safety: $FS_{HorizSliding.E3.1} = 0.47$

Horiz Sliding Factor of Safety Check: $FS_{HorizSliding.E3.1.Check}$ = "Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !"

Sliding Factor of Safety: $FS_{InclinedISlidingE3.1} = 1.4$

Sliding Factor of Safety Check: $FS_{Sliding.E3.1.InclinedCheck}$ = "OKAY "

Eccentricity: $e_{E3.1} = 0.83\,m$

Eccentricity Check: $e_{check.E3.1}$ = "Okay"

Bearing Pressure At Heel: $\sigma_{heel.E3.1} = 68 \cdot \frac{kN}{m^2}$

Bearing Pressure At Heel Check: $\sigma_{heel.E3.1.check}$ = "Okay"

Bearing Pressure At Heel: $\sigma_{toe.E3.1} = 102.8 \cdot \frac{kN}{m^2}$

Bearing Pressure At Toe Check: $\sigma_{toe.E3.1.check}$ = "Okay"

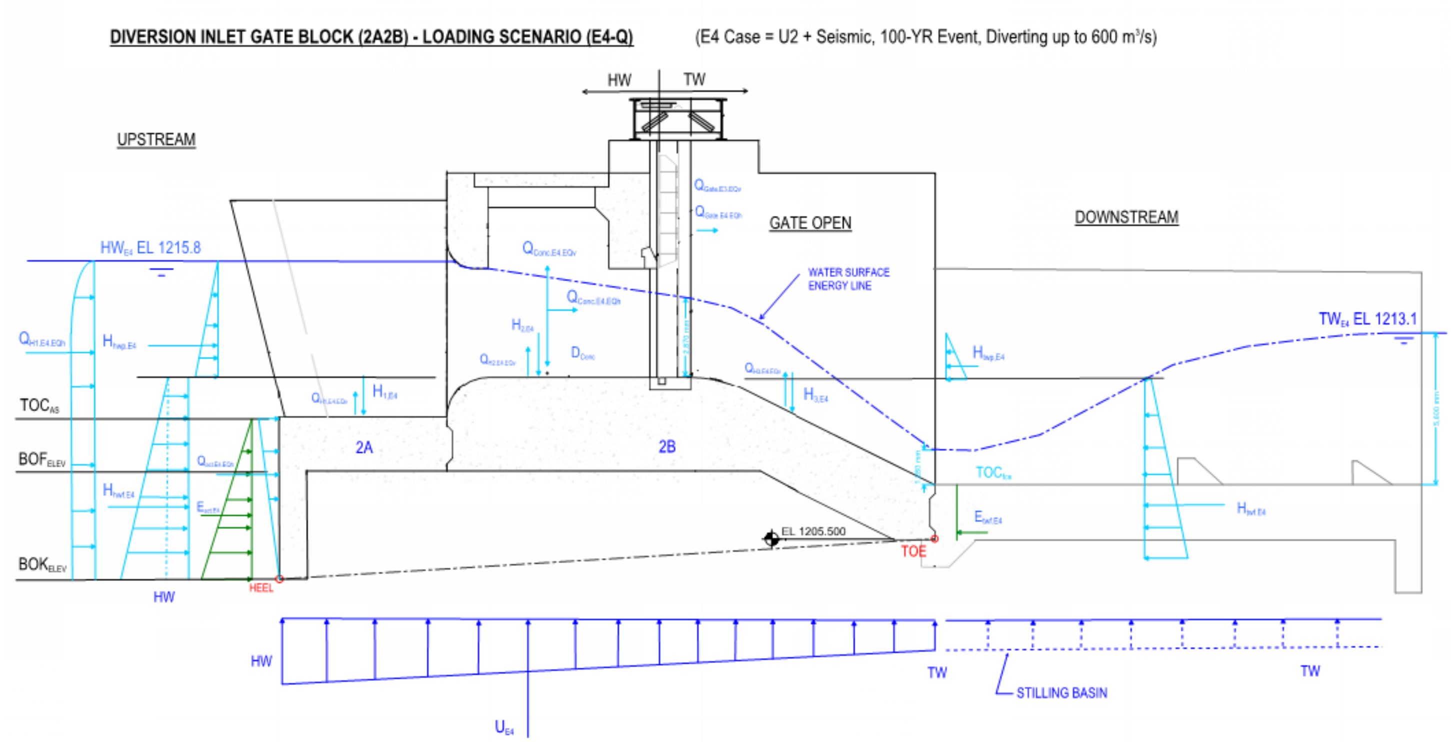
Flotation Factor of Safety: $FS_{Flotation.E3.1} = 1.7$

Flotation Factor of Safety Check: $Flotation_{E3.1.check}$ = "Okay"

Overturning Resultant Ratio: $Ratio_{Overturning.E3.1} = 0.47$

Overturning Stability Check: $Ratio_{Overturning.E3.1.check}$ = "Okay"

E4 DESIGN CASE



E4 Case: U2 CASE PLUS SEISMIC

ACCEPTANCE PARAMETERS

Required Factor of Safety for Sliding: $FS_{req.E4.sl} := 1.0$ (Without Cohesion) (Section 8.1, Design Criteria)

Resultant Within Middle Half of Base: $e \le \frac{L_b}{4} \wedge e \ge \frac{-L_b}{4}$

Allowable Rock Bearing Pressure: $\sigma_{allow.E4} := 1740 \cdot \frac{kN}{m^2}$ (Section 5.2, Design Criteria)

Required Factor of Safety for Flotation: $FS_{req.E.flt} = 1.1$

Overturning Min Required Resultant Ratio: $\frac{X_{R.E}}{Horizontal\_Width\_of\_Base} > 0.167$

(75% Base in Compression, Resultant within Middle Half)

INPUT PARAMETERS

Headwater Elevation: $HW_{E4} := 1215.80m$

Tailwater Elevation: $TW_{E4} := 1213.1m$

(Water Elevations based on Diversion Structure 2D Hydraulic Model Results. See page 6 and Section 8.2, Design Criteria)

Crest Water Elevation, EL.1215.81 $CrestW_{E4} := 2.87 \cdot m$

Chute Block Water Elevation EL.1208.78 $ChuteW_{E4} := 1.28 \cdot m$ $TW_{E4} := TOC_{fce} + ChuteW_{E4} = 1208.8m$

Bottom of Footing Elevation: $BOF_{elev} = 1204.00\,m$

Apron Slab Top of Concrete Elevation at Edge of Slab: $TOC_{as} = 1210.00\,m$

Fixed Crest Top of Concrete Elevation at Downstream Face: $TOC_{fce} = 1207.50\,m$

Fixed Crest Top of Concrete Elevation at Center of Footing: $TOC_{fcc} = 1211.50\,m$

SEISMIC LOAD E4: EDGM Post-Seimic Assessment of Usual Load U2 Event (3 Load Cases)

Seismic Case $Q_{E4.1}$ - 100% Horizontal Seismic Force, No Vertical **E4.1 CASE**

Horizontal Seismic Coefficient: $K_{h.E4.1} := \frac{-2}{3} \cdot 0.26 = -0.17$

Vertical Seismic Coefficient: $K_{v.E4.1} := 0 \frac{-2}{3} \cdot 0.56 \cdot 0.26 = 0$

HORIZONTAL SEISMIC LOADS	Loads	Moment Arm
Horizontal Seismic Component of Concrete Structure:	$Q_{conc.E4.EQh.1} := D_{conc} \cdot K_{h.E4.1} = -4404.1 \cdot kN$	$Y_{conc.loc} = 3.17\,m$
Horizontal Seismic Component of Vertical Lift Gate:	$Q_{Gate.E4.EQh.1} := D_{Gate} \cdot K_{h.E4.1} = -100.5 \cdot kN$	$Y_{gate} = 8.00\,m$
Horizontal Seismic Component of Headwater on Gate: (Section 7.9, Design Criteria)	$Q_{hwg.E4.EQh.1} := \left(\frac{7}{12}\right) \cdot K_{h.E4.1} \cdot \gamma_w \cdot \left(D_{hwg.U2}\right)^2 \cdot W_{hwg.U2} \cdot poss_{U2} = 0 \cdot kN$	$Y_{HWg.E4} := 0.4 \cdot D_{hwg.U2} + \left(TOC_{fcc} - BOF_{elev}\right) = 9.22\,m$
Horizontal Seismic Component of Headwater on Footing: (Section 7.9, Design Criteria)	$Q_{hwf.E4.EQh.1} := \left(\frac{7}{12}\right) \cdot K_{h.E4.1} \cdot \gamma_w \cdot \left(D_{hwf.U2}\right)^2 \cdot W_{hw.U2} = -1657.3 \cdot kN$	$Y_{HWf.E4} := 0.4 \cdot \left(TOC_{fcc} - BOF_{elev}\right) = 3.00\,m$
Horizontal Seismic Component of Active Soil: (Section 5-5, USACE EM_1110-2-2100)	$Q_{act.E4.EQh.1} := \gamma_r \cdot \left(TOC_{as} - BOF_{elev}\right)^2 \cdot K_{h.E4.1} \cdot W_{hw.U2} = -1647.4 \cdot kN$	$Y_{E.act.E4} := 0.63 \cdot \left(TOC_{as} - BOF_{elev}\right) = 3.78\,m$

VERTICAL SEISMIC LOADS	Loads	Moment Arm
Vertical Component of Concrete Structure:	$Q_{conc.E4.EQv.1} := D_{conc} \cdot K_{v.E4.1} = 0 \cdot kN$	$X_{conc.loc} = 12.71\,m$
Vertical Component of Vertical Lift Gate:	$Q_{Gate.E4.EQv.1} := D_{Gate} \cdot K_{v.E4.1} = 0 \cdot kN$	$X_{gate} = 8.75\,m$
Vertical Seismic Component of Headwater over Apron Slab: (Section 7.9, Design Criteria)	$Q_{H1.E4.EQv.1} := K_{v.E4.1} \cdot H_{1.U2} = 0 \cdot kN$	$H_{1.U2.loc} = 21.10\,m$
Vertical Seismic Component of Headwater over Fixed Crest Slab: (Section 7.9, Design Criteria)	$Q_{H2.E4.EQv.1} := K_{v.E4.1} \cdot H_{2.U2} = 0 \cdot kN$	$H_{2.U2.loc} = 14.25\,m$

$$\Sigma H_{Q.E4.EQh.1} := Q_{conc.E4.EQh.1} + Q_{Gate.E4.EQh.1} + Q_{hwg.E4.EQh.1} + Q_{hwf.E4.EQh.1} + Q_{act.E4.EQh.1} = -7809.3 \cdot kN$$

$$\Sigma V_{Q.E4.EQv.1} := Q_{conc.E4.EQv.1} + Q_{Gate.E4.EQv.1} + Q_{H1.E4.EQv.1} + Q_{H2.E4.EQv.1} = 0.0 \cdot kN$$

$$\Sigma M_{Q.E4.1} := Q_{conc.E4.EQh.1} \cdot Y_{conc.loc} + Q_{Gate.E4.EQh.1} \cdot Y_{gate} + Q_{hwg.E4.EQh.1} \cdot Y_{HWg.E4} \cdots + Q_{hwf.E4.EQh.1} \cdot Y_{HWf.E4} + Q_{act.E4.EQh.1} \cdot Y_{E.act.E4} + Q_{conc.E4.EQv.1} \cdot X_{conc.loc} + Q_{Gate.E4.EQv.1} \cdot X_{gate} \cdots + Q_{H1.E4.EQv.1} \cdot H_{1.U2.loc} + Q_{H2.E4.EQv.1} \cdot H_{2.U2.loc} = -25947.6 \cdot kN \cdot m$$

STABILITY ASSESSMENT:

E4.1 CASE

Seismic Case $Q_{E4.1}$: 100% Horizontal Seismic Force, No Vertical

CHECK **SLIDING** ALONG HORIZONTAL PLANE THRU TOE,
IGNORING BEDROCK MOBILIZED BY STRUCTURAL HEEL KEY, OR VOID BEHIND KEY

Sum of Vertical Forces:

$\Sigma V_{E4.1} := \Sigma V_{U2} + \Sigma V_{Q.E4.EQv.1} = 12259.1 \cdot kN$

Sum of Horizontal Forces:

$\Sigma H_{E4.1} := \Sigma H_{U2} + \Sigma H_{Q.E4.EQh.1} = -15304.3 \cdot kN$

Sliding Factor of Safety:

$$FS_{HorizSliding.E4.1} := \frac{\tan_{\phi} \cdot \Sigma V_{E4.1}}{\left|\Sigma H_{E4.1}\right|} = 0.39$$

$FS_{HorizSliding.E4.1.Check} :=$ | "OKAY" if $FS_{HorizSliding.E4.1} \geq FS_{req.E4.sl}$
"Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !" otherwise

$FS_{HorizSliding.E4.1.Check}$ = "Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !"

CHECK **SLIDING** ALONG INCLINED SLIDING PLANE FROM HEEL KEY TO TOE,
WITH BEDROCK MASS MOBILIZED BY REINFOCREDE CONCRETE KEY

Incline angle: $\alpha s = 0.12$ as degrees= $\alpha s \cdot \left(\frac{180}{\pi}\right) = 7.01$

Resolve $\Sigma Vert_{E4.1}$ & $\Sigma Horiz_{E4.1}$

$$\Sigma V_{InclinedE4.1} := \cos(\alpha s) \cdot \left(\Sigma V_{E4.1} + V_{rs}\right) + \sin(\alpha s) \cdot \left|\Sigma H_{E4.1}\right| = 26324.2 \cdot kN$$

$$\Sigma H_{InclinedE4.1} := \cos(\alpha s) \cdot \left|\Sigma H_{E4.1}\right| - \sin(\alpha s) \cdot \left(\Sigma V_{E4.1} + V_{rs}\right) = 12183.0 \cdot kN$$

(With properly engineered reinforced concrete Key, horizontal sliding plane thru Toe is protected, critical sliding plane is relocated to the INCLINED SLIDING PLANE FROM HEEL KEY To TOE, Bedrock Mass above this examing plane is mobilized by reinforced concrete key and combined into Structural Wedge.)

Safety Factor for Sliding
Inclined Failure Plane

$$FS_{InclinedlSlidingE4.1} := \frac{\Sigma V_{InclinedE4.1} \cdot \tan\left(\phi_{rock} \cdot \frac{\pi}{180}\right)}{\left|\Sigma H_{InclinedE4.1}\right|} = 1.05$$

$FS_{Sliding.E4.1.InclinedCheck} :=$ | "OKAY " if $FS_{InclinedlSlidingE4.1} > FS_{req.E4.sl}$
"Revise Structure"" otherwise

= "OKAY "

$FS_{Sliding.E4.1.InclinedCheck}$ = "OKAY "

CHECK ECCENTRICITY ON INCLINED PLANE

E4.1 CASE

Seismic Case $Q_{E4.1}$: 100% Horizontal Seismic Force, No Vertical

Sum of the moments:

$$\Sigma M_{rs.E4.1} := \Sigma M_{DL.U2} + \Sigma M_{HWater.U2} + \Sigma M_{Vwater.U2} + \Sigma M_{I.U2} + \Sigma M_{soil.U2} + \Sigma M_{Q.E4.1} + V_{rs} \cdot L_{rs} = 283616 \cdot kN \cdot m$$

Eccentricity:

$$e_{E4.1} := \frac{L_{incline}}{2} - \frac{\Sigma M_{rs.E4.1}}{\Sigma V_{InclinedE4.1}} = 1.35\,m$$

Eccentricity Check:

$$e_{check.E4.1} := \begin{cases} \text{"Okay"} & \text{if } |e_{E4.1}| \le Ecc_{midhalf} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$$e_{check.E4.1} = \text{"Okay"}$$

Foundation Bearing Pressures on Inclined Plane:

Bearing Pressure at Heel:

$$\sigma_{heel.E4.1} := \begin{cases} 0 & \text{if } |e_{E4.1}| \ge Ecc_{midhalf} \\ \left(\dfrac{\Sigma V_{InclinedE4.1}}{\dfrac{A_b}{\cos(\alpha s)}} - \dfrac{\Sigma V_{InclinedE4.1} \cdot e_{E4.1}}{\dfrac{S_b}{\cos(\alpha s)^2}} \right) & \text{otherwise} \end{cases} = 60.1 \cdot \frac{kN}{m^2}$$

$$\sigma_{heel.E4.1.check} := \left(\begin{cases} \text{"Okay"} & \text{if } \sigma_{heel.E4.1} \le \sigma_{allow.E4} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} \right)$$

$$\sigma_{heel.E4.1.check} = \text{"Okay"}$$

Bearing Pressure at Toe:

$$\sigma_{toe.E4.1} := \begin{cases} \left[\dfrac{4}{3} \cdot \left(\dfrac{\dfrac{\Sigma V_{InclinedE4.1}}{W_b}}{L_{incline} - 2 \cdot e_{E4.1}} \right) \right] & \text{if } |e_{E4.1}| \ge Ecc_{midhalf} \\ \left[\dfrac{\Sigma V_{InclinedE4.1}}{\dfrac{A_b}{\cos(\alpha s)}} + \dfrac{(\Sigma V_{InclinedE4.1} \cdot e_{E4.1})}{\dfrac{S_b}{\cos(\alpha s)^2}} \right] & \text{otherwise} \end{cases} = 119.8 \cdot \frac{kN}{m^2}$$

$$\sigma_{toe.E4.1.check} := \begin{cases} \text{"Okay"} & \text{if } \sigma_{toe.E4.1} \le \sigma_{allow.E4} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$$\sigma_{toe.E4.1.check} = \text{"Okay"}$$

Foundation Flotation Checks:

$$FS_{Flotation.E4.1} := \frac{D_{conc} + D_{Gate} + H_{1.U2} + H_{2.U2} + H_{3.U2} - |\Sigma V_{Q.E4.EQv.1}|}{|Uplift_{U2}|} = 1.5$$

$$Flotation_{E4.1.check} := \begin{cases} \text{"Okay"} & \text{if } FS_{Flotation.E4.1} \ge FS_{req.E.flt} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$$Flotation_{E4.1.check} = \text{"Okay"}$$

E4.1 CASE

MONOLITH OVERTURNING STABILITY ANALYSIS

Seismic Case $Q_{E3.1}$: 100% Horizontal Seismic Force, No Vertical

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.

Assumptions are made in order to compute overturning stability of indetermine forces on monolith with key;

(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.

(b) The horizontal resisting force acting on the key, P.key, is that required for static equilibrium

(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1 $Ratio_{overturning.allow.Extreme} = 0.167$ Resultant within Middle Half

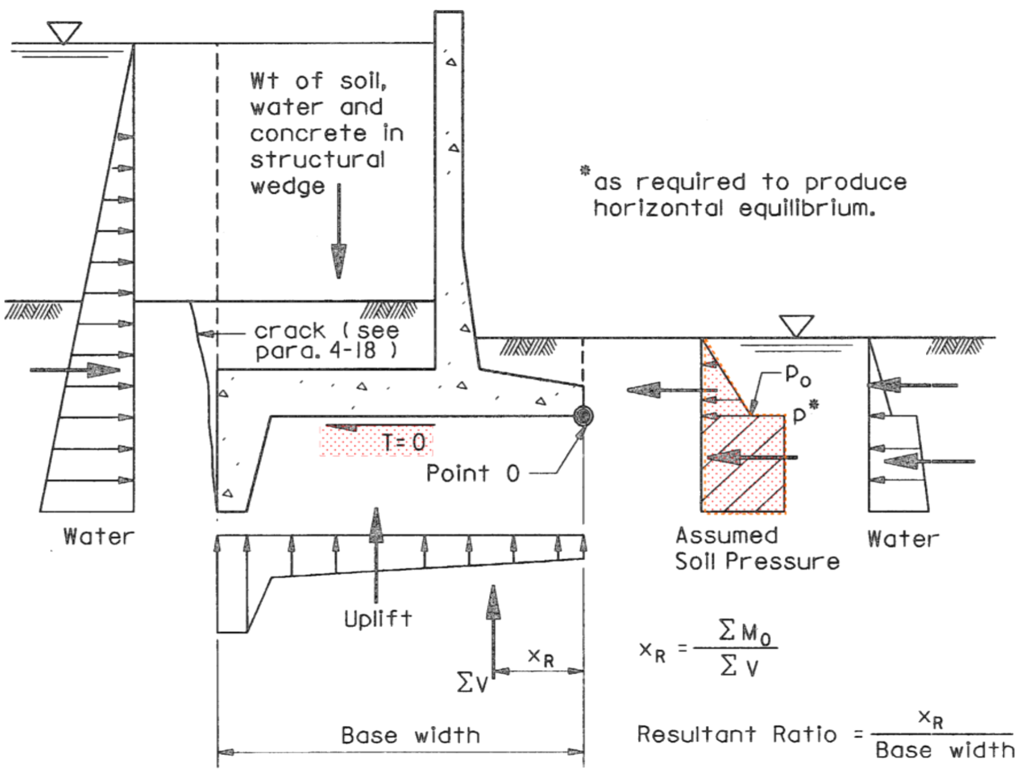


Figure 4-5. Forces for overturning analysis for wall with horizontal base and key

All Vertical Loads Applicable to Overturning Stability Analysis

Total Concrete Dead Loads:	$D_{conc} = 25408.2 \cdot kN$	at:	$X_{conc.loc} = 12.71\,m$
Dead Load of Gate:	$D_{Gate} = 580.0 \cdot kN$		$X_{gate} = 8.75\,m$
Water Weight (HW) on Apron Slab:	$H_{1.U2} = 4233.2 \cdot kN$		$H_{1.U2.loc} = 21.10\,m$
Water Weight (HW) on Fixed Crest:	$H_{2.U2} = 3425.7 \cdot kN$		$H_{2.U2.loc} = 14.25\,m$
Water Weight (TW) on Fixed Crest:	$H_{3.U2} = 2808.8 \cdot kN$		$H_{3.U2.loc} = 5.78\,m$
Vertical Seismic Component of Concrete Structure:	$Q_{conc.E4.EQv.1} = 0$	at:	$X_{conc.loc} = 12.71\,m$
Vertical Seismic Component of Vertical Lift Gate:	$Q_{Gate.E4.EQv.1} = 0$		$X_{gate} = 8.75\,m$
Vertical Seismic Component of Headwater over Apron Slab:	$Q_{H1.E4.EQv.1} = 0$		$H_{1.U2.loc} = 21.10\,m$
Vertical Seismic Component of Headwater over Fixed Crest Slab:	$Q_{H2.E4.EQv.1} = 0$		$H_{2.U2.loc} = 14.25\,m$

Uplift for Overturning Analysis, Line of Creep Method. Pore pressure at base of Concrete, first calculation to presumed inclined straight line from Heel to Toe, thereafter by Archimedes Principle. **E4.1 CASE**

$$U_{E4.1.loc.sliding} := \frac{U_{A.U2} \cdot L_{A.U2} + U_{B.U2} \cdot L_{B.U2} - A_{rs} \cdot w_{as} \cdot \gamma_w \cdot L_{rs}}{U_{A.U2} + U_{B.U2} - A_{rs} \cdot w_{as} \cdot \gamma_w} = 13.81\ m$$

$$U_{E4.1.sliding} := U_{U2} + A_{rs} \cdot w_{as} \cdot \gamma_w = -18095683\ N$$

Uplift for Overturning Analysis, Line of Creep Method. Pore pressure at base of Concrete

$$Uplift_{pore.U1} = -10515.7 \cdot kN$$

$$Uplift_{pore.E4.1.loc} := \frac{Uplift_{BC.U2} \cdot Uplift_{BC.U2.loc} + Uplift_{DE.U2} \cdot Uplift_{DE.U2.loc} + Uplift_{EF.U2} \cdot Uplift_{EF.U2.loc} + Uplift_{FG.U2} \cdot Uplift_{FG.U2.loc}}{Uplift_{pore.U2}} = 13.3\ m$$

Sum of All Water Load for Overturning Analysis

$$\Sigma V_{water.E4.1.OT} := H_{1.U1} + H_{2.U1} + H_{3.U1} + Uplift_{pore.U2} = -15095.6 \cdot kN$$

<u>All Lateral Loads Applicable to Overturning Stability Analysis</u>

Apply Load to Gate?: $poss_{U1} = 1$ — poss = 1 if gate is closed; 0 if gate is open

Headwater Lateral Load on Gate: $H_{hwg.U2} = 0.0 \cdot kN$ — $H_{hwg.U2.loc} = 7.43\ m$

Headwater Lateral Load on Footing: $H_{hwf.U2} = -7107.3 \cdot kN$ — $H_{hwf.U2.loc} = 1.67\ m$

Total Horizontal Tailwater Load on Footing under Gate Openings, i.e., excluding Pier: $H_{twf.U2} = 1344.9 \cdot kN$ — $H_{twf.U2.loc} = 0.09\ m$

Resisting Water on Rear Face of Monolith, i.e., bottom of heel elevation: *(Point O @ TOE: BOFtoe = EL.1205.5)*

Horizontal Seismic Component of Concrete Structure: $Q_{conc.E4.EQh.1} = -4404.1 \cdot kN$ AT $Y_{conc.loc} = 3.17\ m$

Horizontal Seismic Component of Vertical Lift Gate: $Q_{Gate.E4.EQh.1} = -100.5 \cdot kN$ — $Y_{gate} = 8.00\ m$

Horizontal Seismic Component of Headwater on Gate: $Q_{hwg.E4.EQh.1} = 0$ — $Y_{HWg.E4} = 9.2\ m$

Horizontal Seismic Component of Headwater on Footing: $Q_{hwf.E4.EQh.1} = -1657.3 \cdot kN$ — $Y_{HWf.E4} = 3\ m$

Horizontal Seismic Component of Active Soil: (Section 5-5, USACE EM_1110-2-2100) $Q_{act.E4.EQh.1} = -1647.4 \cdot kN$ — $Y_{E.act.E4} = 3.8\ m$

Ice / Impact Load: $I_{U2} = 0.0 \cdot kN$ at: $I_{U2.loc} = 11.50\ m$

Depth of Fill at Heel Side for Overturning Analysis (neglecting resistance by driving below Point O):

$$t_{hf.E4.1} := TOC_{as} - BOF_{toe} = 4.50\ m$$

Driving Soil Load for overturning:

$$E1_{drive.E4.1} := \frac{K_o \cdot t_{hf.U2}^{\ 2}}{2} \cdot \left(\gamma_r - \gamma_w\right) \cdot W_b \cdot -1 = -974.5 \cdot kN$$

Acting at:

$$E1_{drive.loc.E4.1} := \frac{t_{hf.E4.1}}{3} = 1.50\ m$$

Downstream (resisting) Lateral Soil Load
as required to produce horizontal equilibrium:

$$E2_{resistE4.1} := -1 \cdot \left(H_{hwg.U2} + H_{hwf.U2} + H_{twf.U2} + I_{U2} + E1_{drive.U2}\right)$$

$$E2_{resistE4.1} = 6737012.3\,N$$

Assumed Resisting Bedrock at middle of Key, passive soil pressure or lateral bearing contract joint at end of Monolith 3A3B

$$E2_{resistlocE4.1} := E2_{resistlocU2} = -0.75\,m$$

Overturning moment by Dead Loads about Point O @ Toe

$$\Sigma M_{DL.U2} = 322889.4 \cdot kN \cdot m$$

Overturning moment by Vertical Water Loads and Uplift, about Point O @ Toe

$$\Sigma M_{Vwater.U2} = -171722.3 \cdot kN \cdot m$$

Overturning moment by Lateral Hydrostatic Forces of Headwater Pool and Tailwater Pool,about Point O @ Toe

$$\Sigma M_{HWater.U2} = -11727.4 \cdot kN \cdot m$$

Overturning Moment by Impact/Ice Load, about Point O@ Toe

$$\Sigma M_{I.U2} = 0$$

Overturning moment by Lateral Soil Forces about Point O @ Toe

$$\Sigma M_{soil.E4.1} := E1_{drive.E4.1} \cdot E1_{drive.loc.E4.1} + E2_{resistE4.1} \cdot E2_{resistlocE4.1} = -6514.5 \cdot kN \cdot m$$

Sum of the Overturning Moments about Point O @ Toe:

$$\Sigma M_{E4.1.OT} := \Sigma M_{DL.U2} + \Sigma M_{HWater.U2} + \Sigma M_{Vwater.U2.OT} + \Sigma M_{I.U2} + \Sigma M_{soil.E4.1} + \Sigma M_{Q.E4.1} = 204172 \cdot kN \cdot m$$

Sum of Vertical Forces:

$$\Sigma V_{E4.1.OT} := \Sigma V_{DL.U2} + \Sigma V_{water.U2.OT} + \left|\Sigma V_{Q.E4.EQv.1}\right| = 18661.3 \cdot kN$$

Distance X_R: EM 1110-2-2502 Eq.4-1

$$X_{R.E4.1} := \frac{\Sigma M_{E4.1.OT}}{\Sigma V_{E4.1.OT}} = 10.9\,m$$

Overturning Resultant Ratio

$$Ratio_{Overturning.E4.1} := \frac{X_{R.E4.1}}{L_b} = 0.45$$

EM 1110-2-2502

Table 4-1

Retaining Wall Stability Criteria

Loading Condition	Sliding Factor of Safety, FS	Shear Strength Test Required: Soil Foundation	Shear Strength Test Required: Rock Foundation[3]	Overturning Criteria Minimum Base Area in Compression: Soil Foundation	Overturning Criteria Minimum Base Area in Compression: Rock Foundation
Usual	1.5	(Q &/or S)[2,1]	Direct shear	100%[4]	75%[4]
Unusual	1.33	(Q &/or S)[2,1]	Direct shear	75%[4]	50%[4]
Earthquake	1.1	(Q)	Direct shear	Resultant within base	Resultant within base

Overturning Stability Check

$$Ratio_{Overturning.E4.1.check} := \begin{cases} \text{"Okay"} & \text{if } Ratio_{Overturning.E4.1} \ge Ratio_{overturning.allow.Extreme} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$$Ratio_{Overturning.E4.1.check} = \text{"Okay"}$$

Summary of Seismic Results (Only Report Controlling Load Case)

E4.1 CASE

Seismic Case $Q_{E4.1}$: 100% Horizontal Seismic Force, No Vertical

Horiz Sliding Factor of Safety:	$FS_{HorizSliding.E4.1} = 0.39$
Horiz Sliding Factor of Safety Check:	$FS_{HorizSliding.E4.1.Check}$ = "Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !"
Sliding Factor of Safety:	$FS_{InclinedlSlidingE4.1} = 1.1$
Sliding Factor of Safety Check:	$FS_{Sliding.E4.1.InclinedCheck}$ = "OKAY "
Eccentricity:	$e_{E4.1} = 1.35\,m$
Eccentricity Check:	$e_{check.E4.1}$ = "Okay"
Bearing Pressure At Heel:	$\sigma_{heel.E4.1} = 60.1 \cdot \frac{kN}{m^2}$
Bearing Pressure At Heel Check:	$\sigma_{heel.E4.1.check}$ = "Okay"
Bearing Pressure At Heel:	$\sigma_{toe.E4.1} = 119.8 \cdot \frac{kN}{m^2}$
Bearing Pressure At Toe Check:	$\sigma_{toe.E4.1.check}$ = "Okay"
Flotation Factor of Safety	$FS_{Flotation.E4.1} = 1.5$
Flotation Factor of Safety Check:	$Flotation_{E4.1.check}$ = "Okay"
Overturning Resultant Ratio	$Ratio_{Overturning.E4.1} = 0.45$
Overturning Stability Check	$Ratio_{Overturning.E4.1.check}$ = "Okay"

SEISMIC LOAD E3: EDGM Post-Seimic Assessment of Usual Load U1 Event (3 Load Cases)

E3.2 CASE

Seismic Case $Q_{E3.2}$ - 100% Horizontal Seismic Force, 30% Vertical

Horizontal Seismic Coefficient: $K_{h.E3.2} := \frac{-2}{3} \cdot 0.26 = -0.17$

Vertical Seismic Coefficient: $K_{v.E3.2} := 0.3 \cdot \frac{-2}{3} \cdot 0.56 \cdot 0.26 = -0.03$

HORIZONTAL SEISMIC LOADS	**Loads**	**Moment Arm**
Horizontal Seismic Component of Concrete Structure:	$Q_{conc.E3.EQh.2} := D_{conc} \cdot K_{h.E3.2} = -4404.1 \cdot kN$	$Y_{conc.loc} = 3.17\,m$
Horizontal Seismic Component of Vertical Lift Gate:	$Q_{Gate.E3.EQh.2} := D_{Gate} \cdot K_{h.E3.2} = -100.5 \cdot kN$	$Y_{gate} = 8.00\,m$
Horizontal Seismic Component of Headwater on Gate: (Section 7.9, Design Criteria)	$Q_{hwg.E3.EQh.2} := \left(\frac{7}{12}\right) \cdot K_{h.E3.2} \cdot \gamma_w \cdot \left(D_{hwg.U1}\right)^2 \cdot W_{hwg.U1} \cdot poss_{U1} = 0 \cdot kN$	$Y_{HWg.E3} = 7.74\,m$
Horizontal Seismic Component of Headwater on Footing: (Section 7.9, Design Criteria)	$Q_{hwf.E3.EQh.2} := \left(\frac{7}{12}\right) \cdot K_{h.E3.2} \cdot \gamma_w \cdot \left(D_{hwf.U1}\right)^2 \cdot W_{hw.U1} = -780.9 \cdot kN$	3.00 m
Horizontal Seismic Component of Active Soil: (Section 5-5, USACE EM_1110-2-2100)	$Q_{act.E3.EQh.2} := \gamma_r \cdot \left(TOC_{as} - BOF_{elev}\right)^2 \cdot K_{h.E3.2} \cdot W_{hw.U1} = -1647.4 \cdot kN$	$Y_{E.act.E3} = 3.78\,m$

VERTICAL SEISMIC LOADS	**Loads**	**Moment Arm**
Vertical Component of Concrete Structure:	$Q_{conc.E3.EQv.2} := D_{conc} \cdot K_{v.E3.2} = -739.9 \cdot kN$	$X_{conc.loc} = 12.71\,m$
Vertical Component of Vertical Lift Gate:	$Q_{Gate.E3.EQv.2} := D_{Gate} \cdot K_{v.E3.2} = -16.9 \cdot kN$	$X_{gate} = 8.75\,m$
Vertical Seismic Component of Headwater over Apron Slab: (Section 7.9, Design Criteria)	$Q_{H1.E3.EQv.2} := K_{v.E3.2} \cdot H_{1.U1} = -44.6 \cdot kN$	$H_{1.U1.loc} = 21.10\,m$
Vertical Seismic Component of Headwater over Fixed Crest Slab: (Section 7.9, Design Criteria)	$Q_{H2.E3.EQv.2} := K_{v.E3.2} \cdot H_{2.U1} = -17.1 \cdot kN$	$H_{2.U1.loc} = 14.25\,m$

$$\Sigma H_{Q.E3.EQh.2} := Q_{conc.E3.EQh.2} + Q_{Gate.E3.EQh.2} + Q_{hwg.E3.EQh.2} + Q_{hwf.E3.EQh.2} + Q_{act.E3.EQh.2} = -6932.9 \cdot kN$$

$$\Sigma V_{Q.E3.EQv.2} := Q_{conc.E3.EQv.2} + Q_{Gate.E3.EQv.2} + Q_{H1.E3.EQv.2} + Q_{H2.E3.EQv.2} = -818.5 \cdot kN$$

$$\Sigma M_{Q.E3.2} := Q_{conc.E3.EQh.2} \cdot Y_{conc.loc} + Q_{Gate.E3.EQh.2} \cdot Y_{gate} + Q_{hwg.E3.EQh.2} \cdot Y_{HWg.E3} \cdots + Q_{hwf.E3.EQh.2} \cdot Y_{HWf.E3} + Q_{act.E3.EQh.2} \cdot Y_{E.act.E3} + Q_{conc.E3.EQv.2} \cdot X_{conc.loc} + Q_{Gate.E3.EQv.2} \cdot X_{gate} \cdots + Q_{H1.E3.EQv.2} \cdot H_{1.U1.loc} + Q_{H2.E3.EQv.2} \cdot H_{2.U1.loc} = -34053.7 \cdot kN \cdot m$$

E3.2 CASE

STABILITY ASSESSMENT: **Seismic Case $Q_{E3.2}$: 100% Horizontal Seismic Force, 30% Vertical**

CHECK **SLIDING** ALONG HORIZONTAL PLANE THRU TOE,
IGNORING BEDROCK MOBILIZED BY STRUCTURAL HEEL KEY, OR VOID BEHIND KEY

Sum of Vertical Forces:

$\Sigma V_{E3.2} := \Sigma V_{U1} + \Sigma V_{Q.E3.EQv.2} = 10533.5 \cdot kN$

Sum of Horizontal Forces:

$\Sigma H_{E3.2} := \Sigma H_{U1} + \Sigma H_{Q.E3.EQh.2} = -11785 \cdot kN$

Sliding Factor of Safety:

$$FS_{HorizSliding.E3.2} := \frac{\tan_{\phi} \cdot \Sigma V_{E3.2}}{\left|\Sigma H_{E3.2}\right|} = 0.44$$

$FS_{HorizSliding.E3.2.Check} :=$ | "OKAY" if $FS_{HorizSliding.E3.2} \geq FS_{req.E3.sl}$
"Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !" otherwise

$FS_{HorizSliding.E3.2.Check} =$ "Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !"

CHECK **SLIDING** ALONG INCLINED SLIDING PLANE FROM HEEL KEY TO TOE,
WITH BEDROCK MASS MOBILIZED BY REINFOCREDE CONCRETE KEY)

Incline angle: $\alpha s = 0.12$ $\alpha s \cdot \left(\frac{180}{\pi}\right) = 7.01$

Resolve $\Sigma Vert_{E3.2}$ & $\Sigma Horiz_{E3.2}$

$$\Sigma V_{InclinedE3.2} := \cos(\alpha s) \cdot \left(\Sigma V_{E3.2} + V_{rs}\right) + \sin(\alpha s) \cdot \left|\Sigma H_{E3.2}\right| = 24182.0 \cdot kN$$

$$\Sigma H_{InclinedE3.2} := \cos(\alpha s) \cdot \left|\Sigma H_{E3.2}\right| - \sin(\alpha s) \cdot \left(\Sigma V_{E3.2} + V_{rs}\right) = 8900.5 \cdot kN$$

(With properly engineered reinforced concrete Key, horizontal sliding plane thru Toe is protected, critical sliding plane is relocated to the INCLINED SLIDING PLANE FROM HEEL KEY To TOE, Bedrock Mass above this examing plane is mobilized by reinforced concrete key and combined into Structural Wedge)

Safety Factor for Sliding
Inclined Failure Plane

$$FS_{InclinedlSlidingE3.2} := \frac{\Sigma V_{InclinedE3.2} \cdot \tan\left(\phi_{rock} \cdot \frac{\pi}{180}\right)}{\left|\Sigma H_{InclinedE3.2}\right|} = 1.33$$

$FS_{Sliding.E3.2.InclinedCheck} :=$ | "OKAY " if $FS_{InclinedlSlidingE3.2} > FS_{req.E3.sl}$
"Revise Structure"" otherwise

= "OKAY "

$FS_{Sliding.E3.2.InclinedCheck} =$ "OKAY "

CHECK ECCENTRICITY ON INCLINED PLANE

E3.2 CASE

Seismic Case $Q_{E3.2}$: 100% Horizontal Seismic Force, 30% Vertical

Sum of the moments:

$$\Sigma M_{rs.E3.2} := \Sigma M_{DL.U1} + \Sigma M_{HWater.U1} + \Sigma M_{Vwater.U1} + \Sigma M_{I.U1} + \Sigma M_{soil.U1} + \Sigma M_{Q.E3.2} + V_{rs} \cdot L_{rs} = 271597 \cdot kN \cdot m$$

Eccentricity:

$$e_{E3.2} := \frac{L_{incline}}{2} - \frac{\Sigma M_{rs.E3.2}}{\Sigma V_{InclinedE3.2}} = 0.89\,m$$

Eccentricity Check:

$$e_{check.E3.2} := \begin{cases} \text{"Okay"} & \text{if } \left|e_{E3.2}\right| \le Ecc_{midhalf} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$e_{check.E3.2} = \text{"Okay"}$

Foundation Bearing Pressures on Inclined Plane:

Bearing Pressure at Heel:

$$\sigma_{heel.E3.2} := \begin{cases} 0 & \text{if } \left|e_{E3.2}\right| \ge Ecc_{midhalf} \\ \left(\dfrac{\Sigma V_{InclinedE3.2}}{\dfrac{A_b}{\cos(\alpha s)}} - \dfrac{\Sigma V_{InclinedE3.2} \cdot e_{E3.2}}{\dfrac{S_b}{\cos(\alpha s)^2}} \right) & \text{otherwise} \end{cases} = 64.5 \cdot \frac{kN}{m^2}$$

$$\sigma_{heel.E3.2.check} := \left(\begin{cases} \text{"Okay"} & \text{if } \sigma_{heel.E3.2} \le \sigma_{allow.E3} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} \right)$$

$\sigma_{heel.E3.2.check} = \text{"Okay"}$

Bearing Pressure at Toe:

$$\sigma_{toe.E3.2} := \begin{cases} \left[\dfrac{4}{3} \cdot \left(\dfrac{\dfrac{\Sigma V_{InclinedE3.2}}{W_b}}{L_{incline} - 2 \cdot e_{E3.2}} \right) \right] & \text{if } e_{E3.2} \ge Ecc_{midhalf} \\ \left[\dfrac{\Sigma V_{InclinedE3.2}}{\dfrac{A_b}{\cos(\alpha s)}} + \dfrac{\left(\Sigma V_{InclinedE3.2} \cdot e_{E3.2}\right)}{\dfrac{S_b}{\cos(\alpha s)^2}} \right] & \text{otherwise} \end{cases} = 100.8 \cdot \frac{kN}{m^2}$$

$$\sigma_{toe.E3.2.check} := \begin{cases} \text{"Okay"} & \text{if } \sigma_{toe.E3.2} \le \sigma_{allow.E3} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$\sigma_{toe.E3.2.check} = \text{"Okay"}$

Foundation Flotation Checks:

$$FS_{Flotation.E3.2} := \frac{D_{conc} + D_{Gate} + H_{1.U1} + H_{2.U1} + H_{3.U1} - \left|\Sigma V_{Q.E3.EQv.2}\right|}{\left|Uplift_{U1}\right|} = 1.7$$

$$Flotation_{E3.2.check} := \begin{cases} \text{"Okay"} & \text{if } FS_{Flotation.E3.2} \ge FS_{req.E.flt} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$Flotation_{E3.1.check} = \text{"Okay"}$

MONOLITH OVERTURNING STABILITY ANALYSIS

E3.2 CASE

Seismic Case $Q_{E3.2}$: 100% Horizontal Seismic Force, 30% Vertical

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.
Assumptions are made in order to compute overturning stability of indetermine forces on monolith with key;
(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.
(b) The horizontal resisting force acting on the key, P.key, is that required for static equilibrium
(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1 $Ratio_{overturning.allow.Extreme} := 0.167$ Resultant within Middle Half

EM 1110-2-2502
29 Sep 89

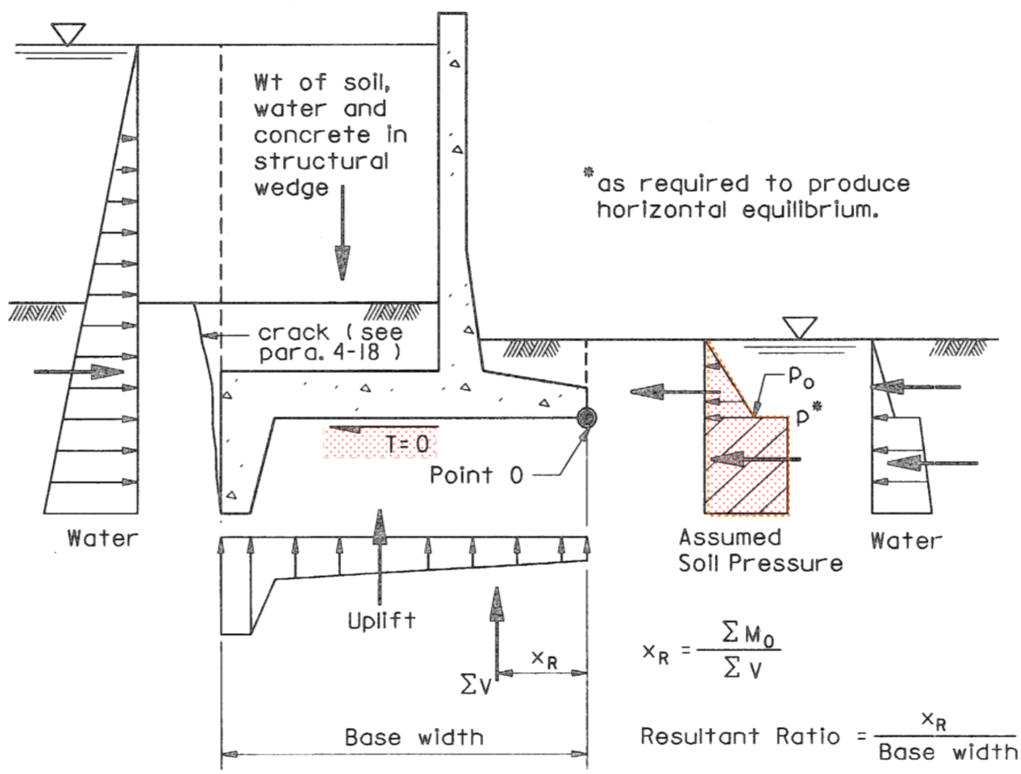


Figure 4-5. Forces for overturning analysis for wall with horizontal base and key

All Vertical Loads Applicable to Overturning Stability Analysis

Total Concrete Dead Loads:	$D_{conc} = 25408.2 \cdot kN$	at:	$X_{conc.loc} = 12.71\,m$
Dead Load of Gate:	$D_{Gate} = 580.0 \cdot kN$		$X_{gate} = 8.75\,m$
Water Weight (HW) on Apron Slab:	$H_{1.U1} = 1532.7 \cdot kN$		$H_{1.U1.loc} = 21.10\,m$
Water Weight (HW) on Fixed Crest:	$H_{2.U1} = 586.2 \cdot kN$		$H_{2.U1.loc} = 14.25\,m$
Water Weight (TW) on Fixed Crest:	$H_{3.U1} = 0.0 \cdot kN$		$H_{3.U1.loc} = 0.00\,m$
Vertical Seismic Component of Concrete Structure:	$Q_{conc.E3.EQv.2} = -739.9 \cdot kN$	at:	$X_{conc.loc} = 12.71\,m$
Vertical Seismic Component of Vertical Lift Gate:	$Q_{Gate.E3.EQv.2} = -16.9 \cdot kN$		$X_{gate} = 8.75\,m$
Vertical Seismic Component of Headwater over Apron Slab:	$Q_{H1.E3.EQv.2} = -44.6 \cdot kN$		$H_{1.U1.loc} = 21.10\,m$
Vertical Seismic Component of Headwater over Fixed Crest Slab:	$Q_{H2.E3.EQv.2} = -17.1 \cdot kN$		$H_{2.U1.loc} = 14.25\,m$

Uplift for Overturning Analysis, Line of Creep Method. Pore pressure at base of Concrete, first calculation to presumed inclined straight line from Heel to Toe, thereafter by Archimedes Principle.

$$U_{E3.2.loc.sliding} := \frac{U_{A.U1} \cdot L_{A.U1} + U_{B.U1} \cdot L_{B.U1} - A_{rs} \cdot w_{as} \cdot \gamma_w \cdot L_{rs}}{U_{A.U1} + U_{B.U1} - A_{rs} \cdot w_{as} \cdot \gamma_w} = 13.73\,m$$

$$U_{E3.2.sliding} := U_{U1} + A_{rs} \cdot w_{as} \cdot \gamma_w = -11002111.2\,N$$

Uplift for Overturning Analysis, Line of Creep Method. Pore pressure at base of Concrete $\quad Uplift_{pore.U1} = -10515.7 \cdot kN$

$$Uplift_{pore.E3.2.loc} := \frac{Uplift_{BC.U1} \cdot Uplift_{BC.U1.loc} + Uplift_{DE.U1} \cdot Uplift_{DE.U1.loc} + Uplift_{EF.U1} \cdot Uplift_{EF.U1.loc} + Uplift_{FG.U1} \cdot Uplift_{FG.U1.loc}}{Uplift_{pore.U1}} = 13.1\,m$$

Sum of All Water Load for Overturning Analysis $\quad \Sigma V_{water.E3.2.OT} := H_{1.U1} + H_{2.U1} + H_{3.U1} + Uplift_{pore.U1} = -8396.7 \cdot kN$

All Lateral Loads Applicable to Overturning Stability Analysis

Apply Load to Gate?: $\quad poss_{U1} = 1 \quad$ poss = 1 if gate is closed
0 if gate is open

Headwater Lateral Load on Gate: $\quad H_{hwg.U1} = 0.0 \cdot kN \quad H_{hwg.U1.loc} = 6.20\,m$

Headwater Lateral Load on Footing: $\quad H_{hwf.U1} = -3840.6 \cdot kN \quad H_{hwf.U1.loc} = 1.17\,m$

Total Horizontal Tailwater Load on Footing under Gate Openings, i.e., excluding Pier $\quad H_{twf.U1} = 721.0 \cdot kN \quad H_{twf.U1.loc} = -0.33\,m$

Resisting Water on Rear Face of Monolith, i.e., bottom of heel elevation: *(Point O @ TOE: BOFtoe = EL.1205.5)*

Horizontal Seismic Component of Concrete Structure: $\quad Q_{conc.E3.EQh.2} = -4404.1 \cdot kN \quad$ AT $\quad Y_{conc.loc} = 3.17\,m$

Horizontal Seismic Component of Vertical Lift Gate: $\quad Q_{Gate.E3.EQh.2} = -100.5 \cdot kN \quad Y_{gate} = 8.00\,m$

Horizontal Seismic Component of Headwater on Gate: $\quad Q_{hwg.E3.EQh.2} = 0 \quad Y_{HWg.E3} = 7.7\,m$

Horizontal Seismic Component of Headwater on Footing: $\quad Q_{hwf.E3.EQh.2} = -780.9 \cdot kN \quad Y_{HWf.E3} = 3\,m$

Horizontal Seismic Component of Active Soil: (Section 5-5, USACE EM_1110-2-2100) $\quad Q_{act.E3.EQh.2} = -1647.4 \cdot kN \quad Y_{E.act.E3} = 3.8\,m$

Ice / Impact Load: $\quad I_{U1} = 0.0 \cdot kN \quad$ at: $\quad I_{U1.loc} = 6.30\,m$

Depth of Fill at Heel Side for Overturning Analysis (neglecting resistance by driving below Point O): $\quad t_{hf.E3.2} := TOC_{as} - BOF_{toe} = 4.50\,m$

Driving Soil Load for overturning:

$$E1_{drive.E3.2} := \frac{K_o \cdot t_{hf.U1}^{\;2}}{2} \cdot (\gamma_r - \gamma_w) \cdot W_b \cdot -1 = -974.5 \cdot kN$$

Acting at:

$$E1_{drive.loc.E3.2} := \frac{t_{hf.E3.2}}{3} = 1.50\,m$$

E3.2 CASE

Downstream (resisting) Lateral Soil Load
as required to produce horizontal equilibrium:

$$E2_{resistE3.2} := -1 \cdot \left(H_{hwg.U1} + H_{hwf.U1} + H_{twf.U1} + I_{U1} + E1_{drive.U1}\right)$$

$$E2_{resistE3.2} = 4094104.1\ N$$

Assumed Resisting Bedrock at middle of Key, passive soil pressure or lateral bearing contract joint at end of Monolith 3A3B

$$E2_{resistlocE3.2} := E2_{resistlocU1} = -0.75\,m$$

Overturning moment by Dead Loads about Point O @ Toe

$$\Sigma M_{DL.U1} = 325934.4 \cdot kN \cdot m$$

Overturning moment by Vertical Water Loads and Uplift, about Point O @ Toe

$$\Sigma M_{Vwater.U1} = -185663.8 \cdot kN \cdot m$$

Overturning moment by Lateral Hydrostatic Forces of Headwater Pool and Tailwater Pool,about Point O @ Toe

$$\Sigma M_{HWater.U1} = -4743.1 \cdot kN \cdot m$$

Overturning Moment by Impact/Ice Load, about Point O@ Toe

$$\Sigma M_{I.U1} = 0$$

Overturning moment by Lateral Soil Forces about Point O @ Toe

$$\Sigma M_{soil.E3.2} := E1_{drive.E3.3} \cdot E1_{drive.loc.E3.3} + E2_{resistE3.2} \cdot E2_{resistlocE3.2} = -4532.4 \cdot kN \cdot m$$

Sum of the Overturning Moments about Point O @ Toe:

$$\Sigma M_{E3.2.OT} := \Sigma M_{DL.U1} + \Sigma M_{HWater.U1} + \Sigma M_{Vwater.U1.OT} + \Sigma M_{I.U1} + \Sigma M_{soil.E3.2} + \Sigma M_{Q.E3.2} = 185477 \cdot kN \cdot m$$

Sum of Vertical Forces:

$$\Sigma V_{E3.2.OT} := \Sigma V_{DL.U1} + \Sigma V_{water.U1.OT} + \left|\Sigma V_{Q.E3.EQv.2}\right| = 18177.9 \cdot kN$$

Distance X_R: EM 1110-2-2502 Eq.4-1

$$X_{R.E3.2} := \frac{\Sigma M_{E3.2.OT}}{\Sigma V_{E3.2.OT}} = 10.2\,m$$

Overturning Resultant Ratio

$$Ratio_{Overturning.E3.2} := \frac{X_{R.E3.2}}{L_b} = 0.42$$

EM 1110-2-2502

Table 4-1

Retaining Wall Stability Criteria

Loading Condition	Sliding Factor of Safety, FS	Shear Strength Test Required: Soil Foundation	Shear Strength Test Required: Rock Foundation[3]	Overturning Criteria Minimum Base Area in Compression: Soil Foundation	Overturning Criteria Minimum Base Area in Compression: Rock Foundation
Usual	1.5	(Q &/or S)[2,1]	Direct shear	100%[4]	75%[4]
Unusual	1.33	(Q &/or S)[2,1]	Direct shear	75%[4]	50%[4]
Earthquake	1.1	(Q)	Direct shear	Resultant within base	Resultant within base

Overturning Stability Check

$$Ratio_{Overturning.E3.2.check} := \begin{cases} \text{"Okay"} & \text{if } Ratio_{Overturning.E3.2} \geq Ratio_{overturning.allow.Extreme} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$$Ratio_{Overturning.E3.2.check} = \text{"Okay"}$$

Summary of Seismic Results (Only Report Controlling Load Case)

E3.2 CASE

Seismic Case $Q_{E3.2}$: 100% Horizontal Seismic Force, 30% Vertical

Horiz Sliding Factor of Safety:	$FS_{HorizSliding.E3.2} = 0.44$
Horiz Sliding Factor of Safety Check:	$FS_{HorizSliding.E3.2.Check}$ = "Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !"
Sliding Factor of Safety:	$FS_{InclinedISlidingE3.2} = 1.3$
Sliding Factor of Safety Check:	$FS_{Sliding.E3.2.InclinedCheck}$ = "OKAY "
Eccentricity:	$e_{E3.2} = 0.89\,m$
Eccentricity Check:	$e_{check.E3.2}$ = "Okay"
Bearing Pressure At Heel:	$\sigma_{heel.E3.2} = 64.5 \cdot \frac{kN}{m^2}$
Bearing Pressure At Heel Check:	$\sigma_{heel.E3.2.check}$ = "Okay"
Bearing Pressure At Heel:	$\sigma_{toe.E3.2} = 100.8 \cdot \frac{kN}{m^2}$
Bearing Pressure At Toe Check:	$\sigma_{toe.E3.2.check}$ = "Okay"
Flotation Factor of Safety	$FS_{Flotation.E3.2} = 1.65$
Flotation Factor of Safety Check:	$Flotation_{E3.2.check}$ = "Okay"
Overturning Resultant Ratio	$Ratio_{Overturning.E3.2} = 0.42$
Overturning Stability Check	$Ratio_{Overturning.E3.2.check}$ = "Okay"

SEISMIC LOAD E4: EDGM Post-Seimic Assessment of Usual Load U2 Event (3 Load Cases)

E4.2 CASE

Seismic Case $Q_{E4.2}$ - 100% Horizontal Seismic Force, 30% Vertical

Horizontal Seismic Coefficient: $K_{h.E4.2} := \frac{-2}{3} \cdot 0.26 = -0.17$

Vertical Seismic Coefficient: $K_{v.E4.2} := 0.3 \cdot \frac{-2}{3} \cdot 0.56 \cdot 0.26 = -0.03$

HORIZONTAL SEISMIC LOADS	Loads	Moment Arm
Horizontal Seismic Component of Concrete Structure:	$Q_{conc.E4.EQh.2} := D_{conc} \cdot K_{h.E4.2} = -4404.1 \cdot kN$	$Y_{conc.loc} = 3.17\, m$
Horizontal Seismic Component of Vertical Lift Gate:	$Q_{Gate.E4.EQh.2} := D_{Gate} \cdot K_{h.E4.2} = -100.5 \cdot kN$	$Y_{gate} = 8.00\, m$
Horizontal Seismic Component of Headwater on Gate: (Section 7.9, Design Criteria)	$Q_{hwg.E4.EQh.2} := \left(\frac{7}{12}\right) \cdot K_{h.E4.2} \cdot \gamma_w \cdot \left(D_{hwg.U2}\right)^2 \cdot W_{hwg.U2} \cdot poss_{U2} = 0 \cdot kN$	$Y_{HWg.E4} = 9.22\, m$
Horizontal Seismic Component of Headwater on Footing: (Section 7.9, Design Criteria)	$Q_{hwf.E4.EQh.2} := \left(\frac{7}{12}\right) \cdot K_{h.E4.2} \cdot \gamma_w \cdot \left(D_{hwf.U2}\right)^2 \cdot W_{hw.U2} = -1657.3 \cdot kN$	$Y_{\ldots E4} = 3.00\, m$
Horizontal Seismic Component of Active Soil: (Section 5-5, USACE EM_1110-2-2100)	$Q_{act.E4.EQh.2} := \gamma_r \cdot \left(TOC_{as} - BOF_{elev}\right)^2 \cdot K_{h.E4.2} \cdot W_{hw.U2} = -1647.4 \cdot kN$	$Y_{E.act.E4} = 3.78\, m$

VERTICAL SEISMIC LOADS	Loads	Moment Arm
Vertical Component of Concrete Structure:	$Q_{conc.E4.EQv.2} := D_{conc} \cdot K_{v.E4.2} = -739.9 \cdot kN$	$X_{conc.loc} = 12.71\, m$
Vertical Component of Vertical Lift Gate:	$Q_{Gate.E4.EQv.2} := D_{Gate} \cdot K_{v.E4.2} = -16.9 \cdot kN$	$X_{gate} = 8.75\, m$
Vertical Seismic Component of Headwater over Apron Slab: (Section 7.9, Design Criteria)	$Q_{H1.E4.EQv.2} := K_{v.E4.2} \cdot H_{1.U2} = -123.3 \cdot kN$	$H_{1.U2.loc} = 21.10\, m$
Vertical Seismic Component of Headwater over Fixed Crest Slab: (Section 7.9, Design Criteria)	$Q_{H2.E4.EQv.2} := K_{v.E4.2} \cdot H_{2.U2} = -99.8 \cdot kN$	$H_{2.U2.loc} = 14.25\, m$

$$\Sigma H_{Q.E4.EQh.2} := Q_{conc.E4.EQh.2} + Q_{Gate.E4.EQh.2} + Q_{hwg.E4.EQh.2} + Q_{hwf.E4.EQh.2} + Q_{act.E4.EQh.2} = -7809.3 \cdot kN$$

$$\Sigma V_{Q.E4.EQv.2} := Q_{conc.E4.EQv.2} + Q_{Gate.E4.EQv.2} + Q_{H1.E4.EQv.2} + Q_{H2.E4.EQv.2} = -979.8 \cdot kN$$

$$\begin{aligned}\Sigma M_{Q.E4.2} := {} & Q_{conc.E4.EQh.2} \cdot Y_{conc.loc} + Q_{Gate.E4.EQh.2} \cdot Y_{gate} + Q_{hwg.E4.EQh.2} \cdot Y_{HWg.E4} \cdots \\ & + Q_{hwf.E4.EQh.2} \cdot Y_{HWf.E4} + Q_{act.E4.EQh.2} \cdot Y_{E.act.E4} + Q_{conc.E4.EQv.2} \cdot X_{conc.loc} + Q_{Gate.E4.EQv.2} \cdot X_{gate} \cdots \\ & + Q_{H1.E4.EQv.2} \cdot H_{1.U2.loc} + Q_{H2.E4.EQv.2} \cdot H_{2.U2.loc} \end{aligned} = -39520.4 \cdot kN \cdot m$$

STABILITY ASSESSMENT: Seismic Case $Q_{E4.2}$: 100% Horizontal Seismic Force, 30% Vertical

E4.2 CASE

CHECK SLIDING ALONG HORIZONTAL PLANE THRU TOE,
IGNORING BEDROCK MOBILIZED BY STRUCTURAL HEEL KEY , OR VOID BEHIND KEY

Sum of Vertical Forces:

$\Sigma V_{E4.2} := \Sigma V_{U2} + \Sigma V_{Q.E4.EQv.2} = 11279.3 \cdot kN$

Sum of Horizontal Forces:

$\Sigma H_{E4.2} := \Sigma H_{U2} + \Sigma H_{Q.E4.EQh.2} = -15304.3 \cdot kN$

Sliding Factor of Safety:

$$FS_{HorizSliding.E4.2} := \frac{\tan_{\phi} \cdot \Sigma V_{E4.2}}{\left|\Sigma H_{E4.2}\right|} = 0.36$$

$$FS_{HorizSliding.E4.2.Check} := \begin{cases} \text{"OKAY"} & \text{if } FS_{HorizSliding.E4.2} \geq FS_{req.E4.sl} \\ \text{"Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !"} & \text{otherwise} \end{cases}$$

$FS_{HorizSliding.E4.2.Check} =$ "Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !"

CHECK SLIDING ALONG INCLINED SLIDING PLANE FROM HEEL KEY TO TOE,
WITH BEDROCK MASS MOBILIZED BY REINFOCREDE CONCRETE KEY)

Incline angle: $\alpha s = 0.12$ $\alpha s \cdot \left(\frac{180}{\pi}\right) = 7.01$

Resolve $\Sigma Vert_{E4.2}$ & $\Sigma Horiz_{E4.2}$

$$\Sigma V_{InclinedE4.2} := \cos(\alpha s) \cdot \left(\Sigma V_{E4.2} + V_{rs}\right) + \sin(\alpha s) \cdot \left|\Sigma H_{E4.2}\right| = 25351.7 \cdot kN$$

$$\Sigma H_{InclinedE4.2} := \cos(\alpha s) \cdot \left|\Sigma H_{E4.2}\right| - \sin(\alpha s) \cdot \left(\Sigma V_{E4.2} + V_{rs}\right) = 12302.5 \cdot kN$$

(With properly engineered reinforced concrete Key, horizontal sliding plane thru Toe is protected, critical sliding plane is relocated to the INCLINED SLIDING PLANE FROM HEEL KEY To TOE, Bedrock Mass above this examing plane is mobilized by reinforced concrete key and combined into Structural Wedge.)

Safety Factor for Sliding
Inclined Failure Plane

$$FS_{InclinedISlidingE4.2} := \frac{\Sigma V_{InclinedE4.2} \cdot \tan\left(\phi_{rock} \cdot \frac{\pi}{180}\right)}{\left|\Sigma H_{InclinedE4.2}\right|} = 1.01$$

$$FS_{Sliding.E4.2.InclinedCheck} := \begin{cases} \text{"OKAY "} & \text{if } FS_{InclinedISlidingE4.2} > FS_{req.E4.sl} \\ \text{"Revise Structure""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

$FS_{Sliding.E4.2.InclinedCheck} =$ "OKAY "

CHECK ECCENTRICITY ON INCLINED PLANE

E4.2 CASE

Seismic Case $Q_{E4.2}$: 100% Horizontal Seismic Force, 30% Vertical

Sum of the moments:

$$\Sigma M_{rs.E4.2} := \Sigma M_{DL.U2} + \Sigma M_{HWater.U2} + \Sigma M_{Vwater.U2} + \Sigma M_{I.U2} + \Sigma M_{soil.U2} + \Sigma M_{Q.E4.2} + V_{rs} \cdot L_{rs} = 270043 \cdot kN \cdot m$$

Eccentricity:

$$e_{E4.2} := \frac{L_{incline}}{2} - \frac{\Sigma M_{rs.E4.2}}{\Sigma V_{InclinedE4.2}} = 1.47\,m$$

Eccentricity Check:

$$e_{check.E4.2} := \begin{cases} \text{"Okay"} & \text{if } \left|e_{E4.2}\right| \le Ecc_{midhalf} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$$e_{check.E4.2} = \text{"Okay"}$$

Foundation Bearing Pressures on Inclined Plane:

Bearing Pressure at Heel:

$$\sigma_{heel.E4.2} := \begin{cases} 0 & \text{if } \left|e_{E4.2}\right| \ge Ecc_{midhalf} \\ \left(\dfrac{\Sigma V_{InclinedE4.2}}{\dfrac{A_b}{\cos(\alpha s)}} - \dfrac{\Sigma V_{InclinedE4.2} \cdot e_{E4.2}}{\dfrac{S_b}{\cos(\alpha s)^2}} \right) & \text{otherwise} \end{cases} = 55.3 \cdot \frac{kN}{m^2}$$

$$\sigma_{heel.E4.2.check} := \left(\begin{cases} \text{"Okay"} & \text{if } \sigma_{heel.E4.2} \le \sigma_{allow.E4} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} \right)$$

$$\sigma_{heel.E4.2.check} = \text{"Okay"}$$

Bearing Pressure at Toe:

$$\sigma_{toe.E4.2} := \begin{cases} \left[\dfrac{4}{3} \cdot \left(\dfrac{\dfrac{\Sigma V_{InclinedE4.2}}{W_b}}{L_{incline} - 2 \cdot e_{E4.2}} \right) \right] & \text{if } \left|e_{E4.2}\right| \ge Ecc_{midhalf} \\ \left[\dfrac{\Sigma V_{InclinedE4.2}}{\dfrac{A_b}{\cos(\alpha s)}} + \dfrac{\left(\Sigma V_{InclinedE4.2} \cdot e_{E4.2}\right)}{\dfrac{S_b}{\cos(\alpha s)^2}} \right] & \text{otherwise} \end{cases} = 118 \cdot \frac{kN}{m^2}$$

$$\sigma_{toe.E4.2.check} := \begin{cases} \text{"Okay"} & \text{if } \sigma_{toe.E4.2} \le \sigma_{allow.E4} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$$\sigma_{toe.E4.2.check} = \text{"Okay"}$$

Foundation Flotation Checks:

$$FS_{Flotation.E4.2} := \frac{D_{conc} + D_{Gate} + H_{1.U2} + H_{2.U2} + H_{3.U2} - \left|\Sigma V_{Q.E4.EQv.2}\right|}{\left|Uplift_{U2}\right|} = 1.5$$

$$Flotation_{E4.2.check} := \begin{cases} \text{"Okay"} & \text{if } FS_{Flotation.E4.2} \ge FS_{req.E.flt} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$$Flotation_{E3.1.check} = \text{"Okay"}$$

MONOLITH OVERTURNING STABILITY ANALYSIS

E4.2 CASE

Seismic Case $Q_{E4.2}$: 100% Horizontal Seismic Force, 30% Vertical

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.

Assumptions are made in order to compute overturning stability of indetermine forces on monolith with key;

(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.

(b) The horizontal resisting force acting on the key, P.key, is that required for static equilibrium

(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1 $Ratio_{overturning.allow.Extreme} = 0.167$ Resultant within Middle Half

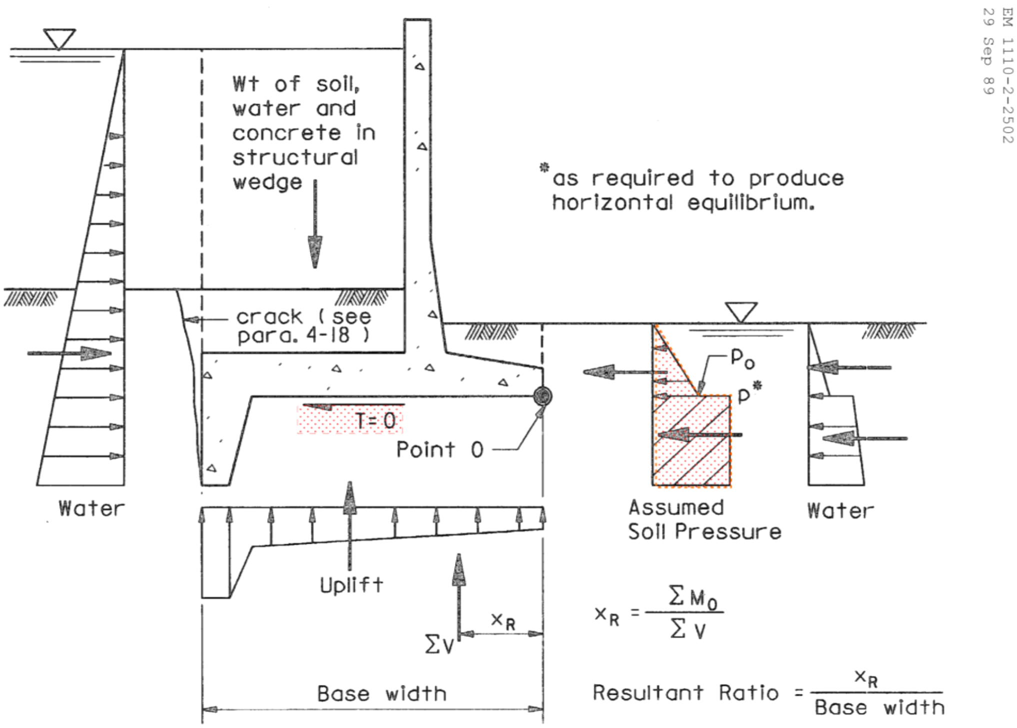


Figure 4-5. Forces for overturning analysis for wall with horizontal base and key

All Vertical Loads Applicable to Overturning Stability Analysis

Total Concrete Dead Loads:	$D_{conc} = 25408.2 \cdot kN$	at:	$X_{conc.loc} = 12.71\ m$
Dead Load of Gate:	$D_{Gate} = 580.0 \cdot kN$		$X_{gate} = 8.75\ m$
Water Weight (HW) on Apron Slab:	$H_{1.U2} = 4233.2 \cdot kN$		$H_{1.U2.loc} = 21.10\ m$
Water Weight (HW) on Fixed Crest:	$H_{2.U2} = 3425.7 \cdot kN$		$H_{2.U2.loc} = 14.25\ m$
Water Weight (TW) on Fixed Crest:	$H_{3.U2} = 2808.8 \cdot kN$		$H_{3.U2.loc} = 5.78\ m$
Vertical Seismic Component of Concrete Structure:	$Q_{conc.E4.EQv.2} = -739.9 \cdot kN$	at:	$X_{conc.loc} = 12.71\ m$
Vertical Seismic Component of Vertical Lift Gate:	$Q_{Gate.E4.EQv.2} = -16.9 \cdot kN$		$X_{gate} = 8.75\ m$
Vertical Seismic Component of Headwater over Apron Slab:	$Q_{H1.E4.EQv.2} = -123.3 \cdot kN$		$H_{1.U2.loc} = 21.10\ m$
Vertical Seismic Component of Headwater over Fixed Crest Slab:	$Q_{H2.E4.EQv.2} = -99.8 \cdot kN$		$H_{2.U2.loc} = 14.25\ m$

Uplift for Overturning Analysis, Line of Creep Method. Pore pressure at base of Concrete, first calculation to presumed inclined straight line from Heel to Toe, thereafter by Archimedes Principle.

E4.2 CASE

$$U_{E4.2.loc.sliding} := \frac{U_{A.U2} \cdot L_{A.U2} + U_{B.U2} \cdot L_{B.U2} - A_{rs} \cdot w_{as} \cdot \gamma_w \cdot L_{rs}}{U_{A.U2} + U_{B.U2} - A_{rs} \cdot w_{as} \cdot \gamma_w} = 13.81\,m$$

$$U_{E4.2.sliding} := U_{U2} + A_{rs} \cdot w_{as} \cdot \gamma_w = -18095683\,N$$

Uplift for Overturning Analysis, Line of Creep Method. Pore pressure at base of Concrete

$$Uplift_{pore.U2} = -17214.6 \cdot kN$$

$$Uplift_{pore.E4.2.loc} := \frac{Uplift_{BC.U2} \cdot Uplift_{BC.U2.loc} + Uplift_{DE.U2} \cdot Uplift_{DE.U2.loc} + Uplift_{EF.U2} \cdot Uplift_{EF.U2.loc} + Uplift_{FG.U2} \cdot Uplift_{FG.U2.loc}}{Uplift_{pore.U2}} = 13.3\,m$$

Sum of All Water Load for Overturning Analysis

$$\Sigma V_{water.E4.2.OT} := H_{1.U1} + H_{2.U1} + H_{3.U1} + Uplift_{pore.U2} = -15095.6 \cdot kN$$

<u>All Lateral Loads Applicable to Overturning Stability Analysis</u>

Apply Load to Gate?: $poss_{U1} = 1$ poss = 1 if gate is closed
0 if gate is open

Headwater Lateral Load on Gate: $H_{hwg.U2} = 0.0 \cdot kN$ $H_{hwg.U2.loc} = 7.43\,m$

Headwater Lateral Load on Footing: $H_{hwf.U2} = -7107.3 \cdot kN$ $H_{hwf.U2.loc} = 1.67\,m$

Total Horizontal Tailwater Load on Footing under Gate Openings, i.e., excluding Pier: $H_{twf.U2} = 1344.9 \cdot kN$ $H_{twf.U2.loc} = 0.09\,m$

Resisting Water on Rear Face of Monolith, i.e., bottom of heel elevation: *(Point O @ TOE: BOFtoe = EL.1205.5)*

Horizontal Seismic Component of Concrete Structure: $Q_{conc.E4.EQh.2} = -4404.1 \cdot kN$ AT $Y_{conc.loc} = 3.17\,m$

Horizontal Seismic Component of Vertical Lift Gate: $Q_{Gate.E4.EQh.2} = -100.5 \cdot kN$ $Y_{gate} = 8.00\,m$

Horizontal Seismic Component of Headwater on Gate: $Q_{hwg.E4.EQh.2} = 0$ $Y_{HWg.E4} = 9.2\,m$

Horizontal Seismic Component of Headwater on Footing: $Q_{hwf.E4.EQh.2} = -1657.3 \cdot kN$ $Y_{HWf.E4} = 3\,m$

Horizontal Seismic Component of Active Soil: (Section 5-5, USACE EM_1110-2-2100) $Q_{act.E4.EQh.2} = -1647.4 \cdot kN$ $Y_{E.act.E4} = 3.8\,m$

Ice / Impact Load: $I_{U2} = 0.0 \cdot kN$ at: $I_{U2.loc} = 11.50\,m$

Depth of Fill at Heel Side for Overturning Analysis (neglecting resistance by driving below Point O):

$$t_{hf.E4.2} := TOC_{as} - BOF_{toe} = 4.50\,m$$

Driving Soil Load for overturning:

$$E1_{drive.E4.2} := \frac{K_o \cdot t_{hf.U2}^{2}}{2} \cdot (\gamma_r - \gamma_w) \cdot W_b \cdot -1 = -974.5 \cdot kN$$

Acting at:

$$E1_{drive.loc.E4.2} := \frac{t_{hf.E4.2}}{3} = 1.50\,m$$

E4.2 CASE

Downstream (resisting) Lateral Soil Load
as required to produce horizontal equilibrium:

$$E2_{resistE4.2} := -1 \cdot \left(H_{hwg.U2} + H_{hwf.U2} + H_{twf.U2} + I_{U2} + E1_{drive.U2}\right)$$

$$E2_{resistE4.2} = 6737012.3\,N$$

Assumed Resisting Bedrock at middle of Key, passive soil pressure or lateral bearing contract joint at end of Monolith 3A3B

$$E2_{resistlocE4.2} := E2_{resistlocU2} = -0.75\,m$$

Overturning moment by Dead Loads about Point O @ Toe

$$\Sigma M_{DL.U2} = 322889.4 \cdot kN \cdot m$$

Overturning moment by Vertical Water Loads and Uplift, about Point O @ Toe

$$\Sigma M_{Vwater.U2} = -171722.3 \cdot kN \cdot m$$

Overturning moment by Lateral Hydrostatic Forces of Headwater Pool and Tailwater Pool,about Point O @ Toe

$$\Sigma M_{HWater.U2} = -11727.4 \cdot kN \cdot m$$

Overturning Moment by Impact/Ice Load, about Point O@ Toe

$$\Sigma M_{I.U2} = 0$$

Overturning moment by Lateral Soil Forces about Point O @ Toe

$$\Sigma M_{soil.E4.2} := E1_{drive.E4.2} \cdot E1_{drive.loc.E4.2} + E2_{resistE4.2} \cdot E2_{resistlocE4.2} = -6514.5 \cdot kN \cdot m$$

Sum of the Overturning Moments about Point O @ Toe:

$$\Sigma M_{E4.2.OT} := \Sigma M_{DL.U2} + \Sigma M_{HWater.U2} + \Sigma M_{Vwater.U2.OT} + \Sigma M_{I.U2} + \Sigma M_{soil.E4.2} + \Sigma M_{Q.E4.2} = 190599 \cdot kN \cdot m$$

Sum of Vertical Forces:

$$\Sigma V_{E4.2.OT} := \Sigma V_{DL.U2} + \Sigma V_{water.U2.OT} + \left|\Sigma V_{Q.E4.EQv.2}\right| = 19641.1 \cdot kN$$

Distance X_R: EM 1110-2-2502 Eq.4-1

$$X_{R.E4.2} := \frac{\Sigma M_{E4.2.OT}}{\Sigma V_{E4.2.OT}} = 9.7\,m$$

Overturning Resultant Ratio

$$Ratio_{Overturning.E4.2} := \frac{X_{R.E4.2}}{L_b} = 0.4$$

EM 1110-2-2502

Table 4-1

Retaining Wall Stability Criteria

Loading Condition	Sliding Factor of Safety, FS	Shear Strength Test Required: Soil Foundation	Shear Strength Test Required: Rock Foundation[3]	Overturning Criteria Minimum Base Area in Compression: Soil Foundation	Overturning Criteria Minimum Base Area in Compression: Rock Foundation
Usual	1.5	(Q &/or S)[2,1]	Direct shear	100%[4]	75%[4]
Unusual	1.33	(Q &/or S)[2,1]	Direct shear	75%[4]	50%[4]
Earthquake	1.1	(Q)	Direct shear	Resultant within base	Resultant within base

Overturning Stability Check

$$Ratio_{Overturning.E4.2.check} := \begin{cases} \text{"Okay"} & \text{if } Ratio_{Overturning.E4.2} \ge Ratio_{overturning.allow.Extreme} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$$Ratio_{Overturning.E4.2.check} = \text{"Okay"}$$

E4.2 CASE

Summary of Seismic Results (Only Report Controlling Load Case)

Seismic Case $Q_{E4.2}$: 100% Horizontal Seismic Force, 30% Vertical

Horiz Sliding Factor of Safety:	$FS_{HorizSliding.E4.2} = 0.36$
Horiz Sliding Factor of Safety Check:	$FS_{HorizSliding.E4.2.Check}$ = "Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !"
Sliding Factor of Safety:	$FS_{InclinedlSlidingE4.2} = 1$
Sliding Factor of Safety Check:	$FS_{Sliding.E4.2.InclinedCheck}$ = "OKAY "
Eccentricity:	$e_{E4.2} = 1.47\,m$
Eccentricity Check:	$e_{check.E4.2}$ = "Okay"
Bearing Pressure At Heel:	$\sigma_{heel.E4.2} = 55.3 \cdot \frac{kN}{m^2}$
Bearing Pressure At Heel Check:	$\sigma_{heel.E4.2.check}$ = "Okay"
Bearing Pressure At Heel:	$\sigma_{toe.E4.2} = 118 \cdot \frac{kN}{m^2}$
Bearing Pressure At Toe Check:	$\sigma_{toe.E4.2.check}$ = "Okay"
Flotation Factor of Safety	$FS_{Flotation.E4.2} = 1.5$
Flotation Factor of Safety Check:	$Flotation_{E4.2.check}$ = "Okay"
Overturning Resultant Ratio	$Ratio_{Overturning.E4.2} = 0.40$
Overturning Stability Check	$Ratio_{Overturning.E4.2.check}$ = "Okay"

SEISMIC LOAD E3: EDGM Post-Seimic Assessment of Usual Load U1 Event (3 Load Cases)

E3.3 CASE

Seismic Case $Q_{E3.3}$ - 30% Horizontal Seismic Force, 100% Vertical

Horizontal Seismic Coefficient: $K_{h.E3.3} := 0.3 \frac{-2}{3} \cdot 0.26 = -0.05$

Vertical Seismic Coefficient: $K_{v.E3.3} := 1 \frac{-2}{3} \cdot 0.56 \cdot 0.26 = -0.10$

HORIZONTAL SEISMIC LOADS	**Loads**	**Moment Arm**
Horizontal Seismic Component of Concrete Structure:	$Q_{conc.E3.EQh.3} := D_{conc} \cdot K_{h.E3.3} = -1321.2 \cdot kN$	$Y_{conc.loc} = 3.17\,m$
Horizontal Seismic Component of Vertical Lift Gate:	$Q_{Gate.E3.EQh.3} := D_{Gate} \cdot K_{h.E3.3} = -30.2 \cdot kN$	$Y_{gate} = 8.00\,m$
Horizontal Seismic Component of Headwater on Gate: (Section 7.9, Design Criteria)	$Q_{hwg.E3.EQh.3} := \left(\frac{7}{12}\right) \cdot K_{h.E3.3} \cdot \gamma_w \cdot \left(D_{hwg.U1}\right)^2 \cdot W_{hwg.U1} \cdot poss_{U1} = 0 \cdot kN$	$Y_{HWg.E3} = 7.74\,m$
Horizontal Seismic Component of Headwater on Footing: (Section 7.9, Design Criteria)	$Q_{hwf.E3.EQh.3} := \left(\frac{7}{12}\right) \cdot K_{h.E3.3} \cdot \gamma_w \cdot \left(D_{hwf.U1}\right)^2 \cdot W_{hw.U1} = -234.3 \cdot kN$	$Y_{HWf.E3} = 3.00\,m$
Horizontal Seismic Component of Active Soil: (Section 5-5, USACE EM_1110-2-2100)	$Q_{act.E3.EQh.3} := \gamma_r \cdot \left(TOC_{as} - BOF_{elev}\right)^2 \cdot K_{h.E3.3} \cdot W_{hw.U1} = -494.2 \cdot kN$	$Y_{E.act.E3} = 3.78\,m$

VERTICAL SEISMIC LOADS	**Loads**	**Moment Arm**
Vertical Component of Concrete Structure:	$Q_{conc.E3.EQv.3} := D_{conc} \cdot K_{v.E3.3} = -2466.3 \cdot kN$	$X_{conc.loc} = 12.71\,m$
Vertical Component of Lift Gate:	$Q_{Gate.E3.EQv.3} := D_{Gate} \cdot K_{v.E3.3} = -56.3 \cdot kN$	$X_{gate} = 8.75\,m$
Vertical Seismic Component of Headwater over Apron Slab: (Section 7.9, Design Criteria)	$Q_{H1.E3.EQv.3} := K_{v.E3.3} \cdot H_{1.U1} = -148.8 \cdot kN$	$H_{1.U1.loc} = 21.10\,m$
Vertical Seismic Component of Headwater over Fixed Crest Slab: (Section 7.9, Design Criteria)	$Q_{H2.E3.EQv.3} := K_{v.E3.3} \cdot H_{2.U1} = -56.9 \cdot kN$	$H_{2.U1.loc} = 14.25\,m$

$$\Sigma H_{Q.E3.EQh.3} := Q_{conc.E3.EQh.3} + Q_{Gate.E3.EQh.3} + Q_{hwg.E3.EQh.3} + Q_{hwf.E3.EQh.3} + Q_{act.E3.EQh.3} = -2079.9 \cdot kN$$

$$\Sigma V_{Q.E3.EQv.3} := Q_{conc.E3.EQv.3} + Q_{Gate.E3.EQv.3} + Q_{H1.E3.EQv.3} + Q_{H2.E3.EQv.3} = -2728.3 \cdot kN$$

$$\Sigma M_{Q.E3.3} := Q_{conc.E3.EQh.3} \cdot Y_{conc.loc} + Q_{Gate.E3.EQh.3} \cdot Y_{gate} + Q_{hwg.E3.EQh.3} \cdot Y_{HWg.E3} \cdots + Q_{hwf.E3.EQh.3} \cdot Y_{HWf.E3} + Q_{act.E3.EQh.3} \cdot Y_{E.act.E3} + Q_{conc.E3.EQv.3} \cdot X_{conc.loc} + Q_{Gate.E3.EQv.3} \cdot X_{gate} \cdots + Q_{H1.E3.EQv.3} \cdot H_{1.U1.loc} + Q_{H2.E3.EQv.3} \cdot H_{2.U1.loc} = -42780 \cdot kN \cdot m$$

STABILITY ASSESSMENT: **E3.3 CASE**

Seismic Case $Q_{E3.3}$ - 30% Horizontal Seismic Force, 100% Vertical

CHECK SLIDING ALONG HORIZONTAL PLANE THRU TOE,
IGNORING BEDROCK MOBILIZED BY STRUCTURAL HEEL KEY_, OR VOID BEHIND KEY

Sum of Vertical Forces:

$\Sigma V_{E3.3} := \Sigma V_{U1} + \Sigma V_{Q.E3.EQv.3} = 8623.7 \cdot kN$

Sum of Horizontal Forces:

$\Sigma H_{E3.3} := \Sigma H_{U1} + \Sigma H_{Q.E3.EQh.3} = -6931.9 \cdot kN$

Sliding Factor of Safety:

$$FS_{HorizSliding.E3.3} := \frac{\tan_{\phi} \cdot \Sigma V_{E3.3}}{\left|\Sigma H_{E3.3}\right|} = 0.61$$

$FS_{HorizSliding.E3.3.Check} :=$ | "OKAY" if $FS_{HorizSliding.E3.3} \geq FS_{req.E3.sl}$
"Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !" otherwise

$FS_{HorizSliding.E3.3.Check} =$ "Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !"

CHECK SLIDING ALONG INCLINED SLIDING PLANE FROM HEEL KEY TO TOE,
WITH BEDROCK MASS MOBILIZED BY REINFOCREDE CONCRETE KEY)

Incline angle: $\alpha s = 0.12$ $\alpha s \cdot \left(\frac{180}{\pi}\right) = 7.01$

Resolve $\Sigma Vert_{E3.3}$ & $\Sigma Horiz_{E3.3}$

$$\Sigma V_{InclinedE3.3} := \cos(\alpha s) \cdot \left(\Sigma V_{E3.3} + V_{rs}\right) + \sin(\alpha s) \cdot \left|\Sigma H_{E3.3}\right| = 21694.2 \cdot kN$$

$$\Sigma H_{InclinedE3.3} := \cos(\alpha s) \cdot \left|\Sigma H_{E3.3}\right| - \sin(\alpha s) \cdot \left(\Sigma V_{E3.3} + V_{rs}\right) = 4316.8 \cdot kN$$

(With properly engineered reinforced concrete Key, horizontal sliding plane thru Toe is protected, critical sliding plane is relocated to the INCLINED SLIDING PLANE FROM HEEL KEY To TOE, Bedrock Mass above this examing plane is mobilized by reinforced concrete key and combined into Structural Wedge.)

Safety Factor for Sliding
Inclined Failure Plane

$$FS_{InclinedlSlidingE3.3} := \frac{\Sigma V_{InclinedE3.3} \cdot \tan\left(\phi_{rock} \cdot \frac{\pi}{180}\right)}{\left|\Sigma H_{InclinedE3.3}\right|} = 2.45$$

$FS_{Sliding.E3.3.InclinedCheck} :=$ | "OKAY " if $FS_{InclinedlSlidingE3.3} > FS_{req.E3.sl}$ = "OKAY "
"Revise Structure"" otherwise

$FS_{Sliding.E3.3.InclinedCheck} =$ "OKAY "

CHECK ECCENTRICITY ON INCLINED PLANE

E3.3 CASE

Seismic Case $Q_{E3.3}$ - 30% Horizontal Seismic Force, 100% Vertical

Sum of the moments:

$$\Sigma M_{rs.E3.3} := \Sigma M_{DL.U1} + \Sigma M_{HWater.U1} + \Sigma M_{Vwater.U1} + \Sigma M_{I.U1} + \Sigma M_{soil.U1} + \Sigma M_{Q.E3.3} + V_{rs} \cdot L_{rs} = 262871 \cdot kN \cdot m$$

Eccentricity:

$$e_{E3.3} := \frac{L_{incline}}{2} - \frac{\Sigma M_{rs.E3.3}}{\Sigma V_{InclinedE3.3}} = 0.01\ m$$

Eccentricity Check:

$$e_{check.E3.3} := \begin{cases} \text{"Okay"} & \text{if } e_{E3.3} \le Ecc_{midhalf} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$$e_{check.E3.3} = \text{"Okay"}$$

Foundation Bearing Pressures on Inclined Plane:

Bearing Pressure at Heel:

$$\sigma_{heel.E3.3} := \begin{cases} 0 & \text{if } \left|e_{E3.3}\right| \ge Ecc_{midhalf} \\ \left(\dfrac{\Sigma V_{InclinedE3.3}}{\dfrac{A_b}{\cos(\alpha s)}} - \dfrac{\Sigma V_{InclinedE3.3} \cdot e_{E3.3}}{\dfrac{S_b}{\cos(\alpha s)^2}} \right) & \text{otherwise} \end{cases} = 74 \cdot \frac{kN}{m^2}$$

$$\sigma_{heel.E3.3.check} := \left(\begin{cases} \text{"Okay"} & \text{if } \sigma_{heel.E3.3} \le \sigma_{allow.E3} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} \right)$$

$$\sigma_{heel.E3.3.check} = \text{"Okay"}$$

Bearing Pressure at Toe:

$$\sigma_{toe.E3.3} := \begin{cases} \left[\dfrac{4}{3} \cdot \left(\dfrac{\dfrac{\Sigma V_{InclinedE3.3}}{W_b}}{L_{incline} - 2 \cdot e_{E3.3}} \right) \right] & \text{if } e_{E3.3} \ge Ecc_{midhalf} \\ \left[\dfrac{\Sigma V_{InclinedE3.3}}{\dfrac{A_b}{\cos(\alpha s)}} + \dfrac{\left(\Sigma V_{InclinedE3.3} \cdot e_{E3.3}\right)}{\dfrac{S_b}{\cos(\alpha s)^2}} \right] & \text{otherwise} \end{cases} = 74.3 \cdot \frac{kN}{m^2}$$

$$\sigma_{toe.E3.3.check} := \begin{cases} \text{"Okay"} & \text{if } \sigma_{toe.E3.3} \le \sigma_{allow.E3} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$$\sigma_{toe.E3.3.check} = \text{"Okay"}$$

Foundation Flotation Checks:

$$FS_{Flotation.E3.3} := \frac{\left(D_{conc} + D_{Gate} + H_{1.U1} + H_{2.U1} + H_{3.U1}\right) - \left|\Sigma V_{Q.E3.EQv.3}\right|}{\left|Uplift_{U1}\right|} = 1.5$$

$$Flotation_{E3.3.check} := \begin{cases} \text{"Okay"} & \text{if } FS_{Flotation.E3.3} \ge FS_{req.E.flt} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$$Flotation_{E3.3.check} = \text{"Okay"}$$

MONOLITH OVERTURNING STABILITY ANALYSIS

E3.3 CASE

Seismic Case $Q_{E3.3}$ - 30% Horizontal Seismic Force, 100% Vertical

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.

Assumptions are made in order to compute overturning stability of indetermine forces on monolith with key;

(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.

(b) The horizontal resisting force acting on the key, P.key, is that required for static equilibrium

(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1

$Ratio_{overturning.allow.Extreme} = 0.167$

Resultant within Middle Half

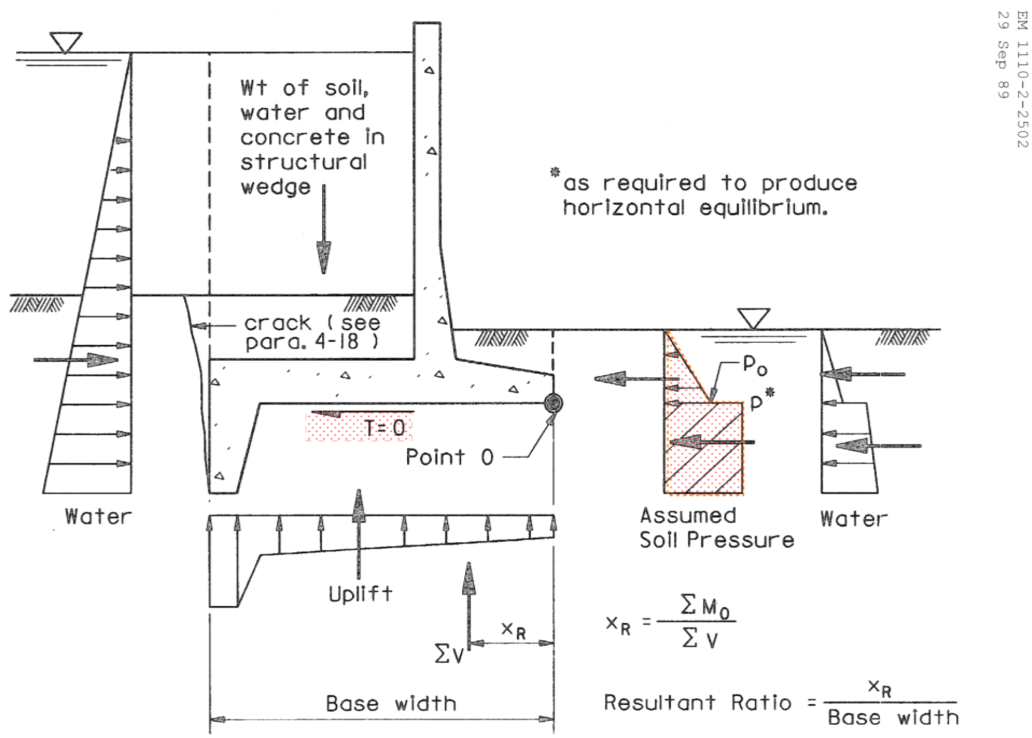


Figure 4-5. Forces for overturning analysis for wall with horizontal base and key

All Vertical Loads Applicable to Overturning Stability Analysis

Total Concrete Dead Loads:	$D_{conc} = 25408.2 \cdot kN$	at:	$X_{conc.loc} = 12.71\,m$
Dead Load of Gate:	$D_{Gate} = 580.0 \cdot kN$		$X_{gate} = 8.75\,m$
Water Weight (HW) on Apron Slab:	$H_{1.U1} = 1532.7 \cdot kN$		$H_{1.U1.loc} = 21.10\,m$
Water Weight (HW) on Fixed Crest:	$H_{2.U1} = 586.2 \cdot kN$		$H_{2.U1.loc} = 14.25\,m$
Water Weight (TW) on Fixed Crest:	$H_{3.U1} = 0.0 \cdot kN$		$H_{3.U1.loc} = 0.00\,m$
Vertical Seismic Component of Concrete Structure:	$Q_{conc.E3.EQv.3} = -2466.3 \cdot kN$	at:	$X_{conc.loc} = 12.71\,m$
Vertical Seismic Component of Vertical Lift Gate:	$Q_{Gate.E3.EQv.3} = -56.3 \cdot kN$		$X_{gate} = 8.75\,m$
Vertical Seismic Component of Headwater over Apron Slab:	$Q_{H1.E3.EQv.3} = -148.8 \cdot kN$		$H_{1.U1.loc} = 21.10\,m$
Vertical Seismic Component of Headwater over Fixed Crest Slab:	$Q_{H2.E3.EQv.3} = -56.9 \cdot kN$		$H_{2.U1.loc} = 14.25\,m$

Uplift for Overturning Analysis, Line of Creep Method. Pore pressure at base of Concrete, first calculation to presumed inclined straight line from Heel to Toe, thereafter by Archimedes Principle.

E3.3 CASE

$$U_{E3.3.loc.sliding} := \frac{U_{A.U1} \cdot L_{A.U1} + U_{B.U1} \cdot L_{B.U1} - A_{rs} \cdot w_{as} \cdot \gamma_w \cdot L_{rs}}{U_{A.U1} + U_{B.U1} - A_{rs} \cdot w_{as} \cdot \gamma_w} = 13.73\,m$$

$$U_{E3.3.sliding} := U_{U1} + A_{rs} \cdot w_{as} \cdot \gamma_w = -11002111.2\,N$$

Uplift for Overturning Analysis, Line of Creep Method. Pore pressure at base of Concrete

$Uplift_{pore.U1} = -10515.7 \cdot kN$

$$Uplift_{pore.E3.3.loc} := \frac{Uplift_{BC.U1} \cdot Uplift_{BC.U1.loc} + Uplift_{DE.U1} \cdot Uplift_{DE.U1.loc} \cdots + Uplift_{EF.U1} \cdot Uplift_{EF.U1.loc} + Uplift_{FG.U1} \cdot Uplift_{FG.U1.loc}}{Uplift_{pore.U1}} = 13.1\,m$$

Sum of All Water Load for Overturning Analysis

$$\Sigma V_{water.E3.3.OT} := H_{1.U1} + H_{2.U1} + H_{3.U1} + Uplift_{pore.U1} = -8396.7 \cdot kN$$

<u>All Lateral Loads Applicable to Overturning Stability Analysis</u>

Apply Load to Gate?: $poss_{U1} = 1$ — poss = 1 if gate is closed, 0 if gate is open

Headwater Lateral Load on Gate: $H_{hwg.U1} = 0.0 \cdot kN$ — $H_{hwg.U1.loc} = 6.20\,m$

Headwater Lateral Load on Footing: $H_{hwf.U1} = -3840.6 \cdot kN$ — $H_{hwf.U1.loc} = 1.17\,m$

Total Horizontal Tailwater Load on Footing under Gate Openings, i.e., excluding Pier: $H_{twf.U1} = 721.0 \cdot kN$ — $H_{twf.U1.loc} = -0.33\,m$

Resisting Water on Rear Face of Monolith, i.e., bottom of heel elevation: *(Point O @ TOE: BOFtoe = EL.1205.5)*

Horizontal Seismic Component of Concrete Structure: $Q_{conc.E3.EQh.3} = -1321.2 \cdot kN$ AT $Y_{conc.loc} = 3.17\,m$

Horizontal Seismic Component of Vertical Lift Gate: $Q_{Gate.E3.EQh.3} = -30.2 \cdot kN$ — $Y_{gate} = 8.00\,m$

Horizontal Seismic Component of Headwater on Gate: $Q_{hwg.E3.EQh.3} = 0$ — $Y_{HWg.E3} = 7.7\,m$

Horizontal Seismic Component of Headwater on Footing: $Q_{hwf.E3.EQh.3} = -234.3 \cdot kN$ — $Y_{HWf.E3} = 3\,m$

Horizontal Seismic Component of Active Soil: (Section 5-5, USACE EM_1110-2-2100): $Q_{act.E3.EQh.3} = -494.2 \cdot kN$ — $Y_{E.act.E3} = 3.8\,m$

Ice / Impact Load: $I_{U1} = 0.0 \cdot kN$ at: $I_{U1.loc} = 6.30\,m$

Depth of Fill at Heel Side for Overturning Analysis (neglecting resistance by driving below Point O):

$$t_{hf.E3.3} := TOC_{as} - BOF_{toe} = 4.50\,m$$

Driving Soil Load for overturning:

$$E1_{drive.E3.3} := \frac{K_o \cdot t_{hf.U1}^{\;2}}{2} \cdot \left(\gamma_r - \gamma_w\right) \cdot W_b \cdot -1 = -974.5 \cdot kN$$

Acting at:

$$E1_{drive.loc.E3.3} := \frac{t_{hf.E3.3}}{3} = 1.50\,m$$

E3.3 CASE

Downstream (resisting) Lateral Soil Load
as required to produce horizontal equilibrium:

$$E2_{resistE3.3} := -1 \cdot \left(H_{hwg.U1} + H_{hwf.U1} + H_{twf.U1} + I_{U1} + E1_{drive.U1}\right)$$

$$E2_{resistE3.3} = 4094104.1\ N$$

Assumed Resisting Bedrock at middle of Key, passive soil pressure or lateral bearing contract joint at end of Monolith 3A3B

$$E2_{resistlocE3.3} := E2_{resistlocU1} = -0.75\,m$$

Overturning moment by Dead Loads about Point O @ Toe

$$\Sigma M_{DL.U1} = 325934.4 \cdot kN \cdot m$$

Overturning moment by Vertical Water Loads and Uplift, about Point O @ Toe

$$\Sigma M_{Vwater.U1} = -185663.8 \cdot kN \cdot m$$

Overturning moment by Lateral Hydrostatic Forces of Headwater Pool and Tailwater Pool,about Point O @ Toe

$$\Sigma M_{HWater.U1} = -4743.1 \cdot kN \cdot m$$

Overturning Moment by Impact/Ice Load, about Point O@ Toe

$$\Sigma M_{I.U1} = 0$$

Overturning moment by Lateral Soil Forces about Point O @ Toe

$$\Sigma M_{soil.E3.3} := E1_{drive.E3.3} \cdot E1_{drive.loc.E3.3} + E2_{resistE3.3} \cdot E2_{resistlocE3.3} = -4532.4 \cdot kN \cdot m$$

Sum of the Overturning Moments about Point O @ Toe:

$$\Sigma M_{E3.3.OT} := \Sigma M_{DL.U1} + \Sigma M_{HWater.U1} + \Sigma M_{Vwater.U1.OT} + \Sigma M_{I.U1} + \Sigma M_{soil.E3.3} + \Sigma M_{Q.E3.3} = 176751 \cdot kN \cdot m$$

Sum of Vertical Forces:

$$\Sigma V_{E3.3.OT} := \Sigma V_{DL.U1} + \Sigma V_{water.U1.OT} + \left|\Sigma V_{Q.E3.EQv.3}\right| = 20087.7 \cdot kN$$

Distance X_R: EM 1110-2-2502 Eq.4-1

$$X_{R.E3.3} := \frac{\Sigma M_{E3.3.OT}}{\Sigma V_{E3.3.OT}} = 8.8\,m$$

Overturning Resultant Ratio

$$Ratio_{Overturning.E3.3} := \frac{X_{R.E3.3}}{L_b} = 0.36$$

EM 1110-2-2502

Table 4-1

Retaining Wall Stability Criteria

Loading Condition	Sliding Factor of Safety, FS	Shear Strength Test Required: Soil Foundation	Shear Strength Test Required: Rock Foundation[3]	Overturning Criteria Minimum Base Area in Compression: Soil Foundation	Overturning Criteria Minimum Base Area in Compression: Rock Foundation
Usual	1.5	(Q &/or S)[2,1]	Direct shear	100%[4]	75%[4]
Unusual	1.33	(Q &/or S)[2,1]	Direct shear	75%[4]	50%[4]
Earthquake	1.1	(Q)	Direct shear	Resultant within base	Resultant within base

Overturning Stability Check

$$Ratio_{Overturning.E3.3.check} := \begin{cases} \text{"Okay"} & \text{if } Ratio_{Overturning.E3.3} \ge Ratio_{overturning.allow.Extreme} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$$Ratio_{Overturning.E3.3.check} = \text{"Okay"}$$

Summary of Seismic Results (Only Report Controlling Load Case)

E3.3 CASE

Seismic Case $Q_{E3.3}$ - 30% Horizontal Seismic Force, 100% Vertical

Horiz Sliding Factor of Safety: $FS_{HorizSliding.E3.3} = 0.61$

Horiz Sliding Factor of Safety Check: $FS_{HorizSliding.E3.3.Check}$ = "Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !"

Sliding Factor of Safety: $FS_{InclinedlSlidingE3.3} = 2.5$

Sliding Factor of Safety Check: $FS_{Sliding.E3.3.InclinedCheck}$ = "OKAY "

Eccentricity: $e_{E3.3} = 0.01\ m$

Eccentricity Check: $e_{check.E3.3}$ = "Okay"

Bearing Pressure At Heel: $\sigma_{heel.E3.3} = 74 \cdot \frac{kN}{m^2}$

Bearing Pressure At Heel Check: $\sigma_{heel.E3.3.check}$ = "Okay"

Bearing Pressure At Heel: $\sigma_{toe.E3.3} = 74.3 \cdot \frac{kN}{m^2}$

Bearing Pressure At Toe Check: $\sigma_{toe.E3.3.check}$ = "Okay"

Flotation Factor of Safety: $FS_{Flotation.E3.3} = 1.54$

Flotation Factor of Safety Check: $Flotation_{E3.3.check}$ = "Okay"

Overturning Resultant Ratio: $Ratio_{Overturning.E3.3} = 0.36$

Overturning Stability Check: $Ratio_{Overturning.E3.3.check}$ = "Okay"

SEISMIC LOAD E4: EDGM Post-Seimic Assessment of Usual Load U2 Event (3 Load Cases)

Seismic Case $Q_{E4.3}$ - 30% Horizontal Seismic Force, 100% Vertical **E4.3 CASE**

Horizontal Seismic Coefficient:

$$K_{h.E4.3} := 0.3 \cdot \frac{-2}{3} \cdot 0.26 = -0.05$$

Vertical Seismic Coefficient:

$$K_{v.E4.3} := 1 \cdot \frac{-2}{3} \cdot 0.56 \cdot 0.26 = -0.10$$

HORIZONTAL SEISMIC LOADS	Loads	Moment Arm
Horizontal Seismic Component of Concrete Structure:	$Q_{conc.E4.EQh.3} := D_{conc} \cdot K_{h.E4.3} = -1321.2 \cdot kN$	$Y_{conc.loc} = 3.17\,m$
Horizontal Seismic Component of Vertical Lift Gate:	$Q_{Gate.E4.EQh.3} := D_{Gate} \cdot K_{h.E4.3} = -30.2 \cdot kN$	$Y_{gate} = 8.00\,m$
Horizontal Seismic Component of Headwater on Gate: (Section 7.9, Design Criteria)	$Q_{hwg.E4.EQh.3} := \left(\frac{7}{12}\right) \cdot K_{h.E4.3} \cdot \gamma_w \cdot \left(D_{hwg.U2}\right)^2 \cdot W_{hwg.U2} \cdot poss_{U2} = 0 \cdot kN$	$Y_{HWg.E4} = 9.22\,m$
Horizontal Seismic Component of Headwater on Footing: (Section 7.9, Design Criteria)	$Q_{hwf.E4.EQh.3} := \left(\frac{7}{12}\right) \cdot K_{h.E4.3} \cdot \gamma_w \cdot \left(D_{hwf.U2}\right)^2 \cdot W_{hw.U2} = -497.2 \cdot kN$	$Y_{HWf.E4} = 3.00\,m$
Horizontal Seismic Component of Active Soil: (Section 5-5, USACE EM_1110-2-2100)	$Q_{act.E4.EQh.3} := \gamma_r \cdot \left(TOC_{as} - BOF_{elev}\right)^2 \cdot K_{h.E4.3} \cdot W_{hw.U2} = -494.2 \cdot kN$	$Y_{E.act.E4} = 3.78\,m$

VERTICAL SEISMIC LOADS	Loads	Moment Arm
Vertical Component of Concrete Structure:	$Q_{conc.E4.EQv.3} := D_{conc} \cdot K_{v.E4.3} = -2466.3 \cdot kN$	$X_{conc.loc} = 12.71\,m$
Vertical Component of Lift Gate:	$Q_{Gate.E4.EQv.3} := D_{Gate} \cdot K_{v.E4.3} = -56.3 \cdot kN$	$X_{gate} = 8.75\,m$
Vertical Seismic Component of Headwater over Apron Slab: (Section 7.9, Design Criteria)	$Q_{H1.E4.EQv.3} := K_{v.E4.3} \cdot H_{1.U2} = -410.9 \cdot kN$	$H_{1.U2.loc} = 21.10\,m$
Vertical Seismic Component of Headwater over Fixed Crest Slab: (Section 7.9, Design Criteria)	$Q_{H2.E4.EQv.3} := K_{v.E4.3} \cdot H_{2.U2} = -332.5 \cdot kN$	$H_{2.U2.loc} = 14.25\,m$

$$\Sigma H_{Q.E4.EQh.3} := Q_{conc.E4.EQh.3} + Q_{Gate.E4.EQh.3} + Q_{hwg.E4.EQh.3} + Q_{hwf.E4.EQh.3} + Q_{act.E4.EQh.3} = -2342.8 \cdot kN$$

$$\Sigma V_{Q.E4.EQv.3} := Q_{conc.E4.EQv.3} + Q_{Gate.E4.EQv.3} + Q_{H1.E4.EQv.3} + Q_{H2.E4.EQv.3} = -3266.0 \cdot kN$$

$$\Sigma M_{Q.E4.3} := Q_{conc.E4.EQh.3} \cdot Y_{conc.loc} + Q_{Gate.E4.EQh.3} \cdot Y_{gate} + Q_{hwg.E4.EQh.3} \cdot Y_{HWg.E4} \cdots + Q_{hwf.E4.EQh.3} \cdot Y_{HWf.E4} + Q_{act.E4.EQh.3} \cdot Y_{E.act.E4} + Q_{conc.E4.EQv.3} \cdot X_{conc.loc} + Q_{Gate.E4.EQv.3} \cdot X_{gate} \cdots + Q_{H1.E4.EQv.3} \cdot H_{1.U2.loc} + Q_{H2.E4.EQv.3} \cdot H_{2.U2.loc} = -53027.1 \cdot kN \cdot m$$

STABILITY ASSESSMENT:

E4.3 CASE

Seismic Case $Q_{E4.3}$ - 30% Horizontal Seismic Force, 100% Vertical

CHECK SLIDING ALONG HORIZONTAL PLANE THRU TOE,
IGNORING BEDROCK MOBILIZED BY STRUCTURAL HEEL KEY, OR VOID BEHIND KEY

Sum of Vertical Forces:

$\Sigma V_{E4.3} := \Sigma V_{U2} + \Sigma V_{Q.E4.EQv.3} = 8993.1 \cdot kN$

Sum of Horizontal Forces:

$\Sigma H_{E4.3} := \Sigma H_{U2} + \Sigma H_{Q.E4.EQh.3} = -9837.8 \cdot kN$

Sliding Factor of Safety:

$$FS_{HorizSliding.E4.3} := \frac{\tan_{\phi} \cdot \Sigma V_{E4.3}}{\left|\Sigma H_{E4.3}\right|} = 0.45$$

$FS_{HorizSliding.E4.3.Check} :=$ | "OKAY" if $FS_{HorizSliding.E4.3} \geq FS_{req.E4.sl}$
"Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !" otherwise

$FS_{HorizSliding.E4.3.Check} =$ "Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !"

CHECK SLIDING ALONG INCLINED SLIDING PLANE FROM HEEL KEY TO TOE,
WITH BEDROCK MASS MOBILIZED BY REINFOCREDE CONCRETE KEY)

Incline angle: $\alpha s = 0.12$ $\qquad \alpha s \cdot \left(\frac{180}{\pi}\right) = 7.01$

Resolve $\Sigma Vert_{E4.3}$ & $\Sigma Horiz_{E4.3}$

$\Sigma V_{InclinedE4.3} := \cos(\alpha s) \cdot \left(\Sigma V_{E4.3} + V_{rs}\right) + \sin(\alpha s) \cdot \left|\Sigma H_{E4.3}\right| = 22415.5 \cdot kN$

$\Sigma H_{InclinedE4.3} := \cos(\alpha s) \cdot \left|\Sigma H_{E4.3}\right| - \sin(\alpha s) \cdot \left(\Sigma V_{E4.3} + V_{rs}\right) = 7155.9 \cdot kN$

(With properly engineered reinforced concrete Key, horizontal sliding plane thru Toe is protected, critical sliding plane is relocated to the INCLINED SLIDING PLANE FROM HEEL KEY To TOE, Bedrock Mass above this examing plane is mobilized by reinforced concrete key and combined into Structural Wedge.)

Safety Factor for Sliding
Inclined Failure Plane

$$FS_{InclinedISlidingE4.3} := \frac{\Sigma V_{InclinedE4.3} \cdot \tan\left(\phi_{rock} \cdot \frac{\pi}{180}\right)}{\left|\Sigma H_{InclinedE4.3}\right|} = 1.53$$

$FS_{Sliding.E4.3.InclinedCheck} :=$ | "OKAY " if $FS_{InclinedISlidingE4.3} > FS_{req.E3.sl}$ = "OKAY "
"Revise Structure"" otherwise

$FS_{Sliding.E4.3.InclinedCheck} =$ "OKAY "

CHECK ECCENTRICITY ON INCLINED PLANE

E4.3 CASE

Seismic Case $Q_{E4.3}$ - 30% Horizontal Seismic Force, 100% Vertical

Sum of the moments:

$$\Sigma M_{rs.E4.3} := \Sigma M_{DL.U2} + \Sigma M_{HWater.U2} + \Sigma M_{Vwater.U2} + \Sigma M_{I.U2} + \Sigma M_{soil.U2} + \Sigma M_{Q.E4.3} + V_{rs} \cdot L_{rs} = 256536 \cdot kN \cdot m$$

Eccentricity:

$$e_{E4.3} := \frac{L_{incline}}{2} - \frac{\Sigma M_{rs.E4.3}}{\Sigma V_{InclinedE4.3}} = 0.68\,m$$

Eccentricity Check:

$$e_{check.E4.3} := \begin{cases} \text{"Okay"} & \text{if } e_{E4.3} \le Ecc_{midhalf} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$$e_{check.E4.3} = \text{"Okay"}$$

Foundation Bearing Pressures on Inclined Plane:

Bearing Pressure at Heel:

$$\sigma_{heel.E4.3} := \begin{cases} 0 & \text{if } \left|e_{E4.3}\right| \ge Ecc_{midhalf} \\ \left(\dfrac{\Sigma V_{InclinedE4.3}}{\dfrac{A_b}{\cos(\alpha s)}} - \dfrac{\Sigma V_{InclinedE4.3} \cdot e_{E4.3}}{\dfrac{S_b}{\cos(\alpha s)^2}} \right) & \text{otherwise} \end{cases} = 63.8 \cdot \frac{kN}{m^2}$$

$$\sigma_{heel.E4.3.check} := \left(\begin{cases} \text{"Okay"} & \text{if } \sigma_{heel.E4.3} \le \sigma_{allow.E4} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} \right)$$

$$\sigma_{heel.E4.3.check} = \text{"Okay"}$$

Bearing Pressure at Toe:

$$\sigma_{toe.E4.3} := \begin{cases} \left[\dfrac{4}{3} \cdot \left[\dfrac{\left(\dfrac{\Sigma V_{InclinedE4.3}}{W_b} \right)}{L_{incline} - 2 \cdot e_{E4.3}} \right] \right] & \text{if } \left|e_{E4.3}\right| \ge Ecc_{midhalf} \\ \left[\dfrac{\Sigma V_{InclinedE4.3}}{\dfrac{A_b}{\cos(\alpha s)}} + \dfrac{\left(\Sigma V_{InclinedE4.3} \cdot e_{E4.3}\right)}{\dfrac{S_b}{\cos(\alpha s)^2}} \right] & \text{otherwise} \end{cases} = 89.4 \cdot \frac{kN}{m^2}$$

$$\sigma_{toe.E4.3.check} := \begin{cases} \text{"Okay"} & \text{if } \sigma_{toe.E4.3} \le \sigma_{allow.E4} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$$\sigma_{toe.E4.3.check} = \text{"Okay"}$$

Foundation Flotation Checks:

$$FS_{Flotation.E4.3} := \frac{\left(D_{conc} + D_{Gate} + H_{1.U2} + H_{2.U2} + H_{3.U2}\right) - \left|\Sigma V_{Q.E4.EQv.3}\right|}{\left|Uplift_{U2}\right|} = 1.4$$

$$Flotation_{E4.3.check} := \begin{cases} \text{"Okay"} & \text{if } FS_{Flotation.E4.3} \ge FS_{req.E.flt} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$$Flotation_{E4.3.check} = \text{"Okay"}$$

MONOLITH OVERTURNING STABILITY ANALYSIS

E4.3 CASE

Seismic Case $Q_{E4.3}$ - 30% Horizontal Seismic Force, 100% Vertical

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.

Assumptions are made in order to compute overturning stability of indetermine forces on monolith with key;

(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.

(b) The horizontal resisting force acting on the key, P.key, is that required for static equilibrium

(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1 $Ratio_{overturning.allow.Extreme} = 0.167$ Resultant within Middle Half

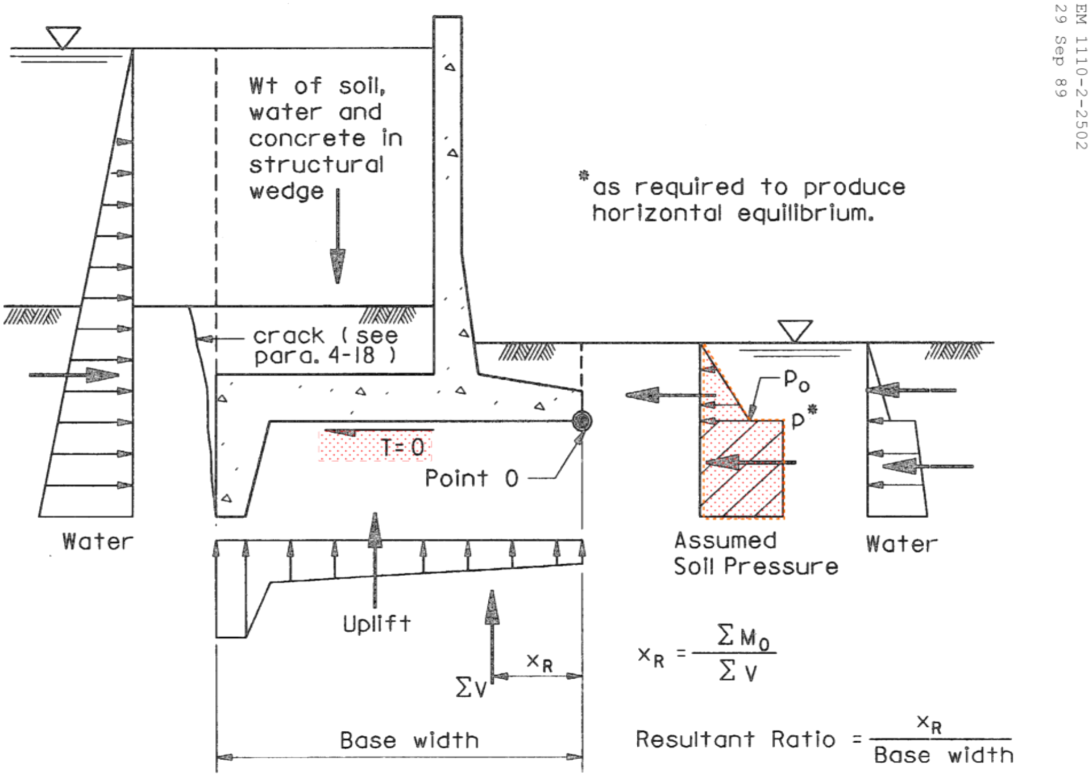


Figure 4-5. Forces for overturning analysis for wall with horizontal base and key

All Vertical Loads Applicable to Overturning Stability Analysis

Total Concrete Dead Loads:	$D_{conc} = 25408.2 \cdot kN$	at:	$X_{conc.loc} = 12.71\ m$
Dead Load of Gate:	$D_{Gate} = 580.0 \cdot kN$		$X_{gate} = 8.75\ m$
Water Weight (HW) on Apron Slab:	$H_{1.U2} = 4233.2 \cdot kN$		$H_{1.U2.loc} = 21.10\ m$
Water Weight (HW) on Fixed Crest:	$H_{2.U2} = 3425.7 \cdot kN$		$H_{2.U2.loc} = 14.25\ m$
Water Weight (TW) on Fixed Crest:	$H_{3.U2} = 2808.8 \cdot kN$		$H_{3.U2.loc} = 5.78\ m$
Vertical Seismic Component of Concrete Structure:	$Q_{conc.E4.EQv.3} = -2466.3 \cdot kN$	at:	$X_{conc.loc} = 12.71\ m$
Vertical Seismic Component of Vertical Lift Gate:	$Q_{Gate.E4.EQv.3} = -56.3 \cdot kN$		$X_{gate} = 8.75\ m$
Vertical Seismic Component of Headwater over Apron Slab:	$Q_{H1.E4.EQv.3} = -410.9 \cdot kN$		$H_{1.U2.loc} = 21.10\ m$
Vertical Seismic Component of Headwater over Fixed Crest Slab:	$Q_{H2.E4.EQv.3} = -332.5 \cdot kN$		$H_{2.U2.loc} = 14.25\ m$

Uplift for Overturning Analysis, Line of Creep Method. Pore pressure at base of Concrete, first calculation to presumed inclined straight line from Heel to Toe, thereafter by Archimedes Principle.

E4.3 CASE

$$U_{E4.3.loc.sliding} := \frac{U_{A.U2} \cdot L_{A.U2} + U_{B.U2} \cdot L_{B.U2} - A_{rs} \cdot w_{as} \cdot \gamma_w \cdot L_{rs}}{U_{A.U2} + U_{B.U2} - A_{rs} \cdot w_{as} \cdot \gamma_w} = 13.81\,m$$

$$U_{E4.3.sliding} := U_{U2} + A_{rs} \cdot w_{as} \cdot \gamma_w = -18095683\,N$$

Uplift for Overturning Analysis, Line of Creep Method. Pore pressure at base of Concrete

$$Uplift_{pore.U2} = -17214.6 \cdot kN$$

$$Uplift_{pore.E4.3.loc} := \frac{Uplift_{BC.U2} \cdot Uplift_{BC.U2.loc} + Uplift_{DE.U2} \cdot Uplift_{DE.U2.loc} \cdots + Uplift_{EF.U2} \cdot Uplift_{EF.U2.loc} + Uplift_{FG.U2} \cdot Uplift_{FG.U2.loc}}{Uplift_{pore.U2}} = 13.3\,m$$

Sum of All Water Load for Overturning Analysis

$$\Sigma V_{water.E4.3.OT} := H_{1.U1} + H_{2.U1} + H_{3.U1} + Uplift_{pore.U2} = -15095.6 \cdot kN$$

<u>All Lateral Loads Applicable to Overturning Stability Analysis</u>

Apply Load to Gate?:	$poss_{U1} = 1$		poss = 1 if gate is closed 0 if gate is open
Headwater Lateral Load on Gate:	$H_{hwg.U2} = 0.0 \cdot kN$		$H_{hwg.U2.loc} = 7.43\,m$
Headwater Lateral Load on Footing:	$H_{hwf.U2} = -7107.3 \cdot kN$		$H_{hwf.U2.loc} = 1.67\,m$
Total Horizontal Tailwater Load on Footing under Gate Openings, i.e., excluding Pier	$H_{twf.U2} = 1344.9 \cdot kN$		$H_{twf.U2.loc} = 0.09\,m$
Resisting Water on Rear Face of Monolith, i.e., bottom of heel elevation:			*(Point O @ TOE: BOFtoe = EL.1205.5)*
Horizontal Seismic Component of Concrete Structure:	$Q_{conc.E4.EQh.3} = -1321.2 \cdot kN$	AT	$Y_{conc.loc} = 3.17\,m$
Horizontal Seismic Component of Vertical Lift Gate:	$Q_{Gate.E4.EQh.3} = -30.2 \cdot kN$		$Y_{gate} = 8.00\,m$
Horizontal Seismic Component of Headwater on Gate:	$Q_{hwg.E4.EQh.3} = 0$		$Y_{HWg.E4} = 9.2\,m$
Horizontal Seismic Component of Headwater on Footing:	$Q_{hwf.E4.EQh.3} = -497.2 \cdot kN$		$Y_{HWf.E4} = 3\,m$
Horizontal Seismic Component of Active Soil: (Section 5-5, USACE EM_1110-2-2100)	$Q_{act.E4.EQh.3} = -494.2 \cdot kN$		$Y_{E.act.E4} = 3.8\,m$
Ice / Impact Load:	$I_{U2} = 0.0 \cdot kN$	at:	$I_{U2.loc} = 11.50\,m$

Depth of Fill at Heel Side for Overturning Analysis (neglecting resistance by driving below Point O):

$$t_{hf.E4.3} := TOC_{as} - BOF_{toe} = 4.50\,m$$

Driving Soil Load for overtuming:

$$E1_{drive.E4.3} := \frac{K_o \cdot t_{hf.U2}^{\,2}}{2} \cdot (\gamma_r - \gamma_w) \cdot W_b \cdot -1 = -974.5 \cdot kN$$

Acting at:

$$E1_{drive.loc.E4.3} := \frac{t_{hf.E4.3}}{3} = 1.50\,m$$

E4.3 CASE

Downstream (resisting) Lateral Soil Load
as required to produce horizontal equilibrium:

$$E2_{resistE4.3} := -1 \cdot \left(H_{hwg.U2} + H_{hwf.U2} + H_{twf.U2} + I_{U2} + E1_{drive.U2}\right)$$

$$E2_{resistE4.3} = 6737012.3\,N$$

Assumed Resisting Bedrock at middle of Key, passive soil pressure or lateral bearing contract joint at end of Monolith 3A3B

$$E2_{resistlocE4.3} := E2_{resistlocU2} = -0.75\,m$$

Overturning moment by Dead Loads about Point O @ Toe

$$\Sigma M_{DL.U2} = 322889.4 \cdot kN \cdot m$$

Overturning moment by Vertical Water Loads and Uplift, about Point O @ Toe

$$\Sigma M_{Vwater.U2} = -171722.3 \cdot kN \cdot m$$

Overturning moment by Lateral Hydrostatic Forces of Headwater Pool and Tailwater Pool,about Point O @ Toe

$$\Sigma M_{HWater.U2} = -11727.4 \cdot kN \cdot m$$

Overturning Moment by Impact/Ice Load, about Point O@ Toe

$$\Sigma M_{I.U2} = 0$$

Overturning moment by Lateral Soil Forces about Point O @ Toe

$$\Sigma M_{soil.E4.3} := E1_{drive.E4.3} \cdot E1_{drive.loc.E4.3} + E2_{resistE4.3} \cdot E2_{resistlocE4.3} = -6514.5 \cdot kN \cdot m$$

Sum of the Overturning Moments about Point O @ Toe:

$$\Sigma M_{E4.3.OT} := \Sigma M_{DL.U2} + \Sigma M_{HWater.U2} + \Sigma M_{Vwater.U2.OT} + \Sigma M_{I.U2} + \Sigma M_{soil.E4.3} + \Sigma M_{Q.E4.3} = 177092 \cdot kN \cdot m$$

Sum of Vertical Forces:

$$\Sigma V_{E4.3.OT} := \Sigma V_{DL.U2} + \Sigma V_{water.U2.OT} + \left|\Sigma V_{Q.E4.EQv.3}\right| = 21927.3 \cdot kN$$

Distance X_R: EM 1110-2-2502 Eq.4-1

$$X_{R.E4.3} := \frac{\Sigma M_{E4.3.OT}}{\Sigma V_{E4.3.OT}} = 8.1\,m$$

Overturning Resultant Ratio

$$Ratio_{Overturning.E4.3} := \frac{X_{R.E4.3}}{L_b} = 0.33$$

EM 1110-2-2502

Table 4-1

Retaining Wall Stability Criteria

Loading Condition	Sliding Factor of Safety, FS	Shear Strength Test Required: Soil Foundation	Shear Strength Test Required: Rock Foundation[3]	Overturning Criteria Minimum Base Area in Compression: Soil Foundation	Overturning Criteria Minimum Base Area in Compression: Rock Foundation
Usual	1.5	(Q &/or S)[2,1]	Direct shear	100%[4]	75%[4]
Unusual	1.33	(Q &/or S)[2,1]	Direct shear	75%[4]	50%[4]
Earthquake	1.1	(Q)	Direct shear	Resultant within base	Resultant within base

Overturning Stability Check

$$Ratio_{Overturning.E4.3.check} := \begin{cases} \text{"Okay"} & \text{if } Ratio_{Overturning.E4.3} \geq Ratio_{overturning.allow.Extreme} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$$Ratio_{Overturning.E4.3.check} = \text{"Okay"}$$

Summary of Seismic Results (Only Report Controlling Load Case)

E4.3 CASE

Seismic Case $Q_{E4.3}$ - 30% Horizontal Seismic Force, 100% Vertical

Horiz Sliding Factor of Safety: $FS_{HorizSliding.E4.3} = 0.45$

Horiz Sliding Factor of Safety Check: $FS_{HorizSliding.E4.3.Check}$ = "Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !"

Sliding Factor of Safety: $FS_{InclinedlSlidingE4.3} = 1.5$

Sliding Factor of Safety Check: $FS_{Sliding.E4.3.InclinedCheck}$ = "OKAY "

Eccentricity: $e_{E4.3} = 0.68\,m$

Eccentricity Check: $e_{check.E4.3}$ = "Okay"

Bearing Pressure At Heel: $\sigma_{heel.E4.3} = 63.8 \cdot \frac{kN}{m^2}$

Bearing Pressure At Heel Check: $\sigma_{heel.E4.3.check}$ = "Okay"

Bearing Pressure At Heel: $\sigma_{toe.E4.3} = 89.4 \cdot \frac{kN}{m^2}$

Bearing Pressure At Toe Check: $\sigma_{toe.E4.3.check}$ = "Okay"

Flotation Factor of Safety $FS_{Flotation.E4.3} = 1.4$

Flotation Factor of Safety Check: $Flotation_{E4.3.check}$ = "Okay"

Overturning Resultant Ratio $Ratio_{Overturning.E4.3} = 0.33$

Overturning Stability Check $Ratio_{Overturning.E4.3.check}$ = "Okay"

Summary of Seismic Results (Controlling Load Cases)

$FS_{InclinedlSlidingE3} := \min\left(FS_{InclinedlSlidingE3.1}, FS_{InclinedlSlidingE3.2}, FS_{InclinedlSlidingE3.3}\right) = 1.33$

$FS_{InclinedlSlidingE4} := \min\left(FS_{InclinedlSlidingE4.1}, FS_{InclinedlSlidingE4.2}, FS_{InclinedlSlidingE4.3}\right) = 1.01$

$\sigma_{heel.E3} := \min\left(\sigma_{heel.E3.1}, \sigma_{heel.E3.2}, \sigma_{heel.E3.3}\right) = 64.5 \cdot \frac{kN}{m^2}$

$\sigma_{heel.E4} := \min\left(\sigma_{heel.E4.1}, \sigma_{heel.E4.2}, \sigma_{heel.E4.3}\right) = 55.3 \cdot \frac{kN}{m^2}$

$\sigma_{toe.E3} := \max\left(\sigma_{toe.E3.1}, \sigma_{toe.E3.2}, \sigma_{toe.E3.3}\right) = 102.8 \cdot \frac{kN}{m^2}$

$\sigma_{toe.E4} := \max\left(\sigma_{toe.E4.1}, \sigma_{toe.E4.2}, \sigma_{toe.E4.3}\right) = 119.8 \cdot \frac{kN}{m^2}$

$FS_{Flotation.E3} := \min\left(FS_{Flotation.E3.1}, FS_{Flotation.E3.2}, FS_{Flotation.E3.3}\right) = 1.5$

$FS_{Flotation.E4} := \min\left(FS_{Flotation.E4.1}, FS_{Flotation.E4.2}, FS_{Flotation.E4.3}\right) = 1.4$

$Ratio_{Overturning.E3} := \min\left(Ratio_{Overturning.E3.1}, Ratio_{Overturning.E3.1}, Ratio_{Overturning.E3.3}\right) = 0.36$

$Ratio_{Overturning.E4} := \min\left(Ratio_{Overturning.E4.1}, Ratio_{Overturning.E4.1}, Ratio_{Overturning.E4.3}\right) = 0.33$

$Ratio_{InComp} := 3 \cdot Ratio_{Overturning.E4} = 1.00$

Appendix E.1-2 STILLING BASINS

Calculation Section I

Results Summary Table (overview)

Table E.1-2.1 – Diversion Inlet - Stilling Basin

Load Case	Headwater/ Tailwater Elevation (m)	Vertical Force Down (kN)	Uplift Force (kN)	Floatation Safety Factor (FSF)		Additional Uplift to be Resisted (kN/m²)
				Required	Calculated	
F1 Usual Diversion Flow	1215.8 / 1213.1	18322	17534	1.50	1.04	36.9
F2 Unusual Const./Dewatered	1215.8 / 1211.0	10152	11654	1.30	0.87	23.1
F3 Extreme Ineffective Drain	1215.8 / 1208.17	10152	7989	1.10	1.27	0

Notes:
1. See Appendix E.1 for definition of monolith description, analysis methodology, and stability calculations.
2. Analysis assumes horizontal sliding plane, interface friction angle Φ = 26 degrees, and no cohesion.

Reported seismic results are controlling values for the three combinations of vertical and horizontal seismic load considered.

Calculation Section II

Results Summary Table (detailed)

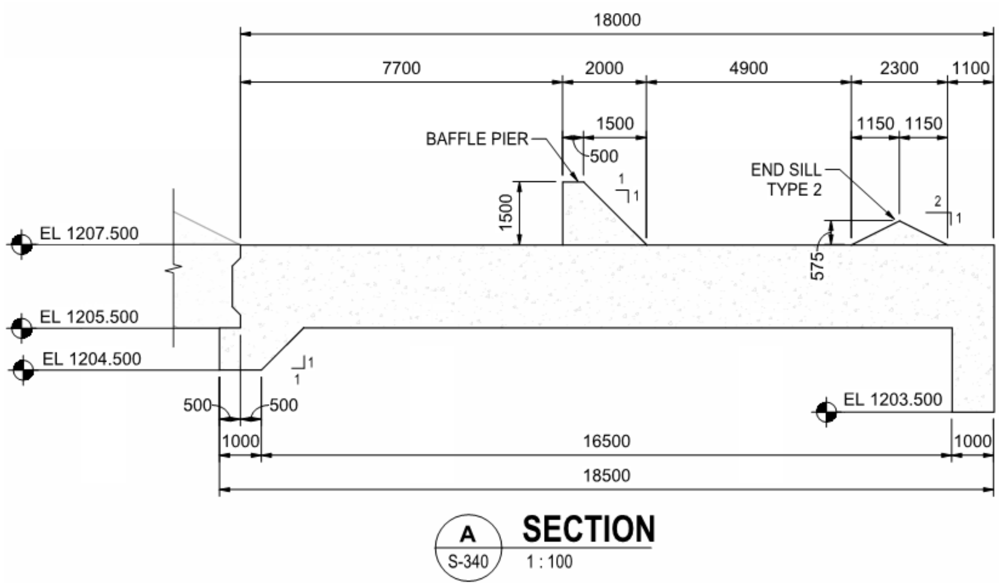
DIVERSION INLET STILLING BASIN FLOATATION SUMMARY (DI-2C)					
Load Combo	Σ Vertical Forces (Down) (kN)	Σ Uplift Forces (kN)	FSF Floatation Required	FSF Floatation Actual	Required Anchor Force (kN/m2)
F1	18321.8	17534.4	1.50	1.04	36.9
F2	10152.0	11654.0	1.30	0.87	23.1
F3	10152.0	7988.8	1.10	1.37	0.0

Calculation Section III

DI-2B/4B Stilling Basin Floatation Calculations

Project Number:	110773396		
Project Title:	SR1 Project		
Client:	Alberta Transportation		
Engineer:	D. Crawford	Date: 2020/06/24	
Checker:	Sean Xiao	Date: 2020/06/24	

Calculation for: Diversion Stilling Basin Monolith 2C Floatation Check



BASE SECTION PROPERTIES

Gate Structure Base Length: $L_b := 24.2m$ (Dwg. S-330 Block-2A + Block 2B)

Base Length: $L_{sb} := 18.0m$ $\quad Kern := \frac{L_{sb}}{6} = 3.00\ m$

Base Width: $W_{sb} := 12.00m$

Area of Base: $A_{sb} := L_{sb} \cdot W_{sb} = 216\ m^2$

Section Modulus of Base: $S_{sb} := \frac{\left(W_{sb} \cdot L_{sb}^2\right)}{6} = 648\ m^3$

Top of Concrete Elevation: $TOC := 1207.50m$

Bottom of Concrete Elevation: $BOF_{elev} := 1205.50m$

FOOTINGS

Stilling Basin Footing Thickness: $h_{sb} := 2.00m$

Stilling Basin Footing Width: $W_{sb} = 12.00\ m$

Stilling Basin Footing Length: $L_{sb} = 18.00\ m$

Total Apron Slab Footing Volume: $V_{sb} := h_{sb} \cdot W_{sb} \cdot L_{sb} = 432.0 \cdot m^3$

MATERIAL PROPERTIES

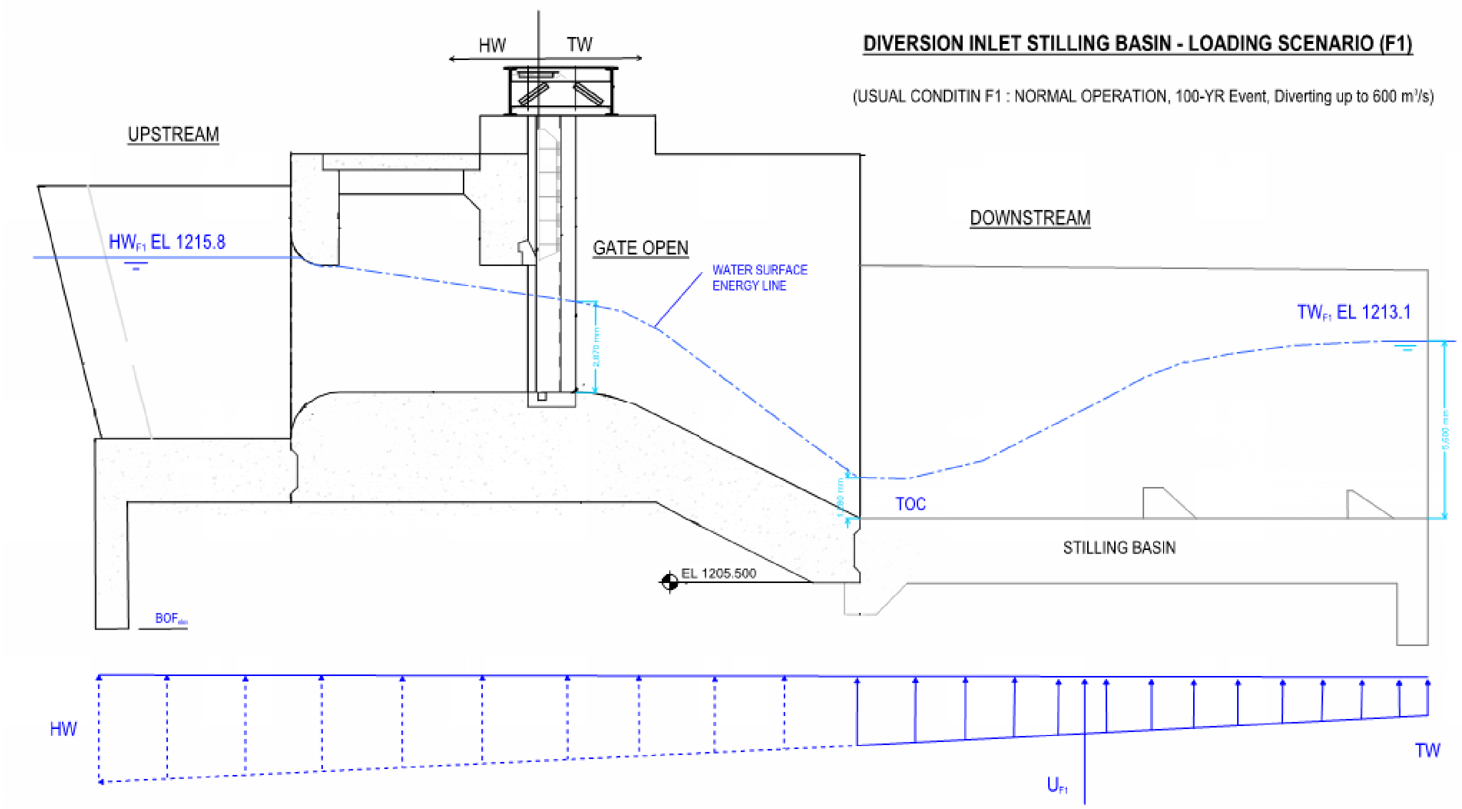
Unit Weight of Concrete: $\gamma_c := 23.5 \frac{kN}{m^3}$ (Section 7.1, Design Criteria)

Unit Weight of Water: $\gamma_w := 9.81 \frac{kN}{m^3}$ (Section 7.2, Design Criteria)

CONCRETE DEAD LOADS

Total Concrete Dead Loads: $D_{conc} := V_{sb} \cdot \gamma_c = 10152.0 \cdot kN$

F1 DESIGN CASE



ACCEPTANCE PARAMETERS

Required Factor of Safety: $FS_{req.F1} := 1.5$

(Without Cohesion)

(Section 8.1, Design Criteria)

VERTICAL WATER LOADS

Headwater Elevation: $H_{hw.F1} := 1215.80m$

Tailwater Elevation: $H_{tw.F1} := 1213.10m$

Include Vertical Water Load in Analysis?: $n_{F1} := 1$

n=1 Yes
n=0 No

Vertical Tailwater Load: $H_{1.F1} := \gamma_w \cdot W_{sb} \cdot (69.4 \cdot m \cdot m) \cdot n_{F1} = 8169.8 \cdot kN$

WATER UPLIFT

Uplift pressure at heel of Gated Structure: $U_{HW.F1} := \left(H_{hw.F1} - BOF_{elev}\right)\cdot\gamma_w = 101.0\cdot\frac{kN}{m^2}$

Uplift pressure at Toe of Stilling Basin: $U_{TW.F1} := \left(H_{tw.F1} - BOF_{elev}\right)\cdot\gamma_w = 74.6\cdot\frac{kN}{m^2}$

Length from Heel of Gate Structure to Toe of Stilling Basin: $L_{overall.F1} := L_b + L_{sb} = 42.20\,m$

Difference between Uplift pressure at Heel of Gate Structure and Uplift Pressure at Toe of Stilling Basin: $U_{diff.F1} := U_{HW.F1} - U_{TW.F1} = 26.5\cdot\frac{kN}{m^2}$

Slope of difference between Uplift pressure at Heel of Gate Structure and Uplift Pressure at Toe of Stilling Basin: $U_{slope.F1} := \frac{U_{diff.F1}}{L_{overall.F1}} = 0.628\cdot\frac{kN}{m^2\cdot m}$

Tailwater Pressure at toe of Gate Structure / Heel of Stilling Basin (Drain considered 50% effective): $U_{press.heel.sb.F1} := U_{TW.F1} + 0.5\cdot U_{diff.F1} = 87.8\cdot\frac{kN}{m^2}$

Uniform uplift force: $U_{A.F1} := U_{TW.F1}\cdot L_{sb}\cdot W_{sb}\cdot -1 = -16104.1\cdot kN$

Triangular uplift force: $U_{B.F1} := \frac{1}{2}\cdot\left(U_{press.heel.sb.F1} - U_{TW.F1}\right)\cdot L_{sb}\cdot W_{sb}\cdot -1 = -1430.3\cdot kN$

Total Resultant Uplift force: $U_{F1} := U_{A.F1} + U_{B.F1} = -17534.4\cdot kN$

$\Sigma V_{water.F1} := H_{1.F1} + U_{F1} = -9364.6\cdot kN$

FLOATATION ANALYSIS:

$\Sigma DL_{F1} := D_{conc} = 10152.0\cdot kN$

$\Sigma H_{vert.F1} := H_{1.F1} = 8169.8\cdot kN$

$\Sigma Up_{F1} := U_{F1} = -17534.4\cdot kN$

$\Sigma Fy_{F1} := \Sigma DL_{F1} + \Sigma H_{vert.F1} + \Sigma Up_{F1} = 787.4\cdot kN$

Factor of Safety: $FS_{act.F1} := \frac{\left(\Sigma DL_{F1} + \Sigma H_{vert.F1}\right)}{\left|\Sigma Up_{F1}\right|} = 1.04$

$$FS_{check.F1} := \begin{array}{|l} \text{"OKAY"} \text{ if } FS_{act.F1} \ge FS_{req.F1} \\ \text{"ANCHORS REQUIRED"} \text{ if } FS_{act.F1} < FS_{req.F1} \end{array} = \text{"ANCHORS REQUIRED"}$$

Anchor Force Required to Meet Factor of Safety Requirements:

$$A_{F1} := \begin{array}{|l} (0.0kN) \text{ if } FS_{act.F1} \ge FS_{req.F1} \\ \left(\left|\Sigma Up_{F1}\right|\cdot FS_{req.F1} - \Sigma DL_{F1} - \Sigma H_{vert.F1}\right) \text{ if } FS_{act.F1} < FS_{req.F1} \end{array} = 7979.8\cdot kN$$

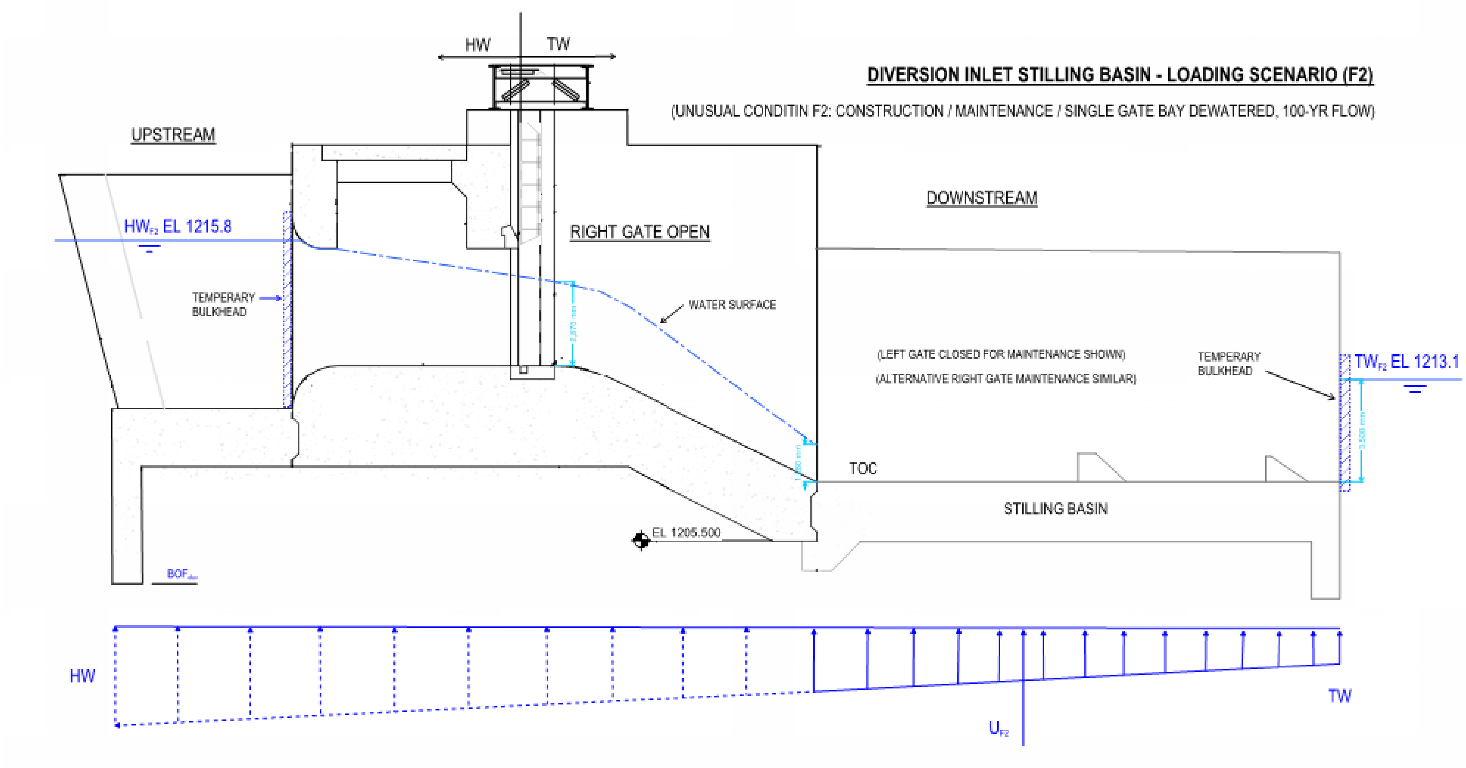
Required anchor resistance over stilling basin Area: $A_{F1.Area} := \frac{A_{F1}}{\left(L_{sb}\cdot W_{sb}\right)} = 36.9\cdot\frac{kN}{m^2}$

Design anchor force and resistance over stilling basin Area by all loading cases

$A_F := \max\left(A_{F1}, A_{F2}, A_{F3}\right) = 7979.8\cdot kN$

$A_{F.Area} := \max\left(A_{F1.Area}, A_{F2.Area}, A_{F3.Area}\right) = 36.9\cdot\frac{kN}{m^2}$

F2 DESIGN CASE



ACCEPTANCE PARAMETERS

Required Factor of Safety: $FS_{req.F2} := 1.3$ (Without Cohesion)

(Section 8.1, Design Criteria)

VERTICAL WATER LOADS

Headwater Elevation: $H_{hw.F2} := 1211.0m$

Tailwater Elevation: $H_{tw.F2} := 1211.0m$

Include Vertical Water Load in Analysis?: $n_{F2} := 0$ n=1 Yes
n=0 No

Vertical Tailwater Load: $H_{1.F2} := \gamma_w \cdot L_{sb} \cdot W_{sb} \cdot \left(H_{tw.F2} - TOC\right) \cdot n_{F2} = 0.0 \cdot kN$

WATER UPLIFT

Uplift pressure at heel of Gated Structure:	$U_{HW.F2} := \left(H_{hw.F2} - BOF_{elev}\right)\cdot\gamma_w = 54.0\cdot\frac{kN}{m^2}$
Uplift pressure at Toe of Stilling Basin:	$U_{TW.F2} := \left(H_{tw.F2} - BOF_{elev}\right)\cdot\gamma_w = 54\cdot\frac{kN}{m^2}$
Length from Heel of Gate Structure to Toe of Stilling Basin:	$L_{overall.F2} := L_b + L_{sb} = 42.20\,m$
Difference between Uplift pressure at Heel of Gate Structure and Uplift Pressure at Toe of Stilling Basin:	$U_{diff.F2} := U_{HW.F2} - U_{TW.F2} = 0\cdot\frac{kN}{m^2}$
Slope of difference between Uplift pressure at Heel of Gate Structure and Uplift Pressure at Toe of Stilling Basin:	$U_{slope.F2} := \frac{U_{diff.F2}}{L_{overall.F2}} = 0.00\cdot\frac{kN}{m^2\cdot m}$
Tailwater Pressure at toe of Gate Structure / Heel of Stilling Basin:	$U_{press.heel.sb.F2} := U_{TW.F2} + \left(L_{sb}\right)\cdot U_{slope.F2} = 54\cdot\frac{kN}{m^2}$
Uniform uplift force:	$U_{A.F2} := U_{TW.F2}\cdot L_{sb}\cdot W_{sb}\cdot -1 = -11654.3\cdot kN$
Triangular uplift force:	$U_{B.F2} := \frac{1}{2}\cdot\left(U_{press.heel.sb.F2} - U_{TW.F2}\right)\cdot L_{sb}\cdot W_{sb}\cdot -1 = 0\cdot kN$
Total Resultant Uplift force:	$U_{F2} := U_{A.F2} + U_{B.F2} = -11654.3\cdot kN$

$$\Sigma V_{water.F2} := H_{1.F2} + U_{F2} = -11654.3\cdot kN$$

FLOATATION ANALYSIS:

$\Sigma DL_{F2} := D_{conc} = 10152.0\cdot kN$

$\Sigma H_{vert.F2} := H_{1.F2} = 0.0\cdot kN$

$\Sigma Up_{F2} := U_{F2} = -11654.3\cdot kN$

$\Sigma Fy_{F2} := \Sigma DL_{F2} + \Sigma H_{vert.F2} + \Sigma Up_{F2} = -1502.3\cdot kN$

Factor of Safety:
$$FS_{act.F2} := \frac{\left(\Sigma DL_{F2} + \Sigma H_{vert.F2}\right)}{\left|\Sigma Up_{F2}\right|} = 0.87$$

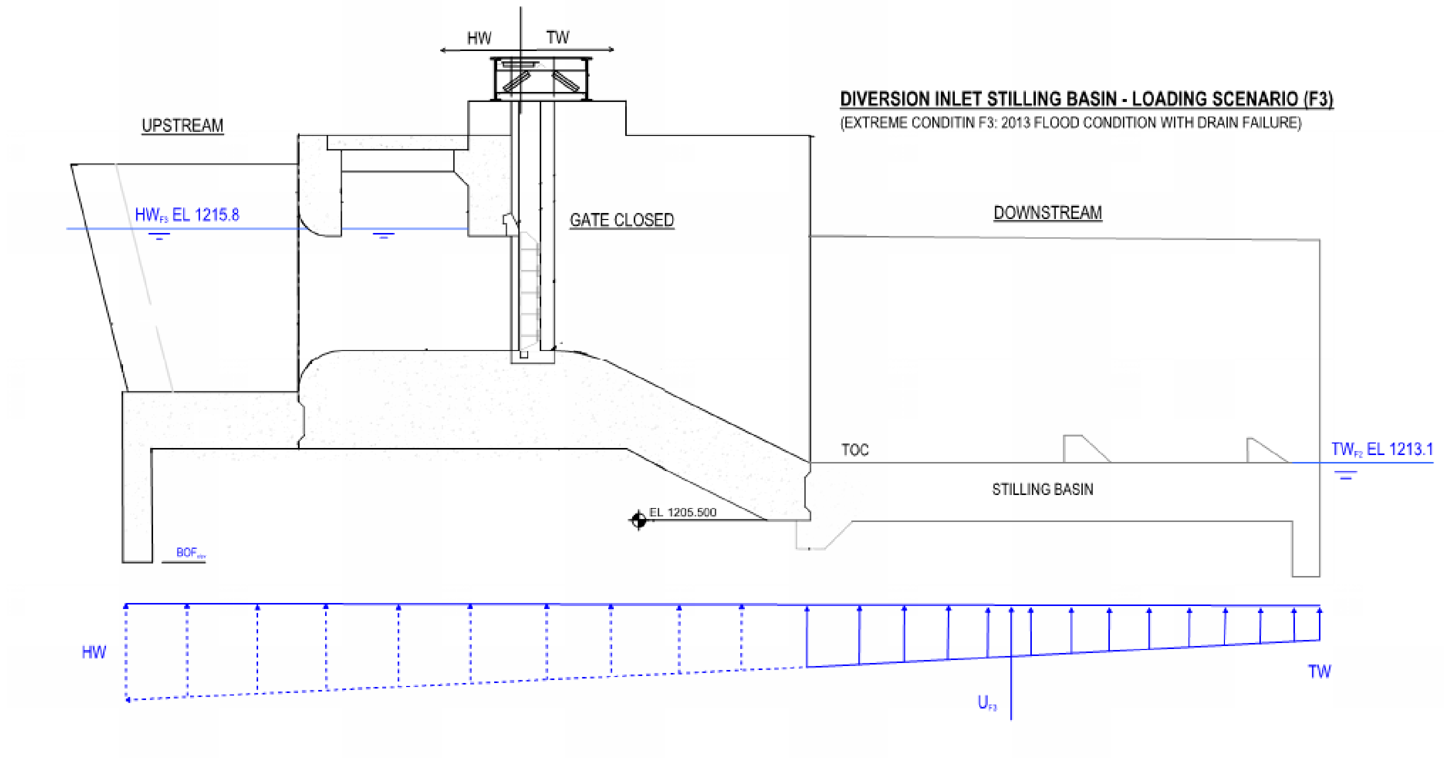
$$FS_{check.F2} := \begin{cases} \text{"OKAY"} & \text{if } FS_{act.F2} \ge FS_{req.F2} \\ \text{"ANCHORS REQUIRED"} & \text{if } FS_{act.F2} < FS_{req.F2} \end{cases} = \text{"ANCHORS REQUIRED"}$$

Anchor Force Required to Meet Factor of Safety Requirements:

$$A_{F2} := \begin{cases} (0.0kN) & \text{if } FS_{act.F2} \ge FS_{req.F2} \\ \left(\left|\Sigma Up_{F2}\right|\cdot FS_{req.F2} - \Sigma DL_{F2} - \Sigma H_{vert.F2}\right) & \text{if } FS_{act.F2} < FS_{req.F2} \end{cases} = 4998.6\cdot kN$$

Required anchor force over stilling basin Area:
$$A_{F2.Area} := \frac{A_{F2}}{\left(L_{sb}\cdot W_{sb}\right)} = 23.1\cdot\frac{kN}{m^2}$$

F3 DESIGN CASE



ACCEPTANCE PARAMETERS

Required Factor of Safety: $FS_{req.F3} := 1.1$ (Without Cohesion)

(Section 8.1, Design Criteria)

VERTICAL WATER LOADS

Headwater Elevation: $H_{hw.F3} := 1215.80m$

Tailwater Elevation: $H_{tw.F3} := 1207.5m$

Include Vertical Water Load in Analysis?: $n_{F3} := 0$

n=1 Yes
n=0 No

Vertical Tailwater Load: $H_{1.F3} := \gamma_w \cdot L_{sb} \cdot W_{sb} \cdot \left(H_{tw.F3} - TOC\right) \cdot n_{F3} = 0.0 \cdot kN$

WATER UPLIFT

F3 CASE

Uplift pressure at heel of Gated Structure: $U_{HW.F3} := \left(H_{hw.F3} - BOF_{elev}\right)\cdot\gamma_w = 101.0\cdot\frac{kN}{m^2}$

Uplift pressure at Toe of Stilling Basin: $U_{TW.F3} := \left(H_{tw.F3} - BOF_{elev}\right)\cdot\gamma_w = 19.6\cdot\frac{kN}{m^2}$

Length from Heel of Gate Structure to Toe of Stilling Basin: $L_{overall.F3} := L_b + L_{sb} = 42.20\,m$

Difference between Uplift pressure at Heel of Gate Structure and Uplift Pressure at Toe of Stilling Basin: $U_{diff.F3} := U_{HW.F3} - U_{TW.F3} = 81.4\cdot\frac{kN}{m^2}$

Slope of difference between Uplift pressure at Heel of Gate Structure and Uplift Pressure at Toe of Stilling Basin: $U_{slope.F3} := \frac{U_{diff.F3}}{L_{overall.F3}} = 1.93\cdot\frac{kN}{m^2\cdot m}$

Tailwater Pressure at toe of Gate Structure / Heel of Stilling Basin: $U_{press.heel.sb.F3} := U_{TW.F3} + \left(L_{sb}\right)\cdot U_{slope.F3} = 54.4\cdot\frac{kN}{m^2}$

Uniform uplift force: $U_{A.F3} := U_{TW.F3}\cdot L_{sb}\cdot W_{sb}\cdot -1 = -4237.9\cdot kN$

Triangular uplift force: $U_{B.F3} := \frac{1}{2}\cdot\left(U_{press.heel.sb.F3} - U_{TW.F3}\right)\cdot L_{sb}\cdot W_{sb}\cdot -1 = -3750.9\cdot kN$

Total Resultant Uplift force: $U_{F3} := U_{A.F3} + U_{B.F3} = -7988.8\cdot kN$

$\Sigma V_{water.F3} := H_{1.F3} + U_{F3} = -7988.8\cdot kN$

FLOATATION ANALYSIS:

$\Sigma DL_{F3} := D_{conc} = 10152.0\cdot kN$

$\Sigma H_{vert.F3} := H_{1.F3} = 0.0\cdot kN$

$\Sigma Up_{F3} := U_{F3} = -7988.8\cdot kN$

$\Sigma Fy_{F3} := \Sigma DL_{F3} + \Sigma H_{vert.F3} + \Sigma Up_{F3} = 2163.2\cdot kN$

Factor of Safety: $FS_{act.F3} := \frac{\left(\Sigma DL_{F3} + \Sigma H_{vert.F3}\right)}{\left|\Sigma Up_{F3}\right|} = 1.27$

$FS_{check.F3} := \begin{cases} \text{"OKAY"} & \text{if } FS_{act.F3} \geq FS_{req.F3} \\ \text{"ANCHORS REQUIRED"} & \text{if } FS_{act.F3} < FS_{req.F3} \end{cases} = \text{"OKAY"}$

Anchor Force Required to Meet Factor of Safety Requirements:

$A_{F3} := \begin{cases} (0.0kN) & \text{if } FS_{act.F3} \geq FS_{req.F3} \\ \left(\left|\Sigma Up_{F3}\right|\cdot FS_{req.F3} - \Sigma DL_{F3} - \Sigma H_{vert.F3}\right) & \text{if } FS_{act.F3} < FS_{req.F3} \end{cases} = 0.0\cdot kN$

Required anchor force over stilling basin Area: $A_{F3.Area} := \frac{A_{F3}}{\left(L_{sb}\cdot W_{sb}\right)} = 0.0\cdot\frac{kN}{m^2}$

Appendix E.1-3 RETAINING WALLS

Calculation Section I

Results Summary Table (overview)

Table E.1-3.1 – Diversion Inlet - Retaining Walls – Stability Analysis Summary

Load Case	Headwater (Heel) Elevation (m)	Tailwater (Toe) Elevation For Uplift (m)	Uplift Force (kN)	Floatation Safety Factor (FSF)		Sliding Safety Factor (SSF)		Foundation Bearing Stress		% Base in Compression
				Req	Calc	Req	Calc	Upstream (Heel) (kPa)	Downstream (Toe) (kPa)	
WALL BLOCK DI-6										
U1 Normal Operation	1213.1	1212.1	494	1.5	3.38	1.5	2.24	76	281	100
UN1 Equip. Surcharge	1213.1	1212.1	494	1.3	3.54	1.3	1.95	58	322	100
UN2 Ineffective Drain	1216.2	1216.2	811	1.3	2.1	1.3	1.34	26	279	100
E1 Seismic	1213.1	1212.1	494	1.1	3.05	1.0	1.78	48	276	100
WALL BLOCK DI-5B										
U1 Normal Operation	1212.0	1210.0	645	1.5	3.99	1.5	2.40	153	228	100
UN1 Equip. Surcharge	1212.0	1210.0	645	1.3	4.12	1.3	2.03	143	256	100
UN2 Ineffective Drain	1215.8	1215.8	1212	1.3	2.16	1.3	1.30	98	203	100
E1 Seismic	1212.0	1210.0	645	1.1	3.60	1.0	1.69	108	236	100
WALL BLOCK DI-5C										
U1 Normal Operation	1210.5	1207.5	529	1.5	5.00	1.5	2.34	151	263	100
UN1 Equip. Surcharge	1210.5	1207.5	529	1.3	5.21	1.3	2.02	137	298	100
UN2 Ineffective Drain	1214.5	1214.5	1171	1.3	2.31	1.3	1.30	97	226	100
E1 Seismic	1210.5	1207.5	529	1.1	4.52	1.0	1.96	123	250	100
WALL BLOCK DI-5D (Upstream)										
U1 Normal Operation	1210.0	1207.5	733	1.5	4.25	1.5	2.21	148	346	100
UN1 Equip. Surcharge	1210.0	1207.5	733	1.3	4.41	1.3	2.02	135	382	100
UN2 Ineffective Drain	1213.5	1213.5	1338	1.3	2.37	1.3	1.31	103	322	100
E1 Seismic	1210.0	1207.5	733	1.1	3.84	1.0	1.85	113	338	100
WALL BLOCK DI-5D (Mid-section)										
U1 Normal Operation	1210.0	1207.5	507	1.5	2.97	1.5	4.09	92	239	100
UN1 Equip. Surcharge	1210.0	1207.5	507	1.3	3.12	1.3	3.26	81	273	100
UN2 Ineffective Drain	1213.5	1213.5	926	1.3	1.67	1.3	1.30	31	244	100
E1 Seismic	1210.0	1207.5	507	1.1	2.68	1.0	2.53	57	250	100
WALL BLOCK DI-5D (Downstream)										
U1 Normal Operation	1209.5	1207.5	265	1.5	2.17	1.5	6.92	53	96	100
UN1 Equip. Surcharge	1209.5	1207.5	265	1.3	2.35	1.3	3.93	54	115	100
UN2 Ineffective Drain	1209.5	1209.5	323	1.3	1.77	1.3	3.60	53	79	100
E1 Seismic	1209.5	1207.5	265	1.1	1.96	1.0	1.88	30	110	100

Notes:
1. See Appendix E.1 for definition of wall section description, analysis methodology, and stability calculations.
2. Analysis assumes inclined sliding plane, interface friction angle Φ = 26 degrees, and no cohesion.
3. Seismic results utilize active soil pressure coefficients for stability values reported.

Calculation Section II

Results Summary Table (detailed)

RETAINING WALL DI-BLOCK 6 STABILITY SUMMARY

Load Combination	Σ Vertical (kN)	Σ Horizontal (kN)	Σ Vertical Inclined Plane (kN)	Σ Horizontal Inclined Plane (kN)	Σ Moments (kN*m)	e Inclined Plane (m)	σ @ Toe (kN/m2)	σ @ Heel (kN/m2)	Base in Compression %	SSF Stability Required	SSF Horiz	SSF Inclined	Σ Vertical Without Uplift (kN)	Σ Uplift (kN)	FSF Floatation Required	FSF Floatation Calculated
U1	1175.7	919.5	1711.4	340.3	6646.0	0.92	280.6	75.5	100.0	1.5	0.62	2.24	1669.7	494	1.5	3.38
UN1	1255.1	1030.1	1824.5	415.9	6735.9	1.11	321.8	57.8	100.0	1.3	0.59	1.95	1749.1	494	1.5	3.54
UN2	893.0	970.8	1464.9	487.5	5522.0	1.33	278.8	26.0	100.0	1.3	0.45	1.34	1704.0	811	2.5	2.10
E1	1013.7	910.4	1556.4	388.7	6834.5	1.13	276.3	47.6	100.0	1.0	0.54	1.78	1507.7	494	3.5	3.05

RETAINING WALL DI-BLOCK 5B STABILITY SUMMARY

Load Combination	Σ Vertical (kN)	Σ Horizontal (kN)	Σ Vertical Inclined Plane (kN)	Σ Horizontal Inclined Plane (kN)	Σ Moments (kN*m)	e Inclined Plane (m)	σ @ Toe (kN/m2)	σ @ Heel (kN/m2)	Base in Compression %	SSF Stability Required	SSF Horiz	SSF Inclined	Σ Vertical Without Uplift (kN)	Σ Uplift (kN)	FSF Floatation Required	FSF Floatation Calculated
U1	1930.0	841.7	2326.5	432.5	13261.2	0.40	228.1	153.4	100.0	1.5	1.12	2.40	2575.0	645	1.5	3.99
UN1	2015.1	960.4	2431.5	534.1	13417.6	0.58	256.2	142.5	100.0	1.3	1.02	2.03	2660.1	645	1.3	4.12
UN2	1410.8	946.0	1834.3	627.9	9881.3	0.71	203.0	97.8	100.0	1.3	0.73	1.30	2623.3	1213	1.3	2.16
E1	1679.9	918.9	2094.2	553.2	13810.0	0.76	235.8	107.6	100.0	1.0	0.89	1.69	2324.9	645	1.1	3.60

RETAINING WALL DI-BLOCK 5C STABILITY SUMMARY

Load Combination	Σ Vertical (kN)	Σ Horizontal (kN)	Σ Vertical Inclined Plane (kN)	Σ Horizontal Inclined Plane (kN)	Σ Moments (kN*m)	e Inclined Plane (m)	σ @ Toe (kN/m2)	σ @ Heel (kN/m2)	Base in Compression %	SSF Stability Required	SSF Horiz	SSF Inclined	Σ Vertical Without Uplift (kN)	Σ Uplift (kN)	FSF Floatation Required	FSF Floatation Calculated
U1	2118.4	924.7	2526.7	480.5	14018.9	0.55	263.2	151.1	100.0	1.5	1.12	2.34	2647.4	529	1.5	5.00
UN1	2224.8	1051.7	2654.1	586.4	14188.6	0.75	298.2	137.1	100.0	1.3	1.03	2.02	2753.8	529	1.3	5.21
UN2	1535.6	1014.8	1969.4	673.3	10406.5	0.80	226.2	96.8	100.0	1.3	0.74	1.30	2706.6	1171	1.3	2.31
E1	1861.4	913.0	2271.8	515.0	9773.7	0.69	249.5	123.1	100.0	1.0	0.99	1.96	2390.4	529	1.1	4.52

RETAINING WALL DI-BLOCK 5D (DOWNSTREAM) STABILITY SUMMARY

Load Combination	Σ Vertical (kN)	Σ Horizontal (kN)	Σ Vertical Inclined Plane (kN)	Σ Horizontal Inclined Plane (kN)	Σ Moments (kN*m)	e Inclined Plane (m)	σ @ Toe (kN/m2)	σ @ Heel (kN/m2)	Base in Compression %	SSF Stability Required	SSF Horiz	SSF Inclined	Σ Vertical Without Uplift (kN)	Σ Uplift (kN)	FSF Floatation Required	FSF Floatation Calculated
U1	308.6	208.1	482.7	31.1	1410.6	0.31	96.1	53.3	100.0	1.5	0.72	6.92	573.2	265	1.5	2.17
UN1	358.2	261.3	548.5	62.1	1559.5	0.39	115.4	54.3	100.0	1.3	0.67	3.93	622.8	265	1.3	2.35
UN2	249.8	208.1	428.1	52.9	1293.0	0.21	79.2	53.3	100.0	1.3	0.59	3.60	573.2	323	1.3	1.77
E1	253.0	268.0	453.3	107.3	1458.0	0.61	110.0	30.3	100.0	1.0	0.46	1.88	517.6	265	1.1	1.96

RETAINING WALL DI-BLOCK 5D - (MIDSECTION) STABILITY SUMMARY

Load Combination	Σ Vertical (kN)	Σ Horizontal (kN)	Σ Vertical Inclined Plane (kN)	Σ Horizontal Inclined Plane (kN)	Σ Moments (kN*m)	e Inclined Plane (m)	σ @ Toe (kN/m2)	σ @ Heel (kN/m2)	Base in Compression %	SSF Stability Required	SSF Horiz	SSF Inclined	Σ Vertical Without Uplift (kN)	Σ Uplift (kN)	FSF Floatation Required	FSF Floatation Calculated
U1	998.1	906.2	1782.3	243.3	7137.6	0.74	238.6	92.2	100.0	1.5	0.54	4.09	1505.3	507	1.5	2.97
UN1	1075.8	1014.7	879.0	222.0	7350.8	0.91	272.9	81.3	100.0	1.3	0.52	3.26	1583.0	507	1.3	3.12
UN2	618.0	1046.0	1386.9	476.1	5180.1	1.30	244.4	31.3	100.0	1.3	0.29	1.30	1544.1	926	1.3	1.67
E1	852.0	934.4	1546.3	271.6	7186.3	1.06	250.4	56.9	100.0	1.0	0.44	2.53	1359.2	507	1.1	2.68

RETAINING WALL DI-BLOCK 5D (UPSTREAM) STABILITY SUMMARY

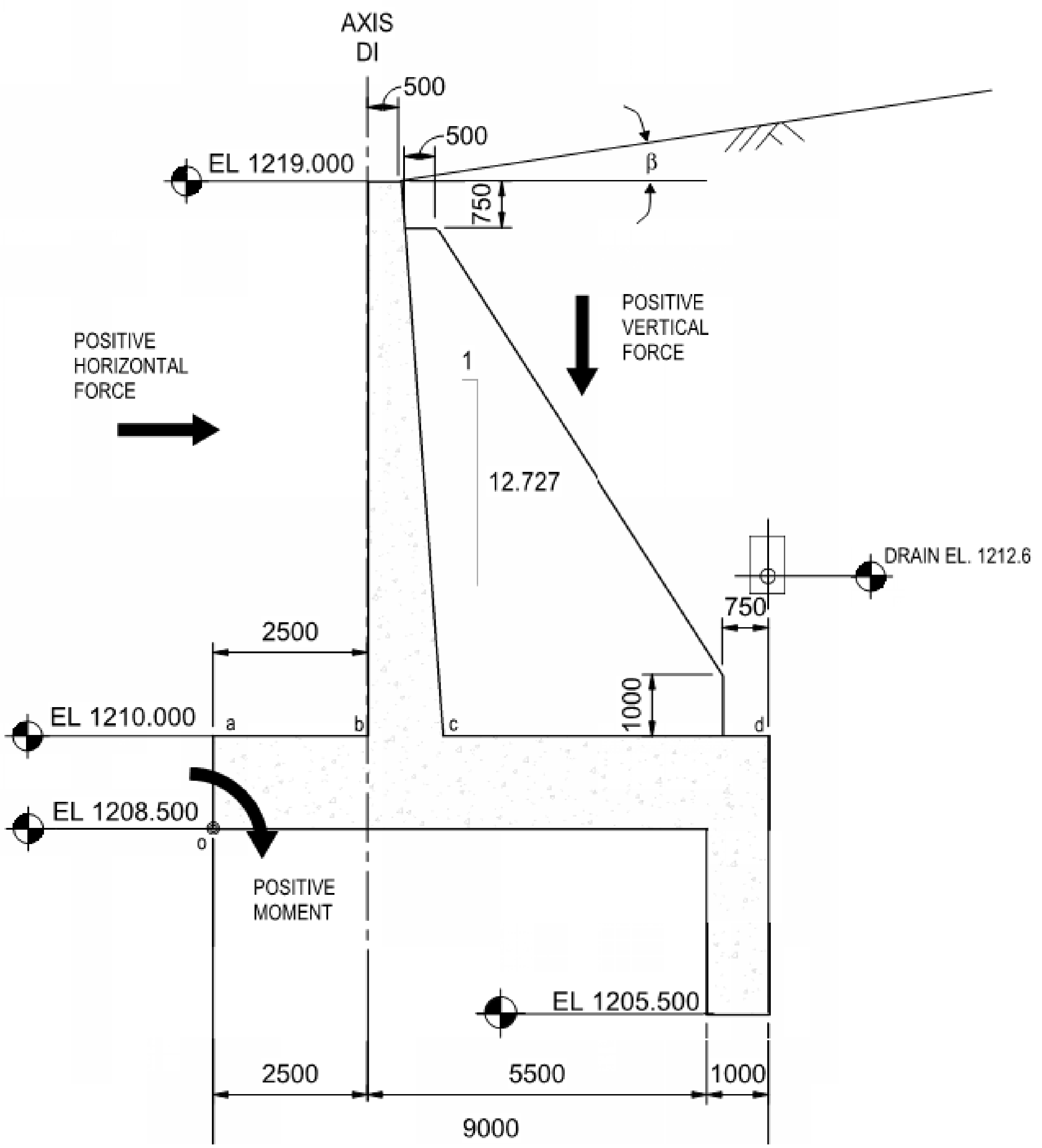
Load Combination	Σ Vertical (kN)	Σ Horizontal (kN)	Σ Vertical Inclined Plane (kN)	Σ Horizontal Inclined Plane (kN)	Σ Moments (kN*m)	e Inclined Plane (m)	σ @ Toe (kN/m2)	σ @ Heel (kN/m2)	Base in Compression %	SSF Stability Required	SSF Horiz	SSF Inclined	Σ Vertical Without Uplift (kN)	Σ Uplift (kN)	FSF Floatation Required	FSF Floatation Calculated
U1	2380.8	1716.6	3384.3	681.4	20075.1	0.92	346.4	147.5	100.0	1.5	0.68	2.21	3113.4	733	1.5	4.25
UN1	2501.7	1864.1	3545.6	783.0	20422.3	1.09	382.4	135.1	100.0	1.3	0.65	2.02	3234.7	733	1.3	4.41
UN2	1834.7	1856.5	2910.5	986.8	16525.6	1.17	321.5	103.2	100.0	1.3	0.48	1.31	3172.4	1338	1.3	2.37
E1	2078.6	1678.8	3085.7	741.1	20888.9	1.14	337.9	112.5	100.0	1.0	0.60	1.85	2811.6	733	1.1	3.84

Calculation Section III

DI-6 Retaining Wall Stability Calculations

Project Number:	110773396		
Project Title:	SR1 - Diversion Structure		
Client:	Alberta Transportation		
Engineer:	Lawrence Choi	Date: 12/11/2018	
Checker:	Sean Xiao	Date: 12/18/2018	

Calculation for: Retaining Wall - Diversion Inlet Left - Block 6



REGION COLOR CONVENTION

User Input

Calulation Highlights

Results

WALL GEOMETRY:

Top of Wall Elevation: $T_w := 1219.0 \cdot m$

Top of Footing Elevation: $Top_{ftg} := 1210.0 \cdot m$

Thickness of Footing: $t_{ftg} := 1.5m$

Bottom of Footing Elevation: $Bot_{ftg} := Top_{ftg} - t_{ftg} = 1208.5 \text{ m}$

Overall Height of wall: $h_w := T_w - Bot_{ftg} = 10.50 \text{ m}$

Thickness of Wall: Base: $t_{wb} := 1.207 \cdot m$ Top: $t_{wt} := 0.50m$

Length of toe: $L_{ab} := 2.5m$

Total Length of Footing: $b := 9.0m$

Length of heel: $L_{cd} := b - L_{ab} - t_{wb} = 5.293 \text{ m}$

Unit Width of Wall for analysis: $B := 1.00m$

SHEAR KEY GEOMETRY:

	Toe	Heel	
Key depth:	$Key_{t.d} := 0m$	$Key_{h.d} := 3.0m$	(Assumption: $Key_{h.d}$ >= $Key_{t.d}$)
Key width:	$Key_{t.w} := 0m$	$Key_{h.w} := 1m$	
Face of Key from Point O:	$Key_{t.loc} := 0 \cdot m$	$Key_{h.loc} := b - Key_{h.w} = 8 \text{ m}$	

Horizontal Distance between Keys: $Key_{hdist} := Key_{h.loc} - Key_{t.loc} - Key_{t.w} = 8 \text{ m}$

Key Depth Diff. (from point O): $Key_{vdist} := -Key_{h.d} + Key_{t.d} = -3 \text{ m}$

BASE PROPERTIES:

Base Area: $A_b := b \cdot B = 9 \text{ m}^2$

Centroidal Distance for Footing (from Toe): $Y_t := \frac{b}{2} = 4.50 \text{ m}$

RETAINED SOIL GEOMETRY:

Slope of retained ground surface: $\beta := 0 \cdot \frac{\pi}{180} = 0.00$

Height of retained earth at heel: $H_w := T_w - Bot_{ftg} + \left(t_{wb} + L_{cd} - t_{wt}\right) \cdot \tan(\beta) = 10.50 \text{ m}$

RETAINING WALL GEOMETRY CHECKS:

(Foundation Analysis & Design Bowles)

$t_{bcheck} := \left| \begin{array}{l} \text{"OKAY"} \quad \text{if} \quad t_{ftg} \geq \frac{H_w}{12} \\ \text{"Warning"} \quad \text{otherwise} \end{array} \right. = \text{"OKAY"}$

$t_{wcheck} := \left| \begin{array}{l} \text{"OKAY"} \quad \text{if} \quad t_{wb} \geq \frac{H_w}{12} \\ \text{"Warning"} \quad \text{otherwise} \end{array} \right. = \text{"OKAY"}$

$b_{check} := \left| \begin{array}{l} \text{"OKAY"} \quad \text{if} \quad \frac{b}{H_w} \geq .4 \wedge \frac{b}{H_w} \leq 80 \\ \text{"Warning"} \quad \text{otherwise} \end{array} \right. = \text{"OKAY"}$

$L_{abcheck} := \left| \begin{array}{l} \text{"OKAY"} \quad \text{if} \quad \frac{L_{ab}}{b} \geq .25 \wedge \frac{L_{ab}}{b} \leq .4 \\ \text{"Warning"} \quad \text{otherwise} \end{array} \right. = \text{"OKAY"}$

Material Properties:

Unit Weight of Water: $\gamma_w := 9.8 \frac{kN}{m^3}$ (Section 7.2, Design Criteria)

Unit Weight of Concrete: $\gamma_c := 23.5 \frac{kN}{m^3}$

Unit Weight of Soil (Moist): $\gamma_m := 20.0 \frac{kN}{m^3}$ (Section 5.3, Design Criteria)
assumed moisture content (w) = 5%

Unit Weight Soil (Saturated): $\gamma_{sat} := 22.0 \frac{kN}{m^3}$ (Assuming Specific Gravity = 2.7

Unit Weight Soil (buoyant): $\gamma_b := \gamma_{sat} - \gamma_w = 12.2 \cdot \frac{kN}{m^3}$

Weight of Soil/Concrete above toe: $\gamma_{toe} := 22.0 \frac{kN}{m^3}$

Unit Weight of Rock: $\gamma_r := 25.6 \frac{kN}{m^3}$ (Section 7.2, Design Criteria)

Foundation Parameters:

Glacial Till Internal Friction: $\phi := 27 \cdot \frac{\pi}{180} = 0.471$

Bedrock Internal Friction Angle: $\phi_r := 24 \cdot \frac{\pi}{180} = 0.419$

Friction Angle at Base
Concrete / Rock Interface: $\phi_{rock} := 26$

Base Friction Coefficient: $tan_{\phi rock} := \tan\left(\phi_{rock} \frac{\pi}{180}\right) = 0.488$ radians

Rip Rap Backfill, Refer Dwg. C-214 $\phi_{backfill} := \left(20 \frac{\pi}{180}\right) = 0.349$ radians

Shear strength along rock
Failure plane $s_r := \frac{13100 \frac{kN}{m^2}}{2} = 6550 \cdot \frac{kN}{m^2}$ (Stantec Design Memo 8/8/16)

CONCRETE DEAD LOAD:

Area of Footing: $A_{ftg} := t_{ftg} \cdot b = 13.5\,m^2$

Weight of Footing: $D_{ftg} := A_{ftg} \cdot B \cdot \gamma_c = 317.3 \cdot kN$

Area of Stem (without batter): $A_{w1} := t_{wt} \cdot (h_w - t_{ftg}) = 4.5\,m^2$

Weight of Stem: $D_{w1} := A_{w1} \cdot B \cdot \gamma_c = 105.8 \cdot kN$

Area of stem Batter: $A_{w2} := \frac{(t_{wb} - t_{wt})}{2} (h_w - t_{ftg}) = 3.18\,m^2$

Weight of Batter: $D_{w2} := A_{w2} \cdot B \cdot \gamma_c = 74.8 \cdot kN$

Slope of batter: $S_{batter} := \frac{t_{wb} - t_{wt}}{h_w - t_{ftg}} = 0.079$

Area of Key $A_{t.key} := Key_{t.d} \cdot Key_{t.w} = 0$ $A_{h.key} := Key_{h.d} \cdot Key_{h.w} = 3\,m^2$

Weight of Key $D_{t.key} := A_{t.key} \cdot B \cdot \gamma_c = 0 \cdot kN$ $D_{h.key} := A_{h.key} \cdot B \cdot \gamma_c = 70.5 \cdot kN$

Centroidal Horizontal Distance of Wall (From Toe):

$$H_{cent} := \frac{A_{w1} \cdot \left(L_{ab} + \frac{t_{wt}}{2}\right) + A_{w2} \cdot \left(L_{ab} + t_{wt} + \frac{t_{wb} - t_{wt}}{3}\right) + A_{ftg} \cdot \frac{b}{2} \ldots + A_{t.key} \cdot \left(Key_{t.loc} + \frac{Key_{t.w}}{2}\right) + A_{h.key} \cdot \left(Key_{h.loc} + \frac{Key_{h.w}}{2}\right)}{A_{w1} + A_{w2} + A_{ftg} + A_{t.key} + A_{h.key}} = 4.50\,m$$

Centroidal Vertical Distance of Wall (Above Base of Footing):

$$V_{Cent} := \frac{A_{ftg} \cdot \frac{t_{ftg}}{2} + A_{w1} \cdot \left[t_{ftg} + \frac{(h_w - t_{ftg})}{2}\right] + A_{w2} \cdot \left[t_{ftg} + \frac{(h_w - t_{ftg})}{3}\right] + A_{t.key} \cdot \left(\frac{-Key_{t.d}}{2}\right) + A_{h.key} \cdot \left(\frac{-Key_{h.d}}{2}\right)}{A_{ftg} + A_{w1} + A_{w2} + A_{t.key} + A_{h.key}} = 1.94\,m$$

$\Sigma V_{conc} := D_{ftg} + D_{w1} + D_{w2} + D_{t.key} + D_{h.key} = 568.3 \cdot kN$

$\Sigma M_{conc} := \Sigma V_{conc} \cdot H_{cent} = 2559.6\,m \cdot kN$

ROCK SECTION MOBILIZED FOR INCLINDED SLIDING FAILURE

Area of Rock Section Mobilized: $A_{rocksection} := (Key_{t.d} + Key_{h.d}) \cdot \frac{Key_{hdist}}{2} = 12\,m^2$

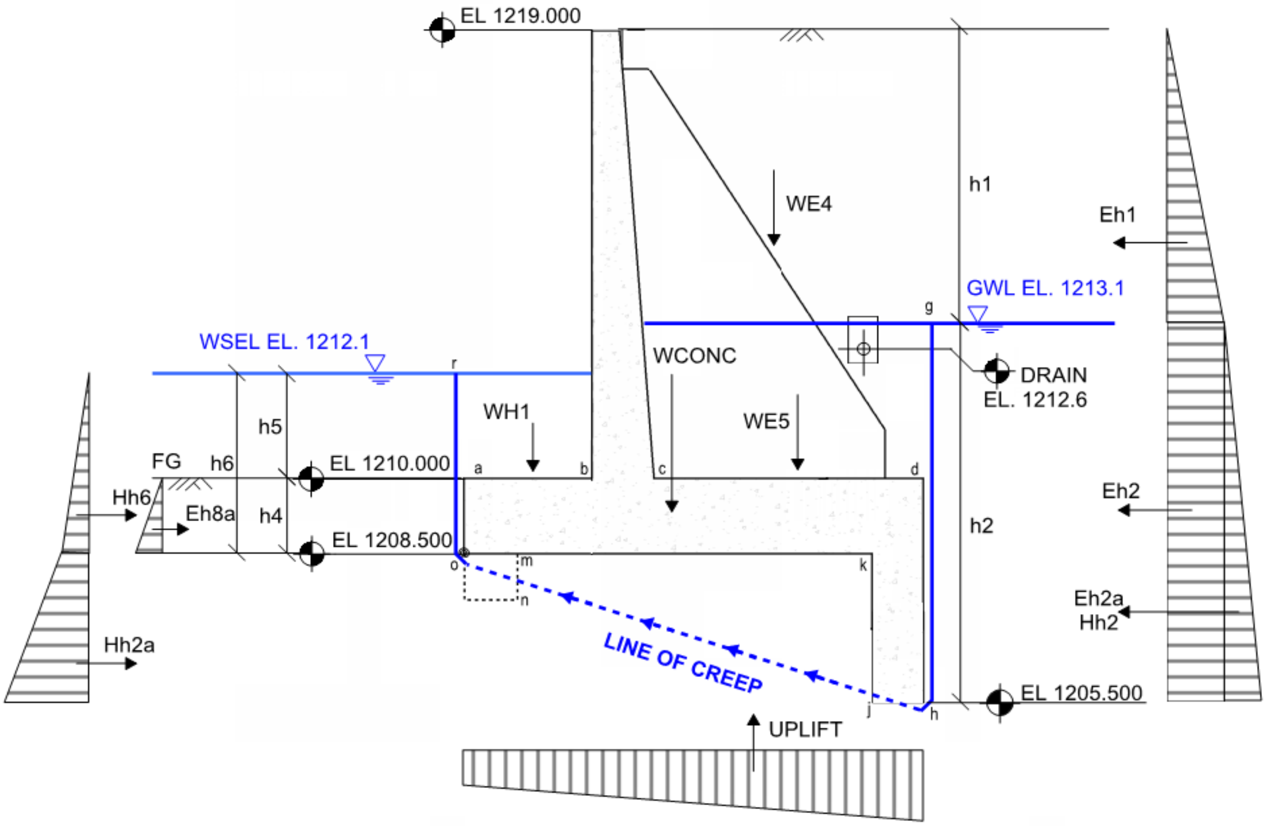
Rock Mass Mobilized: $V_{rocksection} := A_{rocksection} \cdot \gamma_r \cdot B = 307.2 \cdot kN$

(Pore pressure taken along assumed inclined sliding plane)

Distance from Toe to COG of Rock Section: $L_{rocksection} := \frac{Key_{hdist} \cdot (2 \cdot Key_{h.d} + Key_{t.d})}{3(Key_{h.d} + Key_{t.d})} + Key_{t.w} = 5.333\,m$

$\Sigma M_{rocksection} := V_{rocksection} \cdot L_{rocksection} = 1638.4\,m \cdot kN$

LOAD CASE U1 - NORMAL OPERATION



U1 DESIGN CASE

LOAD CASE U1 ACCEPTANCE PARAMETERS

FS sliding:

Usual (U) 1.5 (without cohesion) (Table 3-3, USACE EM 1110-2-2100)

Resultant Location:

Usual (U) Inside middle third ~100% base in compression

Required Factor of Safety for Sliding: $FS_{sliding.reqU1} := 1.5$ (Without Cohesion)

Allowable rock bearing pressure: $\sigma_{allowU1} := 1270kPa$ (Section 5.2, Design Criteria EM 1110-2-2100 Section 3-10)

Overturning Required Resultant Ratio: $X_{R.reqU1} := 0.333$ (EM 1110-2-2502, Figure 4-4)

Required Factor of Safety for Floatation $FS_{req.U1.flt} := 1.5$

SOIL HEIGHTS and Water Levels:

LOAD CASE U1

Heel Conditions:

Groundwater Elevation at Heel: $GWL_{U1} := 1213.1\,m$

Distance from Finish Grade to Groundwater at Heel: $h_{1U1} := \left[T_w - GWL_{U1} + \left(L_{cd} + t_{wb} - t_{wt}\right)\cdot \tan(\beta)\right] = 5.90\,m$

Distance from Water Surface to Bottom of Footing at Heel: $h_{2U1} := GWL_{U1} - Bot_{ftg} + Key_{h.d} = 7.60\,m$

Toe Conditions:

Water Surface Elevation at Toe: $WSEL_{U1} := 1212.1\,m$

Water Surface Elevation at Toe for Uplift: $UWSEL_{U1} := 1212.1\cdot m$

Finish Grade at Toe providing lateral resistance: $FG_{toeU1} := 1210.0\cdot m$

Soil Depth Above top of footing: $h_{3aU1} := FG_{toeU1} - Top_{ftg} = 0\,m$

$$h_{3U1} := \begin{cases} h_{3aU1} & \text{if } FG_{toeU1} - Top_{ftg} \ge 0 \\ 0 & \text{otherwise} \end{cases} = 0$$

Resisting Fill at Toe: $h_{4U1} := FG_{toeU1} - Bot_{ftg} + Key_{t.d} = 1.50\,m$

Distance from Water Level to Top of Footing: $h_{5U1} := WSEL_{U1} - Top_{ftg} = 2.10\,m$

Distance from Water Surface to Bottom of Footing: $h_{6U1} := WSEL_{U1} - Bot_{ftg} + Key_{t.d} = 3.60\cdot m$

Soil Depth Above WSEL: $h_{7aU1} := FG_{toeU1} - WSEL_{U1} = -2.1\,m$

$$h_{7U1} := \begin{cases} h_{7aU1} & \text{if } FG_{toeU1} - WSEL_{U1} \ge 0 \\ 0 & \text{otherwise} \end{cases} = 0$$

Soil Depth Below WSEL:

$$h_{8U1} := \begin{cases} WSEL_{U1} - Bot_{ftg} + Key_{t.d} & \text{if } FG_{toeU1} - WSEL_{U1} \ge 0 \\ h_{4U1} & \text{otherwise} \end{cases} = 1.5$$

For Line of Creep Method: $L_{ho.U1} := \sqrt{b^2 + \left(Key_{h.d} - Key_{t.d}\right)^2} = 9.487\,m$

Head Loss from Point g:

$\Delta h_{g.hj.U1} := h_{2U1} = 7.6\,m$ (to point h & j)

$\Delta h_{g.km.U1} := GWL_{U1} - Bot_{ftg} = 4.6\,m$ (to point k & m)

$\Delta h_{g.no.U1} := GWL_{U1} - Bot_{ftg} + Key_{t.d} = 4.6\,m$ (to point n & o)

$\Delta h_{g.p.U1} := GWL_{U1} - FG_{toeU1} = 3.1\,m$ (to point p*)

$\Delta h_{g.r.U1} := GWL_{U1} - UWSEL_{U1} = 1\,m$ (to point r)

Surcharge

Surcharge on Heel: $S1_{U1} := 0.0\,\frac{kN}{m^2}$

* same as point "a" in this case

Calculate Soil Lateral Pressure Coefficients:

LOAD CASE U1

For all load cases except seismic, soil loading to be based on At-Rest Condition.
Calculate at-rest pressure coefficient Ko based on Jaky's (1944) equation.

Soil At Rest Static Coefficient: $K_o := \dfrac{1 - \sin(\phi)}{1 + \sin(\beta)} = 0.546$ (Eq. 3-6, USACE EM 1110-2-2502)

Lateral - Driving Force (Headwater Side)

Lateral Soil Load:

Surcharge Load: $E_{s1U1} := S1_{U1} \cdot K_o \cdot \left(H_w + Key_{h.d}\right) \cdot B \cdot -1 = 0 \cdot kN$

Moment Arm (from bottom of footing): $E_{s1locU1} := \dfrac{H_w + Key_{h.d}}{2} + Key_{vdist} = 3.75\ m$

Moist Soil Load above GWL: $E_{h1U1} := \dfrac{\gamma_m \cdot K_o \cdot h_{1U1}^{\ 2}}{2} B \cdot -1 = -190.1 \cdot kN$

Moment Arm (from bottom of footing): $E_{h1locU1} := \dfrac{h_{1U1}}{3} + h_{2U1} + Key_{vdist} = 6.57\ m$

Saturated Soil Load below GWL:
(rectangular component)

$E_{h2U1} := \left(\gamma_m \cdot K_o \cdot h_{1U1}\right) \cdot \left(h_{2U1}\right) \cdot B \cdot -1 = -489.7 \cdot kN$

Moment Arm (from bottom of footing): $E_{h2locU1} := \dfrac{h_{2U1}}{2} + Key_{vdist} = 0.80\ m$

Saturated Soil Load below GWL:
(triangular component)

$E_{h2aU1} := \dfrac{\left(\gamma_{sat} - \gamma_w\right) \cdot K_o \cdot h_{2U1}^{\ 2}}{2} \cdot B \cdot -1 = -192.4 \cdot kN$

Moment Arm (from bottom of footing): $E_{h2alocU1} := \dfrac{h_{2U1}}{3} + Key_{vdist} = -0.47\ m$

Lateral Water Load:

Water Load GWL to Bottom of Key: $H_{h2U1} := \dfrac{\gamma_w \cdot h_{2U1}^{\ 2}}{2} \cdot B \cdot -1 = -283.0 \cdot kN$

Moment Arm (from bottom of footing): $H_{h2locU1} := \dfrac{h_{2U1}}{3} + Key_{vdist} = -0.47\ m$

$\Sigma H_{SoildriveU1} := E_{s1U1} + E_{h1U1} + E_{h2U1} + E_{h2aU1} + H_{h2U1} = -1155.1 \cdot kN$

$$\Sigma M_{LateralSoildriveU1} := E_{s1U1} \cdot E_{s1locU1} + E_{h1U1} \cdot E_{h1locU1} + E_{h2U1} \cdot E_{h2locU1} \ldots = -1418.0\ m \cdot kN$$
$$+ E_{h2aU1} \cdot E_{h2alocU1} + H_{h2U1} \cdot H_{h2locU1}$$

Lateral - Resisting Force (Tailwater Side)

LOAD CASE U1

Lateral Water Load:

Water Load WSEL to Bot. of Footing: $H_{h6U1} := \frac{\gamma_w \cdot h_{6U1}^2}{2} \cdot B = 63.5 \cdot kN$

Moment Arm (from bot. of toe key): $H_{h6locU1} := \frac{h_{6U1}}{3} = 1.20\,m$

Water Load Bot. of Footing to Bot. of H. Key: $H_{h2aU1} := \left[\left(UWSEL_{U1} - Bot_{ftg} + Key_{t.d}\right) + h_{2U1}\right] \cdot \frac{Key_{h.d}}{2} \cdot \gamma_w \cdot B = 164.6 \cdot kN$

Moment Arm (from bot. of toe key): $H_{h2alocU1} := \frac{Key_{h.d} \cdot \left[2 \cdot \left(UWSEL_{U1} - Bot_{ftg} + Key_{t.d}\right) + h_{2U1}\right]}{3\left[h_{2U1} + \left(UWSEL_{U1} - Bot_{ftg} + Key_{t.d}\right)\right]} \ldots + Key_{vdist} = -1.68\,m$

Lateral Soil Load:

Moist Soil Load above WSEL: $E_{h7U1} := \frac{\gamma_m \cdot K_o \cdot h_{7U1}^2}{2} B = 0.0 \cdot kN$

Moment Arm (from bot. of toe key): $E_{h7locU1} := h_{6U1} + \frac{h_{7U1}}{3} + Key_{vdist} = 0.60\,m$

Saturated Soil Load below WSEL: (rectangular component) $E_{h8U1} := \left(\gamma_m \cdot K_o \cdot h_{7U1}\right) \cdot h_{8U1} \cdot B = 0.0 \cdot kN$

Moment Arm (from bot. of toe key): $E_{h8locU1} := \frac{h_{8U1}}{2} = 0.75\,m$

Saturated Soil Load below WSEL: (triangular component) $E_{h8aU1} := \frac{\left[\left(\gamma_{sat} - \gamma_w\right) \cdot K_o\right] \cdot h_{8U1}^2}{2} \cdot B = 7.5 \cdot kN$

Moment Arm (from bot. of footing): $E_{h8alocU1} := \frac{h_{8U1}}{3} = 0.50\,m$

$$\Sigma H_{SoilresistU1} := H_{h6U1} + H_{h2aU1} + E_{h7U1} + E_{h8U1} + E_{h8aU1} = 235.6 \cdot kN$$

$$\Sigma M_{HorizSoilResistU1} := H_{h6U1} \cdot H_{h6locU1} + H_{h2aU1} \cdot H_{h2alocU1} + E_{h7U1} \cdot E_{h7locU1} \ldots + E_{h8U1} \cdot E_{h8locU1} + E_{h8aU1} \cdot E_{h8alocU1} = -196.4\,m \cdot kN$$

Vertical Force:

UPLIFT: Linear distribution from water at heel to water at toe:

$$\Sigma V_{UpliftU1} := \left[\left(UWSEL_{U1} - Bot_{ftg} + Key_{t.d}\right) + h_{2U1}\right] \cdot \frac{b}{2} \cdot \gamma_w \cdot B \cdot -1 = -493.92 \cdot kN$$

Moment Arm (from Point O): $V_{UpliftU1aloc} := \frac{b \cdot \left[2 \cdot h_{2U1} + \left(UWSEL_{U1} - Bot_{ftg} + Key_{t.d}\right)\right]}{3\left[h_{2U1} + \left(UWSEL_{U1} - Bot_{ftg} + Key_{t.d}\right)\right]} = 5.036\,m$

$$\Sigma M_{UpliftU1} := \Sigma V_{UpliftU1} \cdot V_{UpliftU1aloc} = -2487.24 \cdot kN \cdot m$$

Vertical Force (con't):

Weight of soil and water over toe:

Water Above the Top of Footing: $W_{H1U1} := \gamma_w \cdot h_{5U1} \cdot L_{ab} \cdot B = 51.45 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E1locU1} := \frac{L_{ab}}{2} = 1.25\,m$

Soil above top of footing: $W_{E6U1} := \gamma_b \cdot h_{3U1} \cdot L_{ab} \cdot B = 0.0 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E6locU1} := \frac{L_{ab}}{2} = 1.25\,m$

Vertical Load Due to Surcharge: $S_{U1} := S1_{U1} \cdot L_{cd} \cdot B = 0$ $\quad S_{U1loc} := b - \frac{L_{cd}}{2} = 6.35\,m$

Weight of soil and water over heel:

Moist Soil for sloped grade above top of wall:

Length of sloped portion of soil above top of wall: $L_{E3U1} := \left(L_{cd} + t_{wb} - t_{wt}\right) = 6.00\,m$

Height of sloped soil above top of wall over heel: $h_{E3locU1} := \left(L_{E3U1}\right) \cdot \tan(\beta) = 0.00\,m$

Weight of sloped soil above top of wall: $W_{E3U1} := \frac{\gamma_m}{2} \cdot h_{E3locU1} \cdot L_{E3U1} \cdot B = 0.0 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E3locU1} := L_{ab} + t_{wt} + \frac{2}{3} \cdot L_{E3U1} = 7.00\,m$

Moist soil from top of wall to groundwater level:

Height of soil from top of wall and top of GWL: $h_{1U1} = 5.90\,m$

Length from edge of wall at GWL to edge of heel: $L_{E4U1} := L_{E3U1} - \left(h_{1U1} \cdot S_{batter}\right) = 5.54\,m$

Weight of soil over heel from top of wall to GWL: $W_{E4U1} := \gamma_m \cdot h_{1U1} \cdot \frac{\left(L_{E3U1} + L_{E4U1}\right)}{2} \cdot B = 680.7 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E4locU1} := b - \frac{L_{E3U1}^2 + L_{E3U1} \cdot L_{E4U1} + L_{E4U1}^2}{3\left(L_{E3U1} + L_{E4U1}\right)} = 6.11\,m$

Saturated soil from groundwater to top of footing:

Height of soil from GWL to top of heel: $h_{E4U1} := h_{2U1} - t_{ftg} - Key_{h.d} = 3.10\,m$

Weight of soil over heel from GWL to top of heel: $W_{E5U1} := \left(\gamma_{sat}\right) \cdot h_{E4U1} \cdot \frac{\left(L_{E4U1} + L_{cd}\right)}{2} \cdot B = 369.3 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E5locU1} := b - \frac{L_{E4U1}^2 + L_{E4U1} \cdot L_{cd} + L_{cd}^2}{3\left(L_{E4U1} + L_{cd}\right)} = 6.29\,m$

$\Sigma V_{SoilWaterU1} := W_{H1U1} + W_{E6U1} + W_{E3U1} + W_{E4U1} + W_{E5U1} + S_{U1} = 1101.4 \cdot kN$

$$\Sigma M_{VertSoilWaterResistU1} := W_{H1U1} \cdot W_{E1locU1} + W_{E6U1} \cdot W_{E6locU1} \cdots + W_{E3U1} \cdot W_{E3locU1} + W_{E4U1} \cdot W_{E4locU1} + W_{E5U1} \cdot W_{E5locU1} + S_{U1} \cdot S_{U1loc} = 6549.7\,m \cdot kN$$

THIS PAGE INTENTIONALLY LEFT BLANK
PLEASE GO TO THE NEXT PAGE

STABILITY ASSESSMENT:

LOAD CASE U1

CHECK SLIDING ALONG HORIZONTAL SLIDING PLANE:

Summation of the vertical forces:

$$\Sigma V_{U1} := \Sigma V_{conc} + \Sigma V_{SoilWaterU1} + \Sigma V_{UpliftU1} = 1175.7 \cdot kN$$

Summation of the horizontal forces:

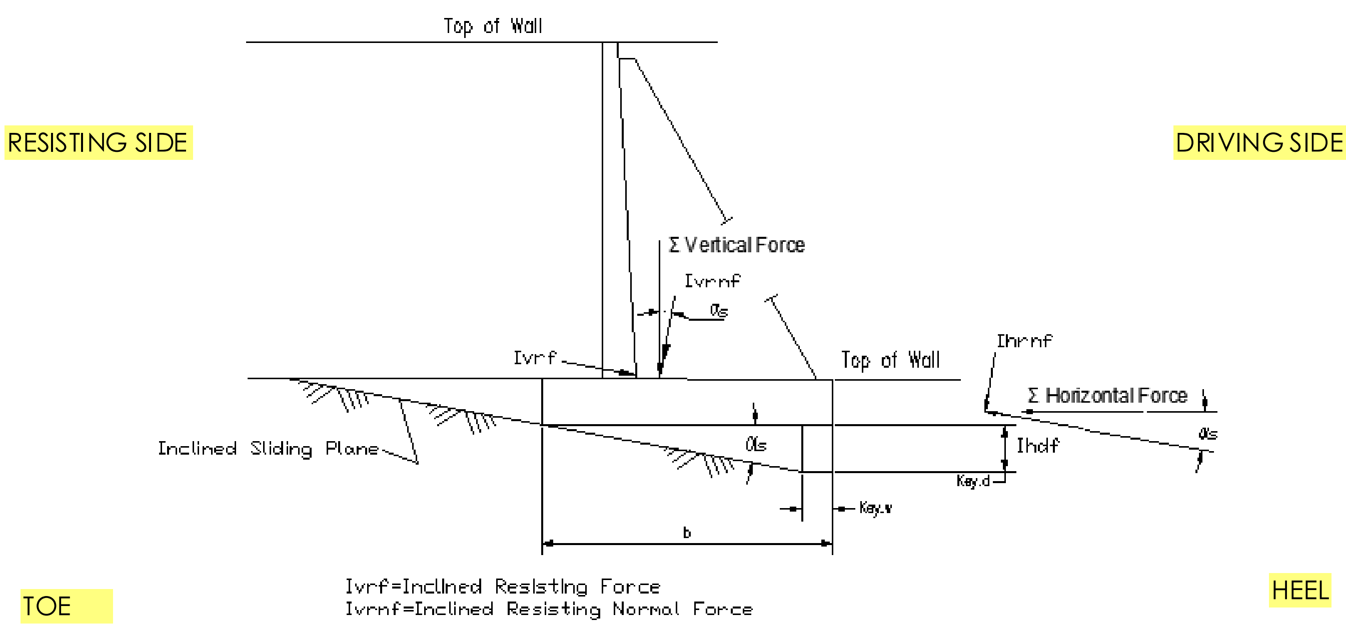
$$\Sigma H_{U1} := \Sigma H_{SoildriveU1} + \Sigma H_{SoilresistU1} = -919.5 \cdot kN$$

Safety Factor for Sliding Horizontal Failure Plane

$$FS_{Horiz.SlidingU1} := \frac{\left|\Sigma V_{U1}\right| \cdot \tan\left(\phi_{rock} \cdot \frac{\pi}{180}\right)}{\left|\Sigma H_{U1}\right|} = 0.62$$

$$FS_{Sliding.check1.U1} := \begin{vmatrix} \text{"OKAY "} & \text{if } FS_{Horiz.SlidingU1} > FS_{sliding.reqU1} \\ \text{"Key req""} & \text{otherwise} \end{vmatrix} = \text{"Key req""}$$

CHECK FACTOR OF SAFETY SLIDING WITH KEY (INCLINED SLIDING PLANE):



Ivrf=Inclined Resisting Force
Ivrnf=Inclined Resisting Normal Force
Ihrnf=Inclined Resisting Normal Force
Ihdf=Inclined Driving Force

$$\alpha s := \operatorname{atan}\left(\frac{-Key_{vdist}}{Key_{hdist}}\right) = 0.359 \qquad \text{as degrees=} \qquad \alpha s \cdot \left(\frac{180}{\pi}\right) = 20.56$$

(With properly engineered reinforced concrete Key, horizontal sliding plane thru Toe is protected, critical sliding plane is relocated to the INCLINED SLIDING PLANE FROM HEEL KEY To TOE, Bedrock Mass above this examing plane is mobilized by reinforced concrete key and combined into Structural Wedge.)

Resolve ΣV_{U1} & ΣH_{U1}

$$\Sigma V_{InclinedU1} := \cos(\alpha s) \cdot \left(\left|\Sigma V_{U1} + V_{rocksection}\right|\right) + \sin(\alpha s) \cdot \left|\Sigma H_{U1}\right| = 1711.4 \cdot kN$$

$$\Sigma H_{InclinedU1} := \cos(\alpha s) \cdot \left|\Sigma H_{U1}\right| - \sin(\alpha s) \cdot \left(\left|\Sigma V_{U1} + V_{rocksection}\right|\right) = 340.3 \cdot kN$$

Safety Factor for Sliding Inclined Failure Plane

$$FS_{InclinedISlidingU1} := \frac{\Sigma V_{InclinedU1} \cdot \tan(\phi_r)}{\Sigma H_{InclinedU1}} = 2.24$$

LOAD CASE U1

$$FS_{Sliding.check2.U1} := \begin{cases} \text{"OKAY"} & \text{if } FS_{InclinedISlidingU1} > FS_{sliding.reqU1} \\ \text{"NG - Revise Structure"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

CHECK FOUNDATION ECCENTRICITY:

Summation of the resisting moments about the toe:

$$\Sigma M_{resU1} := \Sigma M_{conc} + \Sigma M_{VertSoilWaterResistU1} + \Sigma M_{HorizSoilResistU1} + \Sigma M_{rocksection} = 10551 \cdot kN \cdot m$$

Summation of the overturning moments about the toe:

$$\Sigma M_{oU1} := \Sigma M_{LateralSoildriveU1} + \Sigma M_{UpliftU1} = -3905 \cdot kN \cdot m$$

Total moment: $\Sigma M_{U1} := \Sigma M_{resU1} + \Sigma M_{oU1} = 6646.0 \cdot kN \cdot m$

Normal force to base: $\Sigma V_{InclinedU1} = 1711.4 \cdot kN$

Inclined Sliding Plane Length: $L_{incline} := \dfrac{b}{\cos(\alpha s)} = 9.6\,m$

Eccentricity (inclined plane): $ex_{U1} := \dfrac{L_{incline}}{2} - \dfrac{\Sigma M_{U1}}{\Sigma V_{InclinedU1}} = 0.92\,m$ $\qquad Kern := \dfrac{L_{incline}}{6} = 1.602\,m$

Eccentricity Check: $e_{check.U1} := \begin{cases} \text{"Okay"} & \text{if } ex_{U1} \le Kern \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"Okay"}$

CHECK FOUNDATION BEARING CAPACITY:

Base Section Modulus: $S_b := \frac{1}{6}\left(B \cdot L_{incline}^{\;2}\right) = 15.4\,m^3$

Bearing Pressure Under Toe:

$$\sigma_{ToeU1} := \begin{cases} \left(\dfrac{\Sigma V_{InclinedU1}}{L_{incline} \cdot B} + \dfrac{\Sigma V_{InclinedU1} \cdot ex_{U1}}{S_b}\right) & \text{if } \dfrac{\Sigma V_{InclinedU1} \cdot ex_{U1}}{S_b} \le \dfrac{\Sigma V_{InclinedU1}}{L_{incline} \cdot B} \\ \dfrac{2 \cdot \Sigma V_{InclinedU1}}{B \cdot 3\left(\dfrac{b}{2} - ex_{U1}\right)} & \text{otherwise} \end{cases} = 280.6 \cdot kPa$$

$$Bearing_{ChecktoeU1} := \begin{cases} \text{"OKAY"} & \text{if } \sigma_{ToeU1} < \sigma_{allowU1} \\ \text{"NG"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

Bearing Pressure Under Heel:

$$\sigma_{HeelU1} := \begin{cases} \left(\dfrac{\Sigma V_{InclinedU1}}{L_{incline} \cdot B} - \dfrac{\Sigma V_{InclinedU1} \cdot ex_{U1}}{S_b}\right) & \text{if } \dfrac{\Sigma V_{InclinedU1} \cdot ex_{U1}}{S_b} \le \dfrac{\Sigma V_{InclinedU1}}{L_{incline} \cdot B} \\ 0 & \text{otherwise} \end{cases} = 75.5 \cdot kPa$$

$$Bearing_{CheckheelU1} := \left(\begin{cases} \text{"OKAY"} & \text{if } \sigma_{HeelU1} < \sigma_{allowU1} \wedge \sigma_{HeelU1} > 0 \\ \text{"NG - perform cracked base analysis"} & \text{otherwise} \end{cases} \right) = \text{"OKAY"}$$

CHECK FLOATATION:

Safety Factor for Floatation:

$$FS_{FloatationU1} := \frac{\Sigma V_{conc} + \Sigma V_{SoilWaterU1}}{\left|\Sigma V_{UpliftU1}\right|} = 3.38$$

$$FS_{Floatation.U1.check} := \begin{cases} \text{"OKAY"} & \text{if } FS_{FloatationU1} > FS_{req.U1.flt} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

CHECK OVERTURNING

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.
Assumptions are made in order to compute overturning stablity of indetermine forces on monolith with key;
(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.
(b) The horizontal resisting force acting on the key, P.key, is that required for static equilibrium
(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1

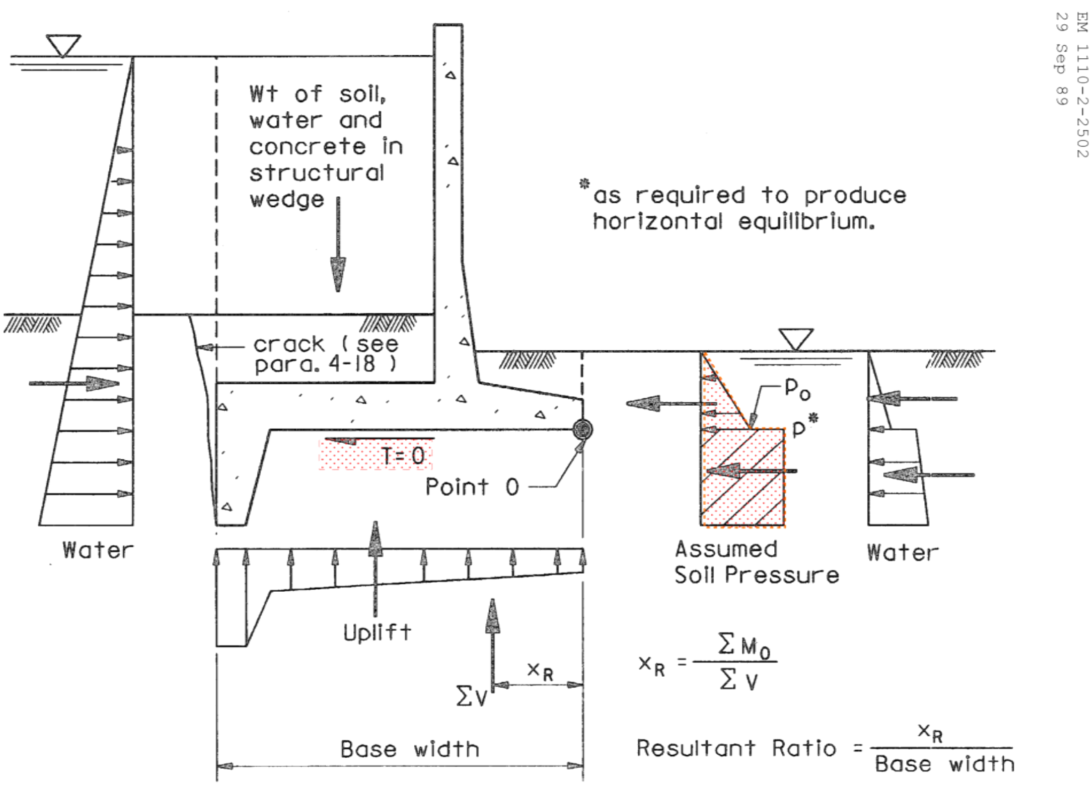


Figure 4-5. Forces for overturning analysis for wall with horizontal base and key

Modify Uplift for Overturning Analysis: **LOAD CASE U1**

(Uplift is calculated along the concrete/rock contact using the Line of Creep method)

Water Pressure at h: $u_{h.U1} := \Delta h_{g.hj.U1} \cdot \gamma_w = 74.48 \cdot kPa$

Water Pressure at o: $u_{o.U1} := \left(\Delta h_{g.no.U1} - \dfrac{\Delta h_{g.r.U1} \cdot L_{ho.U1}}{L_{ho.U1}}\right) \cdot \gamma_w = 35.28 \cdot kPa$

Head loss between point h and o: $\Delta h_{ho.U1} := \Delta h_{g.r.U1} \cdot \dfrac{L_{ho.U1}}{L_{ho.U1}} = 1\,m$

Length of concrete base (h -> o): $L_{baseho.U1} := Key_{h.w} + Key_{h.d} + Key_{hdist} + Key_{t.d} + Key_{t.w} = 12\,m$

Head loss along h -> j: $\Delta h_{hj.U1} := \Delta h_{ho.U1} \cdot \dfrac{Key_{h.w}}{L_{baseho.U1}} = 0.083\,m$

Water Pressure at j: $u_{j.U1} := \left(\Delta h_{g.hj.U1} - \Delta h_{hj.U1}\right) \cdot \gamma_w = 73.66 \cdot kPa$

Head loss along h -> k: $\Delta h_{hjk.U1} := \Delta h_{ho.U1} \cdot \left(\dfrac{Key_{h.w} + Key_{h.d}}{L_{baseho.U1}}\right) = 0.333\,m$

Water Pressure at k: $u_{k.U1} := \left(\Delta h_{g.km.U1} - \Delta h_{hjk.U1}\right) \cdot \gamma_w = 41.81 \cdot kPa$

Head loss along h -> m: $\Delta h_{hjkm.U1} := \Delta h_{ho.U1} \cdot \left(\dfrac{Key_{h.w} + Key_{h.d} + Key_{hdist}}{L_{baseho.U1}}\right) = 1\,m$

Water Pressure at m: $u_{m.U1} := \left(\Delta h_{g.km.U1} - \Delta h_{hjkm.U1}\right) \cdot \gamma_w = 35.28 \cdot kPa$

Head loss along h -> n: $\Delta h_{hjkmn.U1} := \Delta h_{ho.U1} \cdot \left(\dfrac{Key_{h.w} + Key_{h.d} + Key_{hdist} + Key_{t.d}}{L_{baseho.U1}}\right) = 1\,m$

Water Pressure at n: $u_{n.U1} := \left(\Delta h_{g.no.U1} - \Delta h_{hjkmn.U1}\right) \cdot \gamma_w = 35.28 \cdot kPa$

Uplift under key at heel: $V_{ulkeyhU1.OT} := \dfrac{\left(u_{h.U1} + u_{j.U1}\right) \cdot Key_{h.w}}{2} \cdot B \cdot -1 = -74.072 \cdot kN$

Moment Arm (from Point O): $V_{ulkeyhU1loc.OT} := b - \dfrac{Key_{h.w} \cdot \left(2 \cdot u_{j.U1} + u_{h.U1}\right)}{3 \cdot \left(u_{j.U1} + u_{h.U1}\right)} = 8.501\,m$

Uplift under base: $V_{ulbaseU1.OT} := \dfrac{\left(u_{k.U1} + u_{m.U1}\right) \cdot Key_{hdist}}{2} \cdot B \cdot -1 = -308.373 \cdot kN$

Moment Arm (from Point O): $V_{ulbaseU1loc.OT} := b - Key_{h.w} - \dfrac{Key_{hdist} \cdot \left(2 \cdot u_{m.U1} + u_{k.U1}\right)}{3 \cdot \left(u_{m.U1} + u_{k.U1}\right)} = 4.113\,m$

Uplift under key at toe: $V_{ulkeytU1.OT} := \dfrac{\left(u_{n.U1} + u_{o.U1}\right) \cdot Key_{t.w}}{2} \cdot B \cdot -1 = 0 \cdot kN$

Moment Arm (from Point O): $V_{ulkeytU1loc.OT} := \dfrac{Key_{t.w} \cdot \left(2 \cdot u_{n.U1} + u_{o.U1}\right)}{3 \cdot \left(u_{n.U1} + u_{o.U1}\right)} = 0$

$$\Sigma V_{UpliftU1.OT} := V_{ulkeyhU1.OT} + V_{ulbaseU1.OT} + V_{ulkeytU1.OT} = -382 \cdot kN$$

$$U_{U1.loc.OT} := \frac{V_{ulkeyhU1.OT} \cdot V_{ulkeyhU1loc.OT} + V_{ulbaseU1.OT} \cdot V_{ulbaseU1loc.OT} + V_{ulkeytU1.OT} \cdot V_{ulkeytU1loc.OT}}{\Sigma V_{UpliftU1.OT}} = 4.96\,m$$

$$\Sigma M_{UpliftU1.OT} := \Sigma V_{UpliftU1.OT} \cdot U_{U1.loc.OT} = -1898.0 \cdot kN \cdot m$$

Modify Lateral Water Pressure (Resisting) for Overturning Analysis:

(Resisting water pressure is calculated using the Line of Creep method)

Water Load at Key (heel):

$$H_{h2U1.OT} := \frac{u_{k.U1} + u_{j.U1}}{2} \cdot Key_{h.d} B = 173.2 \cdot kN$$

Moment Arm (from Point O):

$$H_{h2locU1.OT} := \frac{Key_{h.d} \cdot (2 \cdot u_{k.U1} + u_{j.U1})}{3(u_{k.U1} + u_{j.U1})} + Key_{vdist} = -1.64\ m$$

Water Load at Key (toe):

$$H_{h6U1.OT} := \frac{u_{o.U1} \cdot (UWSEL_{U1} - Bot_{ftg} + Key_{t.d})}{2} \cdot B = 64 \cdot kN$$

Moment Arm (from Point O):

$$H_{h6locU1.OT} := \frac{UWSEL_{U1} - Bot_{ftg} + Key_{t.d}}{3} = 1.20\ m$$

$$\Sigma H_{waterresistU1.OT} := H_{h2U1.OT} + H_{h6U1.OT} = 236.72 \cdot kN$$

$$H_{waterresistlocU1.OT} := \frac{H_{h2U1.OT} \cdot H_{h2locU1.OT} + H_{h6U1.OT} \cdot H_{h6locU1.OT}}{\Sigma H_{waterresistU1.OT}} = -0.877\ m$$

$$\Sigma M_{waterresistU1.OT} := \Sigma H_{waterresistU1.OT} \cdot H_{waterresistlocU1.OT} = -207.51 \cdot kN \cdot m$$

Modify Lateral Soil Loads for Overturning Analysis:

(Lateral soil loads are calculated down to Point O instead of bottom of shear key)

Driving Soil Load (Headwater Side):

Surcharge Load:

$$E_{s1U1.OT} := S1_{U1} \cdot K_o \cdot (H_w + Key_{h.d} + Key_{vdist}) \cdot B \cdot -1 = 0 \cdot kN$$

Moment Arm (from Point O):

$$E_{s1locU1.OT} := \frac{H_w + Key_{h.d} + Key_{vdist}}{2} = 5.25\ m$$

Moist Soil Load above GWL:

$$E_{h1U1.OT} := \frac{\gamma_m \cdot K_o \cdot h_{1U1}^{\ 2}}{2} B \cdot -1 = -190.1 \cdot kN$$

Moment Arm (from Point O):

$$E_{h1locU1.OT} := \frac{h_{1U1}}{3} + h_{2U1} + Key_{vdist} = 6.57\ m$$

Saturated Soil Load below GWL:
(rectangular component)

$$E_{h2U1.OT} := (\gamma_m \cdot K_o \cdot h_{1U1}) \cdot (h_{2U1} + Key_{vdist}) \cdot B \cdot -1 = -296.4 \cdot kN$$

Moment Arm (from Point O):

$$E_{h2locU1.OT} := \frac{h_{2U1} + Key_{vdist}}{2} = 2.30\ m$$

Saturated Soil Load below GWL:
(triangular component)

$$E_{h2aU1.OT} := \frac{(\gamma_{sat} - \gamma_w) \cdot K_o \cdot (h_{2U1} + Key_{vdist})^2}{2} \cdot B \cdot -1 = -70.5 \cdot kN$$

Moment Arm (from Point O):

$$E_{h2alocU1.OT} := \frac{h_{2U1} + Key_{vdist}}{3} = 1.53\ m$$

Resisting Soil Load (Tailwater Side):

(Determine resisting soil load based on depth variation between the keys (ie. Key_{vdist}). In case where key at heel is deeper than key at toe (ie. $Key_{vdist} < 0$), resisting soil load (p*) is assumed to produce horizontal equilibrium as per Figure 4-5 above. Resisting soil load (p_o) is neglected.)

Total Driving Force: $\Sigma H_{SoildriveU1.OT} := E_{s1U1.OT} + E_{h1U1.OT} + E_{h2U1.OT} + E_{h2aU1.OT} + H_{h2U1} = -839.9 \cdot kN$

Total Resisting Force: $\Sigma H_{waterresistU1.OT} = 236.7 \cdot kN$

Assumed Soil Load p*: $E_{h8U1a.OT} := \left(\Sigma H_{SoildriveU1.OT} + \Sigma H_{waterresistU1.OT}\right) \cdot -1 = 603.222 \cdot kN$

Moment Arm (from Point O): $E_{h8U1a.loc.OT} := \dfrac{Key_{vdist}}{2} = -1.5\,m$

$$E_{h8U1.OT} := \begin{cases} E_{h8U1a.OT} & \text{if } Key_{vdist} < 0 \\ \Sigma H_{SoilresistU1} - H_{h6U1} - H_{h2aU1} & \text{otherwise} \end{cases} = 603.222 \cdot kN$$

$$\Sigma M_{SoilresistU1} := \begin{cases} E_{h8U1a.OT} \cdot E_{h8U1a.loc.OT} & \text{if } Key_{vdist} < 0 \\ \Sigma M_{HorizSoilResistU1} - H_{h6U1} \cdot H_{h6locU1} - H_{h2aU1} \cdot H_{h2alocU1} & \text{otherwise} \end{cases} = -904.832 \cdot kN \cdot m$$

Sum of Moment about Point O:

$$\Sigma M_{LateraldriveU1.OT} := E_{s1U1.OT} \cdot E_{s1locU1.OT} + E_{h1U1.OT} \cdot E_{h1locU1.OT} + E_{h2U1.OT} \cdot E_{h2locU1.OT} \cdots + E_{h2aU1.OT} \cdot E_{h2alocU1.OT} + H_{h2U1} \cdot H_{h2locU1} = -1905.7 \cdot kN \cdot m$$

$$\Sigma M_{LateralresistU1.OT} := \Sigma M_{waterresistU1.OT} + \Sigma M_{SoilresistU1} = -1112.3 \cdot kN \cdot m$$

Total moment:

$$\Sigma M_{U1.OT} := \Sigma M_{conc} + \Sigma M_{VertSoilWaterResistU1} + \Sigma M_{UpliftU1.OT} + \Sigma M_{LateraldriveU1.OT} \cdots + \Sigma M_{LateralresistU1.OT} = 4193.2 \cdot kN \cdot m$$

Total Vertical Force: $\Sigma V_{U1.OT} := \Sigma V_{conc} + \Sigma V_{SoilWaterU1} + \Sigma V_{UplliftU1.OT} = 1287.2 \cdot kN$

Distance X_R: EM 1110-2-2502 Eq.4-1 $X_{R.U1} := \dfrac{\Sigma M_{U1.OT}}{\Sigma V_{U1.OT}} = 3.258\,m$

Overturning Resultant Ratio $Ratio_{U1.OT} := \dfrac{X_{R.U1}}{b} = 0.36$

$$Ratio_{U1.OT.check} := \begin{cases} \text{"OKAY "} & \text{if } Ratio_{U1.OT} > X_{R.reqU1} \\ \text{"Revise Structure""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

CHECK FOUNDATION ECCENTRICITY (HORIZONTAL PLANE):

Eccentricity (horizontal plan): $ex_{U1.OT} := \dfrac{b}{2} - \dfrac{\Sigma M_{U1.OT}}{\Sigma V_{U1.OT}} = 1.24\,m$ $Kern_{OT} := \dfrac{b}{6} = 1.5\,m$

Eccentricity Check:
$$e_{check.U1.OT} := \begin{cases} \text{"Okay"} & \text{if } ex_{U1} \le Kern_{OT} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"Okay"}$$

LOAD CASE U1

CHECK FOUNDATION BEARING CAPACITY (HORIZONTAL PLANE):

Base Section Modulus: $S_{b.OT} := \frac{1}{6}\left(B \cdot b^2\right) = 13.5\,m^3$

Bearing Pressure Under Toe:

$$\sigma_{ToeU1.OT} := \begin{cases} \left(\frac{\Sigma V_{U1.OT}}{b \cdot B} + \frac{\Sigma V_{U1.OT} \cdot ex_{U1.OT}}{S_{b.OT}}\right) & \text{if } \frac{\Sigma V_{U1.OT}}{b \cdot B} \geq \frac{\Sigma V_{U1.OT} \cdot ex_{U1.OT}}{S_{b.OT}} \\ \frac{2 \cdot \Sigma V_{U1.OT}}{B \cdot 3\left(\frac{b}{2} - ex_{U1.OT}\right)} & \text{otherwise} \end{cases} = 261.5 \cdot kPa$$

$$Bearing_{ChecktoeU1.OT} := \begin{cases} \text{"OKAY "} & \text{if } \sigma_{ToeU1.OT} < \sigma_{allowU1} \\ \text{"NG - for reference only""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

Bearing Pressure Under Heel:

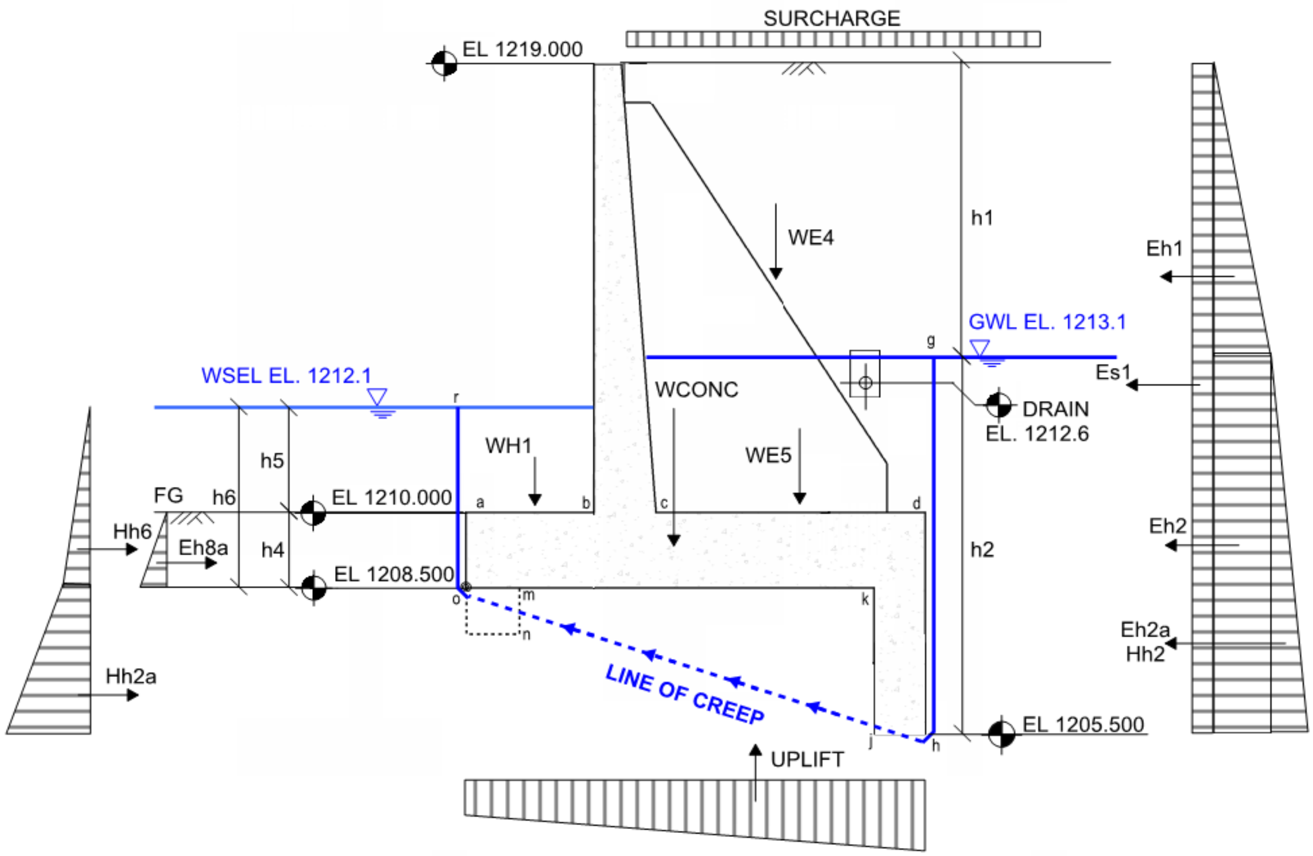
$$\sigma_{HeelU1.OT} := \begin{cases} \left(\frac{\Sigma V_{U1.OT}}{b \cdot B} - \frac{\Sigma V_{U1.OT} \cdot ex_{U1.OT}}{S_{b.OT}}\right) & \text{if } \frac{\Sigma V_{U1.OT}}{b \cdot B} \geq \frac{\Sigma V_{U1.OT} \cdot ex_{U1.OT}}{S_{b.OT}} \\ 0 & \text{otherwise} \end{cases} = 24.6 \cdot kPa$$

$$Bearing_{CheckheelU1.OT} := \left(\begin{cases} \text{"OKAY "} & \text{if } \sigma_{HeelU1.OT} < \sigma_{allowU1} \wedge \sigma_{HeelU1.OT} > 0 \\ \text{"NG - for reference only""} & \text{otherwise} \end{cases}\right) = \text{"OKAY "}$$

SUMMARY OF STABILITY ASSESSMENT:

LOAD CASE U1

Sliding Factor of Safety: (Horizontal Plane - Ref only)	$FS_{Horiz.SlidingU1} = 0.62$	$FS_{Sliding.check1.U1}$ = "Key req""
Sliding Factor of Safety: (Inclined Plane)	$FS_{InclinedlSlidingU1} = 2.24$	$FS_{Sliding.check2.U1}$ = "OKAY "
Eccentricity: (Inclined Plane)	$ex_{U1} = 0.92$ m	$e_{check.U1}$ = "Okay"
Bearing Pressure At Heel: (Inclined Plane)	$\sigma_{HeelU1} = 76 \cdot kPa$	$Bearing_{CheckheelU1}$ = "OKAY "
Bearing Pressure At Toe: (Inclined Plane)	$\sigma_{ToeU1} = 281 \cdot kPa$	$Bearing_{ChecktoeU1}$ = "OKAY "
Flotation Factor of Safety (horizontal plane)	$FS_{FloatationU1} = 3.38$	$FS_{Floatation.U1.check}$ = "OKAY "
Overturning Resultant Ratio: (horizontal plane)	$Ratio_{U1.OT} = 0.36$	$Ratio_{U1.OT.check}$ = "OKAY "
Eccentricity: (horizontal plane - Ref only)	$ex_{U1.OT} = 1.24$ m	$e_{check.U1.OT}$ = "Okay"
Bearing Pressure At Heel: (horizontal plane - Ref only)	$\sigma_{HeelU1.OT} = 25 \cdot kPa$	$Bearing_{CheckheelU1.OT}$ = "OKAY "
Bearing Pressure At Toe: (horizontal plane - Ref only)	$\sigma_{ToeU1.OT} = 261 \cdot kPa$	$Bearing_{ChecktoeU1.OT}$ = "OKAY "



UN1 DESIGN CASE

LOAD CASE UN1 ACCEPTANCE PARAMETERS

FS sliding:

Unusual (UN) 1.3 (without cohesion) (Table 3-3, USACE EM 1110-2-2100)

Resultant Location:

Unsual (UN) Inside middle third ~100% base in compression

Required Factor of Safety for Sliding: $FS_{sliding.reqUN1} := 1.3$ (Without Cohesion)

Allowable rock bearing pressure: $\sigma_{allowUN1} := 1470kPa$ (Section 5.2, Design Criteria EM 1110-2-2100 Section 3-10)

Overturning Required Resultant Ratio: $X_{R.reqUN1} := 0.333$ (EM 1110-2-2502, Figure 4-4)

Required Factor of Safety for Floatation $FS_{req.UN1.flt} := 1.3$

SOIL HEIGHTS and Water Levels:

LOAD CASE UN1

Heel Conditions:

Groundwater Elevation at Heel: $GWL_{UN1} := 1213.1\,m$

Distance from Finish Grade to Groundwater at Heel: $h_{1UN1} := \left[T_w - GWL_{UN1} + \left(L_{cd} + t_{wb} - t_{wt}\right)\cdot \tan(\beta)\right] = 5.90\,m$

Distance from Water Surface to Bottom of Footing at Heel: $h_{2UN1} := GWL_{UN1} - Bot_{ftg} + Key_{h.d} = 7.60\,m$

Toe Conditions:

Water Surface Elevation at Toe: $WSEL_{UN1} := 1212.1\,m$

Water Surface Elevation at Toe for Uplift: $UWSEL_{UN1} := 1212.1\cdot m$

Finish Grade at Toe providing lateral resistance: $FG_{toeUN1} := 1210.0\cdot m$

Soil Depth Above top of footing: $h_{3aUN1} := FG_{toeUN1} - Top_{ftg} = 0\,m$

$$h_{3UN1} := \begin{cases} h_{3aUN1} & \text{if } FG_{toeUN1} - Top_{ftg} \ge 0 \\ 0 & \text{otherwise} \end{cases} = 0$$

Resisting Fill at Toe: $h_{4UN1} := FG_{toeUN1} - Bot_{ftg} + Key_{t.d} = 1.50\,m$

Distance from Water Level to Top of Footing at Toe: $h_{5UN1} := WSEL_{UN1} - Top_{ftg} = 2.10\,m$

Distance from Water Surface to Bottom of Footing at Toe: $h_{6UN1} := WSEL_{UN1} - Bot_{ftg} + Key_{t.d} = 3.60\,m$

Soil Depth Above WSEL: $h_{7aUN1} := FG_{toeUN1} - WSEL_{UN1} = -2.1\,m$

$$h_{7UN1} := \begin{cases} h_{7aUN1} & \text{if } FG_{toeUN1} - WSEL_{UN1} \ge 0 \\ 0 & \text{otherwise} \end{cases} = 0$$

Soil Depth Below WSEL:

$$h_{8UN1} := \begin{cases} WSEL_{UN1} - Bot_{ftg} + Key_{t.d} & \text{if } FG_{toeUN1} - WSEL_{UN1} \ge 0 \\ h_{4UN1} & \text{otherwise} \end{cases} = 1.5$$

For Line of Creep Method: $L_{ho.UN1} := \sqrt{b^2 + \left(Key_{h.d} - Key_{t.d}\right)^2} = 9.487\,m$

Head Loss from Point g:

$\Delta h_{g.hj.UN1} := h_{2UN1} = 7.6\,m$ (to point h & j)

$\Delta h_{g.km.UN1} := GWL_{UN1} - Bot_{ftg} = 4.6\,m$ (to point k & m)

$\Delta h_{g.no.UN1} := GWL_{UN1} - Bot_{ftg} + Key_{t.d} = 4.6\,m$ (to point n & o)

$\Delta h_{g.p.UN1} := GWL_{UN1} - FG_{toeUN1} = 3.1\,m$ (to point p*)

$\Delta h_{g.r.UN1} := GWL_{UN1} - UWSEL_{UN1} = 1\,m$ (to point r)

Surcharge

Surcharge on Heel: $S1_{UN1} := 15.0\,\frac{kN}{m^2}$

* same as point "a" in this case

Calculate Soil Lateral Pressure Coefficients:

LOAD CASE UN1

For all load cases except seismic, soil loading to be based on At-Rest Condition.
Calculate at-rest pressure coefficient Ko based on Jaky's (1944) equation.

Soil At Rest Static Coefficient: $K_o := \frac{1 - \sin(\phi)}{1 + \sin(\beta)} = 0.546$ (Eq. 3-6, USACE EM 1110-2-2502)

Lateral - Driving Force

Static At-Rest:

Surcharge Load: $E_{s1UN1} := S1_{UN1} \cdot K_o \cdot \left(H_w + Key_{h.d}\right) \cdot B \cdot -1 = -110.567 \cdot kN$

Moment Arm (from bottom of footing): $E_{s1locUN1} := \frac{H_w + Key_{h.d}}{2} + Key_{vdist} = 3.75\ m$

Moist Soil Load above GWL: $E_{h1UN1} := \frac{\gamma_m \cdot K_o \cdot h_{1UN1}^{\ 2}}{2} \cdot B \cdot -1 = -190.1 \cdot kN$

Moment Arm (from bottom of footing): $E_{h1locUN1} := \frac{h_{1UN1}}{3} + h_{2UN1} + Key_{vdist} = 6.57\ m$

Saturated Soil Load below GWL:
(rectangular component) $E_{h2UN1} := \left(\gamma_m \cdot K_o \cdot h_{1UN1}\right) \cdot \left(h_{2UN1}\right) \cdot B \cdot -1 = -489.7 \cdot kN$

Moment Arm (from bottom of footing): $E_{h2locUN1} := \frac{h_{2UN1}}{2} + Key_{vdist} = 0.80\ m$

Saturated Soil Load below GWT:
(triangular L $E_{h2aUN1} := \frac{\left(\gamma_{sat} - \gamma_w\right) \cdot K_o \cdot h_{2UN1}^{\ 2}}{2} \cdot B \cdot -1 = -192.4 \cdot kN$

Moment Arm (from bottom of footing): $E_{h2alocUN1} := \frac{h_{2UN1}}{3} + Key_{vdist} = -0.47\ m$

Lateral Water Load:

Water Load GWL to Bottom of Key $H_{h2UN1} := \frac{\gamma_w \cdot h_{2UN1}^{\ 2}}{2} \cdot B \cdot -1 = -283.0 \cdot kN$

Moment Arm (from bottom of footing): $H_{h2locUN1} := \frac{h_{2UN1}}{3} + Key_{vdist} = -0.47\ m$

$$\Sigma H_{SoildriveUN1} := E_{s1UN1} + E_{h1UN1} + E_{h2UN1} + E_{h2aUN1} + H_{h2UN1} = -1265.7 \cdot kN$$

$$\Sigma M_{LateralSoildriveUN1} := E_{s1UN1} \cdot E_{s1locUN1} + E_{h1UN1} \cdot E_{h1locUN1} + E_{h2UN1} \cdot E_{h2locUN1} \ldots + E_{h2aUN1} \cdot E_{h2alocUN1} + H_{h2UN1} \cdot H_{h2locUN1} = -1832.6\ m \cdot kN$$

Lateral - Resisting Force

LOAD CASE UN1

Lateral Water Load:

Water Load WSEL to Bottom of Footing: $H_{h6UN1} := \frac{\gamma_w \cdot h_{6UN1}^{2}}{2} \cdot B = 63.5 \cdot kN$

Moment Arm (from bot. of toe key): $H_{h6locUN1} := \frac{h_{6UN1}}{3} = 1.20\ m$

Water Load Bot. of Footing to Bot. of H. Key: $H_{h2aUN1} := \left[\left(UWSEL_{UN1} - Bot_{ftg} + Key_{t.d}\right) + h_{2UN1}\right] \cdot \frac{Key_{h.d}}{2} \cdot \gamma_w \cdot B = 164.6 \cdot kN$

Moment Arm (from bot. of toe key): $H_{h2alocUN1} := \frac{Key_{h.d} \cdot \left[2 \cdot \left(UWSEL_{UN1} - Bot_{ftg} + Key_{t.d}\right) + h_{2UN1}\right]}{3\left[h_{2UN1} + \left(UWSEL_{UN1} - Bot_{ftg} + Key_{t.d}\right)\right]} \ldots + Key_{vdist} = -1.68\ m$

Lateral Soil Load:

Moist Soil Load above WSEL: $E_{h7UN1} := \frac{\gamma_m \cdot K_o \cdot h_{7UN1}^{2}}{2} \cdot B = 0.0 \cdot kN$

Moment Arm (from bot. of toe key): $E_{h7locUN1} := h_{6UN1} + \frac{h_{7UN1}}{3} + Key_{vdist} = 0.60\ m$

Saturated Soil Load below WSEL: (rectangular component) $E_{h8UN1} := \left(\gamma_m \cdot K_o \cdot h_{7UN1}\right) \cdot h_{8UN1} \cdot B = 0.0 \cdot kN$

Moment Arm (from bot. of toe key): $E_{h8locUN1} := \frac{h_{8UN1}}{2} = 0.75\ m$

Saturated Soil Load below WSEL: (triangular component) $E_{h8aUN1} := \frac{\left[\left(\gamma_{sat} - \gamma_w\right) \cdot K_o\right] \cdot h_{8UN1}^{2}}{2} \cdot B = 7.5 \cdot kN$

Moment Arm (from bot. of footing): $E_{h8alocUN1} := \frac{h_{8UN1}}{3} = 0.50\ m$

$\Sigma H_{SoilresistUN1} := H_{h6UN1} + H_{h2aUN1} + E_{h7UN1} + E_{h8UN1} + E_{h8aUN1} = 235.6 \cdot kN$

$\Sigma M_{HorizSoilResistUN1} := H_{h6UN1} \cdot H_{h6locUN1} + H_{h2aUN1} \cdot H_{h2alocUN1} + E_{h7UN1} \cdot E_{h7locUN1} \ldots + E_{h8UN1} \cdot E_{h8locUN1} + E_{h8aUN1} \cdot E_{h8alocUN1} = -196.4\ m \cdot kN$

Vertical Force:

UPLIFT: Linear distribution from water at heel to water at toe:

$\Sigma V_{UpliftUN1} := \left[\left(UWSEL_{UN1} - Bot_{ftg} + Key_{t.d}\right) + h_{2UN1}\right] \cdot \frac{b}{2} \cdot \gamma_w \cdot B \cdot -1 = -493.92 \cdot kN$

Moment Arm (from Point O): $V_{UpliftUN1aloc} := \frac{b \cdot \left[2 \cdot h_{2UN1} + \left(UWSEL_{UN1} - Bot_{ftg} + Key_{t.d}\right)\right]}{3\left[h_{2UN1} + \left(UWSEL_{UN1} - Bot_{ftg} + Key_{t.d}\right)\right]} = 5.036\ m$

$\Sigma M_{UpliftUN1} := \Sigma V_{UpliftUN1} \cdot V_{UpliftUN1aloc} = -2487.24 \cdot kN \cdot m$

Weight of soil and water over toe:

Water Above the Top of Footing: $W_{H1UN1} := \gamma_w \cdot h_{5UN1} \cdot L_{ab} \cdot B = 51.45 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E1locUN1} := \frac{L_{ab}}{2} = 1.25\ m$

Soil above top of footing: $W_{E6UN1} := \gamma_b \cdot h_{3UN1} \cdot L_{ab} \cdot B = 0.0 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E6locUN1} := \frac{L_{ab}}{2} = 1.25\ m$

Vertical Load Due to Surcharge: $S_{UN1} := S1_{UN1} \cdot L_{cd} \cdot B = 79.395 \cdot kN$ $\quad S_{UN1loc} := b - \frac{L_{cd}}{2} = 6.35\ m$

Weight of soil and water over heel:

Moist Soil for sloped grade above top of wall:

Length of sloped portion of soil above top of wall: $L_{E3UN1} := \left(L_{cd} + t_{wb} - t_{wt}\right) = 6.00\ m$

Height of sloped soil above top of wall over heel: $h_{E3locUN1} := \left(L_{E3UN1}\right) \cdot \tan(\beta) = 0.00\ m$

Weight of sloped soil above top of wall: $W_{E3UN1} := \frac{\gamma_m}{2} \cdot h_{E3locUN1} \cdot L_{E3UN1} \cdot B = 0.0 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E3locUN1} := L_{ab} + t_{wt} + \frac{2}{3} \cdot L_{E3UN1} = 7.00\ m$

Moist soil from top of wall to groundwater level:

Height of soil from top of wall and top of GWL: $h_{1UN1} = 5.90\ m$

Length from edge of wall at GWL to edge of heel: $L_{E4UN1} := L_{E3UN1} - \left(h_{1UN1} \cdot S_{batter}\right) = 5.54\ m$

Weight of soil over heel from top of wall to GWL: $W_{E4UN1} := \gamma_m \cdot h_{1UN1} \cdot \frac{\left(L_{E3UN1} + L_{E4UN1}\right)}{2} \cdot B = 680.7 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E4locUN1} := b - \frac{L_{E3UN1}^2 + L_{E3UN1} \cdot L_{E4UN1} + L_{E4UN1}^2}{3\left(L_{E3UN1} + L_{E4UN1}\right)} = 6.11\ m$

Saturated soil from groundwater to top of footing:

Height of soil from GWL to top of heel: $h_{E4UN1} := h_{2UN1} - t_{ftg} - Key_{h.d} = 3.10\ m$

Weight of soil over heel from GWL to top of heel: $W_{E5UN1} := \left(\gamma_{sat}\right) \cdot h_{E4UN1} \cdot \frac{\left(L_{E4UN1} + L_{cd}\right)}{2} \cdot B = 369.3 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E5locUN1} := b - \frac{L_{E4UN1}^2 + L_{E4UN1} \cdot L_{cd} + L_{cd}^2}{3\left(L_{E4UN1} + L_{cd}\right)} = 6.29\ m$

$$\Sigma V_{SoilWaterUN1} := W_{H1UN1} + W_{E6UN1} + W_{E3UN1} + W_{E4UN1} + W_{E5UN1} + S_{UN1} = 1180.8 \cdot kN$$

$$\Sigma M_{VertSoilWaterResistUN1} := W_{H1UN1} \cdot W_{E1locUN1} + W_{E6UN1} \cdot W_{E6locUN1} \cdots + W_{E3UN1} \cdot W_{E3locUN1} + W_{E4UN1} \cdot W_{E4locUN1} + W_{E5UN1} \cdot W_{E5locUN1} + S_{UN1} \cdot S_{UN1loc} = 7054.1\ m \cdot kN$$

THIS PAGE INTENTIONALLY LEFT BLANK
PLEASE GO TO THE NEXT PAGE

STABILITY ASSESSMENT:

LOAD CASE UN1

CHECK SLIDING ALONG HORIZONTAL SLIDING PLANE:

Summation of the vertical forces:

$$\Sigma V_{UN1} := \Sigma V_{conc} + \Sigma V_{SoilWaterUN1} + \Sigma V_{UpliftUN1} = 1255.1 \cdot kN$$

Summation of the horizontal forces:

$$\Sigma H_{UN1} := \Sigma H_{SoildriveUN1} + \Sigma H_{SoilresistUN1} = -1030.1 \cdot kN$$

Safety Factor for Sliding Horizontal Failure Plane

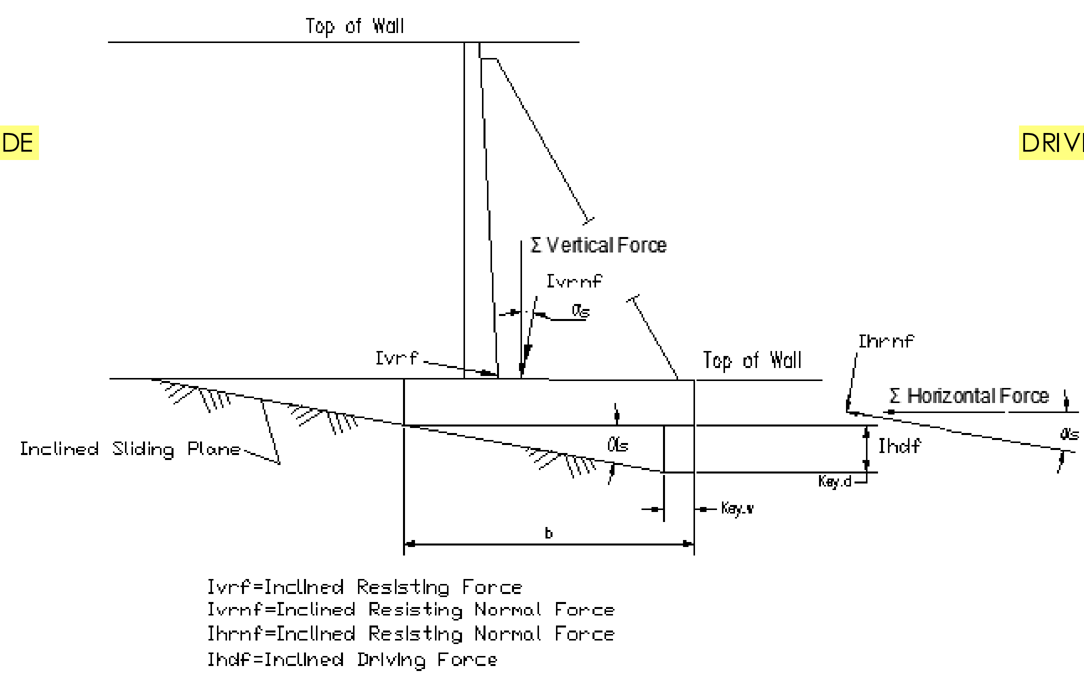
$$FS_{Horiz.SlidingUN1} := \frac{\left|\Sigma V_{UN1}\right| \cdot \tan\left(\phi_{rock} \cdot \frac{\pi}{180}\right)}{\left|\Sigma H_{UN1}\right|} = 0.59$$

$$FS_{Sliding.check1.UN1} := \begin{cases} \text{"OKAY "} & \text{if } FS_{Horiz.SlidingUN1} > FS_{sliding.reqUN1} \\ \text{"NG - key req""} & \text{otherwise} \end{cases} = \text{"NG - key req""}$$

CHECK FACTOR OF SAFETY SLIDING WITH KEY (INCLINED SLIDING PLANE):

RESISTING SIDE

DRIVING SIDE



TOE

HEEL

$\alpha s = 0.359$

(With properly engineered reinforced concrete Key, horizontal sliding plane thru Toe is protected, critical sliding plane is relocated to the INCLINED SLIDING PLANE FROM HEEL KEY To TOE, Bedrock Mass above this examing plane is mobilized by reinforced concrete key and combined into Structural Wedge.)

Resolve ΣV_{UN1} & ΣH_{UN1}

$$\Sigma V_{InclinedUN1} := \cos(\alpha s) \cdot \left(\left|\Sigma V_{UN1} + V_{rocksection}\right|\right) + \sin(\alpha s) \cdot \left|\Sigma H_{UN1}\right| = 1824.5 \cdot kN$$

$$\Sigma H_{InclinedUN1} := \cos(\alpha s) \cdot \left|\Sigma H_{UN1}\right| - \sin(\alpha s) \cdot \left(\left|\Sigma V_{UN1} + V_{rocksection}\right|\right) = 415.9 \cdot kN$$

LOAD CASE UN1

Safety Factor for Sliding Inclined Failure Plane

$$FS_{InclinedlSlidingUN1} := \frac{\Sigma V_{InclinedUN1} \cdot \tan(\phi_r)}{\Sigma H_{InclinedUN1}} = 1.95$$

$$FS_{Sliding.check2.UN1} := \begin{cases} \text{"OKAY "} & \text{if } FS_{InclinedlSlidingUN1} > FS_{sliding.reqUN1} \\ \text{"NG - Revise Structure""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

CHECK FOUNDATION ECCENTRICITY:

Summation of the resisting moments about the toe:

$$\Sigma M_{resUN1} := \Sigma M_{conc} + \Sigma M_{VertSoilWaterResistUN1} + \Sigma M_{HorizSoilResistUN1} + \Sigma M_{rocksection} = 11056 \cdot kN \cdot m$$

Summation of the overturning moments about the toe:

$$\Sigma M_{oUN1} := \Sigma M_{LateralSoildriveUN1} + \Sigma M_{UpliftUN1} = -4320 \cdot kN \cdot m$$

Total moment: $\Sigma M_{UN1} := \Sigma M_{resUN1} + \Sigma M_{oUN1} = 6735.9 \cdot kN \cdot m$

Normal force to base: $\Sigma V_{InclinedUN1} = 1824.5 \cdot kN$

Inclined Sliding Plane Length: $L_{incline} = 9.6 \cdot m$

Eccentricity (inclined plane): $ex_{UN1} := \frac{L_{incline}}{2} - \frac{\Sigma M_{UN1}}{\Sigma V_{InclinedUN1}} = 1.11\ m$ $\quad Kern = 1.602\ m$

Eccentricity Check: $e_{check.UN1} := \begin{cases} \text{"Okay"} & \text{if } ex_{UN1} \le Kern \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"Okay"}$

CHECK FOUNDATION BEARING CAPACITY:

Base Section Modulus: $S_b = 15.4\ m^3$

Bearing Pressure Under Toe:

$$\sigma_{ToeUN1} := \begin{cases} \left(\frac{\Sigma V_{InclinedUN1}}{L_{incline} \cdot B} + \frac{\Sigma V_{InclinedUN1} \cdot ex_{UN1}}{S_b}\right) & \text{if } \frac{\Sigma V_{InclinedUN1} \cdot ex_{UN1}}{S_b} \le \frac{\Sigma V_{InclinedUN1}}{L_{incline} \cdot B} \\ \frac{2 \cdot \Sigma V_{InclinedUN1}}{B \cdot 3\left(\frac{b}{2} - ex_{UN1}\right)} & \text{otherwise} \end{cases} = 321.8 \cdot kPa$$

$$Bearing_{ChecktoeUN1} := \begin{cases} \text{"OKAY "} & \text{if } \sigma_{ToeUN1} < \sigma_{allowUN1} \\ \text{"NG""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

Bearing Pressure Under Heel:

$$\sigma_{HeelUN1} := \begin{cases} \left(\frac{\Sigma V_{InclinedUN1}}{L_{incline} \cdot B} - \frac{\Sigma V_{InclinedUN1} \cdot ex_{UN1}}{S_b}\right) & \text{if } \frac{\Sigma V_{InclinedUN1} \cdot ex_{UN1}}{S_b} \le \frac{\Sigma V_{InclinedUN1}}{L_{incline} \cdot B} \\ 0 & \text{otherwise} \end{cases} = 57.8 \cdot kPa$$

$$Bearing_{CheckheelUN1} := \left(\begin{cases} \text{"OKAY "} & \text{if } \sigma_{HeelUN1} < \sigma_{allowUN1} \wedge \sigma_{HeelUN1} > 0 \\ \text{"NG - perform cracked base analysis""} & \text{otherwise} \end{cases}\right) = \text{"OKAY "}$$

CHECK FLOATATION:

Safety Factor for Floatation:

$$FS_{FloatationUN1} := \frac{\Sigma V_{conc} + \Sigma V_{SoilWaterUN1}}{\left|\Sigma V_{UpliftUN1}\right|} = 3.54$$

$$FS_{Floatation.UN1.check} := \begin{cases} \text{"OKAY "} & \text{if } FS_{FloatationUN1} > FS_{req.UN1.flt} \\ \text{"Revise Structure""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

CHECK OVERTURNING

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.
Assumptions are made in order to compute overturning stablity of indetermine forces on monolith with key;
(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.
(b) The horizontal resisting force acting on the key, P.key, is that required for static equilibrium
(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1

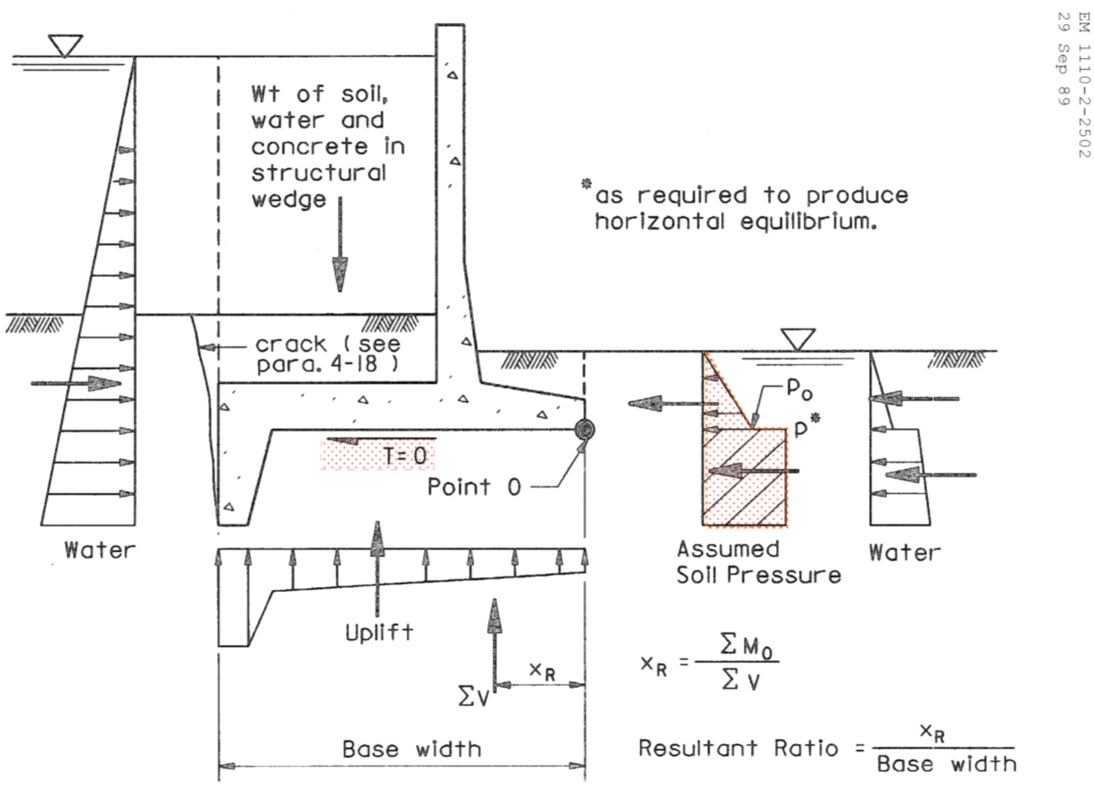


Figure 4-5. Forces for overturning analysis for wall with horizontal base and key

Modify Uplift for Overturning Analysis: **LOAD CASE UN1**

(Uplift is calculated along the concrete/rock contact using the Line of Creep method)

Water Pressure at h: $u_{h.UN1} := \Delta h_{g.hj.UN1} \cdot \gamma_w = 74.48 \cdot kPa$

Water Pressure at o: $u_{o.UN1} := \left(\Delta h_{g.no.UN1} - \dfrac{\Delta h_{g.r.UN1} \cdot L_{ho.UN1}}{L_{ho.UN1}}\right) \cdot \gamma_w = 35.28 \cdot kPa$

Head loss between point h and o: $\Delta h_{ho.UN1} := \Delta h_{g.r.UN1} \cdot \dfrac{L_{ho.UN1}}{L_{ho.UN1}} = 1\,m$

Length of concrete base (h -> o): $L_{baseho.UN1} := Key_{h.w} + Key_{h.d} + Key_{hdist} + Key_{t.d} + Key_{t.w} = 12\,m$

Head loss along h -> j: $\Delta h_{hj.UN1} := \Delta h_{ho.UN1} \cdot \dfrac{Key_{h.w}}{L_{baseho.UN1}} = 0.083\,m$

Water Pressure at j: $u_{j.UN1} := \left(\Delta h_{g.hj.UN1} - \Delta h_{hj.UN1}\right) \cdot \gamma_w = 73.66 \cdot kPa$

Head loss along h -> k: $\Delta h_{hjk.UN1} := \Delta h_{ho.UN1} \cdot \left(\dfrac{Key_{h.w} + Key_{h.d}}{L_{baseho.UN1}}\right) = 0.333\,m$

Water Pressure at k: $u_{k.UN1} := \left(\Delta h_{g.km.UN1} - \Delta h_{hjk.UN1}\right) \cdot \gamma_w = 41.81 \cdot kPa$

Head loss along h -> m: $\Delta h_{hjkm.UN1} := \Delta h_{ho.UN1} \cdot \left(\dfrac{Key_{h.w} + Key_{h.d} + Key_{hdist}}{L_{baseho.UN1}}\right) = 1\,m$

Water Pressure at m: $u_{m.UN1} := \left(\Delta h_{g.km.UN1} - \Delta h_{hjkm.UN1}\right) \cdot \gamma_w = 35.28 \cdot kPa$

Head loss along h -> n: $\Delta h_{hjkmn.UN1} := \Delta h_{ho.UN1} \cdot \left(\dfrac{Key_{h.w} + Key_{h.d} + Key_{hdist} + Key_{t.d}}{L_{baseho.UN1}}\right) = 1\,m$

Water Pressure at n: $u_{n.UN1} := \left(\Delta h_{g.no.UN1} - \Delta h_{hjkmn.UN1}\right) \cdot \gamma_w = 35.28 \cdot kPa$

Uplift under key at heel: $V_{ulkeyhUN1.OT} := \dfrac{\left(u_{h.UN1} + u_{j.UN1}\right) \cdot Key_{h.w}}{2} \cdot B \cdot -1 = -74.072 \cdot kN$

Moment Arm (from Point O): $V_{ulkeyhUN1loc.OT} := b - \dfrac{Key_{h.w} \cdot \left(2 \cdot u_{j.UN1} + u_{h.UN1}\right)}{3 \cdot \left(u_{j.UN1} + u_{h.UN1}\right)} = 8.501\,m$

Uplift under base: $V_{ulbaseUN1.OT} := \dfrac{\left(u_{k.UN1} + u_{m.UN1}\right) \cdot Key_{hdist}}{2} \cdot B \cdot -1 = -308.373 \cdot kN$

Moment Arm (from Point O): $V_{ulbaseUN1loc.OT} := b - Key_{h.w} - \dfrac{Key_{hdist} \cdot \left(2 \cdot u_{m.UN1} + u_{k.UN1}\right)}{3 \cdot \left(u_{m.UN1} + u_{k.UN1}\right)} = 4.113\,m$

Uplift under key at toe $V_{ulkeytUN1.OT} := \dfrac{\left(u_{n.UN1} + u_{o.UN1}\right) \cdot Key_{t.w}}{2} \cdot B \cdot -1 = 0 \cdot kN$

Moment Arm (from Point O): $V_{ulkeytUN1loc.OT} := \dfrac{Key_{t.w} \cdot \left(2 \cdot u_{n.UN1} + u_{o.UN1}\right)}{3 \cdot \left(u_{n.UN1} + u_{o.UN1}\right)} = 0$

$$\Sigma V_{UpliftUN1.OT} := V_{ulkeyhUN1.OT} + V_{ulbaseUN1.OT} + V_{ulkeytUN1.OT} = -382 \cdot kN$$

$$U_{UN1.loc.OT} := \frac{V_{ulkeyhUN1.OT} \cdot V_{ulkeyhUN1loc.OT} + V_{ulbaseUN1.OT} \cdot V_{ulbaseUN1loc.OT} + V_{ulkeytUN1.OT} \cdot V_{ulkeytUN1loc.OT}}{\Sigma V_{UpliftUN1.OT}} = 4.96\,m$$

$$\Sigma M_{UpliftUN1.OT} := \Sigma V_{UpliftUN1.OT} \cdot U_{UN1.loc.OT} = -1898.0 \cdot kN \cdot m$$

Modify Lateral Water Pressure (Resisting) for Overturning Analysis:

(Resisting water pressure is calculated using the Line of Creep method)

Water Load at Key (heel):

$$H_{h2UN1.OT} := \frac{u_{k.UN1} + u_{j.UN1}}{2} \cdot Key_{h.d} B = 173.2 \cdot kN$$

Moment Arm (from Point O):

$$H_{h2locUN1.OT} := \frac{Key_{h.d} \cdot (2 \cdot u_{k.UN1} + u_{j.UN1})}{3(u_{k.UN1} + u_{j.UN1})} + Key_{vdist} = -1.64\ m$$

Water Load at Key (toe):

$$H_{h6UN1.OT} := \frac{u_{o.UN1} \cdot (UWSEL_{UN1} - Bot_{ftg} + Key_{t.d})}{2} \cdot B = 64 \cdot kN$$

Moment Arm (from Point O):

$$H_{h6locUN1.OT} := \frac{UWSEL_{UN1} - Bot_{ftg} + Key_{t.d}}{3} = 1.20\ m$$

$$\Sigma H_{waterresistUN1.OT} := H_{h2UN1.OT} + H_{h6UN1.OT} = 236.72 \cdot kN$$

$$H_{waterresistlocUN1.OT} := \frac{H_{h2UN1.OT} \cdot H_{h2locUN1.OT} + H_{h6UN1.OT} \cdot H_{h6locUN1.OT}}{\Sigma H_{waterresistUN1.OT}} = -0.877\ m$$

$$\Sigma M_{waterresistUN1.OT} := \Sigma H_{waterresistUN1.OT} \cdot H_{waterresistlocUN1.OT} = -207.51 \cdot kN \cdot m$$

Modify Lateral Soil Loads for Overturning Analysis:

(Lateral soil loads are calculated down to Point O instead of bottom of shear key)

Driving Soil Load (Headwater Side):

Surcharge Load:

$$E_{s1UN1.OT} := S1_{UN1} \cdot K_o \cdot (H_w + Key_{h.d} + Key_{vdist}) \cdot B \cdot -1 = -85.996 \cdot kN$$

Moment Arm (from Point O):

$$E_{s1locUN1.OT} := \frac{H_w + Key_{h.d} + Key_{vdist}}{2} = 5.25\ m$$

Moist Soil Load above GWL:

$$E_{h1UN1.OT} := \frac{\gamma_m \cdot K_o \cdot h_{1UN1}^{2}}{2} B \cdot -1 = -190.1 \cdot kN$$

Moment Arm (from Point O):

$$E_{h1locUN1.OT} := \frac{h_{1UN1}}{3} + h_{2UN1} + Key_{vdist} = 6.57\ m$$

Saturated Soil Load below GWL:
(rectangular component)

$$E_{h2UN1.OT} := (\gamma_m \cdot K_o \cdot h_{1UN1}) \cdot (h_{2UN1} + Key_{vdist}) \cdot B \cdot -1 = -296.4 \cdot kN$$

Moment Arm (from Point O):

$$E_{h2locUN1.OT} := \frac{h_{2UN1} + Key_{vdist}}{2} = 2.30\ m$$

Saturated Soil Load below GWL:
(triangular component)

$$E_{h2aUN1.OT} := \frac{(\gamma_{sat} - \gamma_w) \cdot K_o \cdot (h_{2UN1} + Key_{vdist})^2}{2} \cdot B \cdot -1 = -70.5 \cdot kN$$

Moment Arm (from Point O):

$$E_{h2alocUN1.OT} := \frac{h_{2UN1} + Key_{vdist}}{3} = 1.53\ m$$

Resisting Soil Load (Tailwater Side):

(Determine resisting soil load based on depth variation between the keys (ie. Key_{vdist}). In case where key at heel is deeper than key at toe (ie. $Key_{vdist} < 0$), resisting soil load (p*) is assumed to produce horizontal equilibrium as per Figure 4-5 above. Resisting soil load (p_o) is neglected.)

Total Driving Force: $\Sigma H_{SoildriveUN1.OT} := E_{s1UN1.OT} + E_{h1UN1.OT} + E_{h2UN1.OT} + E_{h2aUN1.OT} + H_{h2UN1} = -925.9 \cdot kN$

Total Resisting Force: $\Sigma H_{waterresistUN1.OT} = 236.7 \cdot kN$

Assumed Soil Load p*: $E_{h8UN1a.OT} := \left(\Sigma H_{SoildriveUN1.OT} + \Sigma H_{waterresistU1.OT}\right) \cdot -1 = 689.218 \cdot kN$

Moment Arm (from Point O): $E_{h8UN1a.loc.OT} := \dfrac{Key_{vdist}}{2} = -1.5\,m$

$$E_{h8UN1.OT} := \begin{cases} E_{h8UN1a.OT} & \text{if } Key_{vdist} < 0 \\ \Sigma H_{SoilresistUN1} - H_{h6UN1} - H_{h2aUN1} & \text{otherwise} \end{cases} = 689.218 \cdot kN$$

$$\Sigma M_{SoilresistUN1} := \begin{cases} E_{h8UN1a.OT} \cdot E_{h8UN1a.loc.OT} & \text{if } Key_{vdist} < 0 \\ \Sigma M_{HorizSoilResistUN1} - H_{h6UN1} \cdot H_{h6locUN1} - H_{h2aUN1} \cdot H_{h2alocUN1} & \text{otherwise} \end{cases} = -1033.827 \cdot kN \cdot m$$

Sum of Moment about Point O:

$$\Sigma M_{LateraldriveUN1.OT} := E_{s1UN1.OT} \cdot E_{s1locUN1.OT} + E_{h1UN1.OT} \cdot E_{h1locUN1.OT} + E_{h2UN1.OT} \cdot E_{h2locUN1.OT} \dots + E_{h2aUN1.OT} \cdot E_{h2alocUN1.OT} + H_{h2UN1} \cdot H_{h2locUN1} = -2357.2 \cdot kN \cdot m$$

$$\Sigma M_{LateralresistUN1.OT} := \Sigma M_{waterresistUN1.OT} + \Sigma M_{SoilresistUN1} = -1241.3 \cdot kN \cdot m$$

Total moment:

$$\Sigma M_{UN1.OT} := \Sigma M_{conc} + \Sigma M_{VertSoilWaterResistUN1} + \Sigma M_{UpliftUN1.OT} + \Sigma M_{LateraldriveUN1.OT} \dots + \Sigma M_{LateralresistUN1.OT} = 4117.1 \cdot kN \cdot m$$

Total Vertical Force: $\Sigma V_{UN1.OT} := \Sigma V_{conc} + \Sigma V_{SoilWaterUN1} + \Sigma V_{UpliftUN1.OT} = 1366.6 \cdot kN$

Distance X_R: EM 1110-2-2502 Eq.4-1 $X_{R.UN1} := \dfrac{\Sigma M_{UN1.OT}}{\Sigma V_{UN1.OT}} = 3.013\,m$

Overturning Resultant Ratio $Ratio_{UN1.OT} := \dfrac{X_{R.UN1}}{b} = 0.33$

$$Ratio_{UN1.OT.check} := \begin{cases} \text{"OKAY "} & \text{if } Ratio_{UN1.OT} > X_{R.reqUN1} \\ \text{"Revise Structure""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

CHECK FOUNDATION ECCENTRICITY (HORIZONTAL PLANE):

Eccentricity (horizontal plan): $ex_{UN1.OT} := \dfrac{b}{2} - \dfrac{\Sigma M_{UN1.OT}}{\Sigma V_{UN1.OT}} = 1.49\,m$ $Kern_{OT} = 1.5\,m$

Eccentricity Check: $$e_{check.UN1.OT} := \begin{cases} \text{"Okay"} & \text{if } ex_{UN1} \le Kern_{OT} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"Okay"}$$

CHECK FOUNDATION BEARING CAPACITY (HORIZONTAL PLANE):

Base Section Modulus: $S_{b.OT} = 13.5\,m^3$

Bearing Pressure Under Toe:

$$\sigma_{ToeUN1.OT} := \begin{cases} \left(\dfrac{\Sigma V_{UN1.OT}}{b \cdot B} + \dfrac{\Sigma V_{UN1.OT} \cdot ex_{UN1.OT}}{S_{b.OT}}\right) & \text{if } \dfrac{\Sigma V_{UN1.OT}}{b \cdot B} \ge \dfrac{\Sigma V_{UN1.OT} \cdot ex_{UN1.OT}}{S_{b.OT}} \\ \dfrac{2 \cdot \Sigma V_{UN1.OT}}{B \cdot 3\left(\dfrac{b}{2} - ex_{UN1.OT}\right)} & \text{otherwise} \end{cases} = 302.4 \cdot kPa$$

$$Bearing_{ChecktoeUN1.OT} := \begin{cases} \text{"OKAY "} & \text{if } \sigma_{ToeUN1.OT} < \sigma_{allowUN1} \\ \text{"NG - for reference only""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

Bearing Pressure Under Heel:

$$\sigma_{HeelUN1.OT} := \begin{cases} \left(\dfrac{\Sigma V_{UN1.OT}}{b \cdot B} - \dfrac{\Sigma V_{UN1.OT} \cdot ex_{UN1.OT}}{S_{b.OT}}\right) & \text{if } \dfrac{\Sigma V_{UN1.OT}}{b \cdot B} \ge \dfrac{\Sigma V_{UN1.OT} \cdot ex_{UN1.OT}}{S_{b.OT}} \\ 0 & \text{otherwise} \end{cases} = 1.3 \cdot kPa$$

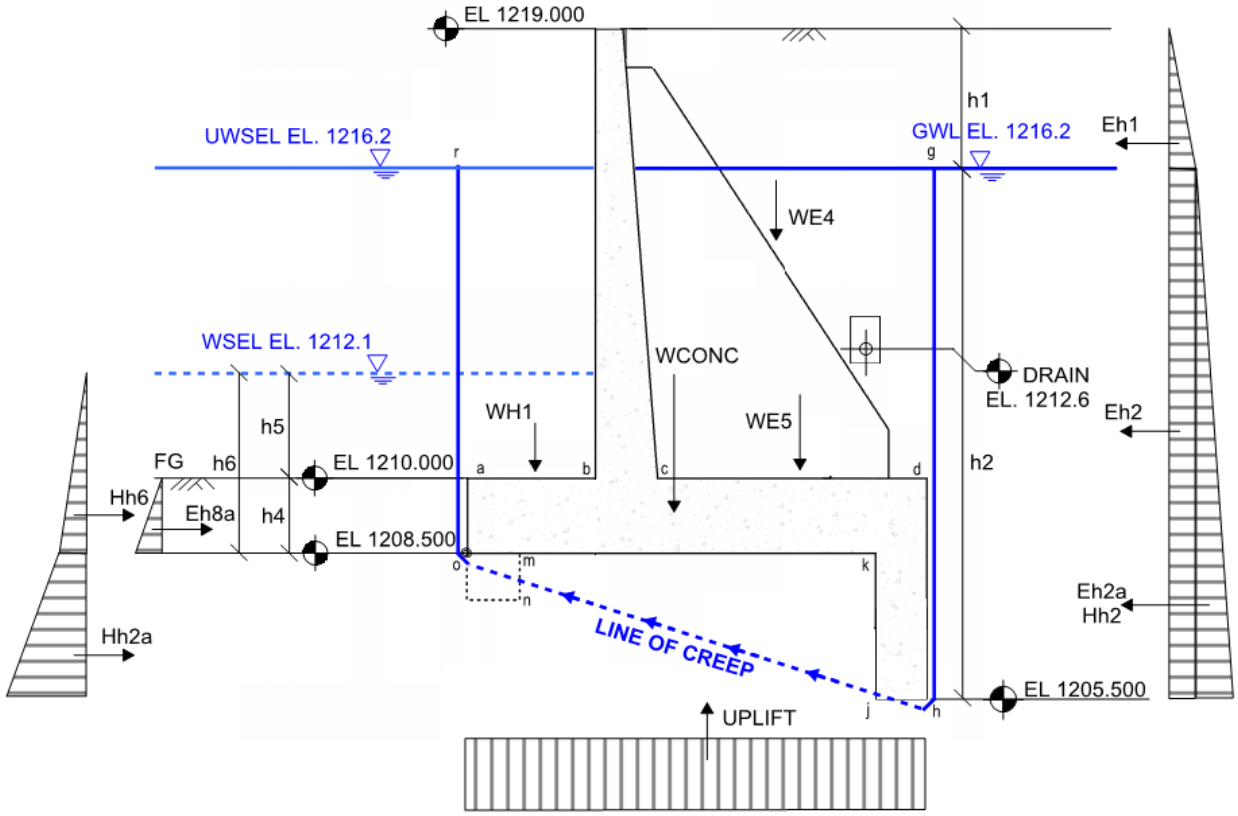
$$Bearing_{CheckheelUN1.OT} := \left(\begin{cases} \text{"OKAY "} & \text{if } \sigma_{HeelUN1.OT} < \sigma_{allowUN1} \wedge \sigma_{HeelUN1.OT} > 0 \\ \text{"NG - for reference only""} & \text{otherwise} \end{cases}\right) = \text{"OKAY "}$$

SUMMARY OF STABILITY ASSESSMENT:

LOAD CASE UN1

Sliding Factor of Safety: (Horizontal Plane - Ref only)	$FS_{Horiz.SlidingUN1} = 0.59$	$FS_{Sliding.check1.UN1}$ = "NG - key req""
Sliding Factor of Safety: (Inclined Plane)	$FS_{InclinedlSlidingUN1} = 1.95$	$FS_{Sliding.check2.UN1}$ = "OKAY "
Eccentricity: (Inclined Plane)	$ex_{UN1} = 1.11\ m$	$e_{check.UN1}$ = "Okay"
Bearing Pressure At Heel: (Inclined Plane)	$\sigma_{HeelUN1} = 58 \cdot kPa$	$Bearing_{CheckheelUN1}$ = "OKAY "
Bearing Pressure At Toe: (Inclined Plane)	$\sigma_{ToeUN1} = 322 \cdot kPa$	$Bearing_{ChecktoeUN1}$ = "OKAY "
Flotation Factor of Safety (horizontal plane)	$FS_{FloatationUN1} = 3.54$	$FS_{Floatation.UN1.check}$ = "OKAY "
Overturning Resultant Ratio: (horizontal plane)	$Ratio_{UN1.OT} = 0.33$	$Ratio_{UN1.OT.check}$ = "OKAY "
Eccentricity: (horizontal plane - Ref only)	$ex_{UN1.OT} = 1.49\ m$	$e_{check.UN1.OT}$ = "Okay"
Bearing Pressure At Heel: (horizontal plane - Ref only)	$\sigma_{HeelUN1.OT} = 1 \cdot kPa$	$Bearing_{CheckheelUN1.OT}$ = "OKAY "
Bearing Pressure At Toe: (horizontal plane - Ref only)	$\sigma_{ToeUN1.OT} = 302 \cdot kPa$	$Bearing_{ChecktoeUN1.OT}$ = "OKAY "

LOAD CASE UN2 - INEFFECTIVE DRAIN



UN2 DESIGN CASE

LOAD CASE UN2 ACCEPTANCE PARAMETERS

FS sliding:

Unusual (UN) 1.3 (without cohesion) (Table 3-3, USACE EM 1110-2-2100)

Resultant Location:

Unsual (UN) Inside middle third ~100% base in compression

Required Factor of Safety for Sliding: $FS_{sliding.reqUN2} := 1.3$ (Without Cohesion)

Allowable rock bearing pressure: $\sigma_{allowUN2} := 1470kPa$ (Section 5.2, Design Criteria EM 1110-2-2100 Section 3-10)

Overturning Required Resultant Ratio: $X_{R.reqUN2} := 0.333$ (EM 1110-2-2502, Figure 4-4)

Required Factor of Safety for Floatation $FS_{req.UN2.flt} := 1.3$

SOIL HEIGHTS and Water Levels:

LOAD CASE UN2

Heel Conditions:

Groundwater Elevation at Heel: $GWL_{UN2} := 1216.2\text{m}$

Distance from Finish Grade to Groundwater at Heel: $h_{1UN2} := \left[T_w - GWL_{UN2} + \left(L_{cd} + t_{wb} - t_{wt}\right)\cdot\tan(\beta)\right] = 2.80\text{ m}$

Distance from Water Surface to Bottom of Footing at Heel: $h_{2UN2} := GWL_{UN2} - Bot_{ftg} + Key_{h.d} = 10.70\text{ m}$

Toe Conditions:

Water Surface Elevation at Toe: $WSEL_{UN2} := 1212.1\text{m}$

Water Surface Elevation at Toe for Uplift: $UWSEL_{UN2} := 1216.2\cdot\text{m}$

Finish Grade at Toe providing lateral resistance: $FG_{toeUN2} := 1210.0\cdot\text{m}$

Soil Depth Above top of footing: $h_{3aUN2} := FG_{toeUN2} - Top_{ftg} = 0\text{ m}$

$$h_{3UN2} := \begin{cases} h_{3aUN2} & \text{if } FG_{toeUN2} - Top_{ftg} \ge 0 \\ 0 & \text{otherwise} \end{cases} = 0$$

Resisting Fill at Toe: $h_{4UN2} := FG_{toeUN2} - Bot_{ftg} + Key_{t.d} = 1.50\text{ m}$

Distance from Water Level to Top of Footing at Toe: $h_{5UN2} := WSEL_{UN2} - Top_{ftg} = 2.10\text{ m}$

Distance from Water Surface to Bottom of Footing at Toe: $h_{6UN2} := WSEL_{UN2} - Bot_{ftg} + Key_{t.d} = 3.60\text{ m}$

Soil Depth Above WSEL: $h_{7aUN2} := FG_{toeUN2} - WSEL_{UN2} = -2.1\text{ m}$

$$h_{7UN2} := \begin{cases} h_{7aUN2} & \text{if } FG_{toeUN2} - WSEL_{UN2} \ge 0 \\ 0 & \text{otherwise} \end{cases} = 0$$

Soil Depth Below WSEL:

$$h_{8UN2} := \begin{cases} WSEL_{UN2} - Bot_{ftg} + Key_{t.d} & \text{if } FG_{toeUN2} - WSEL_{UN2} \ge 0 \\ h_{4UN2} & \text{otherwise} \end{cases} = 1.5$$

For Line of Creep Method: $L_{ho.UN2} := \sqrt{b^2 + \left(Key_{h.d} - Key_{t.d}\right)^2} = 9.487\text{ m}$

Head Loss from Point g:

$\Delta h_{g.hj.UN2} := h_{2UN2} = 10.7\text{ m}$ (to point h & j)

$\Delta h_{g.km.UN2} := GWL_{UN2} - Bot_{ftg} = 7.7\text{ m}$ (to point k & m)

$\Delta h_{g.no.UN2} := GWL_{UN2} - Bot_{ftg} + Key_{t.d} = 7.7\text{ m}$ (to point n & o)

$\Delta h_{g.p.UN2} := GWL_{UN2} - FG_{toeUN2} = 6.2\text{ m}$ (to point p*)

$\Delta h_{g.r.UN2} := GWL_{UN2} - UWSEL_{UN2} = 0\text{ m}$ (to point r)

Surcharge

Surcharge on Heel: $S1_{UN2} := 0.0\,\frac{\text{kN}}{\text{m}^2}$

* same as point "a" in this case

Calculate Soil Lateral Pressure Coefficients:

LOAD CASE UN2

For all load cases except seismic, soil loading to be based on At-Rest Condition.
Calculate at-rest pressure coefficient Ko based on Jaky's (1944) equation.

Soil At Rest Static Coefficient: $K_o := \dfrac{1 - \sin(\phi)}{1 + \sin(\beta)} = 0.546$ (Eq. 3-6, USACE EM 1110-2-2502)

Lateral - Driving Force

Static At-Rest:

Surcharge Load: $E_{s1UN2} := S1_{UN2} \cdot K_o \cdot \left(H_w + Key_{h.d}\right) \cdot B \cdot -1 = 0 \cdot kN$

Moment Arm (from bottom of footing): $E_{s1locUN2} := \dfrac{H_w + Key_{h.d}}{2} + Key_{vdist} = 3.75\ m$

Moist Soil Load above GWL: $E_{h1UN2} := \dfrac{\gamma_m \cdot K_o \cdot h_{1UN2}^{\ 2}}{2} \cdot B \cdot -1 = -42.8 \cdot kN$

Moment Arm (from bottom of footing): $E_{h1locUN2} := \dfrac{h_{1UN2}}{3} + h_{2UN2} + Key_{vdist} = 8.63\ m$

Saturated Soil Load below GWL:
(rectangular component) $E_{h2UN2} := \left(\gamma_m \cdot K_o \cdot h_{1UN2}\right) \cdot h_{2UN2} \cdot B \cdot -1 = -327.2 \cdot kN$

Moment Arm (from bottom of footing): $E_{h2locUN2} := \dfrac{h_{2UN2}}{2} + Key_{vdist} = 2.35\ m$

Saturated Soil Load below GWL:
(triangular component) $E_{h2aUN2} := \dfrac{\left(\gamma_{sat} - \gamma_w\right) \cdot K_o \cdot h_{2UN2}^{\ 2}}{2} \cdot B \cdot -1 = -381.3 \cdot kN$

Moment Arm (from bottom of footing): $E_{h2alocUN2} := \dfrac{h_{2UN2}}{3} + Key_{vdist} = 0.57\ m$

Lateral Water Load:

Water Load GWL to Bottom of Key: $H_{h2UN2} := \dfrac{\gamma_w \cdot h_{2UN2}^{\ 2}}{2} \cdot B \cdot -1 = -561.0 \cdot kN$

Moment Arm (from bottom of footing): $H_{h2locUN2} := \dfrac{h_{2UN2}}{3} + Key_{vdist} = 0.57\ m$

$$\Sigma H_{SoildriveUN2} := E_{s1UN2} + E_{h1UN2} + E_{h2UN2} + E_{h2aUN2} + H_{h2UN2} = -1312.3 \cdot kN$$

$$\Sigma M_{LateralSoildriveUN2} := E_{s1UN2} \cdot E_{s1locUN2} + E_{h1UN2} \cdot E_{h1locUN2} + E_{h2UN2} \cdot E_{h2locUN2} \ldots + E_{h2aUN2} \cdot E_{h2alocUN2} + H_{h2UN2} \cdot H_{h2locUN2} = -1672.4\ m \cdot kN$$

Lateral - Resisting Force

Lateral Water Load:

Water Load WSEL to Bottom of Footing: $H_{h6UN2} := \frac{\gamma_w \cdot h_{6UN2}^{\;2}}{2} \cdot B = 63.5 \cdot kN$

Moment Arm (from bot. of toe key): $H_{h6locUN2} := \frac{h_{6UN2}}{3} = 1.20\ m$

Water Load Bot. of Footing to Bot. of H. Key: $H_{h2aUN2} := \left[\left(UWSEL_{UN2} - Bot_{ftg} + Key_{t.d}\right) + h_{2UN2}\right] \cdot \frac{Key_{h.d}}{2} \cdot \gamma_w \cdot B = 270.5 \cdot kN$

Moment Arm (from bot. of toe key): $H_{h2alocUN2} := \frac{Key_{h.d} \cdot \left[2 \cdot \left(UWSEL_{UN2} - Bot_{ftg} + Key_{t.d}\right) + h_{2UN2}\right]}{3\left[h_{2UN2} + \left(UWSEL_{UN2} - Bot_{ftg} + Key_{t.d}\right)\right]} \ldots + Key_{vdist} = -1.58\ m$

Lateral Soil Load:

Moist Soil Load above WSEL: $E_{h7UN2} := \frac{\gamma_m \cdot K_o \cdot h_{7UN2}^{\;2}}{2} B = 0.0 \cdot kN$

Moment Arm (from bot. of toe key): $E_{h7locUN2} := h_{6UN2} + \frac{h_{7UN2}}{3} + Key_{vdist} = 0.60\ m$

Saturated Soil Load below WSEL: (rectangular component) $E_{h8UN2} := \left(\gamma_m \cdot K_o \cdot h_{7UN2}\right) \cdot h_{8UN2} \cdot B = 0.0 \cdot kN$

Moment Arm (from bot. of toe key): $E_{h8locUN2} := \frac{h_{8UN2}}{2} = 0.75\ m$

Saturated Soil Load below WSEL: (triangular component) $E_{h8aUN2} := \frac{\left[\left(\gamma_{sat} - \gamma_w\right) \cdot K_o\right] \cdot h_{8UN2}^{\;2}}{2} \cdot B = 7.5 \cdot kN$

Moment Arm (from bot. of footing): $E_{h8alocUN2} := \frac{h_{8UN2}}{3} = 0.50\ m$

$\Sigma H_{SoilresistUN2} := H_{h6UN2} + H_{h2aUN2} + E_{h7UN2} + E_{h8UN2} + E_{h8aUN2} = 341.5 \cdot kN$

$\Sigma M_{HorizSoilResistUN2} := H_{h6UN2} \cdot H_{h6locUN2} + H_{h2aUN2} \cdot H_{h2alocUN2} + E_{h7UN2} \cdot E_{h7locUN2} \ldots + E_{h8UN2} \cdot E_{h8locUN2} + E_{h8aUN2} \cdot E_{h8alocUN2} = -347.8\ m \cdot kN$

Vertical Force:

UPLIFT: Linear distribution from water at heel to water at toe:

$\Sigma V_{UpliftUN2} := \left[\left(UWSEL_{UN2} - Bot_{ftg} + Key_{t.d}\right) + h_{2UN2}\right] \cdot \frac{b}{2} \cdot \gamma_w \cdot B \cdot -1 = -811.44 \cdot kN$

Moment Arm (from Point O): $V_{UpliftUN2aloc} := \frac{b \cdot \left[2 \cdot h_{2UN2} + \left(UWSEL_{UN2} - Bot_{ftg} + Key_{t.d}\right)\right]}{3\left[h_{2UN2} + \left(UWSEL_{UN2} - Bot_{ftg} + Key_{t.d}\right)\right]} = 4.745\ m$

$\Sigma M_{UpliftUN2} := \Sigma V_{UpliftUN2} \cdot V_{UpliftUN2aloc} = -3849.93 \cdot kN \cdot m$

Weight of soil and water over toe:

Water Above the Top of Footing: $W_{H1UN2} := \gamma_w \cdot h_{5UN2} \cdot L_{ab} \cdot B = 51.45 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E1locUN2} := \frac{L_{ab}}{2} = 1.25\ m$

Soil above top of footing: $W_{E6UN2} := \gamma_b \cdot h_{3UN2} \cdot L_{ab} \cdot B = 0.0 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E6locUN2} := \frac{L_{ab}}{2} = 1.25\ m$

Vertical Load Due to Surcharge: $S_{UN2} := S1_{UN2} \cdot L_{cd} \cdot B = 0 \cdot kN$ $\quad S_{UN2loc} := b - \frac{L_{cd}}{2} = 6.35\ m$

Weight of soil and water over heel:

Moist Soil for sloped grade above top of wall:

Length of sloped portion of soil above top of wall: $L_{E3UN2} := \left(L_{cd} + t_{wb} - t_{wt}\right) = 6.00\ m$

Height of sloped soil above top of wall over heel: $h_{E3locUN2} := \left(L_{E3UN2}\right) \cdot \tan(\beta) = 0.00\ m$

Weight of sloped soil above top of wall: $W_{E3UN2} := \frac{\gamma_m}{2} \cdot h_{E3locUN2} \cdot L_{E3UN2} \cdot B = 0.0 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E3locUN2} := L_{ab} + t_{wt} + \frac{2}{3} \cdot L_{E3UN2} = 7.00\ m$

Moist soil from top of wall to groundwater level:

Height of soil from top of wall and top of GWL: $h_{1UN2} = 2.80\ m$

Length from edge of wall at GWL to edge of heel: $L_{E4UN2} := L_{E3UN2} - \left(h_{1UN2} \cdot S_{batter}\right) = 5.78\ m$

Weight of soil over heel from top of wall to GWL: $W_{E4UN2} := \gamma_m \cdot h_{1UN2} \cdot \frac{\left(L_{E3UN2} + L_{E4UN2}\right)}{2} \cdot B = 329.8 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E4locUN2} := b - \frac{L_{E3UN2}^{\ 2} + L_{E3UN2} \cdot L_{E4UN2} + L_{E4UN2}^{\ 2}}{3\left(L_{E3UN2} + L_{E4UN2}\right)} = 6.05\ m$

Saturated soil from groundwater to top of footing:

Height of soil from GWL to top of heel: $h_{E4UN2} := h_{2UN2} - t_{ftg} - Key_{h.d} = 6.20\ m$

Weight of soil over heel from GWL to top of heel: $W_{E5UN2} := \left(\gamma_{sat}\right) \cdot h_{E4UN2} \cdot \frac{\left(L_{E4UN2} + L_{cd}\right)}{2} \cdot B = 755.2 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E5locUN2} := b - \frac{L_{E4UN2}^{\ 2} + L_{E4UN2} \cdot L_{cd} + L_{cd}^{\ 2}}{3\left(L_{E4UN2} + L_{cd}\right)} = 6.23\ m$

$$\Sigma V_{SoilWaterUN2} := W_{H1UN2} + W_{E6UN2} + W_{E3UN2} + W_{E4UN2} + W_{E5UN2} + S_{UN2} = 1136.5 \cdot kN$$

$$\Sigma M_{VertSoilWaterResistUN2} := W_{H1UN2} \cdot W_{E1locUN2} + W_{E6UN2} \cdot W_{E6locUN2} \cdots + W_{E3UN2} \cdot W_{E3locUN2} + W_{E4UN2} \cdot W_{E4locUN2} + W_{E5UN2} \cdot W_{E5locUN2} + S_{UN2} \cdot S_{UN2loc} = 6766.1\ m \cdot kN$$

THIS PAGE INTENTIONALLY LEFT BLANK
PLEASE GO TO THE NEXT PAGE

STABILITY ASSESSMENT:

LOAD CASE UN2

CHECK SLIDING ALONG HORIZONTAL SLIDING PLANE:

Summation of the vertical forces:

$$\Sigma V_{UN2} := \Sigma V_{conc} + \Sigma V_{SoilWaterUN2} + \Sigma V_{UpliftUN2} = 893.3 \cdot kN$$

Summation of the horizontal forces:

$$\Sigma H_{UN2} := \Sigma H_{SoildriveUN2} + \Sigma H_{SoilresistUN2} = -970.8 \cdot kN$$

Safety Factor for Sliding Horizontal Failure Plane

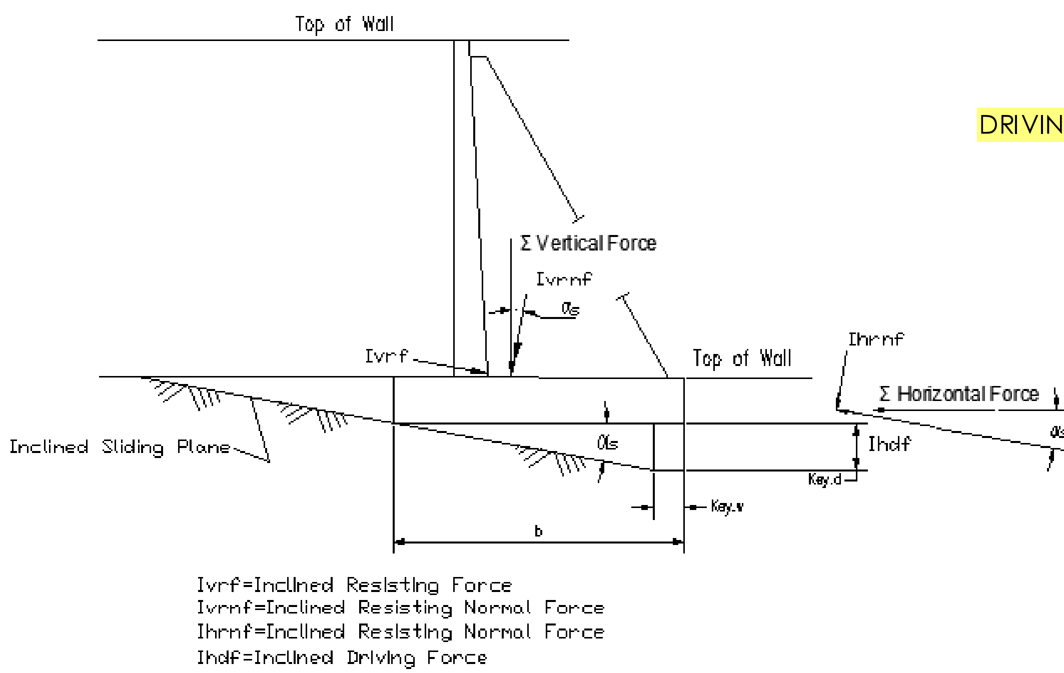
$$FS_{Horiz.SlidingUN2} := \frac{\left|\Sigma V_{UN2}\right| \cdot \tan\left(\phi_{rock} \cdot \frac{\pi}{180}\right)}{\left|\Sigma H_{UN2}\right|} = 0.45$$

$$FS_{Sliding.check1.UN2} := \begin{vmatrix} \text{"OKAY "} & \text{if } FS_{Horiz.SlidingUN2} > FS_{sliding.reqUN2} \\ \text{"NG - key req'"} & \text{otherwise} \end{vmatrix} = \text{"NG - key req'"}$$

CHECK FACTOR OF SAFETY SLIDING WITH KEY (INCLINED SLIDING PLANE):

RESISTING SIDE

DRIVING SIDE



TOE

HEEL

(With properly engineered reinforced concrete Key, horizontal sliding plane thru Toe is protected, critical sliding plane is relocated to the INCLINED SLIDING PLANE FROM HEEL KEY To TOE, Bedrock Mass above this examing plane is mobilized by reinforced concrete key and combined into Structural Wedge.)

Resolve ΣV_{UN2} & ΣH_{UN2}

$$\Sigma V_{InclinedUN2} := \cos(\alpha s) \cdot \left(\left|\Sigma V_{UN2} + V_{rocksection}\right|\right) + \sin(\alpha s) \cdot \left|\Sigma H_{UN2}\right| = 1464.9 \cdot kN$$

$$\Sigma H_{InclinedUN2} := \cos(\alpha s) \cdot \left|\Sigma H_{UN2}\right| - \sin(\alpha s) \cdot \left(\left|\Sigma V_{UN2} + V_{rocksection}\right|\right) = 487.5 \cdot kN$$

Safety Factor for Sliding
Inclined Failure Plane

$$FS_{InclinedISlidingUN2} := \frac{\Sigma V_{InclinedUN2} \cdot \tan(\phi_r)}{\Sigma H_{InclinedUN2}} = 1.34$$

LOAD CASE UN2

$$FS_{Sliding.check2.UN2} := \begin{cases} \text{"OKAY"} & \text{if } FS_{InclinedISlidingUN2} > FS_{sliding.reqUN2} \\ \text{"NG - Revise Structure""} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

CHECK FOUNDATION ECCENTRICITY:

Summation of the resisting moments about the toe:

$$\Sigma M_{resUN2} := \Sigma M_{conc} + \Sigma M_{VertSoilWaterResistUN2} + \Sigma M_{HorizSoilResistUN2} + \Sigma M_{rocksection} = 10616 \cdot kN \cdot m$$

Summation of the overturning moments about the toe:

$$\Sigma M_{oUN2} := \Sigma M_{LateralSoildriveUN2} + \Sigma M_{UpliftUN2} = -5522 \cdot kN \cdot m$$

Total moment: $\Sigma M_{UN2} := \Sigma M_{resUN2} + \Sigma M_{oUN2} = 5094.0\ m \cdot kN$

Normal force to base: $\Sigma V_{InclinedUN2} = 1464.9 \cdot kN$

Inclined Sliding Plane Length: $L_{incline} = 9.6 \cdot m$

Eccentricity (inclined plane): $ex_{UN2} := \frac{L_{incline}}{2} - \frac{\Sigma M_{UN2}}{\Sigma V_{InclinedUN2}} = 1.33\ m$ $\qquad Kern = 1.602\ m$

Eccentricity Check: $e_{check.UN2} := \begin{cases} \text{"Okay"} & \text{if } ex_{UN2} \le Kern \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"Okay"}$

CHECK FOUNDATION BEARING CAPACITY:

Base Section Modulus: $S_b = 15.4\ m^3$

Bearing Pressure Under Toe:

$$\sigma_{ToeUN2} := \begin{cases} \left(\frac{\Sigma V_{InclinedUN2}}{L_{incline} \cdot B} + \frac{\Sigma V_{InclinedUN2} \cdot ex_{UN2}}{S_b} \right) & \text{if } \frac{\Sigma V_{InclinedUN2} \cdot ex_{UN2}}{S_b} \le \frac{\Sigma V_{InclinedUN2}}{L_{incline} \cdot B} \\ \frac{2 \cdot \Sigma V_{InclinedUN2}}{B \cdot 3 \left(\frac{b}{2} - ex_{UN2} \right)} & \text{otherwise} \end{cases} = 278.8 \cdot kPa$$

$$Bearing_{ChecktoeUN2} := \begin{cases} \text{"OKAY"} & \text{if } \sigma_{ToeUN2} < \sigma_{allowUN2} \\ \text{"NG""} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

Bearing Pressure Under Heel:

$$\sigma_{HeelUN2} := \begin{cases} \left(\frac{\Sigma V_{InclinedUN2}}{L_{incline} \cdot B} - \frac{\Sigma V_{InclinedUN2} \cdot ex_{UN2}}{S_b} \right) & \text{if } \frac{\Sigma V_{InclinedUN2} \cdot ex_{UN2}}{S_b} \le \frac{\Sigma V_{InclinedUN2}}{L_{incline} \cdot B} \\ 0 & \text{otherwise} \end{cases} = 26.0 \cdot kPa$$

$$Bearing_{CheckheelUN2} := \left(\begin{cases} \text{"OKAY"} & \text{if } \sigma_{HeelUN2} < \sigma_{allowUN2} \wedge \sigma_{HeelUN2} > 0 \\ \text{"NG - perform cracked base analysis""} & \text{otherwise} \end{cases} \right) = \text{"OKAY"}$$

LOAD CASE UN2

CHECK FLOATATION:

Safety Factor for Floatation:

$$FS_{FloatationUN2} := \frac{\Sigma V_{conc} + \Sigma V_{SoilWaterUN2}}{\left|\Sigma V_{UpliftUN2}\right|} = 2.10$$

$$FS_{Floatation.UN2.check} := \begin{cases} \text{"OKAY "} & \text{if } FS_{FloatationUN2} > FS_{req.UN2.flt} \\ \text{"Revise Structure""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

CHECK OVERTURNING

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.
Assumptions are made in order to compute overturning stablity of indetermine forces on monolith with key;
(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.
(b) The horizontal resisting force acting on the key, P.key, is that required for static equilibrium
(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1

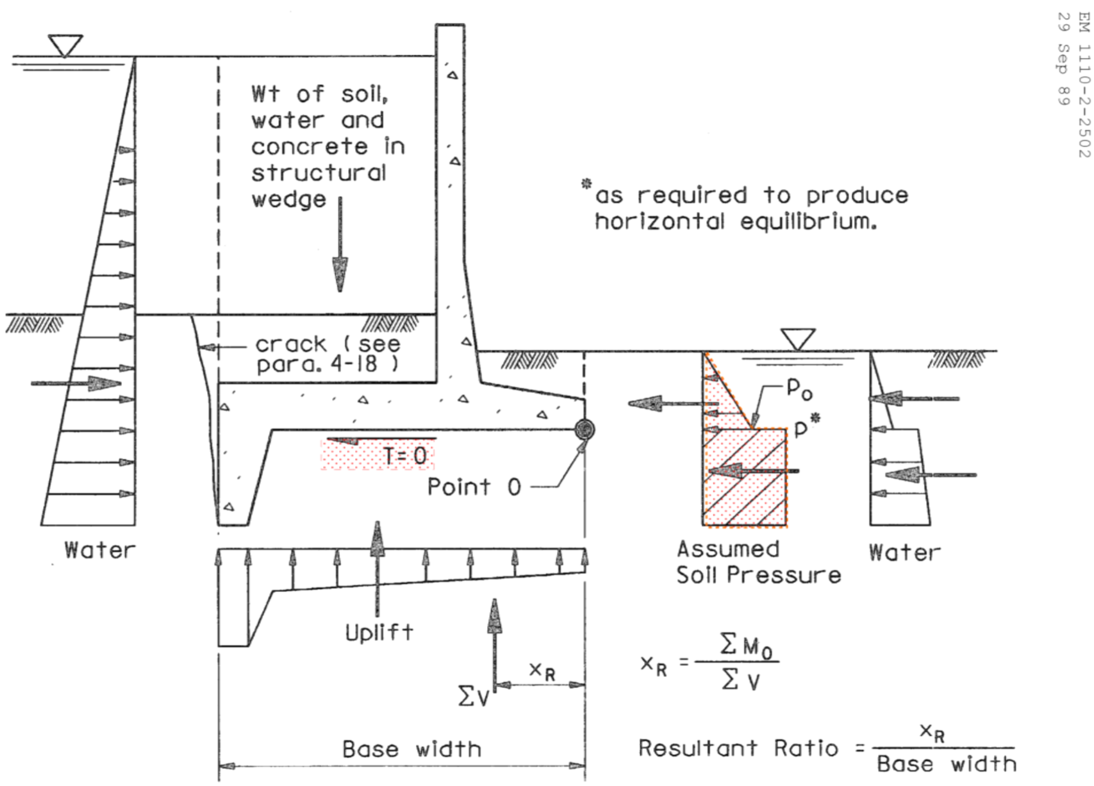


Figure 4-5. Forces for overturning analysis for wall with horizontal base and key

Modify Uplift for Overturning Analysis: **LOAD CASE UN2**

(Uplift is calculated along the concrete/rock contact using the Line of Creep method)

Water Pressure at h: $u_{h.UN2} := \Delta h_{g.hj.UN2} \cdot \gamma_w = 104.86 \cdot kPa$

Water Pressure at o: $u_{o.UN2} := \left(\Delta h_{g.no.UN2} - \frac{\Delta h_{g.r.UN2} \cdot L_{ho.UN2}}{L_{ho.UN2}}\right) \cdot \gamma_w = 75.46 \cdot kPa$

Head loss between point h and o: $\Delta h_{ho.UN2} := \Delta h_{g.r.UN2} \cdot \frac{L_{ho.UN2}}{L_{ho.UN2}} = 0\,m$

Length of concrete base (h -> o): $L_{baseho.UN2} := Key_{h.w} + Key_{h.d} + Key_{hdist} + Key_{t.d} + Key_{t.w} = 12\,m$

Head loss along h -> j: $\Delta h_{hj.UN2} := \Delta h_{ho.UN2} \cdot \frac{Key_{h.w}}{L_{baseho.UN2}} = 0\,m$

Water Pressure at j: $u_{j.UN2} := (\Delta h_{g.hj.UN2} - \Delta h_{hj.UN2}) \cdot \gamma_w = 104.86 \cdot kPa$

Head loss along h -> k: $\Delta h_{hjk.UN2} := \Delta h_{ho.UN2} \cdot \left(\frac{Key_{h.w} + Key_{h.d}}{L_{baseho.UN2}}\right) = 0\,m$

Water Pressure at k: $u_{k.UN2} := (\Delta h_{g.km.UN2} - \Delta h_{hjk.UN2}) \cdot \gamma_w = 75.46 \cdot kPa$

Head loss along h -> m: $\Delta h_{hjkm.UN2} := \Delta h_{ho.UN2} \cdot \left(\frac{Key_{h.w} + Key_{h.d} + Key_{hdist}}{L_{baseho.UN2}}\right) = 0\,m$

Water Pressure at m: $u_{m.UN2} := (\Delta h_{g.km.UN2} - \Delta h_{hjkm.UN2}) \cdot \gamma_w = 75.46 \cdot kPa$

Head loss along h -> n: $\Delta h_{hjkmn.UN2} := \Delta h_{ho.UN2} \cdot \left(\frac{Key_{h.w} + Key_{h.d} + Key_{hdist} + Key_{t.d}}{L_{baseho.UN2}}\right) = 0\,m$

Water Pressure at n: $u_{n.UN2} := (\Delta h_{g.no.UN2} - \Delta h_{hjkmn.UN2}) \cdot \gamma_w = 75.46 \cdot kPa$

Uplift under key at heel: $V_{ulkeyhUN2.OT} := \frac{(u_{h.UN2} + u_{j.UN2}) \cdot Key_{h.w}}{2} \cdot B \cdot -1 = -104.86 \cdot kN$

Moment Arm (from Point O): $V_{ulkeyhUN2loc.OT} := b - \frac{Key_{h.w} \cdot (2 \cdot u_{j.UN2} + u_{h.UN2})}{3 \cdot (u_{j.UN2} + u_{h.UN2})} = 8.5\,m$

Uplift under base: $V_{ulbaseUN2.OT} := \frac{(u_{k.UN2} + u_{m.UN2}) \cdot Key_{hdist}}{2} \cdot B \cdot -1 = -603.68 \cdot kN$

Moment Arm (from Point O): $V_{ulbaseUN2loc.OT} := b - Key_{h.w} - \frac{Key_{hdist} \cdot (2 \cdot u_{m.UN2} + u_{k.UN2})}{3 \cdot (u_{m.UN2} + u_{k.UN2})} = 4\,m$

Uplift under key at toe: $V_{ulkeytUN2.OT} := \frac{(u_{n.UN2} + u_{o.UN2}) \cdot Key_{t.w}}{2} \cdot B \cdot -1 = 0 \cdot kN$

Moment Arm (from Point O): $V_{ulkeytUN2loc.OT} := \frac{Key_{t.w} \cdot (2 \cdot u_{n.UN2} + u_{o.UN2})}{3 \cdot (u_{n.UN2} + u_{o.UN2})} = 0$

$$\Sigma V_{UpliftUN2.OT} := V_{ulkeyhUN2.OT} + V_{ulbaseUN2.OT} + V_{ulkeytUN2.OT} = -709 \cdot kN$$

$$U_{UN2.loc.OT} := \frac{V_{ulkeyhUN2.OT} \cdot V_{ulkeyhUN2loc.OT} + V_{ulbaseUN2.OT} \cdot V_{ulbaseUN2loc.OT} + V_{ulkeytUN2.OT} \cdot V_{ulkeytUN2loc.OT}}{\Sigma V_{UpliftUN2.OT}} = 4.67\,m$$

$$\Sigma M_{UpliftUN2.OT} := \Sigma V_{UpliftUN2.OT} \cdot U_{UN2.loc.OT} = -3306.0 \cdot kN \cdot m$$

Modify Lateral Water Pressure (Resisting) for Overturning Analysis:

(Resisting water pressure is calculated using the Line of Creep method)

Water Load at Key (heel):
$$H_{h2UN2.OT} := \frac{u_{k.UN2} + u_{j.UN2}}{2} \cdot Key_{h.d} B = 270.5 \cdot kN$$

Moment Arm (from Point O):
$$H_{h2locUN2.OT} := \frac{Key_{h.d} \cdot (2 \cdot u_{k.UN2} + u_{j.UN2})}{3(u_{k.UN2} + u_{j.UN2})} + Key_{vdist} = -1.58\ m$$

Water Load at Key (toe):
$$H_{h6UN2.OT} := \frac{u_{o.UN2} \cdot (UWSEL_{UN2} - Bot_{ftg} + Key_{t.d})}{2} \cdot B = 291 \cdot kN$$

Moment Arm (from Point O):
$$H_{h6locUN2.OT} := \frac{UWSEL_{UN2} - Bot_{ftg} + Key_{t.d}}{3} = 2.57\ m$$

$$\Sigma H_{waterresistUN2.OT} := H_{h2UN2.OT} + H_{h6UN2.OT} = 561 \cdot kN$$

$$H_{waterresistlocUN2.OT} := \frac{H_{h2UN2.OT} \cdot H_{h2locUN2.OT} + H_{h6UN2.OT} \cdot H_{h6locUN2.OT}}{\Sigma H_{waterresistUN2.OT}} = 0.567\ m$$

$$\Sigma M_{waterresistUN2.OT} := \Sigma H_{waterresistUN2.OT} \cdot H_{waterresistlocUN2.OT} = 317.9 \cdot kN \cdot m$$

Modify Lateral Soil Loads for Overturning Analysis:

(Lateral soil loads are calculated down to Point O instead of bottom of shear key)

Driving Soil Load (Headwater Side):

Surcharge Load:
$$E_{s1UN2.OT} := S1_{UN2} \cdot K_o \cdot (H_w + Key_{h.d} + Key_{vdist}) \cdot B \cdot -1 = 0 \cdot kN$$

Moment Arm (from Point O):
$$E_{s1locUN2.OT} := \frac{H_w + Key_{h.d} + Key_{vdist}}{2} = 5.25\ m$$

Moist Soil Load above GWL:
$$E_{h1UN2.OT} := \frac{\gamma_m \cdot K_o \cdot h_{1UN2}^{\ 2}}{2} B \cdot -1 = -42.8 \cdot kN$$

Moment Arm (from Point O):
$$E_{h1locUN2.OT} := \frac{h_{1UN2}}{3} + h_{2UN2} + Key_{vdist} = 8.63\ m$$

Saturated Soil Load below GWL:
(rectangular component)
$$E_{h2UN2.OT} := (\gamma_m \cdot K_o \cdot h_{1UN2}) \cdot (h_{2UN2} + Key_{vdist}) \cdot B \cdot -1 = -235.4 \cdot kN$$

Moment Arm (from Point O):
$$E_{h2locUN2.OT} := \frac{h_{2UN2} + Key_{vdist}}{2} = 3.85\ m$$

Saturated Soil Load below GWL:
(triangular component)
$$E_{h2aUN2.OT} := \frac{(\gamma_{sat} - \gamma_w) \cdot K_o \cdot (h_{2UN2} + Key_{vdist})^2}{2} \cdot B \cdot -1 = -197.5 \cdot kN$$

Moment Arm (from Point O):
$$E_{h2alocUN2.OT} := \frac{h_{2UN2} + Key_{vdist}}{3} = 2.57\ m$$

Resisting Soil Load (Tailwater Side):

(Determine resisting soil load based on depth variation between the keys (ie. Key_{vdist}). In case where key at heel is deeper than key at toe (ie. $Key_{vdist} < 0$), resisting soil load (p*) is assumed to produce horizontal equilibrium as per Figure 4-5 above. Resisting soil load (p_o) is neglected.)

Total Driving Force: $\Sigma H_{SoildriveUN2.OT} := E_{s1UN2.OT} + E_{h1UN2.OT} + E_{h2UN2.OT} + E_{h2aUN2.OT} + H_{h2UN2} = -1036.7 \cdot kN$

Total Resisting Force: $\Sigma H_{waterresistUN2.OT} = 561.0 \cdot kN$

Assumed Soil Load p*: $E_{h8UN2a.OT} := (\Sigma H_{SoildriveUN2.OT} + \Sigma H_{waterresistUN2.OT}) \cdot -1 = 475.721 \cdot kN$

Moment Arm (from Point O): $E_{h8UN2a.loc.OT} := \dfrac{Key_{vdist}}{2} = -1.5\,m$

$$E_{h8UN2.OT} := \begin{cases} E_{h8UN2a.OT} & \text{if } Key_{vdist} < 0 \\ \Sigma H_{SoilresistUN2} - H_{h6UN2} - H_{h2aUN2} & \text{otherwise} \end{cases} = 475.721 \cdot kN$$

$$\Sigma M_{SoilresistUN2} := \begin{cases} E_{h8UN2a.OT} \cdot E_{h8UN2a.loc.OT} & \text{if } Key_{vdist} < 0 \\ \Sigma M_{HorizSoilResistUN2} - H_{h6UN2} \cdot H_{h6locUN2} - H_{h2aUN2} \cdot H_{h2alocUN2} & \text{otherwise} \end{cases} = -713.582 \cdot kN \cdot m$$

Sum of Moment about Point O:

$$\Sigma M_{LateraldriveUN2.OT} := E_{s1UN2.OT} \cdot E_{s1locUN2.OT} + E_{h1UN2.OT} \cdot E_{h1locUN2.OT} + E_{h2UN2.OT} \cdot E_{h2locUN2.OT} \cdots + E_{h2aUN2.OT} \cdot E_{h2alocUN2.OT} + H_{h2UN2} \cdot H_{h2locUN2} = -2100.8 \cdot kN \cdot m$$

$$\Sigma M_{LateralresistUN2.OT} := \Sigma M_{waterresistUN2.OT} + \Sigma M_{SoilresistUN2} = -395.7 \cdot kN \cdot m$$

Total moment:

$$\Sigma M_{UN2.OT} := \Sigma M_{conc} + \Sigma M_{VertSoilWaterResistUN2} + \Sigma M_{UpliftUN2.OT} \cdots + \Sigma M_{LateraldriveUN2.OT} + \Sigma M_{LateralresistUN2.OT} = 3523.3 \cdot kN \cdot m$$

Total Vertical Force: $\Sigma V_{UN2.OT} := \Sigma V_{conc} + \Sigma V_{SoilWaterUN2} + \Sigma V_{UplliftUN2.OT} = 996.2 \cdot kN$

Distance X_R: EM 1110-2-2502 Eq.4-1 $X_{R.UN2} := \dfrac{\Sigma M_{UN2.OT}}{\Sigma V_{UN2.OT}} = 3.537\,m$

Overturning Resultant Ratio $Ratio_{UN2.OT} := \dfrac{X_{R.UN2}}{b} = 0.39$

$$Ratio_{UN2.OT.check} := \begin{cases} \text{"OKAY "} & \text{if } Ratio_{UN2.OT} > X_{R.reqUN2} \\ \text{"Revise Structure""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

CHECK FOUNDATION ECCENTRICITY (HORIZONTAL PLANE):

Eccentricity (horizontal plan): $ex_{UN2.OT} := \dfrac{b}{2} - \dfrac{\Sigma M_{UN2.OT}}{\Sigma V_{UN2.OT}} = 0.96\,m$ $Kern_{OT} = 1.5\,m$

Eccentricity Check:

$$e_{check.UN2.OT} := \begin{cases} \text{"Okay"} & \text{if } ex_{UN2} \le Kern_{OT} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"Okay"}$$

LOAD CASE UN2

CHECK FOUNDATION BEARING CAPACITY (HORIZONTAL PLANE):

Base Section Modulus: $S_{b.OT} = 13.5\,m^3$

Bearing Pressure Under Toe:

$$\sigma_{ToeUN2.OT} := \begin{cases} \left(\dfrac{\Sigma V_{UN2.OT}}{b \cdot B} + \dfrac{\Sigma V_{UN2.OT} \cdot ex_{UN2.OT}}{S_{b.OT}}\right) & \text{if } \dfrac{\Sigma V_{UN2.OT}}{b \cdot B} \ge \dfrac{\Sigma V_{UN2.OT} \cdot ex_{UN2.OT}}{S_{b.OT}} \\ \dfrac{2 \cdot \Sigma V_{UN2.OT}}{B \cdot 3\left(\dfrac{b}{2} - ex_{UN2.OT}\right)} & \text{otherwise} \end{cases} = 181.8 \cdot kPa$$

$$Bearing_{ChecktoeUN2.OT} := \begin{cases} \text{"OKAY "} & \text{if } \sigma_{ToeUN2.OT} < \sigma_{allowUN2} \\ \text{"NG - for reference only""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

Bearing Pressure Under Heel:

$$\sigma_{HeelUN2.OT} := \begin{cases} \left(\dfrac{\Sigma V_{UN2.OT}}{b \cdot B} - \dfrac{\Sigma V_{UN2.OT} \cdot ex_{UN2.OT}}{S_{b.OT}}\right) & \text{if } \dfrac{\Sigma V_{UN2.OT}}{b \cdot B} \ge \dfrac{\Sigma V_{UN2.OT} \cdot ex_{UN2.OT}}{S_{b.OT}} \\ 0 & \text{otherwise} \end{cases} = 39.6 \cdot kPa$$

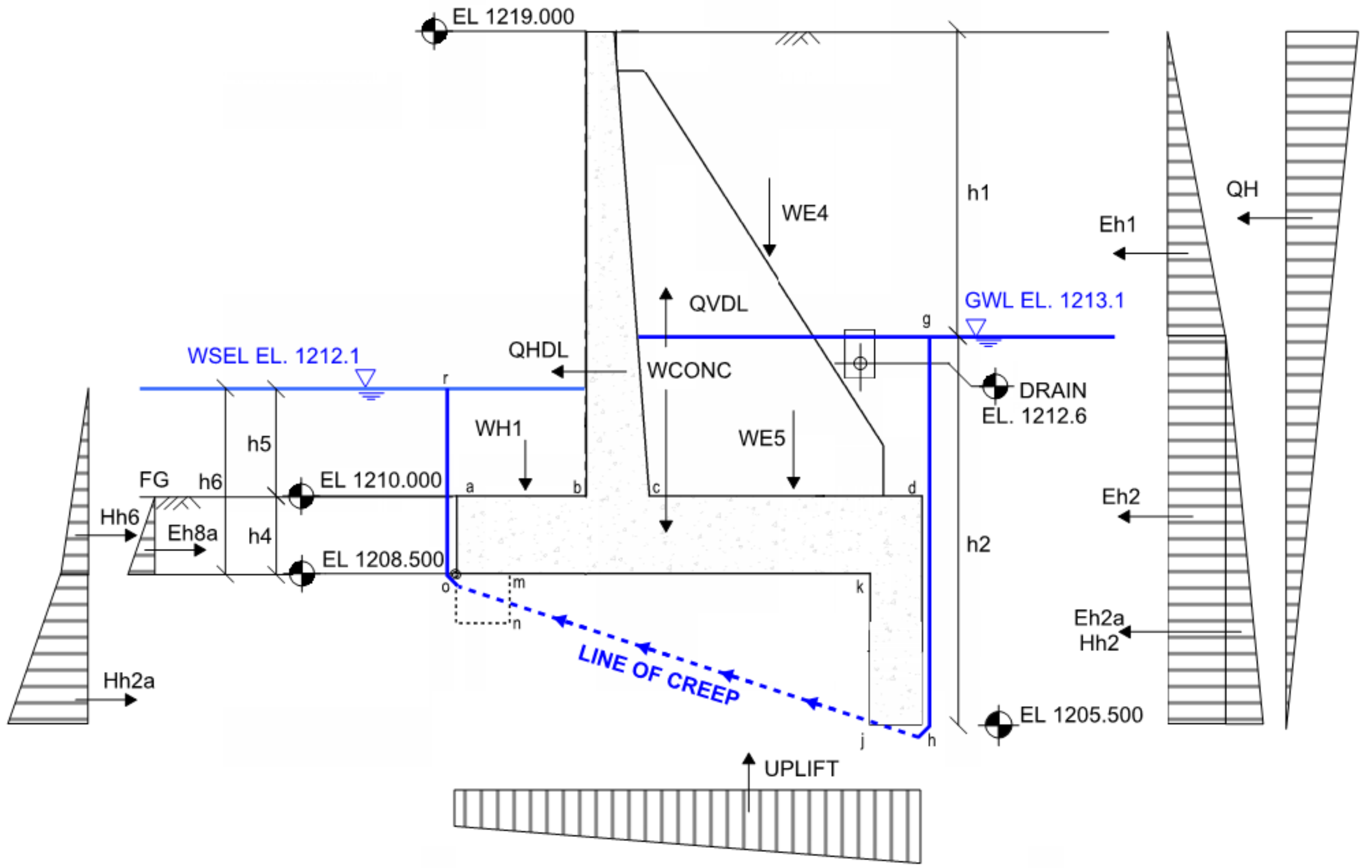
$$Bearing_{CheckheelUN2.OT} := \left(\begin{cases} \text{"OKAY "} & \text{if } \sigma_{HeelUN2.OT} < \sigma_{allowUN2} \wedge \sigma_{HeelUN2.OT} > 0 \\ \text{"NG - for reference only""} & \text{otherwise} \end{cases}\right) = \text{"OKAY "}$$

SUMMARY OF STABILITY ASSESSMENT:

LOAD CASE UN2

Sliding Factor of Safety: (Horizontal Plane - Ref only)	$FS_{Horiz.SlidingUN2} = 0.45$	$FS_{Sliding.check1.UN2}$ = "NG - key req""
Sliding Factor of Safety: (Inclined Plane)	$FS_{InclinedlSlidingUN2} = 1.34$	$FS_{Sliding.check2.UN2}$ = "OKAY "
Eccentricity: (Inclined Plane)	$ex_{UN2} = 1.33\ m$	$e_{check.UN2}$ = "Okay"
Bearing Pressure At Heel: (Inclined Plane)	$\sigma_{HeelUN2} = 26 \cdot kPa$	$Bearing_{CheckheelUN2}$ = "OKAY "
Bearing Pressure At Toe: (Inclined Plane)	$\sigma_{ToeUN2} = 279 \cdot kPa$	$Bearing_{ChecktoeUN2}$ = "OKAY "
Flotation Factor of Safety (horizontal plane)	$FS_{FloatationUN2} = 2.1$	$FS_{Floatation.UN2.check}$ = "OKAY "
Overturning Resultant Ratio: (horizontal plane)	$Ratio_{UN2.OT} = 0.39$	$Ratio_{UN2.OT.check}$ = "OKAY "
Eccentricity: (horizontal plane - Ref only)	$ex_{UN2.OT} = 0.96\ m$	$e_{check.UN2.OT}$ = "Okay"
Bearing Pressure At Heel: (horizontal plane - Ref only)	$\sigma_{HeelUN2.OT} = 40 \cdot kPa$	$Bearing_{CheckheelUN2.OT}$ = "OKAY "
Bearing Pressure At Toe: (horizontal plane - Ref only)	$\sigma_{ToeUN2.OT} = 182 \cdot kPa$	$Bearing_{ChecktoeUN2.OT}$ = "OKAY "

LOAD CASE E1 - SEISMIC LOADING



E1 DESIGN CASE

LOAD CASE E1 ACCEPTANCE PARAMETERS

FS sliding:

Extreme (E) loading) 1.0 (without cohesion, seismic (Table 3-3, USACE EM 1110-2-2100)

Resultant Location:

Extremem (E) Inside middle half ~75% base in compression

Required Factor of Safety for Sliding: $FS_{sliding.reqE1} := 1.0$ (Without Cohesion)

Allowable rock bearing pressure: $\sigma_{allowE1} := 1740kPa$ (Section 5.2, Design Criteria EM 1110-2-2100 Section 3-10)

Overturning Required Resultant Ratio: $X_{R.reqE1} := 0.25$ (EM 1110-2-2502, Figure 4-4)

Required Factor of Safety for Floatation $FS_{req.E1.flt} := 1.1$

SOIL HEIGHTS and Water Levels:

LOAD CASE E1

Heel Conditions:

Groundwater Elevation at Heel: $GWL_{E1} := 1213.1\text{m}$

Distance from Finish Grade to Groundwater at Heel: $h_{1E1} := \left[T_w - GWL_{E1} + \left(L_{cd} + t_{wb} - t_{wt}\right)\cdot\tan(\beta)\right] = 5.90\text{ m}$

Distance from Water Surface to Bottom of Footing at Heel: $h_{2E1} := GWL_{E1} - Bot_{ftg} + Key_{h.d} = 7.60\text{ m}$

Toe Conditions:

Water Surface Elevation at Toe: $WSEL_{E1} := 1212.1\text{m}$

Water Surface Elevation at Toe for Uplift: $UWSEL_{E1} := 1212.1\cdot\text{m}$

Finish Grade at Toe providing lateral resistance: $FG_{toeE1} := 1210.0\cdot\text{m}$

Soil Depth Above top of footing: $h_{3aE1} := FG_{toeE1} - Top_{ftg} = 0\text{ m}$

$$h_{3E1} := \begin{cases} h_{3aE1} & \text{if } FG_{toeE1} - Top_{ftg} \ge 0 \\ 0 & \text{otherwise} \end{cases} = 0$$

Resisting Fill at Toe: $h_{4E1} := FG_{toeE1} - Bot_{ftg} + Key_{t.d} = 1.50\text{ m}$

Distance from Water Level to Top of Footing at Toe: $h_{5E1} := WSEL_{E1} - Top_{ftg} = 2.10\text{ m}$

Distance from Water Surface to Bottom of Footing at Toe: $h_{6E1} := WSEL_{E1} - Bot_{ftg} + Key_{t.d} = 3.60\text{ m}$

Soil Depth Above WSEL: $h_{7aE1} := FG_{toeE1} - WSEL_{E1} = -2.1\text{ m}$

$$h_{7E1} := \begin{cases} h_{7aE1} & \text{if } FG_{toeE1} - WSEL_{E1} \ge 0 \\ 0 & \text{otherwise} \end{cases} = 0$$

Soil Depth Below WSEL:

$$h_{8E1} := \begin{cases} WSEL_{E1} - Bot_{ftg} + Key_{t.d} & \text{if } FG_{toeE1} - WSEL_{E1} \ge 0 \\ h_{4E1} & \text{otherwise} \end{cases} = 1.5$$

For Line of Creep Method: $L_{ho.E1} := \sqrt{b^2 + \left(Key_{h.d} - Key_{t.d}\right)^2} = 9.487\text{ m}$

Head Loss from Point g:

$\Delta h_{g.hj.E1} := h_{2E1} = 7.6\text{ m}$ (to point h & j)

$\Delta h_{g.km.E1} := GWL_{E1} - Bot_{ftg} = 4.6\text{ m}$ (to point k & m)

$\Delta h_{g.no.E1} := GWL_{E1} - Bot_{ftg} + Key_{t.d} = 4.6\text{ m}$ (to point n & o)

$\Delta h_{g.p.E1} := GWL_{E1} - FG_{toeE1} = 3.1\text{ m}$ (to point p*)

$\Delta h_{g.r.E1} := GWL_{E1} - UWSEL_{E1} = 1\text{ m}$ (to point r)

Surcharge

Surcharge on Heel: $S1_{E1} := 0.0\dfrac{\text{kN}}{\text{m}^2}$

* same as point "a" in this case

Calculate Soil Lateral Pressure Coefficients:

LOAD CASE E1

Calculate at-rest pressure coefficient K_o based on Jaky's (1944) equation.

Soil At Rest Static Coefficient:
(apply to resisting soil loads)

$$K_o := \frac{1 - \sin(\phi)}{1 + \sin(\beta)} = 0.546$$

(Eq. 3-6, USACE EM 1110-2-2502)

Calculate active pressure coefficient K_A based on Coulumb equations.

Determine Slope of Active Wedge: (cohesionless backfill with water table)

$$c_1 := 2 \cdot \tan(\phi) = 1.019 \qquad c_2 := 1 - \tan(\phi) \cdot \tan(\beta) - \frac{\tan(\beta)}{\tan(\phi)} = 1$$

(Eq. G-14 / G-15, USACE EM 1110-2-2100)

$$\alpha := \operatorname{atan}\left(\frac{c_1 + \sqrt{c_1^{\,2} + 4 \cdot c_2}}{2}\right) = 1.021 \qquad \alpha_{deg} := \alpha \cdot \frac{180}{\pi} = 58.5$$

degrees (Eq. G-13, USACE EM 1110-2-2100)

Soil Active Coefficient above GWL:

$$K_{Aagwt} := \left(\frac{1 - \tan(\phi) \cdot \cot(\alpha)}{1 + \tan(\phi) \cdot \tan(\alpha)}\right) \cdot \left(\frac{\tan(\alpha)}{\tan(\alpha) - \tan(\beta)}\right) = 0.376$$

Soil Active Coefficient below GWL:

$$K_{Abgwt} := \frac{1 - \tan(\phi) \cdot \cot(\alpha)}{1 + \tan(\phi) \cdot \tan(\alpha)} \cdot \left[1 + \left(\frac{\tan(\alpha)}{\tan(\alpha) - \tan(\beta)} - 1\right) \cdot \left(\frac{\gamma_m}{\gamma_{sat} - \gamma_w}\right)\right] = 0.376$$

(Eq. G-29, USACE EM 1110-2-2100)

Lateral - Driving Force

Static Copmonent : Active Pressure:

Surcharge Load:

$$E_{s1E1} := S1_{E1} \cdot K_{Aagwt} \cdot \left(H_w + Key_{h.d}\right) \cdot B \cdot -1 = 0 \cdot kN$$

Moment Arm (from bottom of footing):

$$E_{s1locE1} := \frac{H_w + Key_{h.d}}{2} + Key_{vdist} = 3.75\ m$$

Moist Soil Load above GWL:

$$E_{h1E1} := \frac{\gamma_m \cdot K_{Aagwt} \cdot h_{1E1}^{\,2}}{2} \cdot B \cdot -1 = -130.7 \cdot kN$$

Moment Arm (from bottom of footing):

$$E_{h1locE1} := \frac{h_{1E1}}{3} + h_{2E1} + Key_{vdist} = 6.57\ m$$

Saturated Soil Load below GWL:
(rectangular component)

$$E_{h2E1} := \left(\gamma_m \cdot K_{Abgwt} \cdot h_{1E1}\right) \cdot h_{2E1} \cdot B \cdot -1 = -336.8 \cdot kN$$

Moment Arm (from bottom of footing):

$$E_{h2locE1} := \frac{h_{2E1}}{2} + Key_{vdist} = 0.80\ m$$

Saturated Soil Load below GWL:
(triangular component)

$$E_{h2aE1} := \frac{\left(\gamma_{sat} - \gamma_w\right) \cdot K_{Abgwt} \cdot h_{2E1}^{\,2}}{2} \cdot B \cdot -1 = -132.3 \cdot kN$$

Moment Arm (from bottom of footing):

$$E_{h2alocE1} := \frac{h_{2E1}}{3} + Key_{vdist} = -0.47\ m$$

Lateral Water Load:

Water Load GWL to Bottom of Key

$$H_{h2E1} := \frac{\gamma_w \cdot h_{2E1}^{\,2}}{2} \cdot B \cdot -1 = -283.0 \cdot kN$$

Moment Arm (from bottom of footing):

$$H_{h2locE1} := \frac{h_{2E1}}{3} + Key_{vdist} = -0.47\ m$$

$$\Sigma H_{SoildriveE1} := E_{s1E1} + E_{h1E1} + E_{h2E1} + E_{h2aE1} + H_{h2E1} = -882.8 \cdot kN$$

$$\Sigma M_{LateralSoildriveE1} := E_{s1E1} \cdot E_{s1locE1} + E_{h1E1} \cdot E_{h1locE1} + E_{h2E1} \cdot E_{h2locE1} \cdots + E_{h2aE1} \cdot E_{h2alocE1} + H_{h2E1} \cdot H_{h2locE1} = -934.0\ m \cdot kN$$

Lateral - Resisting Force

LOAD CASE E1

Note: **Due to the relatively shallow depth of resisting soil/rock, a conservative apporach using at-rest coefficient in lieu of a passive wedge is used to calculate resisting forces.**

Lateral Water Load:

Water Load WSEL to Bottom of Footing: $H_{h6E1} := H_{h6U1} = 63.5 \cdot kN$

Moment Arm (from bot. of toe key): $H_{h6locE1} := H_{h6locU1} = 1.20\ m$

Water Load Bot. of Footing to Bot. of H. Key: $H_{h2aE1} := \left[\left(UWSEL_{E1} - Bot_{ftg} + Key_{t.d}\right) + h_{2E1}\right] \cdot \frac{Key_{h.d}}{2} \cdot \gamma_w \cdot B = 164.6 \cdot kN$

Moment Arm (from bot. of toe key):

$$H_{h2alocE1} := \frac{Key_{h.d} \cdot \left[2 \cdot \left(UWSEL_{E1} - Bot_{ftg} + Key_{t.d}\right) + h_{2E1}\right]}{3\left[h_{2E1} + \left(UWSEL_{E1} - Bot_{ftg} + Key_{t.d}\right)\right]} \ldots = -1.68\ m$$
$$+ Key_{vdist}$$

Lateral Soil Load:

Moist Soil Load above WSEL: $E_{h7E1} := \frac{\gamma_m \cdot K_o \cdot h_{7E1}^{\ 2}}{2} \cdot B = 0.0 \cdot kN$

Moment Arm (from bot. of toe key): $E_{h7locE1} := h_{6E1} + \frac{h_{7E1}}{3} + Key_{vdist} = 0.60\ m$

Saturated Soil Load below WSEL: (rectangular component) $E_{h8E1} := \left(\gamma_m \cdot K_o \cdot h_{7E1}\right) \cdot h_{8E1} \cdot B = 0.0 \cdot kN$

Moment Arm (from bot. of toe key): $E_{h8locE1} := \frac{h_{8E1}}{2} = 0.75\ m$

Saturated Soil Load below WSEL: (triangular component) $E_{h8aE1} := \frac{\left[\left(\gamma_{sat} - \gamma_w\right) \cdot K_o\right] \cdot h_{8E1}^{\ 2}}{2} \cdot B = 7.5 \cdot kN$

Moment Arm (from bot. of footing): $E_{h8alocE1} := \frac{h_{8E1}}{3} = 0.50\ m$

$$\Sigma H_{SoilresistE1} := H_{h6E1} + H_{h2aE1} + E_{h7E1} + E_{h8E1} + E_{h8aE1} = 235.6 \cdot kN$$

$$\Sigma M_{HorizSoilResistE1} := H_{h6E1} \cdot H_{h6locE1} + H_{h2aE1} \cdot H_{h2alocE1} + E_{h7E1} \cdot E_{h7locE1} \ldots = -196.4\ m \cdot kN$$
$$+ E_{h8E1} \cdot E_{h8locE1} + E_{h8aE1} \cdot E_{h8alocE1}$$

Vertical Force:

UPLIFT: Linear distribution from water at heel to water at toe:

$$\Sigma V_{UpliftE1} := \left[\left(UWSEL_{E1} - Bot_{ftg} + Key_{t.d}\right) + h_{2E1}\right] \cdot \frac{b}{2} \cdot \gamma_w \cdot B \cdot -1 = -493.92 \cdot kN$$

Moment Arm (from Point O):

$$V_{UpliftE1aloc} := \frac{b \cdot \left[2 \cdot h_{2E1} + \left(UWSEL_{E1} - Bot_{ftg} + Key_{t.d}\right)\right]}{3\left[h_{2E1} + \left(UWSEL_{E1} - Bot_{ftg} + Key_{t.d}\right)\right]} = 5.036\ m$$

$$\Sigma M_{UpliftE1} := \Sigma V_{UpliftE1} \cdot V_{UpliftE1aloc} = -2487.24 \cdot kN \cdot m$$

Weight of soil and water over toe:

Water Above the Top of Footing: $W_{H1E1} := \gamma_w \cdot h_{5E1} \cdot L_{ab} \cdot B = 51.45 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E1locE1} := \frac{L_{ab}}{2} = 1.25\ m$

Soil above top of footing: $W_{E6E1} := \gamma_b \cdot h_{3E1} \cdot L_{ab} \cdot B = 0.0 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E6locE1} := \frac{L_{ab}}{2} = 1.25\ m$

Vertical Load Due to Surcharge: $S_{E1} := S1_{E1} \cdot L_{cd} \cdot B = 0 \cdot kN$ $\quad S_{E1loc} := b - \frac{L_{cd}}{2} = 6.35\ m$

Weight of soil and water over heel:

Moist Soil for sloped grade above top of wall:

Length of sloped portion of soil above top of wall: $L_{E3E1} := \left(L_{cd} + t_{wb} - t_{wt}\right) = 6.00\ m$

Height of sloped soil above top of wall over heel: $h_{E3locE1} := \left(L_{E3E1}\right) \cdot \tan(\beta) = 0.00\ m$

Weight of sloped soil above top of wall: $W_{E3E1} := \frac{\gamma_m}{2} \cdot h_{E3locE1} \cdot L_{E3E1} \cdot B = 0.0 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E3locE1} := L_{ab} + t_{wt} + \frac{2}{3} \cdot L_{E3E1} = 7.00\ m$

Moist soil from top of wall to groundwater level:

Height of soil from top of wall and top of GWL: $h_{1E1} = 5.90\ m$

Length from edge of wall at GWL to edge of heel: $L_{E4E1} := L_{E3E1} - \left(h_{1E1} \cdot S_{batter}\right) = 5.54\ m$

Weight of soil over heel from top of wall to GWL: $W_{E4E1} := \gamma_m \cdot h_{1E1} \cdot \frac{\left(L_{E3E1} + L_{E4E1}\right)}{2} \cdot B = 680.7 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E4locE1} := b - \frac{L_{E3E1}^2 + L_{E3E1} \cdot L_{E4U1} + L_{E4E1}^2}{3\left(L_{E3E1} + L_{E4E1}\right)} = 6.11\ m$

Saturated soil from groundwater to top of footing:

Height of soil from GWL to top of heel: $h_{E4E1} := h_{2E1} - t_{ftg} - Key_{h.d} = 3.10\ m$

Weight of soil over heel from GWL to top of heel: $W_{E5E1} := \left(\gamma_{sat}\right) \cdot h_{E4E1} \cdot \frac{\left(L_{E4E1} + L_{cd}\right)}{2} \cdot B = 369.3 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E5locE1} := b - \frac{L_{E4E1}^2 + L_{E4E1} \cdot L_{cd} + L_{cd}^2}{3\left(L_{E4E1} + L_{cd}\right)} = 6.29\ m$

$$\Sigma V_{SoilWaterE1} := W_{H1E1} + W_{E6E1} + W_{E3E1} + W_{E4E1} + W_{E5E1} + S_{E1} = 1101.4 \cdot kN$$

$$\Sigma M_{VertSoilWaterResistE1} := W_{H1E1} \cdot W_{E1locE1} + W_{E6E1} \cdot W_{E6locE1} \cdots + W_{E3E1} \cdot W_{E3locE1} + W_{E4E1} \cdot W_{E4locE1} + W_{E5E1} \cdot W_{E5locE1} + S_{E1} \cdot S_{E1loc} = 6549.7\ m \cdot kN$$

SESIMIC ANALYSIS:

LOAD CASE E1

Seismic coefficient will be applied to dead loads to calculate seismic force and force is applied at center of gravity of the mass. Vertical and Horizontal loads are applied in the "destabilizing direction"

SEISMIC PARAMETERS:

Peak Ground Acceleration for Seismic Load $PGA_{Horiz} := 0.26$ $PGA_{Vert} := 0.56 \cdot PGA_{Horiz} = 0.146$ (Section 7.9, Design Criteria)

In accordance with USACE EM 1110-2-2100 Section 4-7.b, consider 2/3 PGA as seismic coefficient for stabilitiy.

Horizontal Seismic coefficient for stabilty: $K_{hE1} := \frac{2}{3} PGA_{Horiz} = 0.173$

Vertical Seismic coefficient for stabilty: $K_{vE1} := \frac{2}{3} PGA_{Vert} = 0.097$

SEISMIC ACCELERATION OF RIGID MASSES (Q_D):

Vertical Load Application:

$\Sigma V_{conc} = 568.3 \cdot kN$

$Q_{v.conc} := \Sigma V_{conc} \cdot K_{vE1} \cdot -1 = -55.2 \cdot kN$ (assume acting upwards for adverse sliding effect)

Moment arm for siesmic load application (From Toe): $H_{cent} = 4.504\,m$

$M_{Qv.conc} := Q_{v.conc} \cdot H_{cent} = -248.5 \cdot kN \cdot m$

Lateral Load Application:

$Q_{h.conc} := \Sigma V_{conc} \cdot K_{hE1} \cdot -1 = -98.5 \cdot kN$

Moment arm for siesmic load application (Above Base of Footing): $V_{Cent} = 1.941\,m$

$M_{Q.conc} := Q_{h.conc} \cdot V_{Cent} = -191.2 \cdot kN \cdot m$

SEISMIC ACCELERATION OF SOIL WEDGE + WATER (Q_{EH}):

Vertical Load Application:

$\Sigma V_{SoilWaterE1} = 1101.4 \cdot kN$

$Q_{v.SoilWaterE1} := \Sigma V_{SoilWaterE1} \cdot K_{vE1} \cdot -1 = -106.9 \cdot kN$ (assume acting upwards for adverse sliding effect)

Moment arm for siesmic load application (From Toe): $e_{QE1} := \dfrac{\Sigma M_{VertSoilWaterResistE1}}{\Sigma V_{SoilWaterE1}} = 5.947\,m$

$M_{Qv.SoilWaterE1} := Q_{v.SoilWaterE1} \cdot e_{QE1} = -635.8 \cdot kN \cdot m$

Lateral Load Application:

Seismic soil load is calculated based on Mononobe-Okabe method to determine combined static and dynamic coefficient (K_{AE}). Coulomb's active component (K_A) is subtracted from K_{AE} to obtain the seismic coefficient (ΔK_{AE}) for dynamic component of soil force.

Glacial Till Internal Friction (radians): $\phi = 0.471$

Seismic Inertia Angle (radians): $\psi := \operatorname{atan}\left(\dfrac{K_{hE1}}{1 - K_{vE1}}\right) = 0.190$

Inclination of batter (radians): $\theta := 0.00$ assuming zero is conservative

Slope of retained ground surface: $\beta = 0.00$

$$K_{AE} := \frac{\cos(\phi - \psi - \theta) \cdot \cos(\phi - \psi - \theta)}{\cos(\psi) \cdot \cos(\theta) \cdot \cos(\theta)\, \cos(\psi + \theta) \cdot \left(1 + \sqrt{\dfrac{\sin(\phi)\, \sin(\phi - \psi - \beta)}{\cos(\beta - \theta) \cdot \cos(\psi + \theta)}}\right)^2} = 0.519$$

$\Delta K_{AE} := K_{AE} - K_{Abgwt} = 0.143$

Dynamic component of active seismic wedge:

$$Q_{h.SoilWaterE1} := \Delta K_{AE} \left[\frac{\gamma_m \cdot \left(H_w + Key_{h.d}\right)^2}{2 \cdot (\tan(\alpha) - \tan(\beta))} + \frac{\left(\gamma_{sat} - \gamma_m\right) \cdot h_{2E1}^{\;2}}{2 \cdot \tan(\alpha)}\right] \cdot B \cdot -1 = -164.8 \cdot kN$$

(Eq. G-64, USACE EM 1110-2-2100)

Moment arm for siesmic load application (About Point O): $Q_{h.SoilWaterlocE1} := \frac{2}{3} \cdot \left(H_w + Key_{h.d}\right) + Key_{vdist} = 6.00\,m$

$M_{Q.h.SoilWaterE1} := Q_{h.SoilWaterE1} \cdot Q_{h.SoilWaterlocE1} = -988.5 \cdot kN \cdot m$

STABILITY ASSESSMENT:

LOAD CASE E1

CHECK SLIDING ALONG HORIZONTAL SLIDING PLANE:

Summation of the vertical forces: $\Sigma V_{E1} := \Sigma V_{conc} + \Sigma V_{SoilWaterE1} + \Sigma V_{UpliftE1} + Q_{v.conc} + Q_{v.SoilWaterE1} = 1013.7 \cdot kN$

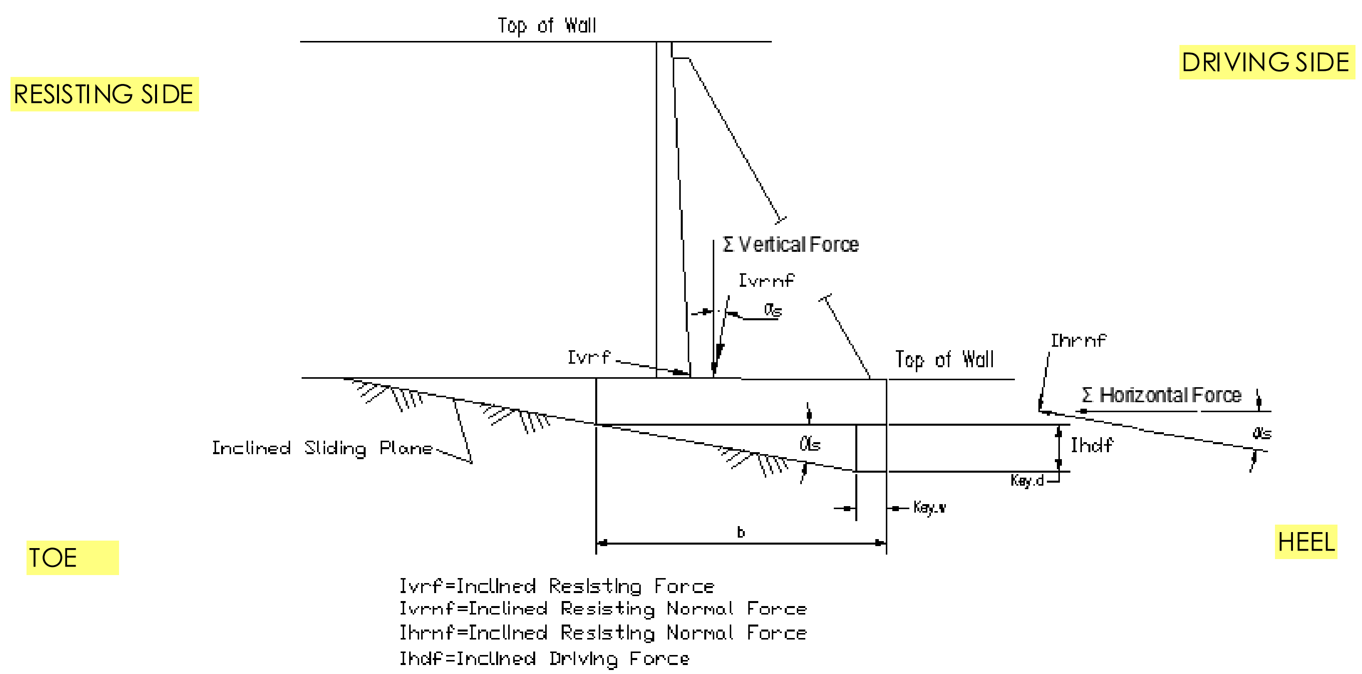
Summation of the horizontal forces: $\Sigma H_{E1} := \Sigma H_{SoildriveE1} + Q_{h.conc} + Q_{h.SoilWaterE1} + \Sigma H_{SoilresistE1} = -910.4 \cdot kN$

Safety Factor for Sliding Horizontal Failure Plane

$$FS_{Horiz.SlidingE1} := \frac{\left|\Sigma V_{E1}\right| \cdot \tan\left(\phi_{rock} \cdot \frac{\pi}{180}\right)}{\left|\Sigma H_{E1}\right|} = 0.54$$

$$FS_{Sliding.check1.E1} := \begin{vmatrix} \text{"OKAY " if } FS_{Horiz.SlidingE1} > FS_{sliding.reqE1} \\ \text{"NG - key req"" otherwise} \end{vmatrix} = \text{"NG - key req""}$$

CHECK FACTOR OF SAFETY SLIDING WITH KEY (INCLINED SLIDING PLANE):



(With properly engineered reinforced concrete Key, horizontal sliding plane thru Toe is protected, critical sliding plane is relocated to the INCLINED SLIDING PLANE FROM HEEL KEY To TOE, Bedrock Mass above this examing plane is mobilized by reinforced concrete key and combined into Structural Wedge.)

Resolve ΣV_{E1} & ΣH_{E1}

$$\Sigma V_{InclinedE1} := \cos(\alpha s) \cdot \left(\left|\Sigma V_{E1} + V_{rocksection}\right|\right) + \sin(\alpha s) \cdot \left|\Sigma H_{E1}\right| = 1556.4 \cdot kN$$

$$\Sigma H_{InclinedE1} := \cos(\alpha s) \cdot \left|\Sigma H_{E1}\right| - \sin(\alpha s) \cdot \left(\left|\Sigma V_{E1} + V_{rocksection}\right|\right) = 388.7 \cdot kN$$

Safety Factor for Sliding Inclined Failure Plane

$$FS_{InclinedISlidingE1} := \frac{\Sigma V_{InclinedE1} \cdot \tan(\phi_r)}{\Sigma H_{InclinedE1}} = 1.78$$

$$FS_{Sliding.check2.E1} := \begin{vmatrix} \text{"OKAY " if } FS_{InclinedISlidingE1} > FS_{sliding.reqE1} \\ \text{"NG"" otherwise} \end{vmatrix} = \text{"OKAY "}$$

CHECK FOUNDATION ECCENTRICITY:

LOAD CASE E1

(Vertical seismic loads from concrete, soil and water are assumed acting downwards for adverse bearing effect)

Summation of the vertical forces: $\Sigma V_{seisE1} := \Sigma V_{conc} + \Sigma V_{SoilWaterE1} + \Sigma V_{UpliftE1} - Q_{v.conc} - Q_{v.SoilWaterE1} = 1337.8 \cdot kN$

Summation of the horizontal forces: $\Sigma H_{seisE1} := \Sigma H_{E1} = -910.4 \cdot kN$

Resolve ΣV_{seisE1} & ΣH_{seisE1}

$$\Sigma V_{InclinedseisE1} := \cos(\alpha s) \cdot \left(\left| \Sigma V_{seisE1} + V_{rocksection} \right| \right) + \sin(\alpha s) \cdot \left| \Sigma H_{seisE1} \right| = 1859.9 \cdot kN$$

$$\Sigma H_{InclinedseisE1} := \cos(\alpha s) \cdot \left| \Sigma H_{seisE1} \right| - \sin(\alpha s) \cdot \left(\left| \Sigma V_{seisE1} + V_{rocksection} \right| \right) = 274.9 \cdot kN$$

Summation of the resisting moments about the toe:

$$\Sigma M_{resE1} := \Sigma M_{conc} + \Sigma M_{VertSoilWaterResistE1} + \Sigma M_{HorizSoilResistE1} + \Sigma M_{rocksection} = 10551 \cdot kN \cdot m$$

Summation of seismic moments about the toe:

$$\Sigma M_{seisE1} := -M_{Qv.conc} + M_{Q.conc} - M_{Qv.SoilWaterE1} + M_{Q.h.SoilWaterE1} = -296 \cdot kN \cdot m$$

Summation of the overturning moments about the toe:

$$\Sigma M_{oE1} := \Sigma M_{LateralSoildriveE1} + \Sigma M_{UpliftE1} = -3421 \cdot kN \cdot m$$

Total moment: $\Sigma M_{E1} := \Sigma M_{resE1} + \Sigma M_{seisE1} + \Sigma M_{oE1} = 6834.5 \cdot kN \cdot m$

Normal force to base: $\Sigma V_{InclinedseisE1} = 1859.9 \cdot kN$

Inclined Sliding Plane Length: $L_{incline} = 9.6 \cdot m$

Eccentricity (inclined plane): $ex_{E1} := \frac{L_{incline}}{2} - \frac{\Sigma M_{E1}}{\Sigma V_{InclinedseisE1}} = 1.13\, m$ $\quad Kern_{E1} := \frac{L_{incline}}{4} = 2.403\, m$

Eccentricity Check: $e_{check.E1} := \begin{cases} \text{"Okay"} & \text{if } ex_{E1} \le Kern_{E1} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"Okay"}$

CHECK FOUNDATION BEARING CAPACITY:

Base Section Modulus: $S_b = 15.4\, m^3$

Bearing Pressure Under Toe:

$$\sigma_{ToeE1} := \begin{cases} \left(\frac{\Sigma V_{InclinedE1}}{L_{incline} \cdot B} + \frac{\Sigma V_{InclinedE1} \cdot ex_{E1}}{S_b} \right) & \text{if } \frac{\Sigma V_{InclinedE1} \cdot ex_{E1}}{S_b} \le \frac{\Sigma V_{InclinedE1}}{L_{incline} \cdot B} \\ \frac{2 \cdot \Sigma V_{InclinedE1}}{B \cdot 3 \left(\frac{b}{2} - ex_{E1} \right)} & \text{otherwise} \end{cases} = 276.3 \cdot kPa$$

$$Bearing_{CheckToeE1} := \begin{cases} \text{"OKAY "} & \text{if } \sigma_{ToeE1} < \sigma_{allowE1} \\ \text{"NG""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

Bearing Pressure Under Heel:

$$\sigma_{HeelE1} := \begin{cases} \left(\frac{\Sigma V_{InclinedE1}}{L_{incline} \cdot B} - \frac{\Sigma V_{InclinedE1} \cdot ex_{E1}}{S_b} \right) & \text{if } \frac{\Sigma V_{InclinedE1} \cdot ex_{E1}}{S_b} \le \frac{\Sigma V_{InclinedE1}}{L_{incline} \cdot B} \\ 0 & \text{otherwise} \end{cases} = 47.6 \cdot kPa$$

$$Bearing_{CheckheelE1} := \left(\begin{cases} \text{"OKAY "} & \text{if } \sigma_{HeelE1} < \sigma_{allowE1} \wedge \sigma_{HeelE1} > 0 \\ \text{"NG - perform cracked base analysis""} & \text{otherwise} \end{cases} \right) = \text{"OKAY "}$$

CHECK FLOATATION:

Safety Factor for Floatation:

$$FS_{FloatationE1} := \frac{\Sigma V_{conc} + \Sigma V_{SoilWaterE1} + Q_{v.conc} + Q_{v.SoilWaterE1}}{\left|\Sigma V_{UpliftE1}\right|} = 3.05$$

$$FS_{Floatation.E1.check} := \begin{cases} \text{"OKAY"} & \text{if } FS_{FloatationE1} > FS_{req.E1.flt} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

CHECK OVERTURNING

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.
Assumptions are made in order to compute overturning stablity of indetermine forces on monolith with key;
(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.
(b) The horizontal resisting force acting on the key, P.key, is that required for static equilibrium
(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1

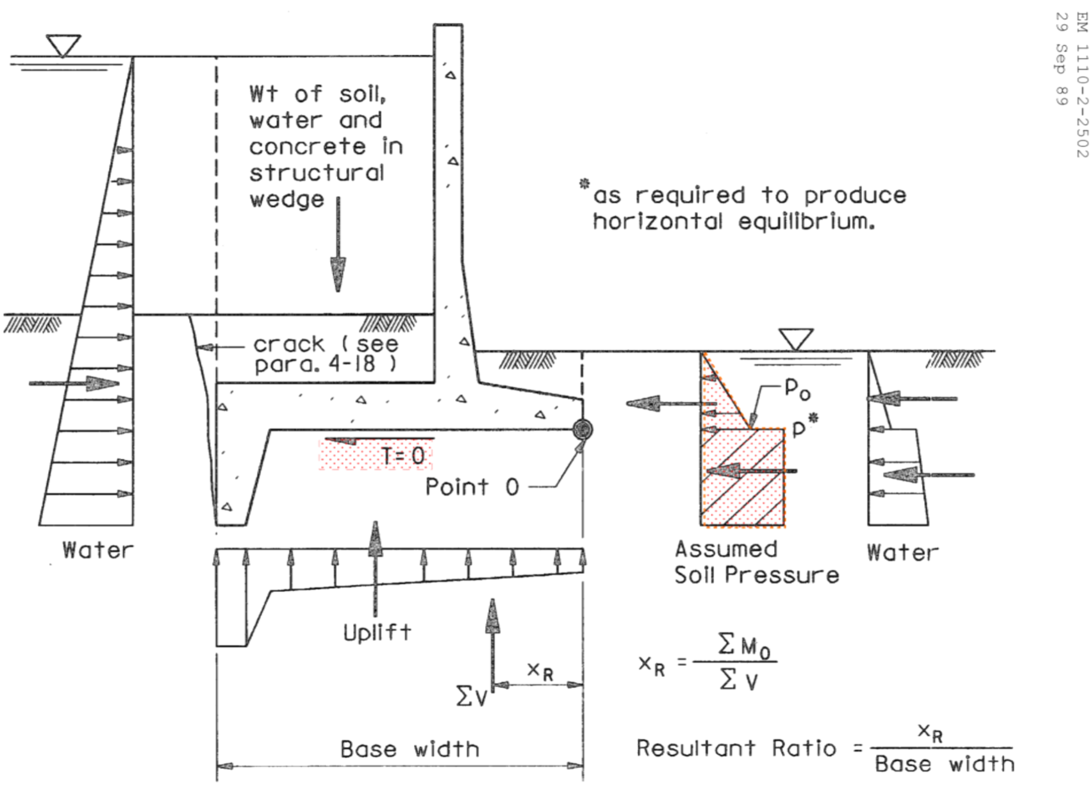


Figure 4-5. Forces for overturning analysis for wall with horizontal base and key

Modify Uplift for Overturning Analysis: **LOAD CASE E1**

(Uplift is calculated along the concrete/rock contact using the Line of Creep method)

Water Pressure at h: $u_{h.E1} := \Delta h_{g.hj.E1} \cdot \gamma_w = 74.48 \cdot kPa$

Water Pressure at o: $u_{o.E1} := \left(\Delta h_{g.no.E1} - \frac{\Delta h_{g.r.E1} \cdot L_{ho.E1}}{L_{ho.E1}} \right) \cdot \gamma_w = 35.28 \cdot kPa$

Head loss between point h and o: $\Delta h_{ho.E1} := \Delta h_{g.r.E1} \cdot \frac{L_{ho.E1}}{L_{ho.E1}} = 1\,m$

Length of concrete base (h -> o): $L_{baseho.E1} := Key_{h.w} + Key_{h.d} + Key_{hdist} + Key_{t.d} + Key_{t.w} = 12\,m$

Head loss along h -> j: $\Delta h_{hj.E1} := \Delta h_{ho.E1} \cdot \frac{Key_{h.w}}{L_{baseho.E1}} = 0.083\,m$

Water Pressure at j: $u_{j.E1} := \left(\Delta h_{g.hj.E1} - \Delta h_{hj.E1} \right) \cdot \gamma_w = 73.66 \cdot kPa$

Head loss along h -> k: $\Delta h_{hjk.E1} := \Delta h_{ho.E1} \cdot \left(\frac{Key_{h.w} + Key_{h.d}}{L_{baseho.E1}} \right) = 0.333\,m$

Water Pressure at k: $u_{k.E1} := \left(\Delta h_{g.km.E1} - \Delta h_{hjk.E1} \right) \cdot \gamma_w = 41.81 \cdot kPa$

Head loss along h -> m: $\Delta h_{hjkm.E1} := \Delta h_{ho.E1} \cdot \left(\frac{Key_{h.w} + Key_{h.d} + Key_{hdist}}{L_{baseho.E1}} \right) = 1\,m$

Water Pressure at m: $u_{m.E1} := \left(\Delta h_{g.km.E1} - \Delta h_{hjkm.E1} \right) \cdot \gamma_w = 35.28 \cdot kPa$

Head loss along h -> n: $\Delta h_{hjkmn.E1} := \Delta h_{ho.E1} \cdot \left(\frac{Key_{h.w} + Key_{h.d} + Key_{hdist} + Key_{t.d}}{L_{baseho.E1}} \right) = 1\,m$

Water Pressure at n: $u_{n.E1} := \left(\Delta h_{g.no.E1} - \Delta h_{hjkmn.E1} \right) \cdot \gamma_w = 35.28 \cdot kPa$

Uplift under key at heel: $V_{ulkeyhE1.OT} := \frac{\left(u_{h.E1} + u_{j.E1} \right) \cdot Key_{h.w}}{2} \cdot B \cdot -1 = -74.072 \cdot kN$

Moment Arm (from Point O): $V_{ulkeyhE1loc.OT} := b - \frac{Key_{h.w} \cdot \left(2 \cdot u_{j.E1} + u_{h.E1} \right)}{3 \cdot \left(u_{j.E1} + u_{h.E1} \right)} = 8.501\,m$

Uplift under base: $V_{ulbaseE1.OT} := \frac{\left(u_{k.E1} + u_{m.E1} \right) \cdot Key_{hdist}}{2} \cdot B \cdot -1 = -308.373 \cdot kN$

Moment Arm (from Point O): $V_{ulbaseE1loc.OT} := b - Key_{h.w} - \frac{Key_{hdist} \cdot \left(2 \cdot u_{m.E1} + u_{k.E1} \right)}{3 \cdot \left(u_{m.E1} + u_{k.E1} \right)} = 4.113\,m$

Uplift under key at toe: $V_{ulkeytE1.OT} := \frac{\left(u_{n.E1} + u_{o.E1} \right) \cdot Key_{t.w}}{2} \cdot B \cdot -1 = 0 \cdot kN$

Moment Arm (from Point O): $V_{ulkeytE1loc.OT} := \frac{Key_{t.w} \cdot \left(2 \cdot u_{n.E1} + u_{o.E1} \right)}{3 \cdot \left(u_{n.E1} + u_{o.E1} \right)} = 0$

$$\Sigma V_{UpliftE1.OT} := V_{ulkeyhE1.OT} + V_{ulbaseE1.OT} + V_{ulkeytE1.OT} = -382 \cdot kN$$

$$U_{E1.loc.OT} := \frac{V_{ulkeyhE1.OT} \cdot V_{ulkeyhE1loc.OT} + V_{ulbaseE1.OT} \cdot V_{ulbaseE1loc.OT} + V_{ulkeytE1.OT} \cdot V_{ulkeytE1loc.OT}}{\Sigma V_{UplliftE1.OT}} = 4.96\,m$$

$$\Sigma M_{UpliftE1.OT} := \Sigma V_{UplliftE1.OT} \cdot U_{E1.loc.OT} = -1898.0 \cdot kN \cdot m$$

LOAD CASE E1

Modify Lateral Water Pressure (Resisting) for Overturning Analysis:

(Resisting water pressure is calculated using the Line of Creep method)

Water Load at Key (heel): $H_{h2E1.OT} := \frac{u_{k.E1} + u_{j.E1}}{2} \cdot Key_{h.d} B = 173.2 \cdot kN$

Moment Arm (from Point O): $H_{h2locE1.OT} := \frac{Key_{h.d} \cdot \left(2 \cdot u_{k.E1} + u_{j.E1}\right)}{3\left(u_{k.E1} + u_{j.E1}\right)} + Key_{vdist} = -1.64\ m$

Water Load at Key (toe): $H_{h6E1.OT} := \frac{u_{o.E1} \cdot \left(UWSEL_{E1} - Bot_{ftg} + Key_{t.d}\right)}{2} \cdot B = 64 \cdot kN$

Moment Arm (from Point O): $H_{h6locE1.OT} := \frac{UWSEL_{E1} - Bot_{ftg} + Key_{t.d}}{3} = 1.20\ m$

$$\Sigma H_{waterresistE1.OT} := H_{h2E1.OT} + H_{h6E1.OT} = 236.72 \cdot kN$$

$$H_{waterresistlocE1.OT} := \frac{H_{h2E1.OT} \cdot H_{h2locE1.OT} + H_{h6E1.OT} \cdot H_{h6locE1.OT}}{\Sigma H_{waterresistE1.OT}} = -0.877\ m$$

$$\Sigma M_{waterresistE1.OT} := \Sigma H_{waterresistE1.OT} \cdot H_{waterresistlocE1.OT} = -207.51 \cdot kN \cdot m$$

Modify Lateral Soil Loads for Overturning Analysis:

(Lateral soil loads are calculated down to Point O instead of bottom of shear key)

Driving Soil Load (Headwater Side):

Surcharge Load: $E_{s1E1.OT} := S1_{E1} \cdot K_{Aagwt} \cdot \left(H_w + Key_{h.d} + Key_{vdist}\right) \cdot B \cdot -1 = 0 \cdot kN$

Moment Arm (from Point O): $E_{s1locE1.OT} := \frac{H_w + Key_{h.d} + Key_{vdist}}{2} = 5.25\ m$

Moist Soil Load above GWL: $E_{h1E1.OT} := \frac{\gamma_m \cdot K_{Aagwt} \cdot h_{1E1}^{\ 2}}{2} B \cdot -1 = -130.7 \cdot kN$

Moment Arm (from Point O): $E_{h1locE1.OT} := \frac{h_{1E1}}{3} + h_{2E1} + Key_{vdist} = 6.57\ m$

Saturated Soil Load below GWL: (rectangular component) $E_{h2E1.OT} := \left(\gamma_m \cdot K_{Aagwt} \cdot h_{1E1}\right) \cdot \left(h_{2E1} + Key_{vdist}\right) \cdot B \cdot -1 = -203.8 \cdot kN$

Moment Arm (from Point O): $E_{h2locE1.OT} := \frac{h_{2E1} + Key_{vdist}}{2} = 2.30\ m$

Saturated Soil Load below GWL: (triangular component) $E_{h2aE1.OT} := \frac{\left(\gamma_{sat} - \gamma_w\right) \cdot K_{Aagwt} \cdot \left(h_{2E1} + Key_{vdist}\right)^2}{2} \cdot B \cdot -1 = -48.5 \cdot kN$

Moment Arm (from Point O): $E_{h2alocE1.OT} := \frac{h_{2E1} + Key_{vdist}}{3} = 1.53\ m$

Resisting Soil Load (Tailwater Side):

LOAD CASE E1

(Determine resisting soil load based on depth variation between the keys (ie. Key_{vdist}). In case where key at heel is deeper than key at toe (ie. $Key_{vdist} < 0$), resisting soil load (p*) is assumed to produce horizontal equilibrium as per Figure 4-5 above. Resisting soil load (p_o) is neglected.)

Total Driving Force:

$$\Sigma H_{SoildriveE1.OT} := E_{s1E1.OT} + E_{h1E1.OT} + E_{h2E1.OT} + E_{h2aE1.OT} + H_{h2E1} \cdots + Q_{h.conc} + Q_{h.SoilWaterE1} = -929.3 \cdot kN$$

Total Resisting Force:

$$\Sigma H_{waterresistE1.OT} = 236.719 \cdot kN$$

Assumed Soil Load p*:

$$E_{h8E1a.OT} := \left(\Sigma H_{SoildriveE1.OT} + \Sigma H_{waterresistE1.OT}\right) \cdot -1 = 692.583 \cdot kN$$

Moment Arm (from Point O):

$$E_{h8E1a.loc.OT} := \frac{Key_{vdist}}{2} = -1.5\,m$$

$$E_{h8E1.OT} := \begin{cases} E_{h8E1a.OT} & \text{if } Key_{vdist} < 0 \\ \Sigma H_{SoilresistE1} - H_{h6E1} - H_{h2aE1} & \text{otherwise} \end{cases} = 692.583 \cdot kN$$

$$\Sigma M_{SoilresistE1} := \begin{cases} E_{h8E1a.OT} \cdot E_{h8E1a.loc.OT} & \text{if } Key_{vdist} < 0 \\ \Sigma M_{HorizSoilResistE1} - H_{h6E1} \cdot H_{h6locE1} - H_{h2aE1} \cdot H_{h2alocE1} & \text{otherwise} \end{cases} = -1038.875 \cdot kN \cdot m$$

Sum of Moment about Point O:

$$\Sigma M_{LateraldriveE1.OT} := E_{s1E1.OT} \cdot E_{s1locE1.OT} + E_{h1E1.OT} \cdot E_{h1locE1.OT} + E_{h2E1.OT} \cdot E_{h2locE1.OT} \cdots + E_{h2aE1.OT} \cdot E_{h2alocE1.OT} + H_{h2E1} \cdot H_{h2locE1} = -1269.5 \cdot kN \cdot m$$

$$\Sigma M_{LateralresistE1.OT} := \Sigma M_{waterresistE1.OT} + \Sigma M_{SoilresistUN2} = -921.1 \cdot kN \cdot m$$

$$\Sigma M_{seisE1.OT} := M_{Qv.conc} + M_{Q.conc} + M_{Qv.SoilWaterE1} + M_{Q.h.SoilWaterE1} = -2064 \cdot kN \cdot m$$

(seismic moment modified for the most adverse overturning effect)

Total moment:

$$\Sigma M_{E1.OT} := \Sigma M_{conc} + \Sigma M_{VertSoilWaterResistE1} + \Sigma M_{UpliftE1.OT} \cdots + \Sigma M_{LateraldriveE1.OT} + \Sigma M_{LateralresistE1.OT} + \Sigma M_{seisE1.OT} = 2956.8 \cdot kN \cdot m$$

Total Vertical Force:

$$\Sigma V_{E1.OT} := \Sigma V_{conc} + \Sigma V_{SoilWaterE1} + \Sigma V_{UplliftE1.OT} + Q_{v.conc} + Q_{v.SoilWaterE1} = 1125.1 \cdot kN$$

Distance X_R: EM 1110-2-2502 Eq.4-1

$$X_{R.E1} := \frac{\Sigma M_{E1.OT}}{\Sigma V_{E1.OT}} = 2.628\,m$$

Overturning Resultant Ratio

$$Ratio_{E1.OT} := \frac{X_{R.E1}}{b} = 0.29$$

$$Ratio_{E1.OT.check} := \begin{cases} \text{"OKAY "} & \text{if } Ratio_{E1.OT} > X_{R.reqE1} \\ \text{"Revise Structure""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

CHECK FOUNDATION ECCENTRICITY (HORIZONTAL PLANE):

Eccentricity (horizontal plan):

$$ex_{E1.OT} := \frac{b}{2} - \frac{\Sigma M_{E1.OT}}{\Sigma V_{E1.OT}} = 1.87\,m \qquad Kern_{E1.OT} := \frac{b}{4} = 2.25\,m$$

Eccentricity Check:

$$e_{check.E1.OT} := \begin{cases} \text{"Okay"} & \text{if } ex_{E1.OT} \le Kern_{E1.OT} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"Okay"}$$

LOAD CASE E1

CHECK FOUNDATION BEARING CAPACITY (HORIZONTAL PLANE):

Base Section Modulus: $S_{b.OT} = 13.5\ m^3$

Bearing Pressure Under Toe:

$$\sigma_{ToeE1.OT} := \begin{cases} \left(\dfrac{\Sigma V_{E1.OT}}{b \cdot B} + \dfrac{\Sigma V_{E1.OT} \cdot ex_{E1.OT}}{S_{b.OT}}\right) & \text{if } \dfrac{\Sigma V_{E1.OT}}{b \cdot B} \geq \dfrac{\Sigma V_{E1.OT} \cdot ex_{E1.OT}}{S_{b.OT}} \\ \dfrac{2 \cdot \Sigma V_{E1.OT}}{B \cdot 3\left(\dfrac{b}{2} - ex_{E1.OT}\right)} & \text{otherwise} \end{cases} = 285.4 \cdot kPa$$

$$Bearing_{ChecktoeE1.OT} := \begin{cases} \text{"OKAY "} & \text{if } \sigma_{ToeE1.OT} < \sigma_{allowE1} \\ \text{"NG - for reference only""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

Bearing Pressure Under Heel:

$$\sigma_{HeelE1.OT} := \begin{cases} \left(\dfrac{\Sigma V_{E1.OT}}{b \cdot B} - \dfrac{\Sigma V_{E1.OT} \cdot ex_{E1.OT}}{S_{b.OT}}\right) & \text{if } \dfrac{\Sigma V_{E1.OT}}{b \cdot B} \geq \dfrac{\Sigma V_{E1.OT} \cdot ex_{E1.OT}}{S_{b.OT}} \\ 0 & \text{otherwise} \end{cases} = 0.0 \cdot kPa$$

$$Bearing_{CheckheelE1.OT} := \left(\begin{cases} \text{"OKAY "} & \text{if } \sigma_{HeelE1.OT} < \sigma_{allowE1} \wedge \sigma_{HeelE1.OT} > 0 \\ \text{"NG - for reference only""} & \text{otherwise} \end{cases} \right) = \text{"NG - for reference only""}$$

SUMMARY OF STABILITY ASSESSMENT:

LOAD CASE E1

Sliding Factor of Safety: (Horizontal Plane - Ref only)	$FS_{Horiz.SlidingE1} = 0.54$	$FS_{Sliding.check1.E1}$ = "NG - key req""
Sliding Factor of Safety: (Inclined Plane)	$FS_{InclinedlSlidingE1} = 1.78$	$FS_{Sliding.check2.E1}$ = "OKAY "
Eccentricity: (Inclined Plane)	$ex_{E1} = 1.13\ m$	$e_{check.E1}$ = "Okay"
Bearing Pressure At Heel: (Inclined Plane)	$\sigma_{HeelE1} = 48 \cdot kPa$	$Bearing_{CheckheelE1}$ = "OKAY "
Bearing Pressure At Toe: (Inclined Plane)	$\sigma_{ToeE1} = 276 \cdot kPa$	$Bearing_{ChecktoeE1}$ = "OKAY "
Flotation Factor of Safety (horizontal plane)	$FS_{FloatationE1} = 3.05$	$FS_{Floatation.E1.check}$ = "OKAY "
Overturning Resultant Ratio: (horizontal plane)	$Ratio_{E1.OT} = 0.29$	$Ratio_{E1.OT.check}$ = "OKAY "
Eccentricity: (horizontal plane - Ref only)	$ex_{E1.OT} = 1.87\ m$	$e_{check.E1.OT}$ = "Okay"
Bearing Pressure At Heel: (horizontal plane - Ref only)	$\sigma_{HeelE1.OT} = 0 \cdot kPa$	$Bearing_{CheckheelE1.OT}$ = "NG - for reference only""
Bearing Pressure At Toe: (horizontal plane - Ref only)	$\sigma_{ToeE1.OT} = 285 \cdot kPa$	$Bearing_{ChecktoeE1.OT}$ = "OKAY "

Calculation Section IV

DI-5B Retaining Wall Stability Calculations

Project Number: 110773396

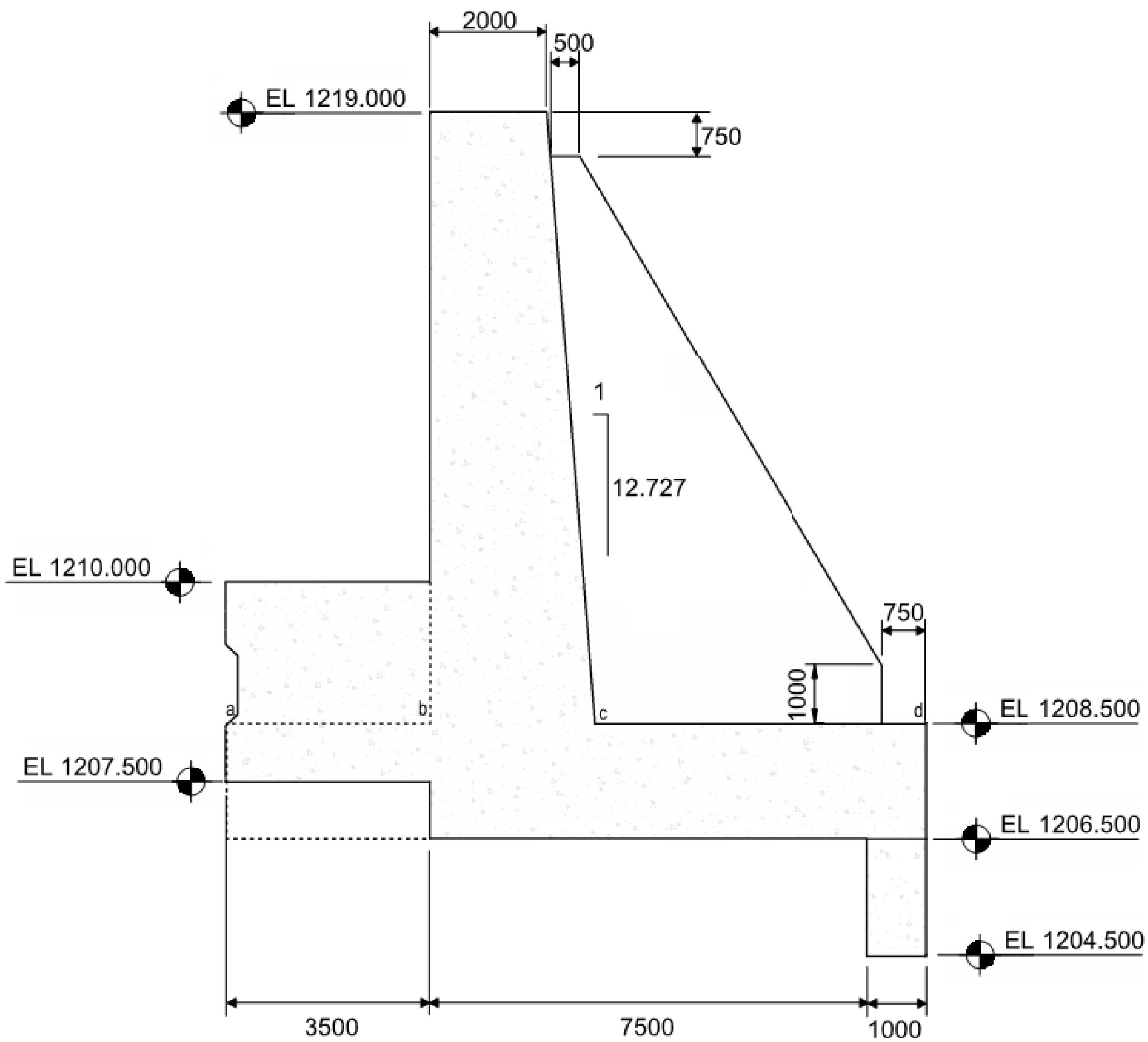
Project Title: SR1 - Diversion Structure

Client: Alberta Transportation

Engineer: Lawrence Choi   Date: 12/11/2018

Checker: Sean Xiao   Date: 12/18/2018

Calculation for: Retaining Wall - Diversion Inlet Left - Block 5B



REGION COLOR CONVENTION

User Input

Calulation Highlights

Results

WALL GEOMETRY:

Top of Wall Elevation: $T_w := 1219.0 \cdot m$

Top of Footing Elevation: $Top_{ftg} := 1208.5 \cdot m$

Thickness of Footing: $t_{ftg} := 2.0m$

Bottom of Footing Elevation: $Bot_{ftg} := Top_{ftg} - t_{ftg} = 1206.5\ m$

Overall Height of wall: $h_w := T_w - Bot_{ftg} = 12.50\ m$

Thickness of Wall: Base: $t_{wb} := 2.825 \cdot m$ Top: $t_{wt} := 2.0m$

Length of toe: $L_{ab} := 3.5m$

Total Length of Footing: $b := 12.0m$

Length of heel: $L_{cd} := b - L_{ab} - t_{wb} = 5.675\ m$

Unit Width of Wall for analysis: $B := 1.00m$

SHEAR KEY GEOMETRY:

	Toe	Heel	
Key depth:	$Key_{t.d} := 0m$	$Key_{h.d} := 2.0m$	(Assumption: $Key_{h.d}$ >= $Key_{t.d}$)
Key width:	$Key_{t.w} := 0m$	$Key_{h.w} := 1m$	
Face of Key from Point O:	$Key_{t.loc} := 0 \cdot m$	$Key_{h.loc} := 11.0 \cdot m$	

Horizontal Distance between Keys: $Key_{hdist} := Key_{h.loc} - Key_{t.loc} - Key_{t.w} = 11\ m$

Key Depth Diff. (from point O): $Key_{vdist} := -Key_{h.d} + Key_{t.d} = -2\ m$

BASE PROPERTIES:

Base Area: $A_b := b \cdot B = 12\ m^2$

Centroidal Distance for Footing (from Toe): $Y_t := \frac{b}{2} = 6.00\ m$

RETAINED SOIL GEOMETRY:

Slope of retained ground surface: $\beta := 0 \cdot \frac{\pi}{180} = 0.00$

Height of retained earth at heel: $H_w := T_w - Bot_{ftg} + \left(t_{wb} + L_{cd} - t_{wt}\right) \cdot \tan(\beta) = 12.50\ m$

RETAINING WALL GEOMETRY CHECKS:

(Foundation Analysis & Design Bowles)

$$t_{bcheck} := \begin{cases} \text{"OKAY"} & \text{if } t_{ftg} \ge \frac{H_w}{12} \\ \text{"Warning"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

$$t_{wcheck} := \begin{cases} \text{"OKAY"} & \text{if } t_{wb} \ge \frac{H_w}{12} \\ \text{"Warning"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

$$b_{check} := \begin{cases} \text{"OKAY"} & \text{if } \frac{b}{H_w} \ge .4 \wedge \frac{b}{H_w} \le 80 \\ \text{"Warning"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

$$L_{abcheck} := \begin{cases} \text{"OKAY"} & \text{if } \frac{L_{ab}}{b} \ge .25 \wedge \frac{L_{ab}}{b} \le .4 \\ \text{"Warning"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

Material Properties:

Unit Weight of Water:	$\gamma_w := 9.8 \frac{kN}{m^3}$	(Section 7.2, Design Criteria)
Unit Weight of Concrete:	$\gamma_c := 23.5 \frac{kN}{m^3}$	
Unit Weight of Soil (Moist):	$\gamma_m := 20.0 \frac{kN}{m^3}$	(Section 5.3, Design Criteria) assumed moisture content (w) = 5%
Unit Weight Soil (Saturated):	$\gamma_{sat} := 22.0 \frac{kN}{m^3}$	(Assuming Specific Gravity = 2.7
Unit Weight Soil (buoyant):	$\gamma_b := \gamma_{sat} - \gamma_w = 12.2 \cdot \frac{kN}{m^3}$	
Weight of Soil/Concrete above toe:	$\gamma_{toe} := 22.0 \frac{kN}{m^3}$	
Unit Weight of Rock:	$\gamma_r := 25.6 \frac{kN}{m^3}$	(Section 7.2, Design Criteria)

Foundation Parameters:

Glacial Till Internal Friction:	$\phi := 27 \cdot \frac{\pi}{180} = 0.471$	
Bedrock Internal Friction Angle:	$\phi_r := 24 \cdot \frac{\pi}{180} = 0.419$	
Friction Angle at Base Concrete / Rock Interface:	$\phi_{rock} := 26$	
Base Friction Coefficient:	$tan_{\phi rock} := \tan\left(\phi_{rock} \frac{\pi}{180}\right) = 0.488$	radians
Rip Rap Backfill, Refer Dwg. C-214	$\phi_{backfill} := \left(20 \frac{\pi}{180}\right) = 0.349$	radians
Shear strength along rock Failure plane	$s_r := \frac{13100 \frac{kN}{m^2}}{2} = 6550 \cdot \frac{kN}{m^2}$	(Stantec Design Memo 8/8/16)

CONCRETE DEAD LOAD:

Area of Footing: $A_{ftg} := t_{ftg} \cdot b = 24\,m^2$

Weight of Footing: $D_{ftg} := A_{ftg} \cdot B \cdot \gamma_c = 564 \cdot kN$

Area of Stem (without batter): $A_{w1} := t_{wt} \cdot (h_w - t_{ftg}) = 21\,m^2$

Weight of Stem: $D_{w1} := A_{w1} \cdot B \cdot \gamma_c = 493.5 \cdot kN$

Area of stem Batter: $A_{w2} := \frac{(t_{wb} - t_{wt})}{2} (h_w - t_{ftg}) = 4.33\,m^2$

Weight of Batter: $D_{w2} := A_{w2} \cdot B \cdot \gamma_c = 101.8 \cdot kN$

Slope of batter: $S_{batter} := \frac{t_{wb} - t_{wt}}{h_w - t_{ftg}} = 0.079$

Area of Key $A_{t.key} := Key_{t.d} \cdot Key_{t.w} = 0$ $A_{h.key} := Key_{h.d} \cdot Key_{h.w} = 2\,m^2$

Weight of Key $D_{t.key} := A_{t.key} \cdot B \cdot \gamma_c = 0 \cdot kN$ $D_{h.key} := A_{h.key} \cdot B \cdot \gamma_c = 47 \cdot kN$

Centroidal Horizontal Distance of Wall (From Toe):

$$H_{cent} := \frac{A_{w1} \cdot \left(L_{ab} + \frac{t_{wt}}{2}\right) + A_{w2} \cdot \left(L_{ab} + t_{wt} + \frac{t_{wb} - t_{wt}}{3}\right) + A_{ftg} \cdot \frac{b}{2} + A_{t.key} \cdot \left(Key_{t.loc} + \frac{Key_{t.w}}{2}\right) + A_{h.key} \cdot \left(Key_{h.loc} + \frac{Key_{h.w}}{2}\right)}{A_{w1} + A_{w2} + A_{ftg} + A_{t.key} + A_{h.key}} = 5.58\,m$$

Centroidal Vertical Distance of Wall (Above Base of Footing):

$$V_{Cent} := \frac{A_{ftg} \cdot \frac{t_{ftg}}{2} + A_{w1} \cdot \left[t_{ftg} + \frac{(h_w - t_{ftg})}{2}\right] + A_{w2} \cdot \left[t_{ftg} + \frac{(h_w - t_{ftg})}{3}\right] + A_{t.key} \cdot \left(\frac{-Key_{t.d}}{2}\right) + A_{h.key} \cdot \left(\frac{-Key_{h.d}}{2}\right)}{A_{ftg} + A_{w1} + A_{w2} + A_{t.key} + A_{h.key}} = 3.86\,m$$

$\Sigma V_{conc} := D_{ftg} + D_{w1} + D_{w2} + D_{t.key} + D_{h.key} = 1206.3 \cdot kN$

$\Sigma M_{conc} := \Sigma V_{conc} \cdot H_{cent} = 6733.1\,m \cdot kN$

ROCK SECTION MOBILIZED FOR INCLINDED SLIDING FAILURE

Area of Rock Section Mobilized: $A_{rocksection} := (Key_{t.d} + Key_{h.d}) \cdot \frac{Key_{hdist}}{2} = 11\,m^2$

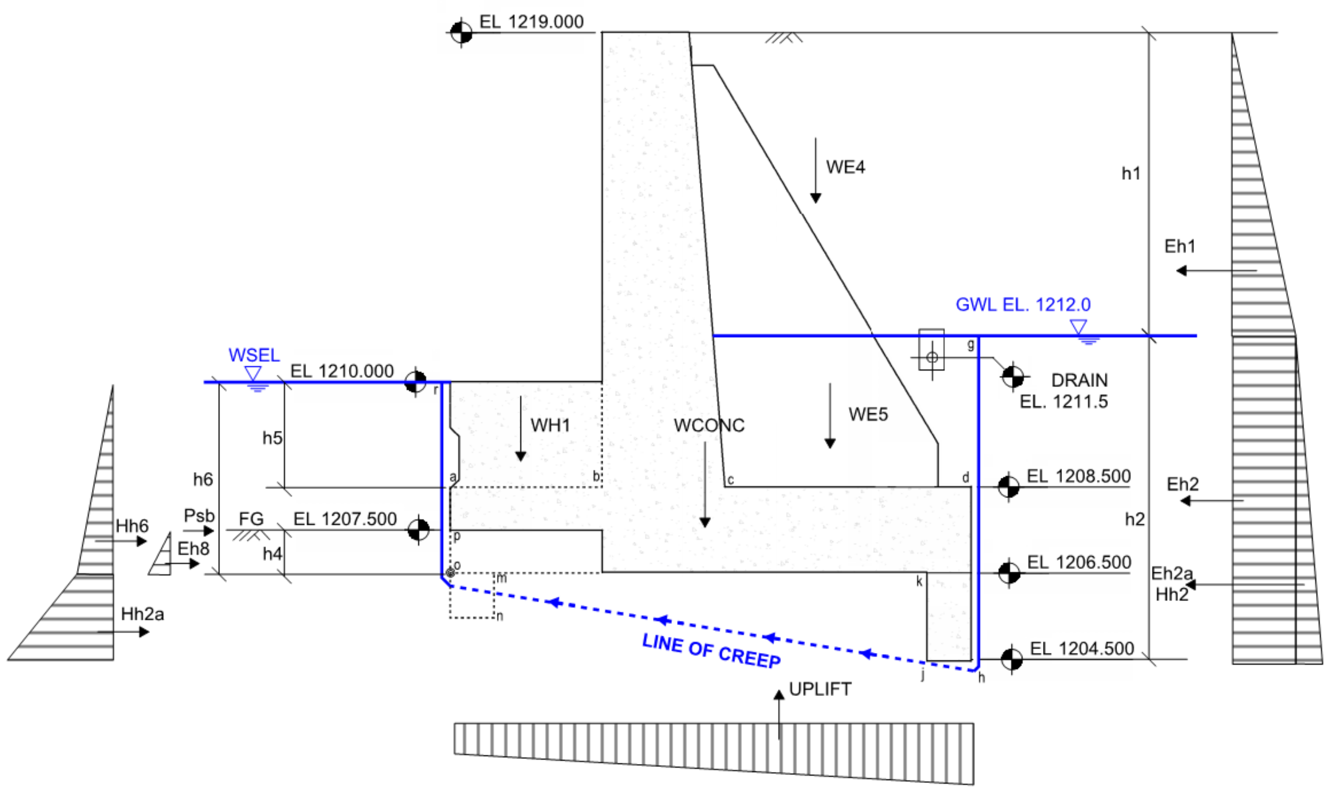
Rock Mass Mobilized: $V_{rocksection} := A_{rocksection} \cdot \gamma_r \cdot B = 281.6 \cdot kN$

(Pore pressure taken along assumed inclined sliding plane)

Distance from Toe to COG of Rock Section: $L_{rocksection} := \frac{Key_{hdist} \cdot (2 \cdot Key_{h.d} + Key_{t.d})}{3(Key_{h.d} + Key_{t.d})} + Key_{t.w} = 7.333\,m$

$\Sigma M_{rocksection} := V_{rocksection} \cdot L_{rocksection} = 2065.1\,m \cdot kN$

LOAD CASE U1 - NORMAL OPERATION



U1 DESIGN CASE

LOAD CASE U1 ACCEPTANCE PARAMETERS

FS sliding:

Usual (U) 1.5 (without cohesion) (Table 3-3, USACE EM 1110-2-2100)

Resultant Location:

Usual (U) Inside middle third ~100% base in compression

Required Factor of Safety for Sliding: $FS_{sliding.reqU1} := 1.5$ (Without Cohesion)

Allowable rock bearing pressure: $\sigma_{allowU1} := 1270kPa$ (Section 5.2, Design Criteria EM 1110-2-2100 Section 3-10)

Overturning Required Resultant Ratio: $X_{R.reqU1} := 0.333$ (EM 1110-2-2502, Figure 4-4)

Required Factor of Safety for Floatation $FS_{req.U1.flt} := 1.5$

SOIL HEIGHTS and Water Levels:

LOAD CASE U1

Heel Conditions:

Groundwater Elevation at Heel: $GWL_{U1} := 1212.0m$

Distance from Finish Grade to Groundwater at Heel: $h_{1U1} := \left[T_w - GWL_{U1} + \left(L_{cd} + t_{wb} - t_{wt}\right)\cdot \tan(\beta)\right] = 7.00\ m$

Distance from Water Surface to Bottom of Footing at Heel: $h_{2U1} := GWL_{U1} - Bot_{ftg} + Key_{h.d} = 7.50\ m$

Toe Conditions:

Water Surface Elevation at Toe: $WSEL_{U1} := 1210.0m$

Water Surface Elevation at Toe for Uplift: $UWSEL_{U1} := 1210.0\cdot m$

Finish Grade at Toe providing lateral resistance: $FG_{toeU1} := 1207.5\cdot m$

Soil Depth Above top of footing: $h_{3aU1} := FG_{toeU1} - Top_{ftg} = -1\ m$

$$h_{3U1} := \begin{cases} h_{3aU1} & \text{if } FG_{toeU1} - Top_{ftg} \ge 0 \\ 0 & \text{otherwise} \end{cases} = 0$$

Resisting Fill at Toe: $h_{4U1} := FG_{toeU1} - Bot_{ftg} + Key_{t.d} = 1.00\ m$

Distance from Water Level to Top of Footing: $h_{5U1} := WSEL_{U1} - Top_{ftg} = 1.50\ m$

Distance from Water Surface to Bottom of Footing: $h_{6U1} := WSEL_{U1} - Bot_{ftg} + Key_{t.d} = 3.50\cdot m$

Soil Depth Above WSEL: $h_{7aU1} := FG_{toeU1} - WSEL_{U1} = -2.5\ m$

$$h_{7U1} := \begin{cases} h_{7aU1} & \text{if } FG_{toeU1} - WSEL_{U1} \ge 0 \\ 0 & \text{otherwise} \end{cases} = 0$$

Soil Depth Below WSEL:

$$h_{8U1} := \begin{cases} WSEL_{U1} - Bot_{ftg} + Key_{t.d} & \text{if } FG_{toeU1} - WSEL_{U1} \ge 0 \\ h_{4U1} & \text{otherwise} \end{cases} = 1$$

For Line of Creep Method: $L_{ho.U1} := \sqrt{b^2 + \left(Key_{h.d} - Key_{t.d}\right)^2} = 12.166\ m$

Head Loss from Point g:

$\Delta h_{g.hj.U1} := h_{2U1} = 7.5\ m$ (to point h & j)

$\Delta h_{g.km.U1} := GWL_{U1} - Bot_{ftg} = 5.5\ m$ (to point k & m)

$\Delta h_{g.no.U1} := GWL_{U1} - Bot_{ftg} + Key_{t.d} = 5.5\ m$ (to point n & o)

$\Delta h_{g.p.U1} := GWL_{U1} - FG_{toeU1} = 4.5\ m$ (to point p)

$\Delta h_{g.r.U1} := GWL_{U1} - UWSEL_{U1} = 2\ m$ (to point r)

Surcharge

Surcharge on Heel: $S1_{U1} := 0.0\ \frac{kN}{m^2}$

Calculate Soil Lateral Pressure Coefficients:

LOAD CASE U1

For all load cases except seismic, soil loading to be based on At-Rest Condition.
Calculate at-rest pressure coefficient Ko based on Jaky's (1944) equation.

Soil At Rest Static Coefficient: $K_o := \dfrac{1 - \sin(\phi)}{1 + \sin(\beta)} = 0.546$ (Eq. 3-6, USACE EM 1110-2-2502)

Lateral - Driving Force (Headwater Side)

Lateral Soil Load:

Surcharge Load: $E_{s1U1} := S1_{U1} \cdot K_o \cdot \left(H_w + Key_{h.d}\right) \cdot B \cdot -1 = 0 \cdot kN$

Moment Arm (from bottom of footing): $E_{s1locU1} := \dfrac{H_w + Key_{h.d}}{2} + Key_{vdist} = 5.25\ m$

Moist Soil Load above GWL: $E_{h1U1} := \dfrac{\gamma_m \cdot K_o \cdot h_{1U1}^{\ 2}}{2} B \cdot -1 = -267.5 \cdot kN$

Moment Arm (from bottom of footing): $E_{h1locU1} := \dfrac{h_{1U1}}{3} + h_{2U1} + Key_{vdist} = 7.83\ m$

Saturated Soil Load below GWL:
(rectangular component) $E_{h2U1} := \left(\gamma_m \cdot K_o \cdot h_{1U1}\right) \cdot \left(h_{2U1}\right) \cdot B \cdot -1 = -573.3 \cdot kN$

Moment Arm (from bottom of footing): $E_{h2locU1} := \dfrac{h_{2U1}}{2} + Key_{vdist} = 1.75\ m$

Saturated Soil Load below GWL:
(triangular component) $E_{h2aU1} := \dfrac{\left(\gamma_{sat} - \gamma_w\right) \cdot K_o \cdot h_{2U1}^{\ 2}}{2} \cdot B \cdot -1 = -187.3 \cdot kN$

Moment Arm (from bottom of footing): $E_{h2alocU1} := \dfrac{h_{2U1}}{3} + Key_{vdist} = 0.50\ m$

Lateral Water Load:

Water Load GWL to Bottom of Key $H_{h2U1} := \dfrac{\gamma_w \cdot h_{2U1}^{\ 2}}{2} \cdot B \cdot -1 = -275.6 \cdot kN$

Moment Arm (from bottom of footing): $H_{h2locU1} := \dfrac{h_{2U1}}{3} + Key_{vdist} = 0.50\ m$

$\Sigma H_{SoildriveU1} := E_{s1U1} + E_{h1U1} + E_{h2U1} + E_{h2aU1} + H_{h2U1} = -1303.8 \cdot kN$

$$\Sigma M_{LateralSoildriveU1} := E_{s1U1} \cdot E_{s1locU1} + E_{h1U1} \cdot E_{h1locU1} + E_{h2U1} \cdot E_{h2locU1} \ \cdots + E_{h2aU1} \cdot E_{h2alocU1} + H_{h2U1} \cdot H_{h2locU1} = -3330.5\ m \cdot kN$$

Lateral - Resisting Force (Tailwater Side)

LOAD CASE U1

Lateral Water Load:

Water Load WSEL to Bot. of Footing: $H_{h6U1} := \dfrac{\gamma_w \cdot h_{6U1}^{\,2}}{2} \cdot B = 60.0 \cdot kN$

Moment Arm (from bot. of toe key): $H_{h6locU1} := \dfrac{h_{6U1}}{3} = 1.17\,m$

Water Load Bot. of Footing to Bot. of H. Key: $H_{h2aU1} := \left[\left(UWSEL_{U1} - Bot_{ftg} + Key_{t.d}\right) + h_{2U1}\right] \cdot \dfrac{Key_{h.d}}{2} \cdot \gamma_w \cdot B = 107.8 \cdot kN$

Moment Arm (from bot. of toe key): $H_{h2alocU1} := \dfrac{Key_{h.d} \cdot \left[2 \cdot \left(UWSEL_{U1} - Bot_{ftg} + Key_{t.d}\right) + h_{2U1}\right]}{3\left[h_{2U1} + \left(UWSEL_{U1} - Bot_{ftg} + Key_{t.d}\right)\right]} \ldots + Key_{vdist} = -1.12\,m$

Lateral Soil Load:

Moist Soil Load above WSEL: $E_{h7U1} := \dfrac{\gamma_m \cdot K_o \cdot h_{7U1}^{\,2}}{2} B = 0.0 \cdot kN$

Moment Arm (from bot. of toe key): $E_{h7locU1} := h_{6U1} + \dfrac{h_{7U1}}{3} + Key_{vdist} = 1.50\,m$

Saturated Soil Load below WSEL:
(rectangular component) $E_{h8U1} := \left(\gamma_m \cdot K_o \cdot h_{7U1}\right) \cdot h_{8U1} \cdot B = 0.0 \cdot kN$

Moment Arm (from bot. of toe key): $E_{h8locU1} := \dfrac{h_{8U1}}{2} = 0.50\,m$

Saturated Soil Load below WSEL:
(triangular component) $E_{h8aU1} := \dfrac{\left[\left(\gamma_{sat} - \gamma_w\right) \cdot K_o\right] \cdot h_{8U1}^{\,2}}{2} \cdot B = 3.3 \cdot kN$

Moment Arm (from bot. of footing): $E_{h8alocU1} := \dfrac{h_{8U1}}{3} = 0.33\,m$

Lateral Resistance from Stilling Basin:

Lateral Resistance from Stilling Basin: $P_{sbU1} := 291kN$ (Force needed to achieve the required sliding factor of safety in case UN2)

Moment Arm (from bot. of toe key): $P_{sblocU1} := \dfrac{t_{ftg}}{2} + Key_{t.d} = 1.00\,m$

$\Sigma H_{SoilresistU1} := H_{h6U1} + H_{h2aU1} + E_{h7U1} + E_{h8U1} + E_{h8aU1} + P_{sbU1} = 462.2 \cdot kN$

$\Sigma M_{HorizSoilResistU1} := H_{h6U1} \cdot H_{h6locU1} + H_{h2aU1} \cdot H_{h2alocU1} + E_{h7U1} \cdot E_{h7locU1} \ldots + E_{h8U1} \cdot E_{h8locU1} + E_{h8aU1} \cdot E_{h8alocU1} + P_{sbU1} \cdot P_{sblocU1} = 241.3\,m \cdot kN$

Vertical Force:

UPLIFT: Linear distribution from water at heel to water at toe:

$\Sigma V_{UpliftU1} := \left[\left(UWSEL_{U1} - Bot_{ftg} + Key_{t.d}\right) + h_{2U1}\right] \cdot \dfrac{b}{2} \cdot \gamma_w \cdot B \cdot -1 = -646.8 \cdot kN$

Moment Arm (from Point O): $V_{UpliftU1aloc} := \dfrac{b \cdot \left[2 \cdot h_{2U1} + \left(UWSEL_{U1} - Bot_{ftg} + Key_{t.d}\right)\right]}{3\left[h_{2U1} + \left(UWSEL_{U1} - Bot_{ftg} + Key_{t.d}\right)\right]} = 6.727\,m$

$\Sigma M_{UpliftU1} := \Sigma V_{UpliftU1} \cdot V_{UpliftU1aloc} = -4351.2 \cdot kN \cdot m$

Vertical Force (con't):

Weight of soil and water over toe:

Water Above the Top of Footing: $W_{H1U1} := \gamma_w \cdot h_{5U1} \cdot L_{ab} \cdot B = 51.45 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E1locU1} := \frac{L_{ab}}{2} = 1.75\,m$

Soil above top of footing: $W_{E6U1} := \gamma_b \cdot h_{3U1} \cdot L_{ab} \cdot B = 0.0 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E6locU1} := \frac{L_{ab}}{2} = 1.75\,m$

Vertical Load Due to Surcharge: $S_{U1} := S1_{U1} \cdot L_{cd} \cdot B = 0$ $\quad S_{U1loc} := b - \frac{L_{cd}}{2} = 9.16\,m$

Weight of soil and water over heel:

Moist Soil for sloped grade above top of wall:

Length of sloped portion of soil above top of wall: $L_{E3U1} := \left(L_{cd} + t_{wb} - t_{wt}\right) = 6.50\,m$

Height of sloped soil above top of wall over heel: $h_{E3locU1} := \left(L_{E3U1}\right) \cdot \tan(\beta) = 0.00\,m$

Weight of sloped soil above top of wall: $W_{E3U1} := \frac{\gamma_m}{2} \cdot h_{E3locU1} \cdot L_{E3U1} \cdot B = 0.0 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E3locU1} := L_{ab} + t_{wt} + \frac{2}{3} \cdot L_{E3U1} = 9.83\,m$

Moist soil from top of wall to groundwater level:

Height of soil from top of wall and top of GWL: $h_{1U1} = 7.00\,m$

Length from edge of wall at GWL to edge of heel: $L_{E4U1} := L_{E3U1} - \left(h_{1U1} \cdot S_{batter}\right) = 5.95\,m$

Weight of soil over heel from top of wall to GWL: $W_{E4U1} := \gamma_m \cdot h_{1U1} \cdot \frac{\left(L_{E3U1} + L_{E4U1}\right)}{2} \cdot B = 871.5 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E4locU1} := b - \frac{L_{E3U1}^2 + L_{E3U1} \cdot L_{E4U1} + L_{E4U1}^2}{3\left(L_{E3U1} + L_{E4U1}\right)} = 8.89\,m$

Saturated soil from groundwater to top of footing:

Height of soil from GWL to top of heel: $h_{E4U1} := h_{2U1} - t_{ftg} - Key_{h.d} = 3.50\,m$

Weight of soil over heel from GWL to top of heel: $W_{E5U1} := \left(\gamma_{sat}\right) \cdot h_{E4U1} \cdot \frac{\left(L_{E4U1} + L_{cd}\right)}{2} \cdot B = 447.6 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E5locU1} := b - \frac{L_{E4U1}^2 + L_{E4U1} \cdot L_{cd} + L_{cd}^2}{3\left(L_{E4U1} + L_{cd}\right)} = 9.09\,m$

$$\Sigma V_{SoilWaterU1} := W_{H1U1} + W_{E6U1} + W_{E3U1} + W_{E4U1} + W_{E5U1} + S_{U1} = 1370.5 \cdot kN$$

$$\Sigma M_{VertSoilWaterResistU1} := W_{H1U1} \cdot W_{E1locU1} + W_{E6U1} \cdot W_{E6locU1} \cdots + W_{E3U1} \cdot W_{E3locU1} + W_{E4U1} \cdot W_{E4locU1} + W_{E5U1} \cdot W_{E5locU1} + S_{U1} \cdot S_{U1loc} = 11903.5\,m \cdot kN$$

THIS PAGE INTENTIONALLY LEFT BLANK
PLEASE GO TO THE NEXT PAGE

STABILITY ASSESSMENT:

LOAD CASE U1

CHECK SLIDING ALONG HORIZONTAL SLIDING PLANE:

Summation of the vertical forces:

$$\Sigma V_{U1} := \Sigma V_{conc} + \Sigma V_{SoilWaterU1} + \Sigma V_{UpliftU1} = 1930.0 \cdot kN$$

Summation of the horizontal forces:

$$\Sigma H_{U1} := \Sigma H_{SoildriveU1} + \Sigma H_{SoilresistU1} = -841.7 \cdot kN$$

Safety Factor for Sliding Horizontal Failure Plane

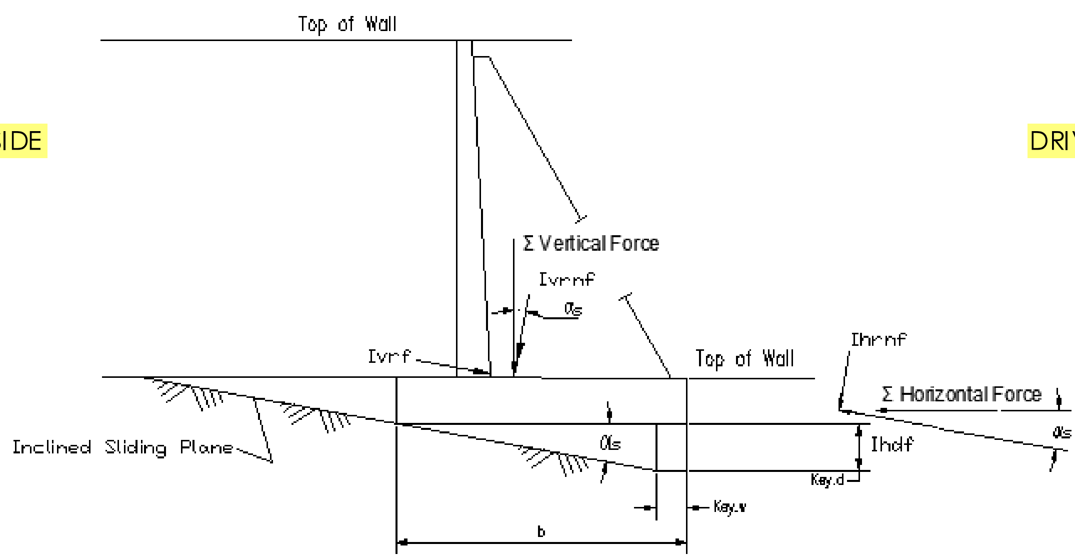
$$FS_{Horiz.SlidingU1} := \frac{\left|\Sigma V_{U1}\right| \cdot \tan\left(\phi_{rock} \cdot \frac{\pi}{180}\right)}{\left|\Sigma H_{U1}\right|} = 1.12$$

$$FS_{Sliding.check1.U1} := \begin{vmatrix} \text{"OKAY "} & \text{if } FS_{Horiz.SlidingU1} > FS_{sliding.reqU1} \\ \text{"Key req""} & \text{otherwise} \end{vmatrix} = \text{"Key req""}$$

CHECK FACTOR OF SAFETY SLIDING WITH KEY (INCLINED SLIDING PLANE):

RESISTING SIDE

DRIVING SIDE



TOE

HEEL

Ivrf=Inclined Resisting Force
Ivrnf=Inclined Resisting Normal Force
Ihrnf=Inclined Resisting Normal Force
Ihdf=Inclined Driving Force

$$\alpha s := \operatorname{atan}\left(\frac{-Key_{vdist}}{Key_{hdist}}\right) = 0.18 \qquad \text{as degrees=} \qquad \alpha s \cdot \left(\frac{180}{\pi}\right) = 10.30$$

(With properly engineered reinforced concrete Key, horizontal sliding plane thru Toe is protected, critical sliding plane is relocated to the INCLINED SLIDING PLANE FROM HEEL KEY To TOE, Bedrock Mass above this examing plane is mobilized by reinforced concrete key and combined into Structural Wedge.)

Resolve ΣV_{U1} & ΣH_{U1}

$$\Sigma V_{InclinedU1} := \cos(\alpha s) \cdot \left(\left|\Sigma V_{U1} + V_{rocksection}\right|\right) + \sin(\alpha s) \cdot \left|\Sigma H_{U1}\right| = 2326.5 \cdot kN$$

$$\Sigma H_{InclinedU1} := \cos(\alpha s) \cdot \left|\Sigma H_{U1}\right| - \sin(\alpha s) \cdot \left(\left|\Sigma V_{U1} + V_{rocksection}\right|\right) = 432.5 \cdot kN$$

LOAD CASE U1

Safety Factor for Sliding Inclined Failure Plane

$$FS_{InclinedlSlidingU1} := \frac{\Sigma V_{InclinedU1} \cdot \tan(\phi_r)}{\Sigma H_{InclinedU1}} = 2.40$$

$$FS_{Sliding.check2.U1} := \begin{cases} \text{"OKAY "} & \text{if } FS_{InclinedlSlidingU1} > FS_{sliding.reqU1} \\ \text{"NG - Revise Structure""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

CHECK FOUNDATION ECCENTRICITY:

Summation of the resisting moments about the toe:

$$\Sigma M_{resU1} := \Sigma M_{conc} + \Sigma M_{VertSoilWaterResistU1} + \Sigma M_{HorizSoilResistU1} + \Sigma M_{rocksection} = 20943 \cdot kN \cdot m$$

Summation of the overturning moments about the toe:

$$\Sigma M_{oU1} := \Sigma M_{LateralSoildriveU1} + \Sigma M_{UpliftU1} = -7682 \cdot kN \cdot m$$

Total moment: $\Sigma M_{U1} := \Sigma M_{resU1} + \Sigma M_{oU1} = 13261.2 \cdot kN \cdot m$

Normal force to base: $\Sigma V_{InclinedU1} = 2326.5 \cdot kN$

Inclined Sliding Plane Length: $L_{incline} := \frac{b}{\cos(\alpha s)} = 12.2\,m$

Eccentricity (inclined plane): $ex_{U1} := \frac{L_{incline}}{2} - \frac{\Sigma M_{U1}}{\Sigma V_{InclinedU1}} = 0.40\,m$ $\quad Kern := \frac{L_{incline}}{6} = 2.033\,m$

Eccentricity Check: $e_{check.U1} := \begin{cases} \text{"Okay"} & \text{if } ex_{U1} \le Kern \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"Okay"}$

CHECK FOUNDATION BEARING CAPACITY:

Base Section Modulus: $S_b := \frac{1}{6}\left(B \cdot L_{incline}^{\ 2}\right) = 24.79\,m^3$

Bearing Pressure Under Toe:

$$\sigma_{ToeU1} := \begin{cases} \left(\frac{\Sigma V_{InclinedU1}}{L_{incline} \cdot B} + \frac{\Sigma V_{InclinedU1} \cdot ex_{U1}}{S_b}\right) & \text{if } \frac{\Sigma V_{InclinedU1} \cdot ex_{U1}}{S_b} \le \frac{\Sigma V_{InclinedU1}}{L_{incline} \cdot B} \\ \frac{2 \cdot \Sigma V_{InclinedU1}}{B \cdot 3\left(\frac{b}{2} - ex_{U1}\right)} & \text{otherwise} \end{cases} = 228.1 \cdot kPa$$

$$Bearing_{ChecktoeU1} := \begin{cases} \text{"OKAY "} & \text{if } \sigma_{ToeU1} < \sigma_{allowU1} \\ \text{"NG""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

Bearing Pressure Under Heel:

$$\sigma_{HeelU1} := \begin{cases} \left(\frac{\Sigma V_{InclinedU1}}{L_{incline} \cdot B} - \frac{\Sigma V_{InclinedU1} \cdot ex_{U1}}{S_b}\right) & \text{if } \frac{\Sigma V_{InclinedU1} \cdot ex_{U1}}{S_b} \le \frac{\Sigma V_{InclinedU1}}{L_{incline} \cdot B} \\ 0 & \text{otherwise} \end{cases} = 153.4 \cdot kPa$$

$$Bearing_{CheckheelU1} := \left(\begin{cases} \text{"OKAY "} & \text{if } \sigma_{HeelU1} < \sigma_{allowU1} \wedge \sigma_{HeelU1} > 0 \\ \text{"NG - perform cracked base analysis""} & \text{otherwise} \end{cases}\right) = \text{"OKAY "}$$

CHECK FLOATATION:

Safety Factor for Floatation:

$$FS_{FloatationU1} := \frac{\Sigma V_{conc} + \Sigma V_{SoilWaterU1}}{\left|\Sigma V_{UpliftU1}\right|} = 3.98$$

$$FS_{Floatation.U1.check} := \begin{cases} \text{"OKAY"} & \text{if } FS_{FloatationU1} > FS_{req.U1.flt} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

CHECK OVERTURNING

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.
Assumptions are made in order to compute overturning stablity of indetermine forces on monolith with key;
(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.
(b) The horizontal resisting force acting on the key, P.key, is that required for static equilibrium
(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1

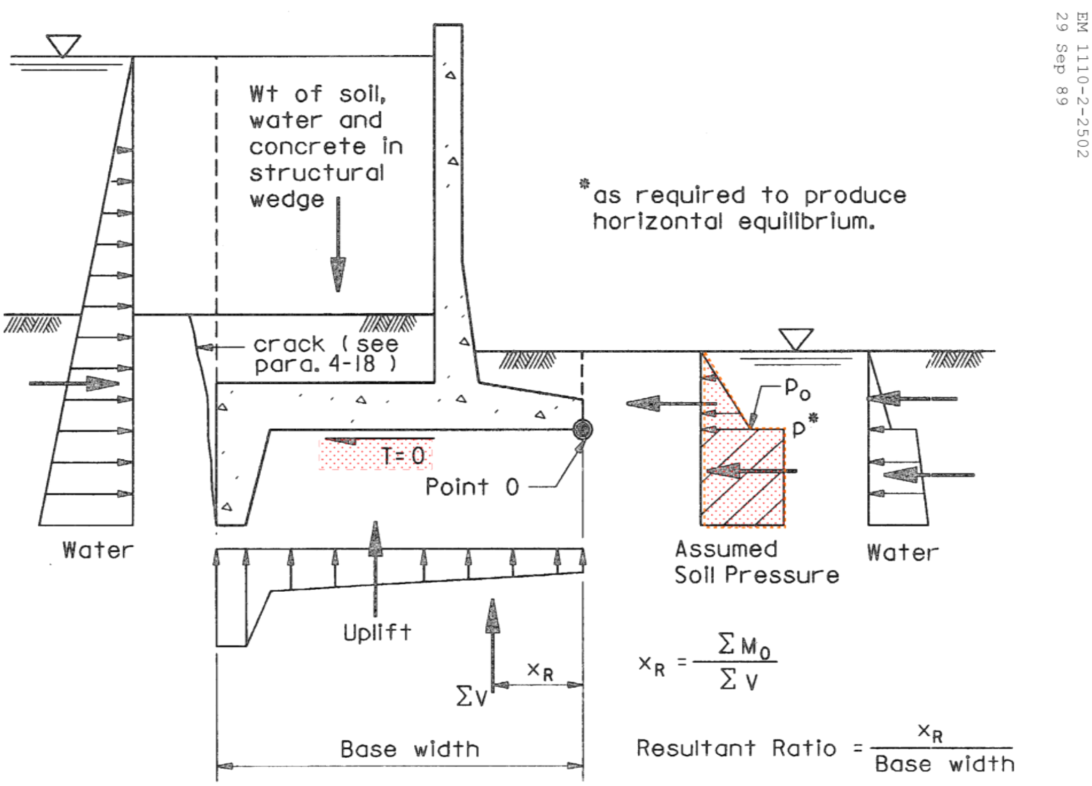


Figure 4-5. Forces for overturning analysis for wall with horizontal base and key

Modify Uplift for Overturning Analysis: **LOAD CASE U1**

(Uplift is calculated along the concrete/rock contact using the Line of Creep method)

Water Pressure at h: $u_{h.U1} := \Delta h_{g.hj.U1} \cdot \gamma_w = 73.50 \cdot kPa$

Water Pressure at o: $u_{o.U1} := \left(\Delta h_{g.no.U1} - \frac{\Delta h_{g.r.U1} \cdot L_{ho.U1}}{L_{ho.U1}}\right) \cdot \gamma_w = 34.3 \cdot kPa$

Head loss between point h and o: $\Delta h_{ho.U1} := \Delta h_{g.r.U1} \cdot \frac{L_{ho.U1}}{L_{ho.U1}} = 2\,m$

Length of concrete base (h -> o): $L_{baseho.U1} := Key_{h.w} + Key_{h.d} + Key_{hdist} + Key_{t.d} + Key_{t.w} = 14\,m$

Head loss along h -> j: $\Delta h_{hj.U1} := \Delta h_{ho.U1} \cdot \frac{Key_{h.w}}{L_{baseho.U1}} = 0.143\,m$

Water Pressure at j: $u_{j.U1} := \left(\Delta h_{g.hj.U1} - \Delta h_{hj.U1}\right) \cdot \gamma_w = 72.10 \cdot kPa$

Head loss along h -> k: $\Delta h_{hjk.U1} := \Delta h_{ho.U1} \cdot \left(\frac{Key_{h.w} + Key_{h.d}}{L_{baseho.U1}}\right) = 0.429\,m$

Water Pressure at k: $u_{k.U1} := \left(\Delta h_{g.km.U1} - \Delta h_{hjk.U1}\right) \cdot \gamma_w = 49.70 \cdot kPa$

Head loss along h -> m: $\Delta h_{hjkm.U1} := \Delta h_{ho.U1} \cdot \left(\frac{Key_{h.w} + Key_{h.d} + Key_{hdist}}{L_{baseho.U1}}\right) = 2\,m$

Water Pressure at m: $u_{m.U1} := \left(\Delta h_{g.km.U1} - \Delta h_{hjkm.U1}\right) \cdot \gamma_w = 34.30 \cdot kPa$

Head loss along h -> n: $\Delta h_{hjkmn.U1} := \Delta h_{ho.U1} \cdot \left(\frac{Key_{h.w} + Key_{h.d} + Key_{hdist} + Key_{t.d}}{L_{baseho.U1}}\right) = 2\,m$

Water Pressure at n: $u_{n.U1} := \left(\Delta h_{g.no.U1} - \Delta h_{hjkmn.U1}\right) \cdot \gamma_w = 34.30 \cdot kPa$

Uplift under key at heel: $V_{ulkeyhU1.OT} := \frac{\left(u_{h.U1} + u_{j.U1}\right) \cdot Key_{h.w}}{2} \cdot B \cdot -1 = -72.8 \cdot kN$

Moment Arm (from Point O): $V_{ulkeyhU1loc.OT} := b - \frac{Key_{h.w} \cdot \left(2 \cdot u_{j.U1} + u_{h.U1}\right)}{3 \cdot \left(u_{j.U1} + u_{h.U1}\right)} = 11.502\,m$

Uplift under base: $V_{ulbaseU1.OT} := \frac{\left(u_{k.U1} + u_{m.U1}\right) \cdot Key_{hdist}}{2} \cdot B \cdot -1 = -462 \cdot kN$

Moment Arm (from Point O): $V_{ulbaseU1loc.OT} := b - Key_{h.w} - \frac{Key_{hdist} \cdot \left(2 \cdot u_{m.U1} + u_{k.U1}\right)}{3 \cdot \left(u_{m.U1} + u_{k.U1}\right)} = 5.836\,m$

Uplift under key at toe: $V_{ulkeytU1.OT} := \frac{\left(u_{n.U1} + u_{o.U1}\right) \cdot Key_{t.w}}{2} \cdot B \cdot -1 = 0 \cdot kN$

Moment Arm (from Point O): $V_{ulkeytU1loc.OT} := \frac{Key_{t.w} \cdot \left(2 \cdot u_{n.U1} + u_{o.U1}\right)}{3 \cdot \left(u_{n.U1} + u_{o.U1}\right)} = 0$

$$\Sigma V_{UpliftU1.OT} := V_{ulkeyhU1.OT} + V_{ulbaseU1.OT} + V_{ulkeytU1.OT} = -535 \cdot kN$$

$$U_{U1.loc.OT} := \frac{V_{ulkeyhU1.OT} \cdot V_{ulkeyhU1loc.OT} + V_{ulbaseU1.OT} \cdot V_{ulbaseU1loc.OT} + V_{ulkeytU1.OT} \cdot V_{ulkeytU1loc.OT}}{\Sigma V_{UpliftU1.OT}} = 6.61\,m$$

$$\Sigma M_{UpliftU1.OT} := \Sigma V_{UpliftU1.OT} \cdot U_{U1.loc.OT} = -3533.6 \cdot kN \cdot m$$

Modify Lateral Water Pressure (Resisting) for Overturning Analysis:

(Resisting water pressure is calculated using the Line of Creep method)

Water Load at Key (heel): $H_{h2U1.OT} := \frac{u_{k.U1} + u_{j.U1}}{2} \cdot Key_{h.d} B = 121.8 \cdot kN$

Moment Arm (from Point O): $H_{h2locU1.OT} := \frac{Key_{h.d} \cdot \left(2 \cdot u_{k.U1} + u_{j.U1}\right)}{3\left(u_{k.U1} + u_{j.U1}\right)} + Key_{vdist} = -1.06\ m$

Water Load at Key (toe): $H_{h6U1.OT} := \frac{u_{o.U1} \cdot \left(UWSEL_{U1} - Bot_{ftg} + Key_{t.d}\right)}{2} \cdot B = 60 \cdot kN$

Moment Arm (from Point O): $H_{h6locU1.OT} := \frac{UWSEL_{U1} - Bot_{ftg} + Key_{t.d}}{3} = 1.17\ m$

$$\Sigma H_{waterresistU1.OT} := H_{h2U1.OT} + H_{h6U1.OT} = 181.82 \cdot kN$$

$$H_{waterresistlocU1.OT} := \frac{H_{h2U1.OT} \cdot H_{h2locU1.OT} + H_{h6U1.OT} \cdot H_{h6locU1.OT}}{\Sigma H_{waterresistU1.OT}} = -0.326\ m$$

$$\Sigma M_{waterresistU1.OT} := \Sigma H_{waterresistU1.OT} \cdot H_{waterresistlocU1.OT} = -59.24 \cdot kN \cdot m$$

Modify Lateral Soil Loads for Overturning Analysis:

(Lateral soil loads are calculated down to Point O instead of bottom of shear key)

Driving Soil Load (Headwater Side):

Surcharge Load: $E_{s1U1.OT} := S1_{U1} \cdot K_o \cdot \left(H_w + Key_{h.d} + Key_{vdist}\right) \cdot B \cdot -1 = 0 \cdot kN$

Moment Arm (from Point O): $E_{s1locU1.OT} := \frac{H_w + Key_{h.d} + Key_{vdist}}{2} = 6.25\ m$

Moist Soil Load above GWL: $E_{h1U1.OT} := \frac{\gamma_m \cdot K_o \cdot h_{1U1}^{\ 2}}{2} B \cdot -1 = -267.5 \cdot kN$

Moment Arm (from Point O): $E_{h1locU1.OT} := \frac{h_{1U1}}{3} + h_{2U1} + Key_{vdist} = 7.83\ m$

Saturated Soil Load below GWL: (rectangular component) $E_{h2U1.OT} := \left(\gamma_m \cdot K_o \cdot h_{1U1}\right) \cdot \left(h_{2U1} + Key_{vdist}\right) \cdot B \cdot -1 = -420.4 \cdot kN$

Moment Arm (from Point O): $E_{h2locU1.OT} := \frac{h_{2U1} + Key_{vdist}}{2} = 2.75\ m$

Saturated Soil Load below GWL: (triangular component) $E_{h2aU1.OT} := \frac{\left(\gamma_{sat} - \gamma_w\right) \cdot K_o \cdot \left(h_{2U1} + Key_{vdist}\right)^2}{2} \cdot B \cdot -1 = -100.8 \cdot kN$

Moment Arm (from Point O): $E_{h2alocU1.OT} := \frac{h_{2U1} + Key_{vdist}}{3} = 1.83\ m$

Resisting Soil Load (Tailwater Side):

(Determine resisting soil load based on depth variation between the keys (ie. Key_{vdist}). In case where key at heel is deeper than key at toe (ie. $Key_{vdist} < 0$), resisting soil load (p*) is assumed to produce horizontal equilibrium as per Figure 4-5 above. Resisting soil load (p_o) is neglected.)

Total Driving Force: $\Sigma H_{SoildriveU1.OT} := E_{s1U1.OT} + E_{h1U1.OT} + E_{h2U1.OT} + E_{h2aU1.OT} + H_{h2U1} = -1064.3 \cdot kN$

Total Resisting Force: $\Sigma H_{waterresistU1.OT} = 181.8 \cdot kN$

Assumed Soil Load p*: $E_{h8U1a.OT} := \left(\Sigma H_{SoildriveU1.OT} + \Sigma H_{waterresistU1.OT}\right) \cdot -1 = 882.524 \cdot kN$

Moment Arm (from Point O): $E_{h8U1a.loc.OT} := \dfrac{Key_{vdist}}{2} = -1\ m$

$$E_{h8U1.OT} := \begin{cases} E_{h8U1a.OT} & \text{if } Key_{vdist} < 0 \\ \Sigma H_{SoilresistU1} - H_{h6U1} - H_{h2aU1} - P_{sbU1} & \text{otherwise} \end{cases} = 882.524 \cdot kN$$

$$\Sigma M_{SoilresistU1} := \begin{cases} E_{h8U1a.OT} \cdot E_{h8U1a.loc.OT} & \text{if } Key_{vdist} < 0 \\ \Sigma M_{HorizSoilResistU1} - H_{h6U1} \cdot H_{h6locU1} - H_{h2aU1} \cdot H_{h2alocU1} - P_{sbU1} \cdot P_{sblocU1} & \text{otherwise} \end{cases} = -882.524 \cdot kN \cdot m$$

Sum of Moment about Point O:

$$\Sigma M_{LateraldriveU1.OT} := E_{s1U1.OT} \cdot E_{s1locU1.OT} + E_{h1U1.OT} \cdot E_{h1locU1.OT} + E_{h2U1.OT} \cdot E_{h2locU1.OT} \dots + E_{h2aU1.OT} \cdot E_{h2alocU1.OT} + H_{h2U1} \cdot H_{h2locU1} = -3574.5 \cdot kN \cdot m$$

$$\Sigma M_{LateralresistU1.OT} := \Sigma M_{waterresistU1.OT} + \Sigma M_{SoilresistU1} = -941.8 \cdot kN \cdot m$$

Total moment:

$$\Sigma M_{U1.OT} := \Sigma M_{conc} + \Sigma M_{VertSoilWaterResistU1} + \Sigma M_{UpliftU1.OT} + \Sigma M_{LateraldriveU1.OT} + \Sigma M_{LateralresistU1.OT} = 10586.7 \cdot kN \cdot m$$

Total Vertical Force: $\Sigma V_{U1.OT} := \Sigma V_{conc} + \Sigma V_{SoilWaterU1} + \Sigma V_{UpliftU1.OT} = 2042.0 \cdot kN$

Distance X_R: EM 1110-2-2502 Eq.4-1 $X_{R.U1} := \dfrac{\Sigma M_{U1.OT}}{\Sigma V_{U1.OT}} = 5.185\ m$

Overturning Resultant Ratio $Ratio_{U1.OT} := \dfrac{X_{R.U1}}{b} = 0.43$

$$Ratio_{U1.OT.check} := \begin{cases} \text{"OKAY "} & \text{if } Ratio_{U1.OT} > X_{R.reqU1} \\ \text{"Revise Structure""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

CHECK FOUNDATION ECCENTRICITY (HORIZONTAL PLANE):

Eccentricity (horizontal plan): $ex_{U1.OT} := \dfrac{b}{2} - \dfrac{\Sigma M_{U1.OT}}{\Sigma V_{U1.OT}} = 0.82\ m$ $\quad Kern_{OT} := \dfrac{b}{6} = 2\ m$

Eccentricity Check:

$$e_{check.U1.OT} := \begin{cases} \text{"Okay"} & \text{if } ex_{U1} \le Kern_{OT} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"Okay"}$$

CHECK FOUNDATION BEARING CAPACITY (HORIZONTAL PLANE):

Base Section Modulus: $S_{b.OT} := \frac{1}{6}\left(B \cdot b^2\right) = 24\,m^3$

Bearing Pressure Under Toe:

$$\sigma_{ToeU1.OT} := \begin{cases} \left(\frac{\Sigma V_{U1.OT}}{b \cdot B} + \frac{\Sigma V_{U1.OT} \cdot ex_{U1.OT}}{S_{b.OT}}\right) & \text{if } \frac{\Sigma V_{U1.OT}}{b \cdot B} \geq \frac{\Sigma V_{U1.OT} \cdot ex_{U1.OT}}{S_{b.OT}} \\ \frac{2 \cdot \Sigma V_{U1.OT}}{B \cdot 3\left(\frac{b}{2} - ex_{U1.OT}\right)} & \text{otherwise} \end{cases} = 239.6 \cdot kPa$$

$$Bearing_{ChecktoeU1.OT} := \begin{cases} \text{"OKAY "} & \text{if } \sigma_{ToeU1.OT} < \sigma_{allowU1} \\ \text{"NG - for reference only""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

Bearing Pressure Under Heel:

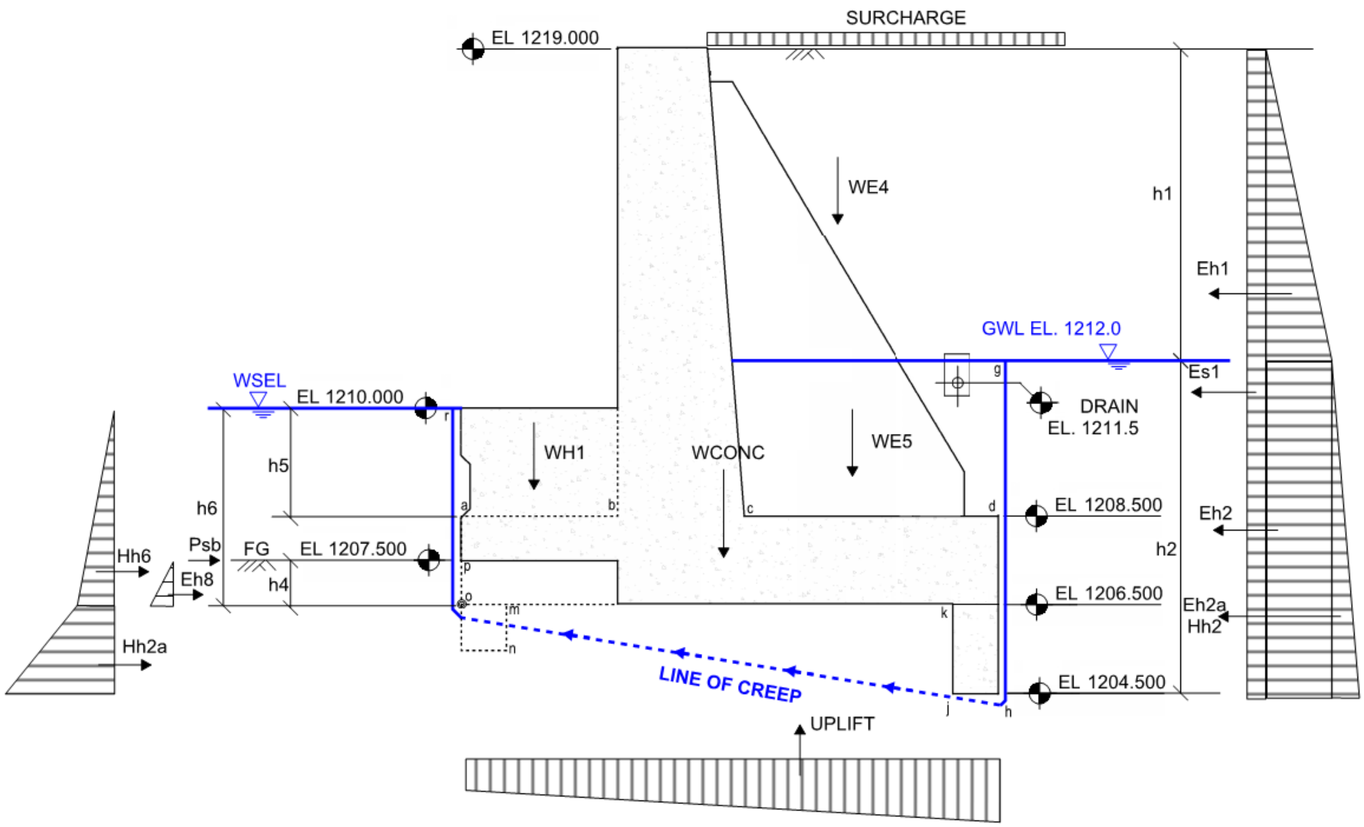
$$\sigma_{HeelU1.OT} := \begin{cases} \left(\frac{\Sigma V_{U1.OT}}{b \cdot B} - \frac{\Sigma V_{U1.OT} \cdot ex_{U1.OT}}{S_{b.OT}}\right) & \text{if } \frac{\Sigma V_{U1.OT}}{b \cdot B} \geq \frac{\Sigma V_{U1.OT} \cdot ex_{U1.OT}}{S_{b.OT}} \\ 0 & \text{otherwise} \end{cases} = 100.8 \cdot kPa$$

$$Bearing_{CheckheelU1.OT} := \left(\begin{cases} \text{"OKAY "} & \text{if } \sigma_{HeelU1.OT} < \sigma_{allowU1} \wedge \sigma_{HeelU1.OT} > 0 \\ \text{"NG - for reference only""} & \text{otherwise} \end{cases}\right) = \text{"OKAY "}$$

SUMMARY OF STABILITY ASSESSMENT:

LOAD CASE U1

Sliding Factor of Safety: (Horizontal Plane - Ref only)	$FS_{Horiz.SlidingU1} = 1.12$	$FS_{Sliding.check1.U1}$ = "Key req""
Sliding Factor of Safety: (Inclined Plane)	$FS_{InclinedlSlidingU1} = 2.4$	$FS_{Sliding.check2.U1}$ = "OKAY "
Eccentricity: (Inclined Plane)	$ex_{U1} = 0.40\ m$	$e_{check.U1}$ = "Okay"
Bearing Pressure At Heel: (Inclined Plane)	$\sigma_{HeelU1} = 153 \cdot kPa$	$Bearing_{CheckheelU1}$ = "OKAY "
Bearing Pressure At Toe: (Inclined Plane)	$\sigma_{ToeU1} = 228 \cdot kPa$	$Bearing_{ChecktoeU1}$ = "OKAY "
Flotation Factor of Safety (horizontal plane)	$FS_{FloatationU1} = 3.98$	$FS_{Floatation.U1.check}$ = "OKAY "
Overturning Resultant Ratio: (horizontal plane)	$Ratio_{U1.OT} = 0.43$	$Ratio_{U1.OT.check}$ = "OKAY "
Eccentricity: (horizontal plane - Ref only)	$ex_{U1.OT} = 0.82\ m$	$e_{check.U1.OT}$ = "Okay"
Bearing Pressure At Heel: (horizontal plane - Ref only)	$\sigma_{HeelU1.OT} = 101 \cdot kPa$	$Bearing_{CheckheelU1.OT}$ = "OKAY "
Bearing Pressure At Toe: (horizontal plane - Ref only)	$\sigma_{ToeU1.OT} = 240 \cdot kPa$	$Bearing_{ChecktoeU1.OT}$ = "OKAY "



UN1 DESIGN CASE

LOAD CASE UN1 ACCEPTANCE PARAMETERS

FS sliding:

Unusual (UN) 1.3 (without cohesion) (Table 3-3, USACE EM 1110-2-2100)

Resultant Location:

Unsual (UN) Inside middle third ~100% base in compression

Required Factor of Safety for Sliding: $FS_{sliding.reqUN1} := 1.3$ (Without Cohesion)

Allowable rock bearing pressure: $\sigma_{allowUN1} := 1470kPa$ (Section 5.2, Design Criteria EM 1110-2-2100 Section 3-10)

Overturning Required Resultant Ratio: $X_{R.reqUN1} := 0.333$ (EM 1110-2-2502, Figure 4-4)

Required Factor of Safety for Floatation $FS_{req.UN1.flt} := 1.3$

SOIL HEIGHTS and Water Levels:

LOAD CASE UN1

Heel Conditions:

Groundwater Elevation at Heel: $GWL_{UN1} := 1212.0m$

Distance from Finish Grade to Groundwater at Heel: $h_{1UN1} := \left[T_w - GWL_{UN1} + \left(L_{cd} + t_{wb} - t_{wt}\right)\cdot \tan(\beta)\right] = 7.00\ m$

Distance from Water Surface to Bottom of Footing at Heel: $h_{2UN1} := GWL_{UN1} - Bot_{ftg} + Key_{h.d} = 7.50\ m$

Toe Conditions:

Water Surface Elevation at Toe: $WSEL_{UN1} := 1210.0m$

Water Surface Elevation at Toe for Uplift: $UWSEL_{UN1} := 1210.0\cdot m$

Finish Grade at Toe providing lateral resistance: $FG_{toeUN1} := 1207.5\cdot m$

Soil Depth Above top of footing: $h_{3aUN1} := FG_{toeUN1} - Top_{ftg} = -1\ m$

$$h_{3UN1} := \begin{cases} h_{3aUN1} & \text{if } FG_{toeUN1} - Top_{ftg} \ge 0 \\ 0 & \text{otherwise} \end{cases} = 0$$

Resisting Fill at Toe: $h_{4UN1} := FG_{toeUN1} - Bot_{ftg} + Key_{t.d} = 1.00\ m$

Distance from Water Level to Top of Footing at Toe: $h_{5UN1} := WSEL_{UN1} - Top_{ftg} = 1.50\ m$

Distance from Water Surface to Bottom of Footing at Toe: $h_{6UN1} := WSEL_{UN1} - Bot_{ftg} + Key_{t.d} = 3.50\ m$

Soil Depth Above WSEL: $h_{7aUN1} := FG_{toeUN1} - WSEL_{UN1} = -2.5\ m$

$$h_{7UN1} := \begin{cases} h_{7aUN1} & \text{if } FG_{toeUN1} - WSEL_{UN1} \ge 0 \\ 0 & \text{otherwise} \end{cases} = 0$$

Soil Depth Below WSEL:

$$h_{8UN1} := \begin{cases} WSEL_{UN1} - Bot_{ftg} + Key_{t.d} & \text{if } FG_{toeUN1} - WSEL_{UN1} \ge 0 \\ h_{4UN1} & \text{otherwise} \end{cases} = 1$$

For Line of Creep Method: $L_{ho.UN1} := \sqrt{b^2 + \left(Key_{h.d} - Key_{t.d}\right)^2} = 12.166\ m$

Head Loss from Point g:

$\Delta h_{g.hj.UN1} := h_{2UN1} = 7.5\ m$ (to point h & j)

$\Delta h_{g.km.UN1} := GWL_{UN1} - Bot_{ftg} = 5.5\ m$ (to point k & m)

$\Delta h_{g.no.UN1} := GWL_{UN1} - Bot_{ftg} + Key_{t.d} = 5.5\ m$ (to point n & o)

$\Delta h_{g.p.UN1} := GWL_{UN1} - FG_{toeUN1} = 4.5\ m$ (to point p)

$\Delta h_{g.r.UN1} := GWL_{UN1} - UWSEL_{UN1} = 2\ m$ (to point r)

Surcharge

Surcharge on Heel: $S1_{UN1} := 15.0\ \frac{kN}{m^2}$

Calculate Soil Lateral Pressure Coefficients:

LOAD CASE UN1

For all load cases except seismic, soil loading to be based on At-Rest Condition.
Calculate at-rest pressure coefficient Ko based on Jaky's (1944) equation.

Soil At Rest Static Coefficient: $K_o := \frac{1 - \sin(\phi)}{1 + \sin(\beta)} = 0.546$ (Eq. 3-6, USACE EM 1110-2-2502)

Lateral - Driving Force

Static At-Rest:

Surcharge Load: $E_{s1UN1} := S1_{UN1} \cdot K_o \cdot \left(H_w + Key_{h.d}\right) \cdot B \cdot -1 = -118.757 \cdot kN$

Moment Arm (from bottom of footing): $E_{s1locUN1} := \frac{H_w + Key_{h.d}}{2} + Key_{vdist} = 5.25\ m$

Moist Soil Load above GWL: $E_{h1UN1} := \frac{\gamma_m \cdot K_o \cdot h_{1UN1}^{\ 2}}{2} \cdot B \cdot -1 = -267.5 \cdot kN$

Moment Arm (from bottom of footing): $E_{h1locUN1} := \frac{h_{1UN1}}{3} + h_{2UN1} + Key_{vdist} = 7.83\ m$

Saturated Soil Load below GWL:
(rectangular component)
$E_{h2UN1} := \left(\gamma_m \cdot K_o \cdot h_{1UN1}\right) \cdot \left(h_{2UN1}\right) \cdot B \cdot -1 = -573.3 \cdot kN$

Moment Arm (from bottom of footing): $E_{h2locUN1} := \frac{h_{2UN1}}{2} + Key_{vdist} = 1.75\ m$

Saturated Soil Load below GWT:
(triangular L
$E_{h2aUN1} := \frac{\left(\gamma_{sat} - \gamma_w\right) \cdot K_o \cdot h_{2UN1}^{\ 2}}{2} \cdot B \cdot -1 = -187.3 \cdot kN$

Moment Arm (from bottom of footing): $E_{h2alocUN1} := \frac{h_{2UN1}}{3} + Key_{vdist} = 0.50\ m$

Lateral Water Load:

Water Load GWL to Bottom of Key: $H_{h2UN1} := \frac{\gamma_w \cdot h_{2UN1}^{\ 2}}{2} \cdot B \cdot -1 = -275.6 \cdot kN$

Moment Arm (from bottom of footing): $H_{h2locUN1} := \frac{h_{2UN1}}{3} + Key_{vdist} = 0.50\ m$

$$\Sigma H_{SoildriveUN1} := E_{s1UN1} + E_{h1UN1} + E_{h2UN1} + E_{h2aUN1} + H_{h2UN1} = -1422.6 \cdot kN$$

$$\Sigma M_{LateralSoildriveUN1} := E_{s1UN1} \cdot E_{s1locUN1} + E_{h1UN1} \cdot E_{h1locUN1} + E_{h2UN1} \cdot E_{h2locUN1} \ldots + E_{h2aUN1} \cdot E_{h2alocUN1} + H_{h2UN1} \cdot H_{h2locUN1} = -3954.0\ m \cdot kN$$

Lateral - Resisting Force

LOAD CASE UN1

Lateral Water Load:

Water Load WSEL to Bottom of Footing: $H_{h6UN1} := \frac{\gamma_w \cdot h_{6UN1}^2}{2} \cdot B = 60.0 \cdot kN$

Moment Arm (from bot. of toe key): $H_{h6locUN1} := \frac{h_{6UN1}}{3} = 1.17\,m$

Water Load Bot. of Footing to Bot. of H. Key: $H_{h2aUN1} := \left[\left(UWSEL_{UN1} - Bot_{ftg} + Key_{t.d}\right) + h_{2UN1}\right] \cdot \frac{Key_{h.d}}{2} \cdot \gamma_w \cdot B = 107.8 \cdot kN$

Moment Arm (from bot. of toe key): $H_{h2alocUN1} := \frac{Key_{h.d} \cdot \left[2 \cdot \left(UWSEL_{UN1} - Bot_{ftg} + Key_{t.d}\right) + h_{2UN1}\right]}{3\left[h_{2UN1} + \left(UWSEL_{UN1} - Bot_{ftg} + Key_{t.d}\right)\right]} \dots + Key_{vdist} = -1.12\,m$

Lateral Soil Load:

Moist Soil Load above WSEL: $E_{h7UN1} := \frac{\gamma_m \cdot K_o \cdot h_{7UN1}^2}{2} \cdot B = 0.0 \cdot kN$

Moment Arm (from bot. of toe key): $E_{h7locUN1} := h_{6UN1} + \frac{h_{7UN1}}{3} + Key_{vdist} = 1.50\,m$

Saturated Soil Load below WSEL: (rectangular component) $E_{h8UN1} := \left(\gamma_m \cdot K_o \cdot h_{7UN1}\right) \cdot h_{8UN1} \cdot B = 0.0 \cdot kN$

Moment Arm (from bot. of toe key): $E_{h8locUN1} := \frac{h_{8UN1}}{2} = 0.50\,m$

Saturated Soil Load below WSEL: (triangular component) $E_{h8aUN1} := \frac{\left[\left(\gamma_{sat} - \gamma_w\right) \cdot K_o\right] \cdot h_{8UN1}^2}{2} \cdot B = 3.3 \cdot kN$

Moment Arm (from bot. of footing): $E_{h8alocUN1} := \frac{h_{8UN1}}{3} = 0.33\,m$

Lateral Resistance from Stilling Basin:

Lateral Resistance from Stilling Basin: $P_{sbUN1} := 291\,kN$ (Force needed to achieve the required sliding factor of safety in case UN2)

Moment Arm (from bot. of toe key): $P_{sblocUN1} := \frac{t_{ftg}}{2} + Key_{t.d} = 1.00\,m$

$$\Sigma H_{SoilresistUN1} := H_{h6UN1} + H_{h2aUN1} + E_{h7UN1} + E_{h8UN1} + E_{h8aUN1} + P_{sbUN1} = 462.2 \cdot kN$$

$$\Sigma M_{HorizSoilResistUN1} := H_{h6UN1} \cdot H_{h6locUN1} + H_{h2aUN1} \cdot H_{h2alocUN1} + E_{h7UN1} \cdot E_{h7locUN1} \dots + E_{h8UN1} \cdot E_{h8locUN1} + E_{h8aUN1} \cdot E_{h8alocUN1} + P_{sbUN1} \cdot P_{sblocUN1} = 241.3\,m \cdot kN$$

Vertical Force:

UPLIFT: Linear distribution from water at heel to water at toe:

$$\Sigma V_{UpliftUN1} := \left[\left(UWSEL_{UN1} - Bot_{ftg} + Key_{t.d}\right) + h_{2UN1}\right] \cdot \frac{b}{2} \cdot \gamma_w \cdot B \cdot -1 = -646.8 \cdot kN$$

Moment Arm (from Point O): $V_{UpliftUN1aloc} := \frac{b \cdot \left[2 \cdot h_{2UN1} + \left(UWSEL_{UN1} - Bot_{ftg} + Key_{t.d}\right)\right]}{3\left[h_{2UN1} + \left(UWSEL_{UN1} - Bot_{ftg} + Key_{t.d}\right)\right]} = 6.727\,m$

$$\Sigma M_{UpliftUN1} := \Sigma V_{UpliftUN1} \cdot V_{UpliftUN1aloc} = -4351.2 \cdot kN \cdot m$$

Weight of soil and water over toe:

Water Above the Top of Footing: $W_{H1UN1} := \gamma_w \cdot h_{5UN1} \cdot L_{ab} \cdot B = 51.45 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E1locUN1} := \frac{L_{ab}}{2} = 1.75\ m$

Soil above top of footing: $W_{E6UN1} := \gamma_b \cdot h_{3UN1} \cdot L_{ab} \cdot B = 0.0 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E6locUN1} := \frac{L_{ab}}{2} = 1.75\ m$

Vertical Load Due to Surcharge: $S_{UN1} := S1_{UN1} \cdot L_{cd} \cdot B = 85.125 \cdot kN$ $\quad S_{UN1loc} := b - \frac{L_{cd}}{2} = 9.16\ m$

Weight of soil and water over heel:

Moist Soil for sloped grade above top of wall:

Length of sloped portion of soil above top of wall: $L_{E3UN1} := \left(L_{cd} + t_{wb} - t_{wt}\right) = 6.50\ m$

Height of sloped soil above top of wall over heel: $h_{E3locUN1} := \left(L_{E3UN1}\right) \cdot \tan(\beta) = 0.00\ m$

Weight of sloped soil above top of wall: $W_{E3UN1} := \frac{\gamma_m}{2} \cdot h_{E3locUN1} \cdot L_{E3UN1} \cdot B = 0.0 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E3locUN1} := L_{ab} + t_{wt} + \frac{2}{3} \cdot L_{E3UN1} = 9.83\ m$

Moist soil from top of wall to groundwater level:

Height of soil from top of wall and top of GWL: $h_{1UN1} = 7.00\ m$

Length from edge of wall at GWL to edge of heel: $L_{E4UN1} := L_{E3UN1} - \left(h_{1UN1} \cdot S_{batter}\right) = 5.95\ m$

Weight of soil over heel from top of wall to GWL: $W_{E4UN1} := \gamma_m \cdot h_{1UN1} \cdot \frac{\left(L_{E3UN1} + L_{E4UN1}\right)}{2} \cdot B = 871.5 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E4locUN1} := b - \frac{L_{E3UN1}^2 + L_{E3UN1} \cdot L_{E4UN1} + L_{E4UN1}^2}{3\left(L_{E3UN1} + L_{E4UN1}\right)} = 8.89\ m$

Saturated soil from groundwater to top of footing:

Height of soil from GWL to top of heel: $h_{E4UN1} := h_{2UN1} - t_{ftg} - Key_{h.d} = 3.50\ m$

Weight of soil over heel from GWL to top of heel: $W_{E5UN1} := \left(\gamma_{sat}\right) \cdot h_{E4UN1} \cdot \frac{\left(L_{E4UN1} + L_{cd}\right)}{2} \cdot B = 447.6 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E5locUN1} := b - \frac{L_{E4UN1}^2 + L_{E4UN1} \cdot L_{cd} + L_{cd}^2}{3\left(L_{E4UN1} + L_{cd}\right)} = 9.09\ m$

$$\Sigma V_{SoilWaterUN1} := W_{H1UN1} + W_{E6UN1} + W_{E3UN1} + W_{E4UN1} + W_{E5UN1} + S_{UN1} = 1455.6 \cdot kN$$

$$\Sigma M_{VertSoilWaterResistUN1} := W_{H1UN1} \cdot W_{E1locUN1} + W_{E6UN1} \cdot W_{E6locUN1} \cdots + W_{E3UN1} \cdot W_{E3locUN1} + W_{E4UN1} \cdot W_{E4locUN1} + W_{E5UN1} \cdot W_{E5locUN1} + S_{UN1} \cdot S_{UN1loc} = 12683.5\ m \cdot kN$$

THIS PAGE INTENTIONALLY LEFT BLANK
PLEASE GO TO THE NEXT PAGE

STABILITY ASSESSMENT:

LOAD CASE UN1

CHECK SLIDING ALONG HORIZONTAL SLIDING PLANE:

Summation of the vertical forces:

$$\Sigma V_{UN1} := \Sigma V_{conc} + \Sigma V_{SoilWaterUN1} + \Sigma V_{UpliftUN1} = 2015.1 \cdot kN$$

Summation of the horizontal forces:

$$\Sigma H_{UN1} := \Sigma H_{SoildriveUN1} + \Sigma H_{SoilresistUN1} = -960.4 \cdot kN$$

Safety Factor for Sliding Horizontal Failure Plane

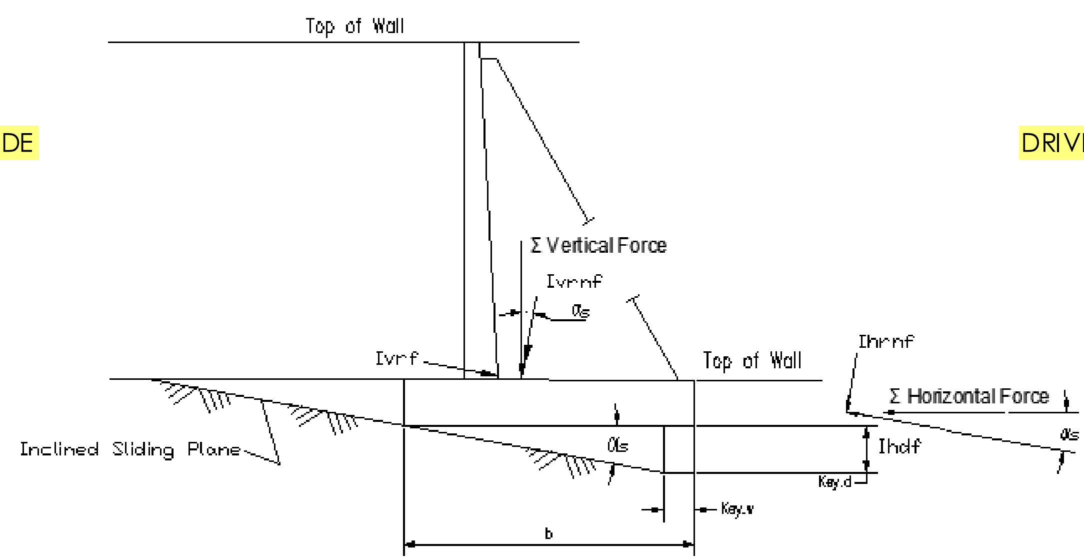
$$FS_{Horiz.SlidingUN1} := \frac{\left|\Sigma V_{UN1}\right| \cdot \tan\left(\phi_{rock} \cdot \frac{\pi}{180}\right)}{\left|\Sigma H_{UN1}\right|} = 1.02$$

$$FS_{Sliding.check1.UN1} := \begin{vmatrix} \text{"OKAY "} & \text{if } FS_{Horiz.SlidingUN1} > FS_{sliding.reqUN1} \\ \text{"NG - key req'"} & \text{otherwise} \end{vmatrix} = \text{"NG - key req'"}$$

CHECK FACTOR OF SAFETY SLIDING WITH KEY (INCLINED SLIDING PLANE):

RESISTING SIDE

DRIVING SIDE



TOE

HEEL

Ivrf=Inclined Resisting Force
Ivrnf=Inclined Resisting Normal Force
Ihrnf=Inclined Resisting Normal Force
Ihdf=Inclined Driving Force

$\alpha s = 0.18$ as degrees= $\alpha s \cdot \left(\frac{180}{\pi}\right) = 10.30$

(With properly engineered reinforced concrete Key, horizontal sliding plane thru Toe is protected, critical sliding plane is relocated to the INCLINED SLIDING PLANE FROM HEEL KEY To TOE, Bedrock Mass above this examing plane is mobilized by reinforced concrete key and combined into Structural Wedge.)

Resolve ΣV_{UN1} & ΣH_{UN1}

$$\Sigma V_{InclinedUN1} := \cos(\alpha s) \cdot \left(\left|\Sigma V_{UN1} + V_{rocksection}\right|\right) + \sin(\alpha s) \cdot \left|\Sigma H_{UN1}\right| = 2431.5 \cdot kN$$

$$\Sigma H_{InclinedUN1} := \cos(\alpha s) \cdot \left|\Sigma H_{UN1}\right| - \sin(\alpha s) \cdot \left(\left|\Sigma V_{UN1} + V_{rocksection}\right|\right) = 534.1 \cdot kN$$

LOAD CASE UN1

Safety Factor for Sliding Inclined Failure Plane

$$FS_{InclinedlSlidingUN1} := \frac{\Sigma V_{InclinedUN1} \cdot \tan(\phi_r)}{\Sigma H_{InclinedUN1}} = 2.03$$

$$FS_{Sliding.check2.UN1} := \begin{cases} \text{"OKAY "} & \text{if } FS_{InclinedlSlidingUN1} > FS_{sliding.reqUN1} \\ \text{"NG - Revise Structure""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

CHECK FOUNDATION ECCENTRICITY:

Summation of the resisting moments about the toe:

$$\Sigma M_{resUN1} := \Sigma M_{conc} + \Sigma M_{VertSoilWaterResistUN1} + \Sigma M_{HorizSoilResistUN1} + \Sigma M_{rocksection} = 21723 \cdot kN \cdot m$$

Summation of the overturning moments about the toe:

$$\Sigma M_{oUN1} := \Sigma M_{LateralSoildriveUN1} + \Sigma M_{UpliftUN1} = -8305 \cdot kN \cdot m$$

Total moment: $\Sigma M_{UN1} := \Sigma M_{resUN1} + \Sigma M_{oUN1} = 13417.6 \cdot kN \cdot m$

Normal force to base: $\Sigma V_{InclinedUN1} = 2431.5 \cdot kN$

Inclined Sliding Plane Length: $L_{incline} = 12.2 \cdot m$

Eccentricity (inclined plane): $ex_{UN1} := \frac{L_{incline}}{2} - \frac{\Sigma M_{UN1}}{\Sigma V_{InclinedUN1}} = 0.58\ m$ $\qquad Kern = 2.033\ m$

Eccentricity Check: $e_{check.UN1} := \begin{cases} \text{"Okay"} & \text{if } ex_{UN1} \le Kern \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"Okay"}$

CHECK FOUNDATION BEARING CAPACITY:

Base Section Modulus: $S_b = 24.79\ m^3$

Bearing Pressure Under Toe:

$$\sigma_{ToeUN1} := \begin{cases} \left(\frac{\Sigma V_{InclinedUN1}}{L_{incline} \cdot B} + \frac{\Sigma V_{InclinedUN1} \cdot ex_{UN1}}{S_b}\right) & \text{if } \frac{\Sigma V_{InclinedUN1} \cdot ex_{UN1}}{S_b} \le \frac{\Sigma V_{InclinedUN1}}{L_{incline} \cdot B} \\ \frac{2 \cdot \Sigma V_{InclinedUN1}}{B \cdot 3\left(\frac{b}{2} - ex_{UN1}\right)} & \text{otherwise} \end{cases} = 256.2 \cdot kPa$$

$$Bearing_{ChecktoeUN1} := \begin{cases} \text{"OKAY "} & \text{if } \sigma_{ToeUN1} < \sigma_{allowUN1} \\ \text{"NG""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

Bearing Pressure Under Heel:

$$\sigma_{HeelUN1} := \begin{cases} \left(\frac{\Sigma V_{InclinedUN1}}{L_{incline} \cdot B} - \frac{\Sigma V_{InclinedUN1} \cdot ex_{UN1}}{S_b}\right) & \text{if } \frac{\Sigma V_{InclinedUN1} \cdot ex_{UN1}}{S_b} \le \frac{\Sigma V_{InclinedUN1}}{L_{incline} \cdot B} \\ 0 & \text{otherwise} \end{cases} = 142.5 \cdot kPa$$

$$Bearing_{CheckheelUN1} := \left(\begin{cases} \text{"OKAY "} & \text{if } \sigma_{HeelUN1} < \sigma_{allowUN1} \wedge \sigma_{HeelUN1} > 0 \\ \text{"NG - perform cracked base analysis""} & \text{otherwise} \end{cases}\right) = \text{"OKAY "}$$

CHECK FLOATATION:

Safety Factor for Floatation:

$$FS_{FloatationUN1} := \frac{\Sigma V_{conc} + \Sigma V_{SoilWaterUN1}}{\left|\Sigma V_{UpliftUN1}\right|} = 4.12$$

$$FS_{Floatation.UN1.check} := \begin{cases} \text{"OKAY "} & \text{if } FS_{FloatationUN1} > FS_{req.UN1.flt} \\ \text{"Revise Structure""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

CHECK OVERTURNING

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.
Assumptions are made in order to compute overturning stablity of indetermine forces on monolith with key;
(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.
(b) The horizontal resisting force acting on the key, P.key, is that required for static equilibrium
(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1

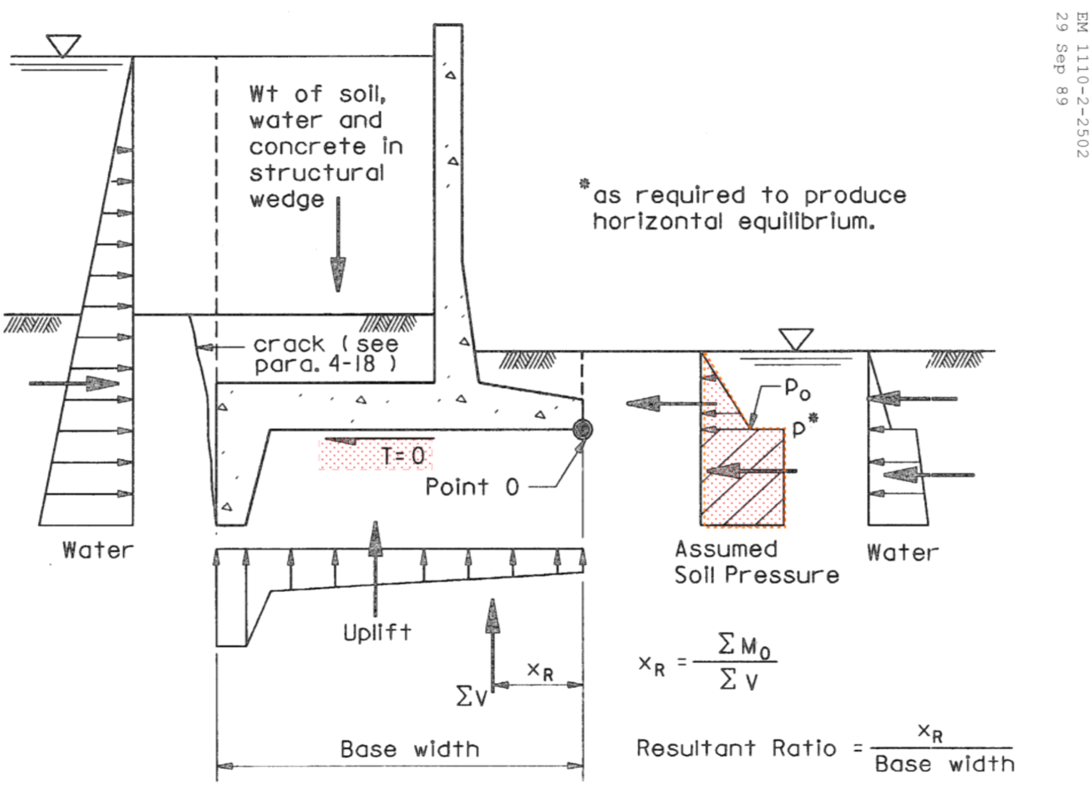


Figure 4-5. Forces for overturning analysis for wall with horizontal base and key

Modify Uplift for Overturning Analysis: **LOAD CASE UN1**

(Uplift is calculated along the concrete/rock contact using the Line of Creep method)

Water Pressure at h: $u_{h.UN1} := \Delta h_{g.hj.UN1} \cdot \gamma_w = 73.50 \cdot kPa$

Water Pressure at o: $u_{o.UN1} := \left(\Delta h_{g.no.UN1} - \frac{\Delta h_{g.r.UN1} \cdot L_{ho.UN1}}{L_{ho.UN1}}\right) \cdot \gamma_w = 34.3 \cdot kPa$

Head loss between point h and o: $\Delta h_{ho.UN1} := \Delta h_{g.r.UN1} \cdot \frac{L_{ho.UN1}}{L_{ho.UN1}} = 2\,m$

Length of concrete base (h -> o): $L_{baseho.UN1} := Key_{h.w} + Key_{h.d} + Key_{hdist} + Key_{t.d} + Key_{t.w} = 14\,m$

Head loss along h -> j: $\Delta h_{hj.UN1} := \Delta h_{ho.UN1} \cdot \frac{Key_{h.w}}{L_{baseho.UN1}} = 0.143\,m$

Water Pressure at j: $u_{j.UN1} := \left(\Delta h_{g.hj.UN1} - \Delta h_{hj.UN1}\right) \cdot \gamma_w = 72.10 \cdot kPa$

Head loss along h -> k: $\Delta h_{hjk.UN1} := \Delta h_{ho.UN1} \cdot \left(\frac{Key_{h.w} + Key_{h.d}}{L_{baseho.UN1}}\right) = 0.429\,m$

Water Pressure at k: $u_{k.UN1} := \left(\Delta h_{g.km.UN1} - \Delta h_{hjk.UN1}\right) \cdot \gamma_w = 49.70 \cdot kPa$

Head loss along h -> m: $\Delta h_{hjkm.UN1} := \Delta h_{ho.UN1} \cdot \left(\frac{Key_{h.w} + Key_{h.d} + Key_{hdist}}{L_{baseho.UN1}}\right) = 2\,m$

Water Pressure at m: $u_{m.UN1} := \left(\Delta h_{g.km.UN1} - \Delta h_{hjkm.UN1}\right) \cdot \gamma_w = 34.30 \cdot kPa$

Head loss along h -> n: $\Delta h_{hjkmn.UN1} := \Delta h_{ho.UN1} \cdot \left(\frac{Key_{h.w} + Key_{h.d} + Key_{hdist} + Key_{t.d}}{L_{baseho.UN1}}\right) = 2\,m$

Water Pressure at n: $u_{n.UN1} := \left(\Delta h_{g.no.UN1} - \Delta h_{hjkmn.UN1}\right) \cdot \gamma_w = 34.30 \cdot kPa$

Uplift under key at heel: $V_{ulkeyhUN1.OT} := \frac{\left(u_{h.UN1} + u_{j.UN1}\right) \cdot Key_{h.w}}{2} \cdot B \cdot -1 = -72.8 \cdot kN$

Moment Arm (from Point O): $V_{ulkeyhUN1loc.OT} := b - \frac{Key_{h.w} \cdot \left(2 \cdot u_{j.UN1} + u_{h.UN1}\right)}{3 \cdot \left(u_{j.UN1} + u_{h.UN1}\right)} = 11.502\,m$

Uplift under base: $V_{ulbaseUN1.OT} := \frac{\left(u_{k.UN1} + u_{m.UN1}\right) \cdot Key_{hdist}}{2} \cdot B \cdot -1 = -462 \cdot kN$

Moment Arm (from Point O): $V_{ulbaseUN1loc.OT} := b - Key_{h.w} - \frac{Key_{hdist} \cdot \left(2 \cdot u_{m.UN1} + u_{k.UN1}\right)}{3 \cdot \left(u_{m.UN1} + u_{k.UN1}\right)} = 5.836\,m$

Uplift under key at toe: $V_{ulkeytUN1.OT} := \frac{\left(u_{n.UN1} + u_{o.UN1}\right) \cdot Key_{t.w}}{2} \cdot B \cdot -1 = 0 \cdot kN$

Moment Arm (from Point O): $V_{ulkeytUN1loc.OT} := \frac{Key_{t.w} \cdot \left(2 \cdot u_{n.UN1} + u_{o.UN1}\right)}{3 \cdot \left(u_{n.UN1} + u_{o.UN1}\right)} = 0$

$$\Sigma V_{UpliftUN1.OT} := V_{ulkeyhUN1.OT} + V_{ulbaseUN1.OT} + V_{ulkeytUN1.OT} = -535 \cdot kN$$

$$U_{UN1.loc.OT} := \frac{V_{ulkeyhUN1.OT} \cdot V_{ulkeyhUN1loc.OT} + V_{ulbaseUN1.OT} \cdot V_{ulbaseUN1loc.OT} + V_{ulkeytUN1.OT} \cdot V_{ulkeytUN1loc.OT}}{\Sigma V_{UpliftUN1.OT}} = 6.61\,m$$

$$\Sigma M_{UpliftUN1.OT} := \Sigma V_{UpliftUN1.OT} \cdot U_{UN1.loc.OT} = -3533.6 \cdot kN \cdot m$$

Modify Lateral Water Pressure (Resisting) for Overturning Analysis:

(Resisting water pressure is calculated using the Line of Creep method)

Water Load at Key (heel):
$$H_{h2UN1.OT} := \frac{u_{k.UN1} + u_{j.UN1}}{2} \cdot Key_{h.d} B = 121.8 \cdot kN$$

Moment Arm (from Point O):
$$H_{h2locUN1.OT} := \frac{Key_{h.d} \cdot (2 \cdot u_{k.UN1} + u_{j.UN1})}{3(u_{k.UN1} + u_{j.UN1})} + Key_{vdist} = -1.06\ m$$

Water Load at Key (toe):
$$H_{h6UN1.OT} := \frac{u_{o.UN1} \cdot (UWSEL_{UN1} - Bot_{ftg} + Key_{t.d})}{2} \cdot B = 60 \cdot kN$$

Moment Arm (from Point O):
$$H_{h6locUN1.OT} := \frac{UWSEL_{UN1} - Bot_{ftg} + Key_{t.d}}{3} = 1.17\ m$$

$$\Sigma H_{waterresistUN1.OT} := H_{h2UN1.OT} + H_{h6UN1.OT} = 181.82 \cdot kN$$

$$H_{waterresistlocUN1.OT} := \frac{H_{h2UN1.OT} \cdot H_{h2locUN1.OT} + H_{h6UN1.OT} \cdot H_{h6locUN1.OT}}{\Sigma H_{waterresistUN1.OT}} = -0.326\ m$$

$$\Sigma M_{waterresistUN1.OT} := \Sigma H_{waterresistUN1.OT} \cdot H_{waterresistlocUN1.OT} = -59.24 \cdot kN \cdot m$$

Modify Lateral Soil Loads for Overturning Analysis:

(Lateral soil loads are calculated down to Point O instead of bottom of shear key)

Driving Soil Load (Headwater Side):

Surcharge Load:
$$E_{s1UN1.OT} := S1_{UN1} \cdot K_o \cdot (H_w + Key_{h.d} + Key_{vdist}) \cdot B \cdot -1 = -102.377 \cdot kN$$

Moment Arm (from Point O):
$$E_{s1locUN1.OT} := \frac{H_w + Key_{h.d} + Key_{vdist}}{2} = 6.25\ m$$

Moist Soil Load above GWL:
$$E_{h1UN1.OT} := \frac{\gamma_m \cdot K_o \cdot h_{1UN1}^{\ 2}}{2} B \cdot -1 = -267.5 \cdot kN$$

Moment Arm (from Point O):
$$E_{h1locUN1.OT} := \frac{h_{1UN1}}{3} + h_{2UN1} + Key_{vdist} = 7.83\ m$$

Saturated Soil Load below GWL:
(rectangular component)
$$E_{h2UN1.OT} := (\gamma_m \cdot K_o \cdot h_{1UN1}) \cdot (h_{2UN1} + Key_{vdist}) \cdot B \cdot -1 = -420.4 \cdot kN$$

Moment Arm (from Point O):
$$E_{h2locUN1.OT} := \frac{h_{2UN1} + Key_{vdist}}{2} = 2.75\ m$$

Saturated Soil Load below GWL:
(triangular component)
$$E_{h2aUN1.OT} := \frac{(\gamma_{sat} - \gamma_w) \cdot K_o \cdot (h_{2UN1} + Key_{vdist})^2}{2} \cdot B \cdot -1 = -100.8 \cdot kN$$

Moment Arm (from Point O):
$$E_{h2alocUN1.OT} := \frac{h_{2UN1} + Key_{vdist}}{3} = 1.83\ m$$

Resisting Soil Load (Tailwater Side):

(Determine resisting soil load based on depth variation between the keys (ie. Key_{vdist}). In case where key at heel is deeper than key at toe (ie. Key_{vdist}< 0), resisting soil load (p*) is assumed to produce horizontal equilibrium as per Figure 4-5 above. Resisting soil load (p_o) is neglected.)

Total Driving Force: $\Sigma H_{SoildriveUN1.OT} := E_{s1UN1.OT} + E_{h1UN1.OT} + E_{h2UN1.OT} + E_{h2aUN1.OT} + H_{h2UN1} = -1166.7 \cdot kN$

Total Resisting Force: $\Sigma H_{waterresistUN1.OT} = 181.8 \cdot kN$

Assumed Soil Load p*: $E_{h8UN1a.OT} := (\Sigma H_{SoildriveUN1.OT} + \Sigma H_{waterresistU1.OT}) \cdot -1 = 984.901 \cdot kN$

Moment Arm (from Point O): $E_{h8UN1a.loc.OT} := \frac{Key_{vdist}}{2} = -1\ m$

$$E_{h8UN1.OT} := \begin{cases} E_{h8UN1a.OT} & \text{if } Key_{vdist} < 0 \\ \Sigma H_{SoilresistUN1} - H_{h6UN1} - H_{h2aUN1} - P_{sbUN1} & \text{otherwise} \end{cases} = 984.901 \cdot kN$$

$$\Sigma M_{SoilresistUN1} := \begin{cases} E_{h8UN1a.OT} \cdot E_{h8UN1a.loc.OT} & \text{if } Key_{vdist} < 0 \\ \Sigma M_{HorizSoilResistUN1} - H_{h6UN1} \cdot H_{h6locUN1} - H_{h2aUN1} \cdot H_{h2alocUN1} - P_{sbUN1} \cdot P_{sblocUN1} & \text{otherwise} \end{cases} = -984.901 \cdot kN \cdot m$$

Sum of Moment about Point O:

$$\Sigma M_{LateraldriveUN1.OT} := E_{s1UN1.OT} \cdot E_{s1locUN1.OT} + E_{h1UN1.OT} \cdot E_{h1locUN1.OT} + E_{h2UN1.OT} \cdot E_{h2locUN1.OT} \dots + E_{h2aUN1.OT} \cdot E_{h2alocUN1.OT} + H_{h2UN1} \cdot H_{h2locUN1} = -4214.3 \cdot kN \cdot m$$

$$\Sigma M_{LateralresistUN1.OT} := \Sigma M_{waterresistUN1.OT} + \Sigma M_{SoilresistUN1} = -1044.1 \cdot kN \cdot m$$

Total moment:

$$\Sigma M_{UN1.OT} := \Sigma M_{conc} + \Sigma M_{VertSoilWaterResistUN1} + \Sigma M_{UpliftUN1.OT} + \Sigma M_{LateraldriveUN1.OT} + \Sigma M_{LateralresistUN1.OT} = 10624.5 \cdot kN \cdot m$$

Total Vertical Force: $\Sigma V_{UN1.OT} := \Sigma V_{conc} + \Sigma V_{SoilWaterUN1} + \Sigma V_{UplliftUN1.OT} = 2127.1 \cdot kN$

Distance X_R: EM 1110-2-2502 Eq.4-1 $X_{R.UN1} := \frac{\Sigma M_{UN1.OT}}{\Sigma V_{UN1.OT}} = 4.995\ m$

Overturning Resultant Ratio $Ratio_{UN1.OT} := \frac{X_{R.UN1}}{b} = 0.42$

$$Ratio_{UN1.OT.check} := \begin{cases} \text{"OKAY "} & \text{if } Ratio_{UN1.OT} > X_{R.reqUN1} \\ \text{"Revise Structure""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

CHECK FOUNDATION ECCENTRICITY (HORIZONTAL PLANE):

Eccentricity (horizontal plan): $ex_{UN1.OT} := \frac{b}{2} - \frac{\Sigma M_{UN1.OT}}{\Sigma V_{UN1.OT}} = 1.01\ m$ $Kern_{OT} = 2\ m$

Eccentricity Check:

$$e_{check.UN1.OT} := \begin{cases} \text{"Okay"} & \text{if } ex_{UN1} \le Kern_{OT} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"Okay"}$$

CHECK FOUNDATION BEARING CAPACITY (HORIZONTAL PLANE):

Base Section Modulus: $S_{b.OT} = 24\,m^3$

Bearing Pressure Under Toe:

$$\sigma_{ToeUN1.OT} := \begin{cases} \left(\dfrac{\Sigma V_{UN1.OT}}{b \cdot B} + \dfrac{\Sigma V_{UN1.OT} \cdot ex_{UN1.OT}}{S_{b.OT}}\right) & \text{if } \dfrac{\Sigma V_{UN1.OT}}{b \cdot B} \geq \dfrac{\Sigma V_{UN1.OT} \cdot ex_{UN1.OT}}{S_{b.OT}} \\ \dfrac{2 \cdot \Sigma V_{UN1.OT}}{B \cdot 3\left(\dfrac{b}{2} - ex_{UN1.OT}\right)} & \text{otherwise} \end{cases} = 266.4 \cdot kPa$$

$$Bearing_{ChecktoeUN1.OT} := \begin{cases} \text{"OKAY "} & \text{if } \sigma_{ToeUN1.OT} < \sigma_{allowUN1} \\ \text{"NG - for reference only""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

Bearing Pressure Under Heel:

$$\sigma_{HeelUN1.OT} := \begin{cases} \left(\dfrac{\Sigma V_{UN1.OT}}{b \cdot B} - \dfrac{\Sigma V_{UN1.OT} \cdot ex_{UN1.OT}}{S_{b.OT}}\right) & \text{if } \dfrac{\Sigma V_{UN1.OT}}{b \cdot B} \geq \dfrac{\Sigma V_{UN1.OT} \cdot ex_{UN1.OT}}{S_{b.OT}} \\ 0 & \text{otherwise} \end{cases} = 88.2 \cdot kPa$$

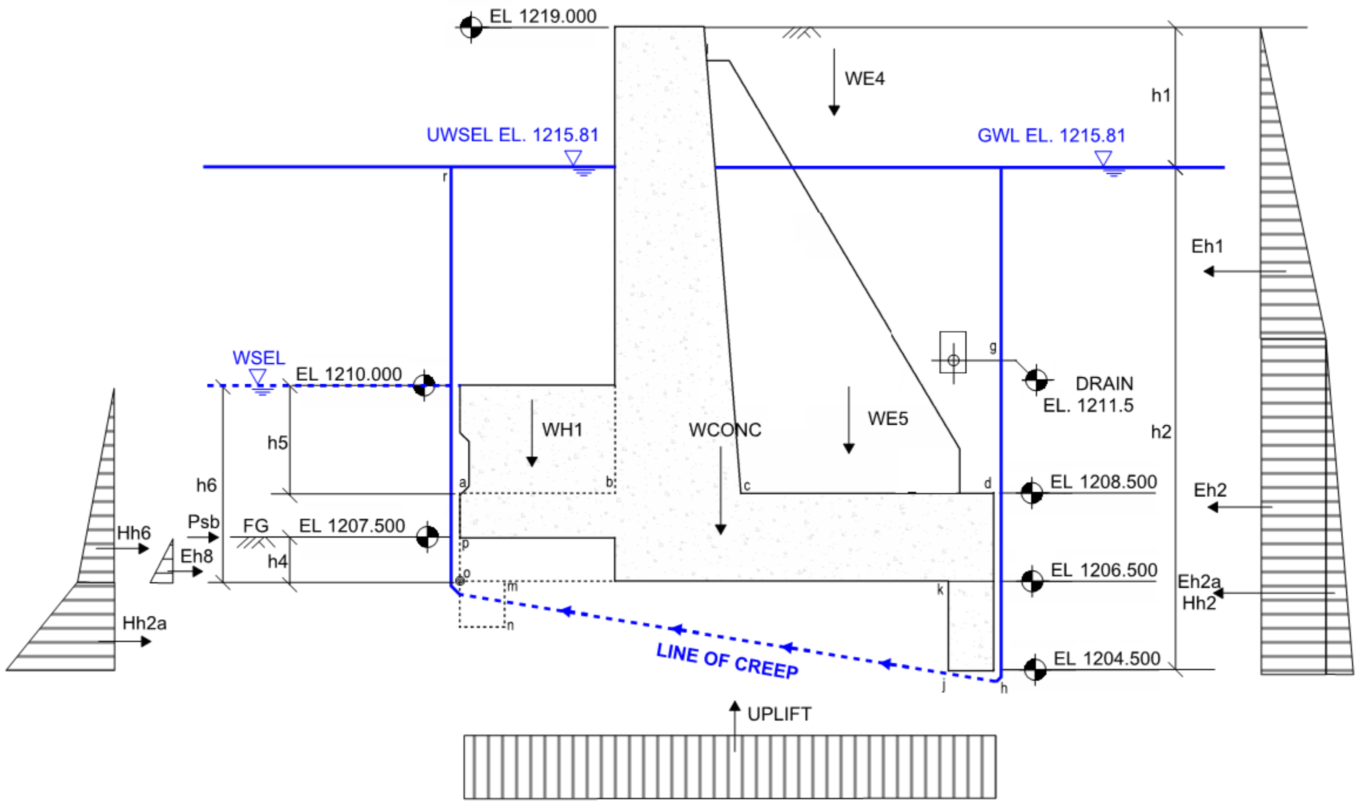
$$Bearing_{CheckheelUN1.OT} := \left(\begin{cases} \text{"OKAY "} & \text{if } \sigma_{HeelUN1.OT} < \sigma_{allowUN1} \wedge \sigma_{HeelUN1.OT} > 0 \\ \text{"NG - for reference only""} & \text{otherwise} \end{cases} \right) = \text{"OKAY "}$$

SUMMARY OF STABILITY ASSESSMENT:

LOAD CASE UN1

Sliding Factor of Safety: (Horizontal Plane - Ref only)	$FS_{Horiz.SlidingUN1} = 1.02$	$FS_{Sliding.check1.UN1}$ = "NG - key req""
Sliding Factor of Safety: (Inclined Plane)	$FS_{InclinedlSlidingUN1} = 2.03$	$FS_{Sliding.check2.UN1}$ = "OKAY "
Eccentricity: (Inclined Plane)	$ex_{UN1} = 0.58\ m$	$e_{check.UN1}$ = "Okay"
Bearing Pressure At Heel: (Inclined Plane)	$\sigma_{HeelUN1} = 142 \cdot kPa$	$Bearing_{CheckheelUN1}$ = "OKAY "
Bearing Pressure At Toe: (Inclined Plane)	$\sigma_{ToeUN1} = 256 \cdot kPa$	$Bearing_{ChecktoeUN1}$ = "OKAY "
Flotation Factor of Safety (horizontal plane)	$FS_{FloatationUN1} = 4.12$	$FS_{Floatation.UN1.check}$ = "OKAY "
Overturning Resultant Ratio: (horizontal plane)	$Ratio_{UN1.OT} = 0.42$	$Ratio_{UN1.OT.check}$ = "OKAY "
Eccentricity: (horizontal plane - Ref only)	$ex_{UN1.OT} = 1.01\ m$	$e_{check.UN1.OT}$ = "Okay"
Bearing Pressure At Heel: (horizontal plane - Ref only)	$\sigma_{HeelUN1.OT} = 88 \cdot kPa$	$Bearing_{CheckheelUN1.OT}$ = "OKAY "
Bearing Pressure At Toe: (horizontal plane - Ref only)	$\sigma_{ToeUN1.OT} = 266 \cdot kPa$	$Bearing_{ChecktoeUN1.OT}$ = "OKAY "

LOAD CASE UN2 - INEFFECTIVE DRAIN



UN2 DESIGN CASE

LOAD CASE UN2 ACCEPTANCE PARAMETERS

FS sliding:

Unusual (UN) 1.3 (without cohesion) (Table 3-3, USACE EM 1110-2-2100)

Resultant Location:

Unsual (UN) Inside middle third ~100% base in compression

Required Factor of Safety for Sliding: $FS_{sliding.reqUN2} := 1.3$ (Without Cohesion)

Allowable rock bearing pressure: $\sigma_{allowUN2} := 1470kPa$ (Section 5.2, Design Criteria EM 1110-2-2100 Section 3-10)

Overturning Required Resultant Ratio: $X_{R.reqUN2} := 0.333$ (EM 1110-2-2502, Figure 4-4)

Required Factor of Safety for Floatation $FS_{req.UN2.flt} := 1.3$

SOIL HEIGHTS and Water Levels:

LOAD CASE UN2

Heel Conditions:

Groundwater Elevation at Heel: $GWL_{UN2} := 1215.81m$

Distance from Finish Grade to Groundwater at Heel: $h_{1UN2} := \left[T_w - GWL_{UN2} + \left(L_{cd} + t_{wb} - t_{wt}\right)\cdot\tan(\beta)\right] = 3.19\ m$

Distance from Water Surface to Bottom of Footing at Heel: $h_{2UN2} := GWL_{UN2} - Bot_{ftg} + Key_{h.d} = 11.31\ m$

Toe Conditions:

Water Surface Elevation at Toe: $WSEL_{UN2} := 1210.0m$

Water Surface Elevation at Toe for Uplift: $UWSEL_{UN2} := 1215.81\cdot m$

Finish Grade at Toe providing lateral resistance: $FG_{toeUN2} := 1207.5\cdot m$

Soil Depth Above top of footing: $h_{3aUN2} := FG_{toeUN2} - Top_{ftg} = -1\ m$

$$h_{3UN2} := \begin{vmatrix} h_{3aUN2} \text{ if } FG_{toeUN2} - Top_{ftg} \geq 0 \\ 0 \text{ otherwise} \end{vmatrix} = 0$$

Resisting Fill at Toe: $h_{4UN2} := FG_{toeUN2} - Bot_{ftg} + Key_{t.d} = 1.00\ m$

Distance from Water Level to Top of Footing at Toe: $h_{5UN2} := WSEL_{UN2} - Top_{ftg} = 1.50\ m$

Distance from Water Surface to Bottom of Footing at Toe: $h_{6UN2} := WSEL_{UN2} - Bot_{ftg} + Key_{t.d} = 3.50\ m$

Soil Depth Above WSEL: $h_{7aUN2} := FG_{toeUN2} - WSEL_{UN2} = -2.5\ m$

$$h_{7UN2} := \begin{vmatrix} h_{7aUN2} \text{ if } FG_{toeUN2} - WSEL_{UN2} \geq 0 \\ 0 \text{ otherwise} \end{vmatrix} = 0$$

Soil Depth Below WSEL:

$$h_{8UN2} := \begin{vmatrix} WSEL_{UN2} - Bot_{ftg} + Key_{t.d} \text{ if } FG_{toeUN2} - WSEL_{UN2} \geq 0 \\ h_{4UN2} \text{ otherwise} \end{vmatrix} = 1$$

For Line of Creep Method: $L_{ho.UN2} := \sqrt{b^2 + \left(Key_{h.d} - Key_{t.d}\right)^2} = 12.166\ m$

Head Loss from Point g:

$\Delta h_{g.hj.UN2} := h_{2UN2} = 11.31\ m$ (to point h & j)

$\Delta h_{g.km.UN2} := GWL_{UN2} - Bot_{ftg} = 9.31\ m$ (to point k & m)

$\Delta h_{g.no.UN2} := GWL_{UN2} - Bot_{ftg} + Key_{t.d} = 9.31\ m$ (to point n & o)

$\Delta h_{g.p.UN2} := GWL_{UN2} - FG_{toeUN2} = 8.31\ m$ (to point p)

$\Delta h_{g.r.UN2} := GWL_{UN2} - UWSEL_{UN2} = 0\ m$ (to point r)

Surcharge

Surcharge on Heel: $S1_{UN2} := 0.0\ \frac{kN}{m^2}$

Calculate Soil Lateral Pressure Coefficients:

LOAD CASE UN2

For all load cases except seismic, soil loading to be based on At-Rest Condition.
Calculate at-rest pressure coefficient Ko based on Jaky's (1944) equation.

Soil At Rest Static Coefficient: $K_o := \frac{1 - \sin(\phi)}{1 + \sin(\beta)} = 0.546$ (Eq. 3-6, USACE EM 1110-2-2502)

Lateral - Driving Force

Static At-Rest:

Surcharge Load: $E_{s1UN2} := S1_{UN2} \cdot K_o \cdot \left(H_w + Key_{h.d}\right) \cdot B \cdot -1 = 0 \cdot kN$

Moment Arm (from bottom of footing): $E_{s1locUN2} := \frac{H_w + Key_{h.d}}{2} + Key_{vdist} = 5.25\ m$

Moist Soil Load above GWL: $E_{h1UN2} := \frac{\gamma_m \cdot K_o \cdot {h_{1UN2}}^2}{2} B \cdot -1 = -55.6 \cdot kN$

Moment Arm (from bottom of footing): $E_{h1locUN2} := \frac{h_{1UN2}}{3} + h_{2UN2} + Key_{vdist} = 10.37\ m$

Saturated Soil Load below GWL:
(rectangular component) $E_{h2UN2} := \left(\gamma_m \cdot K_o \cdot h_{1UN2}\right) \cdot h_{2UN2} \cdot B \cdot -1 = -394.0 \cdot kN$

Moment Arm (from bottom of footing): $E_{h2locUN2} := \frac{h_{2UN2}}{2} + Key_{vdist} = 3.65\ m$

Saturated Soil Load below GWL:
(triangular component) $E_{h2aUN2} := \frac{\left(\gamma_{sat} - \gamma_w\right) \cdot K_o \cdot {h_{2UN2}}^2}{2} \cdot B \cdot -1 = -426.0 \cdot kN$

Moment Arm (from bottom of footing): $E_{h2alocUN2} := \frac{h_{2UN2}}{3} + Key_{vdist} = 1.77\ m$

Lateral Water Load:

Water Load GWL to Bottom of Key: $H_{h2UN2} := \frac{\gamma_w \cdot {h_{2UN2}}^2}{2} \cdot B \cdot -1 = -626.8 \cdot kN$

Moment Arm (from bottom of footing): $H_{h2locUN2} := \frac{h_{2UN2}}{3} + Key_{vdist} = 1.77\ m$

$$\Sigma H_{SoildriveUN2} := E_{s1UN2} + E_{h1UN2} + E_{h2UN2} + E_{h2aUN2} + H_{h2UN2} = -1502.4 \cdot kN$$

$$\Sigma M_{LateralSoildriveUN2} := E_{s1UN2} \cdot E_{s1locUN2} + E_{h1UN2} \cdot E_{h1locUN2} + E_{h2UN2} \cdot E_{h2locUN2} \cdots + E_{h2aUN2} \cdot E_{h2alocUN2} + H_{h2UN2} \cdot H_{h2locUN2} = -3879.9\ m \cdot kN$$

Lateral - Resisting Force

LOAD CASE UN2

Lateral Water Load:

Water Load WSEL to Bottom of Footing: $H_{h6UN2} := \frac{\gamma_w \cdot h_{6UN2}^2}{2} \cdot B = 60.0 \cdot kN$

Moment Arm (from bot. of toe key): $H_{h6locUN2} := \frac{h_{6UN2}}{3} = 1.17\ m$

Water Load Bot. of Footing to Bot. of H. Key: $H_{h2aUN2} := \left[\left(UWSEL_{UN2} - Bot_{ftg} + Key_{t.d}\right) + h_{2UN2}\right] \cdot \frac{Key_{h.d}}{2} \cdot \gamma_w \cdot B = 202.1 \cdot kN$

Moment Arm (from bot. of toe key): $H_{h2alocUN2} := \frac{Key_{h.d} \cdot \left[2 \cdot \left(UWSEL_{UN2} - Bot_{ftg} + Key_{t.d}\right) + h_{2UN2}\right]}{3\left[h_{2UN2} + \left(UWSEL_{UN2} - Bot_{ftg} + Key_{t.d}\right)\right]} \dots + Key_{vdist} = -1.03\ m$

Lateral Soil Load:

Moist Soil Load above WSEL: $E_{h7UN2} := \frac{\gamma_m \cdot K_o \cdot h_{7UN2}^2}{2} \cdot B = 0.0 \cdot kN$

Moment Arm (from bot. of toe key): $E_{h7locUN2} := h_{6UN2} + \frac{h_{7UN2}}{3} + Key_{vdist} = 1.50\ m$

Saturated Soil Load below WSEL:
(rectangular component) $E_{h8UN2} := \left(\gamma_m \cdot K_o \cdot h_{7UN2}\right) \cdot h_{8UN2} \cdot B = 0.0 \cdot kN$

Moment Arm (from bot. of toe key): $E_{h8locUN2} := \frac{h_{8UN2}}{2} = 0.50\ m$

Saturated Soil Load below WSEL:
(triangular component) $E_{h8aUN2} := \frac{\left[\left(\gamma_{sat} - \gamma_w\right) \cdot K_o\right] \cdot h_{8UN2}^2}{2} \cdot B = 3.3 \cdot kN$

Moment Arm (from bot. of footing): $E_{h8alocUN2} := \frac{h_{8UN2}}{3} = 0.33\ m$

Lateral Resistance from Stilling Basin:

Lateral Resistance from Stilling Basin: $P_{sbUN2} := 291 kN$ (Force needed to achieve the required sliding factor of safety in case UN2)

Moment Arm (from bot. of toe key): $P_{sblocUN2} := \frac{t_{ftg}}{2} + Key_{t.d} = 1.00\ m$

$\Sigma H_{SoilresistUN2} := H_{h6UN2} + H_{h2aUN2} + E_{h7UN2} + E_{h8UN2} + E_{h8aUN2} + P_{sbUN2} = 556.4 \cdot kN$

$\Sigma M_{HorizSoilResistUN2} := H_{h6UN2} \cdot H_{h6locUN2} + H_{h2aUN2} \cdot H_{h2alocUN2} + E_{h7UN2} \cdot E_{h7locUN2} \dots + E_{h8UN2} \cdot E_{h8locUN2} + E_{h8aUN2} \cdot E_{h8alocUN2} + P_{sbUN2} \cdot P_{sblocUN2} = 153.5\ m \cdot kN$

Vertical Force:

UPLIFT: Linear distribution from water at heel to water at toe:

$\Sigma V_{UpliftUN2} := \left[\left(UWSEL_{UN2} - Bot_{ftg} + Key_{t.d}\right) + h_{2UN2}\right] \cdot \frac{b}{2} \cdot \gamma_w \cdot B \cdot -1 = -1212.456 \cdot kN$

Moment Arm (from Point O): $V_{UpliftUN2aloc} := \frac{b \cdot \left[2 \cdot h_{2UN2} + \left(UWSEL_{UN2} - Bot_{ftg} + Key_{t.d}\right)\right]}{3\left[h_{2UN2} + \left(UWSEL_{UN2} - Bot_{ftg} + Key_{t.d}\right)\right]} = 6.194\ m$

$\Sigma M_{UpliftUN2} := \Sigma V_{UpliftUN2} \cdot V_{UpliftUN2aloc} = -7509.936 \cdot kN \cdot m$

Weight of soil and water over toe:

Water Above the Top of Footing: $W_{H1UN2} := \gamma_w \cdot h_{5UN2} \cdot L_{ab} \cdot B = 51.45 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E1locUN2} := \frac{L_{ab}}{2} = 1.75\ m$

Soil above top of footing: $W_{E6UN2} := \gamma_b \cdot h_{3UN2} \cdot L_{ab} \cdot B = 0.0 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E6locUN2} := \frac{L_{ab}}{2} = 1.75\ m$

Vertical Load Due to Surcharge: $S_{UN2} := S1_{UN2} \cdot L_{cd} \cdot B = 0 \cdot kN$ $\quad S_{UN2loc} := b - \frac{L_{cd}}{2} = 9.16\ m$

Weight of soil and water over heel:

Moist Soil for sloped grade above top of wall:

Length of sloped portion of soil above top of wall: $L_{E3UN2} := \left(L_{cd} + t_{wb} - t_{wt}\right) = 6.50\ m$

Height of sloped soil above top of wall over heel: $h_{E3locUN2} := \left(L_{E3UN2}\right) \cdot \tan(\beta) = 0.00\ m$

Weight of sloped soil above top of wall: $W_{E3UN2} := \frac{\gamma_m}{2} \cdot h_{E3locUN2} \cdot L_{E3UN2} \cdot B = 0.0 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E3locUN2} := L_{ab} + t_{wt} + \frac{2}{3} \cdot L_{E3UN2} = 9.83\ m$

Moist soil from top of wall to groundwater level:

Height of soil from top of wall and top of GWL: $h_{1UN2} = 3.19\ m$

Length from edge of wall at GWL to edge of heel: $L_{E4UN2} := L_{E3UN2} - \left(h_{1UN2} \cdot S_{batter}\right) = 6.25\ m$

Weight of soil over heel from top of wall to GWL: $W_{E4UN2} := \gamma_m \cdot h_{1UN2} \cdot \frac{\left(L_{E3UN2} + L_{E4UN2}\right)}{2} \cdot B = 406.7 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E4locUN2} := b - \frac{L_{E3UN2}^2 + L_{E3UN2} \cdot L_{E4UN2} + L_{E4UN2}^2}{3\left(L_{E3UN2} + L_{E4UN2}\right)} = 8.81\ m$

Saturated soil from groundwater to top of footing:

Height of soil from GWL to top of heel: $h_{E4UN2} := h_{2UN2} - t_{ftg} - Key_{h.d} = 7.31\ m$

Weight of soil over heel from GWL to top of heel: $W_{E5UN2} := \left(\gamma_{sat}\right) \cdot h_{E4UN2} \cdot \frac{\left(L_{E4UN2} + L_{cd}\right)}{2} \cdot B = 958.8 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E5locUN2} := b - \frac{L_{E4UN2}^2 + L_{E4UN2} \cdot L_{cd} + L_{cd}^2}{3\left(L_{E4UN2} + L_{cd}\right)} = 9.02\ m$

$$\Sigma V_{SoilWaterUN2} := W_{H1UN2} + W_{E6UN2} + W_{E3UN2} + W_{E4UN2} + W_{E5UN2} + S_{UN2} = 1417.0 \cdot kN$$

$$\Sigma M_{VertSoilWaterResistUN2} := W_{H1UN2} \cdot W_{E1locUN2} + W_{E6UN2} \cdot W_{E6locUN2} \cdots + W_{E3UN2} \cdot W_{E3locUN2} + W_{E4UN2} \cdot W_{E4locUN2} + W_{E5UN2} \cdot W_{E5locUN2} + S_{UN2} \cdot S_{UN2loc} = 12319.5\ m \cdot kN$$

THIS PAGE INTENTIONALLY LEFT BLANK
PLEASE GO TO THE NEXT PAGE

STABILITY ASSESSMENT:

LOAD CASE UN2

CHECK SLIDING ALONG HORIZONTAL SLIDING PLANE:

Summation of the vertical forces:

$$\Sigma V_{UN2} := \Sigma V_{conc} + \Sigma V_{SoilWaterUN2} + \Sigma V_{UpliftUN2} = 1410.8 \cdot kN$$

Summation of the horizontal forces:

$$\Sigma H_{UN2} := \Sigma H_{SoildriveUN2} + \Sigma H_{SoilresistUN2} = -946.0 \cdot kN$$

Safety Factor for Sliding Horizontal Failure Plane

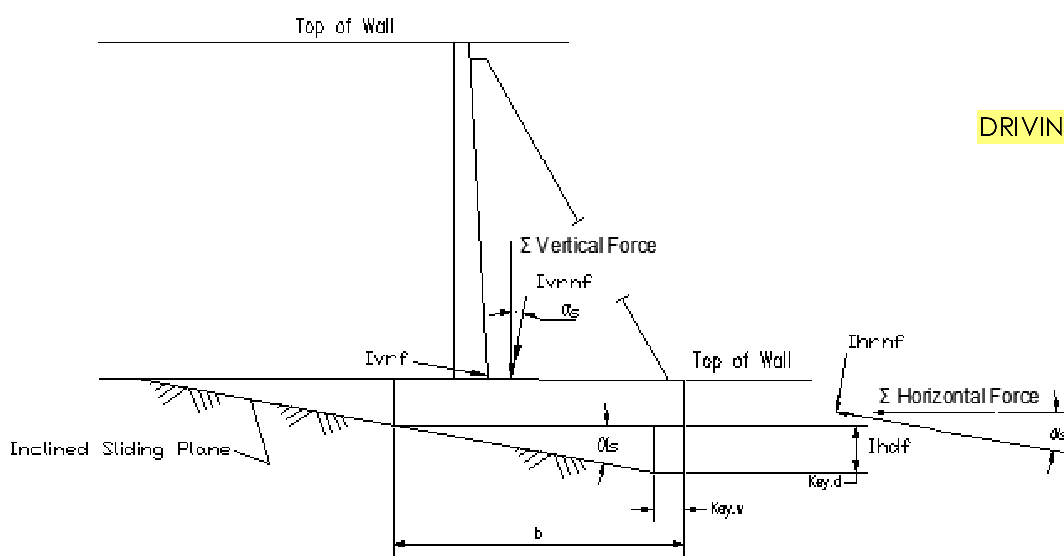
$$FS_{Horiz.SlidingUN2} := \frac{\left|\Sigma V_{UN2}\right| \cdot \tan\left(\phi_{rock} \cdot \frac{\pi}{180}\right)}{\left|\Sigma H_{UN2}\right|} = 0.73$$

$$FS_{Sliding.check1.UN2} := \begin{cases} \text{"OKAY "} & \text{if } FS_{Horiz.SlidingUN2} > FS_{sliding.reqUN2} \\ \text{"NG - key req'"} & \text{otherwise} \end{cases} = \text{"NG - key req'"}$$

CHECK FACTOR OF SAFETY SLIDING WITH KEY (INCLINED SLIDING PLANE):

RESISTING SIDE

DRIVING SIDE



TOE

HEEL

Ivrf=Inclined Resisting Force
Ivrnf=Inclined Resisting Normal Force
Ihrnf=Inclined Resisting Normal Force
Ihdf=Inclined Driving Force

$\alpha s = 0.18$ as degrees= $\alpha s \cdot \left(\frac{180}{\pi}\right) = 10.30$

(With properly engineered reinforced concrete Key, horizontal sliding plane thru Toe is protected, critical sliding plane is relocated to the INCLINED SLIDING PLANE FROM HEEL KEY To TOE, Bedrock Mass above this examing plane is mobilized by reinforced concrete key and combined into Structural Wedge.)

Resolve ΣV_{UN2} & ΣH_{UN2}

$$\Sigma V_{InclinedUN2} := \cos(\alpha s) \cdot \left(\left|\Sigma V_{UN2} + V_{rocksection}\right|\right) + \sin(\alpha s) \cdot \left|\Sigma H_{UN2}\right| = 1834.3 \cdot kN$$

$$\Sigma H_{InclinedUN2} := \cos(\alpha s) \cdot \left|\Sigma H_{UN2}\right| - \sin(\alpha s) \cdot \left(\left|\Sigma V_{UN2} + V_{rocksection}\right|\right) = 627.9 \cdot kN$$

Safety Factor for Sliding Inclined Failure Plane

$$FS_{InclinedSlidingUN2} := \frac{\Sigma V_{InclinedUN2} \cdot \tan(\phi_r)}{\Sigma H_{InclinedUN2}} = 1.30$$

$$FS_{Sliding.check2.UN2} := \begin{cases} \text{"OKAY "} & \text{if } FS_{InclinedSlidingUN2} > FS_{sliding.reqUN2} \\ \text{"NG - Revise Structure""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

CHECK FOUNDATION ECCENTRICITY:

Summation of the resisting moments about the toe:

$$\Sigma M_{resUN2} := \Sigma M_{conc} + \Sigma M_{VertSoilWaterResistUN2} + \Sigma M_{HorizSoilResistUN2} + \Sigma M_{rocksection} = 21271 \cdot kN \cdot m$$

Summation of the overturning moments about the toe:

$$\Sigma M_{oUN2} := \Sigma M_{LateralSoildriveUN2} + \Sigma M_{UpliftUN2} = -11390 \cdot kN \cdot m$$

Total moment: $\Sigma M_{UN2} := \Sigma M_{resUN2} + \Sigma M_{oUN2} = 9881.3\ m \cdot kN$

Normal force to base: $\Sigma V_{InclinedUN2} = 1834.3 \cdot kN$

Inclined Sliding Plane Length: $L_{incline} = 12.2 \cdot m$

Eccentricity (inclined plane): $ex_{UN2} := \frac{L_{incline}}{2} - \frac{\Sigma M_{UN2}}{\Sigma V_{InclinedUN2}} = 0.71\ m$ $\quad Kern = 2.033\ m$

Eccentricity Check: $e_{check.UN2} := \begin{cases} \text{"Okay"} & \text{if } ex_{UN2} \le Kern \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"Okay"}$

CHECK FOUNDATION BEARING CAPACITY:

Base Section Modulus: $S_b = 24.79\ m^3$

Bearing Pressure Under Toe:

$$\sigma_{ToeUN2} := \begin{cases} \left(\frac{\Sigma V_{InclinedUN2}}{L_{incline} \cdot B} + \frac{\Sigma V_{InclinedUN2} \cdot ex_{UN2}}{S_b} \right) & \text{if } \frac{\Sigma V_{InclinedUN2} \cdot ex_{UN2}}{S_b} \le \frac{\Sigma V_{InclinedUN2}}{L_{incline} \cdot B} \\ \frac{2 \cdot \Sigma V_{InclinedUN2}}{B \cdot 3 \left(\frac{b}{2} - ex_{UN2} \right)} & \text{otherwise} \end{cases} = 203.0 \cdot kPa$$

$$Bearing_{ChecktoeUN2} := \begin{cases} \text{"OKAY "} & \text{if } \sigma_{ToeUN2} < \sigma_{allowUN2} \\ \text{"NG""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

Bearing Pressure Under Heel:

$$\sigma_{HeelUN2} := \begin{cases} \left(\frac{\Sigma V_{InclinedUN2}}{L_{incline} \cdot B} - \frac{\Sigma V_{InclinedUN2} \cdot ex_{UN2}}{S_b} \right) & \text{if } \frac{\Sigma V_{InclinedUN2} \cdot ex_{UN2}}{S_b} \le \frac{\Sigma V_{InclinedUN2}}{L_{incline} \cdot B} \\ 0 & \text{otherwise} \end{cases} = 97.8 \cdot kPa$$

$$Bearing_{CheckheelUN2} := \left(\begin{cases} \text{"OKAY "} & \text{if } \sigma_{HeelUN2} < \sigma_{allowUN2} \wedge \sigma_{HeelUN2} > 0 \\ \text{"NG - perform cracked base analysis""} & \text{otherwise} \end{cases} \right) = \text{"OKAY "}$$

CHECK FLOATATION:

Safety Factor for Floatation:

$$FS_{FloatationUN2} := \frac{\Sigma V_{conc} + \Sigma V_{SoilWaterUN2}}{\left|\Sigma V_{UpliftUN2}\right|} = 2.16$$

$$FS_{Floatation.UN2.check} := \begin{cases} \text{"OKAY "} & \text{if } FS_{FloatationUN2} > FS_{req.UN2.flt} \\ \text{"Revise Structure""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

CHECK OVERTURNING

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.
Assumptions are made in order to compute overturning stablity of indetermine forces on monolith with key;
(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.
(b) The horizontal resisting force acting on the key, P.key, is that required for static equilibrium
(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1

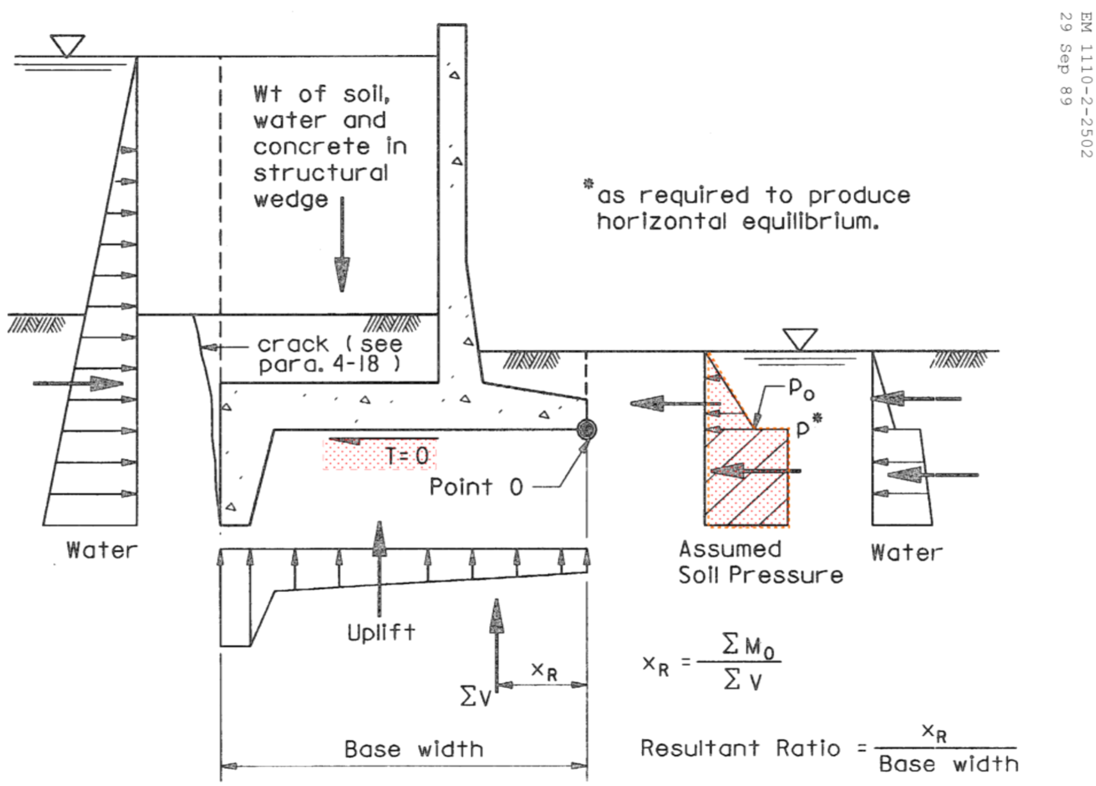


Figure 4-5. Forces for overturning analysis for wall with horizontal base and key

Modify Uplift for Overturning Analysis: **LOAD CASE UN2**

(Uplift is calculated along the concrete/rock contact using the Line of Creep method)

Water Pressure at h: $u_{h.UN2} := \Delta h_{g.hj.UN2} \cdot \gamma_w = 110.84 \cdot kPa$

Water Pressure at o: $u_{o.UN2} := \left(\Delta h_{g.no.UN2} - \frac{\Delta h_{g.r.UN2} \cdot L_{ho.UN2}}{L_{ho.UN2}}\right) \cdot \gamma_w = 91.24 \cdot kPa$

Head loss between point h and o: $\Delta h_{ho.UN2} := \Delta h_{g.r.UN2} \cdot \frac{L_{ho.UN2}}{L_{ho.UN2}} = 0\,m$

Length of concrete base (h -> o): $L_{baseho.UN2} := Key_{h.w} + Key_{h.d} + Key_{hdist} + Key_{t.d} + Key_{t.w} = 14\,m$

Head loss along h -> j: $\Delta h_{hj.UN2} := \Delta h_{ho.UN2} \cdot \frac{Key_{h.w}}{L_{baseho.UN2}} = 0\,m$

Water Pressure at j: $u_{j.UN2} := \left(\Delta h_{g.hj.UN2} - \Delta h_{hj.UN2}\right) \cdot \gamma_w = 110.84 \cdot kPa$

Head loss along h -> k: $\Delta h_{hjk.UN2} := \Delta h_{ho.UN2} \cdot \left(\frac{Key_{h.w} + Key_{h.d}}{L_{baseho.UN2}}\right) = 0\,m$

Water Pressure at k: $u_{k.UN2} := \left(\Delta h_{g.km.UN2} - \Delta h_{hjk.UN2}\right) \cdot \gamma_w = 91.24 \cdot kPa$

Head loss along h -> m: $\Delta h_{hjkm.UN2} := \Delta h_{ho.UN2} \cdot \left(\frac{Key_{h.w} + Key_{h.d} + Key_{hdist}}{L_{baseho.UN2}}\right) = 0\,m$

Water Pressure at m: $u_{m.UN2} := \left(\Delta h_{g.km.UN2} - \Delta h_{hjkm.UN2}\right) \cdot \gamma_w = 91.24 \cdot kPa$

Head loss along h -> n: $\Delta h_{hjkmn.UN2} := \Delta h_{ho.UN2} \cdot \left(\frac{Key_{h.w} + Key_{h.d} + Key_{hdist} + Key_{t.d}}{L_{baseho.UN2}}\right) = 0\,m$

Water Pressure at n: $u_{n.UN2} := \left(\Delta h_{g.no.UN2} - \Delta h_{hjkmn.UN2}\right) \cdot \gamma_w = 91.24 \cdot kPa$

Uplift under key at heel: $V_{ulkeyhUN2.OT} := \frac{\left(u_{h.UN2} + u_{j.UN2}\right) \cdot Key_{h.w}}{2} \cdot B \cdot -1 = -110.838 \cdot kN$

Moment Arm (from Point O): $V_{ulkeyhUN2loc.OT} := b - \frac{Key_{h.w} \cdot \left(2 \cdot u_{j.UN2} + u_{h.UN2}\right)}{3 \cdot \left(u_{j.UN2} + u_{h.UN2}\right)} = 11.5\,m$

Uplift under base: $V_{ulbaseUN2.OT} := \frac{\left(u_{k.UN2} + u_{m.UN2}\right) \cdot Key_{hdist}}{2} \cdot B \cdot -1 = -1003.618 \cdot kN$

Moment Arm (from Point O): $V_{ulbaseUN2loc.OT} := b - Key_{h.w} - \frac{Key_{hdist} \cdot \left(2 \cdot u_{m.UN2} + u_{k.UN2}\right)}{3 \cdot \left(u_{m.UN2} + u_{k.UN2}\right)} = 5.5\,m$

Uplift under key at toe: $V_{ulkeytUN2.OT} := \frac{\left(u_{n.UN2} + u_{o.UN2}\right) \cdot Key_{t.w}}{2} \cdot B \cdot -1 = 0 \cdot kN$

Moment Arm (from Point O): $V_{ulkeytUN2loc.OT} := \frac{Key_{t.w} \cdot \left(2 \cdot u_{n.UN2} + u_{o.UN2}\right)}{3 \cdot \left(u_{n.UN2} + u_{o.UN2}\right)} = 0$

$$\Sigma V_{UpliftUN2.OT} := V_{ulkeyhUN2.OT} + V_{ulbaseUN2.OT} + V_{ulkeytUN2.OT} = -1114 \cdot kN$$

$$U_{UN2.loc.OT} := \frac{V_{ulkeyhUN2.OT} \cdot V_{ulkeyhUN2loc.OT} + V_{ulbaseUN2.OT} \cdot V_{ulbaseUN2loc.OT} + V_{ulkeytUN2.OT} \cdot V_{ulkeytUN2loc.OT}}{\Sigma V_{UpliftUN2.OT}} = 6.10\,m$$

$$\Sigma M_{UpliftUN2.OT} := \Sigma V_{UpliftUN2.OT} \cdot U_{UN2.loc.OT} = -6794.5 \cdot kN \cdot m$$

Modify Lateral Water Pressure (Resisting) for Overturning Analysis:

(Resisting water pressure is calculated using the Line of Creep method)

Water Load at Key (heel): $H_{h2UN2.OT} := \frac{u_{k.UN2} + u_{j.UN2}}{2} \cdot Key_{h.d} \, B = 202.1 \cdot kN$

Moment Arm (from Point O): $H_{h2locUN2.OT} := \frac{Key_{h.d} \cdot (2 \cdot u_{k.UN2} + u_{j.UN2})}{3(u_{k.UN2} + u_{j.UN2})} + Key_{vdist} = -1.03\ m$

Water Load at Key (toe): $H_{h6UN2.OT} := \frac{u_{o.UN2} \cdot (UWSEL_{UN2} - Bot_{ftg} + Key_{t.d})}{2} \cdot B = 425 \cdot kN$

Moment Arm (from Point O): $H_{h6locUN2.OT} := \frac{UWSEL_{UN2} - Bot_{ftg} + Key_{t.d}}{3} = 3.10\ m$

$$\Sigma H_{waterresistUN2.OT} := H_{h2UN2.OT} + H_{h6UN2.OT} = 626.79 \cdot kN$$

$$H_{waterresistlocUN2.OT} := \frac{H_{h2UN2.OT} \cdot H_{h2locUN2.OT} + H_{h6UN2.OT} \cdot H_{h6locUN2.OT}}{\Sigma H_{waterresistUN2.OT}} = 1.77\ m$$

$$\Sigma M_{waterresistUN2.OT} := \Sigma H_{waterresistUN2.OT} \cdot H_{waterresistlocUN2.OT} = 1109.42 \cdot kN \cdot m$$

Modify Lateral Soil Loads for Overturning Analysis:

(Lateral soil loads are calculated down to Point O instead of bottom of shear key)

Driving Soil Load (Headwater Side):

Surcharge Load: $E_{s1UN2.OT} := S1_{UN2} \cdot K_o \cdot (H_w + Key_{h.d} + Key_{vdist}) \cdot B \cdot -1 = 0 \cdot kN$

Moment Arm (from Point O): $E_{s1locUN2.OT} := \frac{H_w + Key_{h.d} + Key_{vdist}}{2} = 6.25\ m$

Moist Soil Load above GWL: $E_{h1UN2.OT} := \frac{\gamma_m \cdot K_o \cdot h_{1UN2}^{\,2}}{2} B \cdot -1 = -55.6 \cdot kN$

Moment Arm (from Point O): $E_{h1locUN2.OT} := \frac{h_{1UN2}}{3} + h_{2UN2} + Key_{vdist} = 10.37\ m$

Saturated Soil Load below GWL:
(rectangular component) $E_{h2UN2.OT} := (\gamma_m \cdot K_o \cdot h_{1UN2}) \cdot (h_{2UN2} + Key_{vdist}) \cdot B \cdot -1 = -324.3 \cdot kN$

Moment Arm (from Point O): $E_{h2locUN2.OT} := \frac{h_{2UN2} + Key_{vdist}}{2} = 4.65\ m$

Saturated Soil Load below GWL:
(triangular component) $E_{h2aUN2.OT} := \frac{(\gamma_{sat} - \gamma_w) \cdot K_o \cdot (h_{2UN2} + Key_{vdist})^2}{2} \cdot B \cdot -1 = -288.7 \cdot kN$

Moment Arm (from Point O): $E_{h2alocUN2.OT} := \frac{h_{2UN2} + Key_{vdist}}{3} = 3.10\ m$

Resisting Soil Load (Tailwater Side):

(Determine resisting soil load based on depth variation between the keys (ie. Key_{vdist}). In case where key at heel is deeper than key at toe (ie. $Key_{vdist} < 0$), resisting soil load (p*) is assumed to produce horizontal equilibrium as per Figure 4-5 above. Resisting soil load (p_o) is neglected.)

Total Driving Force: $\Sigma H_{SoildriveUN2.OT} := E_{s1UN2.OT} + E_{h1UN2.OT} + E_{h2UN2.OT} + E_{h2aUN2.OT} + H_{h2UN2} = -1295.4 \cdot kN$

Total Resisting Force: $\Sigma H_{waterresistUN2.OT} = 626.8 \cdot kN$

Assumed Soil Load p*: $E_{h8UN2a.OT} := \left(\Sigma H_{SoildriveUN2.OT} + \Sigma H_{waterresistUN2.OT}\right) \cdot -1 = 668.569 \cdot kN$

Moment Arm (from Point O): $E_{h8UN2a.loc.OT} := \dfrac{Key_{vdist}}{2} = -1\ m$

$$E_{h8UN2.OT} := \begin{cases} E_{h8UN2a.OT} & \text{if } Key_{vdist} < 0 \\ \Sigma H_{SoilresistUN2} - H_{h6UN2} - H_{h2aUN2} - P_{sbUN2} & \text{otherwise} \end{cases} = 668.569 \cdot kN$$

$$\Sigma M_{SoilresistUN2} := \begin{cases} E_{h8UN2a.OT} \cdot E_{h8UN2a.loc.OT} & \text{if } Key_{vdist} < 0 \\ \Sigma M_{HorizSoilResistUN2} - H_{h6UN2} \cdot H_{h6locUN2} - H_{h2aUN2} \cdot H_{h2alocUN2} - P_{sbUN2} \cdot P_{sblocUN2} & \text{otherwise} \end{cases} = -668.569 \cdot kN \cdot m$$

Sum of Moment about Point O:

$$\Sigma M_{LateraldriveUN2.OT} := E_{s1UN2.OT} \cdot E_{s1locUN2.OT} + E_{h1UN2.OT} \cdot E_{h1locUN2.OT} + E_{h2UN2.OT} \cdot E_{h2locUN2.OT} \dots + E_{h2aUN2.OT} \cdot E_{h2alocUN2.OT} + H_{h2UN2} \cdot H_{h2locUN2} = -4091.4 \cdot kN \cdot m$$

$$\Sigma M_{LateralresistUN2.OT} := \Sigma M_{waterresistUN2.OT} + \Sigma M_{SoilresistUN2} = 440.8 \cdot kN \cdot m$$

Total moment:

$$\Sigma M_{UN2.OT} := \Sigma M_{conc} + \Sigma M_{VertSoilWaterResistUN2} + \Sigma M_{UpliftUN2.OT} + \Sigma M_{LateraldriveUN2.OT} + \Sigma M_{LateralresistUN2.OT} = 8607.5 \cdot kN \cdot m$$

Total Vertical Force: $\Sigma V_{UN2.OT} := \Sigma V_{conc} + \Sigma V_{SoilWaterUN2} + \Sigma V_{UpliftUN2.OT} = 1508.8 \cdot kN$

Distance X_R: EM 1110-2-2502 Eq.4-1 $X_{R.UN2} := \dfrac{\Sigma M_{UN2.OT}}{\Sigma V_{UN2.OT}} = 5.705\ m$

Overturning Resultant Ratio $Ratio_{UN2.OT} := \dfrac{X_{R.UN2}}{b} = 0.48$

$$Ratio_{UN2.OT.check} := \begin{cases} \text{"OKAY "} & \text{if } Ratio_{UN2.OT} > X_{R.reqUN2} \\ \text{"Revise Structure""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

CHECK FOUNDATION ECCENTRICITY (HORIZONTAL PLANE):

Eccentricity (horizontal plan): $ex_{UN2.OT} := \dfrac{b}{2} - \dfrac{\Sigma M_{UN2.OT}}{\Sigma V_{UN2.OT}} = 0.30\ m$ $Kern_{OT} = 2\ m$

Eccentricity Check: $e_{check.UN2.OT} := \begin{cases} \text{"Okay"} & \text{if } ex_{UN2} \le Kern_{OT} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"Okay"}$

LOAD CASE UN2

CHECK FOUNDATION BEARING CAPACITY (HORIZONTAL PLANE):

Base Section Modulus: $S_{b.OT} = 24\,m^3$

Bearing Pressure Under Toe:

$$\sigma_{ToeUN2.OT} := \begin{cases} \left(\dfrac{\Sigma V_{UN2.OT}}{b \cdot B} + \dfrac{\Sigma V_{UN2.OT} \cdot ex_{UN2.OT}}{S_{b.OT}}\right) & \text{if } \dfrac{\Sigma V_{UN2.OT}}{b \cdot B} \geq \dfrac{\Sigma V_{UN2.OT} \cdot ex_{UN2.OT}}{S_{b.OT}} \\ \dfrac{2 \cdot \Sigma V_{UN2.OT}}{B \cdot 3\left(\dfrac{b}{2} - ex_{UN2.OT}\right)} & \text{otherwise} \end{cases} = 144.3 \cdot kPa$$

$$Bearing_{ChecktoeUN2.OT} := \begin{cases} \text{"OKAY "} & \text{if } \sigma_{ToeUN2.OT} < \sigma_{allowUN2} \\ \text{"NG - for reference only""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

Bearing Pressure Under Heel:

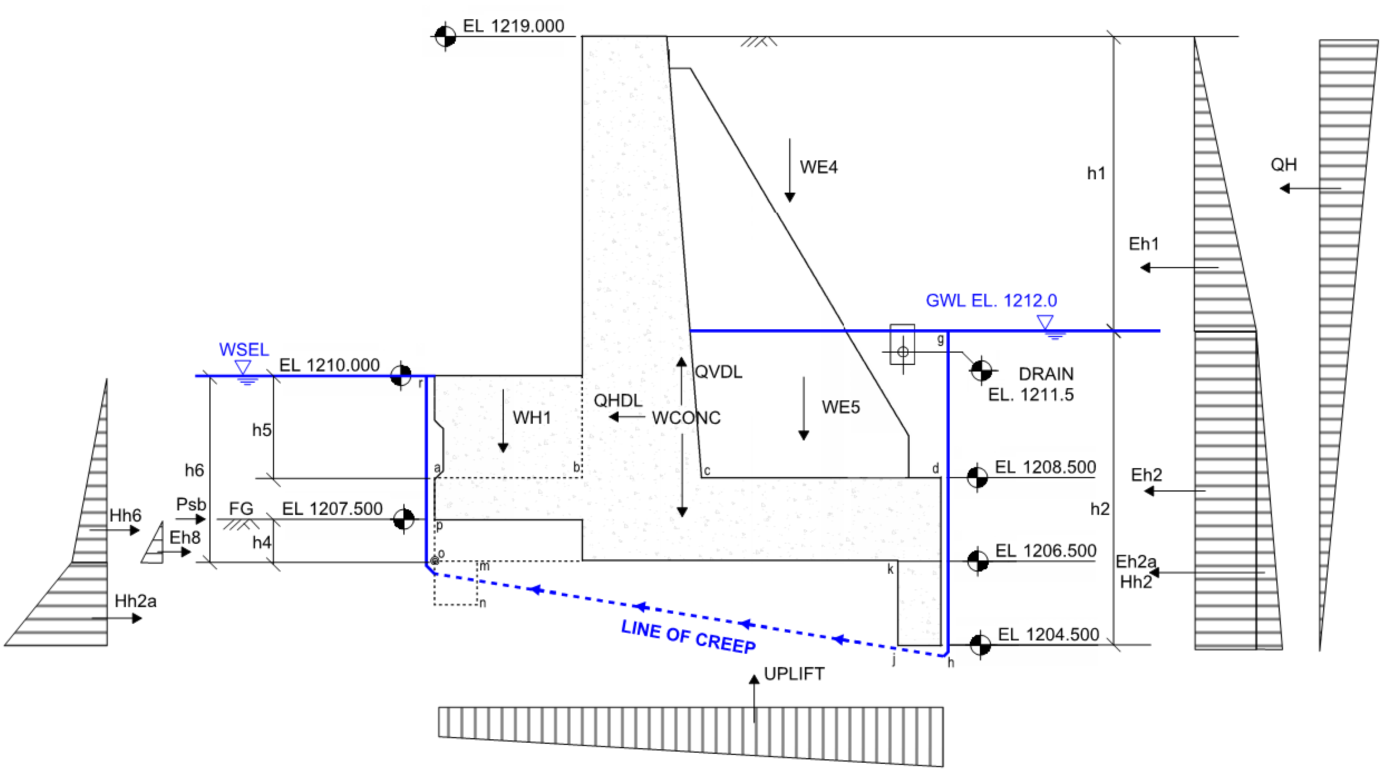
$$\sigma_{HeelUN2.OT} := \begin{cases} \left(\dfrac{\Sigma V_{UN2.OT}}{b \cdot B} - \dfrac{\Sigma V_{UN2.OT} \cdot ex_{UN2.OT}}{S_{b.OT}}\right) & \text{if } \dfrac{\Sigma V_{UN2.OT}}{b \cdot B} \geq \dfrac{\Sigma V_{UN2.OT} \cdot ex_{UN2.OT}}{S_{b.OT}} \\ 0 & \text{otherwise} \end{cases} = 107.2 \cdot kPa$$

$$Bearing_{CheckheelUN2.OT} := \left(\begin{cases} \text{"OKAY "} & \text{if } \sigma_{ToeUN2.OT} < \sigma_{allowUN2} \wedge \sigma_{ToeUN2.OT} > 0 \\ \text{"NG - for reference only""} & \text{otherwise} \end{cases}\right) = \text{"OKAY "}$$

SUMMARY OF STABILITY ASSESSMENT:

LOAD CASE UN2

Sliding Factor of Safety: (Horizontal Plane - Ref only)	$FS_{Horiz.SlidingUN2} = 0.73$	$FS_{Sliding.check1.UN2}$ = "NG - key req""
Sliding Factor of Safety: (Inclined Plane)	$FS_{InclinedlSlidingUN2} = 1.3$	$FS_{Sliding.check2.UN2}$ = "OKAY "
Eccentricity: (Inclined Plane)	$ex_{UN2} = 0.71\ m$	$e_{check.UN2}$ = "Okay"
Bearing Pressure At Heel: (Inclined Plane)	$\sigma_{HeelUN2} = 98 \cdot kPa$	$Bearing_{CheckheelUN2}$ = "OKAY "
Bearing Pressure At Toe: (Inclined Plane)	$\sigma_{ToeUN2} = 203 \cdot kPa$	$Bearing_{ChecktoeUN2}$ = "OKAY "
Flotation Factor of Safety (horizontal plane)	$FS_{FloatationUN2} = 2.16$	$FS_{Floatation.UN2.check}$ = "OKAY "
Overturning Resultant Ratio: (horizontal plane)	$Ratio_{UN2.OT} = 0.48$	$Ratio_{UN2.OT.check}$ = "OKAY "
Eccentricity: (horizontal plane - Ref only)	$ex_{UN2.OT} = 0.30\ m$	$e_{check.UN2.OT}$ = "Okay"
Bearing Pressure At Heel: (horizontal plane - Ref only)	$\sigma_{HeelUN2.OT} = 107 \cdot kPa$	$Bearing_{CheckheelUN2.OT}$ = "OKAY "
Bearing Pressure At Toe: (horizontal plane - Ref only)	$\sigma_{ToeUN2.OT} = 144 \cdot kPa$	$Bearing_{ChecktoeUN2.OT}$ = "OKAY "



E1 DESIGN CASE

LOAD CASE E1 ACCEPTANCE PARAMETERS

FS sliding:

Extreme (E) loading) 1.0 (without cohesion, seismic (Table 3-3, USACE EM 1110-2-2100)

Resultant Location:

Extremem (E) Inside middle half ~75% base in compression

Required Factor of Safety for Sliding: $FS_{sliding.reqE1} := 1.0$ (Without Cohesion)

Allowable rock bearing pressure: $\sigma_{allowE1} := 1740kPa$ (Section 5.2, Design Criteria EM 1110-2-2100 Section 3-10)

Overturning Required Resultant Ratio: $X_{R.reqE1} := 0.25$ (EM 1110-2-2502, Figure 4-4)

Required Factor of Safety for Floatation $FS_{req.E1.flt} := 1.1$

SOIL HEIGHTS and Water Levels:

LOAD CASE E1

Heel Conditions:

Groundwater Elevation at Heel: $GWL_{E1} := 1212.0m$

Distance from Finish Grade to Groundwater at Heel: $h_{1E1} := \left[T_w - GWL_{E1} + \left(L_{cd} + t_{wb} - t_{wt}\right) \cdot \tan(\beta)\right] = 7.00\ m$

Distance from Water Surface to Bottom of Footing at Heel: $h_{2E1} := GWL_{E1} - Bot_{ftg} + Key_{h.d} = 7.50\ m$

Toe Conditions:

Water Surface Elevation at Toe: $WSEL_{E1} := 1210.0m$

Water Surface Elevation at Toe for Uplift: $UWSEL_{E1} := 1210.0 \cdot m$

Finish Grade at Toe providing lateral resistance: $FG_{toeE1} := 1207.5 \cdot m$

Soil Depth Above top of footing: $h_{3aE1} := FG_{toeE1} - Top_{ftg} = -1\ m$

$$h_{3E1} := \begin{vmatrix} h_{3aE1} & \text{if } FG_{toeE1} - Top_{ftg} \geq 0 \\ 0 & \text{otherwise} \end{vmatrix} = 0$$

Resisting Fill at Toe: $h_{4E1} := FG_{toeE1} - Bot_{ftg} + Key_{t.d} = 1.00\ m$

Distance from Water Level to Top of Footing at Toe: $h_{5E1} := WSEL_{E1} - Top_{ftg} = 1.50\ m$

Distance from Water Surface to Bottom of Footing at Toe: $h_{6E1} := WSEL_{E1} - Bot_{ftg} + Key_{t.d} = 3.50\ m$

Soil Depth Above WSEL: $h_{7aE1} := FG_{toeE1} - WSEL_{E1} = -2.5\ m$

$$h_{7E1} := \begin{vmatrix} h_{7aE1} & \text{if } FG_{toeE1} - WSEL_{E1} \geq 0 \\ 0 & \text{otherwise} \end{vmatrix} = 0$$

Soil Depth Below WSEL:

$$h_{8E1} := \begin{vmatrix} WSEL_{E1} - Bot_{ftg} + Key_{t.d} & \text{if } FG_{toeE1} - WSEL_{E1} \geq 0 \\ h_{4E1} & \text{otherwise} \end{vmatrix} = 1$$

For Line of Creep Method: $L_{ho.E1} := \sqrt{b^2 + \left(Key_{h.d} - Key_{t.d}\right)^2} = 12.166\ m$

Head Loss from Point g:

$\Delta h_{g.hj.E1} := h_{2E1} = 7.5\ m$ (to point h & j)

$\Delta h_{g.km.E1} := GWL_{E1} - Bot_{ftg} = 5.5\ m$ (to point k & m)

$\Delta h_{g.no.E1} := GWL_{E1} - Bot_{ftg} + Key_{t.d} = 5.5\ m$ (to point n & o)

$\Delta h_{g.p.E1} := GWL_{E1} - FG_{toeE1} = 4.5\ m$ (to point p)

$\Delta h_{g.r.E1} := GWL_{E1} - UWSEL_{E1} = 2\ m$ (to point r)

Surcharge

Surcharge on Heel: $S1_{E1} := 0.0 \dfrac{kN}{m^2}$

Calculate Soil Lateral Pressure Coefficients:

LOAD CASE E1

Calculate at-rest pressure coefficient K_o based on Jaky's (1944) equation.

Soil At Rest Static Coefficient:
(apply to resisting soil loads)

$$K_o := \frac{1 - \sin(\phi)}{1 + \sin(\beta)} = 0.546$$

(Eq. 3-6, USACE EM 1110-2-2502)

Calculate active pressure coefficient K_A based on Coulumb equations.

Determine Slope of Active Wedge: (cohesionless backfill with water table)

$$c_1 := 2 \cdot \tan(\phi) = 1.019 \qquad c_2 := 1 - \tan(\phi) \cdot \tan(\beta) - \frac{\tan(\beta)}{\tan(\phi)} = 1$$

(Eq. G-14 / G-15, USACE EM 1110-2-2100)

$$\alpha := \operatorname{atan}\left(\frac{c_1 + \sqrt{c_1^{\,2} + 4 \cdot c_2}}{2}\right) = 1.021 \qquad \alpha_{deg} := \alpha \cdot \frac{180}{\pi} = 58.5$$

degrees (Eq. G-13, USACE EM 1110-2-2100)

Soil Active Coefficient above GWL:

$$K_{Aagwt} := \left(\frac{1 - \tan(\phi) \cdot \cot(\alpha)}{1 + \tan(\phi) \cdot \tan(\alpha)}\right) \cdot \left(\frac{\tan(\alpha)}{\tan(\alpha) - \tan(\beta)}\right) = 0.376$$

Soil Active Coefficient below GWL:

$$K_{Abgwt} := \frac{1 - \tan(\phi) \cdot \cot(\alpha)}{1 + \tan(\phi) \cdot \tan(\alpha)} \cdot \left[1 + \left(\frac{\tan(\alpha)}{\tan(\alpha) - \tan(\beta)} - 1\right) \cdot \left(\frac{\gamma_m}{\gamma_{sat} - \gamma_w}\right)\right] = 0.376$$

(Eq. G-29, USACE EM 1110-2-2100)

Lateral - Driving Force

Static Copmonent : Active Pressure:

Surcharge Load:

$$E_{s1E1} := S1_{E1} \cdot K_{Aagwt} \cdot \left(H_w + Key_{h.d}\right) \cdot B \cdot -1 = 0 \cdot kN$$

Moment Arm (from bottom of footing):

$$E_{s1locE1} := \frac{H_w + Key_{h.d}}{2} + Key_{vdist} = 5.25\ m$$

Moist Soil Load above GWL:

$$E_{h1E1} := \frac{\gamma_m \cdot K_{Aagwt} \cdot h_{1E1}^{\,2}}{2} \cdot B \cdot -1 = -184.0 \cdot kN$$

Moment Arm (from bottom of footing):

$$E_{h1locE1} := \frac{h_{1E1}}{3} + h_{2E1} + Key_{vdist} = 7.83\ m$$

Saturated Soil Load below GWL:
(rectangular component)

$$E_{h2E1} := \left(\gamma_m \cdot K_{Abgwt} \cdot h_{1E1}\right) \cdot h_{2E1} \cdot B \cdot -1 = -394.3 \cdot kN$$

Moment Arm (from bottom of footing):

$$E_{h2locE1} := \frac{h_{2E1}}{2} + Key_{vdist} = 1.75\ m$$

Saturated Soil Load below GWL:
(triangular component)

$$E_{h2aE1} := \frac{\left(\gamma_{sat} - \gamma_w\right) \cdot K_{Abgwt} \cdot h_{2E1}^{\,2}}{2} \cdot B \cdot -1 = -128.9 \cdot kN$$

Moment Arm (from bottom of footing):

$$E_{h2alocE1} := \frac{h_{2E1}}{3} + Key_{vdist} = 0.50\ m$$

Lateral Water Load:

Water Load GWL to Bottom of Key

$$H_{h2E1} := \frac{\gamma_w \cdot h_{2E1}^{\,2}}{2} \cdot B \cdot -1 = -275.6 \cdot kN$$

Moment Arm (from bottom of footing):

$$H_{h2locE1} := \frac{h_{2E1}}{3} + Key_{vdist} = 0.50\ m$$

$$\Sigma H_{SoildriveE1} := E_{s1E1} + E_{h1E1} + E_{h2E1} + E_{h2aE1} + H_{h2E1} = -982.8 \cdot kN$$

$$\Sigma M_{LateralSoildriveE1} := E_{s1E1} \cdot E_{s1locE1} + E_{h1E1} \cdot E_{h1locE1} + E_{h2E1} \cdot E_{h2locE1} \ldots + E_{h2aE1} \cdot E_{h2alocE1} + H_{h2E1} \cdot H_{h2locE1} = -2333.7\ m \cdot kN$$

Lateral - Resisting Force

LOAD CASE E1

Note: **Due to the relatively shallow depth of resisting soil/rock, a conservative apporach using at-rest coefficient in lieu of a passive wedge is used to calculate resisting forces.**

Lateral Water Load:

Water Load WSEL to Bottom of Footing: $H_{h6E1} := H_{h6U1} = 60.0 \cdot kN$

Moment Arm (from bot. of toe key): $H_{h6locE1} := H_{h6locU1} = 1.17\ m$

Water Load Bot. of Footing to Bot. of H. Key: $H_{h2aE1} := \left[\left(UWSEL_{E1} - Bot_{ftg} + Key_{t.d}\right) + h_{2E1}\right] \cdot \frac{Key_{h.d}}{2} \cdot \gamma_w \cdot B = 107.8 \cdot kN$

Moment Arm (from bot. of toe key):

$$H_{h2alocE1} := \frac{Key_{h.d} \cdot \left[2 \cdot \left(UWSEL_{E1} - Bot_{ftg} + Key_{t.d}\right) + h_{2E1}\right]}{3\left[h_{2E1} + \left(UWSEL_{E1} - Bot_{ftg} + Key_{t.d}\right)\right]} \ldots = -1.12\ m$$
$$+ Key_{vdist}$$

Lateral Soil Load:

Moist Soil Load above WSEL: $E_{h7E1} := \frac{\gamma_m \cdot K_o \cdot h_{7E1}^{\ 2}}{2} B = 0.0 \cdot kN$

Moment Arm (from bot. of toe key): $E_{h7locE1} := h_{6E1} + \frac{h_{7E1}}{3} + Key_{vdist} = 1.50\ m$

Saturated Soil Load below WSEL: (rectangular component) $E_{h8E1} := \left(\gamma_m \cdot K_o \cdot h_{7E1}\right) \cdot h_{8E1} \cdot B = 0.0 \cdot kN$

Moment Arm (from bot. of toe key): $E_{h8locE1} := \frac{h_{8E1}}{2} = 0.50\ m$

Saturated Soil Load below WSEL: (triangular component) $E_{h8aE1} := \frac{\left[\left(\gamma_{sat} - \gamma_w\right) \cdot K_o\right] \cdot h_{8E1}^{\ 2}}{2} \cdot B = 3.3 \cdot kN$

Moment Arm (from bot. of footing): $E_{h8alocE1} := \frac{h_{8E1}}{3} = 0.33\ m$

Lateral Resistance from Stilling Basin:

Lateral Resistance from Stilling Basin: $P_{sbE1} := 291 kN$ (Force needed to achieve the required sliding factor of safety in case UN2)

Moment Arm (from bot. of toe key): $P_{sblocE1} := \frac{t_{ftg}}{2} + Key_{t.d} = 1.00\ m$

$$\Sigma H_{SoilresistE1} := H_{h6E1} + H_{h2aE1} + E_{h7E1} + E_{h8E1} + E_{h8aE1} + P_{sbE1} = 462.2 \cdot kN$$

$$\Sigma M_{HorizSoilResistE1} := H_{h6E1} \cdot H_{h6locE1} + H_{h2aE1} \cdot H_{h2alocE1} + E_{h7E1} \cdot E_{h7locE1} \ldots = 241.3\ m \cdot kN$$
$$+ E_{h8E1} \cdot E_{h8locE1} + E_{h8aE1} \cdot E_{h8alocE1} + P_{sbE1} \cdot P_{sblocE1}$$

Vertical Force:

UPLIFT: Linear distribution from water at heel to water at toe:

$$\Sigma V_{UpliftE1} := \left[\left(UWSEL_{E1} - Bot_{ftg} + Key_{t.d}\right) + h_{2E1}\right] \cdot \frac{b}{2} \cdot \gamma_w \cdot B \cdot -1 = -646.8 \cdot kN$$

Moment Arm (from Point O):

$$V_{UpliftE1aloc} := \frac{b \cdot \left[2 \cdot h_{2E1} + \left(UWSEL_{E1} - Bot_{ftg} + Key_{t.d}\right)\right]}{3\left[h_{2E1} + \left(UWSEL_{E1} - Bot_{ftg} + Key_{t.d}\right)\right]} = 6.727\ m$$

$$\Sigma M_{UpliftE1} := \Sigma V_{UpliftE1} \cdot V_{UpliftE1aloc} = -4351.2 \cdot kN \cdot m$$

Weight of soil and water over toe:

Water Above the Top of Footing: $W_{H1E1} := \gamma_w \cdot h_{5E1} \cdot L_{ab} \cdot B = 51.45 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E1locE1} := \frac{L_{ab}}{2} = 1.75\ m$

Soil above top of footing: $W_{E6E1} := \gamma_b \cdot h_{3E1} \cdot L_{ab} \cdot B = 0.0 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E6locE1} := \frac{L_{ab}}{2} = 1.75\ m$

Vertical Load Due to Surcharge: $S_{E1} := S1_{E1} \cdot L_{cd} \cdot B = 0 \cdot kN$ $\quad S_{E1loc} := b - \frac{L_{cd}}{2} = 9.16\ m$

Weight of soil and water over heel:

Moist Soil for sloped grade above top of wall:

Length of sloped portion of soil above top of wall: $L_{E3E1} := \left(L_{cd} + t_{wb} - t_{wt}\right) = 6.50\ m$

Height of sloped soil above top of wall over heel: $h_{E3locE1} := \left(L_{E3E1}\right) \cdot \tan(\beta) = 0.00\ m$

Weight of sloped soil above top of wall: $W_{E3E1} := \frac{\gamma_m}{2} \cdot h_{E3locE1} \cdot L_{E3E1} \cdot B = 0.0 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E3locE1} := L_{ab} + t_{wt} + \frac{2}{3} \cdot L_{E3E1} = 9.83\ m$

Moist soil from top of wall to groundwater level:

Height of soil from top of wall and top of GWL: $h_{1E1} = 7.00\ m$

Length from edge of wall at GWL to edge of heel: $L_{E4E1} := L_{E3E1} - \left(h_{1E1} \cdot S_{batter}\right) = 5.95\ m$

Weight of soil over heel from top of wall to GWL: $W_{E4E1} := \gamma_m \cdot h_{1E1} \cdot \frac{\left(L_{E3E1} + L_{E4E1}\right)}{2} \cdot B = 871.5 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E4locE1} := b - \frac{L_{E3E1}^{\ 2} + L_{E3E1} \cdot L_{E4U1} + L_{E4E1}^{\ 2}}{3\left(L_{E3E1} + L_{E4E1}\right)} = 8.89\ m$

Saturated soil from groundwater to top of footing:

Height of soil from GWL to top of heel: $h_{E4E1} := h_{2E1} - t_{ftg} - Key_{h.d} = 3.50\ m$

Weight of soil over heel from GWL to top of heel: $W_{E5E1} := \left(\gamma_{sat}\right) \cdot h_{E4E1} \cdot \frac{\left(L_{E4E1} + L_{cd}\right)}{2} \cdot B = 447.6 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E5locE1} := b - \frac{L_{E4E1}^{\ 2} + L_{E4E1} \cdot L_{cd} + L_{cd}^{\ 2}}{3\left(L_{E4E1} + L_{cd}\right)} = 9.09\ m$

$\Sigma V_{SoilWaterE1} := W_{H1E1} + W_{E6E1} + W_{E3E1} + W_{E4E1} + W_{E5E1} + S_{E1} = 1370.5 \cdot kN$

$\Sigma M_{VertSoilWaterResistE1} := W_{H1E1} \cdot W_{E1locE1} + W_{E6E1} \cdot W_{E6locE1} \cdots + W_{E3E1} \cdot W_{E3locE1} + W_{E4E1} \cdot W_{E4locE1} + W_{E5E1} \cdot W_{E5locE1} + S_{E1} \cdot S_{E1loc} = 11903.5\ m \cdot kN$

SESIMIC ANALYSIS:

LOAD CASE E1

Seismic coefficient will be applied to dead loads to calculate seismic force and force is applied at center of gravity of the mass. Vertical and Horizontal loads are applied in the "destabilizing direction"

SEISMIC PARAMETERS:

Peak Ground Acceleration for Seismic Load $PGA_{Horiz} := 0.26$ $PGA_{Vert} := 0.56 \cdot PGA_{Horiz} = 0.146$ (Section 7.9, Design Criteria)

In accordance with USACE EM 1110-2-2100 Section 4-7.b, consider 2/3 PGA as seismic coefficient for stabilitiy.

Horizontal Seismic coefficient for stabilty: $K_{hE1} := \frac{2}{3} PGA_{Horiz} = 0.173$

Vertical Seismic coefficient for stabilty: $K_{vE1} := \frac{2}{3} PGA_{Vert} = 0.097$

SEISMIC ACCELERATION OF RIGID MASSES (Q_D):

Vertical Load Application:

$\Sigma V_{conc} = 1206.3 \cdot kN$

$Q_{v.conc} := \Sigma V_{conc} \cdot K_{vE1} \cdot -1 = -117.1 \cdot kN$ (assume acting upwards for adverse sliding effect)

Moment arm for siesmic load application (From Toe): $H_{cent} = 5.582\, m$

$M_{Qv.conc} := Q_{v.conc} \cdot H_{cent} = -653.6 \cdot kN \cdot m$

Lateral Load Application:

$Q_{h.conc} := \Sigma V_{conc} \cdot K_{hE1} \cdot -1 = -209.1 \cdot kN$

Moment arm for siesmic load application (Above Base of Footing): $V_{Cent} = 3.859\, m$

$M_{Q.conc} := Q_{h.conc} \cdot V_{Cent} = -806.8 \cdot kN \cdot m$

SEISMIC ACCELERATION OF SOIL WEDGE + WATER (Q_{EH}):

Vertical Load Application:

$\Sigma V_{SoilWaterE1} = 1370.5 \cdot kN$

$Q_{v.SoilWaterE1} := \Sigma V_{SoilWaterE1} \cdot K_{vE1} \cdot -1 = -133 \cdot kN$ (assume acting upwards for adverse sliding effect)

Moment arm for siesmic load application (From Toe): $e_{QE1} := \frac{\Sigma M_{VertSoilWaterResistE1}}{\Sigma V_{SoilWaterE1}} = 8.685\, m$

$M_{Qv.SoilWaterE1} := Q_{v.SoilWaterE1} \cdot e_{QE1} = -1155.4 \cdot kN \cdot m$

Lateral Load Application:

Seismic soil load is calculated based on Mononobe-Okabe method to determine combined static and dynamic coefficient (K_{AE}). Coulomb's active component (K_A) is subtracted from K_{AE} to obtain the seismic coefficient (ΔK_{AE}) for dynamic component of soil force.

Glacial Till Internal Friction (radians): $\phi = 0.471$

Seismic Inertia Angle (radians): $\psi := \operatorname{atan}\left(\frac{K_{hE1}}{1 - K_{vE1}}\right) = 0.190$

Inclination of batter (radians): $\theta := 0.00$ assuming zero is conservative

Slope of retained ground surface: $\beta = 0.00$

$$K_{AE} := \frac{\cos(\phi - \psi - \theta) \cdot \cos(\phi - \psi - \theta)}{\cos(\psi) \cdot \cos(\theta) \cdot \cos(\theta)\, \cos(\psi + \theta) \cdot \left(1 + \sqrt{\frac{\sin(\phi)\, \sin(\phi - \psi - \beta)}{\cos(\beta - \theta) \cdot \cos(\psi + \theta)}}\right)^2} = 0.519$$

$\Delta K_{AE} := K_{AE} - K_{Abgwt} = 0.143$

Dynamic component of active seismic wedge:

$$Q_{h.SoilWaterE1} := \Delta K_{AE} \cdot \left[\frac{\gamma_m \cdot \left(H_w + Key_{h.d}\right)^2}{2 \cdot (\tan(\alpha) - \tan(\beta))} + \frac{\left(\gamma_{sat} - \gamma_m\right) \cdot h_{2E1}{}^2}{2 \cdot \tan(\alpha)}\right] \cdot B \cdot -1 = -189.2 \cdot kN$$

(Eq. G-64, USACE EM 1110-2-2100)

Moment arm for siesmic load application (About Point O): $Q_{h.SoilWaterlocE1} := \frac{2}{3} \cdot \left(H_w + Key_{h.d}\right) + Key_{vdist} = 7.67\, m$

$M_{Q.h.SoilWaterE1} := Q_{h.SoilWaterE1} \cdot Q_{h.SoilWaterlocE1} = -1450.2 \cdot kN \cdot m$

STABILITY ASSESSMENT:

LOAD CASE E1

CHECK SLIDING ALONG HORIZONTAL SLIDING PLANE:

Summation of the vertical forces: $\Sigma V_{E1} := \Sigma V_{conc} + \Sigma V_{SoilWaterE1} + \Sigma V_{UpliftE1} + Q_{v.conc} + Q_{v.SoilWaterE1} = 1679.9 \cdot kN$

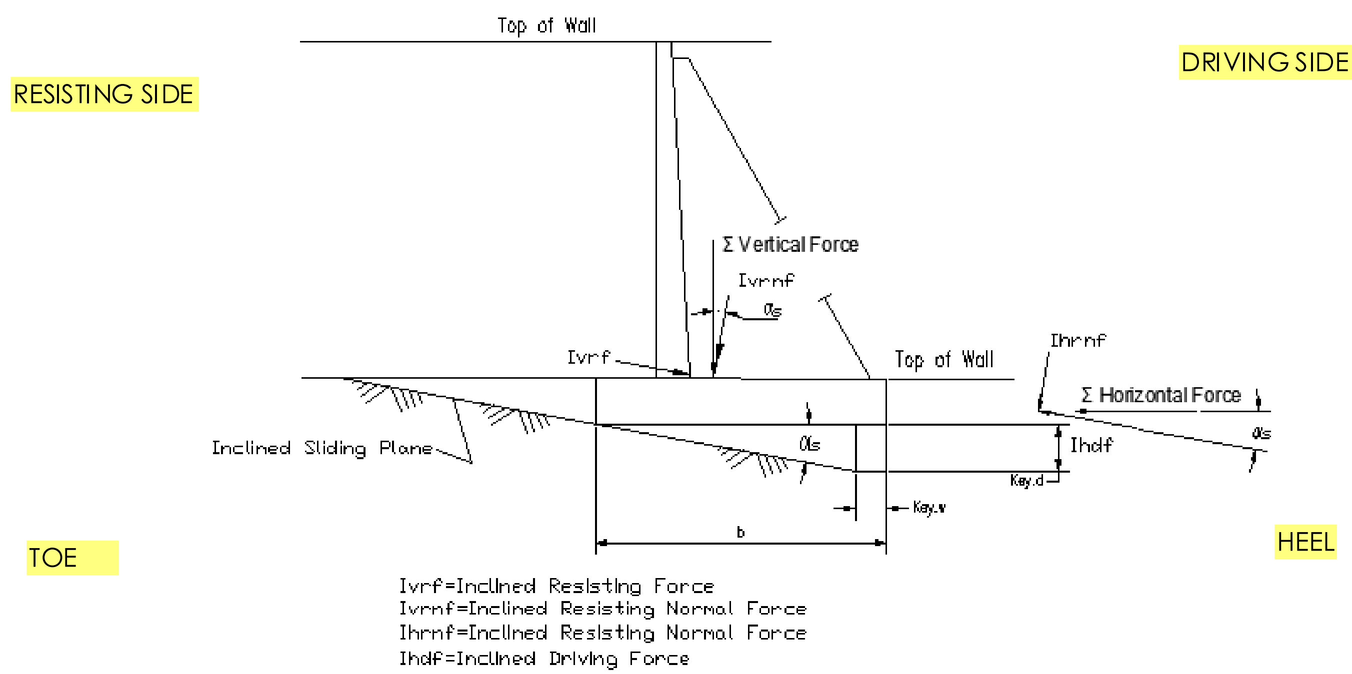
Summation of the horizontal forces: $\Sigma H_{E1} := \Sigma H_{SoildriveE1} + Q_{h.conc} + Q_{h.SoilWaterE1} + \Sigma H_{SoilresistE1} = -918.9 \cdot kN$

Safety Factor for Sliding Horizontal Failure Plane

$$FS_{Horiz.SlidingE1} := \frac{\left|\Sigma V_{E1}\right| \cdot \tan\left(\phi_{rock} \cdot \frac{\pi}{180}\right)}{\left|\Sigma H_{E1}\right|} = 0.89$$

$$FS_{Sliding.check1.E1} := \begin{cases} \text{"OKAY"} & \text{if } FS_{Horiz.SlidingE1} > FS_{sliding.reqE1} \\ \text{"NG - key req"} & \text{otherwise} \end{cases} = \text{"NG - key req"}$$

CHECK FACTOR OF SAFETY SLIDING WITH KEY (INCLINED SLIDING PLANE):



(With properly engineered reinforced concrete Key, horizontal sliding plane thru Toe is protected, critical sliding plane is relocated to the INCLINED SLIDING PLANE FROM HEEL KEY To TOE, Bedrock Mass above this examing plane is mobilized by reinforced concrete key and combined into Structural Wedge.)

Resolve ΣV_{E1} & ΣH_{E1}

$$\Sigma V_{InclinedE1} := \cos(\alpha s) \cdot \left(\left|\Sigma V_{E1} + V_{rocksection}\right|\right) + \sin(\alpha s) \cdot \left|\Sigma H_{E1}\right| = 2094.2 \cdot kN$$

$$\Sigma H_{InclinedE1} := \cos(\alpha s) \cdot \left|\Sigma H_{E1}\right| - \sin(\alpha s) \cdot \left(\left|\Sigma V_{E1} + V_{rocksection}\right|\right) = 553.2 \cdot kN$$

Safety Factor for Sliding Inclined Failure Plane

$$FS_{InclinedISlidingE1} := \frac{\Sigma V_{InclinedE1} \cdot \tan\left(\phi_r\right)}{\Sigma H_{InclinedE1}} = 1.69$$

$$FS_{Sliding.check2.E1} := \begin{cases} \text{"OKAY"} & \text{if } FS_{InclinedISlidingE1} > FS_{sliding.reqE1} \\ \text{"NG"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

CHECK FOUNDATION ECCENTRICITY:

LOAD CASE E1

(Vertical seismic loads from concrete, soil and water are assumed acting downwards for adverse bearing effect)

Summation of the vertical forces: $\Sigma V_{seisE1} := \Sigma V_{conc} + \Sigma V_{SoilWaterE1} + \Sigma V_{UpliftE1} - Q_{v.conc} - Q_{v.SoilWaterE1} = 2180.1 \cdot kN$

Summation of the horizontal forces: $\Sigma H_{seisE1} := \Sigma H_{E1} = -918.9 \cdot kN$

Resolve ΣV_{seisE1} & ΣH_{seisE1}

$$\Sigma V_{InclinedseisE1} := \cos(\alpha s) \cdot \left(\left|\Sigma V_{seisE1} + V_{rocksection}\right|\right) + \sin(\alpha s) \cdot \left|\Sigma H_{seisE1}\right| = 2586.4 \cdot kN$$

$$\Sigma H_{InclinedseisE1} := \cos(\alpha s) \cdot \left|\Sigma H_{seisE1}\right| - \sin(\alpha s) \cdot \left(\left|\Sigma V_{seisE1} + V_{rocksection}\right|\right) = 463.7 \cdot kN$$

Summation of the resisting moments about the toe:

$$\Sigma M_{resE1} := \Sigma M_{conc} + \Sigma M_{VertSoilWaterResistE1} + \Sigma M_{HorizSoilResistE1} + \Sigma M_{rocksection} = 20943 \cdot kN \cdot m$$

Summation of seismic moments about the toe:

$$\Sigma M_{seisE1} := -M_{Qv.conc} + M_{Q.conc} - M_{Qv.SoilWaterE1} + M_{Q.h.SoilWaterE1} = -448 \cdot kN \cdot m$$

Summation of the overturning moments about the toe:

$$\Sigma M_{oE1} := \Sigma M_{LateralSoildriveE1} + \Sigma M_{UpliftE1} = -6685 \cdot kN \cdot m$$

Total moment: $\Sigma M_{E1} := \Sigma M_{resE1} + \Sigma M_{seisE1} + \Sigma M_{oE1} = 13810.0 \cdot kN \cdot m$

Normal force to base: $\Sigma V_{InclinedseisE1} = 2586.4 \cdot kN$

Inclined Sliding Plane Length: $L_{incline} = 12.2 \cdot m$

Eccentricity (inclined plane): $ex_{E1} := \frac{L_{incline}}{2} - \frac{\Sigma M_{E1}}{\Sigma V_{InclinedseisE1}} = 0.76\,m$ $\quad Kern_{E1} := \frac{L_{incline}}{4} = 3.049\,m$

Eccentricity Check: $e_{check.E1} := \begin{cases} \text{"Okay"} & \text{if } ex_{E1} \le Kern_{E1} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"Okay"}$

CHECK FOUNDATION BEARING CAPACITY:

Base Section Modulus: $S_b = 24.79\,m^3$

Bearing Pressure Under Toe:

$$\sigma_{ToeE1} := \begin{cases} \left(\frac{\Sigma V_{InclinedE1}}{L_{incline} \cdot B} + \frac{\Sigma V_{InclinedE1} \cdot ex_{E1}}{S_b}\right) & \text{if } \frac{\Sigma V_{InclinedE1} \cdot ex_{E1}}{S_b} \le \frac{\Sigma V_{InclinedE1}}{L_{incline} \cdot B} \\ \frac{2 \cdot \Sigma V_{InclinedE1}}{B \cdot 3\left(\frac{b}{2} - ex_{E1}\right)} & \text{otherwise} \end{cases} = 235.8 \cdot kPa$$

$$Bearing_{ChecktoeE1} := \begin{cases} \text{"OKAY "} & \text{if } \sigma_{ToeE1} < \sigma_{allowE1} \\ \text{"NG""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

Bearing Pressure Under Heel:

$$\sigma_{HeelE1} := \begin{cases} \left[\frac{\Sigma V_{InclinedE1}}{L_{incline} \cdot B} - \frac{\left(\Sigma V_{InclinedE1} \cdot ex_{E1}\right)}{S_b}\right] & \text{if } \frac{\Sigma V_{InclinedE1} \cdot ex_{E1}}{S_b} \le \frac{\Sigma V_{InclinedE1}}{L_{incline} \cdot B} \\ 0 & \text{otherwise} \end{cases} = 107.6 \cdot kPa$$

$$Bearing_{CheckheelE1} := \left(\begin{cases} \text{"OKAY "} & \text{if } \sigma_{HeelE1} < \sigma_{allowE1} \wedge \sigma_{HeelE1} > 0 \\ \text{"NG - perform cracked base analysis""} & \text{otherwise} \end{cases}\right) = \text{"OKAY "}$$

CHECK FLOATATION:

Safety Factor for Floatation:

$$FS_{FloatationE1} := \frac{\Sigma V_{conc} + \Sigma V_{SoilWaterE1} + Q_{v.conc} + Q_{v.SoilWaterE1}}{\left|\Sigma V_{UpliftE1}\right|} = 3.60$$

$$FS_{Floatation.E1.check} := \begin{cases} \text{"OKAY"} & \text{if } FS_{FloatationE1} > FS_{req.E1.flt} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

CHECK OVERTURNING

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.
Assumptions are made in order to compute overturning stablity of indetermine forces on monolith with key;
(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.
(b) The horizontal resisting force acting on the key, P.key, is that required for static equilibrium
(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1

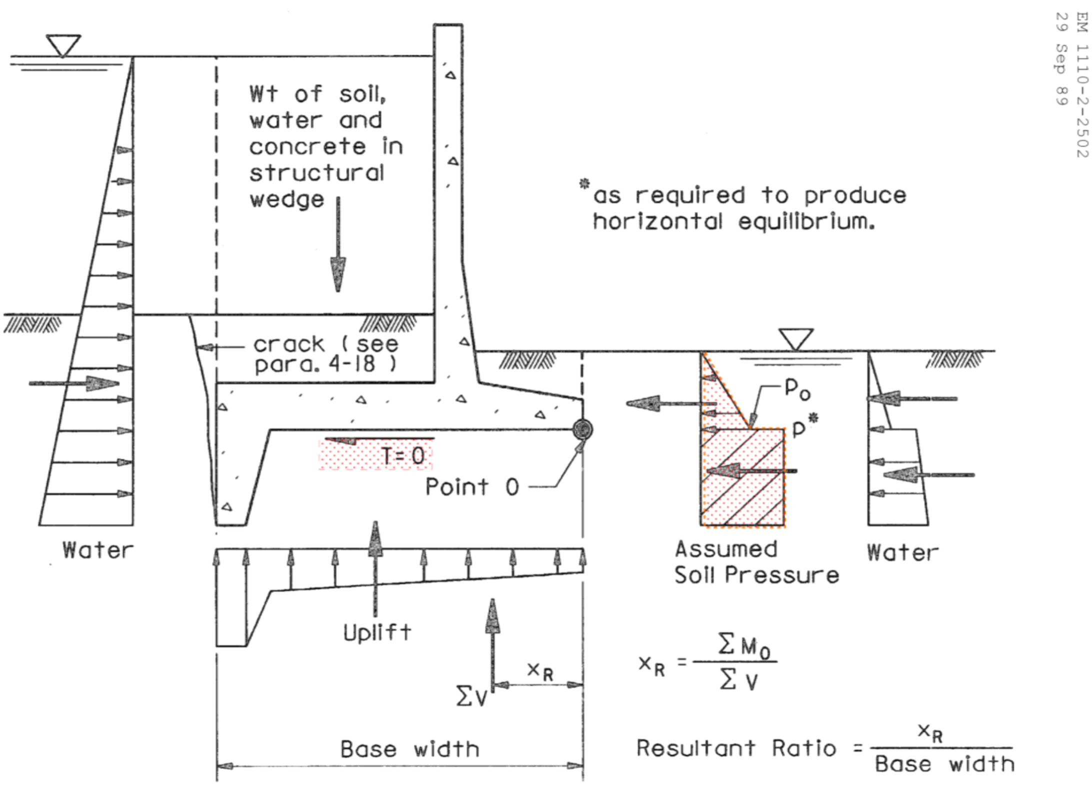


Figure 4-5. Forces for overturning analysis for wall with horizontal base and key

Modify Uplift for Overturning Analysis: **LOAD CASE E1**

(Uplift is calculated along the concrete/rock contact using the Line of Creep method)

Water Pressure at h: $u_{h.E1} := \Delta h_{g.hj.E1} \cdot \gamma_w = 73.50 \cdot kPa$

Water Pressure at o: $u_{o.E1} := \left(\Delta h_{g.no.E1} - \frac{\Delta h_{g.r.E1} \cdot L_{ho.E1}}{L_{ho.E1}}\right) \cdot \gamma_w = 34.3 \cdot kPa$

Head loss between point h and o: $\Delta h_{ho.E1} := \Delta h_{g.r.E1} \cdot \frac{L_{ho.E1}}{L_{ho.E1}} = 2\,m$

Length of concrete base (h -> o): $L_{baseho.E1} := Key_{h.w} + Key_{h.d} + Key_{hdist} + Key_{t.d} + Key_{t.w} = 14\,m$

Head loss along h -> j: $\Delta h_{hj.E1} := \Delta h_{ho.E1} \cdot \frac{Key_{h.w}}{L_{baseho.E1}} = 0.143\,m$

Water Pressure at j: $u_{j.E1} := \left(\Delta h_{g.hj.E1} - \Delta h_{hj.E1}\right) \cdot \gamma_w = 72.10 \cdot kPa$

Head loss along h -> k: $\Delta h_{hjk.E1} := \Delta h_{ho.E1} \cdot \left(\frac{Key_{h.w} + Key_{h.d}}{L_{baseho.E1}}\right) = 0.429\,m$

Water Pressure at k: $u_{k.E1} := \left(\Delta h_{g.km.E1} - \Delta h_{hjk.E1}\right) \cdot \gamma_w = 49.70 \cdot kPa$

Head loss along h -> m: $\Delta h_{hjkm.E1} := \Delta h_{ho.E1} \cdot \left(\frac{Key_{h.w} + Key_{h.d} + Key_{hdist}}{L_{baseho.E1}}\right) = 2\,m$

Water Pressure at m: $u_{m.E1} := \left(\Delta h_{g.km.E1} - \Delta h_{hjkm.E1}\right) \cdot \gamma_w = 34.30 \cdot kPa$

Head loss along h -> n: $\Delta h_{hjkmn.E1} := \Delta h_{ho.E1} \cdot \left(\frac{Key_{h.w} + Key_{h.d} + Key_{hdist} + Key_{t.d}}{L_{baseho.E1}}\right) = 2\,m$

Water Pressure at n: $u_{n.E1} := \left(\Delta h_{g.no.E1} - \Delta h_{hjkmn.E1}\right) \cdot \gamma_w = 34.30 \cdot kPa$

Uplift under key at heel: $V_{ulkeyhE1.OT} := \frac{\left(u_{h.E1} + u_{j.E1}\right) \cdot Key_{h.w}}{2} \cdot B \cdot -1 = -72.8 \cdot kN$

Moment Arm (from Point O): $V_{ulkeyhE1loc.OT} := b - \frac{Key_{h.w} \cdot \left(2 \cdot u_{j.E1} + u_{h.E1}\right)}{3 \cdot \left(u_{j.E1} + u_{h.E1}\right)} = 11.502\,m$

Uplift under base: $V_{ulbaseE1.OT} := \frac{\left(u_{k.E1} + u_{m.E1}\right) \cdot Key_{hdist}}{2} \cdot B \cdot -1 = -462 \cdot kN$

Moment Arm (from Point O): $V_{ulbaseE1loc.OT} := b - Key_{h.w} - \frac{Key_{hdist} \cdot \left(2 \cdot u_{m.E1} + u_{k.E1}\right)}{3 \cdot \left(u_{m.E1} + u_{k.E1}\right)} = 5.836\,m$

Uplift under key at toe: $V_{ulkeytE1.OT} := \frac{\left(u_{n.E1} + u_{o.E1}\right) \cdot Key_{t.w}}{2} \cdot B \cdot -1 = 0 \cdot kN$

Moment Arm (from Point O): $V_{ulkeytE1loc.OT} := \frac{Key_{t.w} \cdot \left(2 \cdot u_{n.E1} + u_{o.E1}\right)}{3 \cdot \left(u_{n.E1} + u_{o.E1}\right)} = 0$

$$\Sigma V_{UpliftE1.OT} := V_{ulkeyhE1.OT} + V_{ulbaseE1.OT} + V_{ulkeytE1.OT} = -535 \cdot kN$$

$$U_{E1.loc.OT} := \frac{V_{ulkeyhE1.OT} \cdot V_{ulkeyhE1loc.OT} + V_{ulbaseE1.OT} \cdot V_{ulbaseE1loc.OT} + V_{ulkeytE1.OT} \cdot V_{ulkeytE1loc.OT}}{\Sigma V_{UpliftE1.OT}} = 6.61\,m$$

$$\Sigma M_{UpliftE1.OT} := \Sigma V_{UpliftE1.OT} \cdot U_{E1.loc.OT} = -3533.6 \cdot kN \cdot m$$

LOAD CASE E1

Modify Lateral Water Pressure (Resisting) for Overturning Analysis:

(Resisting water pressure is calculated using the Line of Creep method)

Water Load at Key (heel): $H_{h2E1.OT} := \frac{u_{k.E1} + u_{j.E1}}{2} \cdot Key_{h.d} B = 121.8 \cdot kN$

Moment Arm (from Point O): $H_{h2locE1.OT} := \frac{Key_{h.d} \cdot (2 \cdot u_{k.E1} + u_{j.E1})}{3(u_{k.E1} + u_{j.E1})} + Key_{vdist} = -1.06\ m$

Water Load at Key (toe): $H_{h6E1.OT} := \frac{u_{o.E1} \cdot (UWSEL_{E1} - Bot_{ftg} + Key_{t.d})}{2} \cdot B = 60 \cdot kN$

Moment Arm (from Point O): $H_{h6locE1.OT} := \frac{UWSEL_{E1} - Bot_{ftg} + Key_{t.d}}{3} = 1.17\ m$

$$\Sigma H_{waterresistE1.OT} := H_{h2E1.OT} + H_{h6E1.OT} = 181.82 \cdot kN$$

$$H_{waterresistlocE1.OT} := \frac{H_{h2E1.OT} \cdot H_{h2locE1.OT} + H_{h6E1.OT} \cdot H_{h6locE1.OT}}{\Sigma H_{waterresistE1.OT}} = -0.326\ m$$

$$\Sigma M_{waterresistE1.OT} := \Sigma H_{waterresistE1.OT} \cdot H_{waterresistlocE1.OT} = -59.24 \cdot kN \cdot m$$

Modify Lateral Soil Loads for Overturning Analysis:

(Lateral soil loads are calculated down to Point O instead of bottom of shear key)

Driving Soil Load (Headwater Side):

Surcharge Load: $E_{s1E1.OT} := S1_{E1} \cdot K_{Aagwt} \cdot (H_w + Key_{h.d} + Key_{vdist}) \cdot B \cdot -1 = 0 \cdot kN$

Moment Arm (from Point O): $E_{s1locE1.OT} := \frac{H_w + Key_{h.d} + Key_{vdist}}{2} = 6.25\ m$

Moist Soil Load above GWL: $E_{h1E1.OT} := \frac{\gamma_m \cdot K_{Aagwt} \cdot h_{1E1}^2}{2} B \cdot -1 = -184.0 \cdot kN$

Moment Arm (from Point O): $E_{h1locE1.OT} := \frac{h_{1E1}}{3} + h_{2E1} + Key_{vdist} = 7.83\ m$

Saturated Soil Load below GWL:
(rectangular component) $E_{h2E1.OT} := (\gamma_m \cdot K_{Aagwt} \cdot h_{1E1}) \cdot (h_{2E1} + Key_{vdist}) \cdot B \cdot -1 = -289.2 \cdot kN$

Moment Arm (from Point O): $E_{h2locE1.OT} := \frac{h_{2E1} + Key_{vdist}}{2} = 2.75\ m$

Saturated Soil Load below GWL:
(triangular component) $E_{h2aE1.OT} := \frac{(\gamma_{sat} - \gamma_w) \cdot K_{Aagwt} \cdot (h_{2E1} + Key_{vdist})^2}{2} \cdot B \cdot -1 = -69.3 \cdot kN$

Moment Arm (from Point O): $E_{h2alocE1.OT} := \frac{h_{2E1} + Key_{vdist}}{3} = 1.83\ m$

Resisting Soil Load (Tailwater Side): **LOAD CASE E1**

(Determine resisting soil load based on depth variation between the keys (ie. Key_{vdist}). In case where key at heel is deeper than key at toe (ie. $Key_{vdist} < 0$), resisting soil load (p*) is assumed to produce horizontal equilibrium as per Figure 4-5 above. Resisting soil load (p_o) is neglected.)

Total Driving Force: $\Sigma H_{SoildriveE1.OT} := E_{s1E1.OT} + E_{h1E1.OT} + E_{h2E1.OT} + E_{h2aE1.OT} + H_{h2E1} \cdots + Q_{h.conc} + Q_{h.SoilWaterE1} = -1216.3 \cdot kN$

Total Resisting Force: $\Sigma H_{waterresistE1.OT} = 181.825 \cdot kN$

Assumed Soil Load p*: $E_{h8E1a.OT} := \left(\Sigma H_{SoildriveE1.OT} + \Sigma H_{waterresistE1.OT}\right) \cdot -1 = 1034.499 \cdot kN$

Moment Arm (from Point O): $E_{h8E1a.loc.OT} := \frac{Key_{vdist}}{2} = -1\ m$

$$E_{h8E1.OT} := \begin{cases} E_{h8E1a.OT} & \text{if } Key_{vdist} < 0 \\ \Sigma H_{SoilresistE1} - H_{h6E1} - H_{h2aE1} - P_{sbE1} & \text{otherwise} \end{cases} = 1034.499 \cdot kN$$

$$\Sigma M_{SoilresistE1} := \begin{cases} E_{h8E1a.OT} \cdot E_{h8E1a.loc.OT} & \text{if } Key_{vdist} < 0 \\ \Sigma M_{HorizSoilResistE1} - H_{h6E1} \cdot H_{h6locE1} - H_{h2aE1} \cdot H_{h2alocE1} - P_{sbE1} \cdot P_{sblocE1} & \text{otherwise} \end{cases} = -1034.499 \cdot kN \cdot m$$

Sum of Moment about Point O:

$$\Sigma M_{LateraldriveE1.OT} := E_{s1E1.OT} \cdot E_{s1locE1.OT} + E_{h1E1.OT} \cdot E_{h1locE1.OT} + E_{h2E1.OT} \cdot E_{h2locE1.OT} \cdots + E_{h2aE1.OT} \cdot E_{h2alocE1.OT} + H_{h2E1} \cdot H_{h2locE1} = -2501.4 \cdot kN \cdot m$$

$$\Sigma M_{LateralresistE1.OT} := \Sigma M_{waterresistE1.OT} + \Sigma M_{SoilresistE1} = -1093.7 \cdot kN \cdot m$$

$$\Sigma M_{seisE1.OT} := M_{Qv.conc} + M_{Q.conc} + M_{Qv.SoilWaterE1} + M_{Q.h.SoilWaterE1} = -4066 \cdot kN \cdot m$$

(seismic moment modified for the most adverse overturning effect)

Total moment:

$$\Sigma M_{E1.OT} := \Sigma M_{conc} + \Sigma M_{VertSoilWaterResistE1} + \Sigma M_{UpliftE1.OT} + \Sigma M_{LateraldriveE1.OT} + \Sigma M_{LateralresistE1.OT} + \Sigma M_{seisE1.OT} = 7441.8 \cdot kN \cdot m$$

Total Vertical Force: $\Sigma V_{E1.OT} := \Sigma V_{conc} + \Sigma V_{SoilWaterE1} + \Sigma V_{UplliftE1.OT} + Q_{v.conc} + Q_{v.SoilWaterE1} = 1791.9 \cdot kN$

Distance X_R: EM 1110-2-2502 Eq.4-1 $X_{R.E1} := \frac{\Sigma M_{E1.OT}}{\Sigma V_{E1.OT}} = 4.153\ m$

Overturning Resultant Ratio $Ratio_{E1.OT} := \frac{X_{R.E1}}{b} = 0.35$

$$Ratio_{E1.OT.check} := \begin{cases} \text{"OKAY "} & \text{if } Ratio_{E1.OT} > X_{R.reqE1} \\ \text{"Revise Structure""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

CHECK FOUNDATION ECCENTRICITY (HORIZONTAL PLANE):

Eccentricity (horizontal plan): $ex_{E1.OT} := \frac{b}{2} - \frac{\Sigma M_{E1.OT}}{\Sigma V_{E1.OT}} = 1.85\ m$ $Kern_{E1.OT} := \frac{b}{4} = 3\ m$

Eccentricity Check:

$$e_{check.E1.OT} := \begin{cases} \text{"Okay"} & \text{if } ex_{E1.OT} \le Kern_{E1.OT} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"Okay"}$$

LOAD CASE E1

CHECK FOUNDATION BEARING CAPACITY (HORIZONTAL PLANE):

Base Section Modulus: $S_{b.OT} = 24\,m^3$

Bearing Pressure Under Toe:

$$\sigma_{ToeE1.OT} := \begin{cases} \left(\dfrac{\Sigma V_{E1.OT}}{b \cdot B} + \dfrac{\Sigma V_{E1.OT} \cdot ex_{E1.OT}}{S_{b.OT}}\right) & \text{if } \dfrac{\Sigma V_{E1.OT}}{b \cdot B} \geq \dfrac{\Sigma V_{E1.OT} \cdot ex_{E1.OT}}{S_{b.OT}} \\ \dfrac{2 \cdot \Sigma V_{E1.OT}}{B \cdot 3\left(\dfrac{b}{2} - ex_{E1.OT}\right)} & \text{otherwise} \end{cases} = 287.2 \cdot kPa$$

$$Bearing_{ChecktoeE1.OT} := \begin{cases} \text{"OKAY "} & \text{if } \sigma_{ToeE1.OT} < \sigma_{allowE1} \\ \text{"NG - for reference only""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

Bearing Pressure Under Heel:

$$\sigma_{HeelE1.OT} := \begin{cases} \left(\dfrac{\Sigma V_{E1.OT}}{b \cdot B} - \dfrac{\Sigma V_{E1.OT} \cdot ex_{E1.OT}}{S_{b.OT}}\right) & \text{if } \dfrac{\Sigma V_{E1.OT}}{b \cdot B} \geq \dfrac{\Sigma V_{E1.OT} \cdot ex_{E1.OT}}{S_{b.OT}} \\ 0 & \text{otherwise} \end{cases} = 11.4 \cdot kPa$$

$$Bearing_{CheckheelE1.OT} := \left(\begin{cases} \text{"OKAY "} & \text{if } \sigma_{HeelE1.OT} < \sigma_{allowE1} \wedge \sigma_{HeelE1.OT} > 0 \\ \text{"NG - for reference only""} & \text{otherwise} \end{cases}\right) = \text{"OKAY "}$$

SUMMARY OF STABILITY ASSESSMENT:

LOAD CASE E1

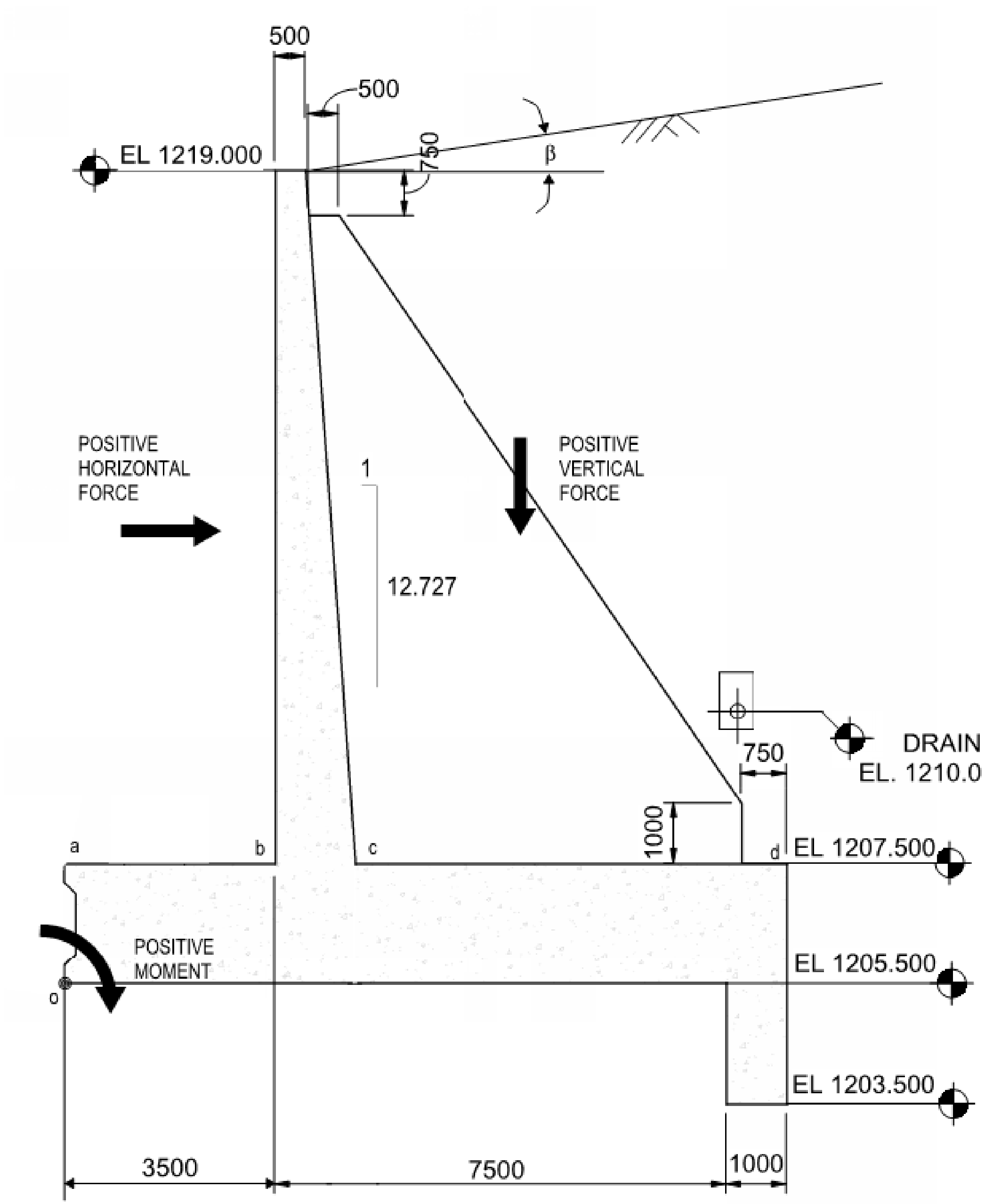
Sliding Factor of Safety: (Horizontal Plane - Ref only)	$FS_{Horiz.SlidingE1} = 0.89$	$FS_{Sliding.check1.E1}$ = "NG - key req""
Sliding Factor of Safety: (Inclined Plane)	$FS_{InclinedlSlidingE1} = 1.69$	$FS_{Sliding.check2.E1}$ = "OKAY "
Eccentricity: (Inclined Plane)	$ex_{E1} = 0.76\ m$	$e_{check.E1}$ = "Okay"
Bearing Pressure At Heel: (Inclined Plane)	$\sigma_{HeelE1} = 108 \cdot kPa$	$Bearing_{CheckheelE1}$ = "OKAY "
Bearing Pressure At Toe: (Inclined Plane)	$\sigma_{ToeE1} = 236 \cdot kPa$	$Bearing_{ChecktoeE1}$ = "OKAY "
Flotation Factor of Safety (horizontal plane)	$FS_{FloatationE1} = 3.6$	$FS_{Floatation.E1.check}$ = "OKAY "
Overturning Resultant Ratio: (horizontal plane)	$Ratio_{E1.OT} = 0.35$	$Ratio_{E1.OT.check}$ = "OKAY "
Eccentricity: (horizontal plane - Ref only)	$ex_{E1.OT} = 1.85\ m$	$e_{check.E1.OT}$ = "Okay"
Bearing Pressure At Heel: (horizontal plane - Ref only)	$\sigma_{HeelE1.OT} = 11 \cdot kPa$	$Bearing_{CheckheelE1.OT}$ = "OKAY "
Bearing Pressure At Toe: (horizontal plane - Ref only)	$\sigma_{ToeE1.OT} = 287 \cdot kPa$	$Bearing_{ChecktoeE1.OT}$ = "OKAY "

Calculation Section V

DI-5C Retaining Wall Stability Calculations

Project Number:	110773396		
Project Title:	SR1 - Diversion Structure		
Client:	Alberta Transportation		
Engineer:	Lawrence Choi	Date: 12/11/2018	
Checker:	Sean Xiao	Date: 12/18/2018	

Calculation for: Retaining Wall - Diversion Inlet Left - Block 5C



REGION COLOR CONVENTION

User Input

Calulation Highlights

Results

WALL GEOMETRY:

Top of Wall Elevation: $T_w := 1219.0 \cdot m$

Top of Footing Elevation: $Top_{ftg} := 1207.5 \cdot m$

Thickness of Footing: $t_{ftg} := 2.0m$

Bottom of Footing Elevation: $Bot_{ftg} := Top_{ftg} - t_{ftg} = 1205.5\ m$

Overall Height of wall: $h_w := T_w - Bot_{ftg} = 13.50\ m$

Thickness of Wall: Base: $t_{wb} := 1.404 \cdot m$ Top: $t_{wt} := 0.5m$

Length of toe: $L_{ab} := 3.5m$

Total Length of Footing: $b := 12.00m$

Length of heel: $L_{cd} := b - L_{ab} - t_{wb} = 7.096\ m$

Unit Width of Wall for analysis: $B := 1.00m$

SHEAR KEY GEOMETRY:

	Toe	Heel	
Key depth:	$Key_{t.d} := 0m$	$Key_{h.d} := 2.0m$	(Assumption: $Key_{h.d}$ >= $Key_{t.d}$)
Key width:	$Key_{t.w} := 0m$	$Key_{h.w} := 1m$	
Face of Key from Point O:	$Key_{t.loc} := 0 \cdot m$	$Key_{h.loc} := 11.00 \cdot m$	

Horizontal Distance between Keys: $Key_{hdist} := Key_{h.loc} - Key_{t.loc} - Key_{t.w} = 11\ m$

Key Depth Diff. (from point O): $Key_{vdist} := -Key_{h.d} + Key_{t.d} = -2\ m$

BASE PROPERTIES:

Base Area: $A_b := b \cdot B = 12\ m^2$

Centroidal Distance for Footing (from Toe): $Y_t := \frac{b}{2} = 6.00\ m$

RETAINED SOIL GEOMETRY:

Slope of retained ground surface: $\beta := 0 \cdot \frac{\pi}{180} = 0.00$

Height of retained earth at heel: $H_w := T_w - Bot_{ftg} + \left(t_{wb} + L_{cd} - t_{wt}\right) \cdot \tan(\beta) = 13.50\ m$

RETAINING WALL GEOMETRY CHECKS:

(Foundation Analysis & Design Bowles)

$$t_{bcheck} := \begin{cases} \text{"OKAY"} & \text{if } t_{ftg} \geq \frac{H_w}{12} \\ \text{"Warning"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

$$t_{wcheck} := \begin{cases} \text{"OKAY"} & \text{if } t_{wb} \geq \frac{H_w}{12} \\ \text{"Warning"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

$$b_{check} := \begin{cases} \text{"OKAY"} & \text{if } \frac{b}{H_w} \geq .4 \wedge \frac{b}{H_w} \leq 80 \\ \text{"Warning"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

$$L_{abcheck} := \begin{cases} \text{"OKAY"} & \text{if } \frac{L_{ab}}{b} \geq .25 \wedge \frac{L_{ab}}{b} \leq .4 \\ \text{"Warning"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

Material Properties:

Unit Weight of Water: $\gamma_w := 9.8 \frac{kN}{m^3}$ (Section 7.2, Design Criteria)

Unit Weight of Concrete: $\gamma_c := 23.5 \frac{kN}{m^3}$

Unit Weight of Soil (Moist): $\gamma_m := 20.0 \frac{kN}{m^3}$ (Section 5.3, Design Criteria)
assumed moisture content (w) = 5%

Unit Weight Soil (Saturated): $\gamma_{sat} := 22.0 \frac{kN}{m^3}$ (Assuming Specific Gravity = 2.7

Unit Weight Soil (buoyant): $\gamma_b := \gamma_{sat} - \gamma_w = 12.2 \cdot \frac{kN}{m^3}$

Weight of Soil/Concrete above toe: $\gamma_{toe} := 22.0 \frac{kN}{m^3}$

Unit Weight of Rock: $\gamma_r := 25.6 \frac{kN}{m^3}$ (Section 7.2, Design Criteria)

Foundation Parameters:

Glacial Till Internal Friction: $\phi := 27 \cdot \frac{\pi}{180} = 0.471$

Bedrock Internal Friction Angle: $\phi_r := 24 \cdot \frac{\pi}{180} = 0.419$

Friction Angle at Base
Concrete / Rock Interface: $\phi_{rock} := 26$

Base Friction Coefficient: $tan_{\phi rock} := \tan\left(\phi_{rock} \frac{\pi}{180}\right) = 0.488$ radians

Rip Rap Backfill, Refer Dwg. C-214 $\phi_{backfill} := \left(20 \frac{\pi}{180}\right) = 0.349$ radians

Shear strength along rock
Failure plane $s_r := \frac{13100 \frac{kN}{m^2}}{2} = 6550 \cdot \frac{kN}{m^2}$ (Stantec Design Memo 8/8/16)

CONCRETE DEAD LOAD:

Area of Footing: $A_{ftg} := t_{ftg} \cdot b = 24\,m^2$

Weight of Footing: $D_{ftg} := A_{ftg} \cdot B \cdot \gamma_c = 564 \cdot kN$

Area of Stem (without batter): $A_{w1} := t_{wt} \cdot (h_w - t_{ftg}) = 5.75\,m^2$

Weight of Stem: $D_{w1} := A_{w1} \cdot B \cdot \gamma_c = 135.1 \cdot kN$

Area of stem Batter: $A_{w2} := \frac{(t_{wb} - t_{wt})}{2} (h_w - t_{ftg}) = 5.2\,m^2$

Weight of Batter: $D_{w2} := A_{w2} \cdot B \cdot \gamma_c = 122.2 \cdot kN$

Slope of batter: $S_{batter} := \frac{t_{wb} - t_{wt}}{h_w - t_{ftg}} = 0.079$

Area of Key $A_{t.key} := Key_{t.d} \cdot Key_{t.w} = 0$ $A_{h.key} := Key_{h.d} \cdot Key_{h.w} = 2\,m^2$

Weight of Key $D_{t.key} := A_{t.key} \cdot B \cdot \gamma_c = 0 \cdot kN$ $D_{h.key} := A_{h.key} \cdot B \cdot \gamma_c = 47 \cdot kN$

Centroidal Horizontal Distance of Wall (From Toe):

$$H_{cent} := \frac{A_{w1} \cdot \left(L_{ab} + \frac{t_{wt}}{2}\right) + A_{w2} \cdot \left(L_{ab} + t_{wt} + \frac{t_{wb} - t_{wt}}{3}\right) + A_{ftg} \cdot \frac{b}{2} \ldots + A_{t.key} \cdot \left(Key_{t.loc} + \frac{Key_{t.w}}{2}\right) + A_{h.key} \cdot \left(Key_{h.loc} + \frac{Key_{h.w}}{2}\right)}{A_{w1} + A_{w2} + A_{ftg} + A_{t.key} + A_{h.key}} = 5.71\,m$$

Centroidal Vertical Distance of Wall (Above Base of Footing):

$$V_{Cent} := \frac{A_{ftg} \cdot \frac{t_{ftg}}{2} + A_{w1} \cdot \left[t_{ftg} + \frac{(h_w - t_{ftg})}{2}\right] + A_{w2} \cdot \left[t_{ftg} + \frac{(h_w - t_{ftg})}{3}\right] + A_{t.key} \cdot \left(\frac{-Key_{t.d}}{2}\right) + A_{h.key} \cdot \left(\frac{-Key_{h.d}}{2}\right)}{A_{ftg} + A_{w1} + A_{w2} + A_{t.key} + A_{h.key}} = 2.62\,m$$

$\Sigma V_{conc} := D_{ftg} + D_{w1} + D_{w2} + D_{t.key} + D_{h.key} = 868.3 \cdot kN$

$\Sigma M_{conc} := \Sigma V_{conc} \cdot H_{cent} = 4956.6\,m \cdot kN$

ROCK SECTION MOBILIZED FOR INCLINDED SLIDING FAILURE

Area of Rock Section Mobilized: $A_{rocksection} := (Key_{t.d} + Key_{h.d}) \cdot \frac{Key_{hdist}}{2} = 11\,m^2$

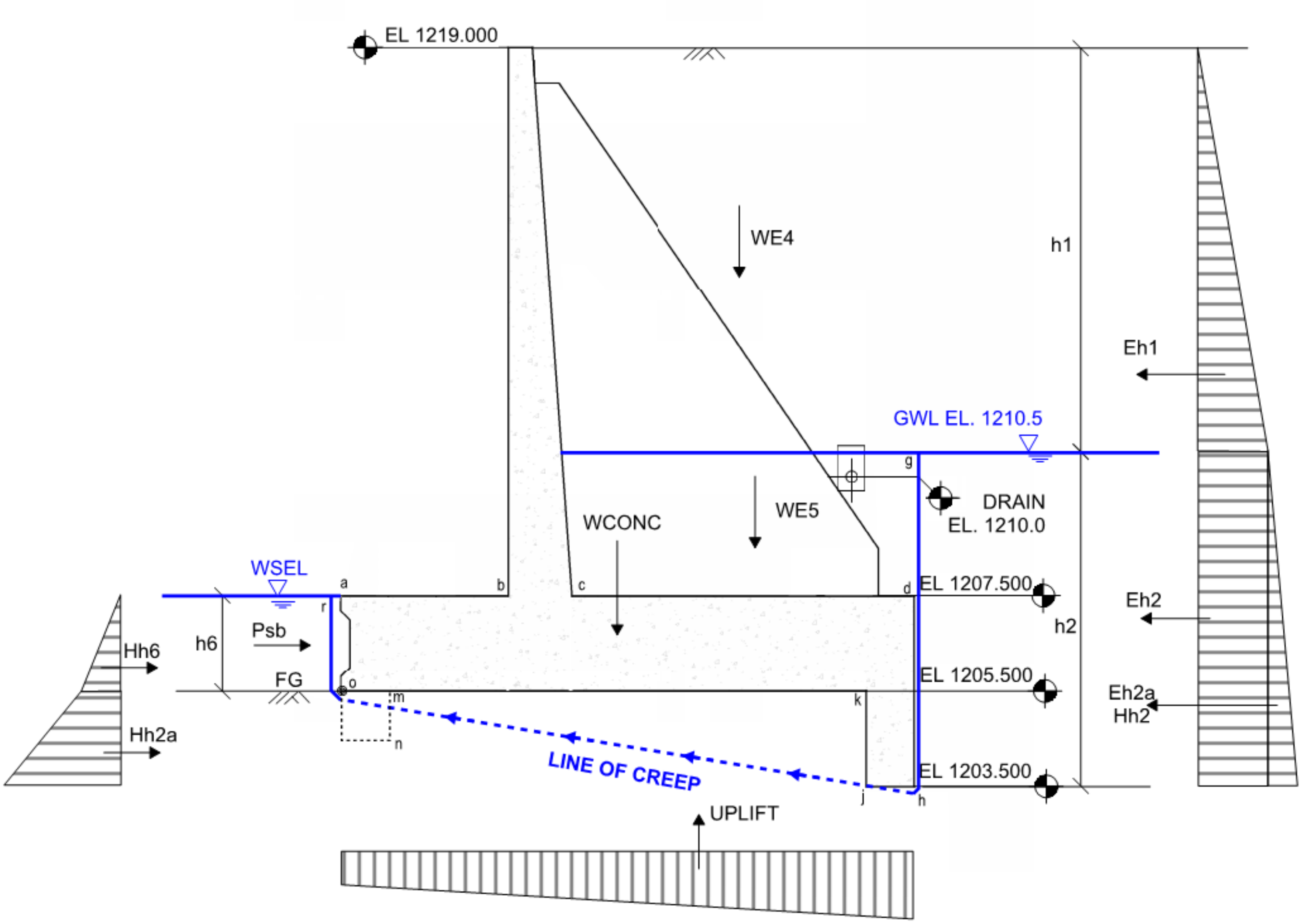
Rock Mass Mobilized: $V_{rocksection} := A_{rocksection} \cdot \gamma_r \cdot B = 281.6 \cdot kN$

(Pore pressure taken along assumed inclined sliding plane)

Distance from Toe to COG of Rock Section: $L_{rocksection} := \frac{Key_{hdist} \cdot (2 \cdot Key_{h.d} + Key_{t.d})}{3(Key_{h.d} + Key_{t.d})} + Key_{t.w} = 7.333\,m$

$\Sigma M_{rocksection} := V_{rocksection} \cdot L_{rocksection} = 2065.1\,m \cdot kN$

LOAD CASE U1 - NORMAL OPERATION



U1 DESIGN CASE

LOAD CASE U1 ACCEPTANCE PARAMETERS

FS sliding:

Usual (U) 1.5 (without cohesion) (Table 3-3, USACE EM 1110-2-2100)

Resultant Location:

Usual (U) Inside middle third ~100% base in compression

Required Factor of Safety for Sliding: $FS_{sliding.reqU1} := 1.5$ (Without Cohesion)

Allowable rock bearing pressure: $\sigma_{allowU1} := 1270kPa$ (Section 5.2, Design Criteria EM 1110-2-2100 Section 3-10)

Overturning Required Resultant Ratio: $X_{R.reqU1} := 0.333$ (EM 1110-2-2502, Figure 4-4)

Required Factor of Safety for Floatation $FS_{req.U1.flt} := 1.5$

SOIL HEIGHTS and Water Levels:

LOAD CASE U1

Heel Conditions:

Groundwater Elevation at Heel: $GWL_{U1} := 1210.5m$

Distance from Finish Grade to Groundwater at Heel: $h_{1U1} := \left[T_w - GWL_{U1} + \left(L_{cd} + t_{wb} - t_{wt}\right)\cdot\tan(\beta)\right] = 8.50\ m$

Distance from Water Surface to Bottom of Footing at Heel: $h_{2U1} := GWL_{U1} - Bot_{ftg} + Key_{h.d} = 7.00\ m$

Toe Conditions:

Water Surface Elevation at Toe: $WSEL_{U1} := 1207.5m$

Water Surface Elevation at Toe for Uplift: $UWSEL_{U1} := 1207.5\cdot m$

Finish Grade at Toe providing lateral resistance: $FG_{toeU1} := 1205.5\cdot m$

Soil Depth Above top of footing: $h_{3aU1} := FG_{toeU1} - Top_{ftg} = -2\ m$

$$h_{3U1} := \begin{cases} h_{3aU1} & \text{if } FG_{toeU1} - Top_{ftg} \geq 0 \\ 0 & \text{otherwise} \end{cases} = 0$$

Resisting Fill at Toe: $h_{4U1} := FG_{toeU1} - Bot_{ftg} + Key_{t.d} = 0.00\ m$

Distance from Water Level to Top of Footing: $h_{5U1} := WSEL_{U1} - Top_{ftg} = 0.00\ m$

Distance from Water Surface to Bottom of Footing: $h_{6U1} := WSEL_{U1} - Bot_{ftg} + Key_{t.d} = 2.00\cdot m$

Soil Depth Above WSEL: $h_{7aU1} := FG_{toeU1} - WSEL_{U1} = -2\ m$

$$h_{7U1} := \begin{cases} h_{7aU1} & \text{if } FG_{toeU1} - WSEL_{U1} \geq 0 \\ 0 & \text{otherwise} \end{cases} = 0$$

Soil Depth Below WSEL:

$$h_{8U1} := \begin{cases} WSEL_{U1} - Bot_{ftg} + Key_{t.d} & \text{if } FG_{toeU1} - WSEL_{U1} \geq 0 \\ h_{4U1} & \text{otherwise} \end{cases} = 0$$

For Line of Creep Method: $L_{ho.U1} := \sqrt{b^2 + \left(Key_{h.d} - Key_{t.d}\right)^2} = 12.166\ m$

Head Loss from Point g:

$\Delta h_{g.hj.U1} := h_{2U1} = 7\ m$ (to point h & j)

$\Delta h_{g.km.U1} := GWL_{U1} - Bot_{ftg} = 5\ m$ (to point k & m)

$\Delta h_{g.no.U1} := GWL_{U1} - Bot_{ftg} + Key_{t.d} = 5\ m$ (to point n & o)

$\Delta h_{g.p.U1} := GWL_{U1} - FG_{toeU1} = 5\ m$ (to point p*)

$\Delta h_{g.r.U1} := GWL_{U1} - UWSEL_{U1} = 3\ m$ (to point r)

Surcharge

Surcharge on Heel: $S1_{U1} := 0.0\ \frac{kN}{m^2}$

* same as point "o" in this case

Calculate Soil Lateral Pressure Coefficients:

LOAD CASE U1

For all load cases except seismic, soil loading to be based on At-Rest Condition.
Calculate at-rest pressure coefficient Ko based on Jaky's (1944) equation.

Soil At Rest Static Coefficient: $K_o := \frac{1 - \sin(\phi)}{1 + \sin(\beta)} = 0.546$ (Eq. 3-6, USACE EM 1110-2-2502)

Lateral - Driving Force (Headwater Side)

Lateral Soil Load:

Surcharge Load: $E_{s1U1} := S1_{U1} \cdot K_o \cdot \left(H_w + Key_{h.d}\right) \cdot B \cdot -1 = 0 \cdot kN$

Moment Arm (from bottom of footing): $E_{s1locU1} := \frac{H_w + Key_{h.d}}{2} + Key_{vdist} = 5.75\ m$

Moist Soil Load above GWL: $E_{h1U1} := \frac{\gamma_m \cdot K_o \cdot h_{1U1}^{\ 2}}{2} B \cdot -1 = -394.5 \cdot kN$

Moment Arm (from bottom of footing): $E_{h1locU1} := \frac{h_{1U1}}{3} + h_{2U1} + Key_{vdist} = 7.83\ m$

Saturated Soil Load below GWL:
(rectangular component) $E_{h2U1} := \left(\gamma_m \cdot K_o \cdot h_{1U1}\right) \cdot \left(h_{2U1}\right) \cdot B \cdot -1 = -649.8 \cdot kN$

Moment Arm (from bottom of footing): $E_{h2locU1} := \frac{h_{2U1}}{2} + Key_{vdist} = 1.50\ m$

Saturated Soil Load below GWL:
(triangular component) $E_{h2aU1} := \frac{\left(\gamma_{sat} - \gamma_w\right) \cdot K_o \cdot h_{2U1}^{\ 2}}{2} \cdot B \cdot -1 = -163.2 \cdot kN$

Moment Arm (from bottom of footing): $E_{h2alocU1} := \frac{h_{2U1}}{3} + Key_{vdist} = 0.33\ m$

Lateral Water Load:

Water Load GWL to Bottom of Key $H_{h2U1} := \frac{\gamma_w \cdot h_{2U1}^{\ 2}}{2} \cdot B \cdot -1 = -240.1 \cdot kN$

Moment Arm (from bottom of footing): $H_{h2locU1} := \frac{h_{2U1}}{3} + Key_{vdist} = 0.33\ m$

$$\Sigma H_{SoildriveU1} := E_{s1U1} + E_{h1U1} + E_{h2U1} + E_{h2aU1} + H_{h2U1} = -1447.5 \cdot kN$$

$$\Sigma M_{LateralSoildriveU1} := E_{s1U1} \cdot E_{s1locU1} + E_{h1U1} \cdot E_{h1locU1} + E_{h2U1} \cdot E_{h2locU1} + E_{h2aU1} \cdot E_{h2alocU1} \ldots + H_{h2U1} \cdot H_{h2locU1} = -4199.2\ m \cdot kN$$

Lateral - Resisting Force (Tailwater Side)

LOAD CASE U1

Lateral Water Load:

Water Load WSEL to Bot. of Footing:

$$H_{h6U1} := \frac{\gamma_w \cdot h_{6U1}^{2}}{2} \cdot B = 19.6 \cdot kN$$

Moment Arm (from bot. of toe key):

$$H_{h6locU1} := \frac{h_{6U1}}{3} = 0.67\ m$$

Water Load Bot. of Footing to Bot. of H. Key:

$$H_{h2aU1} := \left[\left(UWSEL_{U1} - Bot_{ftg} + Key_{t.d}\right) + h_{2U1}\right] \cdot \frac{Key_{h.d}}{2} \cdot \gamma_w \cdot B = 88.2 \cdot kN$$

Moment Arm (from bot. of toe key):

$$H_{h2alocU1} := \frac{Key_{h.d} \cdot \left[2 \cdot \left(UWSEL_{U1} - Bot_{ftg} + Key_{t.d}\right) + h_{2U1}\right]}{3\left[h_{2U1} + \left(UWSEL_{U1} - Bot_{ftg} + Key_{t.d}\right)\right]} \ldots = -1.19\ m$$
$$+ Key_{vdist}$$

Lateral Soil Load:

Moist Soil Load above WSEL:

$$E_{h7U1} := \frac{\gamma_m \cdot K_o \cdot h_{7U1}^{2}}{2} B = 0.0 \cdot kN$$

Moment Arm (from bot. of toe key):

$$E_{h7locU1} := h_{6U1} + \frac{h_{7U1}}{3} + Key_{vdist} = 0.00\ m$$

Saturated Soil Load below WSEL: (rectangular component)

$$E_{h8U1} := \left(\gamma_m \cdot K_o \cdot h_{7U1}\right) \cdot h_{8U1} \cdot B = 0.0 \cdot kN$$

Moment Arm (from bot. of toe key):

$$E_{h8locU1} := \frac{h_{8U1}}{2} = 0.00\ m$$

c

Saturated Soil Load below WSEL: (triangular component)

$$E_{h8aU1} := \frac{\left[\left(\gamma_{sat} - \gamma_w\right) \cdot K_o\right] \cdot h_{8U1}^{2}}{2} \cdot B = 0.0 \cdot kN$$

Moment Arm (from bot. of footing):

$$E_{h8alocU1} := \frac{h_{8U1}}{3} = 0.00\ m$$

Lateral Resistance from Stilling Basin:

Lateral Resistance from Stilling Basin:

$$P_{sbU1} := 415kN$$

(Force needed to achieve the required sliding factor of safety in case UN2)

Moment Arm (from bot. of toe key):

$$P_{sblocU1} := \frac{t_{ftg}}{2} + Key_{t.d} = 1.00\ m$$

$$\Sigma H_{SoilresistU1} := H_{h6U1} + H_{h2aU1} + E_{h7U1} + E_{h8U1} + E_{h8aU1} + P_{sbU1} = 522.8 \cdot kN$$

$$\Sigma M_{HorizSoilResistU1} := H_{h6U1} \cdot H_{h6locU1} + H_{h2aU1} \cdot H_{h2alocU1} + E_{h7U1} \cdot E_{h7locU1} \ldots = 323.5\ m \cdot kN$$
$$+ E_{h8U1} \cdot E_{h8locU1} + E_{h8aU1} \cdot E_{h8alocU1} + P_{sbU1} \cdot P_{sblocU1}$$

Vertical Force:

UPLIFT: Linear distribution from water at heel to water at toe:

$$\Sigma V_{UpliftU1} := \left[\left(UWSEL_{U1} - Bot_{ftg} + Key_{t.d}\right) + h_{2U1}\right] \cdot \frac{b}{2} \cdot \gamma_w \cdot B \cdot -1 = -529.2 \cdot kN$$

Moment Arm (from Point O):

$$V_{UpliftU1aloc} := \frac{b \cdot \left[2 \cdot h_{2U1} + \left(UWSEL_{U1} - Bot_{ftg} + Key_{t.d}\right)\right]}{3\left[h_{2U1} + \left(UWSEL_{U1} - Bot_{ftg} + Key_{t.d}\right)\right]} = 7.111\ m$$

$$\Sigma M_{UpliftU1} := \Sigma V_{UpliftU1} \cdot V_{UpliftU1aloc} = -3763.2 \cdot kN \cdot m$$

Vertical Force (con't):

Weight of soil and water over toe:

Water Above the Top of Footing: $W_{H1U1} := \gamma_w \cdot h_{5U1} \cdot L_{ab} \cdot B = 0 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E1locU1} := \frac{L_{ab}}{2} = 1.75\ m$

Soil above top of footing: $W_{E6U1} := \gamma_b \cdot h_{3U1} \cdot L_{ab} \cdot B = 0.0 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E6locU1} := \frac{L_{ab}}{2} = 1.75\ m$

Vertical Load Due to Surcharge: $S_{U1} := S1_{U1} \cdot L_{cd} \cdot B = 0$ $\quad S_{U1loc} := b - \frac{L_{cd}}{2} = 8.45\ m$

Weight of soil and water over heel:

Moist Soil for sloped grade above top of wall:

Length of sloped portion of soil above top of wall: $L_{E3U1} := \left(L_{cd} + t_{wb} - t_{wt}\right) = 8.00\ m$

Height of sloped soil above top of wall over heel: $h_{E3locU1} := \left(L_{E3U1}\right) \cdot \tan(\beta) = 0.00\ m$

Weight of sloped soil above top of wall: $W_{E3U1} := \frac{\gamma_m}{2} \cdot h_{E3locU1} \cdot L_{E3U1} \cdot B = 0.0 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E3locU1} := L_{ab} + t_{wt} + \frac{2}{3} \cdot L_{E3U1} = 9.33\ m$

Moist soil from top of wall to groundwater level:

Height of soil from top of wall and top of GWL: $h_{1U1} = 8.50\ m$

Length from edge of wall at GWL to edge of heel: $L_{E4U1} := L_{E3U1} - \left(h_{1U1} \cdot S_{batter}\right) = 7.33\ m$

Weight of soil over heel from top of wall to GWL: $W_{E4U1} := \gamma_m \cdot h_{1U1} \cdot \frac{\left(L_{E3U1} + L_{E4U1}\right)}{2} \cdot B = 1303.2 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E4locU1} := b - \frac{L_{E3U1}^{2} + L_{E3U1} \cdot L_{E4U1} + L_{E4U1}^{2}}{3\left(L_{E3U1} + L_{E4U1}\right)} = 8.16\ m$

Saturated soil from groundwater to top of footing:

Height of soil from GWL to top of heel: $h_{E4U1} := h_{2U1} - t_{ftg} - Key_{h.d} = 3.00\ m$

Weight of soil over heel from GWL to top of heel: $W_{E5U1} := \left(\gamma_{sat}\right) \cdot h_{E4U1} \cdot \frac{\left(L_{E4U1} + L_{cd}\right)}{2} \cdot B = 476.1 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E5locU1} := b - \frac{L_{E4U1}^{2} + L_{E4U1} \cdot L_{cd} + L_{cd}^{2}}{3\left(L_{E4U1} + L_{cd}\right)} = 8.39\ m$

$$\Sigma V_{SoilWaterU1} := W_{H1U1} + W_{E6U1} + W_{E3U1} + W_{E4U1} + W_{E5U1} + S_{U1} = 1779.3 \cdot kN$$

$$\Sigma M_{VertSoilWaterResistU1} := W_{H1U1} \cdot W_{E1locU1} + W_{E6U1} \cdot W_{E6locU1} \cdots + W_{E3U1} \cdot W_{E3locU1} + W_{E4U1} \cdot W_{E4locU1} + W_{E5U1} \cdot W_{E5locU1} + S_{U1} \cdot S_{U1loc} = 14636.1\ m \cdot kN$$

THIS PAGE INTENTIONALLY LEFT BLANK
PLEASE GO TO THE NEXT PAGE

STABILITY ASSESSMENT:

LOAD CASE U1

CHECK SLIDING ALONG HORIZONTAL SLIDING PLANE:

Summation of the vertical forces:

$$\Sigma V_{U1} := \Sigma V_{conc} + \Sigma V_{SoilWaterU1} + \Sigma V_{UpliftU1} = 2118.4 \cdot kN$$

Summation of the horizontal forces:

$$\Sigma H_{U1} := \Sigma H_{SoildriveU1} + \Sigma H_{SoilresistU1} = -924.7 \cdot kN$$

Safety Factor for Sliding Horizontal Failure Plane

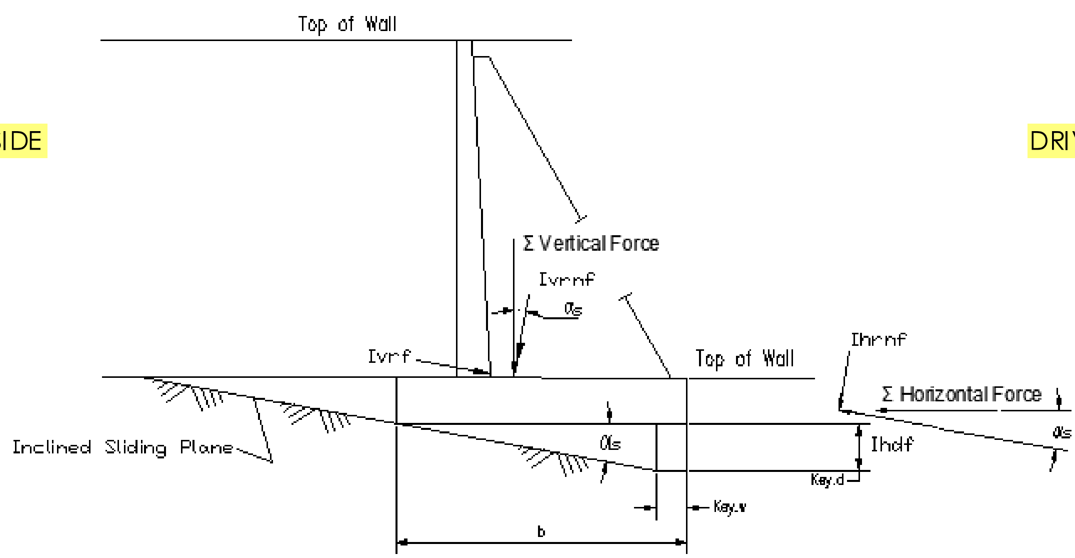
$$FS_{Horiz.SlidingU1} := \frac{\left|\Sigma V_{U1}\right| \cdot \tan\left(\phi_{rock} \cdot \frac{\pi}{180}\right)}{\left|\Sigma H_{U1}\right|} = 1.12$$

$$FS_{Sliding.check1.U1} := \begin{vmatrix} \text{"OKAY "} & \text{if } FS_{Horiz.SlidingU1} > FS_{sliding.reqU1} \\ \text{"Key req""} & \text{otherwise} \end{vmatrix} = \text{"Key req""}$$

CHECK FACTOR OF SAFETY SLIDING WITH KEY (INCLINED SLIDING PLANE):

RESISTING SIDE

DRIVING SIDE



TOE

HEEL

Ivrf=Inclined Resisting Force
Ivrnf=Inclined Resisting Normal Force
Ihrnf=Inclined Resisting Normal Force
Ihdf=Inclined Driving Force

$$\alpha s := \operatorname{atan}\left(\frac{-Key_{vdist}}{Key_{hdist}}\right) = 0.18 \qquad \text{as degrees=} \qquad \alpha s \cdot \left(\frac{180}{\pi}\right) = 10.30$$

(With properly engineered reinforced concrete Key, horizontal sliding plane thru Toe is protected, critical sliding plane is relocated to the INCLINED SLIDING PLANE FROM HEEL KEY To TOE, Bedrock Mass above this examing plane is mobilized by reinforced concrete key and combined into Structural Wedge.)

Resolve ΣV_{U1} & ΣH_{U1}

$$\Sigma V_{InclinedU1} := \cos(\alpha s) \cdot \left(\left|\Sigma V_{U1} + V_{rocksection}\right|\right) + \sin(\alpha s) \cdot \left|\Sigma H_{U1}\right| = 2526.7 \cdot kN$$

$$\Sigma H_{InclinedU1} := \cos(\alpha s) \cdot \left|\Sigma H_{U1}\right| - \sin(\alpha s) \cdot \left(\left|\Sigma V_{U1} + V_{rocksection}\right|\right) = 480.5 \cdot kN$$

Safety Factor for Sliding
Inclined Failure Plane

$$FS_{InclinedISlidingU1} := \frac{\Sigma V_{InclinedU1} \cdot \tan(\phi_r)}{\Sigma H_{InclinedU1}} = 2.34$$

LOAD CASE U1

$$FS_{Sliding.check2.U1} := \begin{cases} \text{"OKAY "} & \text{if } FS_{InclinedISlidingU1} > FS_{sliding.reqU1} \\ \text{"NG - Revise Structure""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

CHECK FOUNDATION ECCENTRICITY:

Summation of the resisting moments about the toe:

$$\Sigma M_{resU1} := \Sigma M_{conc} + \Sigma M_{VertSoilWaterResistU1} + \Sigma M_{HorizSoilResistU1} + \Sigma M_{rocksection} = 21981 \cdot kN \cdot m$$

Summation of the overturning moments about the toe:

$$\Sigma M_{oU1} := \Sigma M_{LateralSoildriveU1} + \Sigma M_{UpliftU1} = -7962 \cdot kN \cdot m$$

Total moment: $\Sigma M_{U1} := \Sigma M_{resU1} + \Sigma M_{oU1} = 14018.9 \cdot kN \cdot m$

Normal force to base: $\Sigma V_{InclinedU1} = 2526.7 \cdot kN$

Inclined Sliding Plane Length: $L_{incline} := \frac{b}{\cos(\alpha s)} = 12.2\, m$

Eccentricity (inclined plane): $ex_{U1} := \frac{L_{incline}}{2} - \frac{\Sigma M_{U1}}{\Sigma V_{InclinedU1}} = 0.55\, m$ $\quad Kern := \frac{L_{incline}}{6} = 2.033\, m$

Eccentricity Check: $e_{check.U1} := \begin{cases} \text{"Okay"} & \text{if } ex_{U1} \le Kern \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"Okay"}$

CHECK FOUNDATION BEARING CAPACITY:

Base Section Modulus: $S_b := \frac{1}{6}\left(B \cdot L_{incline}^{\,2}\right) = 24.79\, m^3$

Bearing Pressure Under Toe:

$$\sigma_{ToeU1} := \begin{cases} \left(\frac{\Sigma V_{InclinedU1}}{L_{incline} \cdot B} + \frac{\Sigma V_{InclinedU1} \cdot ex_{U1}}{S_b}\right) & \text{if } \frac{\Sigma V_{InclinedU1} \cdot ex_{U1}}{S_b} \le \frac{\Sigma V_{InclinedU1}}{L_{incline} \cdot B} \\ \frac{2 \cdot \Sigma V_{InclinedU1}}{B \cdot 3\left(\frac{b}{2} - ex_{U1}\right)} & \text{otherwise} \end{cases} = 263.2 \cdot kPa$$

$$Bearing_{ChecktoeU1} := \begin{cases} \text{"OKAY "} & \text{if } \sigma_{ToeU1} < \sigma_{allowU1} \\ \text{"NG""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

Bearing Pressure Under Heel:

$$\sigma_{HeelU1} := \begin{cases} \left(\frac{\Sigma V_{InclinedU1}}{L_{incline} \cdot B} - \frac{\Sigma V_{InclinedU1} \cdot ex_{U1}}{S_b}\right) & \text{if } \frac{\Sigma V_{InclinedU1} \cdot ex_{U1}}{S_b} \le \frac{\Sigma V_{InclinedU1}}{L_{incline} \cdot B} \\ 0 & \text{otherwise} \end{cases} = 151.1 \cdot kPa$$

$$Bearing_{CheckheelU1} := \left(\begin{cases} \text{"OKAY "} & \text{if } \sigma_{HeelU1} < \sigma_{allowU1} \wedge \sigma_{HeelU1} > 0 \\ \text{"NG - perform cracked base analysis""} & \text{otherwise} \end{cases}\right) = \text{"OKAY "}$$

CHECK FLOATATION:

Safety Factor for Floatation:

$$FS_{FloatationU1} := \frac{\Sigma V_{conc} + \Sigma V_{SoilWaterU1}}{\left|\Sigma V_{UpliftU1}\right|} = 5.00$$

$$FS_{Floatation.U1.check} := \begin{cases} \text{"OKAY"} & \text{if } FS_{FloatationU1} > FS_{req.U1.flt} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

CHECK OVERTURNING

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.
Assumptions are made in order to compute overturning stablity of indetermine forces on monolith with key;
(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.
(b) The horizontal resisting force acting on the key, P.key, is that required for static equilibrium
(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1

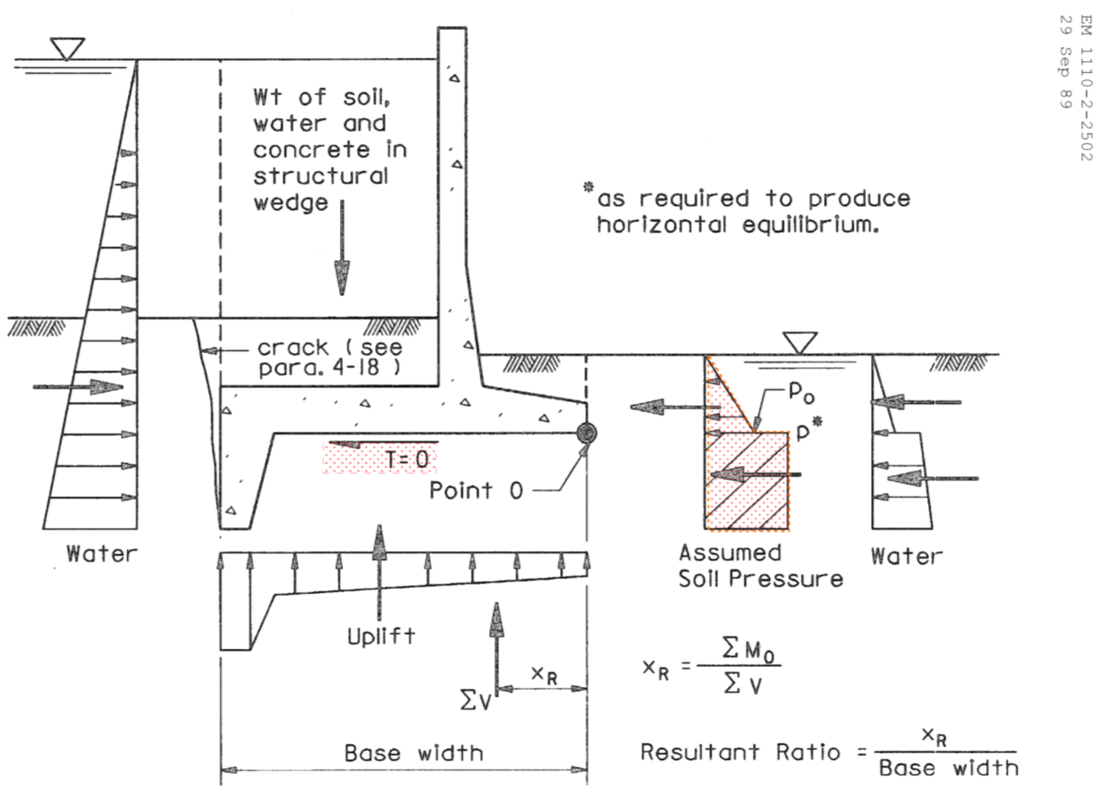


Figure 4-5. Forces for overturning analysis for wall with horizontal base and key

Modify Uplift for Overturning Analysis: **LOAD CASE U1**

(Uplift is calculated along the concrete/rock contact using the Line of Creep method)

Water Pressure at h: $u_{h.U1} := \Delta h_{g.hj.U1} \cdot \gamma_w = 68.60 \cdot kPa$

Water Pressure at o: $u_{o.U1} := \left(\Delta h_{g.no.U1} - \dfrac{\Delta h_{g.r.U1} \cdot L_{ho.U1}}{L_{ho.U1}}\right) \cdot \gamma_w = 19.6 \cdot kPa$

Head loss between point h and o: $\Delta h_{ho.U1} := \Delta h_{g.r.U1} \cdot \dfrac{L_{ho.U1}}{L_{ho.U1}} = 3\,m$

Length of concrete base (h -> o): $L_{baseho.U1} := Key_{h.w} + Key_{h.d} + Key_{hdist} + Key_{t.d} + Key_{t.w} = 14\,m$

Head loss along h -> j: $\Delta h_{hj.U1} := \Delta h_{ho.U1} \cdot \dfrac{Key_{h.w}}{L_{baseho.U1}} = 0.214\,m$

Water Pressure at j: $u_{j.U1} := \left(\Delta h_{g.hj.U1} - \Delta h_{hj.U1}\right) \cdot \gamma_w = 66.50 \cdot kPa$

Head loss along h -> k: $\Delta h_{hjk.U1} := \Delta h_{ho.U1} \cdot \left(\dfrac{Key_{h.w} + Key_{h.d}}{L_{baseho.U1}}\right) = 0.643\,m$

Water Pressure at k: $u_{k.U1} := \left(\Delta h_{g.km.U1} - \Delta h_{hjk.U1}\right) \cdot \gamma_w = 42.70 \cdot kPa$

Head loss along h -> m: $\Delta h_{hjkm.U1} := \Delta h_{ho.U1} \cdot \left(\dfrac{Key_{h.w} + Key_{h.d} + Key_{hdist}}{L_{baseho.U1}}\right) = 3\,m$

Water Pressure at m: $u_{m.U1} := \left(\Delta h_{g.km.U1} - \Delta h_{hjkm.U1}\right) \cdot \gamma_w = 19.60 \cdot kPa$

Head loss along h -> n: $\Delta h_{hjkmn.U1} := \Delta h_{ho.U1} \cdot \left(\dfrac{Key_{h.w} + Key_{h.d} + Key_{hdist} + Key_{t.d}}{L_{baseho.U1}}\right) = 3\,m$

Water Pressure at n: $u_{n.U1} := \left(\Delta h_{g.no.U1} - \Delta h_{hjkmn.U1}\right) \cdot \gamma_w = 19.60 \cdot kPa$

Uplift under key at heel: $V_{ulkeyhU1.OT} := \dfrac{\left(u_{h.U1} + u_{j.U1}\right) \cdot Key_{h.w}}{2} \cdot B \cdot -1 = -67.55 \cdot kN$

Moment Arm (from Point O): $V_{ulkeyhU1loc.OT} := b - \dfrac{Key_{h.w} \cdot \left(2 \cdot u_{j.U1} + u_{h.U1}\right)}{3 \cdot \left(u_{j.U1} + u_{h.U1}\right)} = 11.503\,m$

Uplift under base: $V_{ulbaseU1.OT} := \dfrac{\left(u_{k.U1} + u_{m.U1}\right) \cdot Key_{hdist}}{2} \cdot B \cdot -1 = -342.65 \cdot kN$

Moment Arm (from Point O): $V_{ulbaseU1loc.OT} := b - Key_{h.w} - \dfrac{Key_{hdist} \cdot \left(2 \cdot u_{m.U1} + u_{k.U1}\right)}{3 \cdot \left(u_{m.U1} + u_{k.U1}\right)} = 6.18\,m$

Uplift under key at toe: $V_{ulkeytU1.OT} := \dfrac{\left(u_{n.U1} + u_{o.U1}\right) \cdot Key_{t.w}}{2} \cdot B \cdot -1 = 0 \cdot kN$

Moment Arm (from Point O): $V_{ulkeytU1loc.OT} := \dfrac{Key_{t.w} \cdot \left(2 \cdot u_{n.U1} + u_{o.U1}\right)}{3 \cdot \left(u_{n.U1} + u_{o.U1}\right)} = 0$

$$\Sigma V_{UpliftU1.OT} := V_{ulkeyhU1.OT} + V_{ulbaseU1.OT} + V_{ulkeytU1.OT} = -410 \cdot kN$$

$$U_{U1.loc.OT} := \frac{V_{ulkeyhU1.OT} \cdot V_{ulkeyhU1loc.OT} + V_{ulbaseU1.OT} \cdot V_{ulbaseU1loc.OT} + V_{ulkeytU1.OT} \cdot V_{ulkeytU1loc.OT}}{\Sigma V_{UpliftU1.OT}} = 7.06\,m$$

$$\Sigma M_{UpliftU1.OT} := \Sigma V_{UpliftU1.OT} \cdot U_{U1.loc.OT} = -2894.5 \cdot kN \cdot m$$

Modify Lateral Water Pressure (Resisting) for Overturning Analysis:

(Resisting water pressure is calculated using the Line of Creep method)

Water Load at Key (heel):

$$H_{h2U1.OT} := \frac{u_{k.U1} + u_{j.U1}}{2} \cdot Key_{h.d} \cdot B = 109.2 \cdot kN$$

Moment Arm (from Point O):

$$H_{h2locU1.OT} := \frac{Key_{h.d} \cdot \left(2 \cdot u_{k.U1} + u_{j.U1}\right)}{3\left(u_{k.U1} + u_{j.U1}\right)} + Key_{vdist} = -1.07\ m$$

Water Load at Key (toe):

$$H_{h6U1.OT} := \frac{u_{o.U1} \cdot \left(UWSEL_{U1} - Bot_{ftg} + Key_{t.d}\right)}{2} \cdot B = 20 \cdot kN$$

Moment Arm (from Point O):

$$H_{h6locU1.OT} := \frac{UWSEL_{U1} - Bot_{ftg} + Key_{t.d}}{3} = 0.67\ m$$

$$\Sigma H_{waterresistU1.OT} := H_{h2U1.OT} + H_{h6U1.OT} = 128.8 \cdot kN$$

$$H_{waterresistlocU1.OT} := \frac{H_{h2U1.OT} \cdot H_{h2locU1.OT} + H_{h6U1.OT} \cdot H_{h6locU1.OT}}{\Sigma H_{waterresistU1.OT}} = -0.808\ m$$

$$\Sigma M_{waterresistU1.OT} := \Sigma H_{waterresistU1.OT} \cdot H_{waterresistlocU1.OT} = -104.07 \cdot kN \cdot m$$

Modify Lateral Soil Loads for Overturning Analysis:

(Lateral soil loads are calculated down to Point O instead of bottom of shear key)

Driving Soil Load (Headwater Side):

Surcharge Load:

$$E_{s1U1.OT} := S1_{U1} \cdot K_o \cdot \left(H_w + Key_{h.d} + Key_{vdist}\right) \cdot B \cdot -1 = 0 \cdot kN$$

Moment Arm (from Point O):

$$E_{s1locU1.OT} := \frac{H_w + Key_{h.d} + Key_{vdist}}{2} = 6.75\ m$$

Moist Soil Load above GWL:

$$E_{h1U1.OT} := \frac{\gamma_m \cdot K_o \cdot h_{1U1}^{\ 2}}{2} B \cdot -1 = -394.5 \cdot kN$$

Moment Arm (from Point O):

$$E_{h1locU1.OT} := \frac{h_{1U1}}{3} + h_{2U1} + Key_{vdist} = 7.83\ m$$

Saturated Soil Load below GWL:
(rectangular component)

$$E_{h2U1.OT} := \left(\gamma_m \cdot K_o \cdot h_{1U1}\right) \cdot \left(h_{2U1} + Key_{vdist}\right) \cdot B \cdot -1 = -464.1 \cdot kN$$

Moment Arm (from Point O):

$$E_{h2locU1.OT} := \frac{h_{2U1} + Key_{vdist}}{2} = 2.50\ m$$

Saturated Soil Load below GWL:
(triangular component)

$$E_{h2aU1.OT} := \frac{\left(\gamma_{sat} - \gamma_w\right) \cdot K_o \cdot \left(h_{2U1} + Key_{vdist}\right)^2}{2} \cdot B \cdot -1 = -83.3 \cdot kN$$

Moment Arm (from Point O):

$$E_{h2alocU1.OT} := \frac{h_{2U1} + Key_{vdist}}{3} = 1.67\ m$$

Resisting Soil Load (Tailwater Side):

(Determine resisting soil load based on depth variation between the keys (ie. Key_{vdist}). In case where key at heel is deeper than key at toe (ie. $Key_{vdist} < 0$), resisting soil load (p*) is assumed to produce horizontal equilibrium as per Figure 4-5 above. Resisting soil load (p_o) is neglected.)

Total Driving Force: $\Sigma H_{SoildriveU1.OT} := E_{s1U1.OT} + E_{h1U1.OT} + E_{h2U1.OT} + E_{h2aU1.OT} + H_{h2U1} = -1182.0 \cdot kN$

Total Resisting Force: $\Sigma H_{waterresistU1.OT} = 128.8 \cdot kN$

Assumed Soil Load p*: $E_{h8U1a.OT} := \left(\Sigma H_{SoildriveU1.OT} + \Sigma H_{waterresistU1.OT}\right) \cdot -1 = 1053.166 \cdot kN$

Moment Arm (from Point O): $E_{h8U1a.loc.OT} := \dfrac{Key_{vdist}}{2} = -1\ m$

$$E_{h8U1.OT} := \begin{cases} E_{h8U1a.OT} & \text{if } Key_{vdist} < 0 \\ \Sigma H_{SoilresistU1} - H_{h6U1} - H_{h2aU1} - P_{sbU1} & \text{otherwise} \end{cases} = 1053.166 \cdot kN$$

$$\Sigma M_{SoilresistU1} := \begin{cases} E_{h8U1a.OT} \cdot E_{h8U1a.loc.OT} & \text{if } Key_{vdist} < 0 \\ \Sigma M_{HorizSoilResistU1} - H_{h6U1} \cdot H_{h6locU1} - H_{h2aU1} \cdot H_{h2alocU1} - P_{sbU1} \cdot P_{sblocU1} & \text{otherwise} \end{cases} = -1053.166 \cdot kN \cdot m$$

Sum of Moment about Point O:

$$\Sigma M_{LateraldriveU1.OT} := E_{s1U1.OT} \cdot E_{s1locU1.OT} + E_{h1U1.OT} \cdot E_{h1locU1.OT} + E_{h2U1.OT} \cdot E_{h2locU1.OT} \cdots + E_{h2aU1.OT} \cdot E_{h2alocU1.OT} + H_{h2U1} \cdot H_{h2locU1} = -4469.3 \cdot kN \cdot m$$

$$\Sigma M_{LateralresistU1.OT} := \Sigma M_{waterresistU1.OT} + \Sigma M_{SoilresistU1} = -1157.2 \cdot kN \cdot m$$

Total moment:

$$\Sigma M_{U1.OT} := \Sigma M_{conc} + \Sigma M_{VertSoilWaterResistU1} + \Sigma M_{UpliftU1.OT} + \Sigma M_{LateraldriveU1.OT} + \Sigma M_{LateralresistU1.OT} = 11071.7 \cdot kN \cdot m$$

Total Vertical Force: $\Sigma V_{U1.OT} := \Sigma V_{conc} + \Sigma V_{SoilWaterU1} + \Sigma V_{UpliftU1.OT} = 2237.4 \cdot kN$

Distance X_R: EM 1110-2-2502 Eq.4-1 $X_{R.U1} := \dfrac{\Sigma M_{U1.OT}}{\Sigma V_{U1.OT}} = 4.948\ m$

Overturning Resultant Ratio $Ratio_{U1.OT} := \dfrac{X_{R.U1}}{b} = 0.41$

$$Ratio_{U1.OT.check} := \begin{cases} \text{"OKAY "} & \text{if } Ratio_{U1.OT} > X_{R.reqU1} \\ \text{"Revise Structure""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

CHECK FOUNDATION ECCENTRICITY (HORIZONTAL PLANE):

Eccentricity (horizontal plan): $ex_{U1.OT} := \dfrac{b}{2} - \dfrac{\Sigma M_{U1.OT}}{\Sigma V_{U1.OT}} = 1.05\ m$ $Kern_{OT} := \dfrac{b}{6} = 2\ m$

Eccentricity Check:

$$e_{check.U1.OT} := \begin{cases} \text{"Okay"} & \text{if } ex_{U1} \le Kern_{OT} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"Okay"}$$

LOAD CASE U1

CHECK FOUNDATION BEARING CAPACITY (HORIZONTAL PLANE):

Base Section Modulus:

$$S_{b.OT} := \frac{1}{6}\left(B \cdot b^2\right) = 24\,m^3$$

Bearing Pressure Under Toe:

$$\sigma_{ToeU1.OT} := \begin{cases} \left(\frac{\Sigma V_{U1.OT}}{b \cdot B} + \frac{\Sigma V_{U1.OT} \cdot ex_{U1.OT}}{S_{b.OT}}\right) & \text{if } \frac{\Sigma V_{U1.OT}}{b \cdot B} \geq \frac{\Sigma V_{U1.OT} \cdot ex_{U1.OT}}{S_{b.OT}} \\ \frac{2 \cdot \Sigma V_{U1.OT}}{B \cdot 3\left(\frac{b}{2} - ex_{U1.OT}\right)} & \text{otherwise} \end{cases} = 284.5 \cdot kPa$$

$$Bearing_{ChecktoeU1.OT} := \begin{cases} \text{"OKAY "} & \text{if } \sigma_{ToeU1.OT} < \sigma_{allowU1} \\ \text{"NG - for reference only""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

Bearing Pressure Under Heel:

$$\sigma_{HeelU1.OT} := \begin{cases} \left(\frac{\Sigma V_{U1.OT}}{b \cdot B} - \frac{\Sigma V_{U1.OT} \cdot ex_{U1.OT}}{S_{b.OT}}\right) & \text{if } \frac{\Sigma V_{U1.OT}}{b \cdot B} \geq \frac{\Sigma V_{U1.OT} \cdot ex_{U1.OT}}{S_{b.OT}} \\ 0 & \text{otherwise} \end{cases} = 88.4 \cdot kPa$$

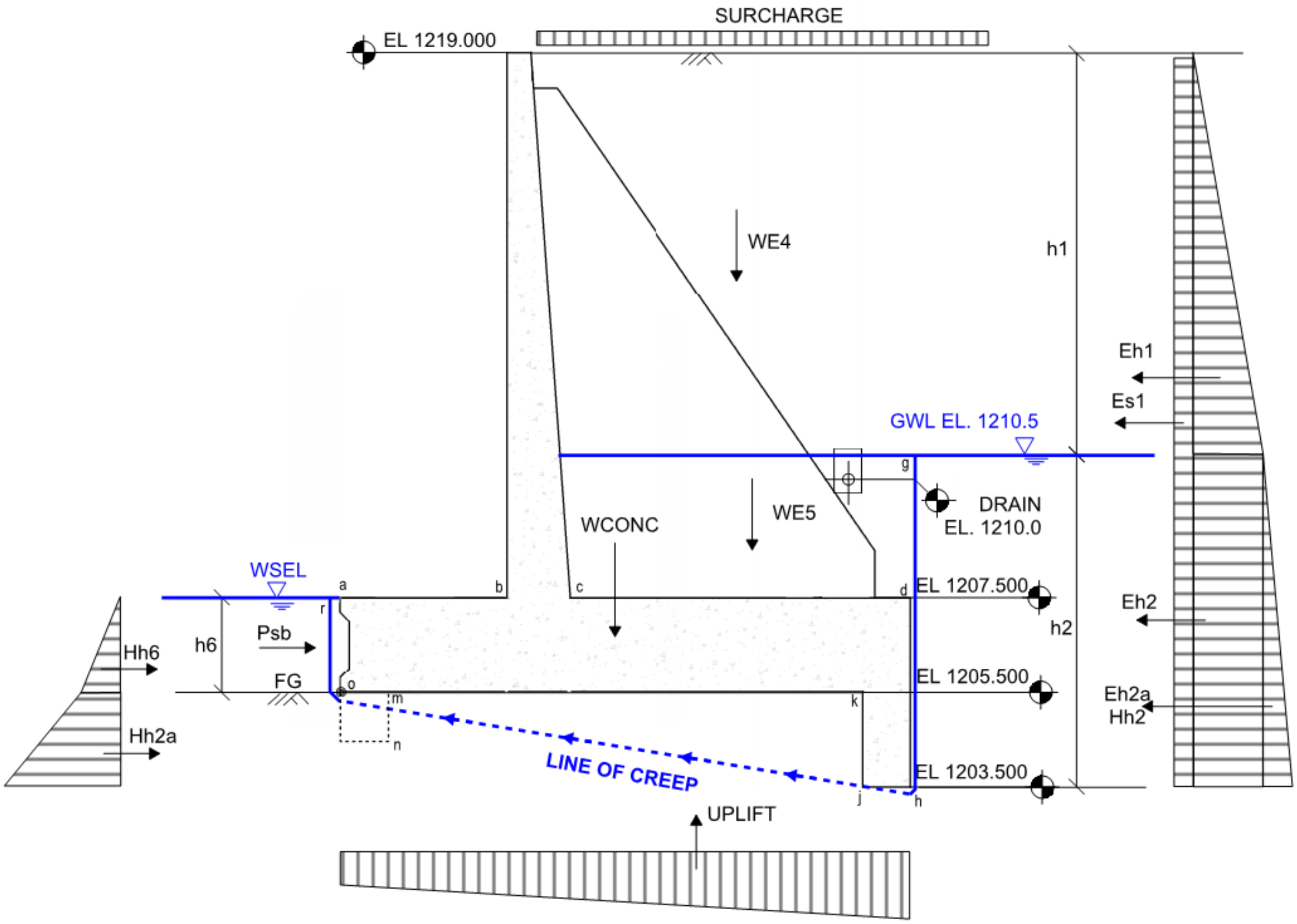
$$Bearing_{CheckheelU1.OT} := \left(\begin{cases} \text{"OKAY "} & \text{if } \sigma_{HeelU1.OT} < \sigma_{allowU1} \wedge \sigma_{HeelU1.OT} > 0 \\ \text{"NG - for reference only""} & \text{otherwise} \end{cases}\right) = \text{"OKAY "}$$

SUMMARY OF STABILITY ASSESSMENT:

LOAD CASE U1

Sliding Factor of Safety: (Horizontal Plane - Ref only)	$FS_{Horiz.SlidingU1} = 1.12$	$FS_{Sliding.check1.U1}$ = "Key req""
Sliding Factor of Safety: (Inclined Plane)	$FS_{InclinedlSlidingU1} = 2.34$	$FS_{Sliding.check2.U1}$ = "OKAY "
Eccentricity: (Inclined Plane)	$ex_{U1} = 0.55\ m$	$e_{check.U1}$ = "Okay"
Bearing Pressure At Heel: (Inclined Plane)	$\sigma_{HeelU1} = 151 \cdot kPa$	$Bearing_{CheckheelU1}$ = "OKAY "
Bearing Pressure At Toe: (Inclined Plane)	$\sigma_{ToeU1} = 263 \cdot kPa$	$Bearing_{ChecktoeU1}$ = "OKAY "
Flotation Factor of Safety (horizontal plane)	$FS_{FloatationU1} = 5$	$FS_{Floatation.U1.check}$ = "OKAY "
Overturning Resultant Ratio: (horizontal plane)	$Ratio_{U1.OT} = 0.41$	$Ratio_{U1.OT.check}$ = "OKAY "
Eccentricity: (horizontal plane - Ref only)	$ex_{U1.OT} = 1.05\ m$	$e_{check.U1.OT}$ = "Okay"
Bearing Pressure At Heel: (horizontal plane - Ref only)	$\sigma_{HeelU1.OT} = 88 \cdot kPa$	$Bearing_{CheckheelU1.OT}$ = "OKAY "
Bearing Pressure At Toe: (horizontal plane - Ref only)	$\sigma_{ToeU1.OT} = 284 \cdot kPa$	$Bearing_{ChecktoeU1.OT}$ = "OKAY "

LOAD CASE UN1 - NORMAL OPERATION + SURCHARGE



UN1 DESIGN CASE

LOAD CASE UN1 ACCEPTANCE PARAMETERS

FS sliding:

Unusual (UN) 1.3 (without cohesion) (Table 3-3, USACE EM 1110-2-2100)

Resultant Location:

Unsual (UN) Inside middle third ~100% base in compression

Required Factor of Safety for Sliding: $FS_{sliding.reqUN1} := 1.3$ (Without Cohesion)

Allowable rock bearing pressure: $\sigma_{allowUN1} := 1470kPa$ (Section 5.2, Design Criteria EM 1110-2-2100 Section 3-10)

Overturning Required Resultant Ratio: $X_{R.reqUN1} := 0.333$ (EM 1110-2-2502, Figure 4-4)

Required Factor of Safety for Floatation $FS_{req.UN1.flt} := 1.3$

SOIL HEIGHTS and Water Levels:

LOAD CASE UN1

Heel Conditions:

Groundwater Elevation at Heel: $GWL_{UN1} := 1210.5m$

Distance from Finish Grade to Groundwater at Heel:

$$h_{1UN1} := \left[T_w - GWL_{UN1} + \left(L_{cd} + t_{wb} - t_{wt}\right) \cdot \tan(\beta)\right] = 8.50\ m$$

Distance from Water Surface to Bottom of Footing at Heel:

$$h_{2UN1} := GWL_{UN1} - Bot_{ftg} + Key_{h.d} = 7.00\ m$$

Toe Conditions:

Water Surface Elevation at Toe: $WSEL_{UN1} := 1207.5m$

Water Surface Elevation at Toe for Uplift: $UWSEL_{UN1} := 1207.5 \cdot m$

Finish Grade at Toe providing lateral resistance: $FG_{toeUN1} := 1205.5 \cdot m$

Soil Depth Above top of footing:

$$h_{3aUN1} := FG_{toeUN1} - Top_{ftg} = -2\ m$$

$$h_{3UN1} := \begin{cases} h_{3aUN1} & \text{if } FG_{toeUN1} - Top_{ftg} \ge 0 \\ 0 & \text{otherwise} \end{cases} = 0$$

Resisting Fill at Toe:

$$h_{4UN1} := FG_{toeUN1} - Bot_{ftg} + Key_{t.d} = 0.00\ m$$

Distance from Water Level to Top of Footing at Toe:

$$h_{5UN1} := WSEL_{UN1} - Top_{ftg} = 0.00\ m$$

Distance from Water Surface to Bottom of Footing at Toe:

$$h_{6UN1} := WSEL_{UN1} - Bot_{ftg} + Key_{t.d} = 2.00\ m$$

Soil Depth Above WSEL:

$$h_{7aUN1} := FG_{toeUN1} - WSEL_{UN1} = -2\ m$$

$$h_{7UN1} := \begin{cases} h_{7aUN1} & \text{if } FG_{toeUN1} - WSEL_{UN1} \ge 0 \\ 0 & \text{otherwise} \end{cases} = 0$$

Soil Depth Below WSEL:

$$h_{8UN1} := \begin{cases} WSEL_{UN1} - Bot_{ftg} + Key_{t.d} & \text{if } FG_{toeUN1} - WSEL_{UN1} \ge 0 \\ h_{4UN1} & \text{otherwise} \end{cases} = 0$$

For Line of Creep Method:

$$L_{ho.UN1} := \sqrt{b^2 + \left(Key_{h.d} - Key_{t.d}\right)^2} = 12.166\ m$$

Head Loss from Point g:

$\Delta h_{g.hj.UN1} := h_{2UN1} = 7\ m$ (to point h & j)

$\Delta h_{g.km.UN1} := GWL_{UN1} - Bot_{ftg} = 5\ m$ (to point k & m)

$\Delta h_{g.no.UN1} := GWL_{UN1} - Bot_{ftg} + Key_{t.d} = 5\ m$ (to point n & o)

$\Delta h_{g.p.UN1} := GWL_{UN1} - FG_{toeUN1} = 5\ m$ (to point p*)

$\Delta h_{g.r.UN1} := GWL_{UN1} - UWSEL_{UN1} = 3\ m$ (to point r)

Surcharge

Surcharge on Heel: $S1_{UN1} := 15.0 \dfrac{kN}{m^2}$

* same as point "o" in this case

Calculate Soil Lateral Pressure Coefficients:

LOAD CASE UN1

For all load cases except seismic, soil loading to be based on At-Rest Condition.
Calculate at-rest pressure coefficient Ko based on Jaky's (1944) equation.

Soil At Rest Static Coefficient: $K_o := \frac{1 - \sin(\phi)}{1 + \sin(\beta)} = 0.546$ (Eq. 3-6, USACE EM 1110-2-2502)

Lateral - Driving Force

Static At-Rest:

Surcharge Load: $E_{s1UN1} := S1_{UN1} \cdot K_o \cdot \left(H_w + Key_{h.d}\right) \cdot B \cdot -1 = -126.947 \cdot kN$

Moment Arm (from bottom of footing): $E_{s1locUN1} := \frac{H_w + Key_{h.d}}{2} + Key_{vdist} = 5.75\ m$

Moist Soil Load above GWL: $E_{h1UN1} := \frac{\gamma_m \cdot K_o \cdot h_{1UN1}^{\ 2}}{2} \cdot B \cdot -1 = -394.5 \cdot kN$

Moment Arm (from bottom of footing): $E_{h1locUN1} := \frac{h_{1UN1}}{3} + h_{2UN1} + Key_{vdist} = 7.83\ m$

Saturated Soil Load below GWL:
(rectangular component) $E_{h2UN1} := \left(\gamma_m \cdot K_o \cdot h_{1UN1}\right) \cdot \left(h_{2UN1}\right) \cdot B \cdot -1 = -649.8 \cdot kN$

Moment Arm (from bottom of footing): $E_{h2locUN1} := \frac{h_{2UN1}}{2} + Key_{vdist} = 1.50\ m$

Saturated Soil Load below GWT:
(triangular L $E_{h2aUN1} := \frac{\left(\gamma_{sat} - \gamma_w\right) \cdot K_o \cdot h_{2UN1}^{\ 2}}{2} \cdot B \cdot -1 = -163.2 \cdot kN$

Moment Arm (from bottom of footing): $E_{h2alocUN1} := \frac{h_{2UN1}}{3} + Key_{vdist} = 0.33\ m$

Lateral Water Load:

Water Load GWL to Bottom of Key $H_{h2UN1} := \frac{\gamma_w \cdot h_{2UN1}^{\ 2}}{2} \cdot B \cdot -1 = -240.1 \cdot kN$

Moment Arm (from bottom of footing): $H_{h2locUN1} := \frac{h_{2UN1}}{3} + Key_{vdist} = 0.33\ m$

$\Sigma H_{SoildriveUN1} := E_{s1UN1} + E_{h1UN1} + E_{h2UN1} + E_{h2aUN1} + H_{h2UN1} = -1574.5 \cdot kN$

$\Sigma M_{LateralSoildriveUN1} := E_{s1UN1} \cdot E_{s1locUN1} + E_{h1UN1} \cdot E_{h1locUN1} + E_{h2UN1} \cdot E_{h2locUN1} + E_{h2aUN1} \cdot E_{h2alocUN1} \ldots + H_{h2UN1} \cdot H_{h2locUN1} = -4929.2\ m \cdot kN$

Lateral - Resisting Force

LOAD CASE UN1

Lateral Water Load:

Water Load WSEL to Bottom of Footing:

$$H_{h6UN1} := \frac{\gamma_w \cdot h_{6UN1}^{\ 2}}{2} \cdot B = 19.6 \cdot kN$$

Moment Arm (from bot. of toe key):

$$H_{h6locUN1} := \frac{h_{6UN1}}{3} = 0.67\ m$$

Water Load Bot. of Footing to Bot. of H. Key:

$$H_{h2aUN1} := \left[\left(UWSEL_{UN1} - Bot_{ftg} + Key_{t.d}\right) + h_{2UN1}\right] \cdot \frac{Key_{h.d}}{2} \cdot \gamma_w \cdot B = 88.2 \cdot kN$$

Moment Arm (from bot. of toe key):

$$H_{h2alocUN1} := \frac{Key_{h.d} \cdot \left[2 \cdot \left(UWSEL_{UN1} - Bot_{ftg} + Key_{t.d}\right) + h_{2UN1}\right]}{3\left[h_{2UN1} + \left(UWSEL_{UN1} - Bot_{ftg} + Key_{t.d}\right)\right]} \ ... \ + Key_{vdist} = -1.19\ m$$

Lateral Soil Load:

Moist Soil Load above WSEL:

$$E_{h7UN1} := \frac{\gamma_m \cdot K_o \cdot h_{7UN1}^{\ 2}}{2} \cdot B = 0.0 \cdot kN$$

Moment Arm (from bot. of toe key): $E_{h7locUN1} := h_{6UN1} + \frac{h_{7UN1}}{3} + Key_{vdist} = 0.00\ m$

Saturated Soil Load below WSEL: (rectangular component)

$$E_{h8UN1} := \left(\gamma_m \cdot K_o \cdot h_{7UN1}\right) \cdot h_{8UN1} \cdot B = 0.0 \cdot kN$$

Moment Arm (from bot. of toe key): $E_{h8locUN1} := \frac{h_{8UN1}}{2} = 0.00\ m$

Saturated Soil Load below WSEL: (triangular component)

$$E_{h8aUN1} := \frac{\left[\left(\gamma_{sat} - \gamma_w\right) \cdot K_o\right] \cdot h_{8UN1}^{\ 2}}{2} \cdot B = 0.0 \cdot kN$$

Moment Arm (from bot. of footing): $E_{h8alocUN1} := \frac{h_{8UN1}}{3} = 0.00\ m$

Lateral Resistance from Stilling Basin:

Lateral Resistance from Stilling Basin: $P_{sbUN1} := 415kN$ (Force needed to achieve the required sliding factor of safety in case UN2)

Moment Arm (from bot. of toe key): $P_{sblocUN1} := \frac{t_{ftg}}{2} + Key_{t.d} = 1.00\ m$

$$\Sigma H_{SoilresistUN1} := H_{h6UN1} + H_{h2aUN1} + E_{h7UN1} + E_{h8UN1} + E_{h8aUN1} + P_{sbUN1} = 522.8 \cdot kN$$

$$\Sigma M_{HorizSoilResistUN1} := H_{h6UN1} \cdot H_{h6locUN1} + H_{h2aUN1} \cdot H_{h2alocUN1} + E_{h7UN1} \cdot E_{h7locUN1} \ ... \ + E_{h8UN1} \cdot E_{h8locUN1} + E_{h8aUN1} \cdot E_{h8alocUN1} + P_{sbUN1} \cdot P_{sblocUN1} = 323.5\ m \cdot kN$$

Vertical Force:

UPLIFT: Linear distribution from water at heel to water at toe:

$$\Sigma V_{UpliftUN1} := \left[\left(UWSEL_{UN1} - Bot_{ftg} + Key_{t.d}\right) + h_{2UN1}\right] \cdot \frac{b}{2} \cdot \gamma_w \cdot B \cdot -1 = -529.2 \cdot kN$$

Moment Arm (from Point O):

$$V_{UpliftUN1aloc} := \frac{b \cdot \left[2 \cdot h_{2UN1} + \left(UWSEL_{UN1} - Bot_{ftg} + Key_{t.d}\right)\right]}{3\left[h_{2UN1} + \left(UWSEL_{UN1} - Bot_{ftg} + Key_{t.d}\right)\right]} = 7.111\ m$$

$$\Sigma M_{UpliftUN1} := \Sigma V_{UpliftUN1} \cdot V_{UpliftUN1aloc} = -3763.2 \cdot kN \cdot m$$

Weight of soil and water over toe:

Water Above the Top of Footing: $W_{H1UN1} := \gamma_w \cdot h_{5UN1} \cdot L_{ab} \cdot B = 0 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E1locUN1} := \frac{L_{ab}}{2} = 1.75\ m$

Soil above top of footing: $W_{E6UN1} := \gamma_b \cdot h_{3UN1} \cdot L_{ab} \cdot B = 0.0 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E6locUN1} := \frac{L_{ab}}{2} = 1.75\ m$

Vertical Load Due to Surcharge: $S_{UN1} := S1_{UN1} \cdot L_{cd} \cdot B = 106.44 \cdot kN$ $\quad S_{UN1loc} := b - \frac{L_{cd}}{2} = 8.45\ m$

Weight of soil and water over heel:

Moist Soil for sloped grade above top of wall:

Length of sloped portion of soil above top of wall: $L_{E3UN1} := \left(L_{cd} + t_{wb} - t_{wt}\right) = 8.00\ m$

Height of sloped soil above top of wall over heel: $h_{E3locUN1} := \left(L_{E3UN1}\right) \cdot \tan(\beta) = 0.00\ m$

Weight of sloped soil above top of wall: $W_{E3UN1} := \frac{\gamma_m}{2} \cdot h_{E3locUN1} \cdot L_{E3UN1} \cdot B = 0.0 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E3locUN1} := L_{ab} + t_{wt} + \frac{2}{3} \cdot L_{E3UN1} = 9.33\ m$

Moist soil from top of wall to groundwater level:

Height of soil from top of wall and top of GWL: $h_{1UN1} = 8.50\ m$

Length from edge of wall at GWL to edge of heel: $L_{E4UN1} := L_{E3UN1} - \left(h_{1UN1} \cdot S_{batter}\right) = 7.33\ m$

Weight of soil over heel from top of wall to GWL: $W_{E4UN1} := \gamma_m \cdot h_{1UN1} \cdot \frac{\left(L_{E3UN1} + L_{E4UN1}\right)}{2} \cdot B = 1303.2 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E4locUN1} := b - \frac{L_{E3UN1}^2 + L_{E3UN1} \cdot L_{E4UN1} + L_{E4UN1}^2}{3\left(L_{E3UN1} + L_{E4UN1}\right)} = 8.16\ m$

Saturated soil from groundwater to top of footing:

Height of soil from GWL to top of heel: $h_{E4UN1} := h_{2UN1} - t_{ftg} - Key_{h.d} = 3.00\ m$

Weight of soil over heel from GWL to top of heel: $W_{E5UN1} := \left(\gamma_{sat}\right) \cdot h_{E4UN1} \cdot \frac{\left(L_{E4UN1} + L_{cd}\right)}{2} \cdot B = 476.1 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E5locUN1} := b - \frac{L_{E4UN1}^2 + L_{E4UN1} \cdot L_{cd} + L_{cd}^2}{3\left(L_{E4UN1} + L_{cd}\right)} = 8.39\ m$

$\Sigma V_{SoilWaterUN1} := W_{H1UN1} + W_{E6UN1} + W_{E3UN1} + W_{E4UN1} + W_{E5UN1} + S_{UN1} = 1885.8 \cdot kN$

$$\Sigma M_{VertSoilWaterResistUN1} := W_{H1UN1} \cdot W_{E1locUN1} + W_{E6UN1} \cdot W_{E6locUN1} \cdots + W_{E3UN1} \cdot W_{E3locUN1} + W_{E4UN1} \cdot W_{E4locUN1} + W_{E5UN1} \cdot W_{E5locUN1} + S_{UN1} \cdot S_{UN1loc} = 15535.7\ m \cdot kN$$

THIS PAGE INTENTIONALLY LEFT BLANK
PLEASE GO TO THE NEXT PAGE

STABILITY ASSESSMENT:

LOAD CASE UN1

CHECK SLIDING ALONG HORIZONTAL SLIDING PLANE:

Summation of the vertical forces:

$$\Sigma V_{UN1} := \Sigma V_{conc} + \Sigma V_{SoilWaterUN1} + \Sigma V_{UpliftUN1} = 2224.8 \cdot kN$$

Summation of the horizontal forces:

$$\Sigma H_{UN1} := \Sigma H_{SoildriveUN1} + \Sigma H_{SoilresistUN1} = -1051.7 \cdot kN$$

Safety Factor for Sliding Horizontal Failure Plane

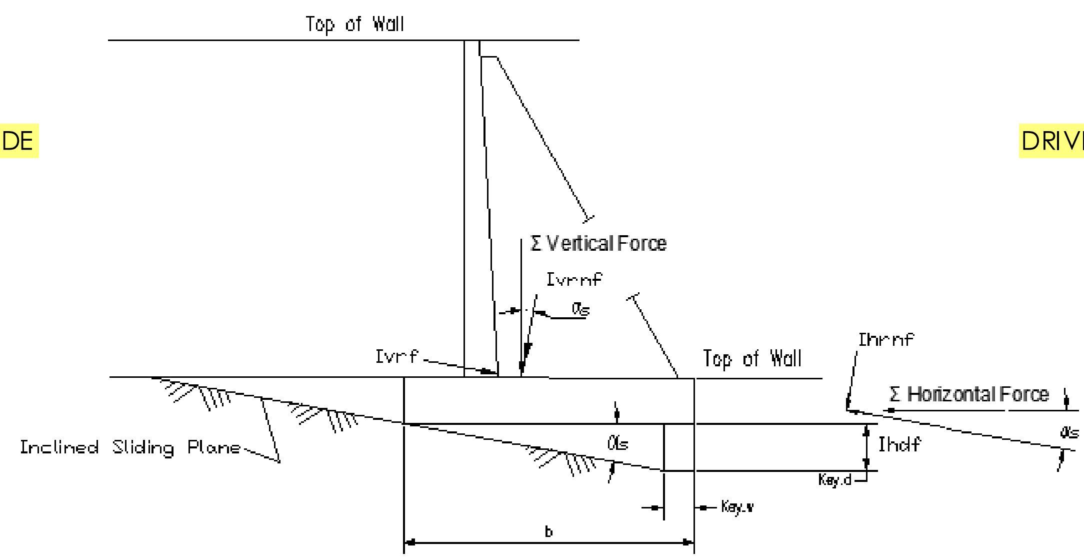
$$FS_{Horiz.SlidingUN1} := \frac{\left|\Sigma V_{UN1}\right| \cdot \tan\left(\phi_{rock} \cdot \frac{\pi}{180}\right)}{\left|\Sigma H_{UN1}\right|} = 1.03$$

$$FS_{Sliding.check1.UN1} := \begin{cases} \text{"OKAY "} & \text{if } FS_{Horiz.SlidingUN1} > FS_{sliding.reqUN1} \\ \text{"NG - key req""} & \text{otherwise} \end{cases} = \text{"NG - key req""}$$

CHECK FACTOR OF SAFETY SLIDING WITH KEY (INCLINED SLIDING PLANE):

RESISTING SIDE

DRIVING SIDE



TOE

HEEL

Ivrf=Inclined Resisting Force
Ivrnf=Inclined Resisting Normal Force
Ihrnf=Inclined Resisting Normal Force
Ihdf=Inclined Driving Force

$\alpha s = 0.18$ as degrees= $\alpha s \cdot \left(\frac{180}{\pi}\right) = 10.30$

(With properly engineered reinforced concrete Key, horizontal sliding plane thru Toe is protected, critical sliding plane is relocated to the INCLINED SLIDING PLANE FROM HEEL KEY To TOE, Bedrock Mass above this examing plane is mobilized by reinforced concrete key and combined into Structural Wedge.)

Resolve ΣV_{UN1} & ΣH_{UN1}

$$\Sigma V_{InclinedUN1} := \cos(\alpha s) \cdot \left(\left|\Sigma V_{UN1} + V_{rocksection}\right|\right) + \sin(\alpha s) \cdot \left|\Sigma H_{UN1}\right| = 2654.1 \cdot kN$$

$$\Sigma H_{InclinedUN1} := \cos(\alpha s) \cdot \left|\Sigma H_{UN1}\right| - \sin(\alpha s) \cdot \left(\left|\Sigma V_{UN1} + V_{rocksection}\right|\right) = 586.4 \cdot kN$$

LOAD CASE UN1

Safety Factor for Sliding Inclined Failure Plane

$$FS_{InclinedlSlidingUN1} := \frac{\Sigma V_{InclinedUN1} \cdot \tan(\phi_r)}{\Sigma H_{InclinedUN1}} = 2.02$$

$$FS_{Sliding.check2.UN1} := \begin{cases} \text{"OKAY "} & \text{if } FS_{InclinedlSlidingUN1} > FS_{sliding.reqUN1} \\ \text{"NG - Revise Structure""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

CHECK FOUNDATION ECCENTRICITY:

Summation of the resisting moments about the toe:

$$\Sigma M_{resUN1} := \Sigma M_{conc} + \Sigma M_{VertSoilWaterResistUN1} + \Sigma M_{HorizSoilResistUN1} + \Sigma M_{rocksection} = 22881 \cdot kN \cdot m$$

Summation of the overturning moments about the toe:

$$\Sigma M_{oUN1} := \Sigma M_{LateralSoildriveUN1} + \Sigma M_{UpliftUN1} = -8692 \cdot kN \cdot m$$

Total moment: $\Sigma M_{UN1} := \Sigma M_{resUN1} + \Sigma M_{oUN1} = 14188.6 \cdot kN \cdot m$

Normal force to base: $\Sigma V_{InclinedUN1} = 2654.1 \cdot kN$

Inclined Sliding Plane Length: $L_{incline} = 12.2 \cdot m$

Eccentricity (inclined plane): $ex_{UN1} := \frac{L_{incline}}{2} - \frac{\Sigma M_{UN1}}{\Sigma V_{InclinedUN1}} = 0.75\,m$

$Kern = 2.033\,m$

Eccentricity Check: $e_{check.UN1} := \begin{cases} \text{"Okay"} & \text{if } ex_{UN1} \le Kern \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"Okay"}$

CHECK FOUNDATION BEARING CAPACITY:

Base Section Modulus: $S_b = 24.79\,m^3$

Bearing Pressure Under Toe:

$$\sigma_{ToeUN1} := \begin{cases} \left(\frac{\Sigma V_{InclinedUN1}}{L_{incline} \cdot B} + \frac{\Sigma V_{InclinedUN1} \cdot ex_{UN1}}{S_b}\right) & \text{if } \frac{\Sigma V_{InclinedUN1} \cdot ex_{UN1}}{S_b} \le \frac{\Sigma V_{InclinedUN1}}{L_{incline} \cdot B} \\ \frac{2 \cdot \Sigma V_{InclinedUN1}}{B \cdot 3\left(\frac{b}{2} - ex_{UN1}\right)} & \text{otherwise} \end{cases} = 298.2 \cdot kPa$$

$$Bearing_{ChecktoeUN1} := \begin{cases} \text{"OKAY "} & \text{if } \sigma_{ToeUN1} < \sigma_{allowUN1} \\ \text{"NG""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

Bearing Pressure Under Heel:

$$\sigma_{HeelUN1} := \begin{cases} \left(\frac{\Sigma V_{InclinedUN1}}{L_{incline} \cdot B} - \frac{\Sigma V_{InclinedUN1} \cdot ex_{UN1}}{S_b}\right) & \text{if } \frac{\Sigma V_{InclinedUN1} \cdot ex_{UN1}}{S_b} \le \frac{\Sigma V_{InclinedUN1}}{L_{incline} \cdot B} \\ 0 & \text{otherwise} \end{cases} = 137.1 \cdot kPa$$

$$Bearing_{CheckheelUN1} := \left(\begin{cases} \text{"OKAY "} & \text{if } \sigma_{HeelUN1} < \sigma_{allowUN1} \wedge \sigma_{HeelUN1} > 0 \\ \text{"NG - perform cracked base analysis""} & \text{otherwise} \end{cases}\right) = \text{"OKAY "}$$

CHECK FLOATATION:

Safety Factor for Floatation: $FS_{FloatationUN1} := \dfrac{\Sigma V_{conc} + \Sigma V_{SoilWaterUN1}}{\left|\Sigma V_{UpliftUN1}\right|} = 5.20$

$FS_{Floatation.UN1.check} :=$ | "OKAY " if $FS_{FloatationUN1} > FS_{req.UN1.flt}$ = "OKAY "
"Revise Structure"" otherwise

CHECK OVERTURNING

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.
Assumptions are made in order to compute overturning stablity of indetermine forces on monolith with key;
(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.
(b) The horizontal resisting force acting on the key, P.key, is that required for static equilibrium
(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1

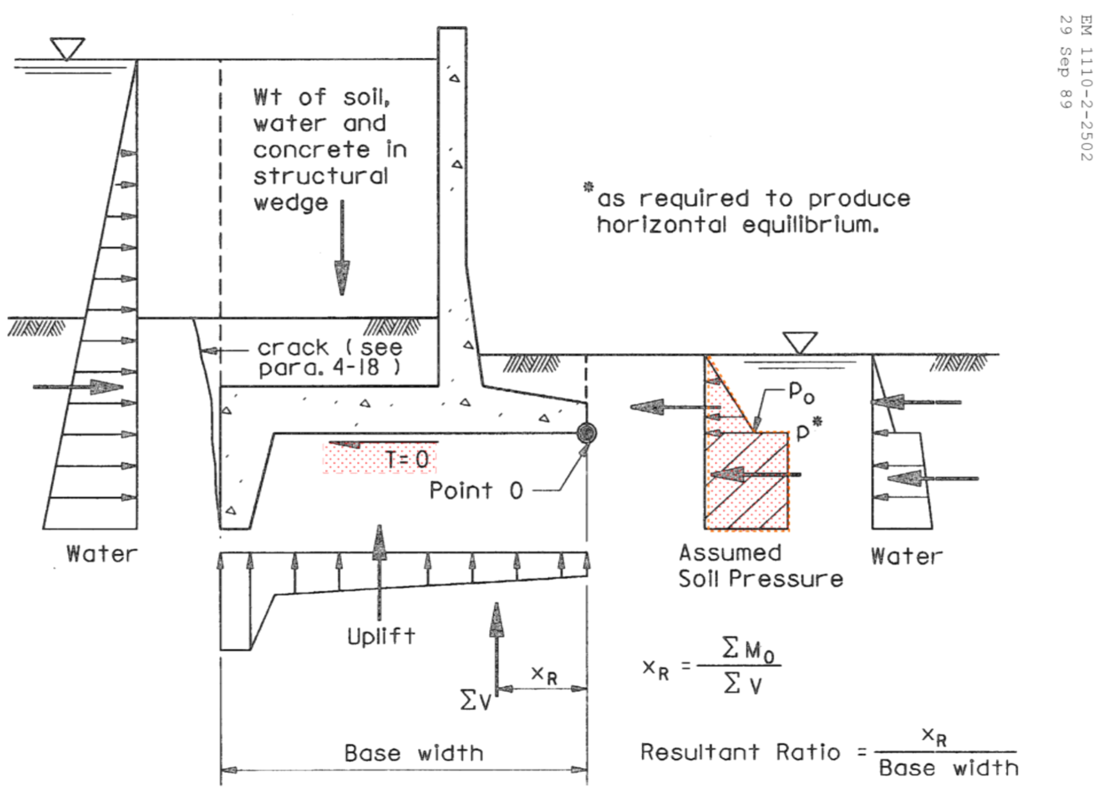


Figure 4-5. Forces for overturning analysis for wall with horizontal base and key

Modify Uplift for Overturning Analysis: **LOAD CASE UN1**

(Uplift is calculated along the concrete/rock contact using the Line of Creep method)

Water Pressure at h: $u_{h.UN1} := \Delta h_{g.hj.UN1} \cdot \gamma_w = 68.60 \cdot kPa$

Water Pressure at o: $u_{o.UN1} := \left(\Delta h_{g.no.UN1} - \frac{\Delta h_{g.r.UN1} \cdot L_{ho.UN1}}{L_{ho.UN1}} \right) \cdot \gamma_w = 19.6 \cdot kPa$

Head loss between point h and o: $\Delta h_{ho.UN1} := \Delta h_{g.r.UN1} \cdot \frac{L_{ho.UN1}}{L_{ho.UN1}} = 3\,m$

Length of concrete base (h -> o): $L_{baseho.UN1} := Key_{h.w} + Key_{h.d} + Key_{hdist} + Key_{t.d} + Key_{t.w} = 14\,m$

Head loss along h -> j: $\Delta h_{hj.UN1} := \Delta h_{ho.UN1} \cdot \frac{Key_{h.w}}{L_{baseho.UN1}} = 0.214\,m$

Water Pressure at j: $u_{j.UN1} := \left(\Delta h_{g.hj.UN1} - \Delta h_{hj.UN1} \right) \cdot \gamma_w = 66.50 \cdot kPa$

Head loss along h -> k: $\Delta h_{hjk.UN1} := \Delta h_{ho.UN1} \cdot \left(\frac{Key_{h.w} + Key_{h.d}}{L_{baseho.UN1}} \right) = 0.643\,m$

Water Pressure at k: $u_{k.UN1} := \left(\Delta h_{g.km.UN1} - \Delta h_{hjk.UN1} \right) \cdot \gamma_w = 42.70 \cdot kPa$

Head loss along h -> m: $\Delta h_{hjkm.UN1} := \Delta h_{ho.UN1} \cdot \left(\frac{Key_{h.w} + Key_{h.d} + Key_{hdist}}{L_{baseho.UN1}} \right) = 3\,m$

Water Pressure at m: $u_{m.UN1} := \left(\Delta h_{g.km.UN1} - \Delta h_{hjkm.UN1} \right) \cdot \gamma_w = 19.60 \cdot kPa$

Head loss along h -> n: $\Delta h_{hjkmn.UN1} := \Delta h_{ho.UN1} \cdot \left(\frac{Key_{h.w} + Key_{h.d} + Key_{hdist} + Key_{t.d}}{L_{baseho.UN1}} \right) = 3\,m$

Water Pressure at n: $u_{n.UN1} := \left(\Delta h_{g.no.UN1} - \Delta h_{hjkmn.UN1} \right) \cdot \gamma_w = 19.60 \cdot kPa$

Uplift under key at heel: $V_{ulkeyhUN1.OT} := \frac{\left(u_{h.UN1} + u_{j.UN1} \right) \cdot Key_{h.w}}{2} \cdot B \cdot -1 = -67.55 \cdot kN$

Moment Arm (from Point O): $V_{ulkeyhUN1loc.OT} := b - \frac{Key_{h.w} \cdot \left(2 \cdot u_{j.UN1} + u_{h.UN1} \right)}{3 \cdot \left(u_{j.UN1} + u_{h.UN1} \right)} = 11.503\,m$

Uplift under base: $V_{ulbaseUN1.OT} := \frac{\left(u_{k.UN1} + u_{m.UN1} \right) \cdot Key_{hdist}}{2} \cdot B \cdot -1 = -342.65 \cdot kN$

Moment Arm (from Point O): $V_{ulbaseUN1loc.OT} := b - Key_{h.w} - \frac{Key_{hdist} \cdot \left(2 \cdot u_{m.UN1} + u_{k.UN1} \right)}{3 \cdot \left(u_{m.UN1} + u_{k.UN1} \right)} = 6.18\,m$

Uplift under key at toe: $V_{ulkeytUN1.OT} := \frac{\left(u_{n.UN1} + u_{o.UN1} \right) \cdot Key_{t.w}}{2} \cdot B \cdot -1 = 0 \cdot kN$

Moment Arm (from Point O): $V_{ulkeytUN1loc.OT} := \frac{Key_{t.w} \cdot \left(2 \cdot u_{n.UN1} + u_{o.UN1} \right)}{3 \cdot \left(u_{n.UN1} + u_{o.UN1} \right)} = 0$

$$\Sigma V_{UpliftUN1.OT} := V_{ulkeyhUN1.OT} + V_{ulbaseUN1.OT} + V_{ulkeytUN1.OT} = -410 \cdot kN$$

$$U_{UN1.loc.OT} := \frac{V_{ulkeyhUN1.OT} \cdot V_{ulkeyhUN1loc.OT} + V_{ulbaseUN1.OT} \cdot V_{ulbaseUN1loc.OT} + V_{ulkeytUN1.OT} \cdot V_{ulkeytUN1loc.OT}}{\Sigma V_{UpliftUN1.OT}} = 7.06\,m$$

$$\Sigma M_{UpliftUN1.OT} := \Sigma V_{UpliftUN1.OT} \cdot U_{UN1.loc.OT} = -2894.5 \cdot kN \cdot m$$

Modify Lateral Water Pressure (Resisting) for Overturning Analysis:

(Resisting water pressure is calculated using the Line of Creep method)

Water Load at Key (heel):

$$H_{h2UN1.OT} := \frac{u_{k.UN1} + u_{j.UN1}}{2} \cdot Key_{h.d} B = 109.2 \cdot kN$$

Moment Arm (from Point O):

$$H_{h2locUN1.OT} := \frac{Key_{h.d} \cdot (2 \cdot u_{k.UN1} + u_{j.UN1})}{3(u_{k.UN1} + u_{j.UN1})} + Key_{vdist} = -1.07\ m$$

Water Load at Key (toe):

$$H_{h6UN1.OT} := \frac{u_{o.UN1} \cdot (UWSEL_{UN1} - Bot_{ftg} + Key_{t.d})}{2} \cdot B = 20 \cdot kN$$

Moment Arm (from Point O):

$$H_{h6locUN1.OT} := \frac{UWSEL_{UN1} - Bot_{ftg} + Key_{t.d}}{3} = 0.67\ m$$

$$\Sigma H_{waterresistUN1.OT} := H_{h2UN1.OT} + H_{h6UN1.OT} = 128.8 \cdot kN$$

$$H_{waterresistlocUN1.OT} := \frac{H_{h2UN1.OT} \cdot H_{h2locUN1.OT} + H_{h6UN1.OT} \cdot H_{h6locUN1.OT}}{\Sigma H_{waterresistUN1.OT}} = -0.808\ m$$

$$\Sigma M_{waterresistUN1.OT} := \Sigma H_{waterresistUN1.OT} \cdot H_{waterresistlocUN1.OT} = -104.07 \cdot kN \cdot m$$

Modify Lateral Soil Loads for Overturning Analysis:

(Lateral soil loads are calculated down to Point O instead of bottom of shear key)

Driving Soil Load (Headwater Side):

Surcharge Load:

$$E_{s1UN1.OT} := S1_{UN1} \cdot K_o \cdot (H_w + Key_{h.d} + Key_{vdist}) \cdot B \cdot -1 = -110.567 \cdot kN$$

Moment Arm (from Point O):

$$E_{s1locUN1.OT} := \frac{H_w + Key_{h.d} + Key_{vdist}}{2} = 6.75\ m$$

Moist Soil Load above GWL:

$$E_{h1UN1.OT} := \frac{\gamma_m \cdot K_o \cdot h_{1UN1}^{\ 2}}{2} B \cdot -1 = -394.5 \cdot kN$$

Moment Arm (from Point O):

$$E_{h1locUN1.OT} := \frac{h_{1UN1}}{3} + h_{2UN1} + Key_{vdist} = 7.83\ m$$

Saturated Soil Load below GWL:
(rectangular component)

$$E_{h2UN1.OT} := (\gamma_m \cdot K_o \cdot h_{1UN1}) \cdot (h_{2UN1} + Key_{vdist}) \cdot B \cdot -1 = -464.1 \cdot kN$$

Moment Arm (from Point O):

$$E_{h2locUN1.OT} := \frac{h_{2UN1} + Key_{vdist}}{2} = 2.50\ m$$

Saturated Soil Load below GWL:
(triangular component)

$$E_{h2aUN1.OT} := \frac{(\gamma_{sat} - \gamma_w) \cdot K_o \cdot (h_{2UN1} + Key_{vdist})^2}{2} \cdot B \cdot -1 = -83.3 \cdot kN$$

Moment Arm (from Point O):

$$E_{h2alocUN1.OT} := \frac{h_{2UN1} + Key_{vdist}}{3} = 1.67\ m$$

Resisting Soil Load (Tailwater Side):

(Determine resisting soil load based on depth variation between the keys (ie. Key_{vdist}). In case where key at heel is deeper than key at toe (ie. $Key_{vdist} < 0$), resisting soil load (p*) is assumed to produce horizontal equilibrium as per Figure 4-5 above. Resisting soil load (p_o) is neglected.)

Total Driving Force: $\Sigma H_{SoildriveUN1.OT} := E_{s1UN1.OT} + E_{h1UN1.OT} + E_{h2UN1.OT} + E_{h2aUN1.OT} + H_{h2UN1} = -1292.5 \cdot kN$

Total Resisting Force: $\Sigma H_{waterresistUN1.OT} = 128.8 \cdot kN$

Assumed Soil Load p*: $E_{h8UN1a.OT} := \left(\Sigma H_{SoildriveUN1.OT} + \Sigma H_{waterresistU1.OT}\right) \cdot -1 = 1163.733 \cdot kN$

Moment Arm (from Point O): $E_{h8UN1a.loc.OT} := \frac{Key_{vdist}}{2} = -1\, m$

$$E_{h8UN1.OT} := \begin{cases} E_{h8UN1a.OT} & \text{if } Key_{vdist} < 0 \\ \Sigma H_{SoilresistUN1} - H_{h6UN1} - H_{h2aUN1} - P_{sbUN1} & \text{otherwise} \end{cases} = 1163.733 \cdot kN$$

$$\Sigma M_{SoilresistUN1} := \begin{cases} E_{h8UN1a.OT} \cdot E_{h8UN1a.loc.OT} & \text{if } Key_{vdist} < 0 \\ \Sigma M_{HorizSoilResistUN1} - H_{h6UN1} \cdot H_{h6locUN1} - H_{h2aUN1} \cdot H_{h2alocUN1} - P_{sbUN1} \cdot P_{sblocUN1} & \text{otherwise} \end{cases} = -1163.733 \cdot kN \cdot m$$

Sum of Moment about Point O:

$$\Sigma M_{LateraldriveUN1.OT} := E_{s1UN1.OT} \cdot E_{s1locUN1.OT} + E_{h1UN1.OT} \cdot E_{h1locUN1.OT} + E_{h2UN1.OT} \cdot E_{h2locUN1.OT} \cdots + E_{h2aUN1.OT} \cdot E_{h2alocUN1.OT} + H_{h2UN1} \cdot H_{h2locUN1} = -5215.6 \cdot kN \cdot m$$

$$\Sigma M_{LateralresistUN1.OT} := \Sigma M_{waterresistUN1.OT} + \Sigma M_{SoilresistUN1} = -1267.8 \cdot kN \cdot m$$

Total moment:

$$\Sigma M_{UN1.OT} := \Sigma M_{conc} + \Sigma M_{VertSoilWaterResistUN1} + \Sigma M_{UpliftUN1.OT} \cdots + \Sigma M_{LateraldriveUN1.OT} + \Sigma M_{LateralresistUN1.OT} = 11114.5 \cdot kN \cdot m$$

Total Vertical Force: $\Sigma V_{UN1.OT} := \Sigma V_{conc} + \Sigma V_{SoilWaterUN1} + \Sigma V_{UpliftUN1.OT} = 2343.8 \cdot kN$

Distance X_R: EM 1110-2-2502 Eq.4-1 $X_{R.UN1} := \frac{\Sigma M_{UN1.OT}}{\Sigma V_{UN1.OT}} = 4.742\, m$

Overturning Resultant Ratio $Ratio_{UN1.OT} := \frac{X_{R.UN1}}{b} = 0.4$

$$Ratio_{UN1.OT.check} := \begin{cases} \text{"OKAY "} & \text{if } Ratio_{UN1.OT} > X_{R.reqUN1} \\ \text{"Revise Structure""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

CHECK FOUNDATION ECCENTRICITY (HORIZONTAL PLANE):

Eccentricity (horizontal plan): $ex_{UN1.OT} := \frac{b}{2} - \frac{\Sigma M_{UN1.OT}}{\Sigma V_{UN1.OT}} = 1.26\, m$ $\quad Kern_{OT} = 2\, m$

Eccentricity Check:

$$e_{check.UN1.OT} := \begin{cases} \text{"Okay"} & \text{if } ex_{UN1} \le Kern_{OT} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"Okay"}$$

LOAD CASE UN1

CHECK FOUNDATION BEARING CAPACITY (HORIZONTAL PLANE):

Base Section Modulus: $S_{b.OT} = 24\,m^3$

Bearing Pressure Under Toe:

$$\sigma_{ToeUN1.OT} := \begin{cases} \left(\dfrac{\Sigma V_{UN1.OT}}{b \cdot B} + \dfrac{\Sigma V_{UN1.OT} \cdot ex_{UN1.OT}}{S_{b.OT}}\right) & \text{if } \dfrac{\Sigma V_{UN1.OT}}{b \cdot B} \geq \dfrac{\Sigma V_{UN1.OT} \cdot ex_{UN1.OT}}{S_{b.OT}} \\ \dfrac{2 \cdot \Sigma V_{UN1.OT}}{B \cdot 3\left(\dfrac{b}{2} - ex_{UN1.OT}\right)} & \text{otherwise} \end{cases} = 318.2 \cdot kPa$$

$$Bearing_{ChecktoeUN1.OT} := \begin{cases} \text{"OKAY "} & \text{if } \sigma_{ToeUN1.OT} < \sigma_{allowUN1} \\ \text{"NG - for reference only""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

Bearing Pressure Under Heel:

$$\sigma_{HeelUN1.OT} := \begin{cases} \left(\dfrac{\Sigma V_{UN1.OT}}{b \cdot B} - \dfrac{\Sigma V_{UN1.OT} \cdot ex_{UN1.OT}}{S_{b.OT}}\right) & \text{if } \dfrac{\Sigma V_{UN1.OT}}{b \cdot B} \geq \dfrac{\Sigma V_{UN1.OT} \cdot ex_{UN1.OT}}{S_{b.OT}} \\ 0 & \text{otherwise} \end{cases} = 72.5 \cdot kPa$$

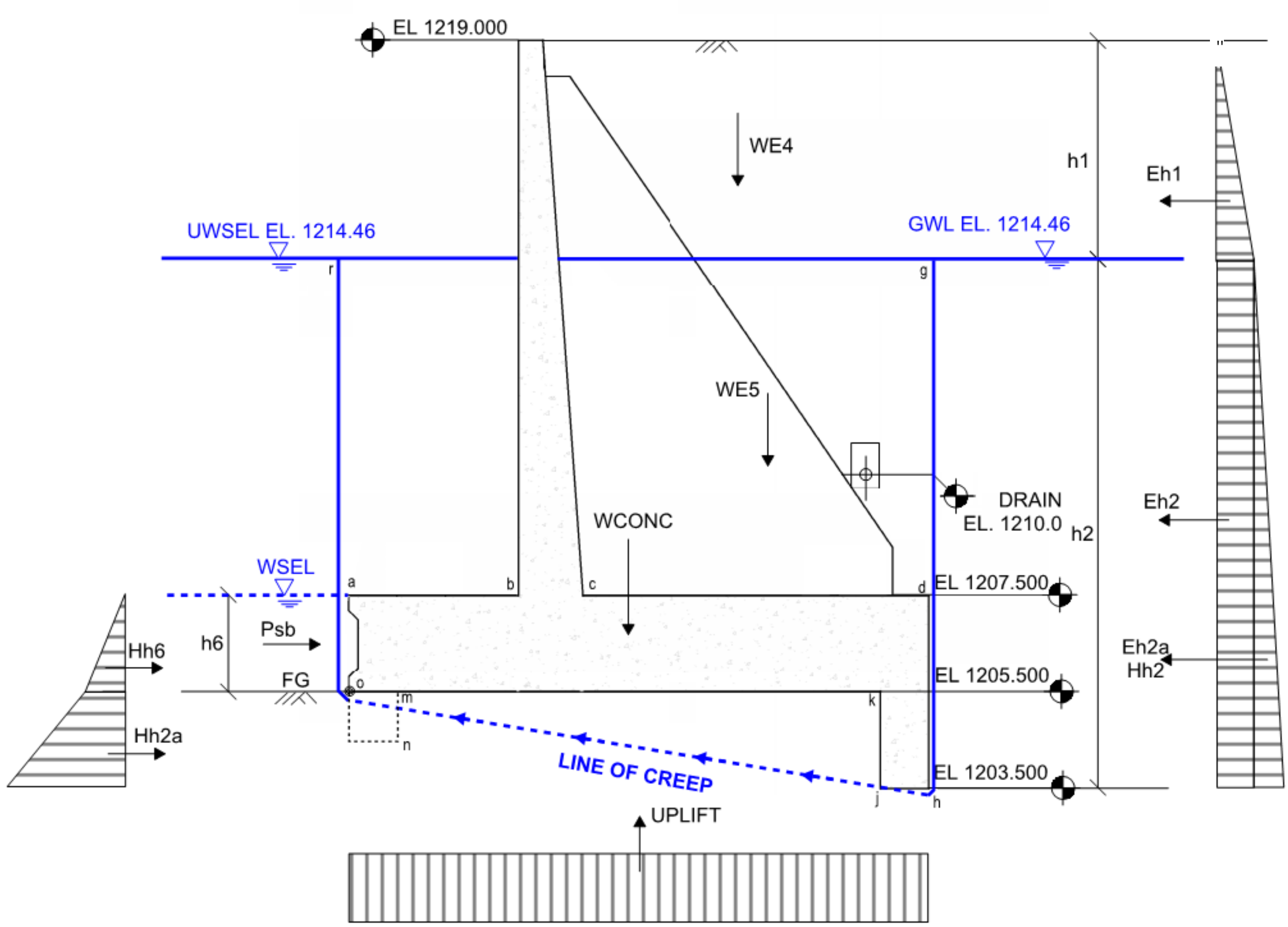
$$Bearing_{CheckheelUN1.OT} := \left(\begin{cases} \text{"OKAY "} & \text{if } \sigma_{HeelUN1.OT} < \sigma_{allowUN1} \wedge \sigma_{HeelUN1.OT} > 0 \\ \text{"NG - for reference only""} & \text{otherwise} \end{cases}\right) = \text{"OKAY "}$$

SUMMARY OF STABILITY ASSESSMENT:

LOAD CASE UN1

Sliding Factor of Safety: (Horizontal Plane - Ref only)	$FS_{Horiz.SlidingUN1} = 1.03$	$FS_{Sliding.check1.UN1}$ = "NG - key req""
Sliding Factor of Safety: (Inclined Plane)	$FS_{InclinedlSlidingUN1} = 2.02$	$FS_{Sliding.check2.UN1}$ = "OKAY "
Eccentricity: (Inclined Plane)	$ex_{UN1} = 0.75\ m$	$e_{check.UN1}$ = "Okay"
Bearing Pressure At Heel: (Inclined Plane)	$\sigma_{HeelUN1} = 137 \cdot kPa$	$Bearing_{CheckheelUN1}$ = "OKAY "
Bearing Pressure At Toe: (Inclined Plane)	$\sigma_{ToeUN1} = 298 \cdot kPa$	$Bearing_{ChecktoeUN1}$ = "OKAY "
Flotation Factor of Safety (horizontal plane)	$FS_{FloatationUN1} = 5.2$	$FS_{Floatation.UN1.check}$ = "OKAY "
Overturning Resultant Ratio: (horizontal plane)	$Ratio_{UN1.OT} = 0.4$	$Ratio_{UN1.OT.check}$ = "OKAY "
Eccentricity: (horizontal plane - Ref only)	$ex_{UN1.OT} = 1.26\ m$	$e_{check.UN1.OT}$ = "Okay"
Bearing Pressure At Heel: (horizontal plane - Ref only)	$\sigma_{HeelUN1.OT} = 72 \cdot kPa$	$Bearing_{CheckheelUN1.OT}$ = "OKAY "
Bearing Pressure At Toe: (horizontal plane - Ref only)	$\sigma_{ToeUN1.OT} = 318 \cdot kPa$	$Bearing_{ChecktoeUN1.OT}$ = "OKAY "

LOAD CASE UN2 - INEFFECTIVE DRAIN



UN2 DESIGN CASE

LOAD CASE UN2 ACCEPTANCE PARAMETERS

FS sliding:

Unusual (UN) 1.3 (without cohesion) (Table 3-3, USACE EM 1110-2-2100)

Resultant Location:

Unsual (UN) Inside middle third ~100% base in compression

Required Factor of Safety for Sliding: $FS_{sliding.reqUN2} := 1.3$ (Without Cohesion)

Allowable rock bearing pressure: $\sigma_{allowUN2} := 1470kPa$ (Section 5.2, Design Criteria EM 1110-2-2100 Section 3-10)

Overturning Required Resultant Ratio: $X_{R.reqUN2} := 0.333$ (EM 1110-2-2502, Figure 4-4)

Required Factor of Safety for Floatation $FS_{req.UN2.flt} := 1.3$

SOIL HEIGHTS and Water Levels:

LOAD CASE UN2

Heel Conditions:

Groundwater Elevation at Heel: $GWL_{UN2} := 1214.46m$

Distance from Finish Grade to Groundwater at Heel: $h_{1UN2} := \left[T_w - GWL_{UN2} + \left(L_{cd} + t_{wb} - t_{wt}\right)\cdot \tan(\beta)\right] = 4.54\ m$

Distance from Water Surface to Bottom of Footing at Heel: $h_{2UN2} := GWL_{UN2} - Bot_{ftg} + Key_{h.d} = 10.96\ m$

Toe Conditions:

Water Surface Elevation at Toe: $WSEL_{UN2} := 1207.5m$

Water Surface Elevation at Toe for Uplift: $UWSEL_{UN2} := 1214.46\cdot m$

Finish Grade at Toe providing lateral resistance: $FG_{toeUN2} := 1205.5\cdot m$

Soil Depth Above top of footing: $h_{3aUN2} := FG_{toeUN2} - Top_{ftg} = -2\ m$

$$h_{3UN2} := \begin{vmatrix} h_{3aUN2} \ \text{ if } \ FG_{toeUN2} - Top_{ftg} \geq 0 \\ 0 \ \text{ otherwise} \end{vmatrix} = 0$$

Resisting Fill at Toe: $h_{4UN2} := FG_{toeUN2} - Bot_{ftg} + Key_{t.d} = 0.00\ m$

Distance from Water Level to Top of Footing at Toe: $h_{5UN2} := WSEL_{UN2} - Top_{ftg} = 0.00\ m$

Distance from Water Surface to Bottom of Footing at Toe: $h_{6UN2} := WSEL_{UN2} - Bot_{ftg} + Key_{t.d} = 2.00\ m$

Soil Depth Above WSEL: $h_{7aUN2} := FG_{toeUN2} - WSEL_{UN2} = -2\ m$

$$h_{7UN2} := \begin{vmatrix} h_{7aUN2} \ \text{ if } \ FG_{toeUN2} - WSEL_{UN2} \geq 0 \\ 0 \ \text{ otherwise} \end{vmatrix} = 0$$

Soil Depth Below WSEL:

$$h_{8UN2} := \begin{vmatrix} WSEL_{UN2} - Bot_{ftg} + Key_{t.d} \ \text{ if } \ FG_{toeUN2} - WSEL_{UN2} \geq 0 \\ h_{4UN2} \ \text{ otherwise} \end{vmatrix} = 0$$

For Line of Creep Method: $L_{ho.UN2} := \sqrt{b^2 + \left(Key_{h.d} - Key_{t.d}\right)^2} = 12.166\ m$

Head Loss from Point g:

$\Delta h_{g.hj.UN2} := h_{2UN2} = 10.96\ m$ (to point h & j)

$\Delta h_{g.km.UN2} := GWL_{UN2} - Bot_{ftg} = 8.96\ m$ (to point k & m)

$\Delta h_{g.no.UN2} := GWL_{UN2} - Bot_{ftg} + Key_{t.d} = 8.96\ m$ (to point n & o)

$\Delta h_{g.p.UN2} := GWL_{UN2} - FG_{toeUN2} = 8.96\ m$ (to point p*)

$\Delta h_{g.r.UN2} := GWL_{UN2} - UWSEL_{UN2} = 0\ m$ (to point r)

Surcharge

Surcharge on Heel: $S1_{UN2} := 0.0\ \frac{kN}{m^2}$

* same as point "o" in this case

Calculate Soil Lateral Pressure Coefficients:

LOAD CASE UN2

For all load cases except seismic, soil loading to be based on At-Rest Condition.
Calculate at-rest pressure coefficient Ko based on Jaky's (1944) equation.

Soil At Rest Static Coefficient: $K_o := \frac{1 - \sin(\phi)}{1 + \sin(\beta)} = 0.546$ (Eq. 3-6, USACE EM 1110-2-2502)

Lateral - Driving Force

Static At-Rest:

Surcharge Load: $E_{s1UN2} := S1_{UN2} \cdot K_o \cdot \left(H_w + Key_{h.d}\right) \cdot B \cdot -1 = 0 \cdot kN$

Moment Arm (from bottom of footing): $E_{s1locUN2} := \frac{H_w + Key_{h.d}}{2} + Key_{vdist} = 5.75\ m$

Moist Soil Load above GWL: $E_{h1UN2} := \frac{\gamma_m \cdot K_o \cdot h_{1UN2}^{\ 2}}{2} \cdot B \cdot -1 = -112.5 \cdot kN$

Moment Arm (from bottom of footing): $E_{h1locUN2} := \frac{h_{1UN2}}{3} + h_{2UN2} + Key_{vdist} = 10.47\ m$

Saturated Soil Load below GWL:
(rectangular component) $E_{h2UN2} := \left(\gamma_m \cdot K_o \cdot h_{1UN2}\right) \cdot h_{2UN2} \cdot B \cdot -1 = -543.4 \cdot kN$

Moment Arm (from bottom of footing): $E_{h2locUN2} := \frac{h_{2UN2}}{2} + Key_{vdist} = 3.48\ m$

Saturated Soil Load below GWL:
(triangular component) $E_{h2aUN2} := \frac{\left(\gamma_{sat} - \gamma_w\right) \cdot K_o \cdot h_{2UN2}^{\ 2}}{2} \cdot B \cdot -1 = -400.1 \cdot kN$

Moment Arm (from bottom of footing): $E_{h2alocUN2} := \frac{h_{2UN2}}{3} + Key_{vdist} = 1.65\ m$

<u>Lateral Water Load:</u>

Water Load GWL to Bottom of Key $H_{h2UN2} := \frac{\gamma_w \cdot h_{2UN2}^{\ 2}}{2} \cdot B \cdot -1 = -588.6 \cdot kN$

Moment Arm (from bottom of footing): $H_{h2locUN2} := \frac{h_{2UN2}}{3} + Key_{vdist} = 1.65\ m$

$$\Sigma H_{SoildriveUN2} := E_{s1UN2} + E_{h1UN2} + E_{h2UN2} + E_{h2aUN2} + H_{h2UN2} = -1644.6 \cdot kN$$

$$\Sigma M_{LateralSoildriveUN2} := E_{s1UN2} \cdot E_{s1locUN2} + E_{h1UN2} \cdot E_{h1locUN2} + E_{h2UN2} \cdot E_{h2locUN2} + E_{h2aUN2} \cdot E_{h2alocUN2} \cdots + H_{h2UN2} \cdot H_{h2locUN2} = -4704.2\ m \cdot kN$$

Lateral - Resisting Force

LOAD CASE UN2

Lateral Water Load:

Water Load WSEL to Bottom of Footing:

$$H_{h6UN2} := \frac{\gamma_w \cdot h_{6UN2}^2}{2} \cdot B = 19.6 \cdot kN$$

Moment Arm (from bot. of toe key):

$$H_{h6locUN2} := \frac{h_{6UN2}}{3} = 0.67\ m$$

Water Load Bot. of Footing to Bot. of H. Key:

$$H_{h2aUN2} := \left[\left(UWSEL_{UN2} - Bot_{ftg} + Key_{t.d}\right) + h_{2UN2}\right] \cdot \frac{Key_{h.d}}{2} \cdot \gamma_w \cdot B = 195.2 \cdot kN$$

Moment Arm (from bot. of toe key):

$$H_{h2alocUN2} := \frac{Key_{h.d} \cdot \left[2 \cdot \left(UWSEL_{UN2} - Bot_{ftg} + Key_{t.d}\right) + h_{2UN2}\right]}{3\left[h_{2UN2} + \left(UWSEL_{UN2} - Bot_{ftg} + Key_{t.d}\right)\right]} \dots + Key_{vdist} = -1.03\ m$$

Lateral Soil Load:

Moist Soil Load above WSEL:

$$E_{h7UN2} := \frac{\gamma_m \cdot K_o \cdot h_{7UN2}^2}{2} \cdot B = 0.0 \cdot kN$$

Moment Arm (from bot. of toe key):

$$E_{h7locUN2} := h_{6UN2} + \frac{h_{7UN2}}{3} + Key_{vdist} = 0.00\ m$$

Saturated Soil Load below WSEL: (rectangular component)

$$E_{h8UN2} := \left(\gamma_m \cdot K_o \cdot h_{7UN2}\right) \cdot h_{8UN2} \cdot B = 0.0 \cdot kN$$

Moment Arm (from bot. of toe key):

$$E_{h8locUN2} := \frac{h_{8UN2}}{2} = 0.00\ m$$

Saturated Soil Load below WSEL: (triangular component)

$$E_{h8aUN2} := \frac{\left[\left(\gamma_{sat} - \gamma_w\right) \cdot K_o\right] \cdot h_{8UN2}^2}{2} \cdot B = 0.0 \cdot kN$$

Moment Arm (from bot. of footing):

$$E_{h8alocUN2} := \frac{h_{8UN2}}{3} = 0.00\ m$$

Lateral Resistance from Stilling Basin:

Lateral Resistance from Stilling Basin:

$$P_{sbUN2} := 415kN$$

(Force needed to achieve the required sliding factor of safety in case UN2)

Moment Arm (from bot. of toe key):

$$P_{sblocUN2} := \frac{t_{ftg}}{2} + Key_{t.d} = 1.00\ m$$

$$\Sigma H_{SoilresistUN2} := H_{h6UN2} + H_{h2aUN2} + E_{h7UN2} + E_{h8UN2} + E_{h8aUN2} + P_{sbUN2} = 629.8 \cdot kN$$

$$\Sigma M_{HorizSoilResistUN2} := H_{h6UN2} \cdot H_{h6locUN2} + H_{h2aUN2} \cdot H_{h2alocUN2} + E_{h7UN2} \cdot E_{h7locUN2} \dots + E_{h8UN2} \cdot E_{h8locUN2} + E_{h8aUN2} \cdot E_{h8alocUN2} + P_{sbUN2} \cdot P_{sblocUN2} = 226.3\ m \cdot kN$$

Vertical Force:

UPLIFT: Linear distribution from water at heel to water at toe:

$$\Sigma V_{UpliftUN2} := \left[\left(UWSEL_{UN2} - Bot_{ftg} + Key_{t.d}\right) + h_{2UN2}\right] \cdot \frac{b}{2} \cdot \gamma_w \cdot B \cdot -1 = -1171.296 \cdot kN$$

Moment Arm (from Point O):

$$V_{UpliftUN2aloc} := \frac{b \cdot \left[2 \cdot h_{2UN2} + \left(UWSEL_{UN2} - Bot_{ftg} + Key_{t.d}\right)\right]}{3\left[h_{2UN2} + \left(UWSEL_{UN2} - Bot_{ftg} + Key_{t.d}\right)\right]} = 6.201\ m$$

$$\Sigma M_{UpliftUN2} := \Sigma V_{UpliftUN2} \cdot V_{UpliftUN2aloc} = -7262.976 \cdot kN \cdot m$$

Weight of soil and water over toe:

Water Above the Top of Footing: $W_{H1UN2} := \gamma_w \cdot h_{5UN2} \cdot L_{ab} \cdot B = 0 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E1locUN2} := \frac{L_{ab}}{2} = 1.75\,m$

Soil above top of footing: $W_{E6UN2} := \gamma_b \cdot h_{3UN2} \cdot L_{ab} \cdot B = 0.0 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E6locUN2} := \frac{L_{ab}}{2} = 1.75\,m$

Vertical Load Due to Surcharge: $S_{UN2} := S1_{UN2} \cdot L_{cd} \cdot B = 0 \cdot kN$ $\quad S_{UN2loc} := b - \frac{L_{cd}}{2} = 8.45\,m$

Weight of soil and water over heel:

Moist Soil for sloped grade above top of wall:

Length of sloped portion of soil above top of wall: $L_{E3UN2} := \left(L_{cd} + t_{wb} - t_{wt}\right) = 8.00\,m$

Height of sloped soil above top of wall over heel: $h_{E3locUN2} := \left(L_{E3UN2}\right) \cdot \tan(\beta) = 0.00\,m$

Weight of sloped soil above top of wall: $W_{E3UN2} := \frac{\gamma_m}{2} \cdot h_{E3locUN2} \cdot L_{E3UN2} \cdot B = 0.0 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E3locUN2} := L_{ab} + t_{wt} + \frac{2}{3} \cdot L_{E3UN2} = 9.33\,m$

Moist soil from top of wall to groundwater level:

Height of soil from top of wall and top of GWL: $h_{1UN2} = 4.54\,m$

Length from edge of wall at GWL to edge of heel: $L_{E4UN2} := L_{E3UN2} - \left(h_{1UN2} \cdot S_{batter}\right) = 7.64\,m$

Weight of soil over heel from top of wall to GWL: $W_{E4UN2} := \gamma_m \cdot h_{1UN2} \cdot \frac{\left(L_{E3UN2} + L_{E4UN2}\right)}{2} \cdot B = 710.2 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E4locUN2} := b - \frac{L_{E3UN2}^2 + L_{E3UN2} \cdot L_{E4UN2} + L_{E4UN2}^2}{3\left(L_{E3UN2} + L_{E4UN2}\right)} = 8.09\,m$

Saturated soil from groundwater to top of footing:

Height of soil from GWL to top of heel: $h_{E4UN2} := h_{2UN2} - t_{ftg} - Key_{h.d} = 6.96\,m$

Weight of soil over heel from GWL to top of heel: $W_{E5UN2} := \left(\gamma_{sat}\right) \cdot h_{E4UN2} \cdot \frac{\left(L_{E4UN2} + L_{cd}\right)}{2} \cdot B = 1128.4 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E5locUN2} := b - \frac{L_{E4UN2}^2 + L_{E4UN2} \cdot L_{cd} + L_{cd}^2}{3\left(L_{E4UN2} + L_{cd}\right)} = 8.31\,m$

$$\Sigma V_{SoilWaterUN2} := W_{H1UN2} + W_{E6UN2} + W_{E3UN2} + W_{E4UN2} + W_{E5UN2} + S_{UN2} = 1838.6 \cdot kN$$

$$\Sigma M_{VertSoilWaterResistUN2} := W_{H1UN2} \cdot W_{E1locUN2} + W_{E6UN2} \cdot W_{E6locUN2} \cdots + W_{E3UN2} \cdot W_{E3locUN2} + W_{E4UN2} \cdot W_{E4locUN2} \cdots + W_{E5UN2} \cdot W_{E5locUN2} + S_{UN2} \cdot S_{UN2loc} = 15125.7\,m \cdot kN$$

THIS PAGE INTENTIONALLY LEFT BLANK
PLEASE GO TO THE NEXT PAGE

STABILITY ASSESSMENT:

LOAD CASE UN2

CHECK SLIDING ALONG HORIZONTAL SLIDING PLANE:

Summation of the vertical forces:

$$\Sigma V_{UN2} := \Sigma V_{conc} + \Sigma V_{SoilWaterUN2} + \Sigma V_{UpliftUN2} = 1535.6 \cdot kN$$

Summation of the horizontal forces:

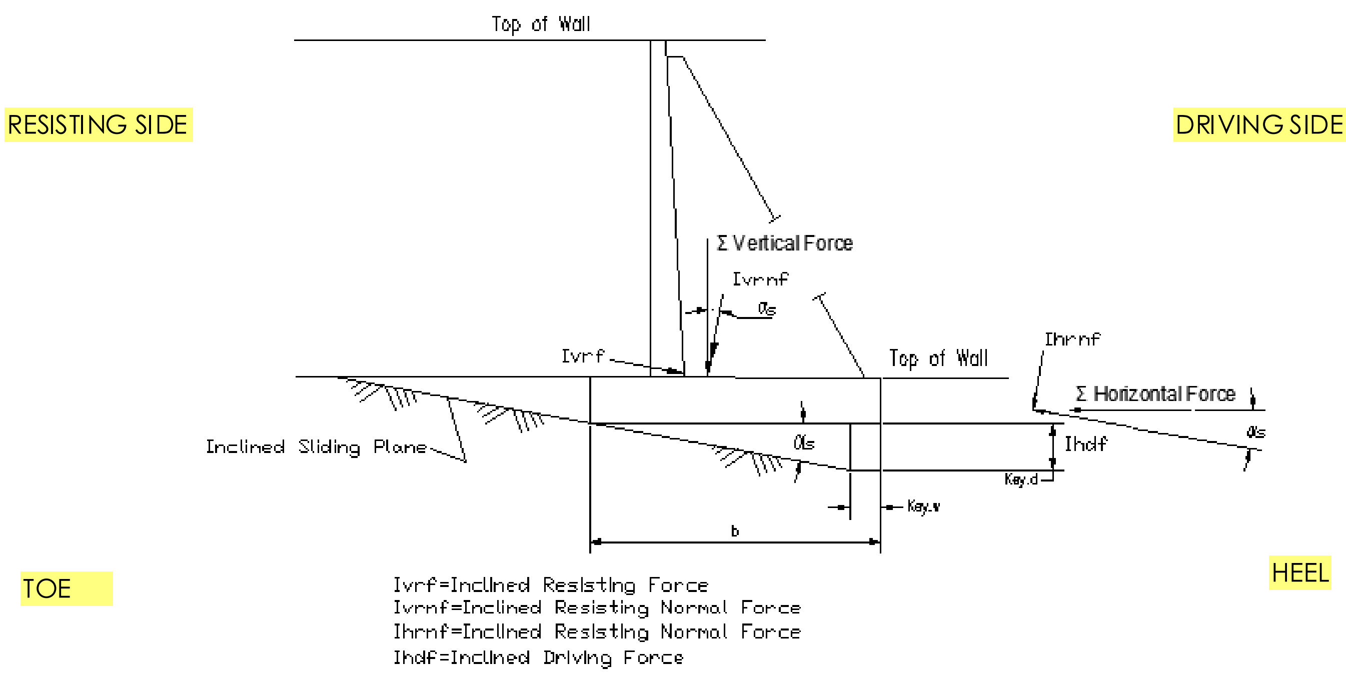
$$\Sigma H_{UN2} := \Sigma H_{SoildriveUN2} + \Sigma H_{SoilresistUN2} = -1014.8 \cdot kN$$

Safety Factor for Sliding Horizontal Failure Plane

$$FS_{Horiz.SlidingUN2} := \frac{\left|\Sigma V_{UN2}\right| \cdot \tan\left(\phi_{rock} \cdot \frac{\pi}{180}\right)}{\left|\Sigma H_{UN2}\right|} = 0.74$$

$$FS_{Sliding.check1.UN2} := \begin{vmatrix} \text{"OKAY" if } FS_{Horiz.SlidingUN2} > FS_{sliding.reqUN2} \\ \text{"NG - key req'"} \text{ otherwise} \end{vmatrix} = \text{"NG - key req'"}$$

CHECK FACTOR OF SAFETY SLIDING WITH KEY (INCLINED SLIDING PLANE):



$\alpha s = 0.18$ as degrees= $\alpha s \cdot \left(\frac{180}{\pi}\right) = 10.30$

(With properly engineered reinforced concrete Key, horizontal sliding plane thru Toe is protected, critical sliding plane is relocated to the INCLINED SLIDING PLANE FROM HEEL KEY To TOE, Bedrock Mass above this examing plane is mobilized by reinforced concrete key and combined into Structural Wedge.)

Resolve ΣV_{UN2} & ΣH_{UN2}

$$\Sigma V_{InclinedUN2} := \cos(\alpha s) \cdot \left(\left|\Sigma V_{UN2} + V_{rocksection}\right|\right) + \sin(\alpha s) \cdot \left|\Sigma H_{UN2}\right| = 1969.4 \cdot kN$$

$$\Sigma H_{InclinedUN2} := \cos(\alpha s) \cdot \left|\Sigma H_{UN2}\right| - \sin(\alpha s) \cdot \left(\left|\Sigma V_{UN2} + V_{rocksection}\right|\right) = 673.3 \cdot kN$$

Safety Factor for Sliding Inclined Failure Plane

$$FS_{InclinedISlidingUN2} := \frac{\Sigma V_{InclinedUN2} \cdot \tan(\phi_r)}{\Sigma H_{InclinedUN2}} = 1.30$$

LOAD CASE UN2

$$FS_{Sliding.check2.UN2} := \begin{cases} \text{"OKAY "} & \text{if } FS_{InclinedISlidingUN2} > FS_{sliding.reqUN2} \\ \text{"NG - Revise Structure""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

CHECK FOUNDATION ECCENTRICITY:

Summation of the resisting moments about the toe:

$$\Sigma M_{resUN2} := \Sigma M_{conc} + \Sigma M_{VertSoilWaterResistUN2} + \Sigma M_{HorizSoilResistUN2} + \Sigma M_{rocksection} = 22374 \cdot kN \cdot m$$

Summation of the overturning moments about the toe:

$$\Sigma M_{oUN2} := \Sigma M_{LateralSoildriveUN2} + \Sigma M_{UpliftUN2} = -11967 \cdot kN \cdot m$$

Total moment: $\Sigma M_{UN2} := \Sigma M_{resUN2} + \Sigma M_{oUN2} = 10406.5\, m \cdot kN$

Normal force to base: $\Sigma V_{InclinedUN2} = 1969.4 \cdot kN$

Inclined Sliding Plane Length: $L_{incline} = 12.2 \cdot m$

Eccentricity (inclined plane): $$ex_{UN2} := \frac{L_{incline}}{2} - \frac{\Sigma M_{UN2}}{\Sigma V_{InclinedUN2}} = 0.81\, m$$

$Kern = 2.033\, m$

Eccentricity Check: $$e_{check.UN2} := \begin{cases} \text{"Okay"} & \text{if } ex_{UN2} \le Kern \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"Okay"}$$

CHECK FOUNDATION BEARING CAPACITY:

Base Section Modulus: $S_b = 24.79\, m^3$

Bearing Pressure Under Toe:

$$\sigma_{ToeUN2} := \begin{cases} \left(\frac{\Sigma V_{InclinedUN2}}{L_{incline} \cdot B} + \frac{\Sigma V_{InclinedUN2} \cdot ex_{UN2}}{S_b}\right) & \text{if } \frac{\Sigma V_{InclinedUN2} \cdot ex_{UN2}}{S_b} \le \frac{\Sigma V_{InclinedUN2}}{L_{incline} \cdot B} \\ \frac{2 \cdot \Sigma V_{InclinedUN2}}{B \cdot 3\left(\frac{b}{2} - ex_{UN2}\right)} & \text{otherwise} \end{cases} = 226.2 \cdot kPa$$

$$Bearing_{ChecktoeUN2} := \begin{cases} \text{"OKAY "} & \text{if } \sigma_{ToeUN2} < \sigma_{allowUN2} \\ \text{"NG""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

Bearing Pressure Under Heel:

$$\sigma_{HeelUN2} := \begin{cases} \left(\frac{\Sigma V_{InclinedUN2}}{L_{incline} \cdot B} - \frac{\Sigma V_{InclinedUN2} \cdot ex_{UN2}}{S_b}\right) & \text{if } \frac{\Sigma V_{InclinedUN2} \cdot ex_{UN2}}{S_b} \le \frac{\Sigma V_{InclinedUN2}}{L_{incline} \cdot B} \\ 0 & \text{otherwise} \end{cases} = 96.8 \cdot kPa$$

$$Bearing_{CheckheelUN2} := \left(\begin{cases} \text{"OKAY "} & \text{if } \sigma_{HeelUN2} < \sigma_{allowUN2} \wedge \sigma_{HeelUN2} > 0 \\ \text{"NG - perform cracked base analysis""} & \text{otherwise} \end{cases} \right) = \text{"OKAY "}$$

CHECK FLOATATION:

Safety Factor for Floatation:

$$FS_{FloatationUN2} := \frac{\Sigma V_{conc} + \Sigma V_{SoilWaterUN2}}{\left|\Sigma V_{UpliftUN2}\right|} = 2.31$$

$$FS_{Floatation.UN2.check} := \left| \begin{array}{ll} \text{"OKAY "} & \text{if } FS_{FloatationUN2} > FS_{req.UN2.flt} \\ \text{"Revise Structure""} & \text{otherwise} \end{array} \right. = \text{"OKAY "}$$

CHECK OVERTURNING

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.
Assumptions are made in order to compute overturning stablity of indetermine forces on monolith with key;
(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.
(b) The horizontal resisting force acting on the key, P.key, is that required for static equilibrium
(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1

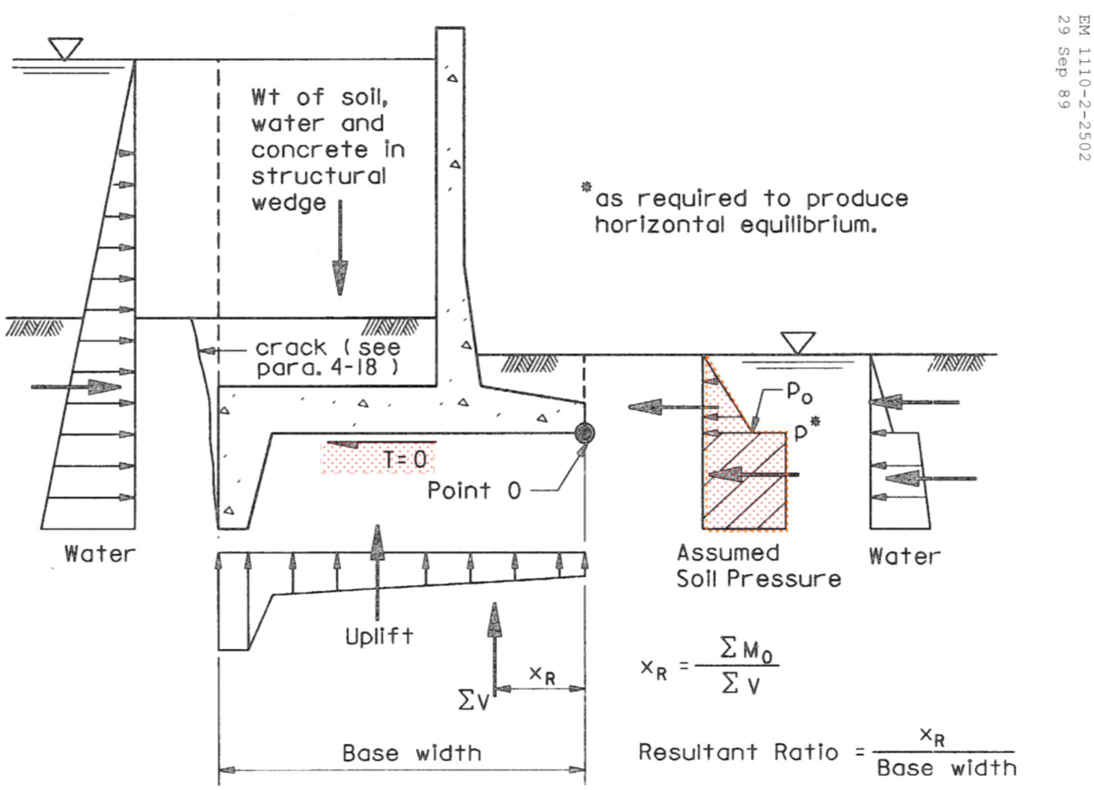


Figure 4-5. Forces for overturning analysis for wall with horizontal base and key

Modify Uplift for Overturning Analysis: **LOAD CASE UN2**

(Uplift is calculated along the concrete/rock contact using the Line of Creep method)

Water Pressure at h: $u_{h.UN2} := \Delta h_{g.hj.UN2} \cdot \gamma_w = 107.41 \cdot kPa$

Water Pressure at o: $u_{o.UN2} := \left(\Delta h_{g.no.UN2} - \frac{\Delta h_{g.r.UN2} \cdot L_{ho.UN2}}{L_{ho.UN2}} \right) \cdot \gamma_w = 87.81 \cdot kPa$

Head loss between point h and o: $\Delta h_{ho.UN2} := \Delta h_{g.r.UN2} \cdot \frac{L_{ho.UN2}}{L_{ho.UN2}} = 0\,m$

Length of concrete base (h -> o): $L_{baseho.UN2} := Key_{h.w} + Key_{h.d} + Key_{hdist} + Key_{t.d} + Key_{t.w} = 14\,m$

Head loss along h -> j: $\Delta h_{hj.UN2} := \Delta h_{ho.UN2} \cdot \frac{Key_{h.w}}{L_{baseho.UN2}} = 0\,m$

Water Pressure at j: $u_{j.UN2} := \left(\Delta h_{g.hj.UN2} - \Delta h_{hj.UN2} \right) \cdot \gamma_w = 107.41 \cdot kPa$

Head loss along h -> k: $\Delta h_{hjk.UN2} := \Delta h_{ho.UN2} \cdot \left(\frac{Key_{h.w} + Key_{h.d}}{L_{baseho.UN2}} \right) = 0\,m$

Water Pressure at k: $u_{k.UN2} := \left(\Delta h_{g.km.UN2} - \Delta h_{hjk.UN2} \right) \cdot \gamma_w = 87.81 \cdot kPa$

Head loss along h -> m: $\Delta h_{hjkm.UN2} := \Delta h_{ho.UN2} \cdot \left(\frac{Key_{h.w} + Key_{h.d} + Key_{hdist}}{L_{baseho.UN2}} \right) = 0\,m$

Water Pressure at m: $u_{m.UN2} := \left(\Delta h_{g.km.UN2} - \Delta h_{hjkm.UN2} \right) \cdot \gamma_w = 87.81 \cdot kPa$

Head loss along h -> n: $\Delta h_{hjkmn.UN2} := \Delta h_{ho.UN2} \cdot \left(\frac{Key_{h.w} + Key_{h.d} + Key_{hdist} + Key_{t.d}}{L_{baseho.UN2}} \right) = 0\,m$

Water Pressure at n: $u_{n.UN2} := \left(\Delta h_{g.no.UN2} - \Delta h_{hjkmn.UN2} \right) \cdot \gamma_w = 87.81 \cdot kPa$

Uplift under key at heel: $V_{ulkeyhUN2.OT} := \frac{\left(u_{h.UN2} + u_{j.UN2} \right) \cdot Key_{h.w}}{2} \cdot B \cdot -1 = -107.408 \cdot kN$

Moment Arm (from Point O): $V_{ulkeyhUN2loc.OT} := b - \frac{Key_{h.w} \cdot \left(2 \cdot u_{j.UN2} + u_{h.UN2} \right)}{3 \cdot \left(u_{j.UN2} + u_{h.UN2} \right)} = 11.5\,m$

Uplift under base: $V_{ulbaseUN2.OT} := \frac{\left(u_{k.UN2} + u_{m.UN2} \right) \cdot Key_{hdist}}{2} \cdot B \cdot -1 = -965.888 \cdot kN$

Moment Arm (from Point O): $V_{ulbaseUN2loc.OT} := b - Key_{h.w} - \frac{Key_{hdist} \cdot \left(2 \cdot u_{m.UN2} + u_{k.UN2} \right)}{3 \cdot \left(u_{m.UN2} + u_{k.UN2} \right)} = 5.5\,m$

Uplift under key at toe: $V_{ulkeytUN2.OT} := \frac{\left(u_{n.UN2} + u_{o.UN2} \right) \cdot Key_{t.w}}{2} \cdot B \cdot -1 = 0 \cdot kN$

Moment Arm (from Point O): $V_{ulkeytUN2loc.OT} := \frac{Key_{t.w} \cdot \left(2 \cdot u_{n.UN2} + u_{o.UN2} \right)}{3 \cdot \left(u_{n.UN2} + u_{o.UN2} \right)} = 0$

$$\Sigma V_{UpliftUN2.OT} := V_{ulkeyhUN2.OT} + V_{ulbaseUN2.OT} + V_{ulkeytUN2.OT} = -1073 \cdot kN$$

$$U_{UN2.loc.OT} := \frac{V_{ulkeyhUN2.OT} \cdot V_{ulkeyhUN2loc.OT} + V_{ulbaseUN2.OT} \cdot V_{ulbaseUN2loc.OT} + V_{ulkeytUN2.OT} \cdot V_{ulkeytUN2loc.OT}}{\Sigma V_{UpliftUN2.OT}} = 6.10\,m$$

$$\Sigma M_{UpliftUN2.OT} := \Sigma V_{UpliftUN2.OT} \cdot U_{UN2.loc.OT} = -6547.6 \cdot kN \cdot m$$

Modify Lateral Water Pressure (Resisting) for Overturning Analysis:

(Resisting water pressure is calculated using the Line of Creep method)

Water Load at Key (heel):

$$H_{h2UN2.OT} := \frac{u_{k.UN2} + u_{j.UN2}}{2} \cdot Key_{h.d} B = 195.2 \cdot kN$$

Moment Arm (from Point O):

$$H_{h2locUN2.OT} := \frac{Key_{h.d} \cdot \left(2 \cdot u_{k.UN2} + u_{j.UN2}\right)}{3\left(u_{k.UN2} + u_{j.UN2}\right)} + Key_{vdist} = -1.03\ m$$

Water Load at Key (toe):

$$H_{h6UN2.OT} := \frac{u_{o.UN2} \cdot \left(UWSEL_{UN2} - Bot_{ftg} + Key_{t.d}\right)}{2} \cdot B = 393 \cdot kN$$

Moment Arm (from Point O):

$$H_{h6locUN2.OT} := \frac{UWSEL_{UN2} - Bot_{ftg} + Key_{t.d}}{3} = 2.99\ m$$

$$\Sigma H_{waterresistUN2.OT} := H_{h2UN2.OT} + H_{h6UN2.OT} = 588.6 \cdot kN$$

$$H_{waterresistlocUN2.OT} := \frac{H_{h2UN2.OT} \cdot H_{h2locUN2.OT} + H_{h6UN2.OT} \cdot H_{h6locUN2.OT}}{\Sigma H_{waterresistUN2.OT}} = 1.653\ m$$

$$\Sigma M_{waterresistUN2.OT} := \Sigma H_{waterresistUN2.OT} \cdot H_{waterresistlocUN2.OT} = 973.15 \cdot kN \cdot m$$

Modify Lateral Soil Loads for Overturning Analysis:

(Lateral soil loads are calculated down to Point O instead of bottom of shear key)

<u>Driving Soil Load (Headwater Side):</u>

Surcharge Load:

$$E_{s1UN2.OT} := S1_{UN2} \cdot K_o \cdot \left(H_w + Key_{h.d} + Key_{vdist}\right) \cdot B \cdot -1 = 0 \cdot kN$$

Moment Arm (from Point O):

$$E_{s1locUN2.OT} := \frac{H_w + Key_{h.d} + Key_{vdist}}{2} = 6.75\ m$$

Moist Soil Load above GWL:

$$E_{h1UN2.OT} := \frac{\gamma_m \cdot K_o \cdot h_{1UN2}^{\ 2}}{2} B \cdot -1 = -112.5 \cdot kN$$

Moment Arm (from Point O):

$$E_{h1locUN2.OT} := \frac{h_{1UN2}}{3} + h_{2UN2} + Key_{vdist} = 10.47\ m$$

Saturated Soil Load below GWL:
(rectangular component)

$$E_{h2UN2.OT} := \left(\gamma_m \cdot K_o \cdot h_{1UN2}\right) \cdot \left(h_{2UN2} + Key_{vdist}\right) \cdot B \cdot -1 = -444.2 \cdot kN$$

Moment Arm (from Point O):

$$E_{h2locUN2.OT} := \frac{h_{2UN2} + Key_{vdist}}{2} = 4.48\ m$$

Saturated Soil Load below GWL:
(triangular component)

$$E_{h2aUN2.OT} := \frac{\left(\gamma_{sat} - \gamma_w\right) \cdot K_o \cdot \left(h_{2UN2} + Key_{vdist}\right)^2}{2} \cdot B \cdot -1 = -267.4 \cdot kN$$

Moment Arm (from Point O):

$$E_{h2alocUN2.OT} := \frac{h_{2UN2} + Key_{vdist}}{3} = 2.99\ m$$

Resisting Soil Load (Tailwater Side):

(Determine resisting soil load based on depth variation between the keys (ie. Key_{vdist}). In case where key at heel is deeper than key at toe (ie. $Key_{vdist} < 0$), resisting soil load (p*) is assumed to produce horizontal equilibrium as per Figure 4-5 above. Resisting soil load (p_o) is neglected.)

Total Driving Force: $\Sigma H_{SoildriveUN2.OT} := E_{s1UN2.OT} + E_{h1UN2.OT} + E_{h2UN2.OT} + E_{h2aUN2.OT} + H_{h2UN2} = -1412.7 \cdot kN$

Total Resisting Force: $\Sigma H_{waterresistUN2.OT} = 588.6 \cdot kN$

Assumed Soil Load p*: $E_{h8UN2a.OT} := (\Sigma H_{SoildriveUN2.OT} + \Sigma H_{waterresistUN2.OT}) \cdot -1 = 824.148 \cdot kN$

Moment Arm (from Point O): $E_{h8UN2a.loc.OT} := \frac{Key_{vdist}}{2} = -1\ m$

$$E_{h8UN2.OT} := \begin{cases} E_{h8UN2a.OT} & \text{if } Key_{vdist} < 0 \\ \Sigma H_{SoilresistUN2} - H_{h6UN2} - H_{h2aUN2} - P_{sbUN2} & \text{otherwise} \end{cases} = 824.148 \cdot kN$$

$$\Sigma M_{SoilresistUN2} := \begin{cases} E_{h8UN2a.OT} \cdot E_{h8UN2a.loc.OT} & \text{if } Key_{vdist} < 0 \\ \Sigma M_{HorizSoilResistUN2} - H_{h6UN2} \cdot H_{h6locUN2} - H_{h2aUN2} \cdot H_{h2alocUN2} - P_{sbUN2} \cdot P_{sblocUN2} & \text{otherwise} \end{cases} = -824.148 \cdot kN \cdot m$$

Sum of Moment about Point O:

$$\Sigma M_{LateraldriveUN2.OT} := E_{s1UN2.OT} \cdot E_{s1locUN2.OT} + E_{h1UN2.OT} \cdot E_{h1locUN2.OT} + E_{h2UN2.OT} \cdot E_{h2locUN2.OT} \cdots + E_{h2aUN2.OT} \cdot E_{h2alocUN2.OT} + H_{h2UN2} \cdot H_{h2locUN2} = -4940.5 \cdot kN \cdot m$$

$$\Sigma M_{LateralresistUN2.OT} := \Sigma M_{waterresistUN2.OT} + \Sigma M_{SoilresistUN2} = 149.0 \cdot kN \cdot m$$

Total moment:

$$\Sigma M_{UN2.OT} := \Sigma M_{conc} + \Sigma M_{VertSoilWaterResistUN2} + \Sigma M_{UpliftUN2.OT} \cdots + \Sigma M_{LateraldriveUN2.OT} + \Sigma M_{LateralresistUN2.OT} = 8743.2 \cdot kN \cdot m$$

Total Vertical Force: $\Sigma V_{UN2.OT} := \Sigma V_{conc} + \Sigma V_{SoilWaterUN2} + \Sigma V_{UpliftUN2.OT} = 1633.6 \cdot kN$

Distance X_R: EM 1110-2-2502 Eq.4-1 $X_{R.UN2} := \frac{\Sigma M_{UN2.OT}}{\Sigma V_{UN2.OT}} = 5.352\ m$

Overturning Resultant Ratio $Ratio_{UN2.OT} := \frac{X_{R.UN2}}{b} = 0.45$

$$Ratio_{UN2.OT.check} := \begin{cases} \text{"OKAY "} & \text{if } Ratio_{UN2.OT} > X_{R.reqUN2} \\ \text{"Revise Structure""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

CHECK FOUNDATION ECCENTRICITY (HORIZONTAL PLANE):

Eccentricity (horizontal plan): $ex_{UN2.OT} := \frac{b}{2} - \frac{\Sigma M_{UN2.OT}}{\Sigma V_{UN2.OT}} = 0.65\ m$ $Kern_{OT} = 2\ m$

Eccentricity Check:

$$e_{check.UN2.OT} := \begin{cases} \text{"Okay"} & \text{if } ex_{UN2} \le Kern_{OT} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"Okay"}$$

CHECK FOUNDATION BEARING CAPACITY (HORIZONTAL PLANE):

Base Section Modulus: $S_{b.OT} = 24\,m^3$

Bearing Pressure Under Toe:

$$\sigma_{ToeUN2.OT} := \begin{cases} \left(\dfrac{\Sigma V_{UN2.OT}}{b \cdot B} + \dfrac{\Sigma V_{UN2.OT} \cdot ex_{UN2.OT}}{S_{b.OT}}\right) & \text{if } \dfrac{\Sigma V_{UN2.OT}}{b \cdot B} \geq \dfrac{\Sigma V_{UN2.OT} \cdot ex_{UN2.OT}}{S_{b.OT}} \\ \dfrac{2 \cdot \Sigma V_{UN2.OT}}{B \cdot 3\left(\dfrac{b}{2} - ex_{UN2.OT}\right)} & \text{otherwise} \end{cases} = 180.2 \cdot kPa$$

$$Bearing_{ChecktoeUN2.OT} := \begin{cases} \text{"OKAY "} & \text{if } \sigma_{ToeUN2.OT} < \sigma_{allowUN2} \\ \text{"NG - for reference only""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

Bearing Pressure Under Heel:

$$\sigma_{HeelUN2.OT} := \begin{cases} \left(\dfrac{\Sigma V_{UN2.OT}}{b \cdot B} - \dfrac{\Sigma V_{UN2.OT} \cdot ex_{UN2.OT}}{S_{b.OT}}\right) & \text{if } \dfrac{\Sigma V_{UN2.OT}}{b \cdot B} \geq \dfrac{\Sigma V_{UN2.OT} \cdot ex_{UN2.OT}}{S_{b.OT}} \\ 0 & \text{otherwise} \end{cases} = 92.0 \cdot kPa$$

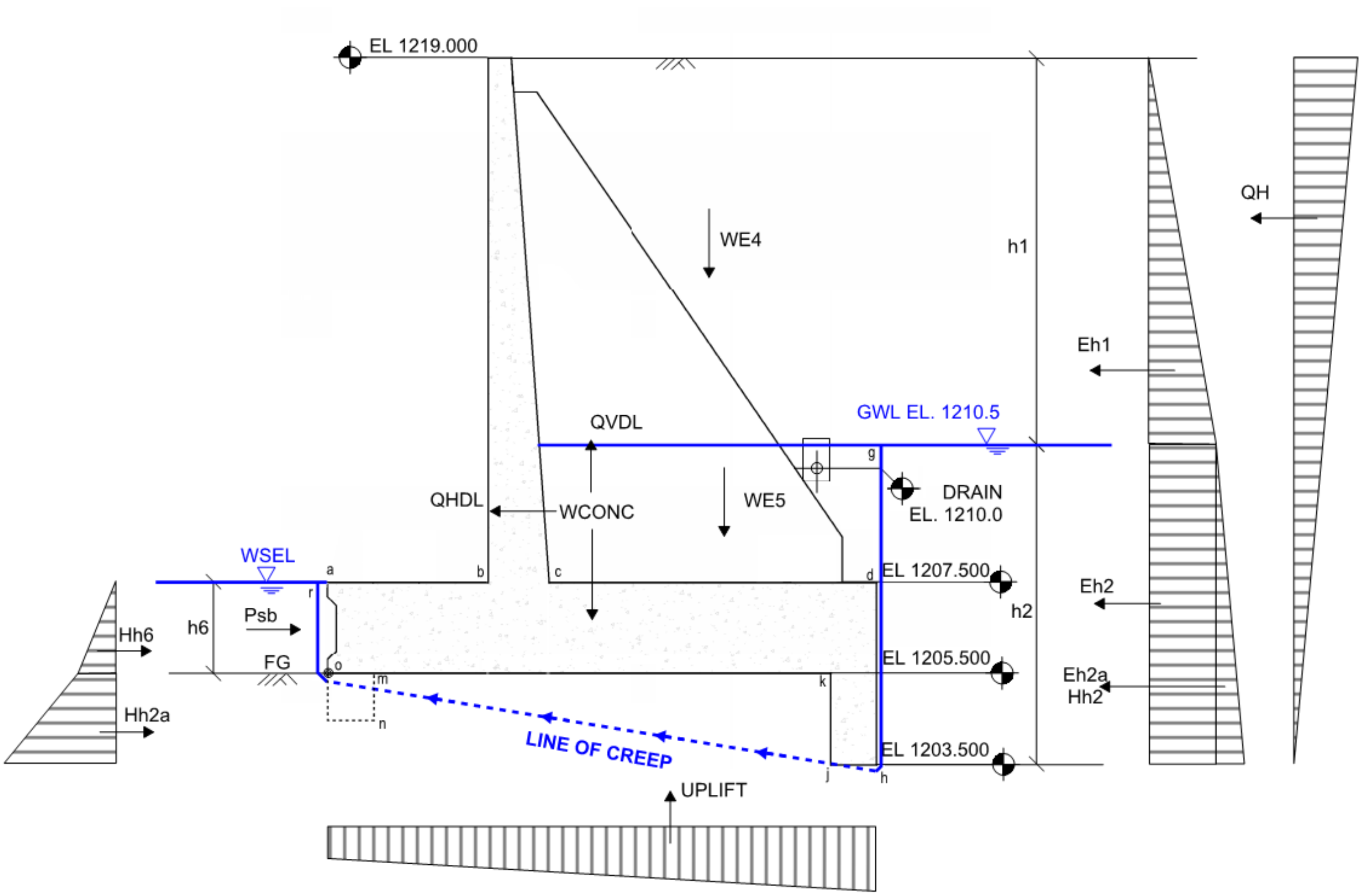
$$Bearing_{CheckheelUN2.OT} := \left(\begin{cases} \text{"OKAY "} & \text{if } \sigma_{ToeUN2.OT} < \sigma_{allowUN2} \wedge \sigma_{ToeUN2.OT} > 0 \\ \text{"NG - for reference only""} & \text{otherwise} \end{cases}\right) = \text{"OKAY "}$$

SUMMARY OF STABILITY ASSESSMENT:

LOAD CASE UN2

Sliding Factor of Safety: (Horizontal Plane - Ref only)	$FS_{Horiz.SlidingUN2} = 0.74$	$FS_{Sliding.check1.UN2}$ = "NG - key req""
Sliding Factor of Safety: (Inclined Plane)	$FS_{InclinedISlidingUN2} = 1.3$	$FS_{Sliding.check2.UN2}$ = "OKAY "
Eccentricity: (Inclined Plane)	$ex_{UN2} = 0.81\ m$	$e_{check.UN2}$ = "Okay"
Bearing Pressure At Heel: (Inclined Plane)	$\sigma_{HeelUN2} = 97 \cdot kPa$	$Bearing_{CheckheelUN2}$ = "OKAY "
Bearing Pressure At Toe: (Inclined Plane)	$\sigma_{ToeUN2} = 226 \cdot kPa$	$Bearing_{ChecktoeUN2}$ = "OKAY "
Flotation Factor of Safety (horizontal plane)	$FS_{FloatationUN2} = 2.31$	$FS_{Floatation.UN2.check}$ = "OKAY "
Overturning Resultant Ratio: (horizontal plane)	$Ratio_{UN2.OT} = 0.45$	$Ratio_{UN2.OT.check}$ = "OKAY "
Eccentricity: (horizontal plane - Ref only)	$ex_{UN2.OT} = 0.65\ m$	$e_{check.UN2.OT}$ = "Okay"
Bearing Pressure At Heel: (horizontal plane - Ref only)	$\sigma_{HeelUN2.OT} = 92 \cdot kPa$	$Bearing_{CheckheelUN2.OT}$ = "OKAY "
Bearing Pressure At Toe: (horizontal plane - Ref only)	$\sigma_{ToeUN2.OT} = 180 \cdot kPa$	$Bearing_{ChecktoeUN2.OT}$ = "OKAY "

LOAD CASE E1 - SEISMIC LOADING



E1 DESIGN CASE

LOAD CASE E1 ACCEPTANCE PARAMETERS

FS sliding:

Extreme (E) 1.0 (without cohesion, seismic loading) (Table 3-3, USACE EM 1110-2-2100)

Resultant Location:

Extremem (E) Inside middle half ~75% base in compression

Required Factor of Safety for Sliding:	$FS_{sliding.reqE1} := 1.0$	(Without Cohesion)
Allowable rock bearing pressure:	$\sigma_{allowE1} := 1740kPa$	(Section 5.2, Design Criteria EM 1110-2-2100 Section 3-10)
Overturning Required Resultant Ratio:	$X_{R.reqE1} := 0.25$	(EM 1110-2-2502, Figure 4-4)
Required Factor of Safety for Floatation	$FS_{req.E1.flt} := 1.1$	

SOIL HEIGHTS and Water Levels:

LOAD CASE E1

Heel Conditions:

Groundwater Elevation at Heel: $GWL_{E1} := 1210.5m$

Distance from Finish Grade to Groundwater at Heel: $h_{1E1} := \left[T_w - GWL_{E1} + \left(L_{cd} + t_{wb} - t_{wt}\right)\cdot \tan(\beta)\right] = 8.50\ m$

Distance from Water Surface to Bottom of Footing at Heel: $h_{2E1} := GWL_{E1} - Bot_{ftg} + Key_{h.d} = 7.00\ m$

Toe Conditions:

Water Surface Elevation at Toe: $WSEL_{E1} := 1207.5m$

Water Surface Elevation at Toe for Uplift: $UWSEL_{E1} := 1207.5\cdot m$

Finish Grade at Toe providing lateral resistance: $FG_{toeE1} := 1205.5\cdot m$

Soil Depth Above top of footing: $h_{3aE1} := FG_{toeE1} - Top_{ftg} = -2\ m$

$$h_{3E1} := \begin{cases} h_{3aE1} & \text{if } FG_{toeE1} - Top_{ftg} \ge 0 \\ 0 & \text{otherwise} \end{cases} = 0$$

Resisting Fill at Toe: $h_{4E1} := FG_{toeE1} - Bot_{ftg} + Key_{t.d} = 0.00\ m$

Distance from Water Level to Top of Footing at Toe: $h_{5E1} := WSEL_{E1} - Top_{ftg} = 0.00\ m$

Distance from Water Surface to Bottom of Footing at Toe: $h_{6E1} := WSEL_{E1} - Bot_{ftg} + Key_{t.d} = 2.00\ m$

Soil Depth Above WSEL: $h_{7aE1} := FG_{toeE1} - WSEL_{E1} = -2\ m$

$$h_{7E1} := \begin{cases} h_{7aE1} & \text{if } FG_{toeE1} - WSEL_{E1} \ge 0 \\ 0 & \text{otherwise} \end{cases} = 0$$

Soil Depth Below WSEL:

$$h_{8E1} := \begin{cases} WSEL_{E1} - Bot_{ftg} + Key_{t.d} & \text{if } FG_{toeE1} - WSEL_{E1} \ge 0 \\ h_{4E1} & \text{otherwise} \end{cases} = 0$$

For Line of Creep Method: $L_{ho.E1} := \sqrt{b^2 + \left(Key_{h.d} - Key_{t.d}\right)^2} = 12.166\ m$

Head Loss from Point g:

$\Delta h_{g.hj.E1} := h_{2E1} = 7\ m$ (to point h & j)

$\Delta h_{g.km.E1} := GWL_{E1} - Bot_{ftg} = 5\ m$ (to point k & m)

$\Delta h_{g.no.E1} := GWL_{E1} - Bot_{ftg} + Key_{t.d} = 5\ m$ (to point n & o)

$\Delta h_{g.p.E1} := GWL_{E1} - FG_{toeE1} = 5\ m$ (to point p*)

$\Delta h_{g.r.E1} := GWL_{E1} - UWSEL_{E1} = 3\ m$ (to point r)

Surcharge

Surcharge on Heel: $S1_{E1} := 0.0\ \frac{kN}{m^2}$

* same as point "o" in this case

Calculate Soil Lateral Pressure Coefficients:

Calculate at-rest pressure coefficient K_o based on Jaky's (1944) equation.

Soil At Rest Static Coefficient:
(apply to resisting soil loads)

$$K_o := \frac{1 - \sin(\phi)}{1 + \sin(\beta)} = 0.546$$

(Eq. 3-6, USACE EM 1110-2-2502)

Calculate active pressure coefficient K_A based on Coulumb equations.

Determine Slope of Active Wedge: (cohesionless backfill with water table)

$$c_1 := 2 \cdot \tan(\phi) = 1.019 \qquad c_2 := 1 - \tan(\phi) \cdot \tan(\beta) - \frac{\tan(\beta)}{\tan(\phi)} = 1$$

(Eq. G-14 / G-15, USACE EM 1110-2-2100)

$$\alpha := \mathrm{atan}\left(\frac{c_1 + \sqrt{c_1^{\,2} + 4 \cdot c_2}}{2}\right) = 1.021 \qquad \alpha_{deg} := \alpha \cdot \frac{180}{\pi} = 58.5$$

degrees (Eq. G-13, USACE EM 1110-2-2100)

Soil Active Coefficient above GWL:

$$K_{Aagwt} := \left(\frac{1 - \tan(\phi) \cdot \cot(\alpha)}{1 + \tan(\phi) \cdot \tan(\alpha)}\right) \cdot \left(\frac{\tan(\alpha)}{\tan(\alpha) - \tan(\beta)}\right) = 0.376$$

Soil Active Coefficient below GWL:

$$K_{Abgwt} := \frac{1 - \tan(\phi) \cdot \cot(\alpha)}{1 + \tan(\phi) \cdot \tan(\alpha)} \cdot \left[1 + \left(\frac{\tan(\alpha)}{\tan(\alpha) - \tan(\beta)} - 1\right) \cdot \left(\frac{\gamma_m}{\gamma_{sat} - \gamma_w}\right)\right] = 0.376$$

(Eq. G-29, USACE EM 1110-2-2100)

Lateral - Driving Force

Static Copmonent : Active Pressure:

Surcharge Load:

$$E_{s1E1} := S1_{E1} \cdot K_{Aagwt} \cdot \left(H_w + Key_{h.d}\right) \cdot B \cdot -1 = 0 \cdot kN$$

Moment Arm (from bottom of footing):

$$E_{s1locE1} := \frac{H_w + Key_{h.d}}{2} + Key_{vdist} = 5.75\ m$$

Moist Soil Load above GWL:

$$E_{h1E1} := \frac{\gamma_m \cdot K_{Aagwt} \cdot h_{1E1}^{\,2}}{2} \cdot B \cdot -1 = -271.3 \cdot kN$$

Moment Arm (from bottom of footing):

$$E_{h1locE1} := \frac{h_{1E1}}{3} + h_{2E1} + Key_{vdist} = 7.83\ m$$

Saturated Soil Load below GWL:
(rectangular component)

$$E_{h2E1} := \left(\gamma_m \cdot K_{Abgwt} \cdot h_{1E1}\right) \cdot h_{2E1} \cdot B \cdot -1 = -446.9 \cdot kN$$

Moment Arm (from bottom of footing):

$$E_{h2locE1} := \frac{h_{2E1}}{2} + Key_{vdist} = 1.50\ m$$

Saturated Soil Load below GWL:
(triangular component)

$$E_{h2aE1} := \frac{\left(\gamma_{sat} - \gamma_w\right) \cdot K_{Abgwt} \cdot h_{2E1}^{\,2}}{2} \cdot B \cdot -1 = -112.2 \cdot kN$$

Moment Arm (from bottom of footing):

$$E_{h2alocE1} := \frac{h_{2E1}}{3} + Key_{vdist} = 0.33\ m$$

Lateral Water Load:

Water Load GWL to Bottom of Key

$$H_{h2E1} := \frac{\gamma_w \cdot h_{2E1}^{\,2}}{2} \cdot B \cdot -1 = -240.1 \cdot kN$$

Moment Arm (from bottom of footing):

$$H_{h2locE1} := \frac{h_{2E1}}{3} + Key_{vdist} = 0.33\ m$$

$$\Sigma H_{SoildriveE1} := E_{s1E1} + E_{h1E1} + E_{h2E1} + E_{h2aE1} + H_{h2E1} = -1070.5 \cdot kN$$

$$\Sigma M_{LateralSoildriveE1} := E_{s1E1} \cdot E_{s1locE1} + E_{h1E1} \cdot E_{h1locE1} + E_{h2E1} \cdot E_{h2locE1} + E_{h2aE1} \cdot E_{h2alocE1} \ldots + H_{h2E1} \cdot H_{h2locE1} = -2913.1\ m \cdot kN$$

Lateral - Resisting Force

LOAD CASE E1

Note: **Due to the relatively shallow depth of resisting soil/rock, a conservative apporach using at-rest coefficient in lieu of a passive wedge is used to calculate resisting forces.**

Lateral Water Load:

Water Load WSEL to Bottom of Footing: $H_{h6E1} := H_{h6U1} = 19.6 \cdot kN$

Moment Arm (from bot. of toe key): $H_{h6locE1} := H_{h6locU1} = 0.67\ m$

Water Load Bot. of Footing to Bot. of H. Key: $H_{h2aE1} := \left[\left(UWSEL_{E1} - Bot_{ftg} + Key_{t.d}\right) + h_{2E1}\right] \cdot \frac{Key_{h.d}}{2} \cdot \gamma_w \cdot B = 88.2 \cdot kN$

Moment Arm (from bot. of toe key): $H_{h2alocE1} := \frac{Key_{h.d} \cdot \left[2 \cdot \left(UWSEL_{E1} - Bot_{ftg} + Key_{t.d}\right) + h_{2E1}\right]}{3\left[h_{2E1} + \left(UWSEL_{E1} - Bot_{ftg} + Key_{t.d}\right)\right]} \ldots = -1.19\ m$
$+ Key_{vdist}$

Lateral Soil Load:

Moist Soil Load above WSEL: $E_{h7E1} := \frac{\gamma_m \cdot K_o \cdot h_{7E1}^2}{2} B = 0.0 \cdot kN$

Moment Arm (from bot. of toe key): $E_{h7locE1} := h_{6E1} + \frac{h_{7E1}}{3} + Key_{vdist} = 0.00\ m$

Saturated Soil Load below WSEL: (rectangular component) $E_{h8E1} := \left(\gamma_m \cdot K_o \cdot h_{7E1}\right) \cdot h_{8E1} \cdot B = 0.0 \cdot kN$

Moment Arm (from bot. of toe key): $E_{h8locE1} := \frac{h_{8E1}}{2} = 0.00\ m$

Saturated Soil Load below WSEL: (triangular component) $E_{h8aE1} := \frac{\left[\left(\gamma_{sat} - \gamma_w\right) \cdot K_o\right] \cdot h_{8E1}^2}{2} \cdot B = 0.0 \cdot kN$

Moment Arm (from bot. of footing): $E_{h8alocE1} := \frac{h_{8E1}}{3} = 0.00\ m$

Lateral Resistance from Stilling Basin:

Lateral Resistance from Stilling Basin: $P_{sbE1} := 415kN$ (Force needed to achieve the required sliding factor of safety in case UN2)

Moment Arm (from bot. of toe key): $P_{sblocE1} := \frac{t_{ftg}}{2} + Key_{t.d} = 1.00\ m$

$\Sigma H_{SoilresistE1} := H_{h6E1} + H_{h2aE1} + E_{h7E1} + E_{h8E1} + E_{h8aE1} + P_{sbE1} = 522.8 \cdot kN$

$\Sigma M_{HorizSoilResistE1} := H_{h6E1} \cdot H_{h6locE1} + H_{h2aE1} \cdot H_{h2alocE1} + E_{h7E1} \cdot E_{h7locE1} \ldots = 323.5\ m \cdot kN$
$+ E_{h8E1} \cdot E_{h8locE1} + E_{h8aE1} \cdot E_{h8alocE1} + P_{sbE1} \cdot P_{sblocE1}$

Vertical Force:

UPLIFT: Linear distribution from water at heel to water at toe:

$\Sigma V_{UpliftE1} := \left[\left(UWSEL_{E1} - Bot_{ftg} + Key_{t.d}\right) + h_{2E1}\right] \cdot \frac{b}{2} \cdot \gamma_w \cdot B \cdot -1 = -529.2 \cdot kN$

Moment Arm (from Point O): $V_{UpliftE1aloc} := \frac{b \cdot \left[2 \cdot h_{2E1} + \left(UWSEL_{E1} - Bot_{ftg} + Key_{t.d}\right)\right]}{3\left[h_{2E1} + \left(UWSEL_{E1} - Bot_{ftg} + Key_{t.d}\right)\right]} = 7.111\ m$

$\Sigma M_{UpliftE1} := \Sigma V_{UpliftE1} \cdot V_{UpliftE1aloc} = -3763.2 \cdot kN \cdot m$

Weight of soil and water over toe:

Water Above the Top of Footing: $W_{H1E1} := \gamma_w \cdot h_{5E1} \cdot L_{ab} \cdot B = 0 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E1locE1} := \frac{L_{ab}}{2} = 1.75\ m$

Soil above top of footing: $W_{E6E1} := \gamma_b \cdot h_{3E1} \cdot L_{ab} \cdot B = 0.0 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E6locE1} := \frac{L_{ab}}{2} = 1.75\ m$

Vertical Load Due to Surcharge: $S_{E1} := S1_{E1} \cdot L_{cd} \cdot B = 0 \cdot kN$ $\quad S_{E1loc} := b - \frac{L_{cd}}{2} = 8.45\ m$

Weight of soil and water over heel:

Moist Soil for sloped grade above top of wall:

Length of sloped portion of soil above top of wall: $L_{E3E1} := \left(L_{cd} + t_{wb} - t_{wt}\right) = 8.00\ m$

Height of sloped soil above top of wall over heel: $h_{E3locE1} := \left(L_{E3E1}\right) \cdot \tan(\beta) = 0.00\ m$

Weight of sloped soil above top of wall: $W_{E3E1} := \frac{\gamma_m}{2} \cdot h_{E3locE1} \cdot L_{E3E1} \cdot B = 0.0 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E3locE1} := L_{ab} + t_{wt} + \frac{2}{3} \cdot L_{E3E1} = 9.33\ m$

Moist soil from top of wall to groundwater level:

Height of soil from top of wall and top of GWL: $h_{1E1} = 8.50\ m$

Length from edge of wall at GWL to edge of heel: $L_{E4E1} := L_{E3E1} - \left(h_{1E1} \cdot S_{batter}\right) = 7.33\ m$

Weight of soil over heel from top of wall to GWL: $W_{E4E1} := \gamma_m \cdot h_{1E1} \cdot \frac{\left(L_{E3E1} + L_{E4E1}\right)}{2} \cdot B = 1303.2 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E4locE1} := b - \frac{L_{E3E1}^2 + L_{E3E1} \cdot L_{E4U1} + L_{E4E1}^2}{3\left(L_{E3E1} + L_{E4E1}\right)} = 8.16\ m$

Saturated soil from groundwater to top of footing:

Height of soil from GWL to top of heel: $h_{E4E1} := h_{2E1} - t_{ftg} - Key_{h.d} = 3.00\ m$

Weight of soil over heel from GWL to top of heel: $W_{E5E1} := \left(\gamma_{sat}\right) \cdot h_{E4E1} \cdot \frac{\left(L_{E4E1} + L_{cd}\right)}{2} \cdot B = 476.1 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E5locE1} := b - \frac{L_{E4E1}^2 + L_{E4E1} \cdot L_{cd} + L_{cd}^2}{3\left(L_{E4E1} + L_{cd}\right)} = 8.39\ m$

$\Sigma V_{SoilWaterE1} := W_{H1E1} + W_{E6E1} + W_{E3E1} + W_{E4E1} + W_{E5E1} + S_{E1} = 1779.3 \cdot kN$

$\Sigma M_{VertSoilWaterResistE1} := W_{H1E1} \cdot W_{E1locE1} + W_{E6E1} \cdot W_{E6locE1} \cdots + W_{E3E1} \cdot W_{E3locE1} + W_{E4E1} \cdot W_{E4locE1} + W_{E5E1} \cdot W_{E5locE1} + S_{E1} \cdot S_{E1loc} = 14636.1\ m \cdot kN$

SESIMIC ANALYSIS:

LOAD CASE E1

Seismic coefficient will be applied to dead loads to calculate seismic force and force is applied at center of gravity of the mass. Vertical and Horizontal loads are applied in the "destabilizing direction"

SEISMIC PARAMETERS:

Peak Ground Acceleration for Seismic Load $PGA_{Horiz} := 0.26$ $PGA_{Vert} := 0.56 \cdot PGA_{Horiz} = 0.146$ (Section 7.9, Design Criteria)

In accordance with USACE EM 1110-2-2100 Section 4-7.b, consider 2/3 PGA as seismic coefficient for stabilitiy.

Horizontal Seismic coefficient for stabilty: $K_{hE1} := \frac{2}{3} PGA_{Horiz} = 0.173$

Vertical Seismic coefficient for stabilty: $K_{vE1} := \frac{2}{3} PGA_{Vert} = 0.097$

SEISMIC ACCELERATION OF RIGID MASSES (Q_D):

Vertical Load Application:

$\Sigma V_{conc} = 868.3 \cdot kN$

$Q_{v.conc} := \Sigma V_{conc} \cdot K_{vE1} \cdot -1 = -84.3 \cdot kN$ (assume acting upwards for adverse sliding effect)

Moment arm for siesmic load application (From Toe): $H_{cent} = 5.709\,m$

$M_{Qv.conc} := Q_{v.conc} \cdot H_{cent} = -481.1 \cdot kN \cdot m$

Lateral Load Application:

$Q_{h.conc} := \Sigma V_{conc} \cdot K_{hE1} \cdot -1 = -150.5 \cdot kN$

Moment arm for siesmic load application (Above Base of Footing): $V_{Cent} = 2.622\,m$

$M_{Q.conc} := Q_{h.conc} \cdot V_{Cent} = -394.6 \cdot kN \cdot m$

SEISMIC ACCELERATION OF SOIL WEDGE + WATER (Q_{EH}):

Vertical Load Application:

$\Sigma V_{SoilWaterE1} = 1779.3 \cdot kN$

$Q_{v.SoilWaterE1} := \Sigma V_{SoilWaterE1} \cdot K_{vE1} \cdot -1 = -172.7 \cdot kN$ (assume acting upwards for adverse sliding effect)

Moment arm for siesmic load application (From Toe): $e_{QE1} := \frac{\Sigma M_{VertSoilWaterResistE1}}{\Sigma V_{SoilWaterE1}} = 8.226\,m$

$M_{Qv.SoilWaterE1} := Q_{v.SoilWaterE1} \cdot e_{QE1} = -1420.7 \cdot kN \cdot m$

Lateral Load Application:

Seismic soil load is calculated based on Mononobe-Okabe method to determine combined static and dynamic coefficient (K_{AE}). Coulomb's active component (K_A) is subtracted from K_{AE} to obtain the seismic coefficient (ΔK_{AE}) for dynamic component of soil force.

Glacial Till Internal Friction (radians): $\phi = 0.471$

Seismic Inertia Angle (radians): $\psi := atan\left(\frac{K_{hE1}}{1 - K_{vE1}}\right) = 0.190$

Inclination of batter (radians): $\theta := 0.00$ assuming zero is conservative

Slope of retained ground surface: $\beta = 0.00$

$$K_{AE} := \frac{\cos(\phi - \psi - \theta) \cdot \cos(\phi - \psi - \theta)}{\cos(\psi) \cdot \cos(\theta) \cdot \cos(\theta)\, \cos(\psi + \theta) \cdot \left(1 + \sqrt{\frac{\sin(\phi)\, \sin(\phi - \psi - \beta)}{\cos(\beta - \theta) \cdot \cos(\psi + \theta)}}\right)^2} = 0.519$$

$\Delta K_{AE} := K_{AE} - K_{Abgwt} = 0.143$

Dynamic component of active seismic wedge:

$$Q_{h.SoilWaterE1} := \Delta K_{AE} \cdot \left[\frac{\gamma_m \cdot \left(H_w + Key_{h.d}\right)^2}{2 \cdot (\tan(\alpha) - \tan(\beta))} + \frac{\left(\gamma_{sat} - \gamma_m\right) \cdot h_{2E1}^{\;2}}{2 \cdot \tan(\alpha)}\right] \cdot B \cdot -1 = -214.8 \cdot kN$$

(Eq. G-64, USACE EM 1110-2-2100)

Moment arm for siesmic load application (About Point O): $Q_{h.SoilWaterlocE1} := \frac{2}{3} \cdot \left(H_w + Key_{h.d}\right) + Key_{vdist} = 8.33\,m$

$M_{Q.h.SoilWaterE1} := Q_{h.SoilWaterE1} \cdot Q_{h.SoilWaterlocE1} = -1790.1 \cdot kN \cdot m$

STABILITY ASSESSMENT:

LOAD CASE E1

CHECK SLIDING ALONG HORIZONTAL SLIDING PLANE:

Summation of the vertical forces: $\Sigma V_{E1} := \Sigma V_{conc} + \Sigma V_{SoilWaterE1} + \Sigma V_{UpliftE1} + Q_{v.conc} + Q_{v.SoilWaterE1} = 1861.4 \cdot kN$

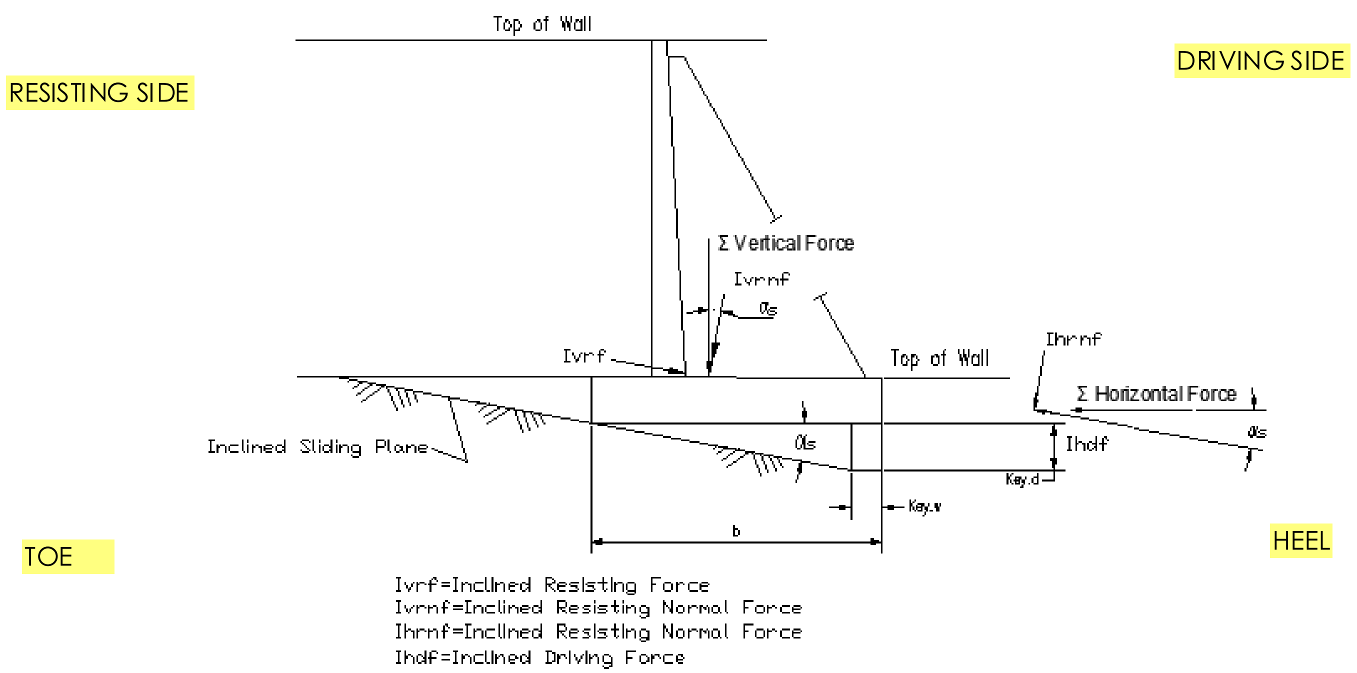
Summation of the horizontal forces: $\Sigma H_{E1} := \Sigma H_{SoildriveE1} + Q_{h.conc} + Q_{h.SoilWaterE1} + \Sigma H_{SoilresistE1} = -913.0 \cdot kN$

Safety Factor for Sliding Horizontal Failure Plane

$$FS_{Horiz.SlidingE1} := \frac{\left|\Sigma V_{E1}\right| \cdot \tan\left(\phi_{rock} \cdot \frac{\pi}{180}\right)}{\left|\Sigma H_{E1}\right|} = 0.99$$

$$FS_{Sliding.check1.E1} := \begin{vmatrix} \text{"OKAY "} & \text{if} & FS_{Horiz.SlidingE1} > FS_{sliding.reqE1} \\ \text{"NG - key req'"} & \text{otherwise} & \end{vmatrix} = \text{"NG - key req'"}$$

CHECK FACTOR OF SAFETY SLIDING WITH KEY (INCLINED SLIDING PLANE):



(With properly engineered reinforced concrete Key, horizontal sliding plane thru Toe is protected, critical sliding plane is relocated to the INCLINED SLIDING PLANE FROM HEEL KEY To TOE, Bedrock Mass above this examing plane is mobilized by reinforced concrete key and combined into Structural Wedge.)

Resolve ΣV_{E1} & ΣH_{E1}

$$\Sigma V_{InclinedE1} := \cos(\alpha s) \cdot \left(\left|\Sigma V_{E1} + V_{rocksection}\right|\right) + \sin(\alpha s) \cdot \left|\Sigma H_{E1}\right| = 2271.8 \cdot kN$$

$$\Sigma H_{InclinedE1} := \cos(\alpha s) \cdot \left|\Sigma H_{E1}\right| - \sin(\alpha s) \cdot \left(\left|\Sigma V_{E1} + V_{rocksection}\right|\right) = 515.0 \cdot kN$$

Safety Factor for Sliding Inclined Failure Plane

$$FS_{InclinedSlidingE1} := \frac{\Sigma V_{InclinedE1} \cdot \tan\left(\phi_r\right)}{\Sigma H_{InclinedE1}} = 1.96$$

$$FS_{Sliding.check2.E1} := \begin{vmatrix} \text{"OKAY "} & \text{if} & FS_{InclinedSlidingE1} > FS_{sliding.reqE1} \\ \text{"NG'"} & \text{otherwise} & \end{vmatrix} = \text{"OKAY "}$$

CHECK FOUNDATION ECCENTRICITY:

LOAD CASE E1

(Vertical seismic loads from concrete, soil and water are assumed acting downwards for adverse bearing effect)

Summation of the vertical forces: $\Sigma V_{seisE1} := \Sigma V_{conc} + \Sigma V_{SoilWaterE1} + \Sigma V_{UpliftE1} - Q_{v.conc} - Q_{v.SoilWaterE1} = 2375.4 \cdot kN$

Summation of the horizontal forces: $\Sigma H_{seisE1} := \Sigma H_{E1} = -913.0 \cdot kN$

Resolve ΣV_{seisE1} & ΣH_{seisE1}

$$\Sigma V_{InclinedseisE1} := \cos(\alpha s) \cdot \left(\left| \Sigma V_{seisE1} + V_{rocksection} \right| \right) + \sin(\alpha s) \cdot \left| \Sigma H_{seisE1} \right| = 2777.5 \cdot kN$$

$$\Sigma H_{InclinedseisE1} := \cos(\alpha s) \cdot \left| \Sigma H_{seisE1} \right| - \sin(\alpha s) \cdot \left(\left| \Sigma V_{seisE1} + V_{rocksection} \right| \right) = 423.0 \cdot kN$$

Summation of the resisting moments about the toe:

$$\Sigma M_{resE1} := \Sigma M_{conc} + \Sigma M_{VertSoilWaterResistE1} + \Sigma M_{HorizSoilResistE1} + \Sigma M_{rocksection} = 21981 \cdot kN \cdot m$$

Summation of seismic moments about the toe:

$$\Sigma M_{seisE1} := -M_{Qv.conc} + M_{Q.conc} - M_{Qv.SoilWaterE1} + M_{Q.h.SoilWaterE1} = -283 \cdot kN \cdot m$$

Summation of the overturning moments about the toe:

$$\Sigma M_{oE1} := \Sigma M_{LateralSoildriveE1} + \Sigma M_{UpliftE1} = -6676 \cdot kN \cdot m$$

Total moment: $\Sigma M_{E1} := \Sigma M_{resE1} + \Sigma M_{seisE1} + \Sigma M_{oE1} = 15022.2 \cdot kN \cdot m$

Normal force to base: $\Sigma V_{InclinedseisE1} = 2777.5 \cdot kN$

Inclined Sliding Plane Length: $L_{incline} = 12.2 \cdot m$

Eccentricity (inclined plane): $ex_{E1} := \frac{L_{incline}}{2} - \frac{\Sigma M_{E1}}{\Sigma V_{InclinedseisE1}} = 0.69\ m$ $\quad Kern_{E1} := \frac{L_{incline}}{4} = 3.049\ m$

Eccentricity Check: $e_{check.E1} := \begin{cases} \text{"Okay"} & \text{if } ex_{E1} \le Kern_{E1} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"Okay"}$

CHECK FOUNDATION BEARING CAPACITY:

Base Section Modulus: $S_b = 24.79\ m^3$

Bearing Pressure Under Toe:

$$\sigma_{ToeE1} := \begin{cases} \left(\frac{\Sigma V_{InclinedE1}}{L_{incline} \cdot B} + \frac{\Sigma V_{InclinedE1} \cdot ex_{E1}}{S_b} \right) & \text{if } \frac{\Sigma V_{InclinedE1} \cdot ex_{E1}}{S_b} \le \frac{\Sigma V_{InclinedE1}}{L_{incline} \cdot B} \\ \frac{2 \cdot \Sigma V_{InclinedE1}}{B \cdot 3 \left(\frac{b}{2} - ex_{E1} \right)} & \text{otherwise} \end{cases} = 249.5 \cdot kPa$$

$$Bearing_{ChecktoeE1} := \begin{cases} \text{"OKAY "} & \text{if } \sigma_{ToeE1} < \sigma_{allowE1} \\ \text{"NG""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

Bearing Pressure Under Heel:

$$\sigma_{HeelE1} := \begin{cases} \left(\frac{\Sigma V_{InclinedE1}}{L_{incline} \cdot B} - \frac{\Sigma V_{InclinedE1} \cdot ex_{E1}}{S_b} \right) & \text{if } \frac{\Sigma V_{InclinedE1} \cdot ex_{E1}}{S_b} \le \frac{\Sigma V_{InclinedE1}}{L_{incline} \cdot B} \\ 0 & \text{otherwise} \end{cases} = 123.1 \cdot kPa$$

$$Bearing_{CheckheelE1} := \left(\begin{cases} \text{"OKAY "} & \text{if } \sigma_{HeelE1} < \sigma_{allowE1} \wedge \sigma_{HeelE1} > 0 \\ \text{"NG - perform cracked base analysis""} & \text{otherwise} \end{cases} \right) = \text{"OKAY "}$$

CHECK FLOATATION:

Safety Factor for Floatation:

$$FS_{FloatationE1} := \frac{\Sigma V_{conc} + \Sigma V_{SoilWaterE1} + Q_{v.conc} + Q_{v.SoilWaterE1}}{\left|\Sigma V_{UpliftE1}\right|} = 4.52$$

$$FS_{Floatation.E1.check} := \begin{cases} \text{"OKAY"} & \text{if } FS_{FloatationE1} > FS_{req.E1.flt} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

CHECK OVERTURNING

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.
Assumptions are made in order to compute overturning stablity of indetermine forces on monolith with key;
(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.
(b) The horizontal resisting force acting on the key, P.key, is that required for static equilibrium
(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1

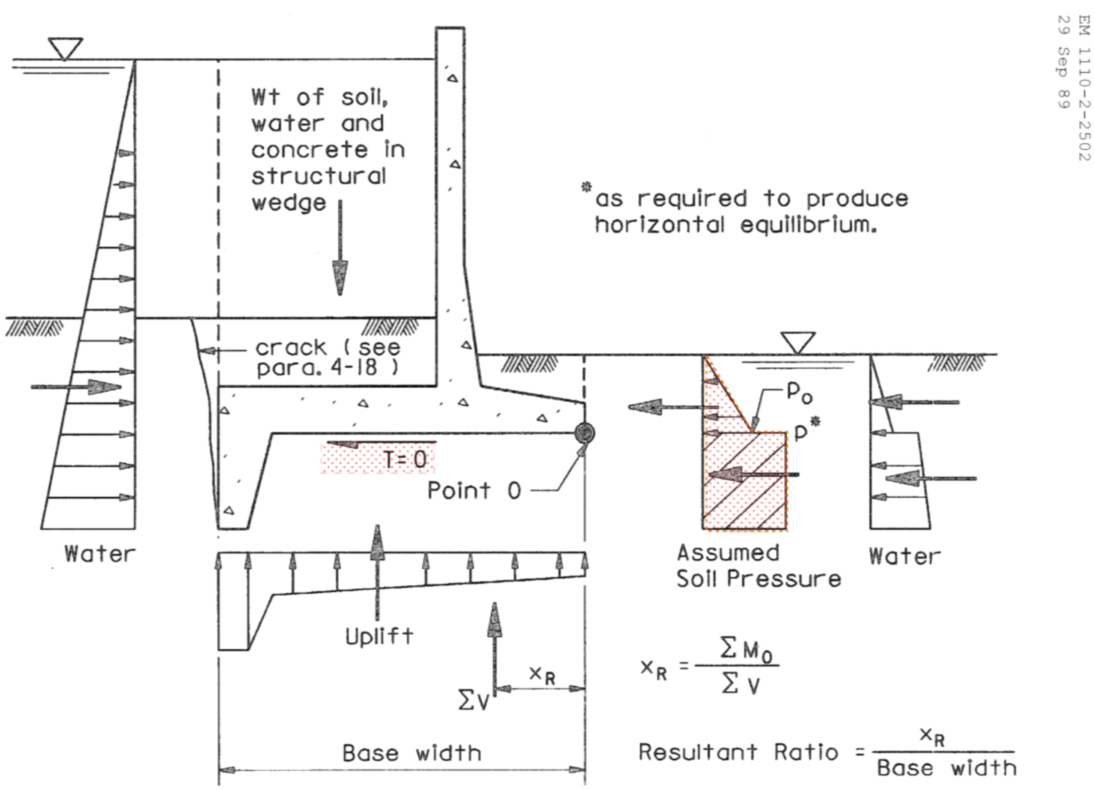


Figure 4-5. Forces for overturning analysis for wall with horizontal base and key

Modify Uplift for Overturning Analysis:

(Uplift is calculated along the concrete/rock contact using the Line of Creep method)

Water Pressure at h: $u_{h.E1} := \Delta h_{g.hj.E1} \cdot \gamma_w = 68.60 \cdot kPa$

Water Pressure at o: $u_{o.E1} := \left(\Delta h_{g.no.E1} - \frac{\Delta h_{g.r.E1} \cdot L_{ho.E1}}{L_{ho.E1}}\right) \cdot \gamma_w = 19.6 \cdot kPa$

Head loss between point h and o: $\Delta h_{ho.E1} := \Delta h_{g.r.E1} \cdot \frac{L_{ho.E1}}{L_{ho.E1}} = 3\,m$

Length of concrete base (h -> o): $L_{baseho.E1} := Key_{h.w} + Key_{h.d} + Key_{hdist} + Key_{t.d} + Key_{t.w} = 14\,m$

Head loss along h -> j: $\Delta h_{hj.E1} := \Delta h_{ho.E1} \cdot \frac{Key_{h.w}}{L_{baseho.E1}} = 0.214\,m$

Water Pressure at j: $u_{j.E1} := \left(\Delta h_{g.hj.E1} - \Delta h_{hj.E1}\right) \cdot \gamma_w = 66.50 \cdot kPa$

Head loss along h -> k: $\Delta h_{hjk.E1} := \Delta h_{ho.E1} \cdot \left(\frac{Key_{h.w} + Key_{h.d}}{L_{baseho.E1}}\right) = 0.643\,m$

Water Pressure at k: $u_{k.E1} := \left(\Delta h_{g.km.E1} - \Delta h_{hjk.E1}\right) \cdot \gamma_w = 42.70 \cdot kPa$

Head loss along h -> m: $\Delta h_{hjkm.E1} := \Delta h_{ho.E1} \cdot \left(\frac{Key_{h.w} + Key_{h.d} + Key_{hdist}}{L_{baseho.E1}}\right) = 3\,m$

Water Pressure at m: $u_{m.E1} := \left(\Delta h_{g.km.E1} - \Delta h_{hjkm.E1}\right) \cdot \gamma_w = 19.60 \cdot kPa$

Head loss along h -> n: $\Delta h_{hjkmn.E1} := \Delta h_{ho.E1} \cdot \left(\frac{Key_{h.w} + Key_{h.d} + Key_{hdist} + Key_{t.d}}{L_{baseho.E1}}\right) = 3\,m$

Water Pressure at n: $u_{n.E1} := \left(\Delta h_{g.no.E1} - \Delta h_{hjkmn.E1}\right) \cdot \gamma_w = 19.60 \cdot kPa$

Uplift under key at heel: $V_{ulkeyhE1.OT} := \frac{\left(u_{h.E1} + u_{j.E1}\right) \cdot Key_{h.w}}{2} \cdot B \cdot -1 = -67.55 \cdot kN$

Moment Arm (from Point O): $V_{ulkeyhE1loc.OT} := b - \frac{Key_{h.w} \cdot \left(2 \cdot u_{j.E1} + u_{h.E1}\right)}{3 \cdot \left(u_{j.E1} + u_{h.E1}\right)} = 11.503\,m$

Uplift under base: $V_{ulbaseE1.OT} := \frac{\left(u_{k.E1} + u_{m.E1}\right) \cdot Key_{hdist}}{2} \cdot B \cdot -1 = -342.65 \cdot kN$

Moment Arm (from Point O): $V_{ulbaseE1loc.OT} := b - Key_{h.w} - \frac{Key_{hdist} \cdot \left(2 \cdot u_{m.E1} + u_{k.E1}\right)}{3 \cdot \left(u_{m.E1} + u_{k.E1}\right)} = 6.18\,m$

Uplift under key at toe: $V_{ulkeytE1.OT} := \frac{\left(u_{n.E1} + u_{o.E1}\right) \cdot Key_{t.w}}{2} \cdot B \cdot -1 = 0 \cdot kN$

Moment Arm (from Point O): $V_{ulkeytE1loc.OT} := \frac{Key_{t.w} \cdot \left(2 \cdot u_{n.E1} + u_{o.E1}\right)}{3 \cdot \left(u_{n.E1} + u_{o.E1}\right)} = 0$

$$\Sigma V_{UpliftE1.OT} := V_{ulkeyhE1.OT} + V_{ulbaseE1.OT} + V_{ulkeytE1.OT} = -410 \cdot kN$$

$$U_{E1.loc.OT} := \frac{V_{ulkeyhE1.OT} \cdot V_{ulkeyhE1loc.OT} + V_{ulbaseE1.OT} \cdot V_{ulbaseE1loc.OT} + V_{ulkeytE1.OT} \cdot V_{ulkeytE1loc.OT}}{\Sigma V_{UpliftE1.OT}} = 7.06\,m$$

$$\Sigma M_{UpliftE1.OT} := \Sigma V_{UpliftE1.OT} \cdot U_{E1.loc.OT} = -2894.5 \cdot kN \cdot m$$

Modify Lateral Water Pressure (Resisting) for Overturning Analysis:

(Resisting water pressure is calculated using the Line of Creep method)

Water Load at Key (heel):
$$H_{h2E1.OT} := \frac{u_{k.E1} + u_{j.E1}}{2} \cdot Key_{h.d} \, B = 109.2 \cdot kN$$

Moment Arm (from Point O):
$$H_{h2locE1.OT} := \frac{Key_{h.d} \cdot \left(2 \cdot u_{k.E1} + u_{j.E1}\right)}{3\left(u_{k.E1} + u_{j.E1}\right)} + Key_{vdist} = -1.07\ m$$

Water Load at Key (toe):
$$H_{h6E1.OT} := \frac{u_{o.E1} \cdot \left(UWSEL_{E1} - Bot_{ftg} + Key_{t.d}\right)}{2} \cdot B = 20 \cdot kN$$

Moment Arm (from Point O):
$$H_{h6locE1.OT} := \frac{UWSEL_{E1} - Bot_{ftg} + Key_{t.d}}{3} = 0.67\ m$$

$$\Sigma H_{waterresistE1.OT} := H_{h2E1.OT} + H_{h6E1.OT} = 128.8 \cdot kN$$

$$H_{waterresistlocE1.OT} := \frac{H_{h2E1.OT} \cdot H_{h2locE1.OT} + H_{h6E1.OT} \cdot H_{h6locE1.OT}}{\Sigma H_{waterresistE1.OT}} = -0.808\ m$$

$$\Sigma M_{waterresistE1.OT} := \Sigma H_{waterresistE1.OT} \cdot H_{waterresistlocE1.OT} = -104.07 \cdot kN \cdot m$$

Modify Lateral Soil Loads for Overturning Analysis:

(Lateral soil loads are calculated down to Point O instead of bottom of shear key)

Driving Soil Load (Headwater Side):

Surcharge Load:
$$E_{s1E1.OT} := S1_{E1} \cdot K_{Aagwt} \cdot \left(H_w + Key_{h.d} + Key_{vdist}\right) \cdot B \cdot -1 = 0 \cdot kN$$

Moment Arm (from Point O):
$$E_{s1locE1.OT} := \frac{H_w + Key_{h.d} + Key_{vdist}}{2} = 6.75\ m$$

Moist Soil Load above GWL:
$$E_{h1E1.OT} := \frac{\gamma_m \cdot K_{Aagwt} \cdot h_{1E1}^{\ 2}}{2} B \cdot -1 = -271.3 \cdot kN$$

Moment Arm (from Point O):
$$E_{h1locE1.OT} := \frac{h_{1E1}}{3} + h_{2E1} + Key_{vdist} = 7.83\ m$$

Saturated Soil Load below GWL:
(rectangular component)
$$E_{h2E1.OT} := \left(\gamma_m \cdot K_{Aagwt} \cdot h_{1E1}\right) \cdot \left(h_{2E1} + Key_{vdist}\right) \cdot B \cdot -1 = -319.2 \cdot kN$$

Moment Arm (from Point O):
$$E_{h2locE1.OT} := \frac{h_{2E1} + Key_{vdist}}{2} = 2.50\ m$$

Saturated Soil Load below GWL:
(triangular component)
$$E_{h2aE1.OT} := \frac{\left(\gamma_{sat} - \gamma_w\right) \cdot K_{Aagwt} \cdot \left(h_{2E1} + Key_{vdist}\right)^2}{2} \cdot B \cdot -1 = -57.3 \cdot kN$$

Moment Arm (from Point O):
$$E_{h2alocE1.OT} := \frac{h_{2E1} + Key_{vdist}}{3} = 1.67\ m$$

Resisting Soil Load (Tailwater Side): **LOAD CASE E1**

(Determine resisting soil load based on depth variation between the keys (ie. Key_{vdist}). In case where key at heel is deeper than key at toe (ie. Key_{vdist}< 0), resisting soil load (p*) is assumed to produce horizontal equilibrium as per Figure 4-5 above. Resisting soil load (p_o) is neglected.)

Total Driving Force: $\Sigma H_{SoildriveE1.OT} := E_{s1E1.OT} + E_{h1E1.OT} + E_{h2E1.OT} + E_{h2aE1.OT} + H_{h2E1} \cdots + Q_{h.conc} + Q_{h.SoilWaterE1} = -1253.2 \cdot kN$

Total Resisting Force: $\Sigma H_{waterresistE1.OT} = 128.8 \cdot kN$

Assumed Soil Load p*: $E_{h8E1a.OT} := \left(\Sigma H_{SoildriveE1.OT} + \Sigma H_{waterresistE1.OT}\right) \cdot -1 = 1124.388 \cdot kN$

Moment Arm (from Point O): $E_{h8E1a.loc.OT} := \dfrac{Key_{vdist}}{2} = -1\ m$

$$E_{h8E1.OT} := \begin{cases} E_{h8E1a.OT} & \text{if } Key_{vdist} < 0 \\ \Sigma H_{SoilresistE1} - H_{h6E1} - H_{h2aE1} - P_{sbE1} & \text{otherwise} \end{cases} = 1124.388 \cdot kN$$

$$\Sigma M_{SoilresistE1} := \begin{cases} E_{h8E1a.OT} \cdot E_{h8E1a.loc.OT} & \text{if } Key_{vdist} < 0 \\ \Sigma M_{HorizSoilResistE1} - H_{h6E1} \cdot H_{h6locE1} - H_{h2aE1} \cdot H_{h2alocE1} - P_{sbE1} \cdot P_{sblocE1} & \text{otherwise} \end{cases} = -1124.388 \cdot kN \cdot m$$

Sum of Moment about Point O:

$$\Sigma M_{LateraldriveE1.OT} := E_{s1E1.OT} \cdot E_{s1locE1.OT} + E_{h1E1.OT} \cdot E_{h1locE1.OT} + E_{h2E1.OT} \cdot E_{h2locE1.OT} \cdots + E_{h2aE1.OT} \cdot E_{h2alocE1.OT} + H_{h2E1} \cdot H_{h2locE1} = -3098.8 \cdot kN \cdot m$$

$$\Sigma M_{LateralresistE1.OT} := \Sigma M_{waterresistE1.OT} + \Sigma M_{SoilresistE1} = -1228.5 \cdot kN \cdot m$$

$$\Sigma M_{seisE1.OT} := M_{Qv.conc} + M_{Q.conc} + M_{Qv.SoilWaterE1} + M_{Q.h.SoilWaterE1} = -4086 \cdot kN \cdot m$$

(seismic moment modified for the most adverse overturning effect)

Total moment:

$$\Sigma M_{E1.OT} := \Sigma M_{conc} + \Sigma M_{VertSoilWaterResistE1} + \Sigma M_{UpliftE1.OT} \cdots + \Sigma M_{LateraldriveE1.OT} + \Sigma M_{LateralresistE1.OT} + \Sigma M_{seisE1.OT} = 8284.5 \cdot kN \cdot m$$

Total Vertical Force:

$$\Sigma V_{E1.OT} := \Sigma V_{conc} + \Sigma V_{SoilWaterE1} + \Sigma V_{UpliftE1.OT} + Q_{v.conc} + Q_{v.SoilWaterE1} = 1980.4 \cdot kN$$

Distance X_R: EM 1110-2-2502 Eq.4-1 $X_{R.E1} := \dfrac{\Sigma M_{E1.OT}}{\Sigma V_{E1.OT}} = 4.183\ m$

Overturning Resultant Ratio $Ratio_{E1.OT} := \dfrac{X_{R.E1}}{b} = 0.35$

$$Ratio_{E1.OT.check} := \begin{cases} \text{"OKAY "} & \text{if } Ratio_{E1.OT} > X_{R.reqE1} \\ \text{"Revise Structure""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

CHECK FOUNDATION ECCENTRICITY (HORIZONTAL PLANE):

Eccentricity (horizontal plan): $ex_{E1.OT} := \dfrac{b}{2} - \dfrac{\Sigma M_{E1.OT}}{\Sigma V_{E1.OT}} = 1.82\ m$ $Kern_{E1.OT} := \dfrac{b}{4} = 3\ m$

Eccentricity Check:

$$e_{check.E1.OT} := \begin{cases} \text{"Okay"} & \text{if } ex_{E1.OT} \le Kern_{E1.OT} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"Okay"}$$

LOAD CASE E1

CHECK FOUNDATION BEARING CAPACITY (HORIZONTAL PLANE):

Base Section Modulus: $S_{b.OT} = 24\,m^3$

Bearing Pressure Under Toe:

$$\sigma_{ToeE1.OT} := \begin{cases} \left(\dfrac{\Sigma V_{E1.OT}}{b \cdot B} + \dfrac{\Sigma V_{E1.OT} \cdot ex_{E1.OT}}{S_{b.OT}}\right) & \text{if } \dfrac{\Sigma V_{E1.OT}}{b \cdot B} \ge \dfrac{\Sigma V_{E1.OT} \cdot ex_{E1.OT}}{S_{b.OT}} \\ \dfrac{2 \cdot \Sigma V_{E1.OT}}{B \cdot 3\left(\dfrac{b}{2} - ex_{E1.OT}\right)} & \text{otherwise} \end{cases} = 314.9 \cdot kPa$$

$$Bearing_{ChecktoeE1.OT} := \begin{cases} \text{"OKAY "} & \text{if } \sigma_{ToeE1.OT} < \sigma_{allowE1} \\ \text{"NG - for reference only""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

Bearing Pressure Under Heel:

$$\sigma_{HeelE1.OT} := \begin{cases} \left(\dfrac{\Sigma V_{E1.OT}}{b \cdot B} - \dfrac{\Sigma V_{E1.OT} \cdot ex_{E1.OT}}{S_{b.OT}}\right) & \text{if } \dfrac{\Sigma V_{E1.OT}}{b \cdot B} \ge \dfrac{\Sigma V_{E1.OT} \cdot ex_{E1.OT}}{S_{b.OT}} \\ 0 & \text{otherwise} \end{cases} = 15.1 \cdot kPa$$

$$Bearing_{CheckheelE1.OT} := \left(\begin{cases} \text{"OKAY "} & \text{if } \sigma_{HeelE1.OT} < \sigma_{allowE1} \wedge \sigma_{HeelE1.OT} > 0 \\ \text{"NG - for reference only""} & \text{otherwise} \end{cases}\right) = \text{"OKAY "}$$

SUMMARY OF STABILITY ASSESSMENT:

LOAD CASE E1

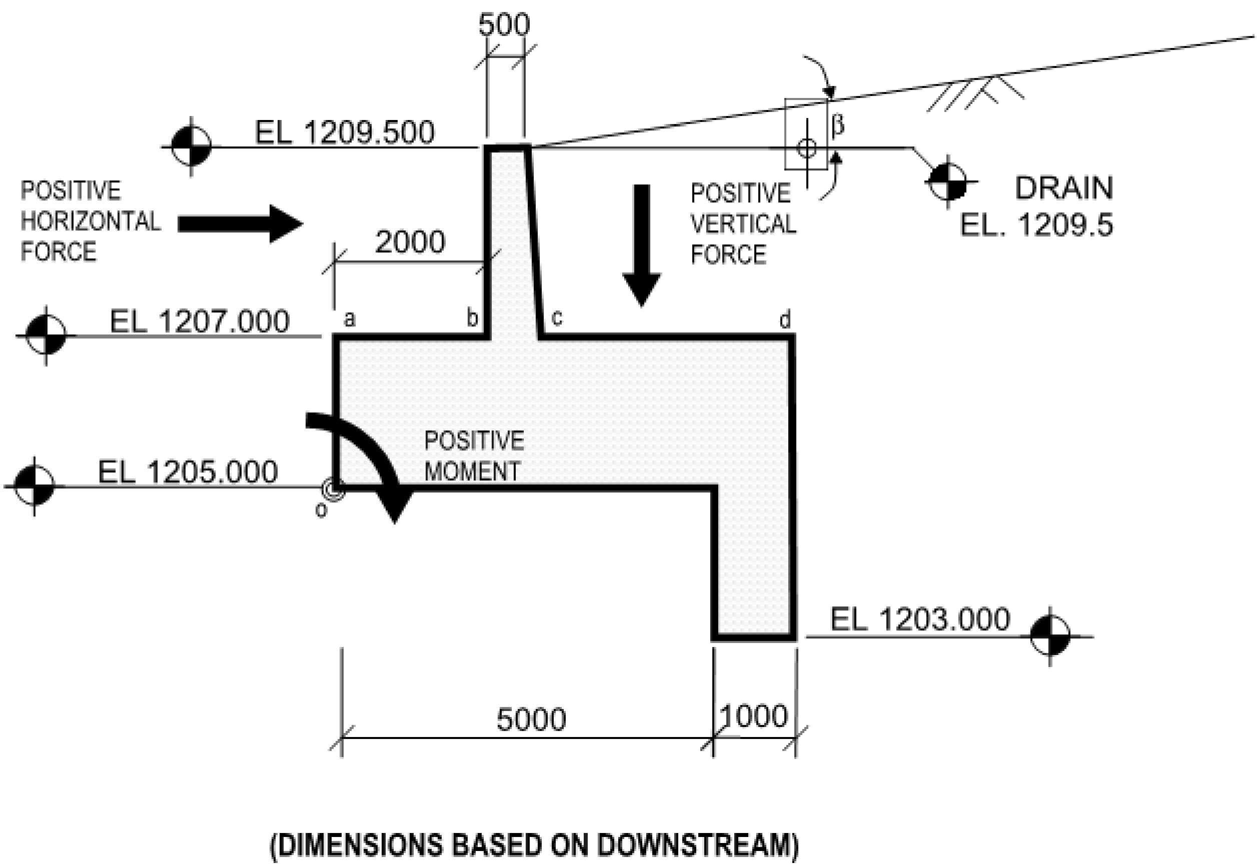
Sliding Factor of Safety: (Horizontal Plane - Ref only)	$FS_{Horiz.SlidingE1} = 0.99$	$FS_{Sliding.check1.E1}$ = "NG - key req""
Sliding Factor of Safety: (Inclined Plane)	$FS_{InclinedlSlidingE1} = 1.96$	$FS_{Sliding.check2.E1}$ = "OKAY "
Eccentricity: (Inclined Plane)	$ex_{E1} = 0.69\ m$	$e_{check.E1}$ = "Okay"
Bearing Pressure At Heel: (Inclined Plane)	$\sigma_{HeelE1} = 123 \cdot kPa$	$Bearing_{CheckheelE1}$ = "OKAY "
Bearing Pressure At Toe: (Inclined Plane)	$\sigma_{ToeE1} = 249 \cdot kPa$	$Bearing_{ChecktoeE1}$ = "OKAY "
Flotation Factor of Safety (horizontal plane)	$FS_{FloatationE1} = 4.52$	$FS_{Floatation.E1.check}$ = "OKAY "
Overturning Resultant Ratio: (horizontal plane)	$Ratio_{E1.OT} = 0.35$	$Ratio_{E1.OT.check}$ = "OKAY "
Eccentricity: (horizontal plane - Ref only)	$ex_{E1.OT} = 1.82\ m$	$e_{check.E1.OT}$ = "Okay"
Bearing Pressure At Heel: (horizontal plane - Ref only)	$\sigma_{HeelE1.OT} = 15 \cdot kPa$	$Bearing_{CheckheelE1.OT}$ = "OKAY "
Bearing Pressure At Toe: (horizontal plane - Ref only)	$\sigma_{ToeE1.OT} = 315 \cdot kPa$	$Bearing_{ChecktoeE1.OT}$ = "OKAY "

Calculation Section VI

DI-Block 5D (Downstream) Retaining Wall Stability Calculations

Project Number:	110773396		
Project Title:	SR1 - Diversion Structure		
Client:	Alberta Transportation		
Engineer:	Lawrence Choi	Date: 12/11/2018	
Checker:	Sean Xiao	Date: 12/18/2018	

Calculation for: Retaining Wall - Diversion Inlet Left - Block 5D (Downstream)



REGION COLOR CONVENTION

User Input

Calulation Highlights

Results

WALL GEOMETRY:

Top of Wall Elevation: $T_w := 1209.5 \cdot m$

Top of Footing Elevation: $Top_{ftg} := 1207.0 \cdot m$

Thickness of Footing: $t_{ftg} := 2.0m$

Bottom of Footing Elevation: $Bot_{ftg} := Top_{ftg} - t_{ftg} = 1205\,m$

Overall Height of wall: $h_w := T_w - Bot_{ftg} = 4.50\,m$

Thickness of Wall: Base: $t_{wb} := 0.696 \cdot m$ Top: $t_{wt} := 0.5m$

Length of toe: $L_{ab} := 2.0m$

Total Length of Footing: $b := 6.0m$

Length of heel: $L_{cd} := b - L_{ab} - t_{wb} = 3.304\,m$

Unit Width of Wall for analysis: $B := 1.00m$

SHEAR KEY GEOMETRY:

	Toe	Heel
Key depth:	$Key_{t.d} := 0m$	$Key_{h.d} := 2.0m$
Key width:	$Key_{t.w} := 0m$	$Key_{h.w} := 1m$
Face of Key from Point O:	$Key_{t.loc} := 0 \cdot m$	$Key_{h.loc} := b - Key_{h.w} = 5\,m$

Horizontal Distance between Keys: $Key_{hdist} := Key_{h.loc} - Key_{t.loc} - Key_{t.w} = 5\,m$

Key Depth Diff. (from point O): $Key_{vdist} := -Key_{h.d} + Key_{t.d} = -2\,m$

BASE PROPERTIES:

Base Area: $A_b := b \cdot B = 6\,m^2$

Centroidal Distance for Footing (from Toe): $Y_t := \frac{b}{2} = 3.00\,m$

RETAINED SOIL GEOMETRY:

Slope of retained ground surface: $\beta := 0 \cdot \frac{\pi}{180} = 0.00$

Height of retained earth at heel: $H_w := T_w - Bot_{ftg} + \left(t_{wb} + L_{cd} - t_{wt}\right) \cdot \tan(\beta) = 4.50\,m$

RETAINING WALL GEOMETRY CHECKS:

(Foundation Analysis & Design Bowles)

$$t_{bcheck} := \begin{cases} \text{"OKAY"} & \text{if } t_{ftg} \geq \frac{H_w}{12} \\ \text{"Warning"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

$$t_{wcheck} := \begin{cases} \text{"OKAY"} & \text{if } t_{wb} \geq \frac{H_w}{12} \\ \text{"Warning"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

$$b_{check} := \begin{cases} \text{"OKAY"} & \text{if } \frac{b}{H_w} \geq .4 \wedge \frac{b}{H_w} \leq 80 \\ \text{"Warning"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

$$L_{abcheck} := \begin{cases} \text{"OKAY"} & \text{if } \frac{L_{ab}}{b} \geq .25 \wedge \frac{L_{ab}}{b} \leq .4 \\ \text{"Warning"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

Material Properties:

Unit Weight of Water:	$\gamma_w := 9.8 \frac{kN}{m^3}$	(Section 7.2, Design Criteria)
Unit Weight of Concrete:	$\gamma_c := 23.5 \frac{kN}{m^3}$	
Unit Weight of Soil (Moist):	$\gamma_m := 20.0 \frac{kN}{m^3}$	(Section 5.3, Design Criteria) assumed moisture content (w) = 5%
Unit Weight Soil (Saturated):	$\gamma_{sat} := 22.0 \frac{kN}{m^3}$	(Assuming Specific Gravity = 2.7
Unit Weight Soil (buoyant):	$\gamma_b := \gamma_{sat} - \gamma_w = 12.2 \cdot \frac{kN}{m^3}$	
Weight of Soil/Concrete above toe:	$\gamma_{toe} := 22.0 \frac{kN}{m^3}$	
Unit Weight of Rock:	$\gamma_r := 25.6 \frac{kN}{m^3}$	(Section 7.2, Design Criteria)

Foundation Parameters:

Glacial Till Internal Friction:	$\phi := 27 \cdot \frac{\pi}{180} = 0.471$	
Bedrock Internal Friction Angle:	$\phi_r := 24 \cdot \frac{\pi}{180} = 0.419$	
Friction Angle at Base Concrete / Rock Interface:	$\phi_{rock} := 26$	
Base Friction Coefficient:	$tan_{\phi rock} := \tan\left(\phi_{rock} \frac{\pi}{180}\right) = 0.488$	radians
Rip Rap Backfill, Refer Dwg. C-214	$\phi_{backfill} := \left(20 \frac{\pi}{180}\right) = 0.349$	radians
Shear strength along rock Failure plane	$s_r := \frac{13100 \frac{kN}{m^2}}{2} = 6550 \cdot \frac{kN}{m^2}$	(Stantec Design Memo 8/8/16)

CONCRETE DEAD LOAD:

Area of Footing: $A_{ftg} := t_{ftg} \cdot b = 12\,m^2$

Weight of Footing: $D_{ftg} := A_{ftg} \cdot B \cdot \gamma_c = 282 \cdot kN$

Area of Stem (without batter): $A_{w1} := t_{wt} \cdot \left(h_w - t_{ftg}\right) = 1.25\,m^2$

Weight of Stem: $D_{w1} := A_{w1} \cdot B \cdot \gamma_c = 29.4 \cdot kN$

Area of stem Batter: $A_{w2} := \dfrac{\left(t_{wb} - t_{wt}\right)}{2} \left(h_w - t_{ftg}\right) = 0.25\,m^2$

Weight of Batter: $D_{w2} := A_{w2} \cdot B \cdot \gamma_c = 5.8 \cdot kN$

Slope of batter: $S_{batter} := \dfrac{t_{wb} - t_{wt}}{h_w - t_{ftg}} = 0.078$

Area of Key $A_{t.key} := Key_{t.d} \cdot Key_{t.w} = 0$ $A_{h.key} := Key_{h.d} \cdot Key_{h.w} = 2\,m^2$

Weight of Key $D_{t.key} := A_{t.key} \cdot B \cdot \gamma_c = 0 \cdot kN$ $D_{h.key} := A_{h.key} \cdot B \cdot \gamma_c = 47 \cdot kN$

Centroidal Horizontal Distance of Wall (From Toe):

$$H_{cent} := \frac{A_{w1} \cdot \left(L_{ab} + \frac{t_{wt}}{2}\right) + A_{w2} \cdot \left(L_{ab} + t_{wt} + \frac{t_{wb} - t_{wt}}{3}\right) + A_{ftg} \cdot \frac{b}{2} + A_{t.key} \cdot \left(Key_{t.loc} + \frac{Key_{t.w}}{2}\right) + A_{h.key} \cdot \left(Key_{h.loc} + \frac{Key_{h.w}}{2}\right)}{A_{w1} + A_{w2} + A_{ftg} + A_{t.key} + A_{h.key}} = 3.26\,m$$

Centroidal Vertical Distance of Wall (Above Base of Footing):

$$V_{Cent} := \frac{A_{ftg} \cdot \frac{t_{ftg}}{2} + A_{w1} \cdot \left[t_{ftg} + \frac{\left(h_w - t_{ftg}\right)}{2}\right] + A_{w2} \cdot \left[t_{ftg} + \frac{\left(h_w - t_{ftg}\right)}{3}\right] + A_{t.key} \cdot \left(\frac{-Key_{t.d}}{2}\right) + A_{h.key} \cdot \left(\frac{-Key_{h.d}}{2}\right)}{A_{ftg} + A_{w1} + A_{w2} + A_{t.key} + A_{h.key}} = 0.95\,m$$

$\Sigma V_{conc} := D_{ftg} + D_{w1} + D_{w2} + D_{t.key} + D_{h.key} = 364.1 \cdot kN$

$\Sigma M_{conc} := \Sigma V_{conc} \cdot H_{cent} = 1185.4\,m \cdot kN$

ROCK SECTION MOBILIZED FOR INCLINDED SLIDING FAILURE

Area of Rock Section Mobilized: $A_{rocksection} := \left(Key_{t.d} + Key_{h.d}\right) \cdot \dfrac{Key_{hdist}}{2} = 5\,m^2$

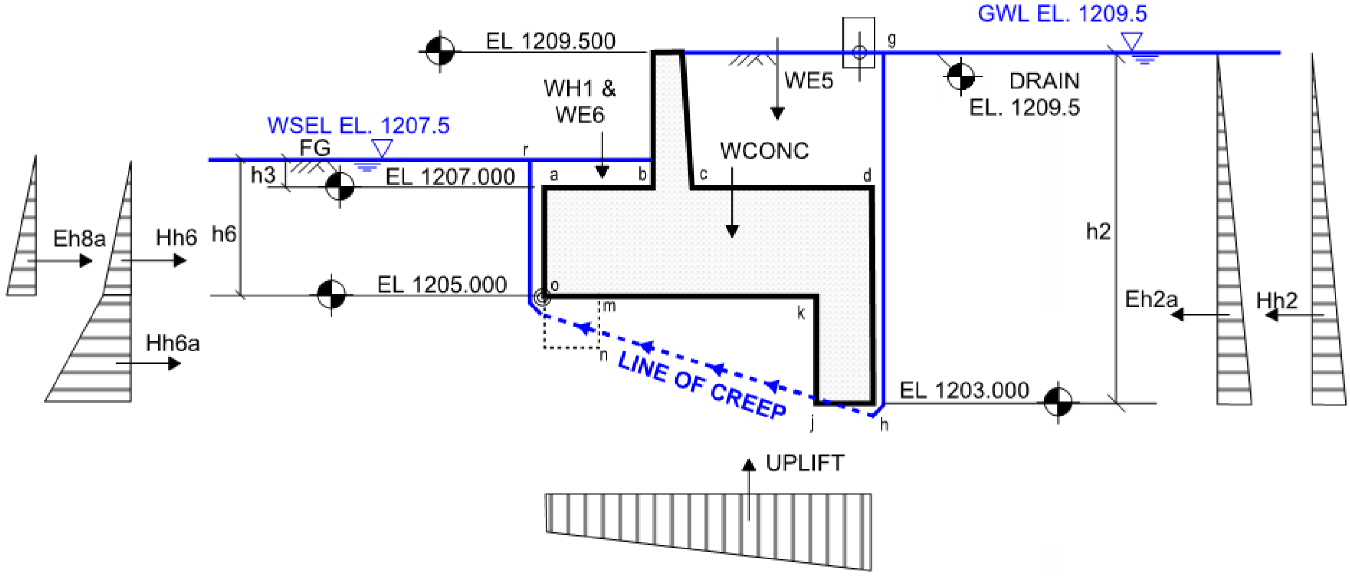
Rock Mass Mobilized: $V_{rocksection} := A_{rocksection} \cdot \gamma_r \cdot B = 128 \cdot kN$

(Pore pressure taken along assumed inclined sliding plane)

Distance from Toe to COG of Rock Section: $L_{rocksection} := \dfrac{Key_{hdist} \cdot \left(2 \cdot Key_{h.d} + Key_{t.d}\right)}{3\left(Key_{h.d} + Key_{t.d}\right)} + Key_{t.w} = 3.333\,m$

$\Sigma M_{rocksection} := V_{rocksection} \cdot L_{rocksection} = 426.7\,m \cdot kN$

LOAD CASE U1 - NORMAL OPERATION



U1 DESIGN CASE

LOAD CASE U1 ACCEPTANCE PARAMETERS

FS sliding:

Usual (U) 1.5 (without cohesion) (Table 3-3, USACE EM 1110-2-2100)

Resultant Location:

Usual (U) Inside middle third ~100% base in compression

Required Factor of Safety for Sliding: $FS_{sliding.reqU1} := 1.5$ (Without Cohesion)

Allowable rock bearing pressure: $\sigma_{allowU1} := 1270kPa$ (Section 5.2, Design Criteria EM 1110-2-2100 Section 3-10)

Overturning Required Resultant Ratio: $X_{R.reqU1} := 0.333$ (EM 1110-2-2502, Figure 4-4)

Required Factor of Safety for Floatation $FS_{req.U1.flt} := 1.5$

SOIL HEIGHTS and Water Levels:

LOAD CASE U1

Heel Conditions:

Groundwater Elevation at Heel: $GWL_{U1} := 1209.5m$

Distance from Finish Grade to Groundwater at Heel: $h_{1U1} := \left[T_w - GWL_{U1} + \left(L_{cd} + t_{wb} - t_{wt}\right)\cdot\tan(\beta)\right] = 0.00\ m$

Distance from Water Surface to Bottom of Footing at Heel: $h_{2U1} := GWL_{U1} - Bot_{ftg} + Key_{h.d} = 6.50\ m$

Toe Conditions:

Water Surface Elevation at Toe: $WSEL_{U1} := 1207.5m$

Water Surface Elevation at Toe for Uplift: $UWSEL_{U1} := 1207.5\cdot m$

Finish Grade at Toe providing lateral resistance: $FG_{toeU1} := 1207.5\cdot m$

Soil Depth Above top of footing: $h_{3aU1} := FG_{toeU1} - Top_{ftg} = 0.5\ m$

$$h_{3U1} := \begin{cases} h_{3aU1} & \text{if } FG_{toeU1} - Top_{ftg} \geq 0 \\ 0 & \text{otherwise} \end{cases} = 0.5$$

Resisting Fill at Toe: $h_{4U1} := FG_{toeU1} - Bot_{ftg} + Key_{t.d} = 2.50\ m$

Distance from Water Level to Top of Footing: $h_{5U1} := WSEL_{U1} - Top_{ftg} = 0.50\ m$

Distance from Water Surface to Bottom of Toe Key: $h_{6U1} := WSEL_{U1} - Bot_{ftg} + Key_{t.d} = 2.50\cdot m$

Soil Depth Above WSEL: $h_{7aU1} := FG_{toeU1} - WSEL_{U1} = 0\ m$

$$h_{7U1} := \begin{cases} h_{7aU1} & \text{if } FG_{toeU1} - WSEL_{U1} \geq 0 \\ 0 & \text{otherwise} \end{cases} = 0$$

Soil Depth Below WSEL:

$$h_{8U1} := \begin{cases} WSEL_{U1} - Bot_{ftg} + Key_{t.d} & \text{if } FG_{toeU1} - WSEL_{U1} \geq 0 \\ h_{4U1} & \text{otherwise} \end{cases} = 2.5$$

For Line of Creep Method: $L_{ho.U1} := \sqrt{b^2 + \left(Key_{h.d} - Key_{t.d}\right)^2} = 6.325\ m$

Head Loss from Point g:

$\Delta h_{g.hj.U1} := h_{2U1} = 6.5\ m$ (to point h & j)

$\Delta h_{g.km.U1} := GWL_{U1} - Bot_{ftg} = 4.5\ m$ (to point k & m)

$\Delta h_{g.no.U1} := GWL_{U1} - Bot_{ftg} + Key_{t.d} = 4.5\ m$ (to point n & o)

$\Delta h_{g.p.U1} := GWL_{U1} - FG_{toeU1} = 2\ m$ (to point p*)

$\Delta h_{g.r.U1} := GWL_{U1} - UWSEL_{U1} = 2\ m$ (to point r)

Surcharge

Surcharge on Heel: $S1_{U1} := 0.0\ \frac{kN}{m^2}$

* same as point "r" in this case

LOAD CASE U1

Calculate Soil Lateral Pressure Coefficients:

For all load cases except seismic, soil loading to be based on At-Rest Condition.
Calculate at-rest pressure coefficient Ko based on Jaky's (1944) equation.

Soil At Rest Static Coefficient: $K_o := \dfrac{1 - \sin(\phi)}{1 + \sin(\beta)} = 0.546$ (Eq. 3-6, USACE EM 1110-2-2502)

Lateral - Driving Force (Headwater Side)

Lateral Soil Load:

Surcharge Load: $E_{s1U1} := S1_{U1} \cdot K_o \cdot \left(H_w + Key_{h.d}\right) \cdot B \cdot -1 = 0 \cdot kN$

Moment Arm (from Point O): $E_{s1locU1} := \dfrac{H_w + Key_{h.d}}{2} + Key_{vdist} = 1.25\ m$

Moist Soil Load above GWL: $E_{h1U1} := \dfrac{\gamma_m \cdot K_o \cdot h_{1U1}^{\ 2}}{2} B \cdot -1 = 0.0 \cdot kN$

Moment Arm (from Point O): $E_{h1locU1} := \dfrac{h_{1U1}}{3} + h_{2U1} + Key_{vdist} = 4.50\ m$

Saturated Soil Load below GWL:
(rectangular component) $E_{h2U1} := \left(\gamma_m \cdot K_o \cdot h_{1U1}\right) \cdot \left(h_{2U1}\right) \cdot B \cdot -1 = 0.0 \cdot kN$

Moment Arm (from Point O): $E_{h2locU1} := \dfrac{h_{2U1}}{2} + Key_{vdist} = 1.25\ m$

Saturated Soil Load below GWL:
(triangular component) $E_{h2aU1} := \dfrac{\left(\gamma_{sat} - \gamma_w\right) \cdot K_o \cdot h_{2U1}^{\ 2}}{2} \cdot B \cdot -1 = -140.7 \cdot kN$

Moment Arm (from Point O): $E_{h2alocU1} := \dfrac{h_{2U1}}{3} + Key_{vdist} = 0.17\ m$

Lateral Water Load:

Water Load GWL to Bottom of Keys:

$$H_{h2U1} := \begin{cases} \dfrac{\gamma_w \cdot h_{2U1}^{\ 2}}{2} \cdot B \cdot -1 & \text{if } Key_{vdist} < 0 \\ \dfrac{\gamma_w \cdot \left(h_{2U1} + Key_{vdist}\right)^2}{2} \cdot B \cdot -1 & \text{otherwise} \end{cases} = -207.0 \cdot kN$$

Moment Arm (from Point O):

$$H_{h2locU1} := \begin{cases} \dfrac{h_{2U1}}{3} + Key_{vdist} & \text{if } Key_{vdist} < 0 \\ \dfrac{h_{2U1} + Key_{vdist}}{3} & \text{otherwise} \end{cases} = 0.17 \cdot m$$

$$\Sigma H_{SoildriveU1} := E_{s1U1} + E_{h1U1} + E_{h2U1} + E_{h2aU1} + H_{h2U1} = -347.7 \cdot kN$$

$$\Sigma M_{LateralSoildriveU1} := E_{s1U1} \cdot E_{s1locU1} + E_{h1U1} \cdot E_{h1locU1} + E_{h2U1} \cdot E_{h2locU1} \ldots + E_{h2aU1} \cdot E_{h2alocU1} + H_{h2U1} \cdot H_{h2locU1} = -58.0\ m \cdot kN$$

Lateral - Resisting Force (Tailwater Side)

LOAD CASE U1

Lateral Water Load:

Water Load WSEL to Bot. of Toe Key: $H_{h6U1} := \frac{\gamma_w \cdot h_{6U1}^2}{2} \cdot B = 30.6 \cdot kN$

Moment Arm (from Point O): $H_{h6locU1} := \frac{h_{6U1}}{3} = 0.83\ m$

Water Load between Keys (if any) $H_{h6aU1} := \begin{cases} \frac{(h_{6U1} + h_{2U1}) \cdot -Key_{vdist}}{2} \cdot \gamma_w \cdot B & \text{if } Key_{vdist} < 0 \\ 0 & \text{otherwise} \end{cases} = 88.2 \cdot kN$

Moment Arm (from Point O): $H_{h6alocU1} := \begin{cases} \frac{Key_{vdist} \cdot (2 \cdot h_{2U1} + h_{6U1})}{3(h_{2U1} + h_{6U1})} & \text{if } Key_{vdist} < 0 \\ 0 & \text{otherwise} \end{cases} = -1.15 \cdot m$

Lateral Soil Load:

Moist Soil Load above WSEL: $E_{h7U1} := \frac{\gamma_m \cdot K_o \cdot h_{7U1}^2}{2} \cdot B = 0.0 \cdot kN$

Moment Arm (from bot. of toe key): $E_{h7locU1} := h_{6U1} + \frac{h_{7U1}}{3} = 2.50\ m$

Saturated Soil Load below WSEL:
(rectangular component) $E_{h8U1} := (\gamma_m \cdot K_o \cdot h_{7U1}) \cdot h_{8U1} \cdot B = 0.0 \cdot kN$

Moment Arm (from bot. of toe key): $E_{h8locU1} := \frac{h_{8U1}}{2} = 1.25\ m$

Saturated Soil Load below WSEL:
(triangular component) $E_{h8aU1} := \frac{[(\gamma_{sat} - \gamma_w) \cdot K_o] \cdot h_{8U1}^2}{2} \cdot B = 20.8 \cdot kN$

Moment Arm (from bot. of footing): $E_{h8alocU1} := \frac{h_{8U1}}{3} = 0.83\ m$

$\Sigma H_{SoilresistU1} := H_{h6U1} + H_{h6aU1} + E_{h7U1} + E_{h8U1} + E_{h8aU1} = 139.6 \cdot kN$

$$\Sigma M_{HorizSoilResistU1} := H_{h6U1} \cdot H_{h6locU1} + H_{h6aU1} \cdot H_{h6alocU1} + E_{h7U1} \cdot E_{h7locU1} \cdots + E_{h8U1} \cdot E_{h8locU1} + E_{h8aU1} \cdot E_{h8alocU1} = -58.4\ m \cdot kN$$

Vertical Force:

UPLIFT: Linear distribution from water at heel to water at toe:

$$\Sigma V_{UpliftU1} := \left[(UWSEL_{U1} - Bot_{ftg} + Key_{t.d}) + h_{2U1}\right] \cdot \frac{b}{2} \cdot \gamma_w \cdot B \cdot -1 = -264.6 \cdot kN$$

Moment Arm (from Point O): $V_{UpliftU1aloc} := \frac{b \cdot [2 \cdot h_{2U1} + (UWSEL_{U1} - Bot_{ftg} + Key_{t.d})]}{3[h_{2U1} + (UWSEL_{U1} - Bot_{ftg} + Key_{t.d})]} = 3.444\ m$

$\Sigma M_{UpliftU1} := \Sigma V_{UpliftU1} \cdot V_{UpliftU1aloc} = -911.4 \cdot kN \cdot m$

Vertical Force (con't):

LOAD CASE U1

Weight of soil and water over toe:

Water Above the Top of Footing: $W_{H1U1} := \gamma_w \cdot h_{5U1} \cdot L_{ab} \cdot B = 9.8 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E1locU1} := \frac{L_{ab}}{2} = 1\ m$

Soil above top of footing: $W_{E6U1} := \gamma_b \cdot h_{3U1} \cdot L_{ab} \cdot B = 12.2 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E6locU1} := \frac{L_{ab}}{2} = 1\ m$

Vertical Load Due to Surcharge: $S_{U1} := S1_{U1} \cdot L_{cd} \cdot B = 0$ $\quad S_{U1loc} := b - \frac{L_{cd}}{2} = 4.35\ m$

Weight of soil and water over heel:

Moist Soil for sloped grade above top of wall:

Length of sloped portion of soil above top of wall: $L_{E3U1} := \left(L_{cd} + t_{wb} - t_{wt}\right) = 3.50\ m$

Height of sloped soil above top of wall over heel: $h_{E3locU1} := \left(L_{E3U1}\right) \cdot \tan(\beta) = 0.00\ m$

Weight of sloped soil above top of wall: $W_{E3U1} := \frac{\gamma_m}{2} \cdot h_{E3locU1} \cdot L_{E3U1} \cdot B = 0.0 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E3locU1} := L_{ab} + t_{wt} + \frac{2}{3} \cdot L_{E3U1} = 4.83\ m$

Moist soil from top of wall to groundwater level:

Height of soil from top of wall and top of GWL: $h_{1U1} = 0.00\ m$

Length from edge of wall at GWL to edge of heel: $L_{E4U1} := L_{E3U1} - \left(h_{1U1} \cdot S_{batter}\right) = 3.50\ m$

Weight of soil over heel from top of wall to GWL: $W_{E4U1} := \gamma_m \cdot h_{1U1} \cdot \frac{\left(L_{E3U1} + L_{E4U1}\right)}{2} \cdot B = 0.0 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E4locU1} := b - \frac{L_{E3U1}^2 + L_{E3U1} \cdot L_{E4U1} + L_{E4U1}^2}{3\left(L_{E3U1} + L_{E4U1}\right)} = 4.25\ m$

Saturated soil from groundwater to top of footing:

Height of soil from GWL to top of heel: $h_{E4U1} := h_{2U1} - t_{ftg} - Key_{h.d} = 2.50\ m$

Weight of soil over heel from GWL to top of heel: $W_{E5U1} := \left(\gamma_{sat}\right) \cdot h_{E4U1} \cdot \frac{\left(L_{E4U1} + L_{cd}\right)}{2} \cdot B = 187.1 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E5locU1} := b - \frac{L_{E4U1}^2 + L_{E4U1} \cdot L_{cd} + L_{cd}^2}{3\left(L_{E4U1} + L_{cd}\right)} = 4.30\ m$

$$\Sigma V_{SoilWaterU1} := W_{H1U1} + W_{E6U1} + W_{E3U1} + W_{E4U1} + W_{E5U1} + S_{U1} = 209.1 \cdot kN$$

$$\Sigma M_{VertSoilWaterResistU1} := W_{H1U1} \cdot W_{E1locU1} + W_{E6U1} \cdot W_{E6locU1} \cdots + W_{E3U1} \cdot W_{E3locU1} + W_{E4U1} \cdot W_{E4locU1} + W_{E5U1} \cdot W_{E5locU1} + S_{U1} \cdot S_{U1loc} = 826.3\ m \cdot kN$$

THIS PAGE INTENTIONALLY LEFT BLANK
PLEASE GO TO THE NEXT PAGE

STABILITY ASSESSMENT:

LOAD CASE U1

CHECK SLIDING ALONG HORIZONTAL SLIDING PLANE:

Summation of the vertical forces:

$$\Sigma V_{U1} := \Sigma V_{conc} + \Sigma V_{SoilWaterU1} + \Sigma V_{UpliftU1} = 308.6 \cdot kN$$

Summation of the horizontal forces:

$$\Sigma H_{U1} := \Sigma H_{SoildriveU1} + \Sigma H_{SoilresistU1} = -208.1 \cdot kN$$

Safety Factor for Sliding Horizontal Failure Plane

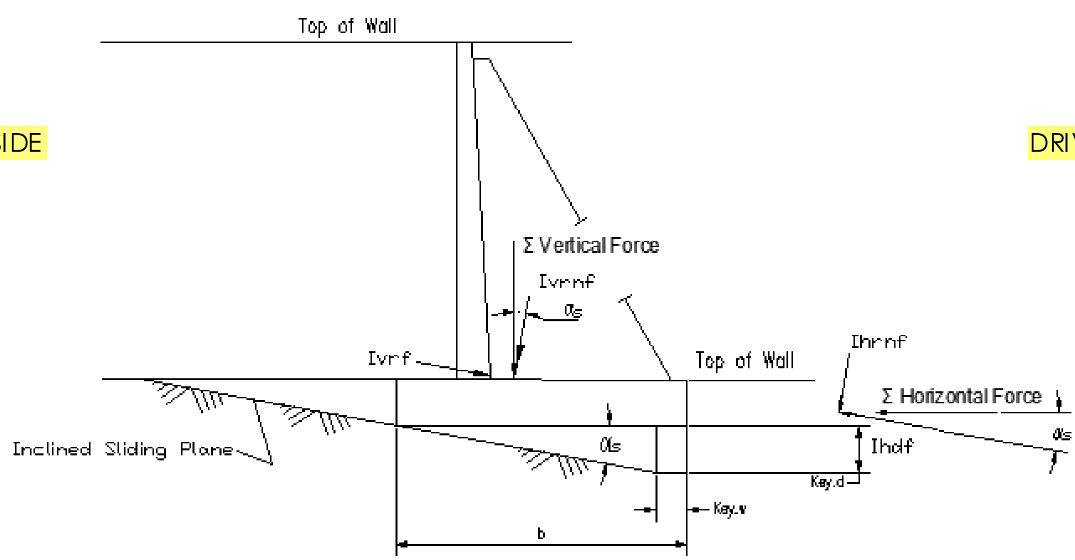
$$FS_{Horiz.SlidingU1} := \frac{\left|\Sigma V_{U1}\right| \cdot \tan\left(\phi_{rock} \cdot \frac{\pi}{180}\right)}{\left|\Sigma H_{U1}\right|} = 0.72$$

$$FS_{Sliding.check1.U1} := \begin{vmatrix} \text{"OKAY"} & \text{if } FS_{Horiz.SlidingU1} > FS_{sliding.reqU1} \\ \text{"Key req'"} & \text{otherwise} \end{vmatrix} = \text{"Key req'"}$$

CHECK FACTOR OF SAFETY SLIDING WITH KEY (INCLINED SLIDING PLANE):

RESISTING SIDE

DRIVING SIDE



TOE

HEEL

Ivrf=Inclined Resisting Force
Ivrnf=Inclined Resisting Normal Force
Ihrnf=Inclined Resisting Normal Force
Ihdf=Inclined Driving Force

$$\alpha s := \operatorname{atan}\left(\frac{-Key_{vdist}}{Key_{hdist}}\right) = 0.381 \qquad \text{as degrees=} \qquad \alpha s \cdot \left(\frac{180}{\pi}\right) = 21.80$$

(With properly engineered reinforced concrete Key, horizontal sliding plane thru Toe is protected, critical sliding plane is relocated to the INCLINED SLIDING PLANE FROM HEEL KEY To TOE, Bedrock Mass above this examing plane is mobilized by reinforced concrete key and combined into Structural Wedge.)

Resolve ΣV_{U1} & ΣH_{U1}

$$\Sigma V_{InclinedU1} := \cos(\alpha s) \cdot \left(\left|\Sigma V_{U1} + V_{rocksection}\right|\right) + \sin(\alpha s) \cdot \left|\Sigma H_{U1}\right| = 482.7 \cdot kN$$

$$\Sigma H_{InclinedU1} := \cos(\alpha s) \cdot \left|\Sigma H_{U1}\right| - \sin(\alpha s) \cdot \left(\left|\Sigma V_{U1} + V_{rocksection}\right|\right) = 31.1 \cdot kN$$

LOAD CASE U1

Safety Factor for Sliding Inclined Failure Plane

$$FS_{InclinedISlidingU1} := \frac{\Sigma V_{InclinedU1} \cdot \tan(\phi_r)}{\Sigma H_{InclinedU1}} = 6.92$$

$$FS_{Sliding.check2.U1} := \begin{cases} \text{"OKAY "} & \text{if } FS_{InclinedISlidingU1} > FS_{sliding.reqU1} \\ \text{"NG - Revise Structure""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

CHECK FOUNDATION ECCENTRICITY:

Summation of the resisting moments about the toe:

$$\Sigma M_{resU1} := \Sigma M_{conc} + \Sigma M_{VertSoilWaterResistU1} + \Sigma M_{HorizSoilResistU1} + \Sigma M_{rocksection} = 2380 \cdot kN \cdot m$$

Summation of the overturning moments about the toe:

$$\Sigma M_{oU1} := \Sigma M_{LateralSoildriveU1} + \Sigma M_{UpliftU1} = -969 \cdot kN \cdot m$$

Total moment: $\Sigma M_{U1} := \Sigma M_{resU1} + \Sigma M_{oU1} = 1410.6 \cdot kN \cdot m$

Normal force to base: $\Sigma V_{InclinedU1} = 482.7 \cdot kN$

Inclined Sliding Plane Length: $L_{incline} := \dfrac{b}{\cos(\alpha s)} = 6.5\,m$

Eccentricity (inclined plane): $ex_{U1} := \dfrac{L_{incline}}{2} - \dfrac{\Sigma M_{U1}}{\Sigma V_{InclinedU1}} = 0.31\,m$ $\qquad Kern := \dfrac{L_{incline}}{6} = 1.077\,m$

Eccentricity Check: $e_{check.U1} := \begin{cases} \text{"Okay"} & \text{if } ex_{U1} \le Kern \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"Okay"}$

CHECK FOUNDATION BEARING CAPACITY:

Base Section Modulus: $S_b := \dfrac{1}{6}\left(B \cdot L_{incline}^{\ 2}\right) = 6.96\,m^3$

Bearing Pressure Under Toe:

$$\sigma_{ToeU1} := \begin{cases} \left[\dfrac{\Sigma V_{InclinedU1}}{L_{incline} \cdot B} + \dfrac{\left(\Sigma V_{InclinedU1} \cdot ex_{U1}\right)}{S_b}\right] & \text{if } \dfrac{\Sigma V_{InclinedU1}}{L_{incline} \cdot B} \ge \dfrac{\Sigma V_{InclinedU1} \cdot ex_{U1}}{S_b} \\ \dfrac{2 \cdot \Sigma V_{InclinedU1}}{B \cdot 3\left(\dfrac{b}{2} - ex_{U1}\right)} & \text{otherwise} \end{cases} = 96.1 \cdot kPa$$

$$Bearing_{ChecktoeU1} := \begin{cases} \text{"OKAY "} & \text{if } \sigma_{ToeU1} < \sigma_{allowU1} \\ \text{"NG""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

Bearing Pressure Under Heel:

$$\sigma_{HeelU1} := \begin{cases} \left[\dfrac{\Sigma V_{InclinedU1}}{L_{incline} \cdot B} - \dfrac{\left(\Sigma V_{InclinedU1} \cdot ex_{U1}\right)}{S_b}\right] & \text{if } \dfrac{\Sigma V_{InclinedU1}}{L_{incline} \cdot B} \ge \dfrac{\Sigma V_{InclinedU1} \cdot ex_{U1}}{S_b} \\ 0 & \text{otherwise} \end{cases} = 53.3 \cdot kPa$$

$$Bearing_{CheckheelU1} := \left(\begin{cases} \text{"OKAY "} & \text{if } \sigma_{HeelU1} < \sigma_{allowU1} \wedge \sigma_{HeelU1} > 0 \\ \text{"NG - perform cracked base analysis""} & \text{otherwise} \end{cases}\right) = \text{"OKAY "}$$

CHECK FLOATATION:

Safety Factor for Floatation:

$$FS_{FloatationU1} := \frac{\Sigma V_{conc} + \Sigma V_{SoilWaterU1}}{\left|\Sigma V_{UpliftU1}\right|} = 2.17$$

$$FS_{Floatation.U1.check} := \begin{cases} \text{"OKAY"} & \text{if } FS_{FloatationU1} > FS_{req.U1.flt} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

CHECK OVERTURNING

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.
Assumptions are made in order to compute overturning stablity of indetermine forces on monolith with key;
(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.
(b) The horizontal resisting force acting on the key, P.key, is that required for static equilibrium
(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1

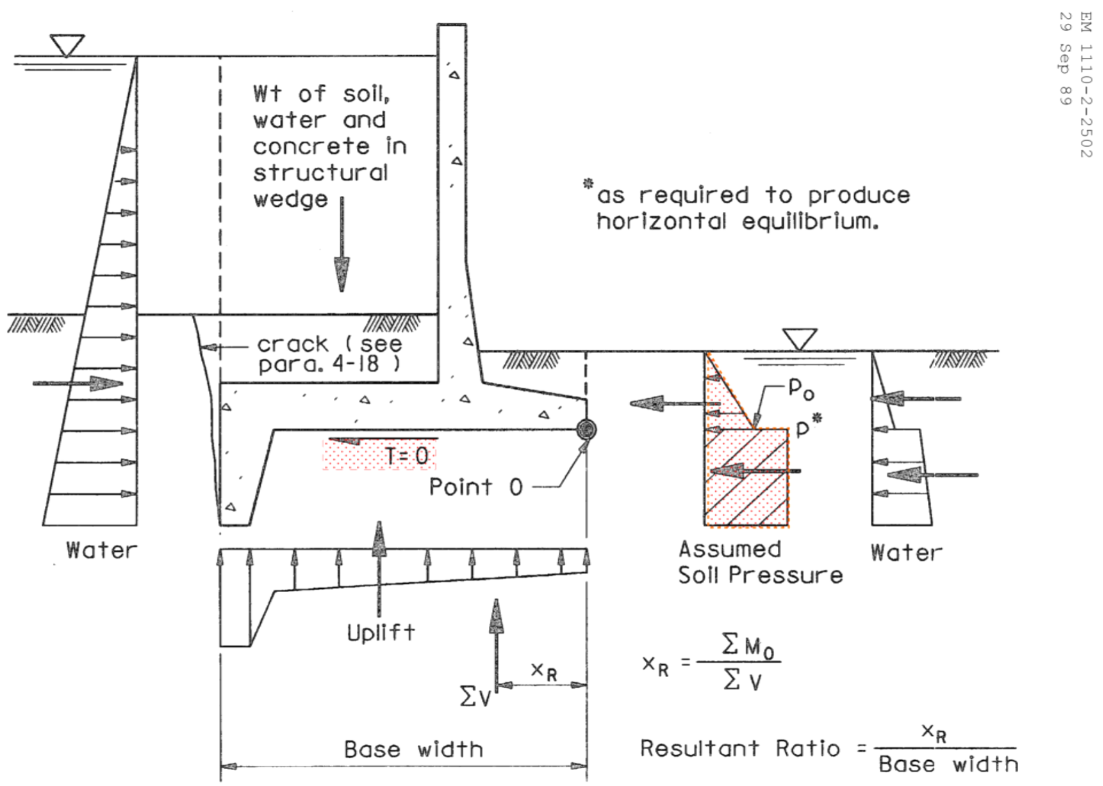


Figure 4-5. Forces for overturning analysis for wall with horizontal base and key

Modify Uplift for Overturning Analysis:

LOAD CASE U1

(Uplift is calculated along the concrete/rock contact using the Line of Creep method)

Water Pressure at h: $u_{h.U1} := \Delta h_{g.hj.U1} \cdot \gamma_w = 63.70 \cdot kPa$

Water Pressure at o: $u_{o.U1} := \left(\Delta h_{g.no.U1} - \frac{\Delta h_{g.r.U1} \cdot L_{ho.U1}}{L_{ho.U1}}\right) \cdot \gamma_w = 24.5 \cdot kPa$

Head loss between point h and o: $\Delta h_{ho.U1} := \Delta h_{g.r.U1} \cdot \frac{L_{ho.U1}}{L_{ho.U1}} = 2\,m$

Length of concrete base (h -> o): $L_{baseho.U1} := Key_{h.w} + Key_{h.d} + Key_{hdist} + Key_{t.d} + Key_{t.w} = 8\,m$

Head loss along h -> j: $\Delta h_{hj.U1} := \Delta h_{ho.U1} \cdot \frac{Key_{h.w}}{L_{baseho.U1}} = 0.25\,m$

Water Pressure at j: $u_{j.U1} := \left(\Delta h_{g.hj.U1} - \Delta h_{hj.U1}\right) \cdot \gamma_w = 61.25 \cdot kPa$

Head loss along h -> k: $\Delta h_{hjk.U1} := \Delta h_{ho.U1} \cdot \left(\frac{Key_{h.w} + Key_{h.d}}{L_{baseho.U1}}\right) = 0.75\,m$

Water Pressure at k: $u_{k.U1} := \left(\Delta h_{g.km.U1} - \Delta h_{hjk.U1}\right) \cdot \gamma_w = 36.75 \cdot kPa$

Head loss along h -> m: $\Delta h_{hjkm.U1} := \Delta h_{ho.U1} \cdot \left(\frac{Key_{h.w} + Key_{h.d} + Key_{hdist}}{L_{baseho.U1}}\right) = 2\,m$

Water Pressure at m: $u_{m.U1} := \left(\Delta h_{g.km.U1} - \Delta h_{hjkm.U1}\right) \cdot \gamma_w = 24.50 \cdot kPa$

Head loss along h -> n: $\Delta h_{hjkmn.U1} := \Delta h_{ho.U1} \cdot \left(\frac{Key_{h.w} + Key_{h.d} + Key_{hdist} + Key_{t.d}}{L_{baseho.U1}}\right) = 2\,m$

Water Pressure at n: $u_{n.U1} := \left(\Delta h_{g.no.U1} - \Delta h_{hjkmn.U1}\right) \cdot \gamma_w = 24.50 \cdot kPa$

Uplift under key at heel: $V_{ulkeyhU1.OT} := \frac{\left(u_{h.U1} + u_{j.U1}\right) \cdot Key_{h.w}}{2} \cdot B \cdot -1 = -62.475 \cdot kN$

Moment Arm (from Point O): $V_{ulkeyhU1loc.OT} := b - \frac{Key_{h.w} \cdot \left(2 \cdot u_{j.U1} + u_{h.U1}\right)}{3 \cdot \left(u_{j.U1} + u_{h.U1}\right)} = 5.503\,m$

Uplift under base: $V_{ulbaseU1.OT} := \frac{\left(u_{k.U1} + u_{m.U1}\right) \cdot Key_{hdist}}{2} \cdot B \cdot -1 = -153.125 \cdot kN$

Moment Arm (from Point O): $V_{ulbaseU1loc.OT} := b - Key_{h.w} - \frac{Key_{hdist} \cdot \left(2 \cdot u_{m.U1} + u_{k.U1}\right)}{3 \cdot \left(u_{m.U1} + u_{k.U1}\right)} = 2.667\,m$

Uplift under key at toe: $V_{ulkeytU1.OT} := \frac{\left(u_{n.U1} + u_{o.U1}\right) \cdot Key_{t.w}}{2} \cdot B \cdot -1 = 0 \cdot kN$

Moment Arm (from Point O): $V_{ulkeytU1loc.OT} := \frac{Key_{t.w} \cdot \left(2 \cdot u_{n.U1} + u_{o.U1}\right)}{3 \cdot \left(u_{n.U1} + u_{o.U1}\right)} = 0$

$$\Sigma V_{UpliftU1.OT} := V_{ulkeyhU1.OT} + V_{ulbaseU1.OT} + V_{ulkeytU1.OT} = -216 \cdot kN$$

$$U_{U1.loc.OT} := \frac{V_{ulkeyhU1.OT} \cdot V_{ulkeyhU1loc.OT} + V_{ulbaseU1.OT} \cdot V_{ulbaseU1loc.OT} + V_{ulkeytU1.OT} \cdot V_{ulkeytU1loc.OT}}{\Sigma V_{UpliftU1.OT}} = 3.49\,m$$

$$\Sigma M_{UpliftU1.OT} := \Sigma V_{UpliftU1.OT} \cdot U_{U1.loc.OT} = -752.1 \cdot kN \cdot m$$

Modify Lateral Water Pressure (Resisting) for Overturning Analysis:

(Resisting water pressure is calculated using the Line of Creep method)

Water Load at Key (heel): $H_{h2U1.OT} := \frac{u_{k.U1} + u_{j.U1}}{2} \cdot Key_{h.d} B = 98.0 \cdot kN$

Moment Arm (from Point O): $H_{h2locU1.OT} := \frac{Key_{h.d} \cdot (2 \cdot u_{k.U1} + u_{j.U1})}{3(u_{k.U1} + u_{j.U1})} + Key_{vdist} = -1.08\ m$

Water Load at Key (toe): $H_{h6U1.OT} := \frac{u_{o.U1} \cdot (UWSEL_{U1} - Bot_{ftg} + Key_{t.d})}{2} \cdot B = 31 \cdot kN$

Moment Arm (from Point O): $H_{h6locU1.OT} := \frac{UWSEL_{U1} - Bot_{ftg} + Key_{t.d}}{3} = 0.83\ m$

$$\Sigma H_{waterresistU1.OT} := H_{h2U1.OT} + H_{h6U1.OT} = 128.63 \cdot kN$$

$$H_{waterresistlocU1.OT} := \frac{H_{h2U1.OT} \cdot H_{h2locU1.OT} + H_{h6U1.OT} \cdot H_{h6locU1.OT}}{\Sigma H_{waterresistU1.OT}} = -0.627\ m$$

$$\Sigma M_{waterresistU1.OT} := \Sigma H_{waterresistU1.OT} \cdot H_{waterresistlocU1.OT} = -80.65 \cdot kN \cdot m$$

Modify Lateral Soil Loads for Overturning Analysis:

(Lateral soil loads are calculated down to Point O instead of bottom of shear key)

Driving Soil Load (Headwater Side):

Surcharge Load: $E_{s1U1.OT} := S1_{U1} \cdot K_o \cdot (H_w + Key_{h.d} + Key_{vdist}) \cdot B \cdot -1 = 0 \cdot kN$

Moment Arm (from Point O): $E_{s1locU1.OT} := \frac{H_w + Key_{h.d} + Key_{vdist}}{2} = 2.25\ m$

Moist Soil Load above GWL: $E_{h1U1.OT} := \frac{\gamma_m \cdot K_o \cdot h_{1U1}^2}{2} B \cdot -1 = 0.0 \cdot kN$

Moment Arm (from Point O): $E_{h1locU1.OT} := \frac{h_{1U1}}{3} + h_{2U1} + Key_{vdist} = 4.50\ m$

Saturated Soil Load below GWL:
(rectangular component)
$E_{h2U1.OT} := (\gamma_m \cdot K_o \cdot h_{1U1}) \cdot (h_{2U1} + Key_{vdist}) \cdot B \cdot -1 = 0.0 \cdot kN$

Moment Arm (from Point O): $E_{h2locU1.OT} := \frac{h_{2U1} + Key_{vdist}}{2} = 2.25\ m$

Saturated Soil Load below GWL:
(triangular component)
$E_{h2aU1.OT} := \frac{(\gamma_{sat} - \gamma_w) \cdot K_o \cdot (h_{2U1} + Key_{vdist})^2}{2} \cdot B \cdot -1 = -67.4 \cdot kN$

Moment Arm (from Point O): $E_{h2alocU1.OT} := \frac{h_{2U1} + Key_{vdist}}{3} = 1.50\ m$

Resisting Soil Load (Tailwater Side):

(Determine resisting soil load based on depth variation between the keys (ie. Key_{vdist}). In case where key at heel is deeper than key at toe (ie. $Key_{vdist} < 0$), resisting soil load (p*) is assumed to produce horizontal equilibrium as per Figure 4-5 above. Resisting soil load (p_o) is neglected.)

Total Driving Force: $\Sigma H_{SoildriveU1.OT} := E_{s1U1.OT} + E_{h1U1.OT} + E_{h2U1.OT} + E_{h2aU1.OT} + H_{h2U1} = -274.5 \cdot kN$

Total Resisting Force: $\Sigma H_{waterresistU1.OT} = 128.6 \cdot kN$

Assumed Soil Load p*: $E_{h8U1a.OT} := \left(\Sigma H_{SoildriveU1.OT} + \Sigma H_{waterresistU1.OT}\right) \cdot -1 = 145.846 \cdot kN$

Moment Arm (from Point O): $E_{h8U1a.loc.OT} := \dfrac{Key_{vdist}}{2} = -1\ m$

$$E_{h8U1.OT} := \begin{cases} E_{h8U1a.OT} & \text{if } Key_{vdist} < 0 \\ \Sigma H_{SoilresistU1} - H_{h6U1} - H_{h6aU1} & \text{otherwise} \end{cases} = 145.846 \cdot kN$$

$$\Sigma M_{SoilresistU1.OT} := \begin{cases} E_{h8U1a.OT} \cdot E_{h8U1a.loc.OT} & \text{if } Key_{vdist} < 0 \\ \Sigma M_{HorizSoilResistU1} - H_{h6U1} \cdot H_{h6locU1} - H_{h6aU1} \cdot H_{h6alocU1} & \text{otherwise} \end{cases} = -145.846 \cdot kN \cdot m$$

Sum of Moment about Point O:

$$\Sigma M_{LateraldriveU1.OT} := E_{s1U1.OT} \cdot E_{s1locU1.OT} + E_{h1U1.OT} \cdot E_{h1locU1.OT} + E_{h2U1.OT} \cdot E_{h2locU1.OT} \cdots + E_{h2aU1.OT} \cdot E_{h2alocU1.OT} + H_{h2U1} \cdot H_{h2locU1} = -135.7 \cdot kN \cdot m$$

$$\Sigma M_{LateralresistU1.OT} := \Sigma M_{waterresistU1.OT} + \Sigma M_{SoilresistU1.OT} = -226.5 \cdot kN \cdot m$$

Total moment:

$$\Sigma M_{U1.OT} := \Sigma M_{conc} + \Sigma M_{VertSoilWaterResistU1} + \Sigma M_{UpliftU1.OT} + \Sigma M_{LateraldriveU1.OT} + \Sigma M_{LateralresistU1.OT} = 897.3 \cdot kN \cdot m$$

Total Vertical Force: $\Sigma V_{U1.OT} := \Sigma V_{conc} + \Sigma V_{SoilWaterU1} + \Sigma V_{UplliftU1.OT} = 357.6 \cdot kN$

Distance X_R: EM 1110-2-2502 Eq.4-1 $X_{R.U1} := \dfrac{\Sigma M_{U1.OT}}{\Sigma V_{U1.OT}} = 2.509\ m$

Overturning Resultant Ratio $Ratio_{U1.OT} := \dfrac{X_{R.U1}}{b} = 0.42$

$$Ratio_{U1.OT.check} := \begin{cases} \text{"OKAY "} & \text{if } Ratio_{U1.OT} > X_{R.reqU1} \\ \text{"Revise Structure""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

CHECK FOUNDATION ECCENTRICITY (HORIZONTAL PLANE):

Eccentricity (horizontal plan): $ex_{U1.OT} := \dfrac{b}{2} - \dfrac{\Sigma M_{U1.OT}}{\Sigma V_{U1.OT}} = 0.49\ m$ $Kern_{OT} := \dfrac{b}{6} = 1\ m$

Eccentricity Check:

$$e_{check.U1.OT} := \begin{cases} \text{"Okay"} & \text{if } ex_{U1} \le Kern_{OT} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"Okay"}$$

CHECK FOUNDATION BEARING CAPACITY (HORIZONTAL PLANE):

Base Section Modulus: $S_{b.OT} := \frac{1}{6}\left(B \cdot b^2\right) = 6\,m^3$

Bearing Pressure Under Toe:

$$\sigma_{ToeU1.OT} := \begin{cases} \left(\frac{\Sigma V_{U1.OT}}{b \cdot B} + \frac{\Sigma V_{U1.OT} \cdot ex_{U1.OT}}{S_{b.OT}}\right) & \text{if } \frac{\Sigma V_{U1.OT}}{b \cdot B} \ge \frac{\Sigma V_{U1.OT} \cdot ex_{U1.OT}}{S_{b.OT}} \\ \frac{2 \cdot \Sigma V_{U1.OT}}{B \cdot 3\left(\frac{b}{2} - ex_{U1.OT}\right)} & \text{otherwise} \end{cases} = 88.9 \cdot kPa$$

$$Bearing_{ChecktoeU1.OT} := \begin{cases} \text{"OKAY "} & \text{if } \sigma_{ToeU1.OT} < \sigma_{allowU1} \\ \text{"NG - for reference only""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

Bearing Pressure Under Heel:

$$\sigma_{HeelU1.OT} := \begin{cases} \left(\frac{\Sigma V_{U1.OT}}{b \cdot B} - \frac{\Sigma V_{U1.OT} \cdot ex_{U1.OT}}{S_{b.OT}}\right) & \text{if } \frac{\Sigma V_{U1.OT}}{b \cdot B} \ge \frac{\Sigma V_{U1.OT} \cdot ex_{U1.OT}}{S_{b.OT}} \\ 0 & \text{otherwise} \end{cases} = 30.3 \cdot kPa$$

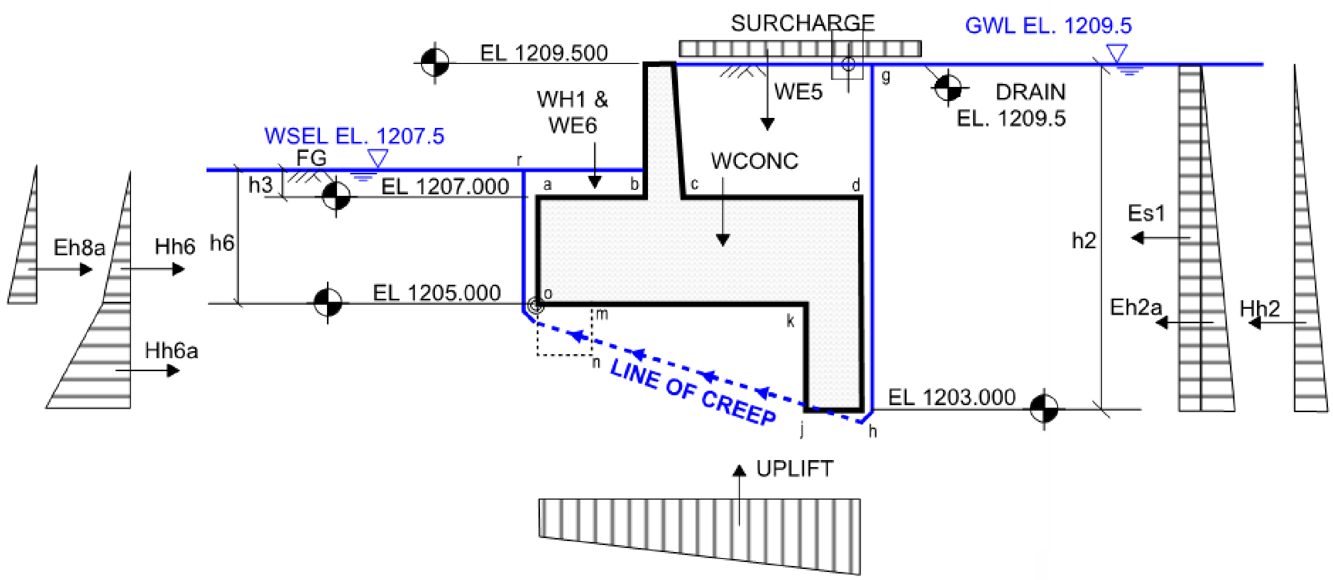
$$Bearing_{CheckheelU1.OT} := \left(\begin{cases} \text{"OKAY "} & \text{if } \sigma_{HeelU1.OT} < \sigma_{allowU1} \wedge \sigma_{HeelU1.OT} > 0 \\ \text{"NG - for reference only""} & \text{otherwise} \end{cases}\right) = \text{"OKAY "}$$

LOAD CASE U1

SUMMARY OF STABILITY ASSESSMENT:

Sliding Factor of Safety: (Horizontal Plane - Ref only)	$FS_{Horiz.SlidingU1} = 0.72$	$FS_{Sliding.check1.U1}$ = "Key req""
Sliding Factor of Safety: (Inclined Plane)	$FS_{InclinedlSlidingU1} = 6.92$	$FS_{Sliding.check2.U1}$ = "OKAY "
Eccentricity: (Inclined Plane)	$ex_{U1} = 0.31\ m$	$e_{check.U1}$ = "Okay"
Bearing Pressure At Heel: (Inclined Plane)	$\sigma_{HeelU1} = 53 \cdot kPa$	$Bearing_{CheckheelU1}$ = "OKAY "
Bearing Pressure At Toe: (Inclined Plane)	$\sigma_{ToeU1} = 96 \cdot kPa$	$Bearing_{ChecktoeU1}$ = "OKAY "
Flotation Factor of Safety (horizontal plane)	$FS_{FloatationU1} = 2.17$	$FS_{Floatation.U1.check}$ = "OKAY "
Overturning Resultant Ratio: (horizontal plane)	$Ratio_{U1.OT} = 0.42$	$Ratio_{U1.OT.check}$ = "OKAY "
Eccentricity: (horizontal plane - Ref only)	$ex_{U1.OT} = 0.49\ m$	$e_{check.U1.OT}$ = "Okay"
Bearing Pressure At Heel: (horizontal plane - Ref only)	$\sigma_{HeelU1.OT} = 30 \cdot kPa$	$Bearing_{CheckheelU1.OT}$ = "OKAY "
Bearing Pressure At Toe: (horizontal plane - Ref only)	$\sigma_{ToeU1.OT} = 89 \cdot kPa$	$Bearing_{ChecktoeU1.OT}$ = "OKAY "

LOAD CASE UN1 - NORMAL OPERATION + SURCHARGE



UN1 DESIGN CASE

LOAD CASE UN1 ACCEPTANCE PARAMETERS

FS sliding:

Unusual (UN) 1.3 (without cohesion) (Table 3-3, USACE EM 1110-2-2100)

Resultant Location:

Unsual (UN) Inside middle third ~100% base in compression

Required Factor of Safety for Sliding: $FS_{sliding.reqUN1} := 1.3$ (Without Cohesion)

Allowable rock bearing pressure: $\sigma_{allowUN1} := 1470kPa$ (Section 5.2, Design Criteria EM 1110-2-2100 Section 3-10)

Overturning Required Resultant Ratio: $X_{R.reqUN1} := 0.333$ (EM 1110-2-2502, Figure 4-4)

Required Factor of Safety for Floatation $FS_{req.UN1.flt} := 1.3$

SOIL HEIGHTS and Water Levels:

LOAD CASE UN1

Heel Conditions:

Groundwater Elevation at Heel: $GWL_{UN1} := 1209.5m$

Distance from Finish Grade to Groundwater at Heel: $h_{1UN1} := \left[T_w - GWL_{UN1} + \left(L_{cd} + t_{wb} - t_{wt}\right)\cdot \tan(\beta)\right] = 0.00\ m$

Distance from Water Surface to Bottom of Footing at Heel: $h_{2UN1} := GWL_{UN1} - Bot_{ftg} + Key_{h.d} = 6.50\ m$

Toe Conditions:

Water Surface Elevation at Toe: $WSEL_{UN1} := 1207.5m$

Water Surface Elevation at Toe for Uplift: $UWSEL_{UN1} := 1207.5\cdot m$

Finish Grade at Toe providing lateral resistance: $FG_{toeUN1} := 1207.5\cdot m$

Soil Depth Above top of footing: $h_{3aUN1} := FG_{toeUN1} - Top_{ftg} = 0.5\ m$

$$h_{3UN1} := \begin{cases} h_{3aUN1} & \text{if } FG_{toeUN1} - Top_{ftg} \geq 0 \\ 0 & \text{otherwise} \end{cases} = 0.5$$

Resisting Fill at Toe: $h_{4UN1} := FG_{toeUN1} - Bot_{ftg} + Key_{t.d} = 2.50\ m$

Distance from Water Level to Top of Footing: $h_{5UN1} := WSEL_{UN1} - Top_{ftg} = 0.50\ m$

Distance from Water Surface to Bottom of Toe Key: $h_{6UN1} := WSEL_{UN1} - Bot_{ftg} + Key_{t.d} = 2.50\ m$

Soil Depth Above WSEL: $h_{7aUN1} := FG_{toeUN1} - WSEL_{UN1} = 0\ m$

$$h_{7UN1} := \begin{cases} h_{7aUN1} & \text{if } FG_{toeUN1} - WSEL_{UN1} \geq 0 \\ 0 & \text{otherwise} \end{cases} = 0$$

Soil Depth Below WSEL:

$$h_{8UN1} := \begin{cases} WSEL_{UN1} - Bot_{ftg} + Key_{t.d} & \text{if } FG_{toeUN1} - WSEL_{UN1} \geq 0 \\ h_{4UN1} & \text{otherwise} \end{cases} = 2.5$$

For Line of Creep Method: $L_{ho.UN1} := \sqrt{b^2 + \left(Key_{h.d} - Key_{t.d}\right)^2} = 6.325\ m$

Head Loss from Point g:

$\Delta h_{g.hj.UN1} := h_{2UN1} = 6.5\ m$ (to point h & j)

$\Delta h_{g.km.UN1} := GWL_{UN1} - Bot_{ftg} = 4.5\ m$ (to point k & m)

$\Delta h_{g.no.UN1} := GWL_{UN1} - Bot_{ftg} + Key_{t.d} = 4.5\ m$ (to point n & o)

$\Delta h_{g.p.UN1} := GWL_{UN1} - FG_{toeUN1} = 2\ m$ (to point p*)

$\Delta h_{g.r.UN1} := GWL_{UN1} - UWSEL_{UN1} = 2\ m$ (to point r)

Surcharge

Surcharge on Heel: $S1_{UN1} := 15.0 \dfrac{kN}{m^2}$

* same as point "r" in this case

Calculate Soil Lateral Pressure Coefficients:

LOAD CASE UN1

For all load cases except seismic, soil loading to be based on At-Rest Condition.
Calculate at-rest pressure coefficient Ko based on Jaky's (1944) equation.

Soil At Rest Static Coefficient: $K_o := \dfrac{1 - \sin(\phi)}{1 + \sin(\beta)} = 0.546$ (Eq. 3-6, USACE EM 1110-2-2502)

Lateral - Driving Force

Static At-Rest:

Surcharge Load: $E_{s1UN1} := S1_{UN1} \cdot K_o \cdot \left(H_w + Key_{h.d}\right) \cdot B \cdot -1 = -53.236 \cdot kN$

Moment Arm (from Point O): $E_{s1locUN1} := \dfrac{H_w + Key_{h.d}}{2} + Key_{vdist} = 1.25\,m$

Moist Soil Load above GWL: $E_{h1UN1} := \dfrac{\gamma_m \cdot K_o \cdot h_{1UN1}^{\,2}}{2} \cdot B \cdot -1 = 0.0 \cdot kN$

Moment Arm (from Point O): $E_{h1locUN1} := \dfrac{h_{1UN1}}{3} + h_{2UN1} + Key_{vdist} = 4.50\,m$

Saturated Soil Load below GWL:
(rectangular component) $E_{h2UN1} := \left(\gamma_m \cdot K_o \cdot h_{1UN1}\right) \cdot \left(h_{2UN1}\right) \cdot B \cdot -1 = 0.0 \cdot kN$

Moment Arm (from Point O): $E_{h2locUN1} := \dfrac{h_{2UN1}}{2} + Key_{vdist} = 1.25\,m$

Saturated Soil Load below GWT:
(triangular L $E_{h2aUN1} := \dfrac{\left(\gamma_{sat} - \gamma_w\right) \cdot K_o \cdot h_{2UN1}^{\,2}}{2} \cdot B \cdot -1 = -140.7 \cdot kN$

Moment Arm (from Point O): $E_{h2alocUN1} := \dfrac{h_{2UN1}}{3} + Key_{vdist} = 0.17\,m$

Lateral Water Load:

Water Load GWL to Bottom of Keys:

$$H_{h2UN1} := \begin{cases} \dfrac{\gamma_w \cdot h_{2UN1}^{\,2}}{2} \cdot B \cdot -1 & \text{if } Key_{vdist} < 0 \\ \dfrac{\gamma_w \cdot \left(h_{2UN1} + Key_{vdist}\right)^2}{2} \cdot B \cdot -1 & \text{otherwise} \end{cases} = -207.0 \cdot kN$$

Moment Arm (from Point O):

$$H_{h2locUN1} := \begin{cases} \dfrac{h_{2UN1}}{3} + Key_{vdist} & \text{if } Key_{vdist} < 0 \\ \dfrac{h_{2UN1} + Key_{vdist}}{3} & \text{otherwise} \end{cases} = 0.17 \cdot m$$

$$\Sigma H_{SoildriveUN1} := E_{s1UN1} + E_{h1UN1} + E_{h2UN1} + E_{h2aUN1} + H_{h2UN1} = -401.0 \cdot kN$$

$$\Sigma M_{LateralSoildriveUN1} := E_{s1UN1} \cdot E_{s1locUN1} + E_{h1UN1} \cdot E_{h1locUN1} + E_{h2UN1} \cdot E_{h2locUN1} \cdots + E_{h2aUN1} \cdot E_{h2alocUN1} + H_{h2UN1} \cdot H_{h2locUN1} = -124.5\,m \cdot kN$$

Lateral - Resisting Force

LOAD CASE UN1

Lateral Water Load:

Water Load WSEL to Bot. of Toe Key:

$$H_{h6UN1} := \frac{\gamma_w \cdot h_{6UN1}^{\ 2}}{2} \cdot B = 30.6 \cdot kN$$

Moment Arm (from Point O):

$$H_{h6locUN1} := \frac{h_{6UN1}}{3} = 0.83\ m$$

Water Load between Keys (if any)

$$H_{h6aUN1} := \begin{cases} \dfrac{(h_{6UN1} + h_{2UN1}) \cdot -Key_{vdist}}{2} \cdot \gamma_w \cdot B & \text{if } Key_{vdist} < 0 \\ 0 & \text{otherwise} \end{cases} = 88.2 \cdot kN$$

Moment Arm (from Point O):

$$H_{h6alocUN1} := \begin{cases} \dfrac{Key_{vdist} \cdot (2 \cdot h_{2UN1} + h_{6UN1})}{3(h_{2UN1} + h_{6UN1})} & \text{if } Key_{vdist} < 0 \\ 0 & \text{otherwise} \end{cases} = -1.15 \cdot m$$

Lateral Soil Load:

Moist Soil Load above WSEL:

$$E_{h7UN1} := \frac{\gamma_m \cdot K_o \cdot h_{7UN1}^{\ 2}}{2} \cdot B = 0.0 \cdot kN$$

Moment Arm (from bot. of toe key):

$$E_{h7locUN1} := h_{6UN1} + \frac{h_{7UN1}}{3} + Key_{vdist} = 0.50\ m$$

Saturated Soil Load below WSEL:
(rectangular component)

$$E_{h8UN1} := (\gamma_m \cdot K_o \cdot h_{7UN1}) \cdot h_{8UN1} \cdot B = 0.0 \cdot kN$$

Moment Arm (from bot. of toe key):

$$E_{h8locUN1} := \frac{h_{8UN1}}{2} = 1.25\ m$$

Saturated Soil Load below WSEL:
(triangular component)

$$E_{h8aUN1} := \frac{\left[(\gamma_{sat} - \gamma_w) \cdot K_o\right] \cdot h_{8UN1}^{\ 2}}{2} \cdot B = 20.8 \cdot kN$$

Moment Arm (from bot. of footing):

$$E_{h8alocUN1} := \frac{h_{8UN1}}{3} = 0.83\ m$$

$$\Sigma H_{SoilresistUN1} := H_{h6UN1} + H_{h6aUN1} + E_{h7UN1} + E_{h8UN1} + E_{h8aUN1} = 139.6 \cdot kN$$

$$\Sigma M_{HorizSoilResistUN1} := H_{h6UN1} \cdot H_{h6locUN1} + H_{h6aUN1} \cdot H_{h6alocUN1} + E_{h7UN1} \cdot E_{h7locUN1} \cdots + E_{h8UN1} \cdot E_{h8locUN1} + E_{h8aUN1} \cdot E_{h8alocUN1} = -58.4\ m \cdot kN$$

Vertical Force:

UPLIFT: Linear distribution from water at heel to water at toe:

$$\Sigma V_{UplliftUN1} := \left[\left(UWSEL_{UN1} - Bot_{ftg} + Key_{t.d}\right) + h_{2UN1}\right] \cdot \frac{b}{2} \cdot \gamma_w \cdot B \cdot -1 = -264.6 \cdot kN$$

Moment Arm (from Point O):

$$V_{UpliftUN1aloc} := \frac{b \cdot \left[2 \cdot h_{2UN1} + \left(UWSEL_{UN1} - Bot_{ftg} + Key_{t.d}\right)\right]}{3\left[h_{2UN1} + \left(UWSEL_{UN1} - Bot_{ftg} + Key_{t.d}\right)\right]} = 3.444\ m$$

$$\Sigma M_{UpliftUN1} := \Sigma V_{UplliftUN1} \cdot V_{UpliftUN1aloc} = -911.4 \cdot kN \cdot m$$

Weight of soil and water over toe:

Water Above the Top of Footing: $W_{H1UN1} := \gamma_w \cdot h_{5UN1} \cdot L_{ab} \cdot B = 9.8 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E1locUN1} := \frac{L_{ab}}{2} = 1\ m$

Soil above top of footing: $W_{E6UN1} := \gamma_b \cdot h_{3UN1} \cdot L_{ab} \cdot B = 12.2 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E6locUN1} := \frac{L_{ab}}{2} = 1\ m$

Vertical Load Due to Surcharge: $S_{UN1} := S1_{UN1} \cdot L_{cd} \cdot B = 49.56 \cdot kN$ $\quad S_{UN1loc} := b - \frac{L_{cd}}{2} = 4.35\ m$

Weight of soil and water over heel:

Moist Soil for sloped grade above top of wall:

Length of sloped portion of soil above top of wall: $L_{E3UN1} := \left(L_{cd} + t_{wb} - t_{wt}\right) = 3.50\ m$

Height of sloped soil above top of wall over heel: $h_{E3locUN1} := \left(L_{E3UN1}\right) \cdot \tan(\beta) = 0.00\ m$

Weight of sloped soil above top of wall: $W_{E3UN1} := \frac{\gamma_m}{2} \cdot h_{E3locUN1} \cdot L_{E3UN1} \cdot B = 0.0 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E3locUN1} := L_{ab} + t_{wt} + \frac{2}{3} \cdot L_{E3UN1} = 4.83\ m$

Moist soil from top of wall to groundwater level:

Height of soil from top of wall and top of GWL: $h_{1UN1} = 0.00\ m$

Length from edge of wall at GWL to edge of heel: $L_{E4UN1} := L_{E3UN1} - \left(h_{1UN1} \cdot S_{batter}\right) = 3.50\ m$

Weight of soil over heel from top of wall to GWL: $W_{E4UN1} := \gamma_m \cdot h_{1UN1} \cdot \frac{\left(L_{E3UN1} + L_{E4UN1}\right)}{2} \cdot B = 0.0 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E4locUN1} := b - \frac{L_{E3UN1}^{2} + L_{E3UN1} \cdot L_{E4UN1} + L_{E4UN1}^{2}}{3\left(L_{E3UN1} + L_{E4UN1}\right)} = 4.25\ m$

Saturated soil from groundwater to top of footing:

Height of soil from GWL to top of heel: $h_{E4UN1} := h_{2UN1} - t_{ftg} - Key_{h.d} = 2.50\ m$

Weight of soil over heel from GWL to top of heel: $W_{E5UN1} := \left(\gamma_{sat}\right) \cdot h_{E4UN1} \cdot \frac{\left(L_{E4UN1} + L_{cd}\right)}{2} \cdot B = 187.1 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E5locUN1} := b - \frac{L_{E4UN1}^{2} + L_{E4UN1} \cdot L_{cd} + L_{cd}^{2}}{3\left(L_{E4UN1} + L_{cd}\right)} = 4.30\ m$

$$\Sigma V_{SoilWaterUN1} := W_{H1UN1} + W_{E6UN1} + W_{E3UN1} + W_{E4UN1} + W_{E5UN1} + S_{UN1} = 258.7 \cdot kN$$

$$\Sigma M_{VertSoilWaterResistUN1} := W_{H1UN1} \cdot W_{E1locUN1} + W_{E6UN1} \cdot W_{E6locUN1} \cdots + W_{E3UN1} \cdot W_{E3locUN1} + W_{E4UN1} \cdot W_{E4locUN1} + W_{E5UN1} \cdot W_{E5locUN1} + S_{UN1} \cdot S_{UN1loc} = 1041.8\ m \cdot kN$$

THIS PAGE INTENTIONALLY LEFT BLANK
PLEASE GO TO THE NEXT PAGE

STABILITY ASSESSMENT:

LOAD CASE UN1

CHECK SLIDING ALONG HORIZONTAL SLIDING PLANE:

Summation of the vertical forces:

$$\Sigma V_{UN1} := \Sigma V_{conc} + \Sigma V_{SoilWaterUN1} + \Sigma V_{UpliftUN1} = 358.2 \cdot kN$$

Summation of the horizontal forces:

$$\Sigma H_{UN1} := \Sigma H_{SoildriveUN1} + \Sigma H_{SoilresistUN1} = -261.3 \cdot kN$$

Safety Factor for Sliding Horizontal Failure Plane

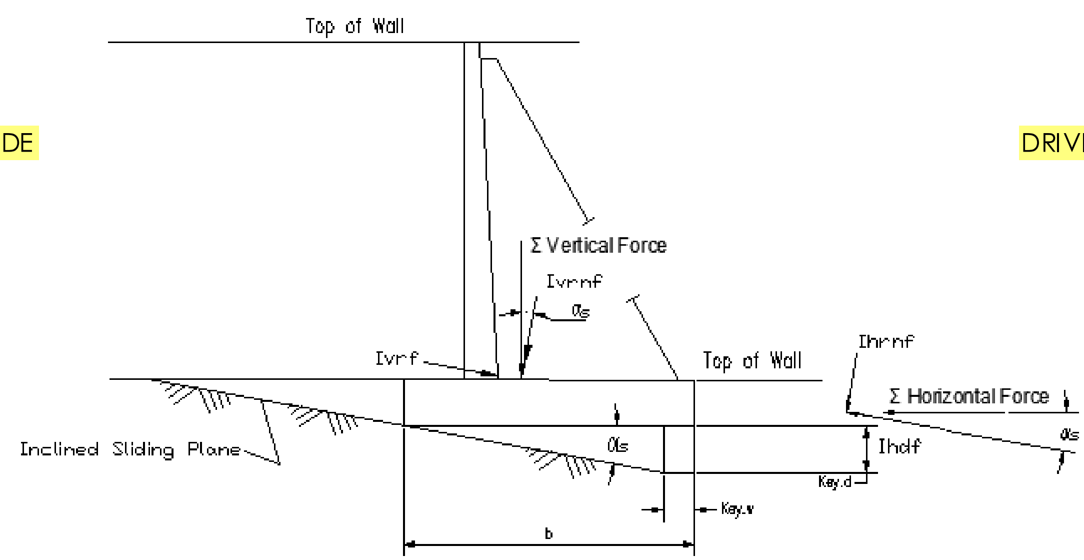
$$FS_{Horiz.SlidingUN1} := \frac{\left|\Sigma V_{UN1}\right| \cdot \tan\left(\phi_{rock} \cdot \frac{\pi}{180}\right)}{\left|\Sigma H_{UN1}\right|} = 0.67$$

$$FS_{Sliding.check1.UN1} := \begin{cases} \text{"OKAY "} & \text{if } FS_{Horiz.SlidingUN1} > FS_{sliding.reqUN1} \\ \text{"NG - key req'"} & \text{otherwise} \end{cases} = \text{"NG - key req'"}$$

CHECK FACTOR OF SAFETY SLIDING WITH KEY (INCLINED SLIDING PLANE):

RESISTING SIDE

DRIVING SIDE



TOE

HEEL

Ivrf=Inclined Resisting Force
Ivrnf=Inclined Resisting Normal Force
Ihrnf=Inclined Resisting Normal Force
Ihdf=Inclined Driving Force

$\alpha s = 0.381$ as degrees= $\alpha s \cdot \left(\frac{180}{\pi}\right) = 21.80$

(With properly engineered reinforced concrete Key, horizontal sliding plane thru Toe is protected, critical sliding plane is relocated to the INCLINED SLIDING PLANE FROM HEEL KEY To TOE, Bedrock Mass above this examing plane is mobilized by reinforced concrete key and combined into Structural Wedge.)

Resolve ΣV_{UN1} & ΣH_{UN1}

$$\Sigma V_{InclinedUN1} := \cos(\alpha s) \cdot \left(\left|\Sigma V_{UN1} + V_{rocksection}\right|\right) + \sin(\alpha s) \cdot \left|\Sigma H_{UN1}\right| = 548.5 \cdot kN$$

$$\Sigma H_{InclinedUN1} := \cos(\alpha s) \cdot \left|\Sigma H_{UN1}\right| - \sin(\alpha s) \cdot \left(\left|\Sigma V_{UN1} + V_{rocksection}\right|\right) = 62.1 \cdot kN$$

LOAD CASE UN1

Safety Factor for Sliding Inclined Failure Plane

$$FS_{InclinedlSlidingUN1} := \frac{\Sigma V_{InclinedUN1} \cdot \tan(\phi_r)}{\Sigma H_{InclinedUN1}} = 3.93$$

$$FS_{Sliding.check2.UN1} := \begin{cases} \text{"OKAY "} & \text{if } FS_{InclinedlSlidingUN1} > FS_{sliding.reqUN1} \\ \text{"NG - Revise Structure""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

CHECK FOUNDATION ECCENTRICITY:

Summation of the resisting moments about the toe:

$$\Sigma M_{resUN1} := \Sigma M_{conc} + \Sigma M_{VertSoilWaterResistUN1} + \Sigma M_{HorizSoilResistUN1} + \Sigma M_{rocksection} = 2595 \cdot kN \cdot m$$

Summation of the overturning moments about the toe:

$$\Sigma M_{oUN1} := \Sigma M_{LateralSoildriveUN1} + \Sigma M_{UpliftUN1} = -1036 \cdot kN \cdot m$$

Total moment: $\Sigma M_{UN1} := \Sigma M_{resUN1} + \Sigma M_{oUN1} = 1559.5 \cdot kN \cdot m$

Normal force to base: $\Sigma V_{InclinedUN1} = 548.5 \cdot kN$

Inclined Sliding Plane Length: $L_{incline} = 6.5 \cdot m$

Eccentricity (inclined plane): $ex_{UN1} := \frac{L_{incline}}{2} - \frac{\Sigma M_{UN1}}{\Sigma V_{InclinedUN1}} = 0.39\ m$

$Kern = 1.077\ m$

Eccentricity Check: $e_{check.UN1} := \begin{cases} \text{"Okay"} & \text{if } ex_{UN1} \le Kern \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"Okay"}$

CHECK FOUNDATION BEARING CAPACITY:

Base Section Modulus: $S_b = 6.96\ m^3$

Bearing Pressure Under Toe:

$$\sigma_{ToeUN1} := \begin{cases} \left[\frac{\Sigma V_{InclinedUN1}}{L_{incline} \cdot B} + \frac{(\Sigma V_{InclinedUN1} \cdot ex_{UN1})}{S_b}\right] & \text{if } \frac{\Sigma V_{InclinedUN1}}{L_{incline} \cdot B} \ge \frac{\Sigma V_{InclinedUN1} \cdot ex_{UN1}}{S_b} \\ \frac{2 \cdot \Sigma V_{InclinedUN1}}{B \cdot 3\left(\frac{b}{2} - ex_{UN1}\right)} & \text{otherwise} \end{cases} = 115.4 \cdot kPa$$

$$Bearing_{ChecktoeUN1} := \begin{cases} \text{"OKAY "} & \text{if } \sigma_{ToeUN1} < \sigma_{allowUN1} \\ \text{"NG""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

Bearing Pressure Under Heel:

$$\sigma_{HeelUN1} := \begin{cases} \left[\frac{\Sigma V_{InclinedUN1}}{L_{incline} \cdot B} - \frac{(\Sigma V_{InclinedUN1} \cdot ex_{UN1})}{S_b}\right] & \text{if } \frac{\Sigma V_{InclinedUN1}}{L_{incline} \cdot B} \ge \frac{\Sigma V_{InclinedUN1} \cdot ex_{UN1}}{S_b} \\ 0 & \text{otherwise} \end{cases} = 54.3 \cdot kPa$$

$$Bearing_{CheckheelUN1} := \left(\begin{cases} \text{"OKAY "} & \text{if } \sigma_{HeelUN1} < \sigma_{allowUN1} \wedge \sigma_{HeelUN1} > 0 \\ \text{"NG - perform cracked base analysis""} & \text{otherwise} \end{cases} \right) = \text{"OKAY "}$$

CHECK FLOATATION:

Safety Factor for Floatation:

$$FS_{FloatationUN1} := \frac{\Sigma V_{conc} + \Sigma V_{SoilWaterUN1}}{\left|\Sigma V_{UplliftUN1}\right|} = 2.35$$

$$FS_{Floatation.UN1.check} := \begin{cases} \text{"OKAY "} & \text{if } FS_{FloatationUN1} > FS_{req.UN1.flt} \\ \text{"Revise Structure""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

CHECK OVERTURNING

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.
Assumptions are made in order to compute overturning stablity of indetermine forces on monolith with key;
(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.
(b) The horizontal resisting force acting on the key, P.key, is that required for static equilibrium
(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1

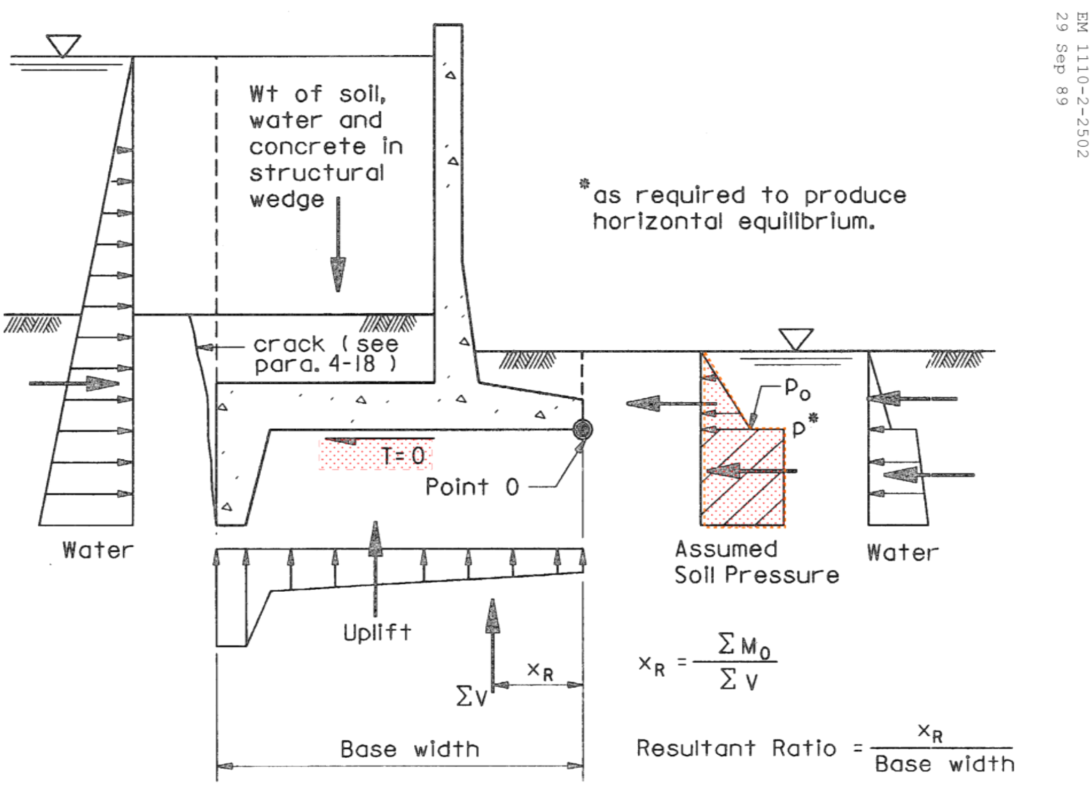


Figure 4-5. Forces for overturning analysis for wall with horizontal base and key

Modify Uplift for Overturning Analysis: **LOAD CASE UN1**

(Uplift is calculated along the concrete/rock contact using the Line of Creep method)

Water Pressure at h: $u_{h.UN1} := \Delta h_{g.hj.UN1} \cdot \gamma_w = 63.70 \cdot kPa$

Water Pressure at o: $u_{o.UN1} := \left(\Delta h_{g.no.UN1} - \dfrac{\Delta h_{g.r.UN1} \cdot L_{ho.UN1}}{L_{ho.UN1}}\right) \cdot \gamma_w = 24.5 \cdot kPa$

Head loss between point h and o: $\Delta h_{ho.UN1} := \Delta h_{g.r.UN1} \cdot \dfrac{L_{ho.UN1}}{L_{ho.UN1}} = 2\,m$

Length of concrete base (h -> o): $L_{baseho.UN1} := Key_{h.w} + Key_{h.d} + Key_{hdist} + Key_{t.d} + Key_{t.w} = 8\,m$

Head loss along h -> j: $\Delta h_{hj.UN1} := \Delta h_{ho.UN1} \cdot \dfrac{Key_{h.w}}{L_{baseho.UN1}} = 0.25\,m$

Water Pressure at j: $u_{j.UN1} := \left(\Delta h_{g.hj.UN1} - \Delta h_{hj.UN1}\right) \cdot \gamma_w = 61.25 \cdot kPa$

Head loss along h -> k: $\Delta h_{hjk.UN1} := \Delta h_{ho.UN1} \cdot \left(\dfrac{Key_{h.w} + Key_{h.d}}{L_{baseho.UN1}}\right) = 0.75\,m$

Water Pressure at k: $u_{k.UN1} := \left(\Delta h_{g.km.UN1} - \Delta h_{hjk.UN1}\right) \cdot \gamma_w = 36.75 \cdot kPa$

Head loss along h -> m: $\Delta h_{hjkm.UN1} := \Delta h_{ho.UN1} \cdot \left(\dfrac{Key_{h.w} + Key_{h.d} + Key_{hdist}}{L_{baseho.UN1}}\right) = 2\,m$

Water Pressure at m: $u_{m.UN1} := \left(\Delta h_{g.km.UN1} - \Delta h_{hjkm.UN1}\right) \cdot \gamma_w = 24.50 \cdot kPa$

Head loss along h -> n: $\Delta h_{hjkmn.UN1} := \Delta h_{ho.UN1} \cdot \left(\dfrac{Key_{h.w} + Key_{h.d} + Key_{hdist} + Key_{t.d}}{L_{baseho.UN1}}\right) = 2\,m$

Water Pressure at n: $u_{n.UN1} := \left(\Delta h_{g.no.UN1} - \Delta h_{hjkmn.UN1}\right) \cdot \gamma_w = 24.50 \cdot kPa$

Uplift under key at heel: $V_{ulkeyhUN1.OT} := \dfrac{\left(u_{h.UN1} + u_{j.UN1}\right) \cdot Key_{h.w}}{2} \cdot B \cdot -1 = -62.475 \cdot kN$

Moment Arm (from Point O): $V_{ulkeyhUN1loc.OT} := b - \dfrac{Key_{h.w} \cdot \left(2 \cdot u_{j.UN1} + u_{h.UN1}\right)}{3 \cdot \left(u_{j.UN1} + u_{h.UN1}\right)} = 5.503\,m$

Uplift under base: $V_{ulbaseUN1.OT} := \dfrac{\left(u_{k.UN1} + u_{m.UN1}\right) \cdot Key_{hdist}}{2} \cdot B \cdot -1 = -153.125 \cdot kN$

Moment Arm (from Point O): $V_{ulbaseUN1loc.OT} := b - Key_{h.w} - \dfrac{Key_{hdist} \cdot \left(2 \cdot u_{m.UN1} + u_{k.UN1}\right)}{3 \cdot \left(u_{m.UN1} + u_{k.UN1}\right)} = 2.667\,m$

Uplift under key at toe $V_{ulkeytUN1.OT} := \dfrac{\left(u_{n.UN1} + u_{o.UN1}\right) \cdot Key_{t.w}}{2} \cdot B \cdot -1 = 0 \cdot kN$

Moment Arm (from Point O): $V_{ulkeytUN1loc.OT} := \dfrac{Key_{t.w} \cdot \left(2 \cdot u_{n.UN1} + u_{o.UN1}\right)}{3 \cdot \left(u_{n.UN1} + u_{o.UN1}\right)} = 0$

$$\Sigma V_{UpliftUN1.OT} := V_{ulkeyhUN1.OT} + V_{ulbaseUN1.OT} + V_{ulkeytUN1.OT} = -216 \cdot kN$$

$$U_{UN1.loc.OT} := \frac{V_{ulkeyhUN1.OT} \cdot V_{ulkeyhUN1loc.OT} + V_{ulbaseUN1.OT} \cdot V_{ulbaseUN1loc.OT} + V_{ulkeytUN1.OT} \cdot V_{ulkeytUN1loc.OT}}{\Sigma V_{UpliftUN1.OT}} = 3.49\,m$$

$$\Sigma M_{UpliftUN1.OT} := \Sigma V_{UpliftUN1.OT} \cdot U_{UN1.loc.OT} = -752.1 \cdot kN \cdot m$$

Modify Lateral Water Pressure (Resisting) for Overturning Analysis:

(Resisting water pressure is calculated using the Line of Creep method)

Water Load at Key (heel): $H_{h2UN1.OT} := \frac{u_{k.UN1} + u_{j.UN1}}{2} \cdot Key_{h.d} B = 98.0 \cdot kN$

Moment Arm (from Point O): $H_{h2locUN1.OT} := \frac{Key_{h.d} \cdot (2 \cdot u_{k.UN1} + u_{j.UN1})}{3(u_{k.UN1} + u_{j.UN1})} + Key_{vdist} = -1.08\ m$

Water Load at Key (toe): $H_{h6UN1.OT} := \frac{u_{o.UN1} \cdot (UWSEL_{UN1} - Bot_{ftg} + Key_{t.d})}{2} \cdot B = 31 \cdot kN$

Moment Arm (from Point O): $H_{h6locUN1.OT} := \frac{UWSEL_{UN1} - Bot_{ftg} + Key_{t.d}}{3} = 0.83\ m$

$$\Sigma H_{waterresistUN1.OT} := H_{h2UN1.OT} + H_{h6UN1.OT} = 128.63 \cdot kN$$

$$H_{waterresistlocUN1.OT} := \frac{H_{h2UN1.OT} \cdot H_{h2locUN1.OT} + H_{h6UN1.OT} \cdot H_{h6locUN1.OT}}{\Sigma H_{waterresistUN1.OT}} = -0.627\ m$$

$$\Sigma M_{waterresistUN1.OT} := \Sigma H_{waterresistUN1.OT} \cdot H_{waterresistlocUN1.OT} = -80.65 \cdot kN \cdot m$$

Modify Lateral Soil Loads for Overturning Analysis:

(Lateral soil loads are calculated down to Point O instead of bottom of shear key)

Driving Soil Load (Headwater Side):

Surcharge Load: $E_{s1UN1.OT} := S1_{UN1} \cdot K_o \cdot (H_w + Key_{h.d} + Key_{vdist}) \cdot B \cdot -1 = -36.856 \cdot kN$

Moment Arm (from Point O): $E_{s1locUN1.OT} := \frac{H_w + Key_{h.d} + Key_{vdist}}{2} = 2.25\ m$

Moist Soil Load above GWL: $E_{h1UN1.OT} := \frac{\gamma_m \cdot K_o \cdot h_{1UN1}^{\ 2}}{2} B \cdot -1 = 0.0 \cdot kN$

Moment Arm (from Point O): $E_{h1locUN1.OT} := \frac{h_{1UN1}}{3} + h_{2UN1} + Key_{vdist} = 4.50\ m$

Saturated Soil Load below GWL:
(rectangular component) $E_{h2UN1.OT} := (\gamma_m \cdot K_o \cdot h_{1UN1}) \cdot (h_{2UN1} + Key_{vdist}) \cdot B \cdot -1 = 0.0 \cdot kN$

Moment Arm (from Point O): $E_{h2locUN1.OT} := \frac{h_{2UN1} + Key_{vdist}}{2} = 2.25\ m$

Saturated Soil Load below GWL:
(triangular component) $E_{h2aUN1.OT} := \frac{(\gamma_{sat} - \gamma_w) \cdot K_o \cdot (h_{2UN1} + Key_{vdist})^2}{2} \cdot B \cdot -1 = -67.4 \cdot kN$

Moment Arm (from Point O): $E_{h2alocUN1.OT} := \frac{h_{2UN1} + Key_{vdist}}{3} = 1.50\ m$

Resisting Soil Load (Tailwater Side):

(Determine resisting soil load based on depth variation between the keys (ie. Key_{vdist}). In case where key at heel is deeper than key at toe (ie. $Key_{vdist} < 0$), resisting soil load (p*) is assumed to produce horizontal equilibrium as per Figure 4-5 above. Resisting soil load (p_o) is neglected.)

Total Driving Force: $\Sigma H_{SoildriveUN1.OT} := E_{s1UN1.OT} + E_{h1UN1.OT} + E_{h2UN1.OT} + E_{h2aUN1.OT} + H_{h2UN1} = -311.3 \cdot kN$

Total Resisting Force: $\Sigma H_{waterresistUN1.OT} = 128.6 \cdot kN$

Assumed Soil Load p*: $E_{h8UN1a.OT} := \left(\Sigma H_{SoildriveUN1.OT} + \Sigma H_{waterresistU1.OT}\right) \cdot -1 = 182.701 \cdot kN$

Moment Arm (from Point O): $E_{h8UN1a.loc.OT} := \dfrac{Key_{vdist}}{2} = -1\ m$

$$E_{h8UN1.OT} := \begin{cases} E_{h8UN1a.OT} & \text{if } Key_{vdist} < 0 \\ \Sigma H_{SoilresistUN1} - H_{h6UN1} - H_{h6aUN1} & \text{otherwise} \end{cases} = 182.701 \cdot kN$$

$$\Sigma M_{SoilresistUN1.OT} := \begin{cases} E_{h8UN1a.OT} \cdot E_{h8UN1a.loc.OT} & \text{if } Key_{vdist} < 0 \\ \Sigma M_{HorizSoilResistUN1} - H_{h6UN1} \cdot H_{h6locUN1} - H_{h6aUN1} \cdot H_{h6alocUN1} & \text{otherwise} \end{cases} = -182.701 \cdot kN \cdot m$$

Sum of Moment about Point O:

$$\Sigma M_{LateraldriveUN1.OT} := E_{s1UN1.OT} \cdot E_{s1locUN1.OT} + E_{h1UN1.OT} \cdot E_{h1locUN1.OT} + E_{h2UN1.OT} \cdot E_{h2locUN1.OT} \ldots + E_{h2aUN1.OT} \cdot E_{h2alocUN1.OT} + H_{h2UN1} \cdot H_{h2locUN1} = -218.6 \cdot kN \cdot m$$

$$\Sigma M_{LateralresistUN1.OT} := \Sigma M_{waterresistUN1.OT} + \Sigma M_{SoilresistUN1.OT} = -263.3 \cdot kN \cdot m$$

Total moment:

$$\Sigma M_{UN1.OT} := \Sigma M_{conc} + \Sigma M_{VertSoilWaterResistUN1} + \Sigma M_{UpliftUN1.OT} + \Sigma M_{LateraldriveUN1.OT} + \Sigma M_{LateralresistUN1.OT} = 993.1 \cdot kN \cdot m$$

Total Vertical Force: $\Sigma V_{UN1.OT} := \Sigma V_{conc} + \Sigma V_{SoilWaterUN1} + \Sigma V_{UplliftUN1.OT} = 407.2 \cdot kN$

Distance X_R: EM 1110-2-2502 Eq.4-1 $X_{R.UN1} := \dfrac{\Sigma M_{UN1.OT}}{\Sigma V_{UN1.OT}} = 2.439\ m$

Overturning Resultant Ratio $Ratio_{UN1.OT} := \dfrac{X_{R.UN1}}{b} = 0.41$

$$Ratio_{UN1.OT.check} := \begin{cases} \text{"OKAY "} & \text{if } Ratio_{UN1.OT} > X_{R.reqUN1} \\ \text{"Revise Structure""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

CHECK FOUNDATION ECCENTRICITY (HORIZONTAL PLANE):

Eccentricity (horizontal plan): $ex_{UN1.OT} := \dfrac{b}{2} - \dfrac{\Sigma M_{UN1.OT}}{\Sigma V_{UN1.OT}} = 0.56\ m$ $Kern_{OT} = 1\ m$

Eccentricity Check:

$$e_{check.UN1.OT} := \begin{cases} \text{"Okay"} & \text{if } ex_{UN1} \le Kern_{OT} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"Okay"}$$

CHECK FOUNDATION BEARING CAPACITY (HORIZONTAL PLANE):

Base Section Modulus: $S_{b.OT} = 6\,m^3$

Bearing Pressure Under Toe:

$$\sigma_{ToeUN1.OT} := \begin{cases} \left(\dfrac{\Sigma V_{UN1.OT}}{b \cdot B} + \dfrac{\Sigma V_{UN1.OT} \cdot ex_{UN1.OT}}{S_{b.OT}}\right) & \text{if } \dfrac{\Sigma V_{UN1.OT}}{b \cdot B} \geq \dfrac{\Sigma V_{UN1.OT} \cdot ex_{UN1.OT}}{S_{b.OT}} \\ \dfrac{2 \cdot \Sigma V_{UN1.OT}}{B \cdot 3\left(\dfrac{b}{2} - ex_{UN1.OT}\right)} & \text{otherwise} \end{cases} = 106.0 \cdot kPa$$

$$Bearing_{ChecktoeUN1.OT} := \begin{cases} \text{"OKAY "} & \text{if } \sigma_{ToeUN1.OT} < \sigma_{allowUN1} \\ \text{"NG - for reference only""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

Bearing Pressure Under Heel:

$$\sigma_{HeelUN1.OT} := \begin{cases} \left(\dfrac{\Sigma V_{UN1.OT}}{b \cdot B} - \dfrac{\Sigma V_{UN1.OT} \cdot ex_{UN1.OT}}{S_{b.OT}}\right) & \text{if } \dfrac{\Sigma V_{UN1.OT}}{b \cdot B} \geq \dfrac{\Sigma V_{UN1.OT} \cdot ex_{UN1.OT}}{S_{b.OT}} \\ 0 & \text{otherwise} \end{cases} = 29.8 \cdot kPa$$

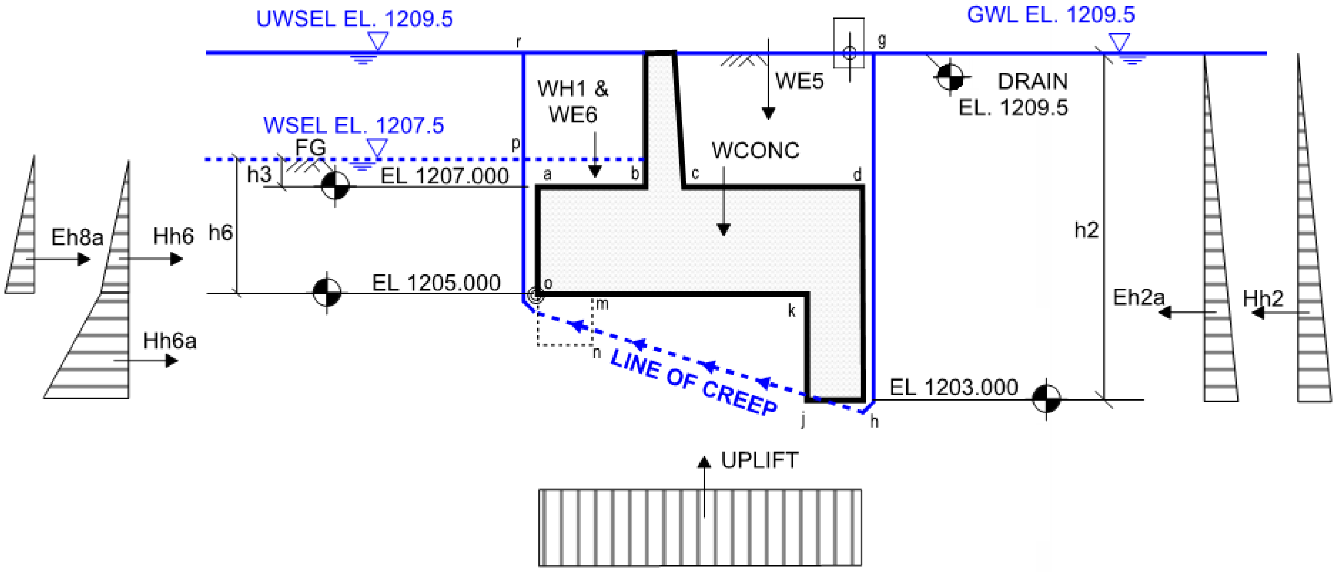
$$Bearing_{CheckheelUN1.OT} := \left(\begin{cases} \text{"OKAY "} & \text{if } \sigma_{HeelUN1.OT} < \sigma_{allowUN1} \wedge \sigma_{HeelUN1.OT} > 0 \\ \text{"NG - for reference only""} & \text{otherwise} \end{cases}\right) = \text{"OKAY "}$$

SUMMARY OF STABILITY ASSESSMENT:

LOAD CASE UN1

Sliding Factor of Safety: (Horizontal Plane - Ref only)	$FS_{Horiz.SlidingUN1} = 0.67$	$FS_{Sliding.check1.UN1}$ = "NG - key req""
Sliding Factor of Safety: (Inclined Plane)	$FS_{InclinedlSlidingUN1} = 3.93$	$FS_{Sliding.check2.UN1}$ = "OKAY "
Eccentricity: (Inclined Plane)	$ex_{UN1} = 0.39\ m$	$e_{check.UN1}$ = "Okay"
Bearing Pressure At Heel: (Inclined Plane)	$\sigma_{HeelUN1} = 54 \cdot kPa$	$Bearing_{CheckheelUN1}$ = "OKAY "
Bearing Pressure At Toe: (Inclined Plane)	$\sigma_{ToeUN1} = 115 \cdot kPa$	$Bearing_{ChecktoeUN1}$ = "OKAY "
Flotation Factor of Safety (horizontal plane)	$FS_{FloatationUN1} = 2.35$	$FS_{Floatation.UN1.check}$ = "OKAY "
Overturning Resultant Ratio: (horizontal plane)	$Ratio_{UN1.OT} = 0.41$	$Ratio_{UN1.OT.check}$ = "OKAY "
Eccentricity: (horizontal plane - Ref only)	$ex_{UN1.OT} = 0.56\ m$	$e_{check.UN1.OT}$ = "Okay"
Bearing Pressure At Heel: (horizontal plane - Ref only)	$\sigma_{HeelUN1.OT} = 30 \cdot kPa$	$Bearing_{CheckheelUN1.OT}$ = "OKAY "
Bearing Pressure At Toe: (horizontal plane - Ref only)	$\sigma_{ToeUN1.OT} = 106 \cdot kPa$	$Bearing_{ChecktoeUN1.OT}$ = "OKAY "

LOAD CASE UN2 - INEFFECTIVE DRAIN



UN2 DESIGN CASE

LOAD CASE UN2 ACCEPTANCE PARAMETERS

FS sliding:

Unusual (UN) 1.3 (without cohesion) (Table 3-3, USACE EM 1110-2-2100)

Resultant Location:

Unsual (UN) Inside middle third ~100% base in compression

Required Factor of Safety for Sliding: $FS_{sliding.reqUN2} := 1.3$ (Without Cohesion)

Allowable rock bearing pressure: $\sigma_{allowUN2} := 1470kPa$ (Section 5.2, Design Criteria EM 1110-2-2100 Section 3-10)

Overturning Required Resultant Ratio: $X_{R.reqUN2} := 0.333$ (EM 1110-2-2502, Figure 4-4)

Required Factor of Safety for Floatation $FS_{req.UN2.flt} := 1.3$

SOIL HEIGHTS and Water Levels:

LOAD CASE UN2

Heel Conditions:

Groundwater Elevation at Heel: $GWL_{UN2} := 1209.5m$

Distance from Finish Grade to Groundwater at Heel: $h_{1UN2} := \left[T_w - GWL_{UN2} + \left(L_{cd} + t_{wb} - t_{wt}\right)\cdot \tan(\beta)\right] = 0.00\ m$

Distance from Water Surface to Bottom of Footing at Heel: $h_{2UN2} := GWL_{UN2} - Bot_{ftg} + Key_{h.d} = 6.50\ m$

Toe Conditions:

Water Surface Elevation at Toe: $WSEL_{UN2} := 1207.5m$

Water Surface Elevation at Toe for Uplift: $UWSEL_{UN2} := 1209.5\cdot m$

Finish Grade at Toe providing lateral resistance: $FG_{toeUN2} := 1207.5\cdot m$

Soil Depth Above top of footing: $h_{3aUN2} := FG_{toeUN2} - Top_{ftg} = 0.5\ m$

$$h_{3UN2} := \begin{cases} h_{3aUN2} & \text{if } FG_{toeUN2} - Top_{ftg} \ge 0 \\ 0 & \text{otherwise} \end{cases} = 0.5$$

Resisting Fill at Toe: $h_{4UN2} := FG_{toeUN2} - Bot_{ftg} + Key_{t.d} = 2.50\ m$

Distance from Water Level to Top of Footing: $h_{5UN2} := WSEL_{UN2} - Top_{ftg} = 0.50\ m$

Distance from Water Surface to Bottom of Toe Key: $h_{6UN2} := WSEL_{UN2} - Bot_{ftg} + Key_{t.d} = 2.50\ m$

Soil Depth Above WSEL: $h_{7aUN2} := FG_{toeUN2} - WSEL_{UN2} = 0\ m$

$$h_{7UN2} := \begin{cases} h_{7aUN2} & \text{if } FG_{toeUN2} - WSEL_{UN2} \ge 0 \\ 0 & \text{otherwise} \end{cases} = 0$$

Soil Depth Below WSEL:

$$h_{8UN2} := \begin{cases} WSEL_{UN2} - Bot_{ftg} + Key_{t.d} & \text{if } FG_{toeUN2} - WSEL_{UN2} \ge 0 \\ h_{4UN2} & \text{otherwise} \end{cases} = 2.5$$

For Line of Creep Method: $L_{ho.UN2} := \sqrt{b^2 + \left(Key_{h.d} - Key_{t.d}\right)^2} = 6.325\ m$

Head Loss from Point g:

$\Delta h_{g.hj.UN2} := h_{2UN2} = 6.5\ m$ (to point h & j)

$\Delta h_{g.km.UN2} := GWL_{UN2} - Bot_{ftg} = 4.5\ m$ (to point k & m)

$\Delta h_{g.no.UN2} := GWL_{UN2} - Bot_{ftg} + Key_{t.d} = 4.5\ m$ (to point n & o)

$\Delta h_{g.p.UN2} := GWL_{UN2} - FG_{toeUN2} = 2\ m$ (to point p)

$\Delta h_{g.r.UN2} := GWL_{UN2} - UWSEL_{UN2} = 0\ m$ (to point r)

Surcharge

Surcharge on Heel: $S1_{UN2} := 0.0\ \frac{kN}{m^2}$

Calculate Soil Lateral Pressure Coefficients:

LOAD CASE UN2

For all load cases except seismic, soil loading to be based on At-Rest Condition.
Calculate at-rest pressure coefficient Ko based on Jaky's (1944) equation.

Soil At Rest Static Coefficient: $K_o := \dfrac{1 - \sin(\phi)}{1 + \sin(\beta)} = 0.546$ (Eq. 3-6, USACE EM 1110-2-2502)

Lateral - Driving Force

Static At-Rest:

Surcharge Load: $E_{s1UN2} := S1_{UN2} \cdot K_o \cdot \left(H_w + Key_{h.d}\right) \cdot B \cdot -1 = 0 \cdot kN$

Moment Arm (from Point O): $E_{s1locUN2} := \dfrac{H_w + Key_{h.d}}{2} + Key_{vdist} = 1.25\ m$

Moist Soil Load above GWL: $E_{h1UN2} := \dfrac{\gamma_m \cdot K_o \cdot h_{1UN2}^{\ 2}}{2} B \cdot -1 = 0.0 \cdot kN$

Moment Arm (from Point O): $E_{h1locUN2} := \dfrac{h_{1UN2}}{3} + h_{2UN2} + Key_{vdist} = 4.50\ m$

Saturated Soil Load below GWL:
(rectangular component)

$E_{h2UN2} := \left(\gamma_m \cdot K_o \cdot h_{1UN2}\right) \cdot h_{2UN2} \cdot B \cdot -1 = 0.0 \cdot kN$

Moment Arm (from Point O): $E_{h2locUN2} := \dfrac{h_{2UN2}}{2} + Key_{vdist} = 1.25\ m$

Saturated Soil Load below GWL:
(triangular component)

$E_{h2aUN2} := \dfrac{\left(\gamma_{sat} - \gamma_w\right) \cdot K_o \cdot h_{2UN2}^{\ 2}}{2} \cdot B \cdot -1 = -140.7 \cdot kN$

Moment Arm (from Point O): $E_{h2alocUN2} := \dfrac{h_{2UN2}}{3} + Key_{vdist} = 0.17\ m$

Lateral Water Load:

Water Load GWL to Bottom of Keys:

$$H_{h2UN2} := \begin{cases} \dfrac{\gamma_w \cdot h_{2UN2}^{\ 2}}{2} \cdot B \cdot -1 & \text{if } Key_{vdist} < 0 \\ \dfrac{\gamma_w \cdot \left(h_{2UN2} + Key_{vdist}\right)^2}{2} \cdot B \cdot -1 & \text{otherwise} \end{cases} = -207.0 \cdot kN$$

Moment Arm (from Point O):

$$H_{h2locUN2} := \begin{cases} \dfrac{h_{2UN2}}{3} + Key_{vdist} & \text{if } Key_{vdist} < 0 \\ \dfrac{h_{2UN2} + Key_{vdist}}{3} & \text{otherwise} \end{cases} = 0.17 \cdot m$$

$$\Sigma H_{SoildriveUN2} := E_{s1UN2} + E_{h1UN2} + E_{h2UN2} + E_{h2aUN2} + H_{h2UN2} = -347.7 \cdot kN$$

$$\Sigma M_{LateralSoildriveUN2} := E_{s1UN2} \cdot E_{s1locUN2} + E_{h1UN2} \cdot E_{h1locUN2} + E_{h2UN2} \cdot E_{h2locUN2} \cdots + E_{h2aUN2} \cdot E_{h2alocUN2} + H_{h2UN2} \cdot H_{h2locUN2} = -58.0\ m \cdot kN$$

Lateral - Resisting Force

LOAD CASE UN2

Lateral Water Load:

Water Load WSEL to Bot. of Toe Key:

$$H_{h6UN2} := \frac{\gamma_w \cdot h_{6UN2}^{\;2}}{2} \cdot B = 30.6 \cdot kN$$

Moment Arm (from Point O):

$$H_{h6locUN2} := \frac{h_{6UN2}}{3} = 0.83\ m$$

Water Load between Keys (if any)

$$H_{h6aUN2} := \begin{cases} \frac{\left(h_{6UN2} + h_{2UN2}\right) \cdot -Key_{vdist}}{2} \cdot \gamma_w \cdot B & \text{if } Key_{vdist} < 0 \\ 0 & \text{otherwise} \end{cases} = 88.2 \cdot kN$$

Moment Arm (from Point O):

$$H_{h6alocUN2} := \begin{cases} \frac{Key_{vdist} \cdot \left(2 \cdot h_{2UN2} + h_{6UN2}\right)}{3\left(h_{2UN2} + h_{6UN2}\right)} & \text{if } Key_{vdist} < 0 \\ 0 & \text{otherwise} \end{cases} = -1.15 \cdot m$$

Lateral Soil Load:

Moist Soil Load above WSEL:

$$E_{h7UN2} := \frac{\gamma_m \cdot K_o \cdot h_{7UN2}^{\;2}}{2} B = 0.0 \cdot kN$$

Moment Arm (from bot. of toe key):

$$E_{h7locUN2} := h_{6UN2} + \frac{h_{7UN2}}{3} + Key_{vdist} = 0.50\ m$$

Saturated Soil Load below WSEL:
(rectangular component)

$$E_{h8UN2} := \left(\gamma_m \cdot K_o \cdot h_{7UN2}\right) \cdot h_{8UN2} \cdot B = 0.0 \cdot kN$$

Moment Arm (from bot. of toe key):

$$E_{h8locUN2} := \frac{h_{8UN2}}{2} = 1.25\ m$$

Saturated Soil Load below WSEL:
(triangular component)

$$E_{h8aUN2} := \frac{\left[\left(\gamma_{sat} - \gamma_w\right) \cdot K_o\right] \cdot h_{8UN2}^{\;2}}{2} \cdot B = 20.8 \cdot kN$$

Moment Arm (from bot. of footing):

$$E_{h8alocUN2} := \frac{h_{8UN2}}{3} = 0.83\ m$$

$$\Sigma H_{SoilresistUN2} := H_{h6UN2} + H_{h6aUN2} + E_{h7UN2} + E_{h8UN2} + E_{h8aUN2} = 139.6 \cdot kN$$

$$\Sigma M_{HorizSoilResistUN2} := H_{h6UN2} \cdot H_{h6locUN2} + H_{h6aUN2} \cdot H_{h6alocUN2} + E_{h7UN2} \cdot E_{h7locUN2} \cdots + E_{h8UN2} \cdot E_{h8locUN2} + E_{h8aUN2} \cdot E_{h8alocUN2} = -58.4\ m \cdot kN$$

Vertical Force:

UPLIFT: Linear distribution from water at heel to water at toe:

$$\Sigma V_{UplliftUN2} := \left[\left(UWSEL_{UN2} - Bot_{ftg} + Key_{t.d}\right) + h_{2UN2}\right] \cdot \frac{b}{2} \cdot \gamma_w \cdot B \cdot -1 = -323.4 \cdot kN$$

Moment Arm (from Point O):

$$V_{UpliftUN2aloc} := \frac{b \cdot \left[2 \cdot h_{2UN2} + \left(UWSEL_{UN2} - Bot_{ftg} + Key_{t.d}\right)\right]}{3\left[h_{2UN2} + \left(UWSEL_{UN2} - Bot_{ftg} + Key_{t.d}\right)\right]} = 3.182\ m$$

$$\Sigma M_{UpliftUN2} := \Sigma V_{UplliftUN2} \cdot V_{UpliftUN2aloc} = -1029 \cdot kN \cdot m$$

Weight of soil and water over toe:

Water Above the Top of Footing: $W_{H1UN2} := \gamma_w \cdot h_{5UN2} \cdot L_{ab} \cdot B = 9.8 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E1locUN2} := \frac{L_{ab}}{2} = 1\ m$

Soil above top of footing: $W_{E6UN2} := \gamma_b \cdot h_{3UN2} \cdot L_{ab} \cdot B = 12.2 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E6locUN2} := \frac{L_{ab}}{2} = 1\ m$

Vertical Load Due to Surcharge: $S_{UN2} := S1_{UN2} \cdot L_{cd} \cdot B = 0 \cdot kN$ $\quad S_{UN2loc} := b - \frac{L_{cd}}{2} = 4.35\ m$

Weight of soil and water over heel:

Moist Soil for sloped grade above top of wall:

Length of sloped portion of soil above top of wall: $L_{E3UN2} := \left(L_{cd} + t_{wb} - t_{wt}\right) = 3.50\ m$

Height of sloped soil above top of wall over heel: $h_{E3locUN2} := \left(L_{E3UN2}\right) \cdot \tan(\beta) = 0.00\ m$

Weight of sloped soil above top of wall: $W_{E3UN2} := \frac{\gamma_m}{2} \cdot h_{E3locUN2} \cdot L_{E3UN2} \cdot B = 0.0 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E3locUN2} := L_{ab} + t_{wt} + \frac{2}{3} \cdot L_{E3UN2} = 4.83\ m$

Moist soil from top of wall to groundwater level:

Height of soil from top of wall and top of GWL: $h_{1UN2} = 0.00\ m$

Length from edge of wall at GWL to edge of heel: $L_{E4UN2} := L_{E3UN2} - \left(h_{1UN2} \cdot S_{batter}\right) = 3.50\ m$

Weight of soil over heel from top of wall to GWL: $W_{E4UN2} := \gamma_m \cdot h_{1UN2} \cdot \frac{\left(L_{E3UN2} + L_{E4UN2}\right)}{2} \cdot B = 0.0 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E4locUN2} := b - \frac{L_{E3UN2}^2 + L_{E3UN2} \cdot L_{E4UN2} + L_{E4UN2}^2}{3\left(L_{E3UN2} + L_{E4UN2}\right)} = 4.25\ m$

Saturated soil from groundwater to top of footing:

Height of soil from GWL to top of heel: $h_{E4UN2} := h_{2UN2} - t_{ftg} - Key_{h.d} = 2.50\ m$

Weight of soil over heel from GWL to top of heel: $W_{E5UN2} := \left(\gamma_{sat}\right) \cdot h_{E4UN2} \cdot \frac{\left(L_{E4UN2} + L_{cd}\right)}{2} \cdot B = 187.1 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E5locUN2} := b - \frac{L_{E4UN2}^2 + L_{E4UN2} \cdot L_{cd} + L_{cd}^2}{3\left(L_{E4UN2} + L_{cd}\right)} = 4.30\ m$

$\Sigma V_{SoilWaterUN2} := W_{H1UN2} + W_{E6UN2} + W_{E3UN2} + W_{E4UN2} + W_{E5UN2} + S_{UN2} = 209.1 \cdot kN$

$$\Sigma M_{VertSoilWaterResistUN2} := W_{H1UN2} \cdot W_{E1locUN2} + W_{E6UN2} \cdot W_{E6locUN2} \cdots + W_{E3UN2} \cdot W_{E3locUN2} + W_{E4UN2} \cdot W_{E4locUN2} + W_{E5UN2} \cdot W_{E5locUN2} + S_{UN2} \cdot S_{UN2loc} = 826.3\ m \cdot kN$$

THIS PAGE INTENTIONALLY LEFT BLANK
PLEASE GO TO THE NEXT PAGE

STABILITY ASSESSMENT:

LOAD CASE UN2

CHECK SLIDING ALONG HORIZONTAL SLIDING PLANE:

Summation of the vertical forces:

$$\Sigma V_{UN2} := \Sigma V_{conc} + \Sigma V_{SoilWaterUN2} + \Sigma V_{UpliftUN2} = 249.8 \cdot kN$$

Summation of the horizontal forces:

$$\Sigma H_{UN2} := \Sigma H_{SoildriveUN2} + \Sigma H_{SoilresistUN2} = -208.1 \cdot kN$$

Safety Factor for Sliding Horizontal Failure Plane

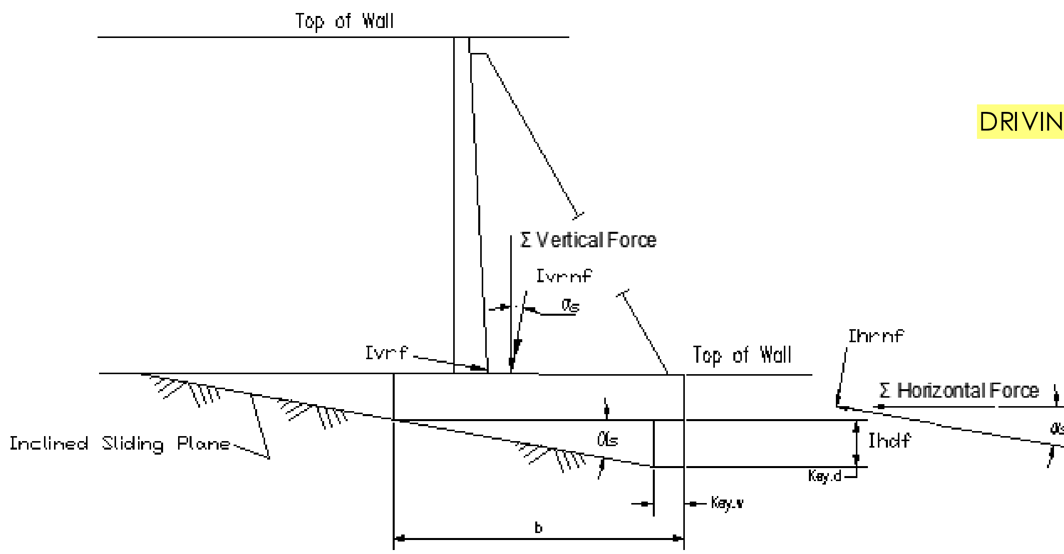
$$FS_{Horiz.SlidingUN2} := \frac{\left|\Sigma V_{UN2}\right| \cdot \tan\left(\phi_{rock} \cdot \frac{\pi}{180}\right)}{\left|\Sigma H_{UN2}\right|} = 0.59$$

$$FS_{Sliding.check1.UN2} := \begin{cases} \text{"OKAY "} & \text{if } FS_{Horiz.SlidingUN2} > FS_{sliding.reqUN2} \\ \text{"NG - key req'"} & \text{otherwise} \end{cases} = \text{"NG - key req'"}$$

CHECK FACTOR OF SAFETY SLIDING WITH KEY (INCLINED SLIDING PLANE):

RESISTING SIDE

DRIVING SIDE



TOE

HEEL

Ivrf=Inclined Resisting Force
Ivrnf=Inclined Resisting Normal Force
Ihrnf=Inclined Resisting Normal Force
Ihdf=Inclined Driving Force

$\alpha s = 0.381$ as degrees= $\alpha s \cdot \left(\frac{180}{\pi}\right) = 21.80$

(With properly engineered reinforced concrete Key, horizontal sliding plane thru Toe is protected, critical sliding plane is relocated to the INCLINED SLIDING PLANE FROM HEEL KEY To TOE, Bedrock Mass above this examing plane is mobilized by reinforced concrete key and combined into Structural Wedge.)

Resolve ΣV_{UN2} & ΣH_{UN2}

$$\Sigma V_{InclinedUN2} := \cos(\alpha s) \cdot \left(\left|\Sigma V_{UN2} + V_{rocksection}\right|\right) + \sin(\alpha s) \cdot \left|\Sigma H_{UN2}\right| = 428.1 \cdot kN$$

$$\Sigma H_{InclinedUN2} := \cos(\alpha s) \cdot \left|\Sigma H_{UN2}\right| - \sin(\alpha s) \cdot \left(\left|\Sigma V_{UN2} + V_{rocksection}\right|\right) = 52.9 \cdot kN$$

LOAD CASE UN2

Safety Factor for Sliding Inclined Failure Plane

$$FS_{InclinedISlidingUN2} := \frac{\Sigma V_{InclinedUN2} \cdot \tan(\phi_r)}{\Sigma H_{InclinedUN2}} = 3.60$$

$$FS_{Sliding.check2.UN2} := \begin{cases} \text{"OKAY"} & \text{if } FS_{InclinedISlidingUN2} > FS_{sliding.reqUN2} \\ \text{"NG - Revise Structure""} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

CHECK FOUNDATION ECCENTRICITY:

Summation of the resisting moments about the toe:

$$\Sigma M_{resUN2} := \Sigma M_{conc} + \Sigma M_{VertSoilWaterResistUN2} + \Sigma M_{HorizSoilResistUN2} + \Sigma M_{rocksection} = 2380 \cdot kN \cdot m$$

Summation of the overturning moments about the toe:

$$\Sigma M_{oUN2} := \Sigma M_{LateralSoildriveUN2} + \Sigma M_{UpliftUN2} = -1087 \cdot kN \cdot m$$

Total moment: $\Sigma M_{UN2} := \Sigma M_{resUN2} + \Sigma M_{oUN2} = 1293.0\ m \cdot kN$

Normal force to base: $\Sigma V_{InclinedUN2} = 428.1 \cdot kN$

Inclined Sliding Plane Length: $L_{incline} = 6.5 \cdot m$

Eccentricity (inclined plane): $ex_{UN2} := \frac{L_{incline}}{2} - \frac{\Sigma M_{UN2}}{\Sigma V_{InclinedUN2}} = 0.21\ m$

$Kern = 1.077\ m$

Eccentricity Check: $e_{check.UN2} := \begin{cases} \text{"Okay"} & \text{if } ex_{UN2} \le Kern \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"Okay"}$

CHECK FOUNDATION BEARING CAPACITY:

Base Section Modulus: $S_b = 6.96\ m^3$

Bearing Pressure Under Toe:

$$\sigma_{ToeUN2} := \begin{cases} \left[\frac{\Sigma V_{InclinedUN2}}{L_{incline} \cdot B} + \frac{(\Sigma V_{InclinedUN2} \cdot ex_{UN2})}{S_b}\right] & \text{if } \frac{\Sigma V_{InclinedUN2}}{L_{incline} \cdot B} \ge \frac{\Sigma V_{InclinedUN2} \cdot ex_{UN2}}{S_b} \\ \frac{2 \cdot \Sigma V_{InclinedUN2}}{B \cdot 3\left(\frac{b}{2} - ex_{UN2}\right)} & \text{otherwise} \end{cases} = 79.2 \cdot kPa$$

$$Bearing_{ChecktoeUN2} := \begin{cases} \text{"OKAY"} & \text{if } \sigma_{ToeUN2} < \sigma_{allowUN2} \\ \text{"NG""} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

Bearing Pressure Under Heel:

$$\sigma_{HeelUN2} := \begin{cases} \left[\frac{\Sigma V_{InclinedUN2}}{L_{incline} \cdot B} - \frac{(\Sigma V_{InclinedUN2} \cdot ex_{UN2})}{S_b}\right] & \text{if } \frac{\Sigma V_{InclinedUN2}}{L_{incline} \cdot B} \ge \frac{\Sigma V_{InclinedUN2} \cdot ex_{UN2}}{S_b} \\ 0 & \text{otherwise} \end{cases} = 53.3 \cdot kPa$$

$$Bearing_{CheckheelUN2} := \left(\begin{cases} \text{"OKAY"} & \text{if } \sigma_{HeelUN2} < \sigma_{allowUN2} \wedge \sigma_{HeelUN2} > 0 \\ \text{"NG - perform cracked base analysis""} & \text{otherwise} \end{cases}\right) = \text{"OKAY"}$$

CHECK FLOATATION:

Safety Factor for Floatation:

$$FS_{FloatationUN2} := \frac{\Sigma V_{conc} + \Sigma V_{SoilWaterUN2}}{\left|\Sigma V_{UpliftUN2}\right|} = 1.77$$

$$FS_{Floatation.UN2.check} := \begin{cases} \text{"OKAY "} & \text{if } FS_{FloatationUN2} > FS_{req.UN2.flt} \\ \text{"Revise Structure""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

CHECK OVERTURNING

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.
Assumptions are made in order to compute overturning stablity of indetermine forces on monolith with key;
(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.
(b) The horizontal resisting force acting on the key, P.key, is that required for static equilibrium
(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1

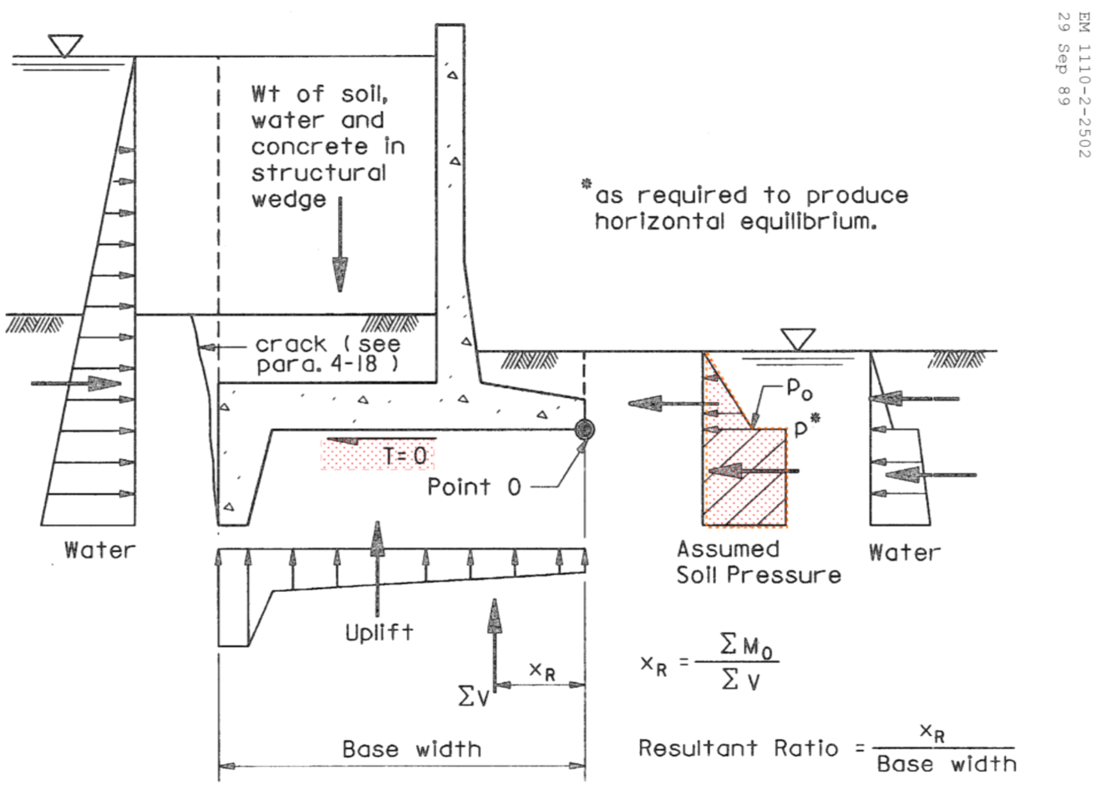


Figure 4-5. Forces for overturning analysis for wall with horizontal base and key

Modify Uplift for Overturning Analysis: **LOAD CASE UN2**

(Uplift is calculated along the concrete/rock contact using the Line of Creep method)

Water Pressure at h: $u_{h.UN2} := \Delta h_{g.hj.UN2} \cdot \gamma_w = 63.70 \cdot kPa$

Water Pressure at o: $u_{o.UN2} := \left(\Delta h_{g.no.UN2} - \frac{\Delta h_{g.r.UN2} \cdot L_{ho.UN2}}{L_{ho.UN2}} \right) \cdot \gamma_w = 44.1 \cdot kPa$

Head loss between point h and o: $\Delta h_{ho.UN2} := \Delta h_{g.r.UN2} \cdot \frac{L_{ho.UN2}}{L_{ho.UN2}} = 0\, m$

Length of concrete base (h -> o): $L_{baseho.UN2} := Key_{h.w} + Key_{h.d} + Key_{hdist} + Key_{t.d} + Key_{t.w} = 8\, m$

Head loss along h -> j: $\Delta h_{hj.UN2} := \Delta h_{ho.UN2} \cdot \frac{Key_{h.w}}{L_{baseho.UN2}} = 0\, m$

Water Pressure at j: $u_{j.UN2} := \left(\Delta h_{g.hj.UN2} - \Delta h_{hj.UN2} \right) \cdot \gamma_w = 63.70 \cdot kPa$

Head loss along h -> k: $\Delta h_{hjk.UN2} := \Delta h_{ho.UN2} \cdot \left(\frac{Key_{h.w} + Key_{h.d}}{L_{baseho.UN2}} \right) = 0\, m$

Water Pressure at k: $u_{k.UN2} := \left(\Delta h_{g.km.UN2} - \Delta h_{hjk.UN2} \right) \cdot \gamma_w = 44.10 \cdot kPa$

Head loss along h -> m: $\Delta h_{hjkm.UN2} := \Delta h_{ho.UN2} \cdot \left(\frac{Key_{h.w} + Key_{h.d} + Key_{hdist}}{L_{baseho.UN2}} \right) = 0\, m$

Water Pressure at m: $u_{m.UN2} := \left(\Delta h_{g.km.UN2} - \Delta h_{hjkm.UN2} \right) \cdot \gamma_w = 44.10 \cdot kPa$

Head loss along h -> n: $\Delta h_{hjkmn.UN2} := \Delta h_{ho.UN2} \cdot \left(\frac{Key_{h.w} + Key_{h.d} + Key_{hdist} + Key_{t.d}}{L_{baseho.UN2}} \right) = 0\, m$

Water Pressure at n: $u_{n.UN2} := \left(\Delta h_{g.no.UN2} - \Delta h_{hjkmn.UN2} \right) \cdot \gamma_w = 44.10 \cdot kPa$

Uplift under key at heel: $V_{ulkeyhUN2.OT} := \frac{\left(u_{h.UN2} + u_{j.UN2} \right) \cdot Key_{h.w}}{2} \cdot B \cdot -1 = -63.7 \cdot kN$

Moment Arm (from Point O): $V_{ulkeyhUN2loc.OT} := b - \frac{Key_{h.w} \cdot \left(2 \cdot u_{j.UN2} + u_{h.UN2} \right)}{3 \cdot \left(u_{j.UN2} + u_{h.UN2} \right)} = 5.5\, m$

Uplift under base: $V_{ulbaseUN2.OT} := \frac{\left(u_{k.UN2} + u_{m.UN2} \right) \cdot Key_{hdist}}{2} \cdot B \cdot -1 = -220.5 \cdot kN$

Moment Arm (from Point O): $V_{ulbaseUN2loc.OT} := b - Key_{h.w} - \frac{Key_{hdist} \cdot \left(2 \cdot u_{m.UN2} + u_{k.UN2} \right)}{3 \cdot \left(u_{m.UN2} + u_{k.UN2} \right)} = 2.5\, m$

Uplift under key at toe: $V_{ulkeytUN2.OT} := \frac{\left(u_{n.UN2} + u_{o.UN2} \right) \cdot Key_{t.w}}{2} \cdot B \cdot -1 = 0 \cdot kN$

Moment Arm (from Point O): $V_{ulkeytUN2loc.OT} := \frac{Key_{t.w} \cdot \left(2 \cdot u_{n.UN2} + u_{o.UN2} \right)}{3 \cdot \left(u_{n.UN2} + u_{o.UN2} \right)} = 0$

$$\Sigma V_{UpliftUN2.OT} := V_{ulkeyhUN2.OT} + V_{ulbaseUN2.OT} + V_{ulkeytUN2.OT} = -284 \cdot kN$$

$$U_{UN2.loc.OT} := \frac{V_{ulkeyhUN2.OT} \cdot V_{ulkeyhUN2loc.OT} + V_{ulbaseUN2.OT} \cdot V_{ulbaseUN2loc.OT} + V_{ulkeytUN2.OT} \cdot V_{ulkeytUN2loc.OT}}{\Sigma V_{UpliftUN2.OT}} = 3.17\, m$$

$$\Sigma M_{UpliftUN2.OT} := \Sigma V_{UpliftUN2.OT} \cdot U_{UN2.loc.OT} = -901.6 \cdot kN \cdot m$$

Modify Lateral Water Pressure (Resisting) for Overturning Analysis:

(Resisting water pressure is calculated using the Line of Creep method)

Water Load at Key (heel): $H_{h2UN2.OT} := \frac{u_{k.UN2} + u_{j.UN2}}{2} \cdot Key_{h.d} B = 107.8 \cdot kN$

Moment Arm (from Point O): $H_{h2locUN2.OT} := \frac{Key_{h.d} \cdot (2 \cdot u_{k.UN2} + u_{j.UN2})}{3(u_{k.UN2} + u_{j.UN2})} + Key_{vdist} = -1.06\ m$

Water Load at Key (toe): $H_{h6UN2.OT} := \frac{u_{o.UN2} \cdot (UWSEL_{UN2} - Bot_{ftg} + Key_{t.d})}{2} \cdot B = 99 \cdot kN$

Moment Arm (from Point O): $H_{h6locUN2.OT} := \frac{UWSEL_{UN2} - Bot_{ftg} + Key_{t.d}}{3} = 1.50\ m$

$$\Sigma H_{waterresistUN2.OT} := H_{h2UN2.OT} + H_{h6UN2.OT} = 207.03 \cdot kN$$

$$H_{waterresistlocUN2.OT} := \frac{H_{h2UN2.OT} \cdot H_{h2locUN2.OT} + H_{h6UN2.OT} \cdot H_{h6locUN2.OT}}{\Sigma H_{waterresistUN2.OT}} = 0.167\ m$$

$$\Sigma M_{waterresistUN2.OT} := \Sigma H_{waterresistUN2.OT} \cdot H_{waterresistlocUN2.OT} = 34.5 \cdot kN \cdot m$$

Modify Lateral Soil Loads for Overturning Analysis:

(Lateral soil loads are calculated down to Point O instead of bottom of shear key)

Driving Soil Load (Headwater Side):

Surcharge Load: $E_{s1UN2.OT} := S1_{UN2} \cdot K_o \cdot (H_w + Key_{h.d} + Key_{vdist}) \cdot B \cdot -1 = 0 \cdot kN$

Moment Arm (from Point O): $E_{s1locUN2.OT} := \frac{H_w + Key_{h.d} + Key_{vdist}}{2} = 2.25\ m$

Moist Soil Load above GWL: $E_{h1UN2.OT} := \frac{\gamma_m \cdot K_o \cdot h_{1UN2}^2}{2} B \cdot -1 = 0.0 \cdot kN$

Moment Arm (from Point O): $E_{h1locUN2.OT} := \frac{h_{1UN2}}{3} + h_{2UN2} + Key_{vdist} = 4.50\ m$

Saturated Soil Load below GWL: (rectangular component) $E_{h2UN2.OT} := (\gamma_m \cdot K_o \cdot h_{1UN2}) \cdot (h_{2UN2} + Key_{vdist}) \cdot B \cdot -1 = 0.0 \cdot kN$

Moment Arm (from Point O): $E_{h2locUN2.OT} := \frac{h_{2UN2} + Key_{vdist}}{2} = 2.25\ m$

Saturated Soil Load below GWL: (triangular component) $E_{h2aUN2.OT} := \frac{(\gamma_{sat} - \gamma_w) \cdot K_o \cdot (h_{2UN2} + Key_{vdist})^2}{2} \cdot B \cdot -1 = -67.4 \cdot kN$

Moment Arm (from Point O): $E_{h2alocUN2.OT} := \frac{h_{2UN2} + Key_{vdist}}{3} = 1.50\ m$

Resisting Soil Load (Tailwater Side):

(Determine resisting soil load based on depth variation between the keys (ie. Key_{vdist}). In case where key at heel is deeper than key at toe (ie. $Key_{vdist} < 0$), resisting soil load (p*) is assumed to produce horizontal equilibrium as per Figure 4-5 above. Resisting soil load (p_o) is neglected.)

Total Driving Force: $\Sigma H_{SoildriveUN2.OT} := E_{s1UN2.OT} + E_{h1UN2.OT} + E_{h2UN2.OT} + E_{h2aUN2.OT} + H_{h2UN2} = -274.5 \cdot kN$

Total Resisting Force: $\Sigma H_{waterresistUN2.OT} = 207.0 \cdot kN$

Assumed Soil Load p*: $E_{h8UN2a.OT} := \left(\Sigma H_{SoildriveUN2.OT} + \Sigma H_{waterresistUN2.OT}\right) \cdot -1 = 67.446 \cdot kN$

Moment Arm (from Point O): $E_{h8UN2a.loc.OT} := \dfrac{Key_{vdist}}{2} = -1\ m$

$$E_{h8UN2.OT} := \begin{cases} E_{h8UN2a.OT} & \text{if } Key_{vdist} < 0 \\ \Sigma H_{SoilresistUN2} - H_{h6UN2} - H_{h6aUN2} & \text{otherwise} \end{cases} = 67.446 \cdot kN$$

$$\Sigma M_{SoilresistUN2.OT} := \begin{cases} E_{h8UN2a.OT} \cdot E_{h8UN2a.loc.OT} & \text{if } Key_{vdist} < 0 \\ \Sigma M_{HorizSoilResistUN2} - H_{h6UN2} \cdot H_{h6locUN2} - H_{h6aUN2} \cdot H_{h6alocUN2} & \text{otherwise} \end{cases} = -67.446 \cdot kN \cdot m$$

Sum of Moment about Point O:

$$\Sigma M_{LateraldriveUN2.OT} := E_{s1UN2.OT} \cdot E_{s1locUN2.OT} + E_{h1UN2.OT} \cdot E_{h1locUN2.OT} + E_{h2UN2.OT} \cdot E_{h2locUN2.OT} \ldots + E_{h2aUN2.OT} \cdot E_{h2alocUN2.OT} + H_{h2UN2} \cdot H_{h2locUN2} = -135.7 \cdot kN \cdot m$$

$$\Sigma M_{LateralresistUN2.OT} := \Sigma M_{waterresistUN2.OT} + \Sigma M_{SoilresistUN2.OT} = -32.9 \cdot kN \cdot m$$

Total moment:

$$\Sigma M_{UN2.OT} := \Sigma M_{conc} + \Sigma M_{VertSoilWaterResistUN2} + \Sigma M_{UpliftUN2.OT} + \Sigma M_{LateraldriveUN2.OT} + \Sigma M_{LateralresistUN2.OT} = 941.4 \cdot kN \cdot m$$

Total Vertical Force: $\Sigma V_{UN2.OT} := \Sigma V_{conc} + \Sigma V_{SoilWaterUN2} + \Sigma V_{UpliftUN2.OT} = 289.0 \cdot kN$

Distance X_R: EM 1110-2-2502 Eq.4-1 $X_{R.UN2} := \dfrac{\Sigma M_{UN2.OT}}{\Sigma V_{UN2.OT}} = 3.257\ m$

Overturning Resultant Ratio $Ratio_{UN2.OT} := \dfrac{X_{R.UN2}}{b} = 0.54$

$$Ratio_{UN2.OT.check} := \begin{cases} \text{"OKAY "} & \text{if } Ratio_{UN2.OT} > X_{R.reqUN2} \\ \text{"Revise Structure""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

CHECK FOUNDATION ECCENTRICITY (HORIZONTAL PLANE):

Eccentricity (horizontal plan): $ex_{UN2.OT} := \dfrac{b}{2} - \dfrac{\Sigma M_{UN2.OT}}{\Sigma V_{UN2.OT}} = -0.26\ m$ $\quad Kern_{OT} = 1\ m$

Eccentricity Check:

$$e_{check.UN2.OT} := \begin{cases} \text{"Okay"} & \text{if } ex_{UN2} \le Kern_{OT} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"Okay"}$$

LOAD CASE UN2

CHECK FOUNDATION BEARING CAPACITY (HORIZONTAL PLANE):

Base Section Modulus: $S_{b.OT} = 6\,m^3$

Bearing Pressure Under Toe:

$$\sigma_{ToeUN2.OT} := \begin{cases} \left(\dfrac{\Sigma V_{UN2.OT}}{b \cdot B} + \dfrac{\Sigma V_{UN2.OT} \cdot ex_{UN2.OT}}{S_{b.OT}}\right) & \text{if } \dfrac{\Sigma V_{UN2.OT}}{b \cdot B} \geq \dfrac{\Sigma V_{UN2.OT} \cdot ex_{UN2.OT}}{S_{b.OT}} \\ \dfrac{2 \cdot \Sigma V_{UN2.OT}}{B \cdot 3\left(\dfrac{b}{2} - ex_{UN2.OT}\right)} & \text{otherwise} \end{cases} = 35.8 \cdot kPa$$

$$Bearing_{ChecktoeUN2.OT} := \begin{cases} \text{"OKAY "} & \text{if } \sigma_{ToeUN2.OT} < \sigma_{allowUN2} \\ \text{"NG - for reference only""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

Bearing Pressure Under Heel:

$$\sigma_{HeelUN2.OT} := \begin{cases} \left(\dfrac{\Sigma V_{UN2.OT}}{b \cdot B} - \dfrac{\Sigma V_{UN2.OT} \cdot ex_{UN2.OT}}{S_{b.OT}}\right) & \text{if } \dfrac{\Sigma V_{UN2.OT}}{b \cdot B} \geq \dfrac{\Sigma V_{UN2.OT} \cdot ex_{UN2.OT}}{S_{b.OT}} \\ 0 & \text{otherwise} \end{cases} = 60.6 \cdot kPa$$

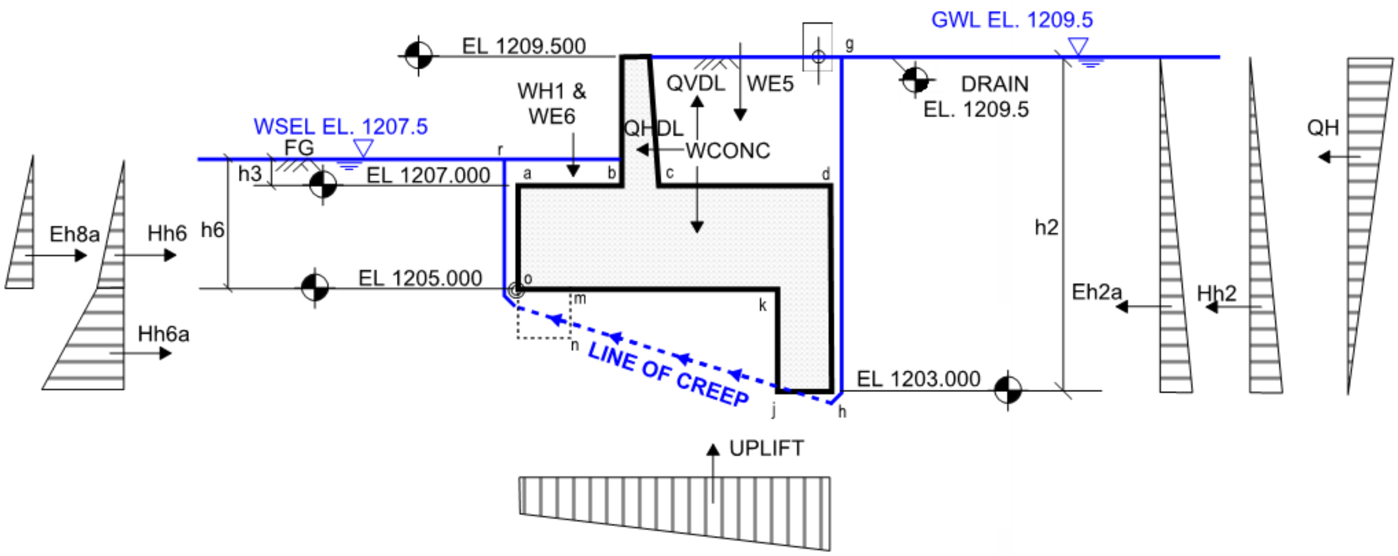
$$Bearing_{CheckheelUN2.OT} := \left(\begin{cases} \text{"OKAY "} & \text{if } \sigma_{HeelUN2.OT} < \sigma_{allowUN2} \wedge \sigma_{HeelUN2.OT} > 0 \\ \text{"NG - for reference only""} & \text{otherwise} \end{cases}\right) = \text{"OKAY "}$$

SUMMARY OF STABILITY ASSESSMENT:

LOAD CASE UN2

Sliding Factor of Safety: (Horizontal Plane - Ref only)	$FS_{Horiz.SlidingUN2} = 0.59$	$FS_{Sliding.check1.UN2}$ = "NG - key req'"
Sliding Factor of Safety: (Inclined Plane)	$FS_{InclinedISlidingUN2} = 3.60$	$FS_{Sliding.check2.UN2}$ = "OKAY "
Eccentricity: (Inclined Plane)	$ex_{UN2} = 0.21\ m$	$e_{check.UN2}$ = "Okay"
Bearing Pressure At Heel: (Inclined Plane)	$\sigma_{HeelUN2} = 53 \cdot kPa$	$Bearing_{CheckheelUN2}$ = "OKAY "
Bearing Pressure At Toe: (Inclined Plane)	$\sigma_{ToeUN2} = 79 \cdot kPa$	$Bearing_{ChecktoeUN2}$ = "OKAY "
Flotation Factor of Safety (horizontal plane)	$FS_{FloatationUN2} = 1.77$	$FS_{Floatation.UN2.check}$ = "OKAY "
Overturning Resultant Ratio: (horizontal plane)	$Ratio_{UN2.OT} = 0.54$	$Ratio_{UN2.OT.check}$ = "OKAY "
Eccentricity: (horizontal plane - Ref only)	$ex_{UN2.OT} = -0.26\ m$	$e_{check.UN2.OT}$ = "Okay"
Bearing Pressure At Heel: (horizontal plane - Ref only)	$\sigma_{HeelUN2.OT} = 61 \cdot kPa$	$Bearing_{CheckheelUN2.OT}$ = "OKAY "
Bearing Pressure At Toe: (horizontal plane - Ref only)	$\sigma_{ToeUN2.OT} = 36 \cdot kPa$	$Bearing_{ChecktoeUN2.OT}$ = "OKAY "

LOAD CASE E1 - SEISMIC LOADING



E1 DESIGN CASE

LOAD CASE E1 ACCEPTANCE PARAMETERS

FS sliding:

Extreme (E) loading) 1.0 (without cohesion, seismic (Table 3-3, USACE EM 1110-2-2100)

Resultant Location:

Extremem (E) Inside middle half ~75% base in compression

Required Factor of Safety for Sliding: $FS_{sliding.reqE1} := 1.0$ (Without Cohesion)

Allowable rock bearing pressure: $\sigma_{allowE1} := 1740kPa$ (Section 5.2, Design Criteria EM 1110-2-2100 Section 3-10)

Overturning Required Resultant Ratio: $X_{R.reqE1} := 0.25$ (EM 1110-2-2502, Figure 4-4)

Required Factor of Safety for Floatation $FS_{req.E1.flt} := 1.1$

SOIL HEIGHTS and Water Levels:

LOAD CASE E1

Heel Conditions:

Groundwater Elevation at Heel: $GWL_{E1} := 1209.5m$

Distance from Finish Grade to Groundwater at Heel: $h_{1E1} := \left[T_w - GWL_{E1} + \left(L_{cd} + t_{wb} - t_{wt}\right)\cdot\tan(\beta)\right] = 0.00\ m$

Distance from Water Surface to Bottom of Footing at Heel: $h_{2E1} := GWL_{E1} - Bot_{ftg} + Key_{h.d} = 6.50\ m$

Toe Conditions:

Water Surface Elevation at Toe: $WSEL_{E1} := 1207.5m$

Water Surface Elevation at Toe for Uplift: $UWSEL_{E1} := 1207.5\cdot m$

Finish Grade at Toe providing lateral resistance: $FG_{toeE1} := 1207.5\cdot m$

Soil Depth Above top of footing: $h_{3aE1} := FG_{toeE1} - Top_{ftg} = 0.5\ m$

$$h_{3E1} := \begin{cases} h_{3aE1} & \text{if } FG_{toeE1} - Top_{ftg} \ge 0 \\ 0 & \text{otherwise} \end{cases} = 0.5$$

Resisting Fill at Toe: $h_{4E1} := FG_{toeE1} - Bot_{ftg} + Key_{t.d} = 2.50\ m$

Distance from Water Level to Top of Footing: $h_{5E1} := WSEL_{E1} - Top_{ftg} = 0.50\ m$

Distance from Water Surface to Bottom of Toe Key: $h_{6E1} := WSEL_{E1} - Bot_{ftg} + Key_{t.d} = 2.50\ m$

Soil Depth Above WSEL: $h_{7aE1} := FG_{toeE1} - WSEL_{E1} = 0\ m$

$$h_{7E1} := \begin{cases} h_{7aE1} & \text{if } FG_{toeE1} - WSEL_{E1} \ge 0 \\ 0 & \text{otherwise} \end{cases} = 0$$

Soil Depth Below WSEL:

$$h_{8E1} := \begin{cases} WSEL_{E1} - Bot_{ftg} + Key_{t.d} & \text{if } FG_{toeE1} - WSEL_{E1} \ge 0 \\ h_{4E1} & \text{otherwise} \end{cases} = 2.5$$

For Line of Creep Method: $L_{ho.E1} := \sqrt{b^2 + \left(Key_{h.d} - Key_{t.d}\right)^2} = 6.325\ m$

Head Loss from Point g:

$\Delta h_{g.hj.E1} := h_{2E1} = 6.5\ m$ (to point h & j)

$\Delta h_{g.km.E1} := GWL_{E1} - Bot_{ftg} = 4.5\ m$ (to point k & m)

$\Delta h_{g.no.E1} := GWL_{E1} - Bot_{ftg} + Key_{t.d} = 4.5\ m$ (to point n & o)

$\Delta h_{g.p.E1} := GWL_{E1} - FG_{toeE1} = 2\ m$ (to point p*)

$\Delta h_{g.r.E1} := GWL_{E1} - UWSEL_{E1} = 2\ m$ (to point r)

Surcharge

Surcharge on Heel: $S1_{E1} := 0.0\ \frac{kN}{m^2}$

* same as point "r" in this case

Calculate Soil Lateral Pressure Coefficients:

LOAD CASE E1

Calculate at-rest pressure coefficient K_o based on Jaky's (1944) equation.

Soil At Rest Static Coefficient:
(apply to resisting soil loads)

$$K_o := \frac{1 - \sin(\phi)}{1 + \sin(\beta)} = 0.546$$

(Eq. 3-6, USACE EM 1110-2-2502)

Calculate active pressure coefficient K_A based on Coulumb equations.

Determine Slope of Active Wedge: (cohesionless backfill with water table)

$$c_1 := 2 \cdot \tan(\phi) = 1.019 \qquad c_2 := 1 - \tan(\phi) \cdot \tan(\beta) - \frac{\tan(\beta)}{\tan(\phi)} = 1$$

(Eq. G-14 / G-15, USACE EM 1110-2-2100)

$$\alpha := \operatorname{atan}\left(\frac{c_1 + \sqrt{c_1^{\,2} + 4 \cdot c_2}}{2}\right) = 1.021 \qquad \alpha_{deg} := \alpha \cdot \frac{180}{\pi} = 58.5 \text{ degrees}$$

(Eq. G-13, USACE EM 1110-2-2100)

Soil Active Coefficient above GWL:

$$K_{Aagwt} := \left(\frac{1 - \tan(\phi) \cdot \cot(\alpha)}{1 + \tan(\phi) \cdot \tan(\alpha)}\right) \cdot \left(\frac{\tan(\alpha)}{\tan(\alpha) - \tan(\beta)}\right) = 0.376$$

Soil Active Coefficient below GWL:

$$K_{Abgwt} := \frac{1 - \tan(\phi) \cdot \cot(\alpha)}{1 + \tan(\phi) \cdot \tan(\alpha)} \cdot \left[1 + \left(\frac{\tan(\alpha)}{\tan(\alpha) - \tan(\beta)} - 1\right) \cdot \left(\frac{\gamma_m}{\gamma_{sat} - \gamma_w}\right)\right] = 0.376$$

(Eq. G-29, USACE EM 1110-2-2100)

Lateral - Driving Force

Static Copmonent : Active Pressure:

Surcharge Load:

$$E_{s1E1} := S1_{E1} \cdot K_{Aagwt} \cdot \left(H_w + Key_{h.d}\right) \cdot B \cdot -1 = 0 \cdot kN$$

Moment Arm (from Point O):

$$E_{s1locE1} := \frac{H_w + Key_{h.d}}{2} + Key_{vdist} = 1.25\,m$$

Moist Soil Load above GWL:

$$E_{h1E1} := \frac{\gamma_m \cdot K_{Aagwt} \cdot h_{1E1}^{\,2}}{2} \cdot B \cdot -1 = 0.0 \cdot kN$$

Moment Arm (from Point O):

$$E_{h1locE1} := \frac{h_{1E1}}{3} + h_{2E1} + Key_{vdist} = 4.50\,m$$

Saturated Soil Load below GWL:
(rectangular component)

$$E_{h2E1} := \left(\gamma_m \cdot K_{Abgwt} \cdot h_{1E1}\right) \cdot h_{2E1} \cdot B \cdot -1 = 0.0 \cdot kN$$

Moment Arm (from Point O):

$$E_{h2locE1} := \frac{h_{2E1}}{2} + Key_{vdist} = 1.25\,m$$

Saturated Soil Load below GWL:
(triangular component)

$$E_{h2aE1} := \frac{\left(\gamma_{sat} - \gamma_w\right) \cdot K_{Abgwt} \cdot h_{2E1}^{\,2}}{2} \cdot B \cdot -1 = -96.8 \cdot kN$$

Moment Arm (from Point O):

$$E_{h2alocE1} := \frac{h_{2E1}}{3} + Key_{vdist} = 0.17\,m$$

Lateral Water Load:

Water Load GWL to Bottom of Keys:

$$H_{h2E1} := \begin{cases} \dfrac{\gamma_w \cdot h_{2E1}^{\,2}}{2} \cdot B \cdot -1 & \text{if } Key_{vdist} < 0 \\ \dfrac{\gamma_w \cdot \left(h_{2E1} + Key_{vdist}\right)^2}{2} \cdot B \cdot -1 & \text{otherwise} \end{cases} = -207.0 \cdot kN$$

Moment Arm (from Point O):

$$H_{h2locE1} := \begin{cases} \dfrac{h_{2E1}}{3} + Key_{vdist} & \text{if } Key_{vdist} < 0 \\ \dfrac{h_{2E1} + Key_{vdist}}{3} & \text{otherwise} \end{cases} = 0.17 \cdot m$$

$$\Sigma H_{SoildriveE1} := E_{s1E1} + E_{h1E1} + E_{h2E1} + E_{h2aE1} + H_{h2E1} = -303.8 \cdot kN$$

$$\Sigma M_{LateralSoildriveE1} := E_{s1E1} \cdot E_{s1locE1} + E_{h1E1} \cdot E_{h1locE1} + E_{h2E1} \cdot E_{h2locE1} \ldots + E_{h2aE1} \cdot E_{h2alocE1} + H_{h2E1} \cdot H_{h2locE1} = -50.6\, m \cdot kN$$

Lateral - Resisting Force

LOAD CASE E1

Note: **Due to the relatively shallow depth of resisting soil/rock, a conservative apporach using at-rest coefficient in lieu of a passive wedge is used to calculate resisting forces.**

Lateral Water Load:

Water Load WSEL to Bot. of Toe Key: $H_{h6E1} := H_{h6U1} = 30.6 \cdot kN$

Moment Arm (from Point O): $H_{h6locE1} := H_{h6locU1} = 0.83\ m$

Water Load between Keys (if any):

$$H_{h6aE1} := \begin{cases} \dfrac{\left(h_{6E1} + h_{2E1}\right) \cdot -Key_{vdist}}{2} \cdot \gamma_w \cdot B & \text{if } Key_{vdist} < 0 \\ 0 & \text{otherwise} \end{cases} = 88.2 \cdot kN$$

Moment Arm (from Point O):

$$H_{h6alocE1} := \begin{cases} \dfrac{Key_{vdist} \cdot \left(2 \cdot h_{2E1} + h_{6E1}\right)}{3\left(h_{2E1} + h_{6E1}\right)} & \text{if } Key_{vdist} < 0 \\ 0 & \text{otherwise} \end{cases} = -1.15 \cdot m$$

Lateral Soil Load:

Moist Soil Load above WSEL: $E_{h7E1} := \dfrac{\gamma_m \cdot K_o \cdot h_{7E1}^{\,2}}{2} \cdot B = 0.0 \cdot kN$

Moment Arm (from bot. of toe key): $E_{h7locE1} := h_{6E1} + \dfrac{h_{7E1}}{3} + Key_{vdist} = 0.50\ m$

Saturated Soil Load below WSEL:
(rectangular component)

$E_{h8E1} := \left(\gamma_m \cdot K_o \cdot h_{7E1}\right) \cdot h_{8E1} \cdot B = 0.0 \cdot kN$

Moment Arm (from bot. of toe key): $E_{h8locE1} := \dfrac{h_{8E1}}{2} = 1.25\ m$

Saturated Soil Load below WSEL:
(triangular component)

$E_{h8aE1} := \dfrac{\left[\left(\gamma_{sat} - \gamma_w\right) \cdot K_o\right] \cdot h_{8E1}^{\,2}}{2} \cdot B = 20.8 \cdot kN$

Moment Arm (from bot. of footing): $E_{h8alocE1} := \dfrac{h_{8E1}}{3} = 0.83\ m$

$\Sigma H_{SoilresistE1} := H_{h6E1} + H_{h6aE1} + E_{h7E1} + E_{h8E1} + E_{h8aE1} = 139.6 \cdot kN$

$$\Sigma M_{HorizSoilResistE1} := H_{h6E1} \cdot H_{h6locE1} + H_{h6aE1} \cdot H_{h6alocE1} + E_{h7E1} \cdot E_{h7locE1} \ldots + E_{h8E1} \cdot E_{h8locE1} + E_{h8aE1} \cdot E_{h8alocE1} = -58.4\ m \cdot kN$$

Vertical Force:

UPLIFT: Linear distribution from water at heel to water at toe:

$$\Sigma V_{UpliftE1} := \left[\left(UWSEL_{E1} - Bot_{ftg} + Key_{t.d}\right) + h_{2E1}\right] \cdot \frac{b}{2} \cdot \gamma_w \cdot B \cdot -1 = -264.6 \cdot kN$$

Moment Arm (from Point O):

$$V_{UpliftE1aloc} := \frac{b \cdot \left[2 \cdot h_{2E1} + \left(UWSEL_{E1} - Bot_{ftg} + Key_{t.d}\right)\right]}{3\left[h_{2E1} + \left(UWSEL_{E1} - Bot_{ftg} + Key_{t.d}\right)\right]} = 3.444\ m$$

$\Sigma M_{UpliftE1} := \Sigma V_{UpliftE1} \cdot V_{UpliftE1aloc} = -911.4 \cdot kN \cdot m$

Weight of soil and water over toe:

Water Above the Top of Footing: $W_{H1E1} := \gamma_w \cdot h_{5E1} \cdot L_{ab} \cdot B = 9.8 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E1locE1} := \frac{L_{ab}}{2} = 1\ m$

Soil above top of footing: $W_{E6E1} := \gamma_b \cdot h_{3E1} \cdot L_{ab} \cdot B = 12.2 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E6locE1} := \frac{L_{ab}}{2} = 1\ m$

Vertical Load Due to Surcharge: $S_{E1} := S1_{E1} \cdot L_{cd} \cdot B = 0 \cdot kN$ $\quad S_{E1loc} := b - \frac{L_{cd}}{2} = 4.35\ m$

Weight of soil and water over heel:

Moist Soil for sloped grade above top of wall:

Length of sloped portion of soil above top of wall: $L_{E3E1} := \left(L_{cd} + t_{wb} - t_{wt}\right) = 3.50\ m$

Height of sloped soil above top of wall over heel: $h_{E3locE1} := \left(L_{E3E1}\right) \cdot \tan(\beta) = 0.00\ m$

Weight of sloped soil above top of wall: $W_{E3E1} := \frac{\gamma_m}{2} \cdot h_{E3locE1} \cdot L_{E3E1} \cdot B = 0.0 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E3locE1} := L_{ab} + t_{wt} + \frac{2}{3} \cdot L_{E3E1} = 4.83\ m$

Moist soil from top of wall to groundwater level:

Height of soil from top of wall and top of GWL: $h_{1E1} = 0.00\ m$

Length from edge of wall at GWL to edge of heel: $L_{E4E1} := L_{E3E1} - \left(h_{1E1} \cdot S_{batter}\right) = 3.50\ m$

Weight of soil over heel from top of wall to GWL: $W_{E4E1} := \gamma_m \cdot h_{1E1} \cdot \frac{\left(L_{E3E1} + L_{E4E1}\right)}{2} \cdot B = 0.0 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E4locE1} := b - \frac{L_{E3E1}^{\ 2} + L_{E3E1} \cdot L_{E4U1} + L_{E4E1}^{\ 2}}{3\left(L_{E3E1} + L_{E4E1}\right)} = 4.25\ m$

Saturated soil from groundwater to top of footing:

Height of soil from GWL to top of heel: $h_{E4E1} := h_{2E1} - t_{ftg} - Key_{h.d} = 2.50\ m$

Weight of soil over heel from GWL to top of heel: $W_{E5E1} := \left(\gamma_{sat}\right) \cdot h_{E4E1} \cdot \frac{\left(L_{E4E1} + L_{cd}\right)}{2} \cdot B = 187.1 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E5locE1} := b - \frac{L_{E4E1}^{\ 2} + L_{E4E1} \cdot L_{cd} + L_{cd}^{\ 2}}{3\left(L_{E4E1} + L_{cd}\right)} = 4.30\ m$

$\Sigma V_{SoilWaterE1} := W_{H1E1} + W_{E6E1} + W_{E3E1} + W_{E4E1} + W_{E5E1} + S_{E1} = 209.1 \cdot kN$

$\Sigma M_{VertSoilWaterResistE1} := W_{H1E1} \cdot W_{E1locE1} + W_{E6E1} \cdot W_{E6locE1} \cdots$
$+ W_{E3E1} \cdot W_{E3locE1} + W_{E4E1} \cdot W_{E4locE1} + W_{E5E1} \cdot W_{E5locE1} + S_{E1} \cdot S_{E1loc} = 826.3\ m \cdot kN$

SESIMIC ANALYSIS:

LOAD CASE E1

Seismic coefficient will be applied to dead loads to calculate seismic force and force is applied at center of gravity of the mass. Vertical and Horizontal loads are applied in the "destabilizing direction"

SEISMIC PARAMETERS:

(Section 7.9, Design Criteria)

Peak Ground Acceleration for Seismic Load $PGA_{Horiz} := 0.26$ $PGA_{Vert} := 0.56 \cdot PGA_{Horiz} = 0.146$

In accordance with USACE EM 1110-2-2100 Section 4-7.b, consider 2/3 PGA as seismic coefficient for stabilitiy.

Horizontal Seismic coefficient for stabilty: $K_{hE1} := \frac{2}{3} PGA_{Horiz} = 0.173$

Vertical Seismic coefficient for stabilty: $K_{vE1} := \frac{2}{3} PGA_{Vert} = 0.097$

SEISMIC ACCELERATION OF RIGID MASSES (Q_D):

Vertical Load Application:

$\Sigma V_{conc} = 364.1 \cdot kN$

$Q_{v.conc} := \Sigma V_{conc} \cdot K_{vE1} \cdot -1 = -35.3 \cdot kN$ (assume acting upwards for adverse sliding effect)

Moment arm for siesmic load application (From Toe): $H_{cent} = 3.255\,m$

$M_{Qv.conc} := Q_{v.conc} \cdot H_{cent} = -115.1 \cdot kN \cdot m$

Lateral Load Application:

$Q_{h.conc} := \Sigma V_{conc} \cdot K_{hE1} \cdot -1 = -63.1 \cdot kN$

Moment arm for siesmic load application (Above Base of Footing): $V_{Cent} = 0.952\,m$

$M_{Q.conc} := Q_{h.conc} \cdot V_{Cent} = -60.1 \cdot kN \cdot m$

SEISMIC ACCELERATION OF SOIL WEDGE + WATER (Q_{EH}):

Vertical Load Application:

$\Sigma V_{SoilWaterE1} = 209.1 \cdot kN$

$Q_{v.SoilWaterE1} := \Sigma V_{SoilWaterE1} \cdot K_{vE1} \cdot -1 = -20.3 \cdot kN$ (assume acting upwards for adverse sliding effect)

Moment arm for siesmic load application (From Toe): $e_{QE1} := \frac{\Sigma M_{VertSoilWaterResistE1}}{\Sigma V_{SoilWaterE1}} = 3.951\,m$

$M_{Qv.SoilWaterE1} := Q_{v.SoilWaterE1} \cdot e_{QE1} = -80.2 \cdot kN \cdot m$

Lateral Load Application:

Seismic soil load is calculated based on Mononobe-Okabe method to determine combined static and dynamic coefficient (K_{AE}). Coulomb's active component (K_A) is subtracted from K_{AE} to obtain the seismic coefficient (ΔK_{AE}) for dynamic component of soil force.

Glacial Till Internal Friction (radians): $\phi = 0.471$

Seismic Inertia Angle (radians): $\psi := \operatorname{atan}\left(\frac{K_{hE1}}{1 - K_{vE1}}\right) = 0.190$

Inclination of batter (radians): $\theta := 0.00$ assuming zero is conservative

Slope of retained ground surface: $\beta = 0.00$

$$K_{AE} := \frac{\cos(\phi - \psi - \theta) \cdot \cos(\phi - \psi - \theta)}{\cos(\psi) \cdot \cos(\theta) \cdot \cos(\theta)\ \cos(\psi + \theta) \cdot \left(1 + \sqrt{\frac{\sin(\phi)\ \sin(\phi - \psi - \beta)}{\cos(\beta - \theta) \cdot \cos(\psi + \theta)}}\right)^2} = 0.519$$

$\Delta K_{AE} := K_{AE} - K_{Abgwt} = 0.143$

Dynamic component of active seismic wedge:

$$Q_{h.SoilWaterE1} := \Delta K_{AE} \cdot \left[\frac{\gamma_m \cdot \left(H_w + Key_{h.d}\right)^2}{2 \cdot (\tan(\alpha) - \tan(\beta))} + \frac{\left(\gamma_{sat} - \gamma_m\right) \cdot h_{2E1}^{\ 2}}{2 \cdot \tan(\alpha)}\right] \cdot B \cdot -1 = -40.7 \cdot kN$$

(Eq. G-64, USACE EM 1110-2-2100)

Moment arm for siesmic load application (About Point O): $Q_{h.SoilWaterlocE1} := \frac{2}{3} \cdot \left(H_w + Key_{h.d}\right) + Key_{vdist} = 2.33\,m$

$M_{Q.h.SoilWaterE1} := Q_{h.SoilWaterE1} \cdot Q_{h.SoilWaterlocE1} = -95 \cdot kN \cdot m$

STABILITY ASSESSMENT:

LOAD CASE E1

CHECK SLIDING ALONG HORIZONTAL SLIDING PLANE:

Summation of the vertical forces: $\Sigma V_{E1} := \Sigma V_{conc} + \Sigma V_{SoilWaterE1} + \Sigma V_{UpliftE1} + Q_{v.conc} + Q_{v.SoilWaterE1} = 253.0 \cdot kN$

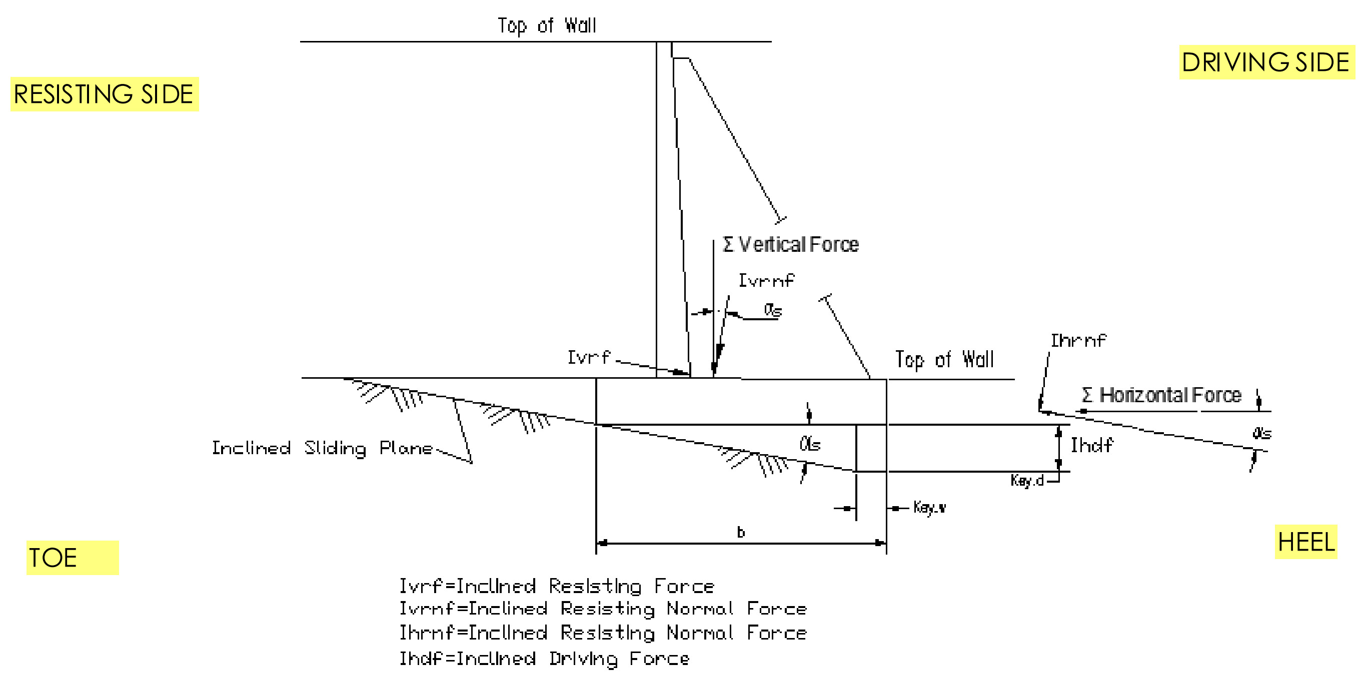
Summation of the horizontal forces: $\Sigma H_{E1} := \Sigma H_{SoildriveE1} + Q_{h.conc} + Q_{h.SoilWaterE1} + \Sigma H_{SoilresistE1} = -268.0 \cdot kN$

Safety Factor for Sliding Horizontal Failure Plane

$$FS_{Horiz.SlidingE1} := \frac{\left|\Sigma V_{E1}\right| \cdot \tan\left(\phi_{rock} \cdot \frac{\pi}{180}\right)}{\left|\Sigma H_{E1}\right|} = 0.46$$

$$FS_{Sliding.check1.E1} := \begin{array}{|l} \text{"OKAY" if } FS_{Horiz.SlidingE1} > FS_{sliding.reqE1} \\ \text{"NG - key req"" otherwise} \end{array} = \text{"NG - key req""}$$

CHECK FACTOR OF SAFETY SLIDING WITH KEY (INCLINED SLIDING PLANE):



(With properly engineered reinforced concrete Key, horizontal sliding plane thru Toe is protected, critical sliding plane is relocated to the INCLINED SLIDING PLANE FROM HEEL KEY To TOE, Bedrock Mass above this examing plane is mobilized by reinforced concrete key and combined into Structural Wedge.)

Resolve ΣV_{E1} & ΣH_{E1}

$$\Sigma V_{InclinedE1} := \cos(\alpha s) \cdot \left(\left|\Sigma V_{E1} + V_{rocksection}\right|\right) + \sin(\alpha s) \cdot \left|\Sigma H_{E1}\right| = 453.3 \cdot kN$$

$$\Sigma H_{InclinedE1} := \cos(\alpha s) \cdot \left|\Sigma H_{E1}\right| - \sin(\alpha s) \cdot \left(\left|\Sigma V_{E1} + V_{rocksection}\right|\right) = 107.3 \cdot kN$$

Safety Factor for Sliding Inclined Failure Plane

$$FS_{InclinedISlidingE1} := \frac{\Sigma V_{InclinedE1} \cdot \tan\left(\phi_r\right)}{\Sigma H_{InclinedE1}} = 1.88$$

$$FS_{Sliding.check2.E1} := \begin{array}{|l} \text{"OKAY" if } FS_{InclinedISlidingE1} > FS_{sliding.reqE1} \\ \text{"NG"" otherwise} \end{array} = \text{"OKAY"}$$

CHECK FOUNDATION ECCENTRICITY:

LOAD CASE E1

(Vertical seismic loads from concrete, soil and water are assumed acting downwards for adverse bearing effect)

Summation of the vertical forces: $\Sigma V_{seisE1} := \Sigma V_{conc} + \Sigma V_{SoilWaterE1} + \Sigma V_{UpliftE1} - Q_{v.conc} - Q_{v.SoilWaterE1} = 364.3 \cdot kN$

Summation of the horizontal forces: $\Sigma H_{seisE1} := \Sigma H_{E1} = -268.0 \cdot kN$

Resolve ΣV_{seisE1} & ΣH_{seisE1}

$$\Sigma V_{InclinedseisE1} := \cos(\alpha s) \cdot \left(\left|\Sigma V_{seisE1} + V_{rocksection}\right|\right) + \sin(\alpha s) \cdot \left|\Sigma H_{seisE1}\right| = 556.6 \cdot kN$$

$$\Sigma H_{InclinedseisE1} := \cos(\alpha s) \cdot \left|\Sigma H_{seisE1}\right| - \sin(\alpha s) \cdot \left(\left|\Sigma V_{seisE1} + V_{rocksection}\right|\right) = 66.0 \cdot kN$$

Summation of the resisting moments about the toe:

$$\Sigma M_{resE1} := \Sigma M_{conc} + \Sigma M_{VertSoilWaterResistE1} + \Sigma M_{HorizSoilResistE1} + \Sigma M_{rocksection} = 2380 \cdot kN \cdot m$$

Summation of seismic moments about the toe:

$$\Sigma M_{seisE1} := -M_{Qv.conc} + M_{Q.conc} - M_{Qv.SoilWaterE1} + M_{Q.h.SoilWaterE1} = 40 \cdot kN \cdot m$$

Summation of the overturning moments about the toe:

$$\Sigma M_{oE1} := \Sigma M_{LateralSoildriveE1} + \Sigma M_{UpliftE1} = -962 \cdot kN \cdot m$$

Total moment: $\Sigma M_{E1} := \Sigma M_{resE1} + \Sigma M_{seisE1} + \Sigma M_{oE1} = 1458.0 \cdot kN \cdot m$

Normal force to base: $\Sigma V_{InclinedseisE1} = 556.6 \cdot kN$

Inclined Sliding Plane Length: $L_{incline} = 6.5 \cdot m$

Eccentricity (inclined plane): $ex_{E1} := \frac{L_{incline}}{2} - \frac{\Sigma M_{E1}}{\Sigma V_{InclinedseisE1}} = 0.61\ m$ $\quad Kern_{E1} := \frac{L_{incline}}{4} = 1.616\ m$

Eccentricity Check:

$$e_{check.E1} := \begin{cases} \text{"Okay"} & \text{if } ex_{E1} \le Kern_{E1} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"Okay"}$$

CHECK FOUNDATION BEARING CAPACITY:

Base Section Modulus: $S_b = 6.96\ m^3$

Bearing Pressure Under Toe:

$$\sigma_{ToeE1} := \begin{cases} \left[\frac{\Sigma V_{InclinedE1}}{L_{incline} \cdot B} + \frac{\left(\Sigma V_{InclinedE1} \cdot ex_{E1}\right)}{S_b}\right] & \text{if } \frac{\Sigma V_{InclinedE1}}{L_{incline} \cdot B} \ge \frac{\Sigma V_{InclinedE1} \cdot ex_{E1}}{S_b} \\ \frac{2 \cdot \Sigma V_{InclinedE1}}{B \cdot 3 \left(\frac{b}{2} - ex_{E1}\right)} & \text{otherwise} \end{cases} = 110.0 \cdot kPa$$

$$Bearing_{ChecktoeE1} := \begin{cases} \text{"OKAY "} & \text{if } \sigma_{ToeE1} < \sigma_{allowE1} \\ \text{"NG""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

Bearing Pressure Under Heel:

$$\sigma_{HeelE1} := \begin{cases} \left[\frac{\Sigma V_{InclinedE1}}{L_{incline} \cdot B} - \frac{\left(\Sigma V_{InclinedE1} \cdot ex_{E1}\right)}{S_b}\right] & \text{if } \frac{\Sigma V_{InclinedE1}}{L_{incline} \cdot B} \ge \frac{\Sigma V_{InclinedE1} \cdot ex_{E1}}{S_b} \\ 0 & \text{otherwise} \end{cases} = 30.3 \cdot kPa$$

$$Bearing_{CheckheelE1} := \left(\begin{cases} \text{"OKAY "} & \text{if } \sigma_{HeelE1} < \sigma_{allowE1} \wedge \sigma_{HeelE1} > 0 \\ \text{"NG - perform cracked base analysis""} & \text{otherwise} \end{cases}\right) = \text{"OKAY "}$$

CHECK FLOATATION:

Safety Factor for Floatation:

$$FS_{FloatationE1} := \frac{\Sigma V_{conc} + \Sigma V_{SoilWaterE1} + Q_{v.conc} + Q_{v.SoilWaterE1}}{\left|\Sigma V_{UpliftE1}\right|} = 1.96$$

$$FS_{Floatation.E1.check} := \begin{cases} \text{"OKAY"} & \text{if } FS_{FloatationE1} > FS_{req.E1.flt} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

CHECK OVERTURNING

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.
Assumptions are made in order to compute overturning stablity of indetermine forces on monolith with key;
(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.
(b) The horizontal resisting force acting on the key, P.key, is that required for static equilibrium
(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1

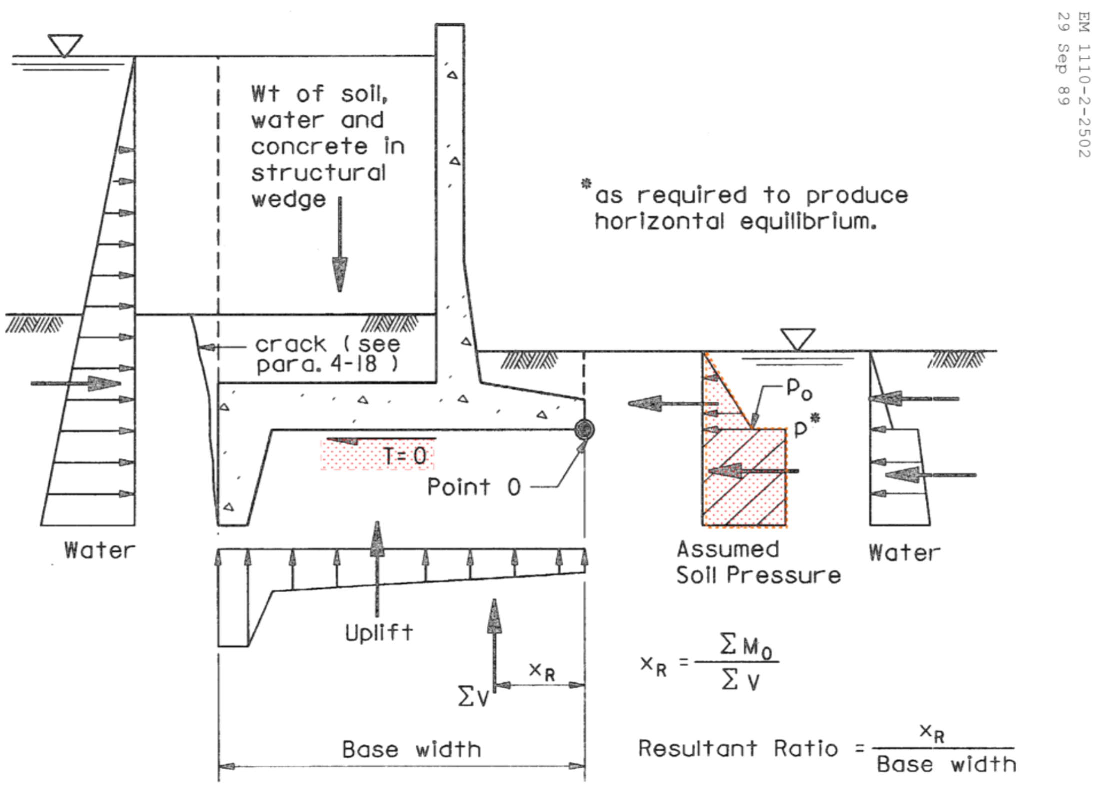


Figure 4-5. Forces for overturning analysis for wall with horizontal base and key

Modify Uplift for Overturning Analysis: **LOAD CASE E1**

(Uplift is calculated along the concrete/rock contact using the Line of Creep method)

Water Pressure at h: $u_{h.E1} := \Delta h_{g.hj.E1} \cdot \gamma_w = 63.70 \cdot kPa$

Water Pressure at o: $u_{o.E1} := \left(\Delta h_{g.no.E1} - \frac{\Delta h_{g.r.E1} \cdot L_{ho.E1}}{L_{ho.E1}}\right) \cdot \gamma_w = 24.5 \cdot kPa$

Head loss between point h and o: $\Delta h_{ho.E1} := \Delta h_{g.r.E1} \cdot \frac{L_{ho.E1}}{L_{ho.E1}} = 2\,m$

Length of concrete base (h -> o): $L_{baseho.E1} := Key_{h.w} + Key_{h.d} + Key_{hdist} + Key_{t.d} + Key_{t.w} = 8\,m$

Head loss along h -> j: $\Delta h_{hj.E1} := \Delta h_{ho.E1} \cdot \frac{Key_{h.w}}{L_{baseho.E1}} = 0.25\,m$

Water Pressure at j: $u_{j.E1} := \left(\Delta h_{g.hj.E1} - \Delta h_{hj.E1}\right) \cdot \gamma_w = 61.25 \cdot kPa$

Head loss along h -> k: $\Delta h_{hjk.E1} := \Delta h_{ho.E1} \cdot \left(\frac{Key_{h.w} + Key_{h.d}}{L_{baseho.E1}}\right) = 0.75\,m$

Water Pressure at k: $u_{k.E1} := \left(\Delta h_{g.km.E1} - \Delta h_{hjk.E1}\right) \cdot \gamma_w = 36.75 \cdot kPa$

Head loss along h -> m: $\Delta h_{hjkm.E1} := \Delta h_{ho.E1} \cdot \left(\frac{Key_{h.w} + Key_{h.d} + Key_{hdist}}{L_{baseho.E1}}\right) = 2\,m$

Water Pressure at m: $u_{m.E1} := \left(\Delta h_{g.km.E1} - \Delta h_{hjkm.E1}\right) \cdot \gamma_w = 24.50 \cdot kPa$

Head loss along h -> n: $\Delta h_{hjkmn.E1} := \Delta h_{ho.E1} \cdot \left(\frac{Key_{h.w} + Key_{h.d} + Key_{hdist} + Key_{t.d}}{L_{baseho.E1}}\right) = 2\,m$

Water Pressure at n: $u_{n.E1} := \left(\Delta h_{g.no.E1} - \Delta h_{hjkmn.E1}\right) \cdot \gamma_w = 24.50 \cdot kPa$

Uplift under key at heel: $V_{ulkeyhE1.OT} := \frac{\left(u_{h.E1} + u_{j.E1}\right) \cdot Key_{h.w}}{2} \cdot B \cdot -1 = -62.475 \cdot kN$

Moment Arm (from Point O): $V_{ulkeyhE1loc.OT} := b - \frac{Key_{h.w} \cdot \left(2 \cdot u_{j.E1} + u_{h.E1}\right)}{3 \cdot \left(u_{j.E1} + u_{h.E1}\right)} = 5.503\,m$

Uplift under base: $V_{ulbaseE1.OT} := \frac{\left(u_{k.E1} + u_{m.E1}\right) \cdot Key_{hdist}}{2} \cdot B \cdot -1 = -153.125 \cdot kN$

Moment Arm (from Point O): $V_{ulbaseE1loc.OT} := b - Key_{h.w} - \frac{Key_{hdist} \cdot \left(2 \cdot u_{m.E1} + u_{k.E1}\right)}{3 \cdot \left(u_{m.E1} + u_{k.E1}\right)} = 2.667\,m$

Uplift under key at toe: $V_{ulkeytE1.OT} := \frac{\left(u_{n.E1} + u_{o.E1}\right) \cdot Key_{t.w}}{2} \cdot B \cdot -1 = 0 \cdot kN$

Moment Arm (from Point O): $V_{ulkeytE1loc.OT} := \frac{Key_{t.w} \cdot \left(2 \cdot u_{n.E1} + u_{o.E1}\right)}{3 \cdot \left(u_{n.E1} + u_{o.E1}\right)} = 0$

$$\Sigma V_{UpliftE1.OT} := V_{ulkeyhE1.OT} + V_{ulbaseE1.OT} + V_{ulkeytE1.OT} = -216 \cdot kN$$

$$U_{E1.loc.OT} := \frac{V_{ulkeyhE1.OT} \cdot V_{ulkeyhE1loc.OT} + V_{ulbaseE1.OT} \cdot V_{ulbaseE1loc.OT} + V_{ulkeytE1.OT} \cdot V_{ulkeytE1loc.OT}}{\Sigma V_{UpliftE1.OT}} = 3.49\,m$$

$$\Sigma M_{UpliftE1.OT} := \Sigma V_{UpliftE1.OT} \cdot U_{E1.loc.OT} = -752.1 \cdot kN \cdot m$$

LOAD CASE E1

Modify Lateral Water Pressure (Resisting) for Overturning Analysis:

(Resisting water pressure is calculated using the Line of Creep method)

Water Load at Key (heel):

$$H_{h2E1.OT} := \frac{u_{k.E1} + u_{j.E1}}{2} \cdot Key_{h.d} B = 98.0 \cdot kN$$

Moment Arm (from Point O):

$$H_{h2locE1.OT} := \frac{Key_{h.d} \cdot (2 \cdot u_{k.E1} + u_{j.E1})}{3(u_{k.E1} + u_{j.E1})} + Key_{vdist} = -1.08\ m$$

Water Load at Key (toe):

$$H_{h6E1.OT} := \frac{u_{o.E1} \cdot (UWSEL_{E1} - Bot_{ftg} + Key_{t.d})}{2} \cdot B = 31 \cdot kN$$

Moment Arm (from Point O):

$$H_{h6locE1.OT} := \frac{UWSEL_{E1} - Bot_{ftg} + Key_{t.d}}{3} = 0.83\ m$$

$$\Sigma H_{waterresistE1.OT} := H_{h2E1.OT} + H_{h6E1.OT} = 128.63 \cdot kN$$

$$H_{waterresistlocE1.OT} := \frac{H_{h2E1.OT} \cdot H_{h2locE1.OT} + H_{h6E1.OT} \cdot H_{h6locE1.OT}}{\Sigma H_{waterresistE1.OT}} = -0.627\ m$$

$$\Sigma M_{waterresistE1.OT} := \Sigma H_{waterresistE1.OT} \cdot H_{waterresistlocE1.OT} = -80.65 \cdot kN \cdot m$$

Modify Lateral Soil Loads for Overturning Analysis:

(Lateral soil loads are calculated down to Point O instead of bottom of shear key)

Driving Soil Load (Headwater Side):

Surcharge Load:

$$E_{s1E1.OT} := S1_{E1} \cdot K_{Aagwt} \cdot (H_w + Key_{h.d} + Key_{vdist}) \cdot B \cdot -1 = 0 \cdot kN$$

Moment Arm (from Point O):

$$E_{s1locE1.OT} := \frac{H_w + Key_{h.d} + Key_{vdist}}{2} = 2.25\ m$$

Moist Soil Load above GWL:

$$E_{h1E1.OT} := \frac{\gamma_m \cdot K_{Aagwt} \cdot h_{1E1}^{\ 2}}{2} B \cdot -1 = 0.0 \cdot kN$$

Moment Arm (from Point O):

$$E_{h1locE1.OT} := \frac{h_{1E1}}{3} + h_{2E1} + Key_{vdist} = 4.50\ m$$

Saturated Soil Load below GWL:
(rectangular component)

$$E_{h2E1.OT} := (\gamma_m \cdot K_{Aagwt} \cdot h_{1E1}) \cdot (h_{2E1} + Key_{vdist}) \cdot B \cdot -1 = 0.0 \cdot kN$$

Moment Arm (from Point O):

$$E_{h2locE1.OT} := \frac{h_{2E1} + Key_{vdist}}{2} = 2.25\ m$$

Saturated Soil Load below GWL:
(triangular component)

$$E_{h2aE1.OT} := \frac{(\gamma_{sat} - \gamma_w) \cdot K_{Aagwt} \cdot (h_{2E1} + Key_{vdist})^2}{2} \cdot B \cdot -1 = -46.4 \cdot kN$$

Moment Arm (from Point O):

$$E_{h2alocE1.OT} := \frac{h_{2E1} + Key_{vdist}}{3} = 1.50\ m$$

Resisting Soil Load (Tailwater Side): **LOAD CASE E1**

(Determine resisting soil load based on depth variation between the keys (ie. Key_{vdist}). In case where key at heel is deeper than key at toe (ie. $Key_{vdist} < 0$), resisting soil load (p*) is assumed to produce horizontal equilibrium as per Figure 4-5 above. Resisting soil load (p_o) is neglected.)

Total Driving Force: $\Sigma H_{SoildriveE1.OT} := E_{s1E1.OT} + E_{h1E1.OT} + E_{h2E1.OT} + E_{h2aE1.OT} + H_{h2E1} \cdots + Q_{h.conc} + Q_{h.SoilWaterE1} = -357.3 \cdot kN$

Total Resisting Force: $\Sigma H_{waterresistE1.OT} = 128.625 \cdot kN$

Assumed Soil Load p*: $E_{h8E1a.OT} := (\Sigma H_{SoildriveE1.OT} + \Sigma H_{waterresistE1.OT}) \cdot -1 = 228.625 \cdot kN$

Moment Arm (from Point O): $E_{h8E1a.loc.OT} := \dfrac{Key_{vdist}}{2} = -1\,m$

$$E_{h8E1.OT} := \begin{cases} E_{h8E1a.OT} & \text{if } Key_{vdist} < 0 \\ \Sigma H_{SoilresistE1} - H_{h6E1} - H_{h6aE1} & \text{otherwise} \end{cases} = 228.625 \cdot kN$$

$$\Sigma M_{SoilresistE1.OT} := \begin{cases} E_{h8E1a.OT} \cdot E_{h8E1a.loc.OT} & \text{if } Key_{vdist} < 0 \\ \Sigma M_{HorizSoilResistE1} - H_{h6E1} \cdot H_{h6locE1} - H_{h6aE1} \cdot H_{h6alocE1} & \text{otherwise} \end{cases} = -228.625 \cdot kN \cdot m$$

Sum of Moment about Point O:

$$\Sigma M_{LateraldriveE1.OT} := E_{s1E1.OT} \cdot E_{s1locE1.OT} + E_{h1E1.OT} \cdot E_{h1locE1.OT} + E_{h2E1.OT} \cdot E_{h2locE1.OT} \cdots + E_{h2aE1.OT} \cdot E_{h2alocE1.OT} + H_{h2E1} \cdot H_{h2locE1} = -104.1 \cdot kN \cdot m$$

$$\Sigma M_{LateralresistE1.OT} := \Sigma M_{waterresistE1.OT} + \Sigma M_{SoilresistE1.OT} = -309.3 \cdot kN \cdot m$$

$$\Sigma M_{seisE1.OT} := M_{Qv.conc} + M_{Q.conc} + M_{Qv.SoilWaterE1} + M_{Q.h.SoilWaterE1} = -350 \cdot kN \cdot m$$

(seismic moment modified for the most adverse overturning effect)

Total moment:

$$\Sigma M_{E1.OT} := \Sigma M_{conc} + \Sigma M_{VertSoilWaterResistE1} + \Sigma M_{UpliftE1.OT} + \Sigma M_{LateraldriveE1.OT} + \Sigma M_{LateralresistE1.OT} + \Sigma M_{seisE1.OT} = 495.8 \cdot kN \cdot m$$

Total Vertical Force: $\Sigma V_{E1.OT} := \Sigma V_{conc} + \Sigma V_{SoilWaterE1} + \Sigma V_{UpliftE1.OT} + Q_{v.conc} + Q_{v.SoilWaterE1} = 302.0 \cdot kN$

Distance X_R: EM 1110-2-2502 Eq.4-1 $X_{R.E1} := \dfrac{\Sigma M_{E1.OT}}{\Sigma V_{E1.OT}} = 1.642\,m$

Overturning Resultant Ratio $Ratio_{E1.OT} := \dfrac{X_{R.E1}}{b} = 0.27$

$$Ratio_{E1.OT.check} := \begin{cases} \text{"OKAY "} & \text{if } Ratio_{E1.OT} > X_{R.reqE1} \\ \text{"Revise Structure""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

CHECK FOUNDATION ECCENTRICITY (HORIZONTAL PLANE):

Eccentricity (horizontal plan): $ex_{E1.OT} := \dfrac{b}{2} - \dfrac{\Sigma M_{E1.OT}}{\Sigma V_{E1.OT}} = 1.36\,m$ $Kern_{E1.OT} := \dfrac{b}{4} = 1.5\,m$

Eccentricity Check: $$e_{check.E1.OT} := \begin{cases} \text{"Okay"} & \text{if } ex_{E1.OT} \le Kern_{E1.OT} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"Okay"}$$

CHECK FOUNDATION BEARING CAPACITY (HORIZONTAL PLANE):

Base Section Modulus: $S_{b.OT} = 6\,m^3$

Bearing Pressure Under Toe:

$$\sigma_{ToeE1.OT} := \begin{cases} \left(\dfrac{\Sigma V_{E1.OT}}{b \cdot B} + \dfrac{\Sigma V_{E1.OT} \cdot ex_{E1.OT}}{S_{b.OT}}\right) & \text{if } \dfrac{\Sigma V_{E1.OT}}{b \cdot B} \geq \dfrac{\Sigma V_{E1.OT} \cdot ex_{E1.OT}}{S_{b.OT}} \\ \dfrac{2 \cdot \Sigma V_{E1.OT}}{B \cdot 3\left(\dfrac{b}{2} - ex_{E1.OT}\right)} & \text{otherwise} \end{cases} = 122.6 \cdot kPa$$

$$Bearing_{ChecktoeE1.OT} := \begin{cases} \text{"OKAY "} & \text{if } \sigma_{ToeE1.OT} < \sigma_{allowE1} \\ \text{"NG - for reference only""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

Bearing Pressure Under Heel:

$$\sigma_{HeelE1.OT} := \begin{cases} \left(\dfrac{\Sigma V_{E1.OT}}{b \cdot B} - \dfrac{\Sigma V_{E1.OT} \cdot ex_{E1.OT}}{S_{b.OT}}\right) & \text{if } \dfrac{\Sigma V_{E1.OT}}{b \cdot B} \geq \dfrac{\Sigma V_{E1.OT} \cdot ex_{E1.OT}}{S_{b.OT}} \\ 0 & \text{otherwise} \end{cases} = 0.0 \cdot kPa$$

$$Bearing_{CheckheelE1.OT} := \left(\begin{cases} \text{"OKAY "} & \text{if } \sigma_{HeelE1.OT} < \sigma_{allowE1} \wedge \sigma_{HeelE1.OT} > 0 \\ \text{"NG - for reference only""} & \text{otherwise} \end{cases}\right) = \text{"NG - for reference only""}$$

SUMMARY OF STABILITY ASSESSMENT:

LOAD CASE E1

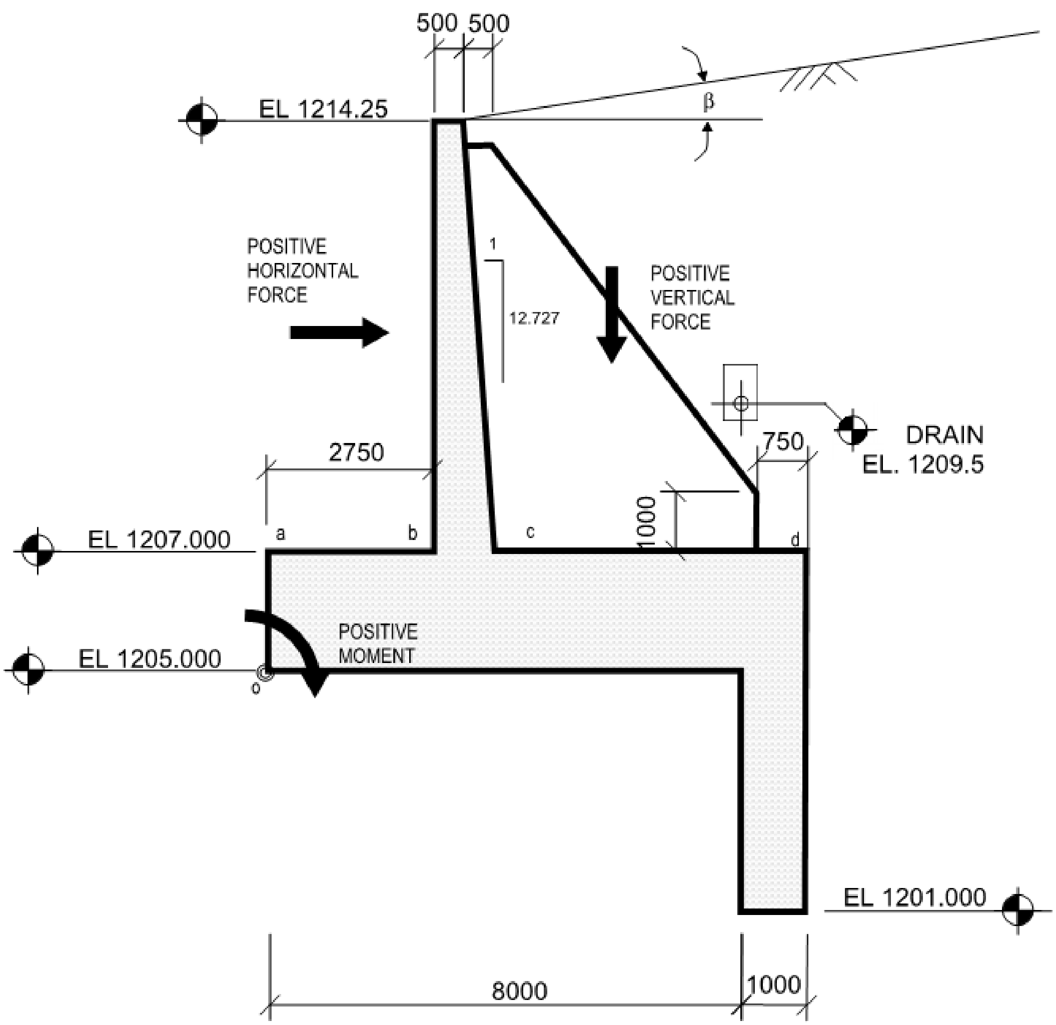
Sliding Factor of Safety: (Horizontal Plane - Ref only)	$FS_{Horiz.SlidingE1} = 0.46$	$FS_{Sliding.check1.E1}$ = "NG - key req""
Sliding Factor of Safety: (Inclined Plane)	$FS_{InclinedlSlidingE1} = 1.88$	$FS_{Sliding.check2.E1}$ = "OKAY "
Eccentricity: (Inclined Plane)	$ex_{E1} = 0.61\ m$	$e_{check.E1}$ = "Okay"
Bearing Pressure At Heel: (Inclined Plane)	$\sigma_{HeelE1} = 30 \cdot kPa$	$Bearing_{CheckheelE1}$ = "OKAY "
Bearing Pressure At Toe: (Inclined Plane)	$\sigma_{ToeE1} = 110 \cdot kPa$	$Bearing_{ChecktoeE1}$ = "OKAY "
Flotation Factor of Safety (horizontal plane)	$FS_{FloatationE1} = 1.96$	$FS_{Floatation.E1.check}$ = "OKAY "
Overturning Resultant Ratio: (horizontal plane)	$Ratio_{E1.OT} = 0.27$	$Ratio_{E1.OT.check}$ = "OKAY "
Eccentricity: (horizontal plane - Ref only)	$ex_{E1.OT} = 1.36\ m$	$e_{check.E1.OT}$ = "Okay"
Bearing Pressure At Heel: (horizontal plane - Ref only)	$\sigma_{HeelE1.OT} = 0 \cdot kPa$	$Bearing_{CheckheelE1.OT}$ = "NG - for reference only""
Bearing Pressure At Toe: (horizontal plane - Ref only)	$\sigma_{ToeE1.OT} = 123 \cdot kPa$	$Bearing_{ChecktoeE1.OT}$ = "OKAY "

Calculation Section VII

DI-Block 5D (Midsection) Retaining Wall Stability Calculations

Project Number:	110773396		
Project Title:	SR1 - Diversion Structure		
Client:	Alberta Transportation		
Engineer:	Lawrence Choi	Date: 12/11/2018	
Checker:	Sean Xiao	Date: 12/18/2018	

Calculation for: Retaining Wall - Diversion Inlet Left - Block 5D (Mid-section)



(DIMENSIONS BASED ON MID SECTION)

REGION COLOR CONVENTION

User Input

Calulation Highlights

Results

WALL GEOMETRY:

Top of Wall Elevation: $T_w := 1214.25 \cdot m$

Top of Footing Elevation: $Top_{ftg} := 1207.0 \cdot m$

Thickness of Footing: $t_{ftg} := 2.0m$

Bottom of Footing Elevation: $Bot_{ftg} := Top_{ftg} - t_{ftg} = 1205\,m$

Overall Height of wall: $h_w := T_w - Bot_{ftg} = 9.25\,m$

Thickness of Wall: Base: $t_{wb} := 1.070 \cdot m$ Top: $t_{wt} := 0.5m$

Length of toe: $L_{ab} := 2.75m$

Total Length of Footing: $b := 9.0m$

Length of heel: $L_{cd} := b - L_{ab} - t_{wb} = 5.18\,m$

Unit Width of Wall for analysis: $B := 1.00m$

SHEAR KEY GEOMETRY:

	Toe	Heel
Key depth:	$Key_{t.d} := 0m$	$Key_{h.d} := 4.0m$
Key width:	$Key_{t.w} := 0m$	$Key_{h.w} := 1m$
Face of Key from Point O:	$Key_{t.loc} := 0 \cdot m$	$Key_{h.loc} := b - Key_{h.w} = 8\,m$

Horizontal Distance between Keys: $Key_{hdist} := Key_{h.loc} - Key_{t.loc} - Key_{t.w} = 8\,m$

Key Depth Diff. (from point O): $Key_{vdist} := -Key_{h.d} + Key_{t.d} = -4\,m$

BASE PROPERTIES:

Base Area: $A_b := b \cdot B = 9\,m^2$

Centroidal Distance for Footing (from Toe): $Y_t := \frac{b}{2} = 4.50\,m$

RETAINED SOIL GEOMETRY:

Slope of retained ground surface: $\beta := 0 \cdot \frac{\pi}{180} = 0.00$

Height of retained earth at heel: $H_w := T_w - Bot_{ftg} + \left(t_{wb} + L_{cd} - t_{wt}\right) \cdot \tan(\beta) = 9.25\,m$

RETAINING WALL GEOMETRY CHECKS:

(Foundation Analysis & Design Bowles)

$$t_{bcheck} := \begin{cases} \text{"OKAY"} & \text{if } t_{ftg} \ge \frac{H_w}{12} \\ \text{"Warning"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

$$t_{wcheck} := \begin{cases} \text{"OKAY"} & \text{if } t_{wb} \ge \frac{H_w}{12} \\ \text{"Warning"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

$$b_{check} := \begin{cases} \text{"OKAY"} & \text{if } \frac{b}{H_w} \ge .4 \wedge \frac{b}{H_w} \le 80 \\ \text{"Warning"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

$$L_{abcheck} := \begin{cases} \text{"OKAY"} & \text{if } \frac{L_{ab}}{b} \ge .25 \wedge \frac{L_{ab}}{b} \le .4 \\ \text{"Warning"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

Material Properties:

Unit Weight of Water: $\gamma_w := 9.8 \frac{kN}{m^3}$ (Section 7.2, Design Criteria)

Unit Weight of Concrete: $\gamma_c := 23.5 \frac{kN}{m^3}$

Unit Weight of Soil (Moist): $\gamma_m := 20.0 \frac{kN}{m^3}$ (Section 5.3, Design Criteria) assumed moisture content (w) = 5%

Unit Weight Soil (Saturated): $\gamma_{sat} := 22.0 \frac{kN}{m^3}$ (Assuming Specific Gravity = 2.7

Unit Weight Soil (buoyant): $\gamma_b := \gamma_{sat} - \gamma_w = 12.2 \cdot \frac{kN}{m^3}$

Weight of Soil/Concrete above toe: $\gamma_{toe} := 22.0 \frac{kN}{m^3}$

Unit Weight of Rock: $\gamma_r := 25.6 \frac{kN}{m^3}$ (Section 7.2, Design Criteria)

Foundation Parameters:

Glacial Till Internal Friction: $\phi := 27 \cdot \frac{\pi}{180} = 0.471$

Bedrock Internal Friction Angle: $\phi_r := 24 \cdot \frac{\pi}{180} = 0.419$

Friction Angle at Base
Concrete / Rock Interface: $\phi_{rock} := 26$

Base Friction Coefficient: $tan_{\phi rock} := \tan\left(\phi_{rock} \frac{\pi}{180}\right) = 0.488$ radians

Rip Rap Backfill, Refer Dwg. C-214 $\phi_{backfill} := \left(20 \frac{\pi}{180}\right) = 0.349$ radians

Shear strength along rock
Failure plane $s_r := \dfrac{13100 \frac{kN}{m^2}}{2} = 6550 \cdot \frac{kN}{m^2}$ (Stantec Design Memo 8/8/16)

CONCRETE DEAD LOAD:

Area of Footing: $A_{ftg} := t_{ftg} \cdot b = 18\,m^2$

Weight of Footing: $D_{ftg} := A_{ftg} \cdot B \cdot \gamma_c = 423 \cdot kN$

Area of Stem (without batter): $A_{w1} := t_{wt} \cdot \left(h_w - t_{ftg}\right) = 3.63\,m^2$

Weight of Stem: $D_{w1} := A_{w1} \cdot B \cdot \gamma_c = 85.2 \cdot kN$

Area of stem Batter: $A_{w2} := \dfrac{\left(t_{wb} - t_{wt}\right)}{2} \left(h_w - t_{ftg}\right) = 2.07\,m^2$

Weight of Batter: $D_{w2} := A_{w2} \cdot B \cdot \gamma_c = 48.6 \cdot kN$

Slope of batter: $S_{batter} := \dfrac{t_{wb} - t_{wt}}{h_w - t_{ftg}} = 0.079$

Area of Key $A_{t.key} := Key_{t.d} \cdot Key_{t.w} = 0$ $A_{h.key} := Key_{h.d} \cdot Key_{h.w} = 4\,m^2$

Weight of Key $D_{t.key} := A_{t.key} \cdot B \cdot \gamma_c = 0 \cdot kN$ $D_{h.key} := A_{h.key} \cdot B \cdot \gamma_c = 94 \cdot kN$

Centroidal Horizontal Distance of Wall (From Toe):

$$H_{cent} := \frac{A_{w1} \cdot \left(L_{ab} + \frac{t_{wt}}{2}\right) + A_{w2} \cdot \left(L_{ab} + t_{wt} + \frac{t_{wb} - t_{wt}}{3}\right) + A_{ftg} \cdot \frac{b}{2} + A_{t.key} \cdot \left(Key_{t.loc} + \frac{Key_{t.w}}{2}\right) + A_{h.key} \cdot \left(Key_{h.loc} + \frac{Key_{h.w}}{2}\right)}{A_{w1} + A_{w2} + A_{ftg} + A_{t.key} + A_{h.key}} = 4.80\,m$$

Centroidal Vertical Distance of Wall (Above Base of Footing):

$$V_{Cent} := \frac{A_{ftg} \cdot \frac{t_{ftg}}{2} + A_{w1} \cdot \left[t_{ftg} + \frac{\left(h_w - t_{ftg}\right)}{2}\right] + A_{w2} \cdot \left[t_{ftg} + \frac{\left(h_w - t_{ftg}\right)}{3}\right] + A_{t.key} \cdot \left(\frac{-Key_{t.d}}{2}\right) + A_{h.key} \cdot \left(\frac{-Key_{h.d}}{2}\right)}{A_{ftg} + A_{w1} + A_{w2} + A_{t.key} + A_{h.key}} = 1.43\,m$$

$\Sigma V_{conc} := D_{ftg} + D_{w1} + D_{w2} + D_{t.key} + D_{h.key} = 650.7 \cdot kN$

$\Sigma M_{conc} := \Sigma V_{conc} \cdot H_{cent} = 3125.1\,m \cdot kN$

ROCK SECTION MOBILIZED FOR INCLINDED SLIDING FAILURE

Area of Rock Section Mobilized: $A_{rocksection} := \left(Key_{t.d} + Key_{h.d}\right) \cdot \dfrac{Key_{hdist}}{2} = 16\,m^2$

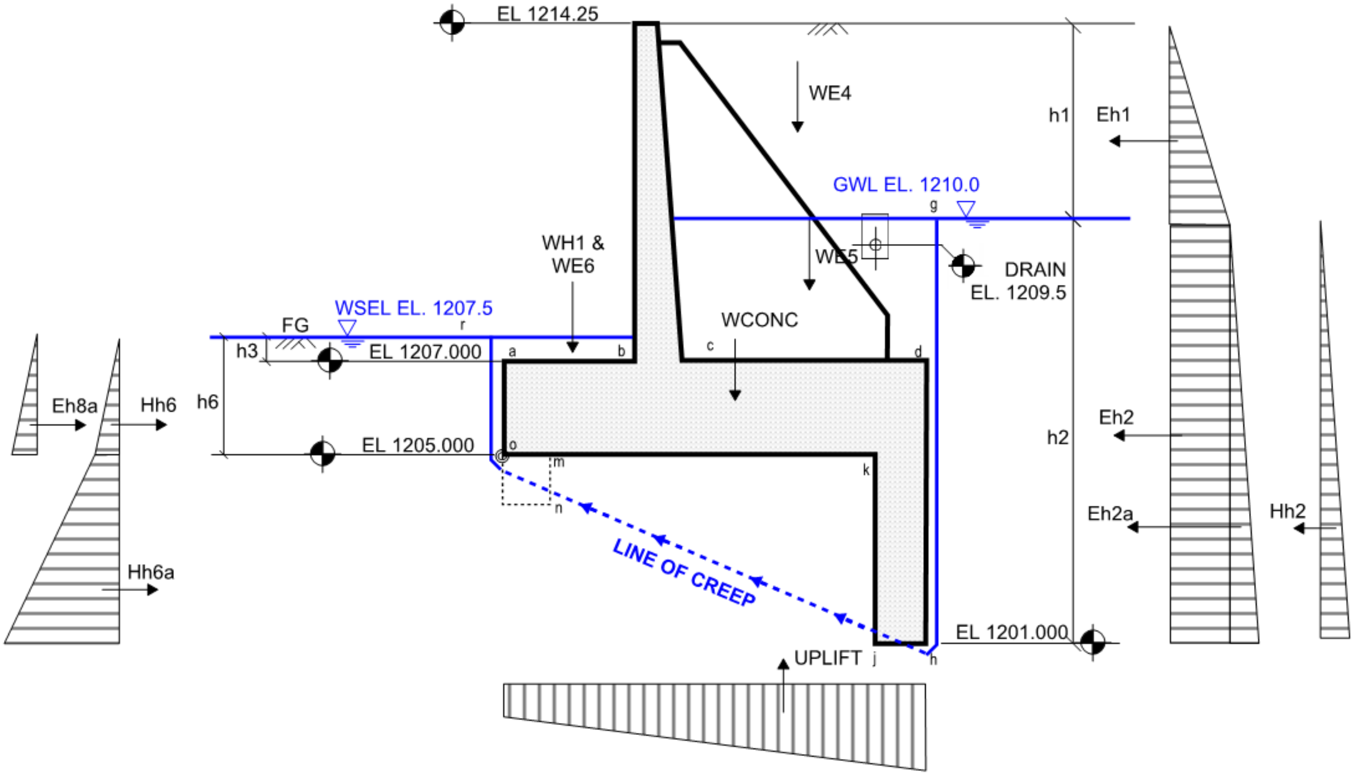
Rock Mass Mobilized: $V_{rocksection} := A_{rocksection} \cdot \gamma_r \cdot B = 409.6 \cdot kN$

(Pore pressure taken along assumed inclined sliding plane)

Distance from Toe to COG of Rock Section: $L_{rocksection} := \dfrac{Key_{hdist} \cdot \left(2 \cdot Key_{h.d} + Key_{t.d}\right)}{3\left(Key_{h.d} + Key_{t.d}\right)} + Key_{t.w} = 5.333\,m$

$\Sigma M_{rocksection} := V_{rocksection} \cdot L_{rocksection} = 2184.5\,m \cdot kN$

LOAD CASE U1 - NORMAL OPERATION



U1 DESIGN CASE

LOAD CASE U1 ACCEPTANCE PARAMETERS

FS sliding:

Usual (U) 1.5 (without cohesion) (Table 3-3, USACE EM 1110-2-2100)

Resultant Location:

Usual (U) Inside middle third ~100% base in compression

Required Factor of Safety for Sliding: $FS_{sliding.reqU1} := 1.5$ (Without Cohesion)

Allowable rock bearing pressure: $\sigma_{allowU1} := 1270kPa$ (Section 5.2, Design Criteria EM 1110-2-2100 Section 3-10)

Overturning Required Resultant Ratio: $X_{R.reqU1} := 0.333$ (EM 1110-2-2502, Figure 4-4)

Required Factor of Safety for Floatation $FS_{req.U1.flt} := 1.5$

SOIL HEIGHTS and Water Levels:

LOAD CASE U1

Heel Conditions:

Groundwater Elevation at Heel: $GWL_{U1} := 1210.0m$

Distance from Finish Grade to Groundwater at Heel: $h_{1U1} := \left[T_w - GWL_{U1} + \left(L_{cd} + t_{wb} - t_{wt}\right) \cdot \tan(\beta)\right] = 4.25\,m$

Distance from Water Surface to Bottom of Footing at Heel: $h_{2U1} := GWL_{U1} - Bot_{ftg} + Key_{h.d} = 9.00\,m$

Toe Conditions:

Water Surface Elevation at Toe: $WSEL_{U1} := 1207.5m$

Water Surface Elevation at Toe for Uplift: $UWSEL_{U1} := 1207.5 \cdot m$

Finish Grade at Toe providing lateral resistance: $FG_{toeU1} := 1207.5 \cdot m$

Soil Depth Above top of footing: $h_{3aU1} := FG_{toeU1} - Top_{ftg} = 0.5\,m$

$$h_{3U1} := \begin{vmatrix} h_{3aU1} \ \text{if} \ FG_{toeU1} - Top_{ftg} \geq 0 \\ 0 \ \text{otherwise} \end{vmatrix} = 0.5$$

Resisting Fill at Toe: $h_{4U1} := FG_{toeU1} - Bot_{ftg} + Key_{t.d} = 2.50\,m$

Distance from Water Level to Top of Footing: $h_{5U1} := WSEL_{U1} - Top_{ftg} = 0.50\,m$

Distance from Water Surface to Bottom of Toe Key: $h_{6U1} := WSEL_{U1} - Bot_{ftg} + Key_{t.d} = 2.50 \cdot m$

Soil Depth Above WSEL: $h_{7aU1} := FG_{toeU1} - WSEL_{U1} = 0\,m$

$$h_{7U1} := \begin{vmatrix} h_{7aU1} \ \text{if} \ FG_{toeU1} - WSEL_{U1} \geq 0 \\ 0 \ \text{otherwise} \end{vmatrix} = 0$$

Soil Depth Below WSEL:

$$h_{8U1} := \begin{vmatrix} WSEL_{U1} - Bot_{ftg} + Key_{t.d} \ \text{if} \ FG_{toeU1} - WSEL_{U1} \geq 0 \\ h_{4U1} \ \text{otherwise} \end{vmatrix} = 2.5$$

For Line of Creep Method: $L_{ho.U1} := \sqrt{b^2 + \left(Key_{h.d} - Key_{t.d}\right)^2} = 9.849\,m$

Head Loss from Point g:

$\Delta h_{g.hj.U1} := h_{2U1} = 9\,m$ (to point h & j)

$\Delta h_{g.km.U1} := GWL_{U1} - Bot_{ftg} = 5\,m$ (to point k & m)

$\Delta h_{g.no.U1} := GWL_{U1} - Bot_{ftg} + Key_{t.d} = 5\,m$ (to point n & o)

$\Delta h_{g.p.U1} := GWL_{U1} - FG_{toeU1} = 2.5\,m$ (to point p*)

$\Delta h_{g.r.U1} := GWL_{U1} - UWSEL_{U1} = 2.5\,m$ (to point r)

Surcharge

Surcharge on Heel: $S1_{U1} := 0.0 \frac{kN}{m^2}$

* same as point "a" in this case

Calculate Soil Lateral Pressure Coefficients:

LOAD CASE U1

For all load cases except seismic, soil loading to be based on At-Rest Condition.
Calculate at-rest pressure coefficient Ko based on Jaky's (1944) equation.

Soil At Rest Static Coefficient: $K_o := \dfrac{1 - \sin(\phi)}{1 + \sin(\beta)} = 0.546$ (Eq. 3-6, USACE EM 1110-2-2502)

Lateral - Driving Force (Headwater Side)

Lateral Soil Load:

Surcharge Load: $E_{s1U1} := S1_{U1} \cdot K_o \cdot \left(H_w + Key_{h.d}\right) \cdot B \cdot -1 = 0 \cdot kN$

Moment Arm (from Point O): $E_{s1locU1} := \dfrac{H_w + Key_{h.d}}{2} + Key_{vdist} = 2.63\ m$

Moist Soil Load above GWL: $E_{h1U1} := \dfrac{\gamma_m \cdot K_o \cdot h_{1U1}^{\ 2}}{2} B \cdot -1 = -98.6 \cdot kN$

Moment Arm (from Point O): $E_{h1locU1} := \dfrac{h_{1U1}}{3} + h_{2U1} + Key_{vdist} = 6.42\ m$

Saturated Soil Load below GWL:
(rectangular component) $E_{h2U1} := \left(\gamma_m \cdot K_o \cdot h_{1U1}\right) \cdot \left(h_{2U1}\right) \cdot B \cdot -1 = -417.7 \cdot kN$

Moment Arm (from Point O): $E_{h2locU1} := \dfrac{h_{2U1}}{2} + Key_{vdist} = 0.50\ m$

Saturated Soil Load below GWL:
(triangular component) $E_{h2aU1} := \dfrac{\left(\gamma_{sat} - \gamma_w\right) \cdot K_o \cdot h_{2U1}^{\ 2}}{2} \cdot B \cdot -1 = -269.8 \cdot kN$

Moment Arm (from Point O): $E_{h2alocU1} := \dfrac{h_{2U1}}{3} + Key_{vdist} = -1.00\ m$

Lateral Water Load:

Water Load GWL to Bottom of Keys:

$$H_{h2U1} := \begin{cases} \dfrac{\gamma_w \cdot h_{2U1}^{\ 2}}{2} \cdot B \cdot -1 & \text{if } Key_{vdist} < 0 \\ \dfrac{\gamma_w \cdot \left(h_{2U1} + Key_{vdist}\right)^2}{2} \cdot B \cdot -1 & \text{otherwise} \end{cases} = -396.9 \cdot kN$$

Moment Arm (from Point O):

$$H_{h2locU1} := \begin{cases} \dfrac{h_{2U1}}{3} + Key_{vdist} & \text{if } Key_{vdist} < 0 \\ \dfrac{h_{2U1} + Key_{vdist}}{3} & \text{otherwise} \end{cases} = -1.00 \cdot m$$

$$\Sigma H_{SoildriveU1} := E_{s1U1} + E_{h1U1} + E_{h2U1} + E_{h2aU1} + H_{h2U1} = -1183.0 \cdot kN$$

$$\Sigma M_{LateralSoildriveU1} := E_{s1U1} \cdot E_{s1locU1} + E_{h1U1} \cdot E_{h1locU1} + E_{h2U1} \cdot E_{h2locU1} \cdots + E_{h2aU1} \cdot E_{h2alocU1} + H_{h2U1} \cdot H_{h2locU1} = -175.0\ m \cdot kN$$

Lateral - Resisting Force (Tailwater Side)

LOAD CASE U1

Lateral Water Load:

Water Load WSEL to Bot. of Toe Key: $H_{h6U1} := \dfrac{\gamma_w \cdot h_{6U1}^2}{2} \cdot B = 30.6 \cdot kN$

Moment Arm (from Point O): $H_{h6locU1} := \dfrac{h_{6U1}}{3} = 0.83\ m$

Water Load between Keys (if any) $H_{h6aU1} := \begin{cases} \dfrac{\left(h_{6U1} + h_{2U1}\right) \cdot -Key_{vdist}}{2} \cdot \gamma_w \cdot B & \text{if } Key_{vdist} < 0 \\ 0 & \text{otherwise} \end{cases} = 225.4 \cdot kN$

Moment Arm (from Point O): $H_{h6alocU1} := \begin{cases} \dfrac{Key_{vdist} \cdot \left(2 \cdot h_{2U1} + h_{6U1}\right)}{3\left(h_{2U1} + h_{6U1}\right)} & \text{if } Key_{vdist} < 0 \\ 0 & \text{otherwise} \end{cases} = -2.38 \cdot m$

Lateral Soil Load:

Moist Soil Load above WSEL: $E_{h7U1} := \dfrac{\gamma_m \cdot K_o \cdot h_{7U1}^2}{2} B = 0.0 \cdot kN$

Moment Arm (from bot. of toe key): $E_{h7locU1} := h_{6U1} + \dfrac{h_{7U1}}{3} = 2.50\ m$

Saturated Soil Load below WSEL:
(rectangular component) $E_{h8U1} := \left(\gamma_m \cdot K_o \cdot h_{7U1}\right) \cdot h_{8U1} \cdot B = 0.0 \cdot kN$

Moment Arm (from bot. of toe key): $E_{h8locU1} := \dfrac{h_{8U1}}{2} = 1.25\ m$

Saturated Soil Load below WSEL:
(triangular component) $E_{h8aU1} := \dfrac{\left[\left(\gamma_{sat} - \gamma_w\right) \cdot K_o\right] \cdot h_{8U1}^2}{2} \cdot B = 20.8 \cdot kN$

Moment Arm (from bot. of footing): $E_{h8alocU1} := \dfrac{h_{8U1}}{3} = 0.83\ m$

$$\Sigma H_{SoilresistU1} := H_{h6U1} + H_{h6aU1} + E_{h7U1} + E_{h8U1} + E_{h8aU1} = 276.8 \cdot kN$$

$$\Sigma M_{HorizSoilResistU1} := H_{h6U1} \cdot H_{h6locU1} + H_{h6aU1} \cdot H_{h6alocU1} + E_{h7U1} \cdot E_{h7locU1} \dots + E_{h8U1} \cdot E_{h8locU1} + E_{h8aU1} \cdot E_{h8alocU1} = -492.9\ m \cdot kN$$

Vertical Force:

UPLIFT: Linear distribution from water at heel to water at toe:

$$\Sigma V_{UpliftU1} := \left[\left(UWSEL_{U1} - Bot_{ftg} + Key_{t.d}\right) + h_{2U1}\right] \cdot \frac{b}{2} \cdot \gamma_w \cdot B \cdot -1 = -507.15 \cdot kN$$

Moment Arm (from Point O): $V_{UpliftU1aloc} := \dfrac{b \cdot \left[2 \cdot h_{2U1} + \left(UWSEL_{U1} - Bot_{ftg} + Key_{t.d}\right)\right]}{3\left[h_{2U1} + \left(UWSEL_{U1} - Bot_{ftg} + Key_{t.d}\right)\right]} = 5.348\ m$

$$\Sigma M_{UpliftU1} := \Sigma V_{UpliftU1} \cdot V_{UpliftU1aloc} = -2712.15 \cdot kN \cdot m$$

Vertical Force (con't):

LOAD CASE U1

Weight of soil and water over toe:

Water Above the Top of Footing: $W_{H1U1} := \gamma_w \cdot h_{5U1} \cdot L_{ab} \cdot B = 13.475 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E1locU1} := \dfrac{L_{ab}}{2} = 1.375\,m$

Soil above top of footing: $W_{E6U1} := \gamma_b \cdot h_{3U1} \cdot L_{ab} \cdot B = 16.8 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E6locU1} := \dfrac{L_{ab}}{2} = 1.375\,m$

Vertical Load Due to Surcharge: $S_{U1} := S1_{U1} \cdot L_{cd} \cdot B = 0$ $\quad S_{U1loc} := b - \dfrac{L_{cd}}{2} = 6.41\,m$

Weight of soil and water over heel:

Moist Soil for sloped grade above top of wall:

Length of sloped portion of soil above top of wall: $L_{E3U1} := \left(L_{cd} + t_{wb} - t_{wt}\right) = 5.75\,m$

Height of sloped soil above top of wall over heel: $h_{E3locU1} := \left(L_{E3U1}\right) \cdot \tan(\beta) = 0.00\,m$

Weight of sloped soil above top of wall: $W_{E3U1} := \dfrac{\gamma_m}{2} \cdot h_{E3locU1} \cdot L_{E3U1} \cdot B = 0.0 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E3locU1} := L_{ab} + t_{wt} + \dfrac{2}{3} \cdot L_{E3U1} = 7.08\,m$

Moist soil from top of wall to groundwater level:

Height of soil from top of wall and top of GWL: $h_{1U1} = 4.25\,m$

Length from edge of wall at GWL to edge of heel: $L_{E4U1} := L_{E3U1} - \left(h_{1U1} \cdot S_{batter}\right) = 5.42\,m$

Weight of soil over heel from top of wall to GWL: $W_{E4U1} := \gamma_m \cdot h_{1U1} \cdot \dfrac{\left(L_{E3U1} + L_{E4U1}\right)}{2} \cdot B = 474.5 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E4locU1} := b - \dfrac{L_{E3U1}^2 + L_{E3U1} \cdot L_{E4U1} + L_{E4U1}^2}{3\left(L_{E3U1} + L_{E4U1}\right)} = 6.21\,m$

Saturated soil from groundwater to top of footing:

Height of soil from GWL to top of heel: $h_{E4U1} := h_{2U1} - t_{ftg} - Key_{h.d} = 3.00\,m$

Weight of soil over heel from GWL to top of heel: $W_{E5U1} := \left(\gamma_{sat}\right) \cdot h_{E4U1} \cdot \dfrac{\left(L_{E4U1} + L_{cd}\right)}{2} \cdot B = 349.7 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E5locU1} := b - \dfrac{L_{E4U1}^2 + L_{E4U1} \cdot L_{cd} + L_{cd}^2}{3\left(L_{E4U1} + L_{cd}\right)} = 6.35\,m$

$$\Sigma V_{SoilWaterU1} := W_{H1U1} + W_{E6U1} + W_{E3U1} + W_{E4U1} + W_{E5U1} + S_{U1} = 854.5 \cdot kN$$

$$\Sigma M_{VertSoilWaterResistU1} := W_{H1U1} \cdot W_{E1locU1} + W_{E6U1} \cdot W_{E6locU1} \cdots + W_{E3U1} \cdot W_{E3locU1} + W_{E4U1} \cdot W_{E4locU1} + W_{E5U1} \cdot W_{E5locU1} + S_{U1} \cdot S_{U1loc} = 5208.0\,m \cdot kN$$

THIS PAGE INTENTIONALLY LEFT BLANK
PLEASE GO TO THE NEXT PAGE

STABILITY ASSESSMENT:

LOAD CASE U1

CHECK SLIDING ALONG HORIZONTAL SLIDING PLANE:

Summation of the vertical forces:

$$\Sigma V_{U1} := \Sigma V_{conc} + \Sigma V_{SoilWaterU1} + \Sigma V_{UpliftU1} = 998.1 \cdot kN$$

Summation of the horizontal forces:

$$\Sigma H_{U1} := \Sigma H_{SoildriveU1} + \Sigma H_{SoilresistU1} = -906.2 \cdot kN$$

Safety Factor for Sliding Horizontal Failure Plane

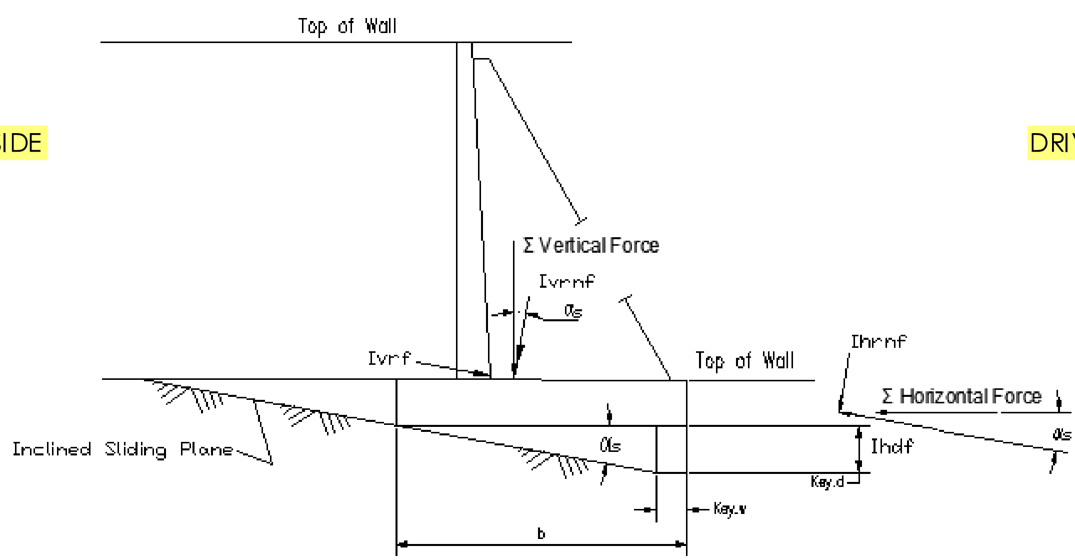
$$FS_{Horiz.SlidingU1} := \frac{\left|\Sigma V_{U1}\right| \cdot \tan\left(\phi_{rock} \cdot \frac{\pi}{180}\right)}{\left|\Sigma H_{U1}\right|} = 0.54$$

$$FS_{Sliding.check1.U1} := \begin{cases} \text{"OKAY "} & \text{if } FS_{Horiz.SlidingU1} > FS_{sliding.reqU1} \\ \text{"Key req'"} & \text{otherwise} \end{cases} = \text{"Key req'"}$$

CHECK FACTOR OF SAFETY SLIDING WITH KEY (INCLINED SLIDING PLANE):

RESISTING SIDE

DRIVING SIDE



TOE

HEEL

Ivrf=Inclined Resisting Force
Ivrnf=Inclined Resisting Normal Force
Ihrnf=Inclined Resisting Normal Force
Ihdf=Inclined Driving Force

$$\alpha s := \text{atan}\left(\frac{-Key_{vdist}}{Key_{hdist}}\right) = 0.464 \qquad \text{as degrees=} \qquad \alpha s \cdot \left(\frac{180}{\pi}\right) = 26.57$$

(With properly engineered reinforced concrete Key, horizontal sliding plane thru Toe is protected, critical sliding plane is relocated to the INCLINED SLIDING PLANE FROM HEEL KEY To TOE, Bedrock Mass above this examing plane is mobilized by reinforced concrete key and combined into Structural Wedge.)

Resolve ΣV_{U1} & ΣH_{U1}

$$\Sigma V_{InclinedU1} := \cos(\alpha s) \cdot \left(\left|\Sigma V_{U1} + V_{rocksection}\right|\right) + \sin(\alpha s) \cdot \left|\Sigma H_{U1}\right| = 1664.3 \cdot kN$$

$$\Sigma H_{InclinedU1} := \cos(\alpha s) \cdot \left|\Sigma H_{U1}\right| - \sin(\alpha s) \cdot \left(\left|\Sigma V_{U1} + V_{rocksection}\right|\right) = 181.0 \cdot kN$$

LOAD CASE U1

Safety Factor for Sliding Inclined Failure Plane

$$FS_{InclinedlSlidingU1} := \frac{\Sigma V_{InclinedU1} \cdot \tan(\phi_r)}{\Sigma H_{InclinedU1}} = 4.09$$

$$FS_{Sliding.check2.U1} := \left| \begin{array}{ll} \text{"OKAY "} & \text{if } FS_{InclinedlSlidingU1} > FS_{sliding.reqU1} \\ \text{"NG - Revise Structure""} & \text{otherwise} \end{array} \right. = \text{"OKAY "}$$

CHECK FOUNDATION ECCENTRICITY:

Summation of the resisting moments about the toe:

$$\Sigma M_{resU1} := \Sigma M_{conc} + \Sigma M_{VertSoilWaterResistU1} + \Sigma M_{HorizSoilResistU1} + \Sigma M_{rocksection} = 10025 \cdot kN \cdot m$$

Summation of the overturning moments about the toe:

$$\Sigma M_{oU1} := \Sigma M_{LateralSoildriveU1} + \Sigma M_{UpliftU1} = -2887 \cdot kN \cdot m$$

Total moment: $\Sigma M_{U1} := \Sigma M_{resU1} + \Sigma M_{oU1} = 7137.6 \cdot kN \cdot m$

Normal force to base: $\Sigma V_{InclinedU1} = 1664.3 \cdot kN$

Inclined Sliding Plane Length: $L_{incline} := \dfrac{b}{\cos(\alpha s)} = 10.1\ m$

Eccentricity (inclined plane): $ex_{U1} := \dfrac{L_{incline}}{2} - \dfrac{\Sigma M_{U1}}{\Sigma V_{InclinedU1}} = 0.74\ m$ $\qquad Kern := \dfrac{L_{incline}}{6} = 1.677\ m$

Eccentricity Check:

$$e_{check.U1} := \left| \begin{array}{ll} \text{"Okay"} & \text{if } ex_{U1} \le Kern \\ \text{"Revise Structure"} & \text{otherwise} \end{array} \right. = \text{"Okay"}$$

CHECK FOUNDATION BEARING CAPACITY:

Base Section Modulus: $S_b := \dfrac{1}{6}\left(B \cdot L_{incline}{}^2\right) = 16.88\ m^3$

Bearing Pressure Under Toe:

$$\sigma_{ToeU1} := \left| \begin{array}{ll} \left[\dfrac{\Sigma V_{InclinedU1}}{L_{incline} \cdot B} + \dfrac{\left(\Sigma V_{InclinedU1} \cdot ex_{U1}\right)}{S_b}\right] & \text{if } \dfrac{\Sigma V_{InclinedU1}}{L_{incline} \cdot B} \ge \dfrac{\Sigma V_{InclinedU1} \cdot ex_{U1}}{S_b} \\ \dfrac{2 \cdot \Sigma V_{InclinedU1}}{B \cdot 3\left(\dfrac{b}{2} - ex_{U1}\right)} & \text{otherwise} \end{array} \right. = 238.6 \cdot kPa$$

$$Bearing_{ChecktoeU1} := \left| \begin{array}{ll} \text{"OKAY "} & \text{if } \sigma_{ToeU1} < \sigma_{allowU1} \\ \text{"NG""} & \text{otherwise} \end{array} \right. = \text{"OKAY "}$$

Bearing Pressure Under Heel:

$$\sigma_{HeelU1} := \left| \begin{array}{ll} \left[\dfrac{\Sigma V_{InclinedU1}}{L_{incline} \cdot B} - \dfrac{\left(\Sigma V_{InclinedU1} \cdot ex_{U1}\right)}{S_b}\right] & \text{if } \dfrac{\Sigma V_{InclinedU1}}{L_{incline} \cdot B} \ge \dfrac{\Sigma V_{InclinedU1} \cdot ex_{U1}}{S_b} \\ 0 & \text{otherwise} \end{array} \right. = 92.2 \cdot kPa$$

$$Bearing_{CheckheelU1} := \left(\left| \begin{array}{ll} \text{"OKAY "} & \text{if } \sigma_{HeelU1} < \sigma_{allowU1} \wedge \sigma_{HeelU1} > 0 \\ \text{"NG - perform cracked base analysis""} & \text{otherwise} \end{array} \right. \right) = \text{"OKAY "}$$

CHECK FLOATATION:

Safety Factor for Floatation:

$$FS_{FloatationU1} := \frac{\Sigma V_{conc} + \Sigma V_{SoilWaterU1}}{\left|\Sigma V_{UpliftU1}\right|} = 2.97$$

$$FS_{Floatation.U1.check} := \begin{cases} \text{"OKAY "} & \text{if } FS_{FloatationU1} > FS_{req.U1.flt} \\ \text{"Revise Structure""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

CHECK OVERTURNING

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.
Assumptions are made in order to compute overturning stablity of indetermine forces on monolith with key;
(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.
(b) The horizontal resisting force acting on the key, P.key, is that required for static equilibrium
(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1

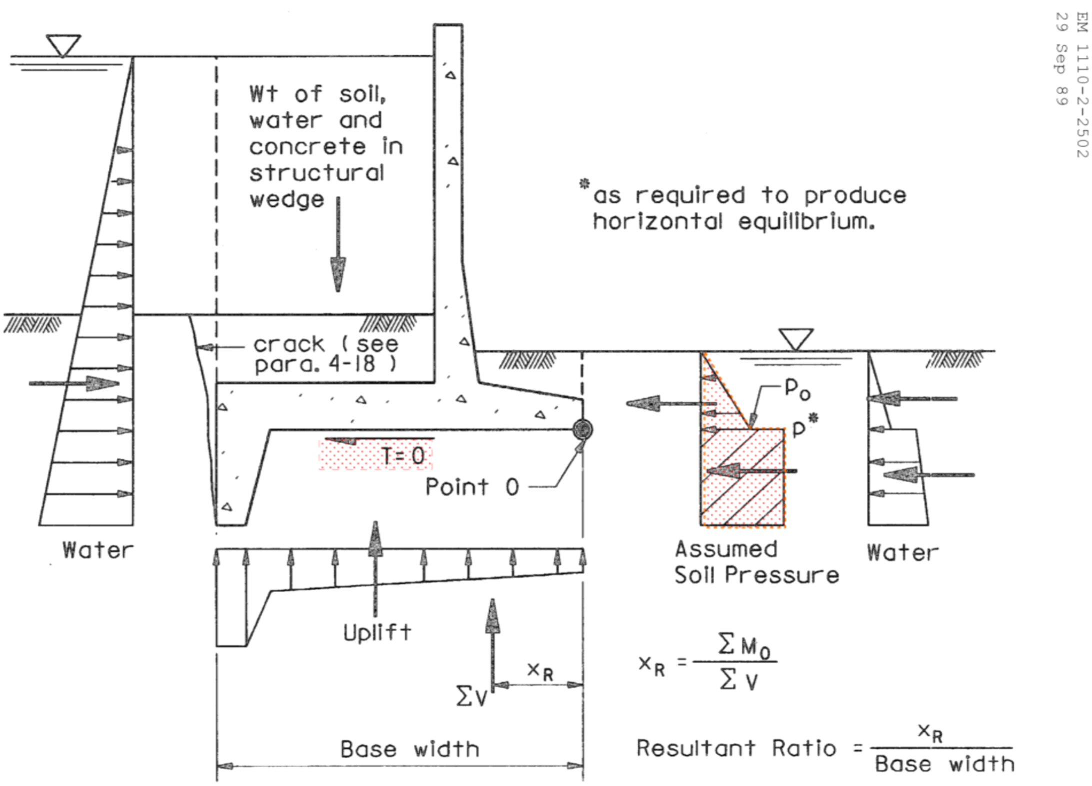


Figure 4-5. Forces for overturning analysis for wall with horizontal base and key

Modify Uplift for Overturning Analysis: **LOAD CASE U1**

(Uplift is calculated along the concrete/rock contact using the Line of Creep method)

Water Pressure at h: $u_{h.U1} := \Delta h_{g.hj.U1} \cdot \gamma_w = 88.20 \cdot kPa$

Water Pressure at o: $u_{o.U1} := \left(\Delta h_{g.no.U1} - \frac{\Delta h_{g.r.U1} \cdot L_{ho.U1}}{L_{ho.U1}}\right) \cdot \gamma_w = 24.5 \cdot kPa$

Head loss between point h and o: $\Delta h_{ho.U1} := \Delta h_{g.r.U1} \cdot \frac{L_{ho.U1}}{L_{ho.U1}} = 2.5\,m$

Length of concrete base (h -> o): $L_{baseho.U1} := Key_{h.w} + Key_{h.d} + Key_{hdist} + Key_{t.d} + Key_{t.w} = 13\,m$

Head loss along h -> j: $\Delta h_{hj.U1} := \Delta h_{ho.U1} \cdot \frac{Key_{h.w}}{L_{baseho.U1}} = 0.192\,m$

Water Pressure at j: $u_{j.U1} := \left(\Delta h_{g.hj.U1} - \Delta h_{hj.U1}\right) \cdot \gamma_w = 86.32 \cdot kPa$

Head loss along h -> k: $\Delta h_{hjk.U1} := \Delta h_{ho.U1} \cdot \left(\frac{Key_{h.w} + Key_{h.d}}{L_{baseho.U1}}\right) = 0.962\,m$

Water Pressure at k: $u_{k.U1} := \left(\Delta h_{g.km.U1} - \Delta h_{hjk.U1}\right) \cdot \gamma_w = 39.58 \cdot kPa$

Head loss along h -> m: $\Delta h_{hjkm.U1} := \Delta h_{ho.U1} \cdot \left(\frac{Key_{h.w} + Key_{h.d} + Key_{hdist}}{L_{baseho.U1}}\right) = 2.5\,m$

Water Pressure at m: $u_{m.U1} := \left(\Delta h_{g.km.U1} - \Delta h_{hjkm.U1}\right) \cdot \gamma_w = 24.50 \cdot kPa$

Head loss along h -> n: $\Delta h_{hjkmn.U1} := \Delta h_{ho.U1} \cdot \left(\frac{Key_{h.w} + Key_{h.d} + Key_{hdist} + Key_{t.d}}{L_{baseho.U1}}\right) = 2.5\,m$

Water Pressure at n: $u_{n.U1} := \left(\Delta h_{g.no.U1} - \Delta h_{hjkmn.U1}\right) \cdot \gamma_w = 24.50 \cdot kPa$

Uplift under key at heel: $V_{ulkeyhU1.OT} := \frac{\left(u_{h.U1} + u_{j.U1}\right) \cdot Key_{h.w}}{2} \cdot B \cdot -1 = -87.258 \cdot kN$

Moment Arm (from Point O): $V_{ulkeyhU1loc.OT} := b - \frac{Key_{h.w} \cdot \left(2 \cdot u_{j.U1} + u_{h.U1}\right)}{3 \cdot \left(u_{j.U1} + u_{h.U1}\right)} = 8.502\,m$

Uplift under base: $V_{ulbaseU1.OT} := \frac{\left(u_{k.U1} + u_{m.U1}\right) \cdot Key_{hdist}}{2} \cdot B \cdot -1 = -256.308 \cdot kN$

Moment Arm (from Point O): $V_{ulbaseU1loc.OT} := b - Key_{h.w} - \frac{Key_{hdist} \cdot \left(2 \cdot u_{m.U1} + u_{k.U1}\right)}{3 \cdot \left(u_{m.U1} + u_{k.U1}\right)} = 4.314\,m$

Uplift under key at toe: $V_{ulkeytU1.OT} := \frac{\left(u_{n.U1} + u_{o.U1}\right) \cdot Key_{t.w}}{2} \cdot B \cdot -1 = 0 \cdot kN$

Moment Arm (from Point O): $V_{ulkeytU1loc.OT} := \frac{Key_{t.w} \cdot \left(2 \cdot u_{n.U1} + u_{o.U1}\right)}{3 \cdot \left(u_{n.U1} + u_{o.U1}\right)} = 0$

$$\Sigma V_{UpliftU1.OT} := V_{ulkeyhU1.OT} + V_{ulbaseU1.OT} + V_{ulkeytU1.OT} = -344 \cdot kN$$

$$U_{U1.loc.OT} := \frac{V_{ulkeyhU1.OT} \cdot V_{ulkeyhU1loc.OT} + V_{ulbaseU1.OT} \cdot V_{ulbaseU1loc.OT} + V_{ulkeytU1.OT} \cdot V_{ulkeytU1loc.OT}}{\Sigma V_{UpliftU1.OT}} = 5.38\,m$$

$$\Sigma M_{UpliftU1.OT} := \Sigma V_{UpliftU1.OT} \cdot U_{U1.loc.OT} = -1847.5 \cdot kN \cdot m$$

Modify Lateral Water Pressure (Resisting) for Overturning Analysis:

(Resisting water pressure is calculated using the Line of Creep method)

Water Load at Key (heel):

$$H_{h2U1.OT} := \frac{u_{k.U1} + u_{j.U1}}{2} \cdot Key_{h.d} B = 251.8 \cdot kN$$

Moment Arm (from Point O):

$$H_{h2locU1.OT} := \frac{Key_{h.d} \cdot (2 \cdot u_{k.U1} + u_{j.U1})}{3(u_{k.U1} + u_{j.U1})} + Key_{vdist} = -2.25\ m$$

Water Load at Key (toe):

$$H_{h6U1.OT} := \frac{u_{o.U1} \cdot (UWSEL_{U1} - Bot_{ftg} + Key_{t.d})}{2} \cdot B = 31 \cdot kN$$

Moment Arm (from Point O):

$$H_{h6locU1.OT} := \frac{UWSEL_{U1} - Bot_{ftg} + Key_{t.d}}{3} = 0.83\ m$$

$$\Sigma H_{waterresistU1.OT} := H_{h2U1.OT} + H_{h6U1.OT} = 282.41 \cdot kN$$

$$H_{waterresistlocU1.OT} := \frac{H_{h2U1.OT} \cdot H_{h2locU1.OT} + H_{h6U1.OT} \cdot H_{h6locU1.OT}}{\Sigma H_{waterresistU1.OT}} = -1.913\ m$$

$$\Sigma M_{waterresistU1.OT} := \Sigma H_{waterresistU1.OT} \cdot H_{waterresistlocU1.OT} = -540.37 \cdot kN \cdot m$$

Modify Lateral Soil Loads for Overturning Analysis:

(Lateral soil loads are calculated down to Point O instead of bottom of shear key)

Driving Soil Load (Headwater Side):

Surcharge Load:

$$E_{s1U1.OT} := S1_{U1} \cdot K_o \cdot (H_w + Key_{h.d} + Key_{vdist}) \cdot B \cdot -1 = 0 \cdot kN$$

Moment Arm (from Point O):

$$E_{s1locU1.OT} := \frac{H_w + Key_{h.d} + Key_{vdist}}{2} = 4.63\ m$$

Moist Soil Load above GWL:

$$E_{h1U1.OT} := \frac{\gamma_m \cdot K_o \cdot h_{1U1}^{\ 2}}{2} B \cdot -1 = -98.6 \cdot kN$$

Moment Arm (from Point O):

$$E_{h1locU1.OT} := \frac{h_{1U1}}{3} + h_{2U1} + Key_{vdist} = 6.42\ m$$

Saturated Soil Load below GWL:
(rectangular component)

$$E_{h2U1.OT} := (\gamma_m \cdot K_o \cdot h_{1U1}) \cdot (h_{2U1} + Key_{vdist}) \cdot B \cdot -1 = -232.1 \cdot kN$$

Moment Arm (from Point O):

$$E_{h2locU1.OT} := \frac{h_{2U1} + Key_{vdist}}{2} = 2.50\ m$$

Saturated Soil Load below GWL:
(triangular component)

$$E_{h2aU1.OT} := \frac{(\gamma_{sat} - \gamma_w) \cdot K_o \cdot (h_{2U1} + Key_{vdist})^2}{2} \cdot B \cdot -1 = -83.3 \cdot kN$$

Moment Arm (from Point O):

$$E_{h2alocU1.OT} := \frac{h_{2U1} + Key_{vdist}}{3} = 1.67\ m$$

LOAD CASE U1

Resisting Soil Load (Tailwater Side):

(Determine resisting soil load based on depth variation between the keys (ie. Key_{vdist}). In case where key at heel is deeper than key at toe (ie. $Key_{vdist} < 0$), resisting soil load (p*) is assumed to produce horizontal equilibrium as per Figure 4-5 above. Resisting soil load (p_o) is neglected.)

Total Driving Force: $\Sigma H_{SoildriveU1.OT} := E_{s1U1.OT} + E_{h1U1.OT} + E_{h2U1.OT} + E_{h2aU1.OT} + H_{h2U1} = -810.8 \cdot kN$

Total Resisting Force: $\Sigma H_{waterresistU1.OT} = 282.4 \cdot kN$

Assumed Soil Load p*: $E_{h8U1a.OT} := \left(\Sigma H_{SoildriveU1.OT} + \Sigma H_{waterresistU1.OT}\right) \cdot -1 = 528.434 \cdot kN$

Moment Arm (from Point O): $E_{h8U1a.loc.OT} := \dfrac{Key_{vdist}}{2} = -2\,m$

$$E_{h8U1.OT} := \begin{cases} E_{h8U1a.OT} & \text{if } Key_{vdist} < 0 \\ \Sigma H_{SoilresistU1} - H_{h6U1} - H_{h6aU1} & \text{otherwise} \end{cases} = 528.434 \cdot kN$$

$$\Sigma M_{SoilresistU1.OT} := \begin{cases} E_{h8U1a.OT} \cdot E_{h8U1a.loc.OT} & \text{if } Key_{vdist} < 0 \\ \Sigma M_{HorizSoilResistU1} - H_{h6U1} \cdot H_{h6locU1} - H_{h6aU1} \cdot H_{h6alocU1} & \text{otherwise} \end{cases} = -1056.868 \cdot kN \cdot m$$

Sum of Moment about Point O:

$$\Sigma M_{LateraldriveU1.OT} := E_{s1U1.OT} \cdot E_{s1locU1.OT} + E_{h1U1.OT} \cdot E_{h1locU1.OT} + E_{h2U1.OT} \cdot E_{h2locU1.OT} \cdots + E_{h2aU1.OT} \cdot E_{h2alocU1.OT} + H_{h2U1} \cdot H_{h2locU1} = -954.8 \cdot kN \cdot m$$

$$\Sigma M_{LateralresistU1.OT} := \Sigma M_{waterresistU1.OT} + \Sigma M_{SoilresistU1.OT} = -1597.2 \cdot kN \cdot m$$

Total moment:

$$\Sigma M_{U1.OT} := \Sigma M_{conc} + \Sigma M_{VertSoilWaterResistU1} + \Sigma M_{UpliftU1.OT} + \Sigma M_{LateraldriveU1.OT} + \Sigma M_{LateralresistU1.OT} = 3933.6 \cdot kN \cdot m$$

Total Vertical Force: $\Sigma V_{U1.OT} := \Sigma V_{conc} + \Sigma V_{SoilWaterU1} + \Sigma V_{UpliftU1.OT} = 1161.6 \cdot kN$

Distance X_R: EM 1110-2-2502 Eq.4-1 $X_{R.U1} := \dfrac{\Sigma M_{U1.OT}}{\Sigma V_{U1.OT}} = 3.386\,m$

Overturning Resultant Ratio $Ratio_{U1.OT} := \dfrac{X_{R.U1}}{b} = 0.38$

$$Ratio_{U1.OT.check} := \begin{cases} \text{"OKAY "} & \text{if } Ratio_{U1.OT} > X_{R.reqU1} \\ \text{"Revise Structure""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

CHECK FOUNDATION ECCENTRICITY (HORIZONTAL PLANE):

Eccentricity (horizontal plan): $ex_{U1.OT} := \dfrac{b}{2} - \dfrac{\Sigma M_{U1.OT}}{\Sigma V_{U1.OT}} = 1.11\,m$ $Kern_{OT} := \dfrac{b}{6} = 1.5\,m$

Eccentricity Check:

$$e_{check.U1.OT} := \begin{cases} \text{"Okay"} & \text{if } ex_{U1} \le Kern_{OT} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"Okay"}$$

CHECK FOUNDATION BEARING CAPACITY (HORIZONTAL PLANE):

Base Section Modulus: $S_{b.OT} := \frac{1}{6}\left(B \cdot b^2\right) = 13.5\,m^3$

Bearing Pressure Under Toe:

$$\sigma_{ToeU1.OT} := \begin{cases} \left(\frac{\Sigma V_{U1.OT}}{b \cdot B} + \frac{\Sigma V_{U1.OT} \cdot ex_{U1.OT}}{S_{b.OT}}\right) & \text{if } \frac{\Sigma V_{U1.OT}}{b \cdot B} \geq \frac{\Sigma V_{U1.OT} \cdot ex_{U1.OT}}{S_{b.OT}} \\ \frac{2 \cdot \Sigma V_{U1.OT}}{B \cdot 3\left(\frac{b}{2} - ex_{U1.OT}\right)} & \text{otherwise} \end{cases} = 224.9 \cdot kPa$$

$$Bearing_{CheckToeU1.OT} := \begin{cases} \text{"OKAY "} & \text{if } \sigma_{ToeU1.OT} < \sigma_{allowU1} \\ \text{"NG - for reference only""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

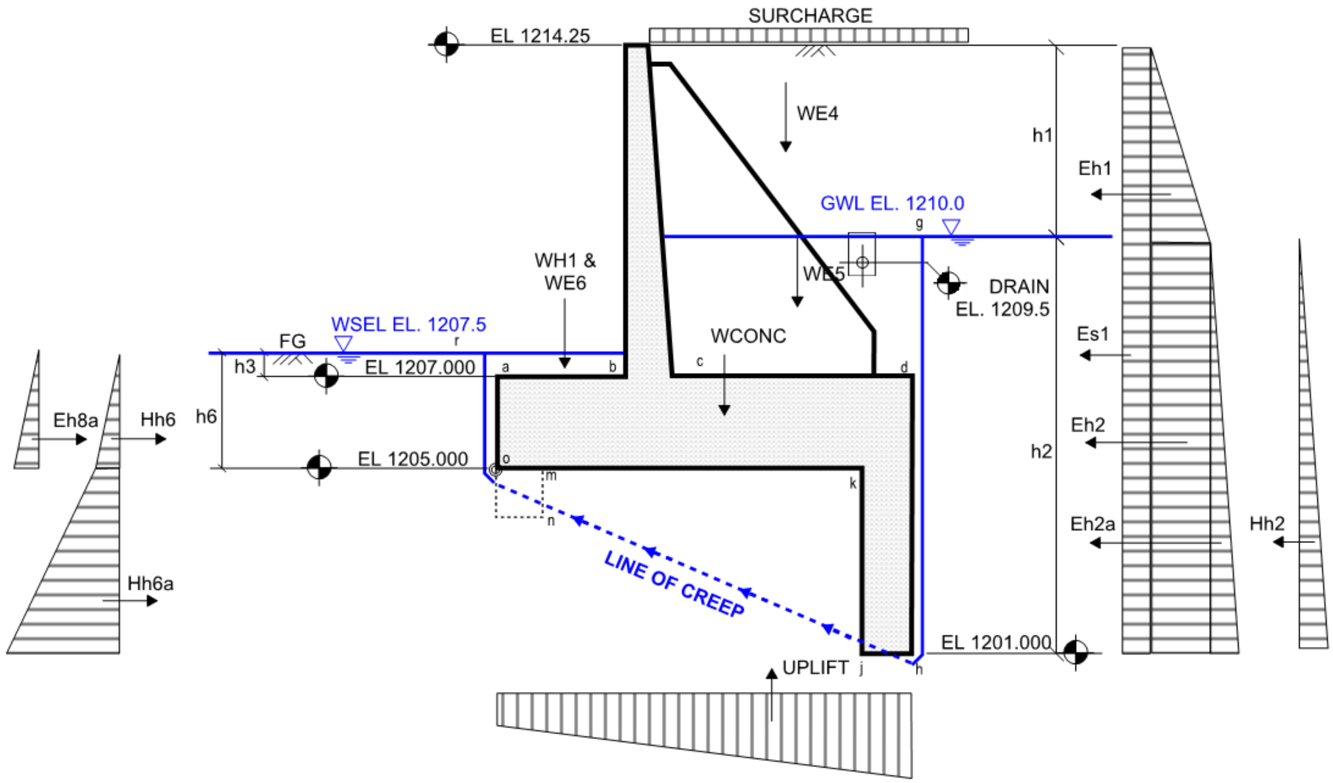
Bearing Pressure Under Heel:

$$\sigma_{HeelU1.OT} := \begin{cases} \left(\frac{\Sigma V_{U1.OT}}{b \cdot B} - \frac{\Sigma V_{U1.OT} \cdot ex_{U1.OT}}{S_{b.OT}}\right) & \text{if } \frac{\Sigma V_{U1.OT}}{b \cdot B} \geq \frac{\Sigma V_{U1.OT} \cdot ex_{U1.OT}}{S_{b.OT}} \\ 0 & \text{otherwise} \end{cases} = 33.2 \cdot kPa$$

$$Bearing_{CheckheelU1.OT} := \left(\begin{cases} \text{"OKAY "} & \text{if } \sigma_{HeelU1.OT} < \sigma_{allowU1} \wedge \sigma_{HeelU1.OT} > 0 \\ \text{"NG - for reference only""} & \text{otherwise} \end{cases}\right) = \text{"OKAY "}$$

SUMMARY OF STABILITY ASSESSMENT:

Sliding Factor of Safety: (Horizontal Plane - Ref only)	$FS_{Horiz.SlidingU1} = 0.54$	$FS_{Sliding.check1.U1} =$ "Key req""
Sliding Factor of Safety: (Inclined Plane)	$FS_{InclinedlSlidingU1} = 4.09$	$FS_{Sliding.check2.U1} =$ "OKAY "
Eccentricity: (Inclined Plane)	$ex_{U1} = 0.74\ m$	$e_{check.U1} =$ "Okay"
Bearing Pressure At Heel: (Inclined Plane)	$\sigma_{HeelU1} = 92 \cdot kPa$	$Bearing_{CheckheelU1} =$ "OKAY "
Bearing Pressure At Toe: (Inclined Plane)	$\sigma_{ToeU1} = 239 \cdot kPa$	$Bearing_{ChecktoeU1} =$ "OKAY "
Flotation Factor of Safety (horizontal plane)	$FS_{FloatationU1} = 2.97$	$FS_{Floatation.U1.check} =$ "OKAY "
Overturning Resultant Ratio: (horizontal plane)	$Ratio_{U1.OT} = 0.38$	$Ratio_{U1.OT.check} =$ "OKAY "
Eccentricity: (horizontal plane - Ref only)	$ex_{U1.OT} = 1.11\ m$	$e_{check.U1.OT} =$ "Okay"
Bearing Pressure At Heel: (horizontal plane - Ref only)	$\sigma_{HeelU1.OT} = 33 \cdot kPa$	$Bearing_{CheckheelU1.OT} =$ "OKAY "
Bearing Pressure At Toe: (horizontal plane - Ref only)	$\sigma_{ToeU1.OT} = 225 \cdot kPa$	$Bearing_{ChecktoeU1.OT} =$ "OKAY "



UN1 DESIGN CASE

LOAD CASE UN1 ACCEPTANCE PARAMETERS

FS sliding:

Unusual (UN) 1.3 (without cohesion) (Table 3-3, USACE EM 1110-2-2100)

Resultant Location:

Unsual (UN) Inside middle third ~100% base in compression

Required Factor of Safety for Sliding: $FS_{sliding.reqUN1} := 1.3$ (Without Cohesion)

Allowable rock bearing pressure: $\sigma_{allowUN1} := 1470kPa$ (Section 5.2, Design Criteria EM 1110-2-2100 Section 3-10)

Overturning Required Resultant Ratio: $X_{R.reqUN1} := 0.333$ (EM 1110-2-2502, Figure 4-4)

Required Factor of Safety for Floatation $FS_{req.UN1.flt} := 1.3$

SOIL HEIGHTS and Water Levels:

LOAD CASE UN1

Heel Conditions:

Groundwater Elevation at Heel: $GWL_{UN1} := 1210.0m$

Distance from Finish Grade to Groundwater at Heel: $h_{1UN1} := \left[T_w - GWL_{UN1} + \left(L_{cd} + t_{wb} - t_{wt}\right)\cdot \tan(\beta)\right] = 4.25\,m$

Distance from Water Surface to Bottom of Footing at Heel: $h_{2UN1} := GWL_{UN1} - Bot_{ftg} + Key_{h.d} = 9.00\,m$

Toe Conditions:

Water Surface Elevation at Toe: $WSEL_{UN1} := 1207.5m$

Water Surface Elevation at Toe for Uplift: $UWSEL_{UN1} := 1207.5\cdot m$

Finish Grade at Toe providing lateral resistance: $FG_{toeUN1} := 1207.5\cdot m$

Soil Depth Above top of footing: $h_{3aUN1} := FG_{toeUN1} - Top_{ftg} = 0.5\,m$

$$h_{3UN1} := \begin{cases} h_{3aUN1} & \text{if } FG_{toeUN1} - Top_{ftg} \ge 0 \\ 0 & \text{otherwise} \end{cases} = 0.5$$

Resisting Fill at Toe: $h_{4UN1} := FG_{toeUN1} - Bot_{ftg} + Key_{t.d} = 2.50\,m$

Distance from Water Level to Top of Footing: $h_{5UN1} := WSEL_{UN1} - Top_{ftg} = 0.50\,m$

Distance from Water Surface to Bottom of Toe Key: $h_{6UN1} := WSEL_{UN1} - Bot_{ftg} + Key_{t.d} = 2.50\,m$

Soil Depth Above WSEL: $h_{7aUN1} := FG_{toeUN1} - WSEL_{UN1} = 0\,m$

$$h_{7UN1} := \begin{cases} h_{7aUN1} & \text{if } FG_{toeUN1} - WSEL_{UN1} \ge 0 \\ 0 & \text{otherwise} \end{cases} = 0$$

Soil Depth Below WSEL:

$$h_{8UN1} := \begin{cases} WSEL_{UN1} - Bot_{ftg} + Key_{t.d} & \text{if } FG_{toeUN1} - WSEL_{UN1} \ge 0 \\ h_{4UN1} & \text{otherwise} \end{cases} = 2.5$$

For Line of Creep Method: $L_{ho.UN1} := \sqrt{b^2 + \left(Key_{h.d} - Key_{t.d}\right)^2} = 9.849\,m$

Head Loss from Point g:

$\Delta h_{g.hj.UN1} := h_{2UN1} = 9\,m$ (to point h & j)

$\Delta h_{g.km.UN1} := GWL_{UN1} - Bot_{ftg} = 5\,m$ (to point k & m)

$\Delta h_{g.no.UN1} := GWL_{UN1} - Bot_{ftg} + Key_{t.d} = 5\,m$ (to point n & o)

$\Delta h_{g.p.UN1} := GWL_{UN1} - FG_{toeUN1} = 2.5\,m$ (to point p*)

$\Delta h_{g.r.UN1} := GWL_{UN1} - UWSEL_{UN1} = 2.5\,m$ (to point r)

Surcharge

Surcharge on Heel: $S1_{UN1} := 15.0\,\frac{kN}{m^2}$

* same as point "a" in this case

Calculate Soil Lateral Pressure Coefficients:

For all load cases except seismic, soil loading to be based on At-Rest Condition.
Calculate at-rest pressure coefficient Ko based on Jaky's (1944) equation.

Soil At Rest Static Coefficient: $K_o := \dfrac{1 - \sin(\phi)}{1 + \sin(\beta)} = 0.546$ (Eq. 3-6, USACE EM 1110-2-2502)

Lateral - Driving Force

Static At-Rest:

Surcharge Load: $E_{s1UN1} := S1_{UN1} \cdot K_o \cdot \left(H_w + Key_{h.d}\right) \cdot B \cdot -1 = -108.519 \cdot kN$

Moment Arm (from Point O): $E_{s1locUN1} := \dfrac{H_w + Key_{h.d}}{2} + Key_{vdist} = 2.63\ m$

Moist Soil Load above GWL: $E_{h1UN1} := \dfrac{\gamma_m \cdot K_o \cdot h_{1UN1}^{\ 2}}{2} \cdot B \cdot -1 = -98.6 \cdot kN$

Moment Arm (from Point O): $E_{h1locUN1} := \dfrac{h_{1UN1}}{3} + h_{2UN1} + Key_{vdist} = 6.42\ m$

Saturated Soil Load below GWL:
(rectangular component) $E_{h2UN1} := \left(\gamma_m \cdot K_o \cdot h_{1UN1}\right) \cdot \left(h_{2UN1}\right) \cdot B \cdot -1 = -417.7 \cdot kN$

Moment Arm (from Point O): $E_{h2locUN1} := \dfrac{h_{2UN1}}{2} + Key_{vdist} = 0.50\ m$

Saturated Soil Load below GWT:
(triangular L $E_{h2aUN1} := \dfrac{\left(\gamma_{sat} - \gamma_w\right) \cdot K_o \cdot h_{2UN1}^{\ 2}}{2} \cdot B \cdot -1 = -269.8 \cdot kN$

Moment Arm (from Point O): $E_{h2alocUN1} := \dfrac{h_{2UN1}}{3} + Key_{vdist} = -1.00\ m$

Lateral Water Load:

Water Load GWL to Bottom of Keys:

$$H_{h2UN1} := \begin{cases} \dfrac{\gamma_w \cdot h_{2UN1}^{\ 2}}{2} \cdot B \cdot -1 & \text{if } Key_{vdist} < 0 \\ \dfrac{\gamma_w \cdot \left(h_{2UN1} + Key_{vdist}\right)^2}{2} \cdot B \cdot -1 & \text{otherwise} \end{cases} = -396.9 \cdot kN$$

Moment Arm (from Point O):

$$H_{h2locUN1} := \begin{cases} \dfrac{h_{2UN1}}{3} + Key_{vdist} & \text{if } Key_{vdist} < 0 \\ \dfrac{h_{2UN1} + Key_{vdist}}{3} & \text{otherwise} \end{cases} = -1.00 \cdot m$$

$$\Sigma H_{SoildriveUN1} := E_{s1UN1} + E_{h1UN1} + E_{h2UN1} + E_{h2aUN1} + H_{h2UN1} = -1291.5 \cdot kN$$

$$\Sigma M_{LateralSoildriveUN1} := E_{s1UN1} \cdot E_{s1locUN1} + E_{h1UN1} \cdot E_{h1locUN1} + E_{h2UN1} \cdot E_{h2locUN1} \cdots + E_{h2aUN1} \cdot E_{h2alocUN1} + H_{h2UN1} \cdot H_{h2locUN1} = -459.9\ m \cdot kN$$

Lateral - Resisting Force

LOAD CASE UN1

Lateral Water Load:

Water Load WSEL to Bot. of Toe Key: $H_{h6UN1} := \frac{\gamma_w \cdot h_{6UN1}^2}{2} \cdot B = 30.6 \cdot kN$

Moment Arm (from Point O): $H_{h6locUN1} := \frac{h_{6UN1}}{3} = 0.83\ m$

Water Load between Keys (if any) $H_{h6aUN1} := \begin{cases} \frac{(h_{6UN1} + h_{2UN1}) \cdot -Key_{vdist}}{2} \cdot \gamma_w \cdot B & \text{if } Key_{vdist} < 0 \\ 0 & \text{otherwise} \end{cases} = 225.4 \cdot kN$

Moment Arm (from Point O): $H_{h6alocUN1} := \begin{cases} \frac{Key_{vdist} \cdot (2 \cdot h_{2UN1} + h_{6UN1})}{3(h_{2UN1} + h_{6UN1})} & \text{if } Key_{vdist} < 0 \\ 0 & \text{otherwise} \end{cases} = -2.38 \cdot m$

Lateral Soil Load:

Moist Soil Load above WSEL: $E_{h7UN1} := \frac{\gamma_m \cdot K_o \cdot h_{7UN1}^2}{2} B = 0.0 \cdot kN$

Moment Arm (from bot. of toe key): $E_{h7locUN1} := h_{6UN1} + \frac{h_{7UN1}}{3} + Key_{vdist} = -1.50\ m$

Saturated Soil Load below WSEL:
(rectangular component) $E_{h8UN1} := (\gamma_m \cdot K_o \cdot h_{7UN1}) \cdot h_{8UN1} \cdot B = 0.0 \cdot kN$

Moment Arm (from bot. of toe key): $E_{h8locUN1} := \frac{h_{8UN1}}{2} = 1.25\ m$

Saturated Soil Load below WSEL:
(triangular component) $E_{h8aUN1} := \frac{\left[(\gamma_{sat} - \gamma_w) \cdot K_o\right] \cdot h_{8UN1}^2}{2} \cdot B = 20.8 \cdot kN$

Moment Arm (from bot. of footing): $E_{h8alocUN1} := \frac{h_{8UN1}}{3} = 0.83\ m$

$\Sigma H_{SoilresistUN1} := H_{h6UN1} + H_{h6aUN1} + E_{h7UN1} + E_{h8UN1} + E_{h8aUN1} = 276.8 \cdot kN$

$\Sigma M_{HorizSoilResistUN1} := H_{h6UN1} \cdot H_{h6locUN1} + H_{h6aUN1} \cdot H_{h6alocUN1} + E_{h7UN1} \cdot E_{h7locUN1} \cdots + E_{h8UN1} \cdot E_{h8locUN1} + E_{h8aUN1} \cdot E_{h8alocUN1} = -492.9\ m \cdot kN$

Vertical Force:

UPLIFT: Linear distribution from water at heel to water at toe:

$\Sigma V_{UplliftUN1} := \left[(UWSEL_{UN1} - Bot_{ftg} + Key_{t.d}) + h_{2UN1}\right] \cdot \frac{b}{2} \cdot \gamma_w \cdot B \cdot -1 = -507.15 \cdot kN$

Moment Arm (from Point O): $V_{UpliftUN1aloc} := \frac{b \cdot \left[2 \cdot h_{2UN1} + (UWSEL_{UN1} - Bot_{ftg} + Key_{t.d})\right]}{3\left[h_{2UN1} + (UWSEL_{UN1} - Bot_{ftg} + Key_{t.d})\right]} = 5.348\ m$

$\Sigma M_{UpliftUN1} := \Sigma V_{UplliftUN1} \cdot V_{UpliftUN1aloc} = -2712.15 \cdot kN \cdot m$

Weight of soil and water over toe:

Water Above the Top of Footing: $W_{H1UN1} := \gamma_w \cdot h_{5UN1} \cdot L_{ab} \cdot B = 13.475 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E1locUN1} := \frac{L_{ab}}{2} = 1.375\,m$

Soil above top of footing: $W_{E6UN1} := \gamma_b \cdot h_{3UN1} \cdot L_{ab} \cdot B = 16.8 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E6locUN1} := \frac{L_{ab}}{2} = 1.375\,m$

Vertical Load Due to Surcharge: $S_{UN1} := S1_{UN1} \cdot L_{cd} \cdot B = 77.7 \cdot kN$ $\quad S_{UN1loc} := b - \frac{L_{cd}}{2} = 6.41\,m$

Weight of soil and water over heel:

Moist Soil for sloped grade above top of wall:

Length of sloped portion of soil above top of wall: $L_{E3UN1} := \left(L_{cd} + t_{wb} - t_{wt}\right) = 5.75\,m$

Height of sloped soil above top of wall over heel: $h_{E3locUN1} := \left(L_{E3UN1}\right) \cdot \tan(\beta) = 0.00\,m$

Weight of sloped soil above top of wall: $W_{E3UN1} := \frac{\gamma_m}{2} \cdot h_{E3locUN1} \cdot L_{E3UN1} \cdot B = 0.0 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E3locUN1} := L_{ab} + t_{wt} + \frac{2}{3} \cdot L_{E3UN1} = 7.08\,m$

Moist soil from top of wall to groundwater level:

Height of soil from top of wall and top of GWL: $h_{1UN1} = 4.25\,m$

Length from edge of wall at GWL to edge of heel: $L_{E4UN1} := L_{E3UN1} - \left(h_{1UN1} \cdot S_{batter}\right) = 5.42\,m$

Weight of soil over heel from top of wall to GWL: $W_{E4UN1} := \gamma_m \cdot h_{1UN1} \cdot \frac{\left(L_{E3UN1} + L_{E4UN1}\right)}{2} \cdot B = 474.5 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E4locUN1} := b - \frac{L_{E3UN1}^2 + L_{E3UN1} \cdot L_{E4UN1} + L_{E4UN1}^2}{3\left(L_{E3UN1} + L_{E4UN1}\right)} = 6.21\,m$

Saturated soil from groundwater to top of footing:

Height of soil from GWL to top of heel: $h_{E4UN1} := h_{2UN1} - t_{ftg} - Key_{h.d} = 3.00\,m$

Weight of soil over heel from GWL to top of heel: $W_{E5UN1} := \left(\gamma_{sat}\right) \cdot h_{E4UN1} \cdot \frac{\left(L_{E4UN1} + L_{cd}\right)}{2} \cdot B = 349.7 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E5locUN1} := b - \frac{L_{E4UN1}^2 + L_{E4UN1} \cdot L_{cd} + L_{cd}^2}{3\left(L_{E4UN1} + L_{cd}\right)} = 6.35\,m$

$$\Sigma V_{SoilWaterUN1} := W_{H1UN1} + W_{E6UN1} + W_{E3UN1} + W_{E4UN1} + W_{E5UN1} + S_{UN1} = 932.2 \cdot kN$$

$$\Sigma M_{VertSoilWaterResistUN1} := W_{H1UN1} \cdot W_{E1locUN1} + W_{E6UN1} \cdot W_{E6locUN1} \cdots + W_{E3UN1} \cdot W_{E3locUN1} + W_{E4UN1} \cdot W_{E4locUN1} + W_{E5UN1} \cdot W_{E5locUN1} + S_{UN1} \cdot S_{UN1loc} = 5706.1\,m \cdot kN$$

THIS PAGE INTENTIONALLY LEFT BLANK
PLEASE GO TO THE NEXT PAGE

STABILITY ASSESSMENT:

LOAD CASE UN1

CHECK SLIDING ALONG HORIZONTAL SLIDING PLANE:

Summation of the vertical forces:

$$\Sigma V_{UN1} := \Sigma V_{conc} + \Sigma V_{SoilWaterUN1} + \Sigma V_{UpliftUN1} = 1075.8 \cdot kN$$

Summation of the horizontal forces:

$$\Sigma H_{UN1} := \Sigma H_{SoildriveUN1} + \Sigma H_{SoilresistUN1} = -1014.7 \cdot kN$$

Safety Factor for Sliding Horizontal Failure Plane

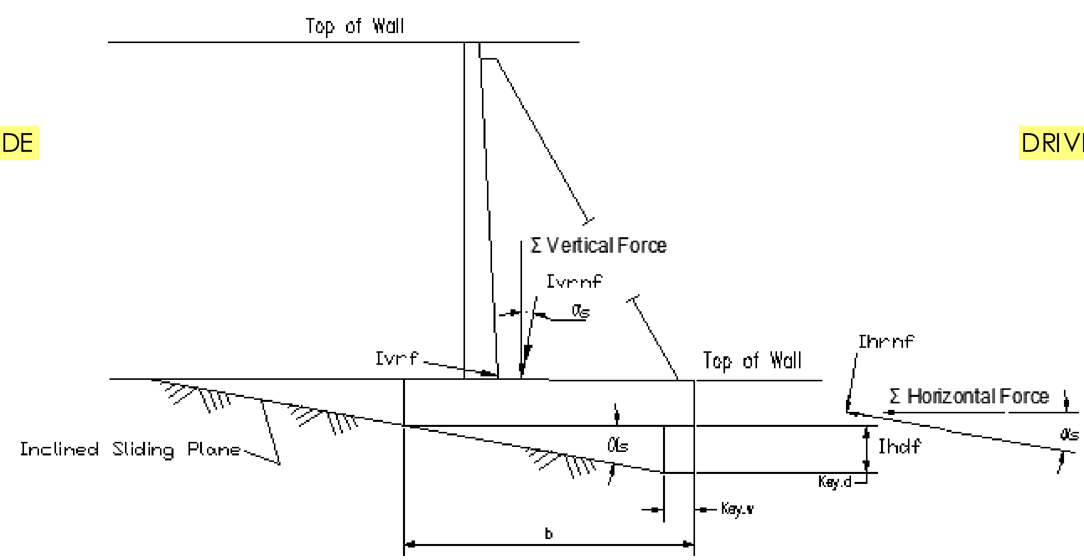
$$FS_{Horiz.SlidingUN1} := \frac{\left|\Sigma V_{UN1}\right| \cdot \tan\left(\phi_{rock} \cdot \frac{\pi}{180}\right)}{\left|\Sigma H_{UN1}\right|} = 0.52$$

$$FS_{Sliding.check1.UN1} := \begin{cases} \text{"OKAY "} & \text{if } FS_{Horiz.SlidingUN1} > FS_{sliding.reqUN1} \\ \text{"NG - key req""} & \text{otherwise} \end{cases} = \text{"NG - key req""}$$

CHECK FACTOR OF SAFETY SLIDING WITH KEY (INCLINED SLIDING PLANE):

RESISTING SIDE

DRIVING SIDE



TOE

HEEL

Ivrf=Inclined Resisting Force
Ivrnf=Inclined Resisting Normal Force
Ihrnf=Inclined Resisting Normal Force
Ihdf=Inclined Driving Force

$\alpha s = 0.464$ as degrees= $\alpha s \cdot \left(\frac{180}{\pi}\right) = 26.57$

(With properly engineered reinforced concrete Key, horizontal sliding plane thru Toe is protected, critical sliding plane is relocated to the INCLINED SLIDING PLANE FROM HEEL KEY To TOE, Bedrock Mass above this examing plane is mobilized by reinforced concrete key and combined into Structural Wedge.)

Resolve ΣV_{UN1} & ΣH_{UN1}

$$\Sigma V_{InclinedUN1} := \cos(\alpha s) \cdot \left(\left|\Sigma V_{UN1} + V_{rocksection}\right|\right) + \sin(\alpha s) \cdot \left|\Sigma H_{UN1}\right| = 1782.3 \cdot kN$$

$$\Sigma H_{InclinedUN1} := \cos(\alpha s) \cdot \left|\Sigma H_{UN1}\right| - \sin(\alpha s) \cdot \left(\left|\Sigma V_{UN1} + V_{rocksection}\right|\right) = 243.3 \cdot kN$$

LOAD CASE UN1

Safety Factor for Sliding Inclined Failure Plane

$$FS_{InclinedlSlidingUN1} := \frac{\Sigma V_{InclinedUN1} \cdot \tan(\phi_r)}{\Sigma H_{InclinedUN1}} = 3.26$$

$$FS_{Sliding.check2.UN1} := \begin{vmatrix} \text{"OKAY "} & \text{if } FS_{InclinedlSlidingUN1} > FS_{sliding.reqUN1} \\ \text{"NG - Revise Structure""} & \text{otherwise} \end{vmatrix} = \text{"OKAY "}$$

CHECK FOUNDATION ECCENTRICITY:

Summation of the resisting moments about the toe:

$$\Sigma M_{resUN1} := \Sigma M_{conc} + \Sigma M_{VertSoilWaterResistUN1} + \Sigma M_{HorizSoilResistUN1} + \Sigma M_{rocksection} = 10523 \cdot kN \cdot m$$

Summation of the overturning moments about the toe:

$$\Sigma M_{oUN1} := \Sigma M_{LateralSoildriveUN1} + \Sigma M_{UpliftUN1} = -3172 \cdot kN \cdot m$$

Total moment: $\Sigma M_{UN1} := \Sigma M_{resUN1} + \Sigma M_{oUN1} = 7350.8 \cdot kN \cdot m$

Normal force to base: $\Sigma V_{InclinedUN1} = 1782.3 \cdot kN$

Inclined Sliding Plane Length: $L_{incline} = 10.1 \cdot m$

Eccentricity (inclined plane): $ex_{UN1} := \frac{L_{incline}}{2} - \frac{\Sigma M_{UN1}}{\Sigma V_{InclinedUN1}} = 0.91\ m$ $\quad Kern = 1.677\ m$

Eccentricity Check:

$$e_{check.UN1} := \begin{vmatrix} \text{"Okay"} & \text{if } ex_{UN1} \le Kern \\ \text{"Revise Structure"} & \text{otherwise} \end{vmatrix} = \text{"Okay"}$$

CHECK FOUNDATION BEARING CAPACITY:

Base Section Modulus: $S_b = 16.88\ m^3$

Bearing Pressure Under Toe:

$$\sigma_{ToeUN1} := \begin{vmatrix} \left[\frac{\Sigma V_{InclinedUN1}}{L_{incline} \cdot B} + \frac{(\Sigma V_{InclinedUN1} \cdot ex_{UN1})}{S_b}\right] & \text{if } \frac{\Sigma V_{InclinedUN1}}{L_{incline} \cdot B} \ge \frac{\Sigma V_{InclinedUN1} \cdot ex_{UN1}}{S_b} \\ \frac{2 \cdot \Sigma V_{InclinedUN1}}{B \cdot 3\left(\frac{b}{2} - ex_{UN1}\right)} & \text{otherwise} \end{vmatrix} = 272.9 \cdot kPa$$

$$Bearing_{ChecktoeUN1} := \begin{vmatrix} \text{"OKAY "} & \text{if } \sigma_{ToeUN1} < \sigma_{allowUN1} \\ \text{"NG""} & \text{otherwise} \end{vmatrix} = \text{"OKAY "}$$

Bearing Pressure Under Heel:

$$\sigma_{HeelUN1} := \begin{vmatrix} \left[\frac{\Sigma V_{InclinedUN1}}{L_{incline} \cdot B} - \frac{(\Sigma V_{InclinedUN1} \cdot ex_{UN1})}{S_b}\right] & \text{if } \frac{\Sigma V_{InclinedUN1}}{L_{incline} \cdot B} \ge \frac{\Sigma V_{InclinedUN1} \cdot ex_{UN1}}{S_b} \\ 0 & \text{otherwise} \end{vmatrix} = 81.3 \cdot kPa$$

$$Bearing_{CheckheelUN1} := \left(\begin{vmatrix} \text{"OKAY "} & \text{if } \sigma_{HeelUN1} < \sigma_{allowUN1} \wedge \sigma_{HeelUN1} > 0 \\ \text{"NG - perform cracked base analysis""} & \text{otherwise} \end{vmatrix} \right) = \text{"OKAY "}$$

CHECK FLOATATION:

Safety Factor for Floatation:

$$FS_{FloatationUN1} := \frac{\Sigma V_{conc} + \Sigma V_{SoilWaterUN1}}{\left|\Sigma V_{UpliftUN1}\right|} = 3.12$$

$$FS_{Floatation.UN1.check} := \begin{cases} \text{"OKAY "} & \text{if } FS_{FloatationUN1} > FS_{req.UN1.flt} \\ \text{"Revise Structure""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

CHECK OVERTURNING

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.
Assumptions are made in order to compute overturning stablity of indetermine forces on monolith with key;
(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.
(b) The horizontal resisting force acting on the key, P.key, is that required for static equilibrium
(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1

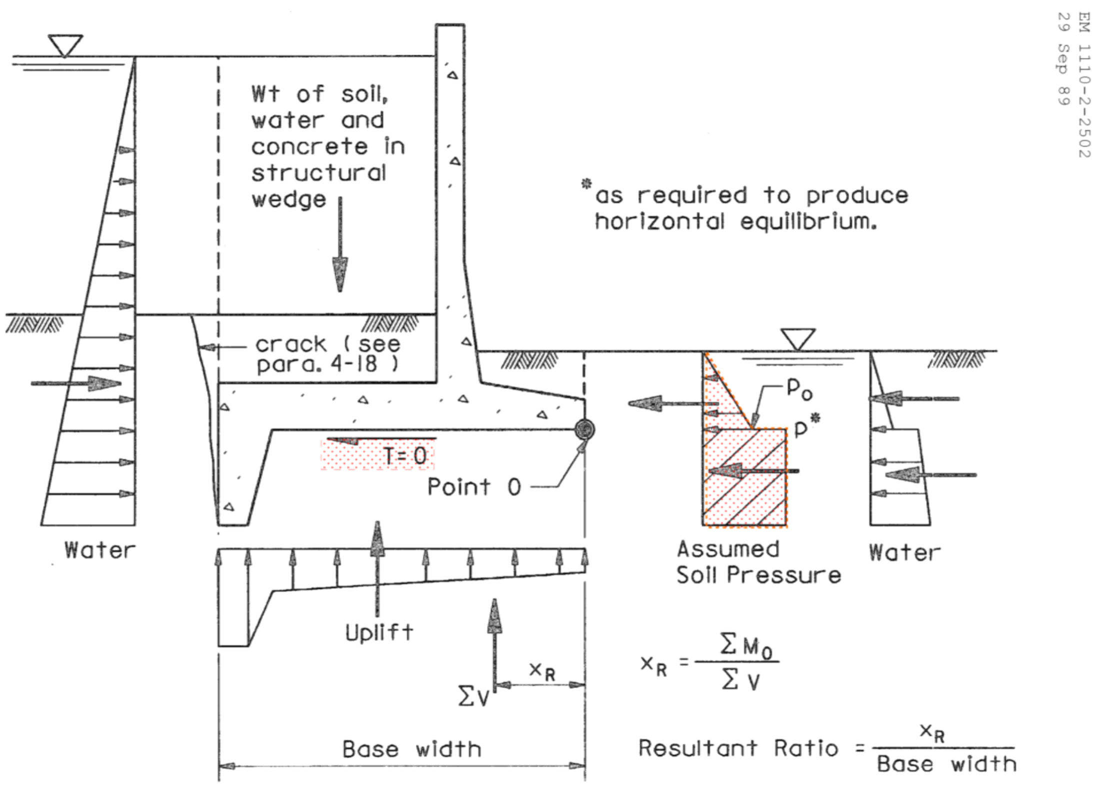


Figure 4-5. Forces for overturning analysis for wall with horizontal base and key

Modify Uplift for Overturning Analysis: **LOAD CASE UN1**

(Uplift is calculated along the concrete/rock contact using the Line of Creep method)

Water Pressure at h: $u_{h.UN1} := \Delta h_{g.hj.UN1} \cdot \gamma_w = 88.20 \cdot kPa$

Water Pressure at o: $u_{o.UN1} := \left(\Delta h_{g.no.UN1} - \frac{\Delta h_{g.r.UN1} \cdot L_{ho.UN1}}{L_{ho.UN1}} \right) \cdot \gamma_w = 24.5 \cdot kPa$

Head loss between point h and o: $\Delta h_{ho.UN1} := \Delta h_{g.r.UN1} \cdot \frac{L_{ho.UN1}}{L_{ho.UN1}} = 2.5\,m$

Length of concrete base (h -> o): $L_{baseho.UN1} := Key_{h.w} + Key_{h.d} + Key_{hdist} + Key_{t.d} + Key_{t.w} = 13\,m$

Head loss along h -> j: $\Delta h_{hj.UN1} := \Delta h_{ho.UN1} \cdot \frac{Key_{h.w}}{L_{baseho.UN1}} = 0.192\,m$

Water Pressure at j: $u_{j.UN1} := \left(\Delta h_{g.hj.UN1} - \Delta h_{hj.UN1} \right) \cdot \gamma_w = 86.32 \cdot kPa$

Head loss along h -> k: $\Delta h_{hjk.UN1} := \Delta h_{ho.UN1} \cdot \left(\frac{Key_{h.w} + Key_{h.d}}{L_{baseho.UN1}} \right) = 0.962\,m$

Water Pressure at k: $u_{k.UN1} := \left(\Delta h_{g.km.UN1} - \Delta h_{hjk.UN1} \right) \cdot \gamma_w = 39.58 \cdot kPa$

Head loss along h -> m: $\Delta h_{hjkm.UN1} := \Delta h_{ho.UN1} \cdot \left(\frac{Key_{h.w} + Key_{h.d} + Key_{hdist}}{L_{baseho.UN1}} \right) = 2.5\,m$

Water Pressure at m: $u_{m.UN1} := \left(\Delta h_{g.km.UN1} - \Delta h_{hjkm.UN1} \right) \cdot \gamma_w = 24.50 \cdot kPa$

Head loss along h -> n: $\Delta h_{hjkmn.UN1} := \Delta h_{ho.UN1} \cdot \left(\frac{Key_{h.w} + Key_{h.d} + Key_{hdist} + Key_{t.d}}{L_{baseho.UN1}} \right) = 2.5\,m$

Water Pressure at n: $u_{n.UN1} := \left(\Delta h_{g.no.UN1} - \Delta h_{hjkmn.UN1} \right) \cdot \gamma_w = 24.50 \cdot kPa$

Uplift under key at heel: $V_{ulkeyhUN1.OT} := \frac{\left(u_{h.UN1} + u_{j.UN1} \right) \cdot Key_{h.w}}{2} \cdot B \cdot -1 = -87.258 \cdot kN$

Moment Arm (from Point O): $V_{ulkeyhUN1loc.OT} := b - \frac{Key_{h.w} \cdot \left(2 \cdot u_{j.UN1} + u_{h.UN1} \right)}{3 \cdot \left(u_{j.UN1} + u_{h.UN1} \right)} = 8.502\,m$

Uplift under base: $V_{ulbaseUN1.OT} := \frac{\left(u_{k.UN1} + u_{m.UN1} \right) \cdot Key_{hdist}}{2} \cdot B \cdot -1 = -256.308 \cdot kN$

Moment Arm (from Point O): $V_{ulbaseUN1loc.OT} := b - Key_{h.w} - \frac{Key_{hdist} \cdot \left(2 \cdot u_{m.UN1} + u_{k.UN1} \right)}{3 \cdot \left(u_{m.UN1} + u_{k.UN1} \right)} = 4.314\,m$

Uplift under key at toe: $V_{ulkeytUN1.OT} := \frac{\left(u_{n.UN1} + u_{o.UN1} \right) \cdot Key_{t.w}}{2} \cdot B \cdot -1 = 0 \cdot kN$

Moment Arm (from Point O): $V_{ulkeytUN1loc.OT} := \frac{Key_{t.w} \cdot \left(2 \cdot u_{n.UN1} + u_{o.UN1} \right)}{3 \cdot \left(u_{n.UN1} + u_{o.UN1} \right)} = 0$

$$\Sigma V_{UpliftUN1.OT} := V_{ulkeyhUN1.OT} + V_{ulbaseUN1.OT} + V_{ulkeytUN1.OT} = -344 \cdot kN$$

$$U_{UN1.loc.OT} := \frac{V_{ulkeyhUN1.OT} \cdot V_{ulkeyhUN1loc.OT} + V_{ulbaseUN1.OT} \cdot V_{ulbaseUN1loc.OT} + V_{ulkeytUN1.OT} \cdot V_{ulkeytUN1loc.OT}}{\Sigma V_{UpliftUN1.OT}} = 5.38\,m$$

$$\Sigma M_{UpliftUN1.OT} := \Sigma V_{UpliftUN1.OT} \cdot U_{UN1.loc.OT} = -1847.5 \cdot kN \cdot m$$

Modify Lateral Water Pressure (Resisting) for Overturning Analysis:

(Resisting water pressure is calculated using the Line of Creep method)

Water Load at Key (heel): $H_{h2UN1.OT} := \frac{u_{k.UN1} + u_{j.UN1}}{2} \cdot Key_{h.d} B = 251.8 \cdot kN$

Moment Arm (from Point O): $H_{h2locUN1.OT} := \frac{Key_{h.d} \cdot (2 \cdot u_{k.UN1} + u_{j.UN1})}{3(u_{k.UN1} + u_{j.UN1})} + Key_{vdist} = -2.25\ m$

Water Load at Key (toe): $H_{h6UN1.OT} := \frac{u_{o.UN1} \cdot (UWSEL_{UN1} - Bot_{ftg} + Key_{t.d})}{2} \cdot B = 31 \cdot kN$

Moment Arm (from Point O): $H_{h6locUN1.OT} := \frac{UWSEL_{UN1} - Bot_{ftg} + Key_{t.d}}{3} = 0.83\ m$

$$\Sigma H_{waterresistUN1.OT} := H_{h2UN1.OT} + H_{h6UN1.OT} = 282.41 \cdot kN$$

$$H_{waterresistlocUN1.OT} := \frac{H_{h2UN1.OT} \cdot H_{h2locUN1.OT} + H_{h6UN1.OT} \cdot H_{h6locUN1.OT}}{\Sigma H_{waterresistUN1.OT}} = -1.913\ m$$

$$\Sigma M_{waterresistUN1.OT} := \Sigma H_{waterresistUN1.OT} \cdot H_{waterresistlocUN1.OT} = -540.37 \cdot kN \cdot m$$

Modify Lateral Soil Loads for Overturning Analysis:

(Lateral soil loads are calculated down to Point O instead of bottom of shear key)

Driving Soil Load (Headwater Side):

Surcharge Load: $E_{s1UN1.OT} := S1_{UN1} \cdot K_o \cdot (H_w + Key_{h.d} + Key_{vdist}) \cdot B \cdot -1 = -75.759 \cdot kN$

Moment Arm (from Point O): $E_{s1locUN1.OT} := \frac{H_w + Key_{h.d} + Key_{vdist}}{2} = 4.63\ m$

Moist Soil Load above GWL: $E_{h1UN1.OT} := \frac{\gamma_m \cdot K_o \cdot h_{1UN1}^{\ 2}}{2} B \cdot -1 = -98.6 \cdot kN$

Moment Arm (from Point O): $E_{h1locUN1.OT} := \frac{h_{1UN1}}{3} + h_{2UN1} + Key_{vdist} = 6.42\ m$

Saturated Soil Load below GWL: (rectangular component) $E_{h2UN1.OT} := (\gamma_m \cdot K_o \cdot h_{1UN1}) \cdot (h_{2UN1} + Key_{vdist}) \cdot B \cdot -1 = -232.1 \cdot kN$

Moment Arm (from Point O): $E_{h2locUN1.OT} := \frac{h_{2UN1} + Key_{vdist}}{2} = 2.50\ m$

Saturated Soil Load below GWL: (triangular component) $E_{h2aUN1.OT} := \frac{(\gamma_{sat} - \gamma_w) \cdot K_o \cdot (h_{2UN1} + Key_{vdist})^2}{2} \cdot B \cdot -1 = -83.3 \cdot kN$

Moment Arm (from Point O): $E_{h2alocUN1.OT} := \frac{h_{2UN1} + Key_{vdist}}{3} = 1.67\ m$

Resisting Soil Load (Tailwater Side):

(Determine resisting soil load based on depth variation between the keys (ie. Key_{vdist}). In case where key at heel is deeper than key at toe (ie. $Key_{vdist} < 0$), resisting soil load (p*) is assumed to produce horizontal equilibrium as per Figure 4-5 above. Resisting soil load (p_o) is neglected.)

Total Driving Force: $\Sigma H_{SoildriveUN1.OT} := E_{s1UN1.OT} + E_{h1UN1.OT} + E_{h2UN1.OT} + E_{h2aUN1.OT} + H_{h2UN1} = -886.6 \cdot kN$

Total Resisting Force: $\Sigma H_{waterresistUN1.OT} = 282.4 \cdot kN$

Assumed Soil Load p*: $E_{h8UN1a.OT} := \left(\Sigma H_{SoildriveUN1.OT} + \Sigma H_{waterresistU1.OT}\right) \cdot -1 = 604.193 \cdot kN$

Moment Arm (from Point O): $E_{h8UN1a.loc.OT} := \dfrac{Key_{vdist}}{2} = -2\,m$

$$E_{h8UN1.OT} := \begin{cases} E_{h8UN1a.OT} & \text{if } Key_{vdist} < 0 \\ \Sigma H_{SoilresistUN1} - H_{h6UN1} - H_{h6aUN1} & \text{otherwise} \end{cases} = 604.193 \cdot kN$$

$$\Sigma M_{SoilresistUN1.OT} := \begin{cases} E_{h8UN1a.OT} \cdot E_{h8UN1a.loc.OT} & \text{if } Key_{vdist} < 0 \\ \Sigma M_{HorizSoilResistUN1} - H_{h6UN1} \cdot H_{h6locUN1} - H_{h6aUN1} \cdot H_{h6alocUN1} & \text{otherwise} \end{cases} = -1208.385 \cdot kN \cdot m$$

Sum of Moment about Point O:

$$\Sigma M_{LateraldriveUN1.OT} := E_{s1UN1.OT} \cdot E_{s1locUN1.OT} + E_{h1UN1.OT} \cdot E_{h1locUN1.OT} + E_{h2UN1.OT} \cdot E_{h2locUN1.OT} \dots + E_{h2aUN1.OT} \cdot E_{h2alocUN1.OT} + H_{h2UN1} \cdot H_{h2locUN1} = -1305.2 \cdot kN \cdot m$$

$$\Sigma M_{LateralresistUN1.OT} := \Sigma M_{waterresistUN1.OT} + \Sigma M_{SoilresistUN1.OT} = -1748.8 \cdot kN \cdot m$$

Total moment:

$$\Sigma M_{UN1.OT} := \Sigma M_{conc} + \Sigma M_{VertSoilWaterResistUN1} + \Sigma M_{UpliftUN1.OT} + \Sigma M_{LateraldriveUN1.OT} + \Sigma M_{LateralresistUN1.OT} = 3929.7 \cdot kN \cdot m$$

Total Vertical Force: $\Sigma V_{UN1.OT} := \Sigma V_{conc} + \Sigma V_{SoilWaterUN1} + \Sigma V_{UpliftUN1.OT} = 1239.3 \cdot kN$

Distance X_R: EM 1110-2-2502 Eq.4-1 $X_{R.UN1} := \dfrac{\Sigma M_{UN1.OT}}{\Sigma V_{UN1.OT}} = 3.171\,m$

Overturning Resultant Ratio $Ratio_{UN1.OT} := \dfrac{X_{R.UN1}}{b} = 0.35$

$$Ratio_{UN1.OT.check} := \begin{cases} \text{"OKAY "} & \text{if } Ratio_{UN1.OT} > X_{R.reqUN1} \\ \text{"Revise Structure""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

CHECK FOUNDATION ECCENTRICITY (HORIZONTAL PLANE):

Eccentricity (horizontal plan): $ex_{UN1.OT} := \dfrac{b}{2} - \dfrac{\Sigma M_{UN1.OT}}{\Sigma V_{UN1.OT}} = 1.33\,m$ $Kern_{OT} = 1.5\,m$

Eccentricity Check:

$$e_{check.UN1.OT} := \begin{cases} \text{"Okay"} & \text{if } ex_{UN1} \le Kern_{OT} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"Okay"}$$

LOAD CASE UN1

CHECK FOUNDATION BEARING CAPACITY (HORIZONTAL PLANE):

Base Section Modulus: $S_{b.OT} = 13.5\,m^3$

Bearing Pressure Under Toe:

$$\sigma_{ToeUN1.OT} := \begin{cases} \left(\dfrac{\Sigma V_{UN1.OT}}{b \cdot B} + \dfrac{\Sigma V_{UN1.OT} \cdot ex_{UN1.OT}}{S_{b.OT}}\right) & \text{if } \dfrac{\Sigma V_{UN1.OT}}{b \cdot B} \ge \dfrac{\Sigma V_{UN1.OT} \cdot ex_{UN1.OT}}{S_{b.OT}} \\ \dfrac{2 \cdot \Sigma V_{UN1.OT}}{B \cdot 3 \left(\dfrac{b}{2} - ex_{UN1.OT}\right)} & \text{otherwise} \end{cases} = 259.7 \cdot kPa$$

$$Bearing_{ChecktoeUN1.OT} := \begin{cases} \text{"OKAY "} & \text{if } \sigma_{ToeUN1.OT} < \sigma_{allowUN1} \\ \text{"NG - for reference only""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

Bearing Pressure Under Heel:

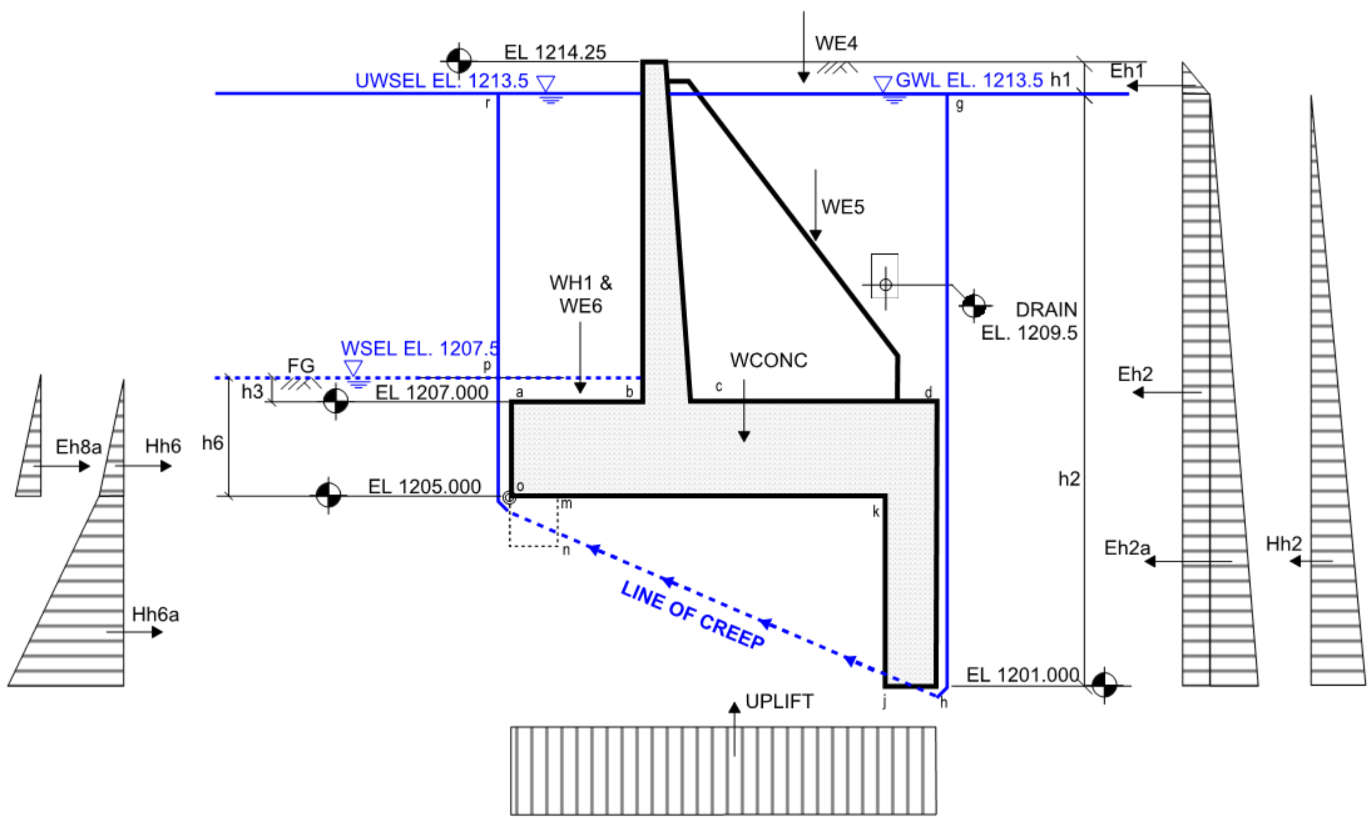
$$\sigma_{HeelUN1.OT} := \begin{cases} \left(\dfrac{\Sigma V_{UN1.OT}}{b \cdot B} - \dfrac{\Sigma V_{UN1.OT} \cdot ex_{UN1.OT}}{S_{b.OT}}\right) & \text{if } \dfrac{\Sigma V_{UN1.OT}}{b \cdot B} \ge \dfrac{\Sigma V_{UN1.OT} \cdot ex_{UN1.OT}}{S_{b.OT}} \\ 0 & \text{otherwise} \end{cases} = 15.7 \cdot kPa$$

$$Bearing_{CheckheelUN1.OT} := \left(\begin{cases} \text{"OKAY "} & \text{if } \sigma_{HeelUN1.OT} < \sigma_{allowUN1} \wedge \sigma_{HeelUN1.OT} > 0 \\ \text{"NG - for reference only""} & \text{otherwise} \end{cases}\right) = \text{"OKAY "}$$

SUMMARY OF STABILITY ASSESSMENT:

Sliding Factor of Safety: (Horizontal Plane - Ref only)	$FS_{Horiz.SlidingUN1} = 0.52$	$FS_{Sliding.check1.UN1}$ = "NG - key req""
Sliding Factor of Safety: (Inclined Plane)	$FS_{InclinedlSlidingUN1} = 3.26$	$FS_{Sliding.check2.UN1}$ = "OKAY "
Eccentricity: (Inclined Plane)	$ex_{UN1} = 0.91\ m$	$e_{check.UN1}$ = "Okay"
Bearing Pressure At Heel: (Inclined Plane)	$\sigma_{HeelUN1} = 81 \cdot kPa$	$Bearing_{CheckheelUN1}$ = "OKAY "
Bearing Pressure At Toe: (Inclined Plane)	$\sigma_{ToeUN1} = 273 \cdot kPa$	$Bearing_{ChecktoeUN1}$ = "OKAY "
Flotation Factor of Safety (horizontal plane)	$FS_{FloatationUN1} = 3.12$	$FS_{Floatation.UN1.check}$ = "OKAY "
Overturning Resultant Ratio: (horizontal plane)	$Ratio_{UN1.OT} = 0.35$	$Ratio_{UN1.OT.check}$ = "OKAY "
Eccentricity: (horizontal plane - Ref only)	$ex_{UN1.OT} = 1.33\ m$	$e_{check.UN1.OT}$ = "Okay"
Bearing Pressure At Heel: (horizontal plane - Ref only)	$\sigma_{HeelUN1.OT} = 16 \cdot kPa$	$Bearing_{CheckheelUN1.OT}$ = "OKAY "
Bearing Pressure At Toe: (horizontal plane - Ref only)	$\sigma_{ToeUN1.OT} = 260 \cdot kPa$	$Bearing_{ChecktoeUN1.OT}$ = "OKAY "

LOAD CASE UN2 - INEFFECTIVE DRAIN



UN2 DESIGN CASE

LOAD CASE UN2 ACCEPTANCE PARAMETERS

FS sliding:

Unusual (UN) 1.3 (without cohesion) (Table 3-3, USACE EM 1110-2-2100)

Resultant Location:

Unsual (UN) Inside middle third ~100% base in compression

Required Factor of Safety for Sliding: $FS_{sliding.reqUN2} := 1.3$ (Without Cohesion)

Allowable rock bearing pressure: $\sigma_{allowUN2} := 1470kPa$ (Section 5.2, Design Criteria EM 1110-2-2100 Section 3-10)

Overturning Required Resultant Ratio: $X_{R.reqUN2} := 0.333$ (EM 1110-2-2502, Figure 4-4)

Required Factor of Safety for Floatation $FS_{req.UN2.flt} := 1.3$

SOIL HEIGHTS and Water Levels:

LOAD CASE UN2

Heel Conditions:

Groundwater Elevation at Heel: $GWL_{UN2} := 1213.5m$

Distance from Finish Grade to Groundwater at Heel: $h_{1UN2} := \left[T_w - GWL_{UN2} + \left(L_{cd} + t_{wb} - t_{wt}\right)\cdot \tan(\beta)\right] = 0.75\,m$

Distance from Water Surface to Bottom of Footing at Heel: $h_{2UN2} := GWL_{UN2} - Bot_{ftg} + Key_{h.d} = 12.50\,m$

Toe Conditions:

Water Surface Elevation at Toe: $WSEL_{UN2} := 1207.5m$

Water Surface Elevation at Toe for Uplift: $UWSEL_{UN2} := 1213.5\cdot m$

Finish Grade at Toe providing lateral resistance: $FG_{toeUN2} := 1207.5\cdot m$

Soil Depth Above top of footing: $h_{3aUN2} := FG_{toeUN2} - Top_{ftg} = 0.5\,m$

$$h_{3UN2} := \begin{cases} h_{3aUN2} & \text{if } FG_{toeUN2} - Top_{ftg} \ge 0 \\ 0 & \text{otherwise} \end{cases} = 0.5$$

Resisting Fill at Toe: $h_{4UN2} := FG_{toeUN2} - Bot_{ftg} + Key_{t.d} = 2.50\,m$

Distance from Water Level to Top of Footing: $h_{5UN2} := WSEL_{UN2} - Top_{ftg} = 0.50\,m$

Distance from Water Surface to Bottom of Toe Key: $h_{6UN2} := WSEL_{UN2} - Bot_{ftg} + Key_{t.d} = 2.50\,m$

Soil Depth Above WSEL: $h_{7aUN2} := FG_{toeUN2} - WSEL_{UN2} = 0\,m$

$$h_{7UN2} := \begin{cases} h_{7aUN2} & \text{if } FG_{toeUN2} - WSEL_{UN2} \ge 0 \\ 0 & \text{otherwise} \end{cases} = 0$$

Soil Depth Below WSEL:

$$h_{8UN2} := \begin{cases} WSEL_{UN2} - Bot_{ftg} + Key_{t.d} & \text{if } FG_{toeUN2} - WSEL_{UN2} \ge 0 \\ h_{4UN2} & \text{otherwise} \end{cases} = 2.5$$

For Line of Creep Method: $L_{ho.UN2} := \sqrt{b^2 + \left(Key_{h.d} - Key_{t.d}\right)^2} = 9.849\,m$

Head Loss from Point g:

$\Delta h_{g.hj.UN2} := h_{2UN2} = 12.5\,m$ (to point h & j)

$\Delta h_{g.km.UN2} := GWL_{UN2} - Bot_{ftg} = 8.5\,m$ (to point k & m)

$\Delta h_{g.no.UN2} := GWL_{UN2} - Bot_{ftg} + Key_{t.d} = 8.5\,m$ (to point n & o)

$\Delta h_{g.p.UN2} := GWL_{UN2} - FG_{toeUN2} = 6\,m$ (to point p)

$\Delta h_{g.r.UN2} := GWL_{UN2} - UWSEL_{UN2} = 0\,m$ (to point r)

Surcharge

Surcharge on Heel: $S1_{UN2} := 0.0\,\dfrac{kN}{m^2}$

Calculate Soil Lateral Pressure Coefficients:

LOAD CASE UN2

For all load cases except seismic, soil loading to be based on At-Rest Condition.
Calculate at-rest pressure coefficient Ko based on Jaky's (1944) equation.

Soil At Rest Static Coefficient: $K_o := \dfrac{1 - \sin(\phi)}{1 + \sin(\beta)} = 0.546$ (Eq. 3-6, USACE EM 1110-2-2502)

Lateral - Driving Force

Static At-Rest:

Surcharge Load: $E_{s1UN2} := S1_{UN2} \cdot K_o \cdot \left(H_w + Key_{h.d}\right) \cdot B \cdot -1 = 0 \cdot kN$

Moment Arm (from Point O): $E_{s1locUN2} := \dfrac{H_w + Key_{h.d}}{2} + Key_{vdist} = 2.63\ m$

Moist Soil Load above GWL: $E_{h1UN2} := \dfrac{\gamma_m \cdot K_o \cdot h_{1UN2}^{\ 2}}{2} B \cdot -1 = -3.1 \cdot kN$

Moment Arm (from Point O): $E_{h1locUN2} := \dfrac{h_{1UN2}}{3} + h_{2UN2} + Key_{vdist} = 8.75\ m$

Saturated Soil Load below GWL:
(rectangular component) $E_{h2UN2} := \left(\gamma_m \cdot K_o \cdot h_{1UN2}\right) \cdot h_{2UN2} \cdot B \cdot -1 = -102.4 \cdot kN$

Moment Arm (from Point O): $E_{h2locUN2} := \dfrac{h_{2UN2}}{2} + Key_{vdist} = 2.25\ m$

Saturated Soil Load below GWL:
(triangular component) $E_{h2aUN2} := \dfrac{\left(\gamma_{sat} - \gamma_w\right) \cdot K_o \cdot h_{2UN2}^{\ 2}}{2} \cdot B \cdot -1 = -520.4 \cdot kN$

Moment Arm (from Point O): $E_{h2alocUN2} := \dfrac{h_{2UN2}}{3} + Key_{vdist} = 0.17\ m$

Lateral Water Load:

Water Load GWL to Bottom of Keys:

$$H_{h2UN2} := \begin{cases} \dfrac{\gamma_w \cdot h_{2UN2}^{\ 2}}{2} \cdot B \cdot -1 & \text{if } Key_{vdist} < 0 \\ \dfrac{\gamma_w \cdot \left(h_{2UN2} + Key_{vdist}\right)^2}{2} \cdot B \cdot -1 & \text{otherwise} \end{cases} = -765.6 \cdot kN$$

Moment Arm (from Point O):

$$H_{h2locUN2} := \begin{cases} \dfrac{h_{2UN2}}{3} + Key_{vdist} & \text{if } Key_{vdist} < 0 \\ \dfrac{h_{2UN2} + Key_{vdist}}{3} & \text{otherwise} \end{cases} = 0.17 \cdot m$$

$$\Sigma H_{SoildriveUN2} := E_{s1UN2} + E_{h1UN2} + E_{h2UN2} + E_{h2aUN2} + H_{h2UN2} = -1391.5 \cdot kN$$

$$\Sigma M_{LateralSoildriveUN2} := E_{s1UN2} \cdot E_{s1locUN2} + E_{h1UN2} \cdot E_{h1locUN2} + E_{h2UN2} \cdot E_{h2locUN2} \cdots + E_{h2aUN2} \cdot E_{h2alocUN2} + H_{h2UN2} \cdot H_{h2locUN2} = -471.6\ m \cdot kN$$

Lateral - Resisting Force

LOAD CASE UN2

Lateral Water Load:

Water Load WSEL to Bot. of Toe Key: $H_{h6UN2} := \frac{\gamma_w \cdot h_{6UN2}^2}{2} \cdot B = 30.6 \cdot kN$

Moment Arm (from Point O): $H_{h6locUN2} := \frac{h_{6UN2}}{3} = 0.83\ m$

Water Load between Keys (if any) $H_{h6aUN2} := \begin{cases} \frac{(h_{6UN2} + h_{2UN2}) \cdot -Key_{vdist}}{2} \cdot \gamma_w \cdot B & \text{if } Key_{vdist} < 0 \\ 0 & \text{otherwise} \end{cases} = 294.0 \cdot kN$

Moment Arm (from Point O): $H_{h6alocUN2} := \begin{cases} \frac{Key_{vdist} \cdot (2 \cdot h_{2UN2} + h_{6UN2})}{3(h_{2UN2} + h_{6UN2})} & \text{if } Key_{vdist} < 0 \\ 0 & \text{otherwise} \end{cases} = -2.44 \cdot m$

Lateral Soil Load:

Moist Soil Load above WSEL: $E_{h7UN2} := \frac{\gamma_m \cdot K_o \cdot h_{7UN2}^2}{2} \cdot B = 0.0 \cdot kN$

Moment Arm (from bot. of toe key): $E_{h7locUN2} := h_{6UN2} + \frac{h_{7UN2}}{3} + Key_{vdist} = -1.50\ m$

Saturated Soil Load below WSEL: (rectangular component) $E_{h8UN2} := (\gamma_m \cdot K_o \cdot h_{7UN2}) \cdot h_{8UN2} \cdot B = 0.0 \cdot kN$

Moment Arm (from bot. of toe key): $E_{h8locUN2} := \frac{h_{8UN2}}{2} = 1.25\ m$

Saturated Soil Load below WSEL: (triangular component) $E_{h8aUN2} := \frac{[(\gamma_{sat} - \gamma_w) \cdot K_o] \cdot h_{8UN2}^2}{2} \cdot B = 20.8 \cdot kN$

Moment Arm (from bot. of footing): $E_{h8alocUN2} := \frac{h_{8UN2}}{3} = 0.83\ m$

$\Sigma H_{SoilresistUN2} := H_{h6UN2} + H_{h6aUN2} + E_{h7UN2} + E_{h8UN2} + E_{h8aUN2} = 345.4 \cdot kN$

$$\Sigma M_{HorizSoilResistUN2} := H_{h6UN2} \cdot H_{h6locUN2} + H_{h6aUN2} \cdot H_{h6alocUN2} + E_{h7UN2} \cdot E_{h7locUN2} \cdots + E_{h8UN2} \cdot E_{h8locUN2} + E_{h8aUN2} \cdot E_{h8alocUN2} = -675.8\ m \cdot kN$$

Vertical Force:

UPLIFT: Linear distribution from water at heel to water at toe:

$\Sigma V_{UplliftUN2} := \left[(UWSEL_{UN2} - Bot_{ftg} + Key_{t.d}) + h_{2UN2}\right] \cdot \frac{b}{2} \cdot \gamma_w \cdot B \cdot -1 = -926.1 \cdot kN$

Moment Arm (from Point O): $V_{UpliftUN2aloc} := \frac{b \cdot \left[2 \cdot h_{2UN2} + (UWSEL_{UN2} - Bot_{ftg} + Key_{t.d})\right]}{3\left[h_{2UN2} + (UWSEL_{UN2} - Bot_{ftg} + Key_{t.d})\right]} = 4.786\ m$

$\Sigma M_{UpliftUN2} := \Sigma V_{UplliftUN2} \cdot V_{UpliftUN2aloc} = -4432.05 \cdot kN \cdot m$

Weight of soil and water over toe:

Water Above the Top of Footing: $W_{H1UN2} := \gamma_w \cdot h_{5UN2} \cdot L_{ab} \cdot B = 13.475 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E1locUN2} := \frac{L_{ab}}{2} = 1.375\,m$

Soil above top of footing: $W_{E6UN2} := \gamma_b \cdot h_{3UN2} \cdot L_{ab} \cdot B = 16.8 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E6locUN2} := \frac{L_{ab}}{2} = 1.375\,m$

Vertical Load Due to Surcharge: $S_{UN2} := S1_{UN2} \cdot L_{cd} \cdot B = 0 \cdot kN$ $\quad S_{UN2loc} := b - \frac{L_{cd}}{2} = 6.41\,m$

Weight of soil and water over heel:

Moist Soil for sloped grade above top of wall:

Length of sloped portion of soil above top of wall: $L_{E3UN2} := \left(L_{cd} + t_{wb} - t_{wt}\right) = 5.75\,m$

Height of sloped soil above top of wall over heel: $h_{E3locUN2} := \left(L_{E3UN2}\right) \cdot \tan(\beta) = 0.00\,m$

Weight of sloped soil above top of wall: $W_{E3UN2} := \frac{\gamma_m}{2} \cdot h_{E3locUN2} \cdot L_{E3UN2} \cdot B = 0.0 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E3locUN2} := L_{ab} + t_{wt} + \frac{2}{3} \cdot L_{E3UN2} = 7.08\,m$

Moist soil from top of wall to groundwater level:

Height of soil from top of wall and top of GWL: $h_{1UN2} = 0.75\,m$

Length from edge of wall at GWL to edge of heel: $L_{E4UN2} := L_{E3UN2} - \left(h_{1UN2} \cdot S_{batter}\right) = 5.69\,m$

Weight of soil over heel from top of wall to GWL: $W_{E4UN2} := \gamma_m \cdot h_{1UN2} \cdot \frac{\left(L_{E3UN2} + L_{E4UN2}\right)}{2} \cdot B = 85.8 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E4locUN2} := b - \frac{L_{E3UN2}^2 + L_{E3UN2} \cdot L_{E4UN2} + L_{E4UN2}^2}{3\left(L_{E3UN2} + L_{E4UN2}\right)} = 6.14\,m$

Saturated soil from groundwater to top of footing:

Height of soil from GWL to top of heel: $h_{E4UN2} := h_{2UN2} - t_{ftg} - Key_{h.d} = 6.50\,m$

Weight of soil over heel from GWL to top of heel: $W_{E5UN2} := \left(\gamma_{sat}\right) \cdot h_{E4UN2} \cdot \frac{\left(L_{E4UN2} + L_{cd}\right)}{2} \cdot B = 777.3 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E5locUN2} := b - \frac{L_{E4UN2}^2 + L_{E4UN2} \cdot L_{cd} + L_{cd}^2}{3\left(L_{E4UN2} + L_{cd}\right)} = 6.28\,m$

$$\Sigma V_{SoilWaterUN2} := W_{H1UN2} + W_{E6UN2} + W_{E3UN2} + W_{E4UN2} + W_{E5UN2} + S_{UN2} = 893.3 \cdot kN$$

$$\Sigma M_{VertSoilWaterResistUN2} := W_{H1UN2} \cdot W_{E1locUN2} + W_{E6UN2} \cdot W_{E6locUN2} \cdots + W_{E3UN2} \cdot W_{E3locUN2} + W_{E4UN2} \cdot W_{E4locUN2} + W_{E5UN2} \cdot W_{E5locUN2} + S_{UN2} \cdot S_{UN2loc} = 5449.9\,m \cdot kN$$

THIS PAGE INTENTIONALLY LEFT BLANK
PLEASE GO TO THE NEXT PAGE

STABILITY ASSESSMENT:

LOAD CASE UN2

CHECK SLIDING ALONG HORIZONTAL SLIDING PLANE:

Summation of the vertical forces:

$$\Sigma V_{UN2} := \Sigma V_{conc} + \Sigma V_{SoilWaterUN2} + \Sigma V_{UpliftUN2} = 618.0 \cdot kN$$

Summation of the horizontal forces:

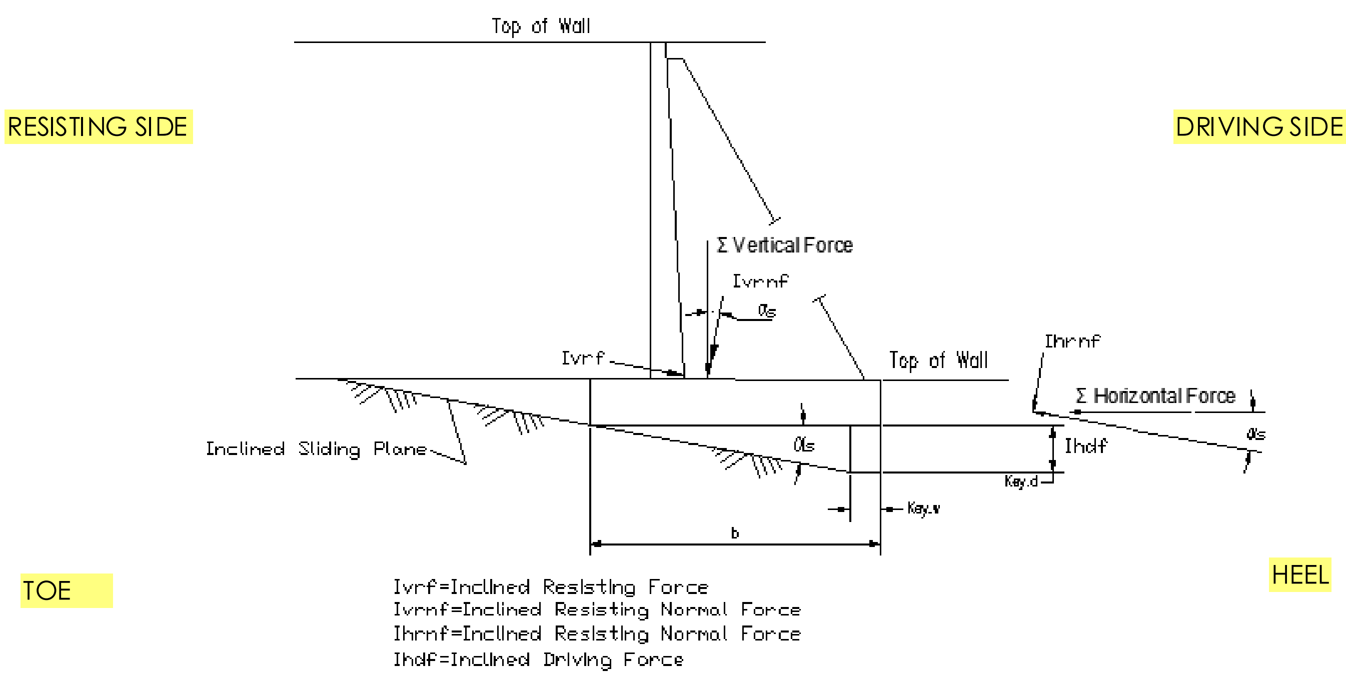
$$\Sigma H_{UN2} := \Sigma H_{SoildriveUN2} + \Sigma H_{SoilresistUN2} = -1046.0 \cdot kN$$

Safety Factor for Sliding Horizontal Failure Plane

$$FS_{Horiz.SlidingUN2} := \frac{\left|\Sigma V_{UN2}\right| \cdot \tan\left(\phi_{rock} \cdot \frac{\pi}{180}\right)}{\left|\Sigma H_{UN2}\right|} = 0.29$$

$$FS_{Sliding.check1.UN2} := \begin{vmatrix} \text{"OKAY "} & \text{if} \quad FS_{Horiz.SlidingUN2} > FS_{sliding.reqUN2} \\ \text{"NG - key req'"} & \text{otherwise} \end{vmatrix} = \text{"NG - key req'"}$$

CHECK FACTOR OF SAFETY SLIDING WITH KEY (INCLINED SLIDING PLANE):



$\alpha s = 0.464$ as degrees= $\alpha s \cdot \left(\frac{180}{\pi}\right) = 26.57$

(With properly engineered reinforced concrete Key, horizontal sliding plane thru Toe is protected, critical sliding plane is relocated to the INCLINED SLIDING PLANE FROM HEEL KEY To TOE, Bedrock Mass above this examing plane is mobilized by reinforced concrete key and combined into Structural Wedge.)

Resolve ΣV_{UN2} & ΣH_{UN2}

$$\Sigma V_{InclinedUN2} := \cos(\alpha s) \cdot \left(\left|\Sigma V_{UN2} + V_{rocksection}\right|\right) + \sin(\alpha s) \cdot \left|\Sigma H_{UN2}\right| = 1386.9 \cdot kN$$

$$\Sigma H_{InclinedUN2} := \cos(\alpha s) \cdot \left|\Sigma H_{UN2}\right| - \sin(\alpha s) \cdot \left(\left|\Sigma V_{UN2} + V_{rocksection}\right|\right) = 476.1 \cdot kN$$

Safety Factor for Sliding Inclined Failure Plane

$$FS_{InclinedISlidingUN2} := \frac{\Sigma V_{InclinedUN2} \cdot \tan(\phi_r)}{\Sigma H_{InclinedUN2}} = 1.30$$

$$FS_{Sliding.check2.UN2} := \begin{cases} \text{"OKAY "} & \text{if } FS_{InclinedISlidingUN2} > FS_{sliding.reqUN2} \\ \text{"NG - Revise Structure""} & \text{otherwise} \end{cases} = \text{"NG - Revise Structure""}$$

CHECK FOUNDATION ECCENTRICITY:

Summation of the resisting moments about the toe:

$$\Sigma M_{resUN2} := \Sigma M_{conc} + \Sigma M_{VertSoilWaterResistUN2} + \Sigma M_{HorizSoilResistUN2} + \Sigma M_{rocksection} = 10084 \cdot kN \cdot m$$

Summation of the overturning moments about the toe:

$$\Sigma M_{oUN2} := \Sigma M_{LateralSoildriveUN2} + \Sigma M_{UpliftUN2} = -4904 \cdot kN \cdot m$$

Total moment: $\Sigma M_{UN2} := \Sigma M_{resUN2} + \Sigma M_{oUN2} = 5180.1\ m \cdot kN$

Normal force to base: $\Sigma V_{InclinedUN2} = 1386.9 \cdot kN$

Inclined Sliding Plane Length: $L_{incline} = 10.1 \cdot m$

Eccentricity (inclined plane): $ex_{UN2} := \frac{L_{incline}}{2} - \frac{\Sigma M_{UN2}}{\Sigma V_{InclinedUN2}} = 1.30\ m$

Kern = 1.677 m

Eccentricity Check: $e_{check.UN2} := \begin{cases} \text{"Okay"} & \text{if } ex_{UN2} \le Kern \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"Okay"}$

CHECK FOUNDATION BEARING CAPACITY:

Base Section Modulus: $S_b = 16.88\ m^3$

Bearing Pressure Under Toe:

$$\sigma_{ToeUN2} := \begin{cases} \left[\frac{\Sigma V_{InclinedUN2}}{L_{incline} \cdot B} + \frac{(\Sigma V_{InclinedUN2} \cdot ex_{UN2})}{S_b}\right] & \text{if } \frac{\Sigma V_{InclinedUN2}}{L_{incline} \cdot B} \ge \frac{\Sigma V_{InclinedUN2} \cdot ex_{UN2}}{S_b} \\ \frac{2 \cdot \Sigma V_{InclinedUN2}}{B \cdot 3 \left(\frac{b}{2} - ex_{UN2}\right)} & \text{otherwise} \end{cases} = 244.4 \cdot kPa$$

$$Bearing_{ChecktoeUN2} := \begin{cases} \text{"OKAY "} & \text{if } \sigma_{ToeUN2} < \sigma_{allowUN2} \\ \text{"NG""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

Bearing Pressure Under Heel:

$$\sigma_{HeelUN2} := \begin{cases} \left[\frac{\Sigma V_{InclinedUN2}}{L_{incline} \cdot B} - \frac{(\Sigma V_{InclinedUN2} \cdot ex_{UN2})}{S_b}\right] & \text{if } \frac{\Sigma V_{InclinedUN2}}{L_{incline} \cdot B} \ge \frac{\Sigma V_{InclinedUN2} \cdot ex_{UN2}}{S_b} \\ 0 & \text{otherwise} \end{cases} = 31.3 \cdot kPa$$

$$Bearing_{CheckheelUN2} := \left(\begin{cases} \text{"OKAY "} & \text{if } \sigma_{HeelUN2} < \sigma_{allowUN2} \wedge \sigma_{HeelUN2} > 0 \\ \text{"NG - perform cracked base analysis""} & \text{otherwise} \end{cases} \right) = \text{"OKAY "}$$

CHECK FLOATATION:

Safety Factor for Floatation:

$$FS_{FloatationUN2} := \frac{\Sigma V_{conc} + \Sigma V_{SoilWaterUN2}}{\left|\Sigma V_{UpliftUN2}\right|} = 1.67$$

$$FS_{Floatation.UN2.check} := \begin{cases} \text{"OKAY "} & \text{if } FS_{FloatationUN2} > FS_{req.UN2.flt} \\ \text{"Revise Structure""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

CHECK OVERTURNING

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.
Assumptions are made in order to compute overturning stablity of indetermine forces on monolith with key;
(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.
(b) The horizontal resisting force acting on the key, P.key, is that required for static equilibrium
(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1

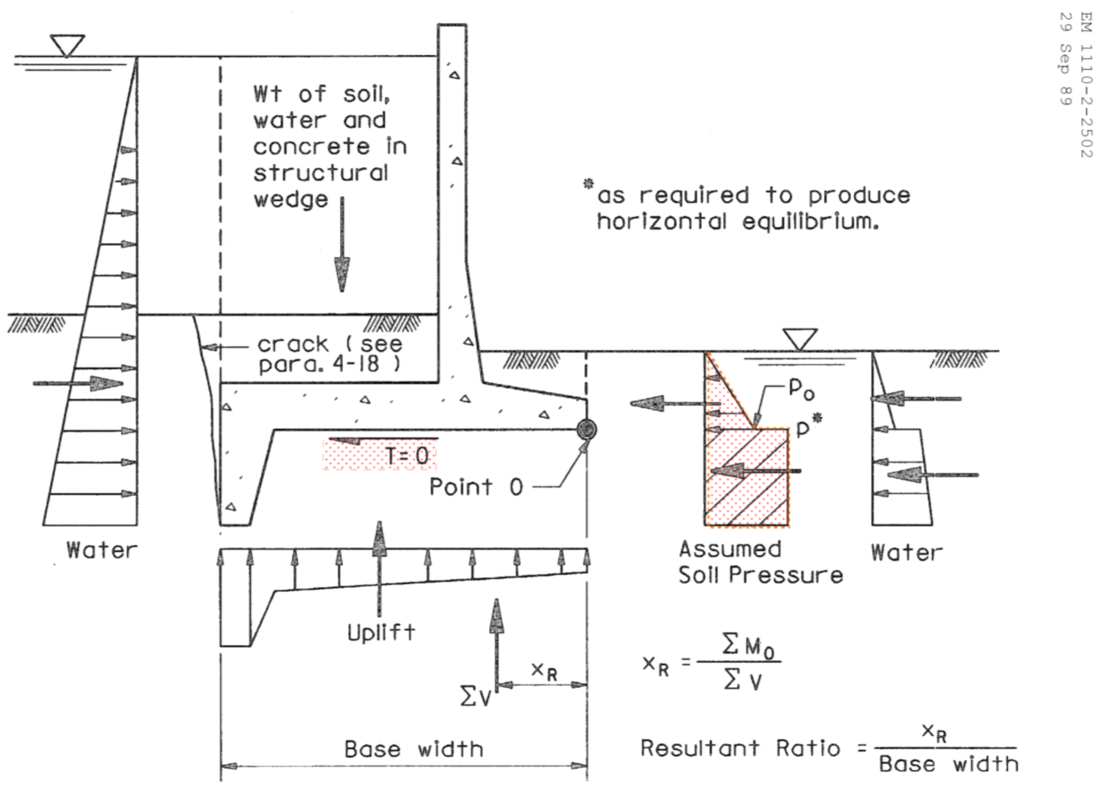


Figure 4-5. Forces for overturning analysis for wall with horizontal base and key

Modify Uplift for Overturning Analysis: **LOAD CASE UN2**

(Uplift is calculated along the concrete/rock contact using the Line of Creep method)

Water Pressure at h: $u_{h.UN2} := \Delta h_{g.hj.UN2} \cdot \gamma_w = 122.50 \cdot kPa$

Water Pressure at o: $u_{o.UN2} := \left(\Delta h_{g.no.UN2} - \frac{\Delta h_{g.r.UN2} \cdot L_{ho.UN2}}{L_{ho.UN2}}\right) \cdot \gamma_w = 83.3 \cdot kPa$

Head loss between point h and o: $\Delta h_{ho.UN2} := \Delta h_{g.r.UN2} \cdot \frac{L_{ho.UN2}}{L_{ho.UN2}} = 0\,m$

Length of concrete base (h -> o): $L_{baseho.UN2} := Key_{h.w} + Key_{h.d} + Key_{hdist} + Key_{t.d} + Key_{t.w} = 13\,m$

Head loss along h -> j: $\Delta h_{hj.UN2} := \Delta h_{ho.UN2} \cdot \frac{Key_{h.w}}{L_{baseho.UN2}} = 0\,m$

Water Pressure at j: $u_{j.UN2} := \left(\Delta h_{g.hj.UN2} - \Delta h_{hj.UN2}\right) \cdot \gamma_w = 122.50 \cdot kPa$

Head loss along h -> k: $\Delta h_{hjk.UN2} := \Delta h_{ho.UN2} \cdot \left(\frac{Key_{h.w} + Key_{h.d}}{L_{baseho.UN2}}\right) = 0\,m$

Water Pressure at k: $u_{k.UN2} := \left(\Delta h_{g.km.UN2} - \Delta h_{hjk.UN2}\right) \cdot \gamma_w = 83.30 \cdot kPa$

Head loss along h -> m: $\Delta h_{hjkm.UN2} := \Delta h_{ho.UN2} \cdot \left(\frac{Key_{h.w} + Key_{h.d} + Key_{hdist}}{L_{baseho.UN2}}\right) = 0\,m$

Water Pressure at m: $u_{m.UN2} := \left(\Delta h_{g.km.UN2} - \Delta h_{hjkm.UN2}\right) \cdot \gamma_w = 83.30 \cdot kPa$

Head loss along h -> n: $\Delta h_{hjkmn.UN2} := \Delta h_{ho.UN2} \cdot \left(\frac{Key_{h.w} + Key_{h.d} + Key_{hdist} + Key_{t.d}}{L_{baseho.UN2}}\right) = 0\,m$

Water Pressure at n: $u_{n.UN2} := \left(\Delta h_{g.no.UN2} - \Delta h_{hjkmn.UN2}\right) \cdot \gamma_w = 83.30 \cdot kPa$

Uplift under key at heel: $V_{ulkeyhUN2.OT} := \frac{\left(u_{h.UN2} + u_{j.UN2}\right) \cdot Key_{h.w}}{2} \cdot B \cdot -1 = -122.5 \cdot kN$

Moment Arm (from Point O): $V_{ulkeyhUN2loc.OT} := b - \frac{Key_{h.w} \cdot \left(2 \cdot u_{j.UN2} + u_{h.UN2}\right)}{3 \cdot \left(u_{j.UN2} + u_{h.UN2}\right)} = 8.5\,m$

Uplift under base: $V_{ulbaseUN2.OT} := \frac{\left(u_{k.UN2} + u_{m.UN2}\right) \cdot Key_{hdist}}{2} \cdot B \cdot -1 = -666.4 \cdot kN$

Moment Arm (from Point O): $V_{ulbaseUN2loc.OT} := b - Key_{h.w} - \frac{Key_{hdist} \cdot \left(2 \cdot u_{m.UN2} + u_{k.UN2}\right)}{3 \cdot \left(u_{m.UN2} + u_{k.UN2}\right)} = 4\,m$

Uplift under key at toe: $V_{ulkeytUN2.OT} := \frac{\left(u_{n.UN2} + u_{o.UN2}\right) \cdot Key_{t.w}}{2} \cdot B \cdot -1 = 0 \cdot kN$

Moment Arm (from Point O): $V_{ulkeytUN2loc.OT} := \frac{Key_{t.w} \cdot \left(2 \cdot u_{n.UN2} + u_{o.UN2}\right)}{3 \cdot \left(u_{n.UN2} + u_{o.UN2}\right)} = 0$

$$\Sigma V_{UpliftUN2.OT} := V_{ulkeyhUN2.OT} + V_{ulbaseUN2.OT} + V_{ulkeytUN2.OT} = -789 \cdot kN$$

$$U_{UN2.loc.OT} := \frac{V_{ulkeyhUN2.OT} \cdot V_{ulkeyhUN2loc.OT} + V_{ulbaseUN2.OT} \cdot V_{ulbaseUN2loc.OT} + V_{ulkeytUN2.OT} \cdot V_{ulkeytUN2loc.OT}}{\Sigma V_{UpliftUN2.OT}} = 4.70\,m$$

$$\Sigma M_{UpliftUN2.OT} := \Sigma V_{UpliftUN2.OT} \cdot U_{UN2.loc.OT} = -3706.9 \cdot kN \cdot m$$

Modify Lateral Water Pressure (Resisting) for Overturning Analysis:

(Resisting water pressure is calculated using the Line of Creep method)

Water Load at Key (heel):

$$H_{h2UN2.OT} := \frac{u_{k.UN2} + u_{j.UN2}}{2} \cdot Key_{h.d} B = 411.6 \cdot kN$$

Moment Arm (from Point O):

$$H_{h2locUN2.OT} := \frac{Key_{h.d} \cdot (2 \cdot u_{k.UN2} + u_{j.UN2})}{3(u_{k.UN2} + u_{j.UN2})} + Key_{vdist} = -2.13\ m$$

Water Load at Key (toe):

$$H_{h6UN2.OT} := \frac{u_{o.UN2} \cdot (UWSEL_{UN2} - Bot_{ftg} + Key_{t.d})}{2} \cdot B = 354 \cdot kN$$

Moment Arm (from Point O):

$$H_{h6locUN2.OT} := \frac{UWSEL_{UN2} - Bot_{ftg} + Key_{t.d}}{3} = 2.83\ m$$

$$\Sigma H_{waterresistUN2.OT} := H_{h2UN2.OT} + H_{h6UN2.OT} = 765.63 \cdot kN$$

$$H_{waterresistlocUN2.OT} := \frac{H_{h2UN2.OT} \cdot H_{h2locUN2.OT} + H_{h6UN2.OT} \cdot H_{h6locUN2.OT}}{\Sigma H_{waterresistUN2.OT}} = 0.167\ m$$

$$\Sigma M_{waterresistUN2.OT} := \Sigma H_{waterresistUN2.OT} \cdot H_{waterresistlocUN2.OT} = 127.6 \cdot kN \cdot m$$

Modify Lateral Soil Loads for Overturning Analysis:

(Lateral soil loads are calculated down to Point O instead of bottom of shear key)

__**Driving Soil Load (Headwater Side):**__

Surcharge Load:

$$E_{s1UN2.OT} := S1_{UN2} \cdot K_o \cdot (H_w + Key_{h.d} + Key_{vdist}) \cdot B \cdot -1 = 0 \cdot kN$$

Moment Arm (from Point O):

$$E_{s1locUN2.OT} := \frac{H_w + Key_{h.d} + Key_{vdist}}{2} = 4.63\ m$$

Moist Soil Load above GWL:

$$E_{h1UN2.OT} := \frac{\gamma_m \cdot K_o \cdot h_{1UN2}^{\ 2}}{2} B \cdot -1 = -3.1 \cdot kN$$

Moment Arm (from Point O):

$$E_{h1locUN2.OT} := \frac{h_{1UN2}}{3} + h_{2UN2} + Key_{vdist} = 8.75\ m$$

Saturated Soil Load below GWL:
(rectangular component)

$$E_{h2UN2.OT} := (\gamma_m \cdot K_o \cdot h_{1UN2}) \cdot (h_{2UN2} + Key_{vdist}) \cdot B \cdot -1 = -69.6 \cdot kN$$

Moment Arm (from Point O):

$$E_{h2locUN2.OT} := \frac{h_{2UN2} + Key_{vdist}}{2} = 4.25\ m$$

Saturated Soil Load below GWL:
(triangular component)

$$E_{h2aUN2.OT} := \frac{(\gamma_{sat} - \gamma_w) \cdot K_o \cdot (h_{2UN2} + Key_{vdist})^2}{2} \cdot B \cdot -1 = -240.6 \cdot kN$$

Moment Arm (from Point O):

$$E_{h2alocUN2.OT} := \frac{h_{2UN2} + Key_{vdist}}{3} = 2.83\ m$$

Resisting Soil Load (Tailwater Side):

(Determine resisting soil load based on depth variation between the keys (ie. Key_{vdist}). In case where key at heel is deeper than key at toe (ie. $Key_{vdist} < 0$), resisting soil load (p*) is assumed to produce horizontal equilibrium as per Figure 4-5 above. Resisting soil load (p_o) is neglected.)

Total Driving Force: $\Sigma H_{SoildriveUN2.OT} := E_{s1UN2.OT} + E_{h1UN2.OT} + E_{h2UN2.OT} + E_{h2aUN2.OT} + H_{h2UN2} = -1079.0 \cdot kN$

Total Resisting Force: $\Sigma H_{waterresistUN2.OT} = 765.6 \cdot kN$

Assumed Soil Load p*: $E_{h8UN2a.OT} := \left(\Sigma H_{SoildriveUN2.OT} + \Sigma H_{waterresistUN2.OT}\right) \cdot -1 = 313.328 \cdot kN$

Moment Arm (from Point O): $E_{h8UN2a.loc.OT} := \dfrac{Key_{vdist}}{2} = -2\,m$

$$E_{h8UN2.OT} := \begin{cases} E_{h8UN2a.OT} & \text{if } Key_{vdist} < 0 \\ \Sigma H_{SoilresistUN2} - H_{h6UN2} - H_{h6aUN2} & \text{otherwise} \end{cases} = 313.328 \cdot kN$$

$$\Sigma M_{SoilresistUN2.OT} := \begin{cases} E_{h8UN2a.OT} \cdot E_{h8UN2a.loc.OT} & \text{if } Key_{vdist} < 0 \\ \Sigma M_{HorizSoilResistUN2} - H_{h6UN2} \cdot H_{h6locUN2} - H_{h6aUN2} \cdot H_{h6alocUN2} & \text{otherwise} \end{cases} = -626.655 \cdot kN \cdot m$$

Sum of Moment about Point O:

$$\Sigma M_{LateraldriveUN2.OT} := E_{s1UN2.OT} \cdot E_{s1locUN2.OT} + E_{h1UN2.OT} \cdot E_{h1locUN2.OT} + E_{h2UN2.OT} \cdot E_{h2locUN2.OT} \cdots + E_{h2aUN2.OT} \cdot E_{h2alocUN2.OT} + H_{h2UN2} \cdot H_{h2locUN2} = -1132.2 \cdot kN \cdot m$$

$$\Sigma M_{LateralresistUN2.OT} := \Sigma M_{waterresistUN2.OT} + \Sigma M_{SoilresistUN2.OT} = -499.1 \cdot kN \cdot m$$

Total moment:

$$\Sigma M_{UN2.OT} := \Sigma M_{conc} + \Sigma M_{VertSoilWaterResistUN2} + \Sigma M_{UpliftUN2.OT} + \Sigma M_{LateraldriveUN2.OT} + \Sigma M_{LateralresistUN2.OT} = 3237.0 \cdot kN \cdot m$$

Total Vertical Force: $\Sigma V_{UN2.OT} := \Sigma V_{conc} + \Sigma V_{SoilWaterUN2} + \Sigma V_{UpliftUN2.OT} = 755.2 \cdot kN$

Distance X_R: EM 1110-2-2502 Eq.4-1 $X_{R.UN2} := \dfrac{\Sigma M_{UN2.OT}}{\Sigma V_{UN2.OT}} = 4.286\,m$

Overturning Resultant Ratio $Ratio_{UN2.OT} := \dfrac{X_{R.UN2}}{b} = 0.48$

$$Ratio_{UN2.OT.check} := \begin{cases} \text{"OKAY "} & \text{if } Ratio_{UN2.OT} > X_{R.reqUN2} \\ \text{"Revise Structure""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

CHECK FOUNDATION ECCENTRICITY (HORIZONTAL PLANE):

Eccentricity (horizontal plan): $ex_{UN2.OT} := \dfrac{b}{2} - \dfrac{\Sigma M_{UN2.OT}}{\Sigma V_{UN2.OT}} = 0.21\,m$ $Kern_{OT} = 1.5\,m$

Eccentricity Check:

$$e_{check.UN2.OT} := \begin{cases} \text{"Okay"} & \text{if } ex_{UN2} \le Kern_{OT} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"Okay"}$$

CHECK FOUNDATION BEARING CAPACITY (HORIZONTAL PLANE):

Base Section Modulus: $S_{b.OT} = 13.5\,m^3$

Bearing Pressure Under Toe:

$$\sigma_{ToeUN2.OT} := \begin{cases} \left(\dfrac{\Sigma V_{UN2.OT}}{b \cdot B} + \dfrac{\Sigma V_{UN2.OT} \cdot ex_{UN2.OT}}{S_{b.OT}}\right) & \text{if } \dfrac{\Sigma V_{UN2.OT}}{b \cdot B} \geq \dfrac{\Sigma V_{UN2.OT} \cdot ex_{UN2.OT}}{S_{b.OT}} \\ \dfrac{2 \cdot \Sigma V_{UN2.OT}}{B \cdot 3\left(\dfrac{b}{2} - ex_{UN2.OT}\right)} & \text{otherwise} \end{cases} = 95.9 \cdot kPa$$

$$Bearing_{ChecktoeUN2.OT} := \begin{cases} \text{"OKAY "} & \text{if } \sigma_{ToeUN2.OT} < \sigma_{allowUN2} \\ \text{"NG - for reference only""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

Bearing Pressure Under Heel:

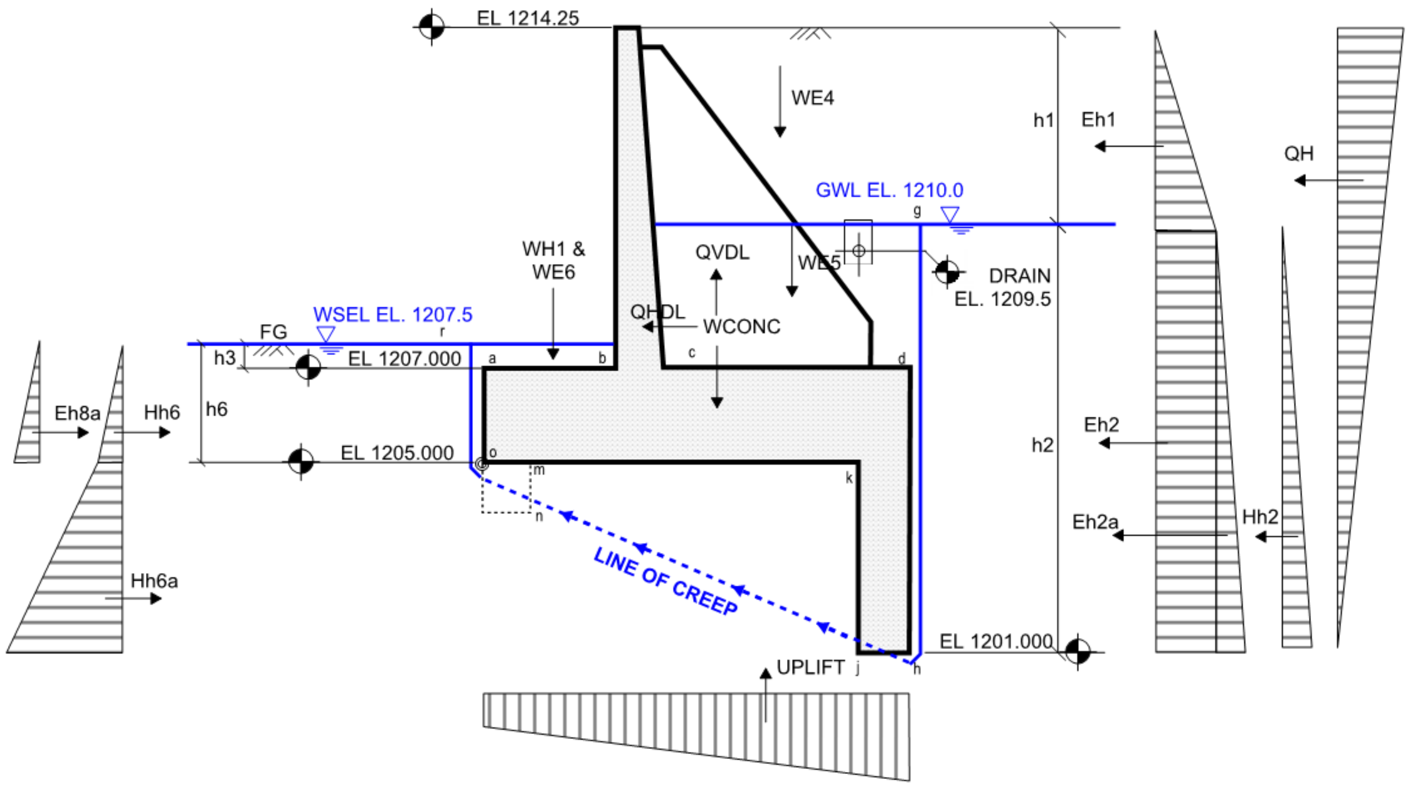
$$\sigma_{HeelUN2.OT} := \begin{cases} \left(\dfrac{\Sigma V_{UN2.OT}}{b \cdot B} - \dfrac{\Sigma V_{UN2.OT} \cdot ex_{UN2.OT}}{S_{b.OT}}\right) & \text{if } \dfrac{\Sigma V_{UN2.OT}}{b \cdot B} \geq \dfrac{\Sigma V_{UN2.OT} \cdot ex_{UN2.OT}}{S_{b.OT}} \\ 0 & \text{otherwise} \end{cases} = 72.0 \cdot kPa$$

$$Bearing_{CheckheelUN2.OT} := \left(\begin{cases} \text{"OKAY "} & \text{if } \sigma_{HeelUN2.OT} < \sigma_{allowUN2} \wedge \sigma_{HeelUN2.OT} > 0 \\ \text{"NG - for reference only""} & \text{otherwise} \end{cases}\right) = \text{"OKAY "}$$

SUMMARY OF STABILITY ASSESSMENT:

Sliding Factor of Safety: (Horizontal Plane - Ref only)	$FS_{Horiz.SlidingUN2} = 0.29$	$FS_{Sliding.check1.UN2}$ = "NG - key req""
Sliding Factor of Safety: (Inclined Plane)	$FS_{InclinedlSlidingUN2} = 1.30$	$FS_{Sliding.check2.UN2}$ = "NG - Revise Structure""
Eccentricity: (Inclined Plane)	$ex_{UN2} = 1.30\ m$	$e_{check.UN2}$ = "Okay"
Bearing Pressure At Heel: (Inclined Plane)	$\sigma_{HeelUN2} = 31 \cdot kPa$	$Bearing_{CheckheelUN2}$ = "OKAY "
Bearing Pressure At Toe: (Inclined Plane)	$\sigma_{ToeUN2} = 244 \cdot kPa$	$Bearing_{ChecktoeUN2}$ = "OKAY "
Flotation Factor of Safety (horizontal plane)	$FS_{FloatationUN2} = 1.67$	$FS_{Floatation.UN2.check}$ = "OKAY "
Overturning Resultant Ratio: (horizontal plane)	$Ratio_{UN2.OT} = 0.48$	$Ratio_{UN2.OT.check}$ = "OKAY "
Eccentricity: (horizontal plane - Ref only)	$ex_{UN2.OT} = 0.21\ m$	$e_{check.UN2.OT}$ = "Okay"
Bearing Pressure At Heel: (horizontal plane - Ref only)	$\sigma_{HeelUN2.OT} = 72 \cdot kPa$	$Bearing_{CheckheelUN2.OT}$ = "OKAY "
Bearing Pressure At Toe: (horizontal plane - Ref only)	$\sigma_{ToeUN2.OT} = 96 \cdot kPa$	$Bearing_{ChecktoeUN2.OT}$ = "OKAY "

LOAD CASE E1 - SEISMIC LOADING



E1 DESIGN CASE

LOAD CASE E1 ACCEPTANCE PARAMETERS

FS sliding:

Extreme (E) loading) 1.0 (without cohesion, seismic (Table 3-3, USACE EM 1110-2-2100)

Resultant Location:

Extremem (E) Inside middle half ~75% base in compression

Required Factor of Safety for Sliding: $FS_{sliding.reqE1} := 1.0$ (Without Cohesion)

Allowable rock bearing pressure: $\sigma_{allowE1} := 1740kPa$ (Section 5.2, Design Criteria EM 1110-2-2100 Section 3-10)

Overturning Required Resultant Ratio: $X_{R.reqE1} := 0.25$ (EM 1110-2-2502, Figure 4-4)

Required Factor of Safety for Floatation $FS_{req.E1.flt} := 1.1$

SOIL HEIGHTS and Water Levels:

LOAD CASE E1

Heel Conditions:

Groundwater Elevation at Heel: $GWL_{E1} := 1210.0m$

Distance from Finish Grade to Groundwater at Heel: $h_{1E1} := \left[T_w - GWL_{E1} + \left(L_{cd} + t_{wb} - t_{wt}\right)\cdot \tan(\beta)\right] = 4.25\text{ m}$

Distance from Water Surface to Bottom of Footing at Heel: $h_{2E1} := GWL_{E1} - Bot_{ftg} + Key_{h.d} = 9.00\text{ m}$

Toe Conditions:

Water Surface Elevation at Toe: $WSEL_{E1} := 1207.5m$

Water Surface Elevation at Toe for Uplift: $UWSEL_{E1} := 1207.5\cdot m$

Finish Grade at Toe providing lateral resistance: $FG_{toeE1} := 1207.5\cdot m$

Soil Depth Above top of footing: $h_{3aE1} := FG_{toeE1} - Top_{ftg} = 0.5\text{ m}$

$$h_{3E1} := \begin{cases} h_{3aE1} & \text{if } FG_{toeE1} - Top_{ftg} \ge 0 \\ 0 & \text{otherwise} \end{cases} = 0.5$$

Resisting Fill at Toe: $h_{4E1} := FG_{toeE1} - Bot_{ftg} + Key_{t.d} = 2.50\text{ m}$

Distance from Water Level to Top of Footing: $h_{5E1} := WSEL_{E1} - Top_{ftg} = 0.50\text{ m}$

Distance from Water Surface to Bottom of Toe Key: $h_{6E1} := WSEL_{E1} - Bot_{ftg} + Key_{t.d} = 2.50\text{ m}$

Soil Depth Above WSEL: $h_{7aE1} := FG_{toeE1} - WSEL_{E1} = 0\text{ m}$

$$h_{7E1} := \begin{cases} h_{7aE1} & \text{if } FG_{toeE1} - WSEL_{E1} \ge 0 \\ 0 & \text{otherwise} \end{cases} = 0$$

Soil Depth Below WSEL:

$$h_{8E1} := \begin{cases} WSEL_{E1} - Bot_{ftg} + Key_{t.d} & \text{if } FG_{toeE1} - WSEL_{E1} \ge 0 \\ h_{4E1} & \text{otherwise} \end{cases} = 2.5$$

For Line of Creep Method: $L_{ho.E1} := \sqrt{b^2 + \left(Key_{h.d} - Key_{t.d}\right)^2} = 9.849\text{ m}$

Head Loss from Point g:

$\Delta h_{g.hj.E1} := h_{2E1} = 9\text{ m}$ (to point h & j)

$\Delta h_{g.km.E1} := GWL_{E1} - Bot_{ftg} = 5\text{ m}$ (to point k & m)

$\Delta h_{g.no.E1} := GWL_{E1} - Bot_{ftg} + Key_{t.d} = 5\text{ m}$ (to point n & o)

$\Delta h_{g.p.E1} := GWL_{E1} - FG_{toeE1} = 2.5\text{ m}$ (to point p*)

$\Delta h_{g.r.E1} := GWL_{E1} - UWSEL_{E1} = 2.5\text{ m}$ (to point r)

Surcharge

Surcharge on Heel: $S1_{E1} := 0.0 \dfrac{kN}{m^2}$

* same as point "a" in this case

Calculate Soil Lateral Pressure Coefficients:

LOAD CASE E1

Calculate at-rest pressure coefficient K_o based on Jaky's (1944) equation.

Soil At Rest Static Coefficient: (apply to resisting soil loads)

$$K_o := \frac{1 - \sin(\phi)}{1 + \sin(\beta)} = 0.546$$

(Eq. 3-6, USACE EM 1110-2-2502)

Calculate active pressure coefficient K_A based on Coulumb equations.

Determine Slope of Active Wedge: (cohesionless backfill with water table)

$$c_1 := 2\cdot\tan(\phi) = 1.019 \qquad c_2 := 1 - \tan(\phi)\cdot\tan(\beta) - \frac{\tan(\beta)}{\tan(\phi)} = 1$$

(Eq. G-14 / G-15, USACE EM 1110-2-2100)

$$\alpha := \operatorname{atan}\left(\frac{c_1 + \sqrt{c_1^{\,2} + 4\cdot c_2}}{2}\right) = 1.021 \qquad \alpha_{deg} := \alpha\cdot\frac{180}{\pi} = 58.5 \text{ degrees}$$

(Eq. G-13, USACE EM 1110-2-2100)

Soil Active Coefficient above GWL:

$$K_{Aagwt} := \left(\frac{1 - \tan(\phi)\cdot\cot(\alpha)}{1 + \tan(\phi)\cdot\tan(\alpha)}\right)\cdot\left(\frac{\tan(\alpha)}{\tan(\alpha) - \tan(\beta)}\right) = 0.376$$

Soil Active Coefficient below GWL:

$$K_{Abgwt} := \frac{1 - \tan(\phi)\cdot\cot(\alpha)}{1 + \tan(\phi)\cdot\tan(\alpha)}\cdot\left[1 + \left(\frac{\tan(\alpha)}{\tan(\alpha) - \tan(\beta)} - 1\right)\cdot\left(\frac{\gamma_m}{\gamma_{sat} - \gamma_w}\right)\right] = 0.376$$

(Eq. G-29, USACE EM 1110-2-2100)

Lateral - Driving Force

Static Copmonent : Active Pressure:

Surcharge Load:

$$E_{s1E1} := S1_{E1}\cdot K_{Aagwt}\cdot\left(H_w + Key_{h.d}\right)\cdot B\cdot -1 = 0\cdot kN$$

Moment Arm (from Point O):

$$E_{s1locE1} := \frac{H_w + Key_{h.d}}{2} + Key_{vdist} = 2.63\ m$$

Moist Soil Load above GWL:

$$E_{h1E1} := \frac{\gamma_m\cdot K_{Aagwt}\cdot h_{1E1}^{\,2}}{2}\cdot B\cdot -1 = -67.8\cdot kN$$

Moment Arm (from Point O):

$$E_{h1locE1} := \frac{h_{1E1}}{3} + h_{2E1} + Key_{vdist} = 6.42\ m$$

Saturated Soil Load below GWL: (rectangular component)

$$E_{h2E1} := \left(\gamma_m\cdot K_{Abgwt}\cdot h_{1E1}\right)\cdot h_{2E1}\cdot B\cdot -1 = -287.3\cdot kN$$

Moment Arm (from Point O):

$$E_{h2locE1} := \frac{h_{2E1}}{2} + Key_{vdist} = 0.50\ m$$

Saturated Soil Load below GWL: (triangular component)

$$E_{h2aE1} := \frac{\left(\gamma_{sat} - \gamma_w\right)\cdot K_{Abgwt}\cdot h_{2E1}^{\,2}}{2}\cdot B\cdot -1 = -185.5\cdot kN$$

Moment Arm (from Point O):

$$E_{h2alocE1} := \frac{h_{2E1}}{3} + Key_{vdist} = -1.00\ m$$

Lateral Water Load:

Water Load GWL to Bottom of Keys:

$$H_{h2E1} := \begin{cases} \dfrac{\gamma_w\cdot h_{2E1}^{\,2}}{2}\cdot B\cdot -1 & \text{if } Key_{vdist} < 0 \\[2ex] \dfrac{\gamma_w\cdot\left(h_{2E1} + Key_{vdist}\right)^2}{2}\cdot B\cdot -1 & \text{otherwise} \end{cases} = -396.9\cdot kN$$

Moment Arm (from Point O):

$$H_{h2locE1} := \begin{cases} \dfrac{h_{2E1}}{3} + Key_{vdist} & \text{if } Key_{vdist} < 0 \\[2ex] \dfrac{h_{2E1} + Key_{vdist}}{3} & \text{otherwise} \end{cases} = -1.00\cdot m$$

$$\Sigma H_{SoildriveE1} := E_{s1E1} + E_{h1E1} + E_{h2E1} + E_{h2aE1} + H_{h2E1} = -937.6\cdot kN$$

$$\Sigma M_{LateralSoildriveE1} := E_{s1E1}\cdot E_{s1locE1} + E_{h1E1}\cdot E_{h1locE1} + E_{h2E1}\cdot E_{h2locE1} \ldots + E_{h2aE1}\cdot E_{h2alocE1} + H_{h2E1}\cdot H_{h2locE1} = 3.6\ m\cdot kN$$

Lateral - Resisting Force

LOAD CASE E1

Note: **Due to the relatively shallow depth of resisting soil/rock, a conservative apporach using at-rest coefficient in lieu of a passive wedge is used to calculate resisting forces.**

Lateral Water Load:

Water Load WSEL to Bot. of Toe Key: $H_{h6E1} := H_{h6U1} = 30.6 \cdot kN$

Moment Arm (from Point O): $H_{h6locE1} := H_{h6locU1} = 0.83\ m$

Water Load between Keys (if any):

$$H_{h6aE1} := \begin{cases} \dfrac{\left(h_{6E1} + h_{2E1}\right) \cdot -Key_{vdist}}{2} \cdot \gamma_w \cdot B & \text{if } Key_{vdist} < 0 \\ 0 & \text{otherwise} \end{cases} = 225.4 \cdot kN$$

Moment Arm (from Point O):

$$H_{h6alocE1} := \begin{cases} \dfrac{Key_{vdist} \cdot \left(2 \cdot h_{2E1} + h_{6E1}\right)}{3\left(h_{2E1} + h_{6E1}\right)} & \text{if } Key_{vdist} < 0 \\ 0 & \text{otherwise} \end{cases} = -2.38 \cdot m$$

Lateral Soil Load:

Moist Soil Load above WSEL: $E_{h7E1} := \dfrac{\gamma_m \cdot K_o \cdot h_{7E1}^{\ 2}}{2} \cdot B = 0.0 \cdot kN$

Moment Arm (from bot. of toe key): $E_{h7locE1} := h_{6E1} + \dfrac{h_{7E1}}{3} + Key_{vdist} = -1.50\ m$

Saturated Soil Load below WSEL: (rectangular component) $E_{h8E1} := \left(\gamma_m \cdot K_o \cdot h_{7E1}\right) \cdot h_{8E1} \cdot B = 0.0 \cdot kN$

Moment Arm (from bot. of toe key): $E_{h8locE1} := \dfrac{h_{8E1}}{2} = 1.25\ m$

Saturated Soil Load below WSEL: (triangular component) $E_{h8aE1} := \dfrac{\left[\left(\gamma_{sat} - \gamma_w\right) \cdot K_o\right] \cdot h_{8E1}^{\ 2}}{2} \cdot B = 20.8 \cdot kN$

Moment Arm (from bot. of footing): $E_{h8alocE1} := \dfrac{h_{8E1}}{3} = 0.83\ m$

$$\Sigma H_{SoilresistE1} := H_{h6E1} + H_{h6aE1} + E_{h7E1} + E_{h8E1} + E_{h8aE1} = 276.8 \cdot kN$$

$$\Sigma M_{HorizSoilResistE1} := H_{h6E1} \cdot H_{h6locE1} + H_{h6aE1} \cdot H_{h6alocE1} + E_{h7E1} \cdot E_{h7locE1} \cdots + E_{h8E1} \cdot E_{h8locE1} + E_{h8aE1} \cdot E_{h8alocE1} = -492.9\ m \cdot kN$$

Vertical Force:

UPLIFT: Linear distribution from water at heel to water at toe:

$$\Sigma V_{UpliftE1} := \left[\left(UWSEL_{E1} - Bot_{ftg} + Key_{t.d}\right) + h_{2E1}\right] \cdot \frac{b}{2} \cdot \gamma_w \cdot B \cdot -1 = -507.15 \cdot kN$$

Moment Arm (from Point O):

$$V_{UpliftE1aloc} := \frac{b \cdot \left[2 \cdot h_{2E1} + \left(UWSEL_{E1} - Bot_{ftg} + Key_{t.d}\right)\right]}{3\left[h_{2E1} + \left(UWSEL_{E1} - Bot_{ftg} + Key_{t.d}\right)\right]} = 5.348\ m$$

$$\Sigma M_{UpliftE1} := \Sigma V_{UpliftE1} \cdot V_{UpliftE1aloc} = -2712.15 \cdot kN \cdot m$$

Weight of soil and water over toe:

Water Above the Top of Footing: $W_{H1E1} := \gamma_w \cdot h_{5E1} \cdot L_{ab} \cdot B = 13.475 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E1locE1} := \frac{L_{ab}}{2} = 1.375\,m$

Soil above top of footing: $W_{E6E1} := \gamma_b \cdot h_{3E1} \cdot L_{ab} \cdot B = 16.8 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E6locE1} := \frac{L_{ab}}{2} = 1.375\,m$

Vertical Load Due to Surcharge: $S_{E1} := S1_{E1} \cdot L_{cd} \cdot B = 0 \cdot kN$ $\quad S_{E1loc} := b - \frac{L_{cd}}{2} = 6.41\,m$

Weight of soil and water over heel:

Moist Soil for sloped grade above top of wall:

Length of sloped portion of soil above top of wall: $L_{E3E1} := \left(L_{cd} + t_{wb} - t_{wt}\right) = 5.75\,m$

Height of sloped soil above top of wall over heel: $h_{E3locE1} := \left(L_{E3E1}\right) \cdot \tan(\beta) = 0.00\,m$

Weight of sloped soil above top of wall: $W_{E3E1} := \frac{\gamma_m}{2} \cdot h_{E3locE1} \cdot L_{E3E1} \cdot B = 0.0 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E3locE1} := L_{ab} + t_{wt} + \frac{2}{3} \cdot L_{E3E1} = 7.08\,m$

Moist soil from top of wall to groundwater level:

Height of soil from top of wall and top of GWL: $h_{1E1} = 4.25\,m$

Length from edge of wall at GWL to edge of heel: $L_{E4E1} := L_{E3E1} - \left(h_{1E1} \cdot S_{batter}\right) = 5.42\,m$

Weight of soil over heel from top of wall to GWL: $W_{E4E1} := \gamma_m \cdot h_{1E1} \cdot \frac{\left(L_{E3E1} + L_{E4E1}\right)}{2} \cdot B = 474.5 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E4locE1} := b - \frac{L_{E3E1}^{\ 2} + L_{E3E1} \cdot L_{E4U1} + L_{E4E1}^{\ 2}}{3\left(L_{E3E1} + L_{E4E1}\right)} = 6.21\,m$

Saturated soil from groundwater to top of footing:

Height of soil from GWL to top of heel: $h_{E4E1} := h_{2E1} - t_{ftg} - Key_{h.d} = 3.00\,m$

Weight of soil over heel from GWL to top of heel: $W_{E5E1} := \left(\gamma_{sat}\right) \cdot h_{E4E1} \cdot \frac{\left(L_{E4E1} + L_{cd}\right)}{2} \cdot B = 349.7 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E5locE1} := b - \frac{L_{E4E1}^{\ 2} + L_{E4E1} \cdot L_{cd} + L_{cd}^{\ 2}}{3\left(L_{E4E1} + L_{cd}\right)} = 6.35\,m$

$\Sigma V_{SoilWaterE1} := W_{H1E1} + W_{E6E1} + W_{E3E1} + W_{E4E1} + W_{E5E1} + S_{E1} = 854.5 \cdot kN$

$\Sigma M_{VertSoilWaterResistE1} := W_{H1E1} \cdot W_{E1locE1} + W_{E6E1} \cdot W_{E6locE1} \cdots + W_{E3E1} \cdot W_{E3locE1} + W_{E4E1} \cdot W_{E4locE1} + W_{E5E1} \cdot W_{E5locE1} + S_{E1} \cdot S_{E1loc} = 5208.0\,m \cdot kN$

SESIMIC ANALYSIS:

LOAD CASE E1

Seismic coefficient will be applied to dead loads to calculate seismic force and force is applied at center of gravity of the mass. Vertical and Horizontal loads are applied in the "destabilizing direction"

SEISMIC PARAMETERS:

(Section 7.9, Design Criteria)

Peak Ground Acceleration for Seismic Load $PGA_{Horiz} := 0.26$ $PGA_{Vert} := 0.56 \cdot PGA_{Horiz} = 0.146$

In accordance with USACE EM 1110-2-2100 Section 4-7.b, consider 2/3 PGA as seismic coefficient for stabilitiy.

Horizontal Seismic coefficient for stabilty: $K_{hE1} := \frac{2}{3} PGA_{Horiz} = 0.173$

Vertical Seismic coefficient for stabilty: $K_{vE1} := \frac{2}{3} PGA_{Vert} = 0.097$

SEISMIC ACCELERATION OF RIGID MASSES (Q_D):

Vertical Load Application:

$\Sigma V_{conc} = 650.7 \cdot kN$

$Q_{v.conc} := \Sigma V_{conc} \cdot K_{vE1} \cdot -1 = -63.2 \cdot kN$ (assume acting upwards for adverse sliding effect)

Moment arm for siesmic load application (From Toe): $H_{cent} = 4.802\, m$

$M_{Qv.conc} := Q_{v.conc} \cdot H_{cent} = -303.3 \cdot kN \cdot m$

Lateral Load Application:

$Q_{h.conc} := \Sigma V_{conc} \cdot K_{hE1} \cdot -1 = -112.8 \cdot kN$

Moment arm for siesmic load application (Above Base of Footing): $V_{Cent} = 1.427\, m$

$M_{Q.conc} := Q_{h.conc} \cdot V_{Cent} = -161 \cdot kN \cdot m$

SEISMIC ACCELERATION OF SOIL WEDGE + WATER (Q_{EH}):

Vertical Load Application:

$\Sigma V_{SoilWaterE1} = 854.5 \cdot kN$

$Q_{v.SoilWaterE1} := \Sigma V_{SoilWaterE1} \cdot K_{vE1} \cdot -1 = -82.9 \cdot kN$ (assume acting upwards for adverse sliding effect)

Moment arm for siesmic load application (From Toe): $e_{QE1} := \dfrac{\Sigma M_{VertSoilWaterResistE1}}{\Sigma V_{SoilWaterE1}} = 6.095\, m$

$M_{Qv.SoilWaterE1} := Q_{v.SoilWaterE1} \cdot e_{QE1} = -505.5 \cdot kN \cdot m$

Lateral Load Application:

Seismic soil load is calculated based on Mononobe-Okabe method to determine combined static and dynamic coefficient (K_{AE}). Coulomb's active component (K_A) is subtracted from $K_{AE}$to obtain the seismic coefficient (ΔK_{AE}) for dynamic component of soil force.

Glacial Till Internal Friction (radians): $\phi = 0.471$

Seismic Inertia Angle (radians): $\psi := \operatorname{atan}\left(\dfrac{K_{hE1}}{1 - K_{vE1}}\right) = 0.190$

Inclination of batter (radians): $\theta := 0.00$ assuming zero is conservative

Slope of retained ground surface: $\beta = 0.00$

$$K_{AE} := \frac{\cos(\phi - \psi - \theta) \cdot \cos(\phi - \psi - \theta)}{\cos(\psi) \cdot \cos(\theta) \cdot \cos(\theta)\, \cos(\psi + \theta) \cdot \left(1 + \sqrt{\dfrac{\sin(\phi)\, \sin(\phi - \psi - \beta)}{\cos(\beta - \theta) \cdot \cos(\psi + \theta)}}\right)^2} = 0.519$$

$\Delta K_{AE} := K_{AE} - K_{Abgwt} = 0.143$

Dynamic component of active seismic wedge:

$$Q_{h.SoilWaterE1} := \Delta K_{AE} \cdot \left[\frac{\gamma_m \cdot \left(H_w + Key_{h.d}\right)^2}{2 \cdot (\tan(\alpha) - \tan(\beta))} + \frac{\left(\gamma_{sat} - \gamma_m\right) \cdot h_{2E1}{}^2}{2 \cdot \tan(\alpha)}\right] \cdot B \cdot -1 = -160.9 \cdot kN$$

(Eq. G-64, USACE EM 1110-2-2100)

Moment arm for siesmic load application (About Point O): $Q_{h.SoilWaterlocE1} := \frac{2}{3} \cdot \left(H_w + Key_{h.d}\right) + Key_{vdist} = 4.83\, m$

$M_{Q.h.SoilWaterE1} := Q_{h.SoilWaterE1} \cdot Q_{h.SoilWaterlocE1} = -777.8 \cdot kN \cdot m$

STABILITY ASSESSMENT:

LOAD CASE E1

CHECK SLIDING ALONG HORIZONTAL SLIDING PLANE:

Summation of the vertical forces: $\Sigma V_{E1} := \Sigma V_{conc} + \Sigma V_{SoilWaterE1} + \Sigma V_{UpliftE1} + Q_{v.conc} + Q_{v.SoilWaterE1} = 852.0 \cdot kN$

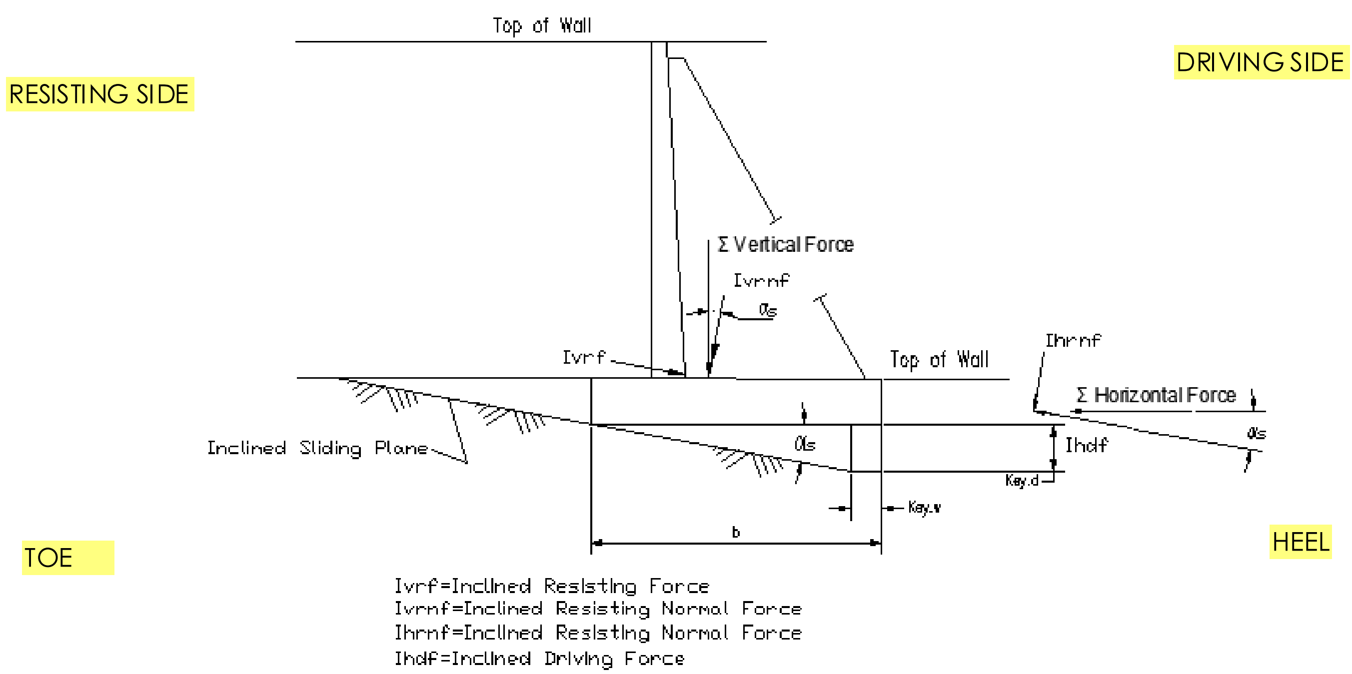
Summation of the horizontal forces: $\Sigma H_{E1} := \Sigma H_{SoildriveE1} + Q_{h.conc} + Q_{h.SoilWaterE1} + \Sigma H_{SoilresistE1} = -934.4 \cdot kN$

Safety Factor for Sliding Horizontal Failure Plane

$$FS_{Horiz.SlidingE1} := \frac{\left|\Sigma V_{E1}\right| \cdot \tan\left(\phi_{rock} \cdot \frac{\pi}{180}\right)}{\left|\Sigma H_{E1}\right|} = 0.44$$

$$FS_{Sliding.check1.E1} := \begin{vmatrix} \text{"OKAY " if } FS_{Horiz.SlidingE1} > FS_{sliding.reqE1} \\ \text{"NG - key req"" otherwise} \end{vmatrix} = \text{"NG - key req""}$$

CHECK FACTOR OF SAFETY SLIDING WITH KEY (INCLINED SLIDING PLANE):



(With properly engineered reinforced concrete Key, horizontal sliding plane thru Toe is protected, critical sliding plane is relocated to the INCLINED SLIDING PLANE FROM HEEL KEY To TOE, Bedrock Mass above this examing plane is mobilized by reinforced concrete key and combined into Structural Wedge.)

Resolve ΣV_{E1} & ΣH_{E1}

$$\Sigma V_{InclinedE1} := \cos(\alpha s) \cdot \left(\left|\Sigma V_{E1} + V_{rocksection}\right|\right) + \sin(\alpha s) \cdot \left|\Sigma H_{E1}\right| = 1546.3 \cdot kN$$

$$\Sigma H_{InclinedE1} := \cos(\alpha s) \cdot \left|\Sigma H_{E1}\right| - \sin(\alpha s) \cdot \left(\left|\Sigma V_{E1} + V_{rocksection}\right|\right) = 271.6 \cdot kN$$

Safety Factor for Sliding Inclined Failure Plane

$$FS_{InclinedISlidingE1} := \frac{\Sigma V_{InclinedE1} \cdot \tan\left(\phi_r\right)}{\Sigma H_{InclinedE1}} = 2.53$$

$$FS_{Sliding.check2.E1} := \begin{vmatrix} \text{"OKAY " if } FS_{InclinedISlidingE1} > FS_{sliding.reqE1} \\ \text{"NG"" otherwise} \end{vmatrix} = \text{"OKAY "}$$

CHECK FOUNDATION ECCENTRICITY:

LOAD CASE E1

(Vertical seismic loads from concrete, soil and water are assumed acting downwards for adverse bearing effect)

Summation of the vertical forces: $\Sigma V_{seisE1} := \Sigma V_{conc} + \Sigma V_{SoilWaterE1} + \Sigma V_{UpliftE1} - Q_{v.conc} - Q_{v.SoilWaterE1} = 1144.2 \cdot kN$

Summation of the horizontal forces: $\Sigma H_{seisE1} := \Sigma H_{E1} = -934.4 \cdot kN$

Resolve ΣV_{seisE1} & ΣH_{seisE1}

$$\Sigma V_{InclinedseisE1} := \cos(\alpha s) \cdot \left(\left| \Sigma V_{seisE1} + V_{rocksection} \right| \right) + \sin(\alpha s) \cdot \left| \Sigma H_{seisE1} \right| = 1807.6 \cdot kN$$

$$\Sigma H_{InclinedseisE1} := \cos(\alpha s) \cdot \left| \Sigma H_{seisE1} \right| - \sin(\alpha s) \cdot \left(\left| \Sigma V_{seisE1} + V_{rocksection} \right| \right) = 140.9 \cdot kN$$

Summation of the resisting moments about the toe:

$$\Sigma M_{resE1} := \Sigma M_{conc} + \Sigma M_{VertSoilWaterResistE1} + \Sigma M_{HorizSoilResistE1} + \Sigma M_{rocksection} = 10025 \cdot kN \cdot m$$

Summation of seismic moments about the toe:

$$\Sigma M_{seisE1} := -M_{Qv.conc} + M_{Q.conc} - M_{Qv.SoilWaterE1} + M_{Q.h.SoilWaterE1} = -130 \cdot kN \cdot m$$

Summation of the overturning moments about the toe:

$$\Sigma M_{oE1} := \Sigma M_{LateralSoildriveE1} + \Sigma M_{UpliftE1} = -2709 \cdot kN \cdot m$$

Total moment: $\Sigma M_{E1} := \Sigma M_{resE1} + \Sigma M_{seisE1} + \Sigma M_{oE1} = 7186.3 \cdot kN \cdot m$

Normal force to base: $\Sigma V_{InclinedseisE1} = 1807.6 \cdot kN$

Inclined Sliding Plane Length: $L_{incline} = 10.1 \cdot m$

Eccentricity (inclined plane): $ex_{E1} := \frac{L_{incline}}{2} - \frac{\Sigma M_{E1}}{\Sigma V_{InclinedseisE1}} = 1.06\,m$ $\quad Kern_{E1} := \frac{L_{incline}}{4} = 2.516\,m$

Eccentricity Check:

$$e_{check.E1} := \begin{cases} \text{"Okay"} & \text{if } ex_{E1} \le Kern_{E1} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"Okay"}$$

CHECK FOUNDATION BEARING CAPACITY:

Base Section Modulus: $S_b = 16.88\,m^3$

Bearing Pressure Under Toe:

$$\sigma_{ToeE1} := \begin{cases} \left[\frac{\Sigma V_{InclinedE1}}{L_{incline} \cdot B} + \frac{\left(\Sigma V_{InclinedE1} \cdot ex_{E1} \right)}{S_b} \right] & \text{if } \frac{\Sigma V_{InclinedE1}}{L_{incline} \cdot B} \ge \frac{\Sigma V_{InclinedE1} \cdot ex_{E1}}{S_b} \\ \frac{2 \cdot \Sigma V_{InclinedE1}}{B \cdot 3 \left(\frac{b}{2} - ex_{E1} \right)} & \text{otherwise} \end{cases} = 250.4 \cdot kPa$$

$$Bearing_{ChecktoeE1} := \begin{cases} \text{"OKAY "} & \text{if } \sigma_{ToeE1} < \sigma_{allowE1} \\ \text{"NG""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

Bearing Pressure Under Heel:

$$\sigma_{HeelE1} := \begin{cases} \left[\frac{\Sigma V_{InclinedE1}}{L_{incline} \cdot B} - \frac{\left(\Sigma V_{InclinedE1} \cdot ex_{E1} \right)}{S_b} \right] & \text{if } \frac{\Sigma V_{InclinedE1}}{L_{incline} \cdot B} \ge \frac{\Sigma V_{InclinedE1} \cdot ex_{E1}}{S_b} \\ 0 & \text{otherwise} \end{cases} = 56.9 \cdot kPa$$

$$Bearing_{CheckheelE1} := \left(\begin{cases} \text{"OKAY "} & \text{if } \sigma_{HeelE1} < \sigma_{allowE1} \wedge \sigma_{HeelE1} > 0 \\ \text{"NG - perform cracked base analysis""} & \text{otherwise} \end{cases} \right) = \text{"OKAY "}$$

CHECK FLOATATION:

Safety Factor for Floatation:

$$FS_{FloatationE1} := \frac{\Sigma V_{conc} + \Sigma V_{SoilWaterE1} + Q_{v.conc} + Q_{v.SoilWaterE1}}{\left|\Sigma V_{UpliftE1}\right|} = 2.68$$

$$FS_{Floatation.E1.check} := \begin{cases} \text{"OKAY"} & \text{if } FS_{FloatationE1} > FS_{req.E1.flt} \\ \text{"Revise Structure""} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

CHECK OVERTURNING

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.
Assumptions are made in order to compute overturning stablity of indetermine forces on monolith with key;
(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.
(b) The horizontal resisting force acting on the key, P.key, is that required for static equilibrium
(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1

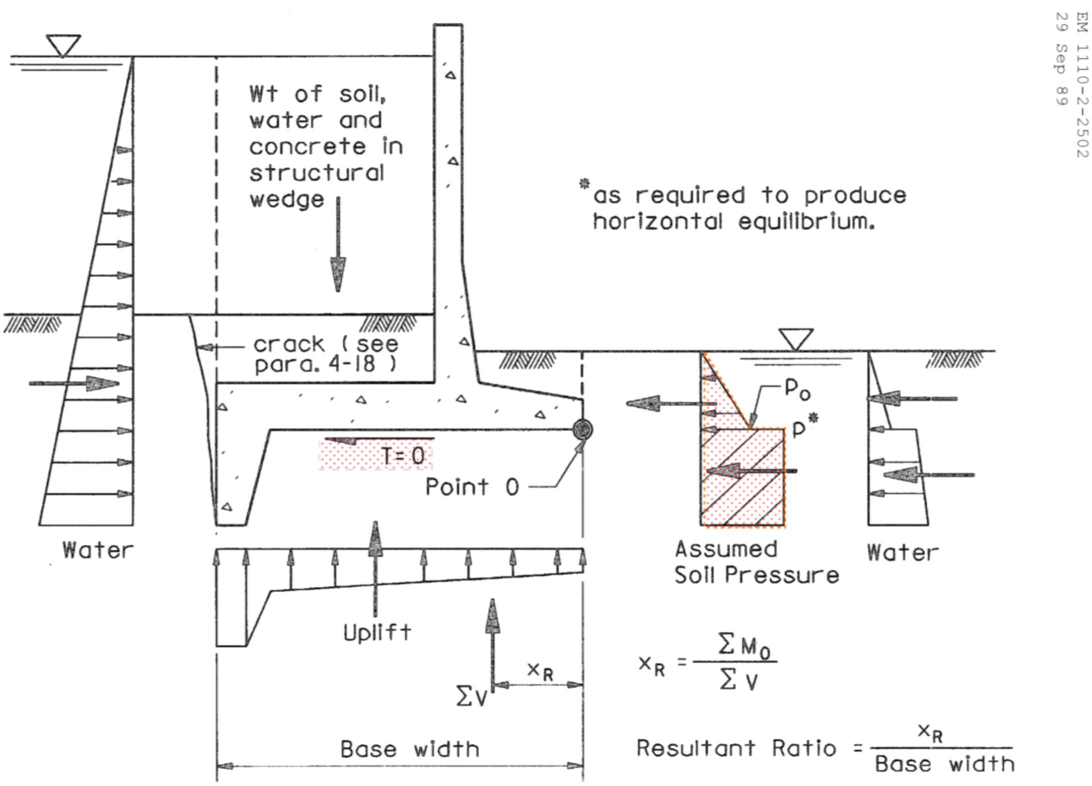


Figure 4-5. Forces for overturning analysis for wall with horizontal base and key

Modify Uplift for Overturning Analysis: **LOAD CASE E1**

(Uplift is calculated along the concrete/rock contact using the Line of Creep method)

Water Pressure at h: $u_{h.E1} := \Delta h_{g.hj.E1} \cdot \gamma_w = 88.20 \cdot kPa$

Water Pressure at o: $u_{o.E1} := \left(\Delta h_{g.no.E1} - \frac{\Delta h_{g.r.E1} \cdot L_{ho.E1}}{L_{ho.E1}}\right) \cdot \gamma_w = 24.5 \cdot kPa$

Head loss between point h and o: $\Delta h_{ho.E1} := \Delta h_{g.r.E1} \cdot \frac{L_{ho.E1}}{L_{ho.E1}} = 2.5\,m$

Length of concrete base (h -> o): $L_{baseho.E1} := Key_{h.w} + Key_{h.d} + Key_{hdist} + Key_{t.d} + Key_{t.w} = 13\,m$

Head loss along h -> j: $\Delta h_{hj.E1} := \Delta h_{ho.E1} \cdot \frac{Key_{h.w}}{L_{baseho.E1}} = 0.192\,m$

Water Pressure at j: $u_{j.E1} := \left(\Delta h_{g.hj.E1} - \Delta h_{hj.E1}\right) \cdot \gamma_w = 86.32 \cdot kPa$

Head loss along h -> k: $\Delta h_{hjk.E1} := \Delta h_{ho.E1} \cdot \left(\frac{Key_{h.w} + Key_{h.d}}{L_{baseho.E1}}\right) = 0.962\,m$

Water Pressure at k: $u_{k.E1} := \left(\Delta h_{g.km.E1} - \Delta h_{hjk.E1}\right) \cdot \gamma_w = 39.58 \cdot kPa$

Head loss along h -> m: $\Delta h_{hjkm.E1} := \Delta h_{ho.E1} \cdot \left(\frac{Key_{h.w} + Key_{h.d} + Key_{hdist}}{L_{baseho.E1}}\right) = 2.5\,m$

Water Pressure at m: $u_{m.E1} := \left(\Delta h_{g.km.E1} - \Delta h_{hjkm.E1}\right) \cdot \gamma_w = 24.50 \cdot kPa$

Head loss along h -> n: $\Delta h_{hjkmn.E1} := \Delta h_{ho.E1} \cdot \left(\frac{Key_{h.w} + Key_{h.d} + Key_{hdist} + Key_{t.d}}{L_{baseho.E1}}\right) = 2.5\,m$

Water Pressure at n: $u_{n.E1} := \left(\Delta h_{g.no.E1} - \Delta h_{hjkmn.E1}\right) \cdot \gamma_w = 24.50 \cdot kPa$

Uplift under key at heel: $V_{ulkeyhE1.OT} := \frac{\left(u_{h.E1} + u_{j.E1}\right) \cdot Key_{h.w}}{2} \cdot B \cdot -1 = -87.258 \cdot kN$

Moment Arm (from Point O): $V_{ulkeyhE1loc.OT} := b - \frac{Key_{h.w} \cdot \left(2 \cdot u_{j.E1} + u_{h.E1}\right)}{3 \cdot \left(u_{j.E1} + u_{h.E1}\right)} = 8.502\,m$

Uplift under base: $V_{ulbaseE1.OT} := \frac{\left(u_{k.E1} + u_{m.E1}\right) \cdot Key_{hdist}}{2} \cdot B \cdot -1 = -256.308 \cdot kN$

Moment Arm (from Point O): $V_{ulbaseE1loc.OT} := b - Key_{h.w} - \frac{Key_{hdist} \cdot \left(2 \cdot u_{m.E1} + u_{k.E1}\right)}{3 \cdot \left(u_{m.E1} + u_{k.E1}\right)} = 4.314\,m$

Uplift under key at toe: $V_{ulkeytE1.OT} := \frac{\left(u_{n.E1} + u_{o.E1}\right) \cdot Key_{t.w}}{2} \cdot B \cdot -1 = 0 \cdot kN$

Moment Arm (from Point O): $V_{ulkeytE1loc.OT} := \frac{Key_{t.w} \cdot \left(2 \cdot u_{n.E1} + u_{o.E1}\right)}{3 \cdot \left(u_{n.E1} + u_{o.E1}\right)} = 0$

$$\Sigma V_{UpliftE1.OT} := V_{ulkeyhE1.OT} + V_{ulbaseE1.OT} + V_{ulkeytE1.OT} = -344 \cdot kN$$

$$U_{E1.loc.OT} := \frac{V_{ulkeyhE1.OT} \cdot V_{ulkeyhE1loc.OT} + V_{ulbaseE1.OT} \cdot V_{ulbaseE1loc.OT} + V_{ulkeytE1.OT} \cdot V_{ulkeytE1loc.OT}}{\Sigma V_{UpliftE1.OT}} = 5.38\,m$$

$$\Sigma M_{UpliftE1.OT} := \Sigma V_{UpliftE1.OT} \cdot U_{E1.loc.OT} = -1847.5 \cdot kN \cdot m$$

LOAD CASE E1

Modify Lateral Water Pressure (Resisting) for Overturning Analysis:

(Resisting water pressure is calculated using the Line of Creep method)

Water Load at Key (heel): $H_{h2E1.OT} := \frac{u_{k.E1} + u_{j.E1}}{2} \cdot Key_{h.d} B = 251.8 \cdot kN$

Moment Arm (from Point O): $H_{h2locE1.OT} := \frac{Key_{h.d} \cdot \left(2 \cdot u_{k.E1} + u_{j.E1}\right)}{3\left(u_{k.E1} + u_{j.E1}\right)} + Key_{vdist} = -2.25\ m$

Water Load at Key (toe): $H_{h6E1.OT} := \frac{u_{o.E1} \cdot \left(UWSEL_{E1} - Bot_{ftg} + Key_{t.d}\right)}{2} \cdot B = 31 \cdot kN$

Moment Arm (from Point O): $H_{h6locE1.OT} := \frac{UWSEL_{E1} - Bot_{ftg} + Key_{t.d}}{3} = 0.83\ m$

$$\Sigma H_{waterresistE1.OT} := H_{h2E1.OT} + H_{h6E1.OT} = 282.41 \cdot kN$$

$$H_{waterresistlocE1.OT} := \frac{H_{h2E1.OT} \cdot H_{h2locE1.OT} + H_{h6E1.OT} \cdot H_{h6locE1.OT}}{\Sigma H_{waterresistE1.OT}} = -1.913\ m$$

$$\Sigma M_{waterresistE1.OT} := \Sigma H_{waterresistE1.OT} \cdot H_{waterresistlocE1.OT} = -540.37 \cdot kN \cdot m$$

Modify Lateral Soil Loads for Overturning Analysis:

(Lateral soil loads are calculated down to Point O instead of bottom of shear key)

Driving Soil Load (Headwater Side):

Surcharge Load: $E_{s1E1.OT} := S1_{E1} \cdot K_{Aagwt} \cdot \left(H_w + Key_{h.d} + Key_{vdist}\right) \cdot B \cdot -1 = 0 \cdot kN$

Moment Arm (from Point O): $E_{s1locE1.OT} := \frac{H_w + Key_{h.d} + Key_{vdist}}{2} = 4.63\ m$

Moist Soil Load above GWL: $E_{h1E1.OT} := \frac{\gamma_m \cdot K_{Aagwt} \cdot h_{1E1}^{\ 2}}{2} B \cdot -1 = -67.8 \cdot kN$

Moment Arm (from Point O): $E_{h1locE1.OT} := \frac{h_{1E1}}{3} + h_{2E1} + Key_{vdist} = 6.42\ m$

Saturated Soil Load below GWL: (rectangular component) $E_{h2E1.OT} := \left(\gamma_m \cdot K_{Aagwt} \cdot h_{1E1}\right) \cdot \left(h_{2E1} + Key_{vdist}\right) \cdot B \cdot -1 = -159.6 \cdot kN$

Moment Arm (from Point O): $E_{h2locE1.OT} := \frac{h_{2E1} + Key_{vdist}}{2} = 2.50\ m$

Saturated Soil Load below GWL: (triangular component) $E_{h2aE1.OT} := \frac{\left(\gamma_{sat} - \gamma_w\right) \cdot K_{Aagwt} \cdot \left(h_{2E1} + Key_{vdist}\right)^2}{2} \cdot B \cdot -1 = -57.3 \cdot kN$

Moment Arm (from Point O): $E_{h2alocE1.OT} := \frac{h_{2E1} + Key_{vdist}}{3} = 1.67\ m$

Resisting Soil Load (Tailwater Side):

LOAD CASE E1

(Determine resisting soil load based on depth variation between the keys (ie. Key_{vdist}). In case where key at heel is deeper than key at toe (ie. Key_{vdist}< 0), resisting soil load (p*) is assumed to produce horizontal equilibrium as per Figure 4-5 above. Resisting soil load (p_o) is neglected.)

Total Driving Force: $\Sigma H_{SoildriveE1.OT} := E_{s1E1.OT} + E_{h1E1.OT} + E_{h2E1.OT} + E_{h2aE1.OT} + H_{h2E1} \cdots + Q_{h.conc} + Q_{h.SoilWaterE1} = -955.3 \cdot kN$

Total Resisting Force: $\Sigma H_{waterresistE1.OT} = 282.41 \cdot kN$

Assumed Soil Load p*: $E_{h8E1a.OT} := \left(\Sigma H_{SoildriveE1.OT} + \Sigma H_{waterresistE1.OT}\right) \cdot -1 = 672.91 \cdot kN$

Moment Arm (from Point O): $E_{h8E1a.loc.OT} := \dfrac{Key_{vdist}}{2} = -2\,m$

$$E_{h8E1.OT} := \begin{cases} E_{h8E1a.OT} & \text{if } Key_{vdist} < 0 \\ \Sigma H_{SoilresistE1} - H_{h6E1} - H_{h6aE1} & \text{otherwise} \end{cases} = 672.91 \cdot kN$$

$$\Sigma M_{SoilresistE1.OT} := \begin{cases} E_{h8E1a.OT} \cdot E_{h8E1a.loc.OT} & \text{if } Key_{vdist} < 0 \\ \Sigma M_{HorizSoilResistE1} - H_{h6E1} \cdot H_{h6locE1} - H_{h6aE1} \cdot H_{h6alocE1} & \text{otherwise} \end{cases} = -1345.82 \cdot kN \cdot m$$

Sum of Moment about Point O:

$$\Sigma M_{LateraldriveE1.OT} := E_{s1E1.OT} \cdot E_{s1locE1.OT} + E_{h1E1.OT} \cdot E_{h1locE1.OT} + E_{h2E1.OT} \cdot E_{h2locE1.OT} \cdots + E_{h2aE1.OT} \cdot E_{h2alocE1.OT} + H_{h2E1} \cdot H_{h2locE1} = -532.8 \cdot kN \cdot m$$

$$\Sigma M_{LateralresistE1.OT} := \Sigma M_{waterresistE1.OT} + \Sigma M_{SoilresistE1.OT} = -1886.2 \cdot kN \cdot m$$

$$\Sigma M_{seisE1.OT} := M_{Qv.conc} + M_{Q.conc} + M_{Qv.SoilWaterE1} + M_{Q.h.SoilWaterE1} = -1748 \cdot kN \cdot m$$

(seismic moment modified for the most adverse overturning effect)

Total moment:

$$\Sigma M_{E1.OT} := \Sigma M_{conc} + \Sigma M_{VertSoilWaterResistE1} + \Sigma M_{UpliftE1.OT} + \Sigma M_{LateraldriveE1.OT} + \Sigma M_{LateralresistE1.OT} + \Sigma M_{seisE1.OT} = 2319.0 \cdot kN \cdot m$$

Total Vertical Force: $\Sigma V_{E1.OT} := \Sigma V_{conc} + \Sigma V_{SoilWaterE1} + \Sigma V_{UpliftE1.OT} + Q_{v.conc} + Q_{v.SoilWaterE1} = 1015.5 \cdot kN$

Distance X_R: EM 1110-2-2502 Eq.4-1 $X_{R.E1} := \dfrac{\Sigma M_{E1.OT}}{\Sigma V_{E1.OT}} = 2.284\,m$

Overturning Resultant Ratio $Ratio_{E1.OT} := \dfrac{X_{R.E1}}{b} = 0.25$

$$Ratio_{E1.OT.check} := \begin{cases} \text{"OKAY "} & \text{if } Ratio_{E1.OT} > X_{R.reqE1} \\ \text{"Revise Structure""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

CHECK FOUNDATION ECCENTRICITY (HORIZONTAL PLANE):

Eccentricity (horizontal plan): $ex_{E1.OT} := \dfrac{b}{2} - \dfrac{\Sigma M_{E1.OT}}{\Sigma V_{E1.OT}} = 2.22\,m$ $Kern_{E1.OT} := \dfrac{b}{4} = 2.25\,m$

Eccentricity Check: $$e_{check.E1.OT} := \begin{cases} \text{"Okay"} & \text{if } ex_{E1.OT} \le Kern_{E1.OT} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"Okay"}$$

LOAD CASE E1

CHECK FOUNDATION BEARING CAPACITY (HORIZONTAL PLANE):

Base Section Modulus: $S_{b.OT} = 13.5\,m^3$

Bearing Pressure Under Toe:

$$\sigma_{ToeE1.OT} := \begin{cases} \left(\frac{\Sigma V_{E1.OT}}{b \cdot B} + \frac{\Sigma V_{E1.OT} \cdot ex_{E1.OT}}{S_{b.OT}}\right) & \text{if } \frac{\Sigma V_{E1.OT}}{b \cdot B} \ge \frac{\Sigma V_{E1.OT} \cdot ex_{E1.OT}}{S_{b.OT}} \\ \frac{2 \cdot \Sigma V_{E1.OT}}{B \cdot 3\left(\frac{b}{2} - ex_{E1.OT}\right)} & \text{otherwise} \end{cases} = 296.5 \cdot kPa$$

$$Bearing_{ChecktoeE1.OT} := \begin{cases} \text{"OKAY "} & \text{if } \sigma_{ToeE1.OT} < \sigma_{allowE1} \\ \text{"NG - for reference only""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

Bearing Pressure Under Heel:

$$\sigma_{HeelE1.OT} := \begin{cases} \left(\frac{\Sigma V_{E1.OT}}{b \cdot B} - \frac{\Sigma V_{E1.OT} \cdot ex_{E1.OT}}{S_{b.OT}}\right) & \text{if } \frac{\Sigma V_{E1.OT}}{b \cdot B} \ge \frac{\Sigma V_{E1.OT} \cdot ex_{E1.OT}}{S_{b.OT}} \\ 0 & \text{otherwise} \end{cases} = 0.0 \cdot kPa$$

$$Bearing_{CheckheelE1.OT} := \left(\begin{cases} \text{"OKAY "} & \text{if } \sigma_{HeelE1.OT} < \sigma_{allowE1} \wedge \sigma_{HeelE1.OT} > 0 \\ \text{"NG - for reference only""} & \text{otherwise} \end{cases}\right) = \text{"NG - for reference only""}$$

SUMMARY OF STABILITY ASSESSMENT:

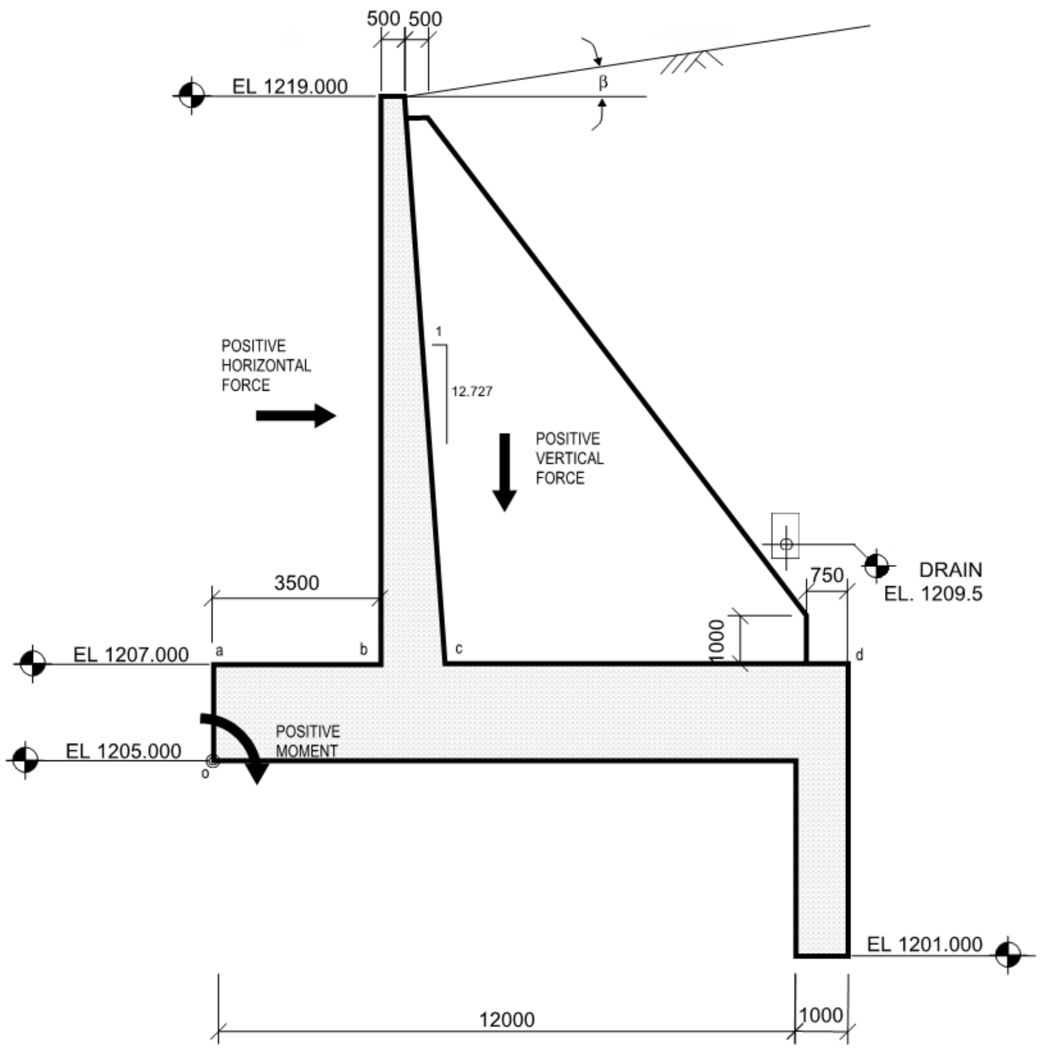
Sliding Factor of Safety: (Horizontal Plane - Ref only)	$FS_{Horiz.SlidingE1} = 0.44$	$FS_{Sliding.check1.E1}$ = "NG - key req""
Sliding Factor of Safety: (Inclined Plane)	$FS_{InclinedlSlidingE1} = 2.53$	$FS_{Sliding.check2.E1}$ = "OKAY "
Eccentricity: (Inclined Plane)	$ex_{E1} = 1.06\ m$	$e_{check.E1}$ = "Okay"
Bearing Pressure At Heel: (Inclined Plane)	$\sigma_{HeelE1} = 57 \cdot kPa$	$Bearing_{CheckheelE1}$ = "OKAY "
Bearing Pressure At Toe: (Inclined Plane)	$\sigma_{ToeE1} = 250 \cdot kPa$	$Bearing_{ChecktoeE1}$ = "OKAY "
Flotation Factor of Safety (horizontal plane)	$FS_{FloatationE1} = 2.68$	$FS_{Floatation.E1.check}$ = "OKAY "
Overturning Resultant Ratio: (horizontal plane)	$Ratio_{E1.OT} = 0.25$	$Ratio_{E1.OT.check}$ = "OKAY "
Eccentricity: (horizontal plane - Ref only)	$ex_{E1.OT} = 2.22\ m$	$e_{check.E1.OT}$ = "Okay"
Bearing Pressure At Heel: (horizontal plane - Ref only)	$\sigma_{HeelE1.OT} = 0 \cdot kPa$	$Bearing_{CheckheelE1.OT}$ = "NG - for reference only""
Bearing Pressure At Toe: (horizontal plane - Ref only)	$\sigma_{ToeE1.OT} = 296 \cdot kPa$	$Bearing_{ChecktoeE1.OT}$ = "OKAY "

Calculation Section VIII

DI-Block 5D (Upstream) Retaining Wall Stability Calculations

Project Number:	110773396		
Project Title:	SR1 - Diversion Structure		
Client:	Alberta Transportation		
Engineer:	Lawrence Choi	Date: 12/11/2018	
Checker:	Sean Xiao	Date: 12/18/2018	

Calculation for: Retaining Wall - Diversion Inlet Left - Block 5D (Upstream)



(DIMENSIONS BASED ON UPSTREAM SECTION)

REGION COLOR CONVENTION

User Input

Calulation Highlights

Results

WALL GEOMETRY:

Top of Wall Elevation: $T_w := 1219.0 \cdot m$

Top of Footing Elevation: $Top_{ftg} := 1207.0 \cdot m$

Thickness of Footing: $t_{ftg} := 2.0m$

Bottom of Footing Elevation: $Bot_{ftg} := Top_{ftg} - t_{ftg} = 1205\, m$

Overall Height of wall: $h_w := T_w - Bot_{ftg} = 14.00\, m$

Thickness of Wall: Base: $t_{wb} := 1.443 \cdot m$ Top: $t_{wt} := 0.5m$

Length of toe: $L_{ab} := 3.5m$

Total Length of Footing: $b := 13.0m$

Length of heel: $L_{cd} := b - L_{ab} - t_{wb} = 8.057\, m$

Unit Width of Wall for analysis: $B := 1.00m$

SHEAR KEY GEOMETRY:

	Toe	Heel
Key depth:	$Key_{t.d} := 0m$	$Key_{h.d} := 4.0m$
Key width:	$Key_{t.w} := 0m$	$Key_{h.w} := 1m$
Face of Key from Point O:	$Key_{t.loc} := 0 \cdot m$	$Key_{h.loc} := b - Key_{h.w} = 12\, m$

Horizontal Distance between Keys: $Key_{hdist} := Key_{h.loc} - Key_{t.loc} - Key_{t.w} = 12\, m$

Key Depth Diff. (from point O): $Key_{vdist} := -Key_{h.d} + Key_{t.d} = -4\, m$

BASE PROPERTIES:

Base Area: $A_b := b \cdot B = 13\, m^2$

Centroidal Distance for Footing (from Toe): $Y_t := \frac{b}{2} = 6.50\, m$

RETAINED SOIL GEOMETRY:

Slope of retained ground surface: $\beta := 0 \cdot \frac{\pi}{180} = 0.00$

Height of retained earth at heel: $H_w := T_w - Bot_{ftg} + \left(t_{wb} + L_{cd} - t_{wt}\right) \cdot \tan(\beta) = 14.00\, m$

RETAINING WALL GEOMETRY CHECKS:

(Foundation Analysis & Design Bowles)

$$t_{bcheck} := \begin{cases} \text{"OKAY"} & \text{if } t_{ftg} \ge \frac{H_w}{12} \\ \text{"Warning"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

$$t_{wcheck} := \begin{cases} \text{"OKAY"} & \text{if } t_{wb} \ge \frac{H_w}{12} \\ \text{"Warning"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

$$b_{check} := \begin{cases} \text{"OKAY"} & \text{if } \frac{b}{H_w} \ge .4 \wedge \frac{b}{H_w} \le 80 \\ \text{"Warning"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

$$L_{abcheck} := \begin{cases} \text{"OKAY"} & \text{if } \frac{L_{ab}}{b} \ge .25 \wedge \frac{L_{ab}}{b} \le .4 \\ \text{"Warning"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

Material Properties:

Unit Weight of Water:	$\gamma_w := 9.8 \frac{kN}{m^3}$	(Section 7.2, Design Criteria)
Unit Weight of Concrete:	$\gamma_c := 23.5 \frac{kN}{m^3}$	
Unit Weight of Soil (Moist):	$\gamma_m := 20.0 \frac{kN}{m^3}$	(Section 5.3, Design Criteria) assumed moisture content (w) = 5%
Unit Weight Soil (Saturated):	$\gamma_{sat} := 22.0 \frac{kN}{m^3}$	(Assuming Specific Gravity = 2.7
Unit Weight Soil (buoyant):	$\gamma_b := \gamma_{sat} - \gamma_w = 12.2 \cdot \frac{kN}{m^3}$	
Weight of Soil/Concrete above toe:	$\gamma_{toe} := 22.0 \frac{kN}{m^3}$	
Unit Weight of Rock:	$\gamma_r := 25.6 \frac{kN}{m^3}$	(Section 7.2, Design Criteria)

Foundation Parameters:

Glacial Till Internal Friction:	$\phi := 27 \cdot \frac{\pi}{180} = 0.471$	
Bedrock Internal Friction Angle:	$\phi_r := 24 \cdot \frac{\pi}{180} = 0.419$	
Friction Angle at Base Concrete / Rock Interface:	$\phi_{rock} := 26$	
Base Friction Coefficient:	$tan_{\phi rock} := \tan\left(\phi_{rock} \frac{\pi}{180}\right) = 0.488$	radians
Rip Rap Backfill, Refer Dwg. C-214	$\phi_{backfill} := \left(20 \frac{\pi}{180}\right) = 0.349$	radians
Shear strength along rock Failure plane	$s_r := \frac{13100 \frac{kN}{m^2}}{2} = 6550 \cdot \frac{kN}{m^2}$	(Stantec Design Memo 8/8/16)

CONCRETE DEAD LOAD:

Area of Footing: $A_{ftg} := t_{ftg} \cdot b = 26\,m^2$

Weight of Footing: $D_{ftg} := A_{ftg} \cdot B \cdot \gamma_c = 611 \cdot kN$

Area of Stem (without batter): $A_{w1} := t_{wt} \cdot (h_w - t_{ftg}) = 6\,m^2$

Weight of Stem: $D_{w1} := A_{w1} \cdot B \cdot \gamma_c = 141 \cdot kN$

Area of stem Batter: $A_{w2} := \frac{(t_{wb} - t_{wt})}{2} (h_w - t_{ftg}) = 5.66\,m^2$

Weight of Batter: $D_{w2} := A_{w2} \cdot B \cdot \gamma_c = 133 \cdot kN$

Slope of batter: $S_{batter} := \frac{t_{wb} - t_{wt}}{h_w - t_{ftg}} = 0.079$

Area of Key $A_{t.key} := Key_{t.d} \cdot Key_{t.w} = 0$ $A_{h.key} := Key_{h.d} \cdot Key_{h.w} = 4\,m^2$

Weight of Key $D_{t.key} := A_{t.key} \cdot B \cdot \gamma_c = 0 \cdot kN$ $D_{h.key} := A_{h.key} \cdot B \cdot \gamma_c = 94 \cdot kN$

Centroidal Horizontal Distance of Wall (From Toe):

$$H_{cent} := \frac{A_{w1} \cdot \left(L_{ab} + \frac{t_{wt}}{2}\right) + A_{w2} \cdot \left(L_{ab} + t_{wt} + \frac{t_{wb} - t_{wt}}{3}\right) + A_{ftg} \cdot \frac{b}{2} + A_{t.key} \cdot \left(Key_{t.loc} + \frac{Key_{t.w}}{2}\right) + A_{h.key} \cdot \left(Key_{h.loc} + \frac{Key_{h.w}}{2}\right)}{A_{w1} + A_{w2} + A_{ftg} + A_{t.key} + A_{h.key}} = 6.38\,m$$

Centroidal Vertical Distance of Wall (Above Base of Footing):

$$V_{Cent} := \frac{A_{ftg} \cdot \frac{t_{ftg}}{2} + A_{w1} \cdot \left[t_{ftg} + \frac{(h_w - t_{ftg})}{2}\right] + A_{w2} \cdot \left[t_{ftg} + \frac{(h_w - t_{ftg})}{3}\right] + A_{t.key} \cdot \left(\frac{-Key_{t.d}}{2}\right) + A_{h.key} \cdot \left(\frac{-Key_{h.d}}{2}\right)}{A_{ftg} + A_{w1} + A_{w2} + A_{t.key} + A_{h.key}} = 2.40\,m$$

$\Sigma V_{conc} := D_{ftg} + D_{w1} + D_{w2} + D_{t.key} + D_{h.key} = 979 \cdot kN$

$\Sigma M_{conc} := \Sigma V_{conc} \cdot H_{cent} = 6248.9\,m \cdot kN$

ROCK SECTION MOBILIZED FOR INCLINDED SLIDING FAILURE

Area of Rock Section Mobilized: $A_{rocksection} := (Key_{t.d} + Key_{h.d}) \cdot \frac{Key_{hdist}}{2} = 24\,m^2$

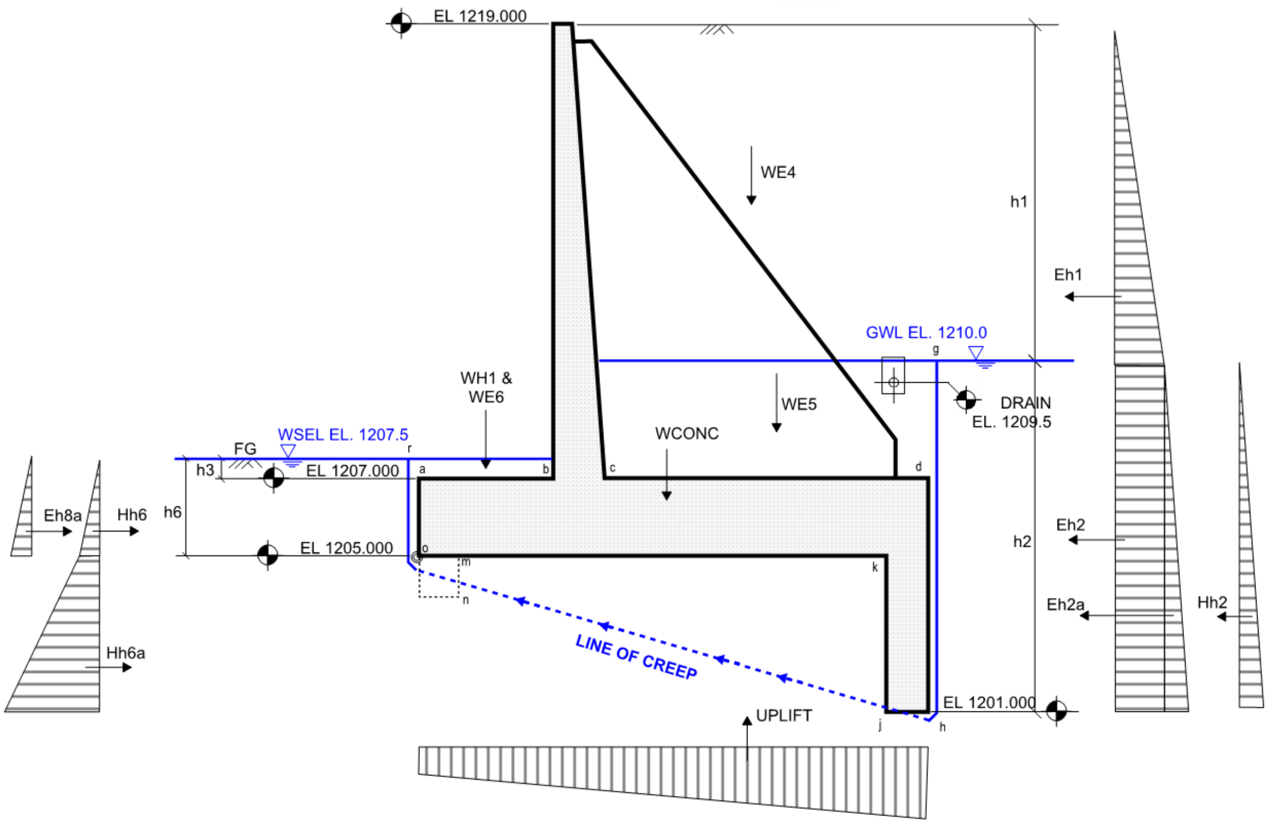
Rock Mass Mobilized: $V_{rocksection} := A_{rocksection} \cdot \gamma_r \cdot B = 614.4 \cdot kN$

(Pore pressure taken along assumed inclined sliding plane)

Distance from Toe to COG of Rock Section: $L_{rocksection} := \frac{Key_{hdist} \cdot (2 \cdot Key_{h.d} + Key_{t.d})}{3(Key_{h.d} + Key_{t.d})} + Key_{t.w} = 8\,m$

$\Sigma M_{rocksection} := V_{rocksection} \cdot L_{rocksection} = 4915.2\,m \cdot kN$

LOAD CASE U1 - NORMAL OPERATION



U1 DESIGN CASE

LOAD CASE U1 ACCEPTANCE PARAMETERS

FS sliding:

Usual (U) 1.5 (without cohesion) (Table 3-3, USACE EM 1110-2-2100)

Resultant Location:

Usual (U) Inside middle third ~100% base in compression

Required Factor of Safety for Sliding: $FS_{sliding.reqU1} := 1.5$ (Without Cohesion)

Allowable rock bearing pressure: $\sigma_{allowU1} := 1270\text{kPa}$ (Section 5.2, Design Criteria EM 1110-2-2100 Section 3-10)

Overturning Required Resultant Ratio: $X_{R.reqU1} := 0.333$ (EM 1110-2-2502, Figure 4-4)

Required Factor of Safety for Floatation $FS_{req.U1.flt} := 1.5$

SOIL HEIGHTS and Water Levels:

LOAD CASE U1

Heel Conditions:

Groundwater Elevation at Heel: $GWL_{U1} := 1210.0m$

Distance from Finish Grade to Groundwater at Heel: $h_{1U1} := \left[T_w - GWL_{U1} + \left(L_{cd} + t_{wb} - t_{wt}\right)\cdot\tan(\beta)\right] = 9.00\ m$

Distance from Water Surface to Bottom of Footing at Heel: $h_{2U1} := GWL_{U1} - Bot_{ftg} + Key_{h.d} = 9.00\ m$

Toe Conditions:

Water Surface Elevation at Toe: $WSEL_{U1} := 1207.5m$

Water Surface Elevation at Toe for Uplift: $UWSEL_{U1} := 1207.5\cdot m$

Finish Grade at Toe providing lateral resistance: $FG_{toeU1} := 1207.5\cdot m$

Soil Depth Above top of footing: $h_{3aU1} := FG_{toeU1} - Top_{ftg} = 0.5\ m$

$$h_{3U1} := \begin{cases} h_{3aU1} & \text{if } FG_{toeU1} - Top_{ftg} \geq 0 \\ 0 & \text{otherwise} \end{cases} = 0.5$$

Resisting Fill at Toe: $h_{4U1} := FG_{toeU1} - Bot_{ftg} + Key_{t.d} = 2.50\ m$

Distance from Water Level to Top of Footing: $h_{5U1} := WSEL_{U1} - Top_{ftg} = 0.50\ m$

Distance from Water Surface to Bottom of Toe Key: $h_{6U1} := WSEL_{U1} - Bot_{ftg} + Key_{t.d} = 2.50\cdot m$

Soil Depth Above WSEL: $h_{7aU1} := FG_{toeU1} - WSEL_{U1} = 0\ m$

$$h_{7U1} := \begin{cases} h_{7aU1} & \text{if } FG_{toeU1} - WSEL_{U1} \geq 0 \\ 0 & \text{otherwise} \end{cases} = 0$$

Soil Depth Below WSEL:

$$h_{8U1} := \begin{cases} WSEL_{U1} - Bot_{ftg} + Key_{t.d} & \text{if } FG_{toeU1} - WSEL_{U1} \geq 0 \\ h_{4U1} & \text{otherwise} \end{cases} = 2.5$$

For Line of Creep Method: $L_{ho.U1} := \sqrt{b^2 + \left(Key_{h.d} - Key_{t.d}\right)^2} = 13.601\ m$

Head Loss from Point g:

$\Delta h_{g.hj.U1} := h_{2U1} = 9\ m$ (to point h & j)

$\Delta h_{g.km.U1} := GWL_{U1} - Bot_{ftg} = 5\ m$ (to point k & m)

$\Delta h_{g.no.U1} := GWL_{U1} - Bot_{ftg} + Key_{t.d} = 5\ m$ (to point n & o)

$\Delta h_{g.p.U1} := GWL_{U1} - FG_{toeU1} = 2.5\ m$ (to point p*)

$\Delta h_{g.r.U1} := GWL_{U1} - UWSEL_{U1} = 2.5\ m$ (to point r)

Surcharge

Surcharge on Heel: $S1_{U1} := 0.0\ \frac{kN}{m^2}$

* same as point "r" in this case

Calculate Soil Lateral Pressure Coefficients:

For all load cases except seismic, soil loading to be based on At-Rest Condition.
Calculate at-rest pressure coefficient Ko based on Jaky's (1944) equation.

Soil At Rest Static Coefficient: $K_o := \frac{1 - \sin(\phi)}{1 + \sin(\beta)} = 0.546$ (Eq. 3-6, USACE EM 1110-2-2502)

Lateral - Driving Force (Headwater Side)

Lateral Soil Load:

Surcharge Load: $E_{s1U1} := S1_{U1} \cdot K_o \cdot \left(H_w + Key_{h.d}\right) \cdot B \cdot -1 = 0 \cdot kN$

Moment Arm (from Point O): $E_{s1locU1} := \frac{H_w + Key_{h.d}}{2} + Key_{vdist} = 5.00\ m$

Moist Soil Load above GWL: $E_{h1U1} := \frac{\gamma_m \cdot K_o \cdot h_{1U1}^{\ 2}}{2} B \cdot -1 = -442.3 \cdot kN$

Moment Arm (from Point O): $E_{h1locU1} := \frac{h_{1U1}}{3} + h_{2U1} + Key_{vdist} = 8.00\ m$

Saturated Soil Load below GWL:
(rectangular component) $E_{h2U1} := \left(\gamma_m \cdot K_o \cdot h_{1U1}\right) \cdot \left(h_{2U1}\right) \cdot B \cdot -1 = -884.5 \cdot kN$

Moment Arm (from Point O): $E_{h2locU1} := \frac{h_{2U1}}{2} + Key_{vdist} = 0.50\ m$

Saturated Soil Load below GWL:
(triangular component) $E_{h2aU1} := \frac{\left(\gamma_{sat} - \gamma_w\right) \cdot K_o \cdot h_{2U1}^{\ 2}}{2} \cdot B \cdot -1 = -269.8 \cdot kN$

Moment Arm (from Point O): $E_{h2alocU1} := \frac{h_{2U1}}{3} + Key_{vdist} = -1.00\ m$

Lateral Water Load:

Water Load GWL to Bottom of Keys:

$$H_{h2U1} := \left| \begin{array}{ll} \frac{\gamma_w \cdot h_{2U1}^{\ 2}}{2} \cdot B \cdot -1 & \text{if } Key_{vdist} < 0 \\ \frac{\gamma_w \cdot \left(h_{2U1} + Key_{vdist}\right)^2}{2} \cdot B \cdot -1 & \text{otherwise} \end{array} \right. = -396.9 \cdot kN$$

Moment Arm (from Point O):

$$H_{h2locU1} := \left| \begin{array}{ll} \frac{h_{2U1}}{3} + Key_{vdist} & \text{if } Key_{vdist} < 0 \\ \frac{h_{2U1} + Key_{vdist}}{3} & \text{otherwise} \end{array} \right. = -1.00 \cdot m$$

$$\Sigma H_{SoildriveU1} := E_{s1U1} + E_{h1U1} + E_{h2U1} + E_{h2aU1} + H_{h2U1} = -1993.5 \cdot kN$$

$$\Sigma M_{LateralSoildriveU1} := E_{s1U1} \cdot E_{s1locU1} + E_{h1U1} \cdot E_{h1locU1} + E_{h2U1} \cdot E_{h2locU1} \cdots + E_{h2aU1} \cdot E_{h2alocU1} + H_{h2U1} \cdot H_{h2locU1} = -3313.7\ m \cdot kN$$

Lateral - Resisting Force (Tailwater Side)

LOAD CASE U1

Lateral Water Load:

Water Load WSEL to Bot. of Toe Key: $H_{h6U1} := \frac{\gamma_w \cdot h_{6U1}^2}{2} \cdot B = 30.6 \cdot kN$

Moment Arm (from Point O): $H_{h6locU1} := \frac{h_{6U1}}{3} = 0.83\ m$

Water Load between Keys (if any) $H_{h6aU1} := \begin{cases} \frac{\left(h_{6U1} + h_{2U1}\right) \cdot -Key_{vdist}}{2} \cdot \gamma_w \cdot B & \text{if } Key_{vdist} < 0 \\ 0 & \text{otherwise} \end{cases} = 225.4 \cdot kN$

Moment Arm (from Point O): $H_{h6alocU1} := \begin{cases} \frac{Key_{vdist} \cdot \left(2 \cdot h_{2U1} + h_{6U1}\right)}{3\left(h_{2U1} + h_{6U1}\right)} & \text{if } Key_{vdist} < 0 \\ 0 & \text{otherwise} \end{cases} = -2.38 \cdot m$

Lateral Soil Load:

Moist Soil Load above WSEL: $E_{h7U1} := \frac{\gamma_m \cdot K_o \cdot h_{7U1}^2}{2} \cdot B = 0.0 \cdot kN$

Moment Arm (from bot. of toe key): $E_{h7locU1} := h_{6U1} + \frac{h_{7U1}}{3} = 2.50\ m$

Saturated Soil Load below WSEL:
(rectangular component) $E_{h8U1} := \left(\gamma_m \cdot K_o \cdot h_{7U1}\right) \cdot h_{8U1} \cdot B = 0.0 \cdot kN$

Moment Arm (from bot. of toe key): $E_{h8locU1} := \frac{h_{8U1}}{2} = 1.25\ m$

Saturated Soil Load below WSEL:
(triangular component) $E_{h8aU1} := \frac{\left[\left(\gamma_{sat} - \gamma_w\right) \cdot K_o\right] \cdot h_{8U1}^2}{2} \cdot B = 20.8 \cdot kN$

Moment Arm (from bot. of footing): $E_{h8alocU1} := \frac{h_{8U1}}{3} = 0.83\ m$

$\Sigma H_{SoilresistU1} := H_{h6U1} + H_{h6aU1} + E_{h7U1} + E_{h8U1} + E_{h8aU1} = 276.8 \cdot kN$

$$\Sigma M_{HorizSoilResistU1} := H_{h6U1} \cdot H_{h6locU1} + H_{h6aU1} \cdot H_{h6alocU1} + E_{h7U1} \cdot E_{h7locU1} \ldots + E_{h8U1} \cdot E_{h8locU1} + E_{h8aU1} \cdot E_{h8alocU1} = -492.9\ m \cdot kN$$

Vertical Force:

UPLIFT: Linear distribution from water at heel to water at toe:

$$\Sigma V_{UpliftU1} := \left[\left(UWSEL_{U1} - Bot_{ftg} + Key_{t.d}\right) + h_{2U1}\right] \cdot \frac{b}{2} \cdot \gamma_w \cdot B \cdot -1 = -732.55 \cdot kN$$

Moment Arm (from Point O): $V_{UpliftU1aloc} := \frac{b \cdot \left[2 \cdot h_{2U1} + \left(UWSEL_{U1} - Bot_{ftg} + Key_{t.d}\right)\right]}{3\left[h_{2U1} + \left(UWSEL_{U1} - Bot_{ftg} + Key_{t.d}\right)\right]} = 7.725\ m$

$\Sigma M_{UpliftU1} := \Sigma V_{UpliftU1} \cdot V_{UpliftU1aloc} = -5658.683 \cdot kN \cdot m$

Vertical Force (con't):

Weight of soil and water over toe:

Water Above the Top of Footing: $W_{H1U1} := \gamma_w \cdot h_{5U1} \cdot L_{ab} \cdot B = 17.15 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E1locU1} := \frac{L_{ab}}{2} = 1.75\, m$

Soil above top of footing: $W_{E6U1} := \gamma_b \cdot h_{3U1} \cdot L_{ab} \cdot B = 21.4 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E6locU1} := \frac{L_{ab}}{2} = 1.75\, m$

Vertical Load Due to Surcharge: $S_{U1} := S1_{U1} \cdot L_{cd} \cdot B = 0$ $\quad S_{U1loc} := b - \frac{L_{cd}}{2} = 8.97\, m$

Weight of soil and water over heel:

Moist Soil for sloped grade above top of wall:

Length of sloped portion of soil above top of wall: $L_{E3U1} := \left(L_{cd} + t_{wb} - t_{wt}\right) = 9.00\, m$

Height of sloped soil above top of wall over heel: $h_{E3locU1} := \left(L_{E3U1}\right) \cdot \tan(\beta) = 0.00\, m$

Weight of sloped soil above top of wall: $W_{E3U1} := \frac{\gamma_m}{2} \cdot h_{E3locU1} \cdot L_{E3U1} \cdot B = 0.0 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E3locU1} := L_{ab} + t_{wt} + \frac{2}{3} \cdot L_{E3U1} = 10.00\, m$

Moist soil from top of wall to groundwater level:

Height of soil from top of wall and top of GWL: $h_{1U1} = 9.00\, m$

Length from edge of wall at GWL to edge of heel: $L_{E4U1} := L_{E3U1} - \left(h_{1U1} \cdot S_{batter}\right) = 8.29\, m$

Weight of soil over heel from top of wall to GWL: $W_{E4U1} := \gamma_m \cdot h_{1U1} \cdot \frac{\left(L_{E3U1} + L_{E4U1}\right)}{2} \cdot B = 1556.3 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E4locU1} := b - \frac{L_{E3U1}^2 + L_{E3U1} \cdot L_{E4U1} + L_{E4U1}^2}{3\left(L_{E3U1} + L_{E4U1}\right)} = 8.67\, m$

Saturated soil from groundwater to top of footing:

Height of soil from GWL to top of heel: $h_{E4U1} := h_{2U1} - t_{ftg} - Key_{h.d} = 3.00\, m$

Weight of soil over heel from GWL to top of heel: $W_{E5U1} := \left(\gamma_{sat}\right) \cdot h_{E4U1} \cdot \frac{\left(L_{E4U1} + L_{cd}\right)}{2} \cdot B = 539.5 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E5locU1} := b - \frac{L_{E4U1}^2 + L_{E4U1} \cdot L_{cd} + L_{cd}^2}{3\left(L_{E4U1} + L_{cd}\right)} = 8.91\, m$

$\Sigma V_{SoilWaterU1} := W_{H1U1} + W_{E6U1} + W_{E3U1} + W_{E4U1} + W_{E5U1} + S_{U1} = 2134.4 \cdot kN$

$$\Sigma M_{VertSoilWaterResistU1} := W_{H1U1} \cdot W_{E1locU1} + W_{E6U1} \cdot W_{E6locU1} \cdots + W_{E3U1} \cdot W_{E3locU1} + W_{E4U1} \cdot W_{E4locU1} + W_{E5U1} \cdot W_{E5locU1} + S_{U1} \cdot S_{U1loc} = 18376.3\, m \cdot kN$$

THIS PAGE INTENTIONALLY LEFT BLANK
PLEASE GO TO THE NEXT PAGE

STABILITY ASSESSMENT:

LOAD CASE U1

CHECK SLIDING ALONG HORIZONTAL SLIDING PLANE:

Summation of the vertical forces:

$$\Sigma V_{U1} := \Sigma V_{conc} + \Sigma V_{SoilWaterU1} + \Sigma V_{UpliftU1} = 2380.8 \cdot kN$$

Summation of the horizontal forces:

$$\Sigma H_{U1} := \Sigma H_{SoildriveU1} + \Sigma H_{SoilresistU1} = -1716.6 \cdot kN$$

Safety Factor for Sliding Horizontal Failure Plane

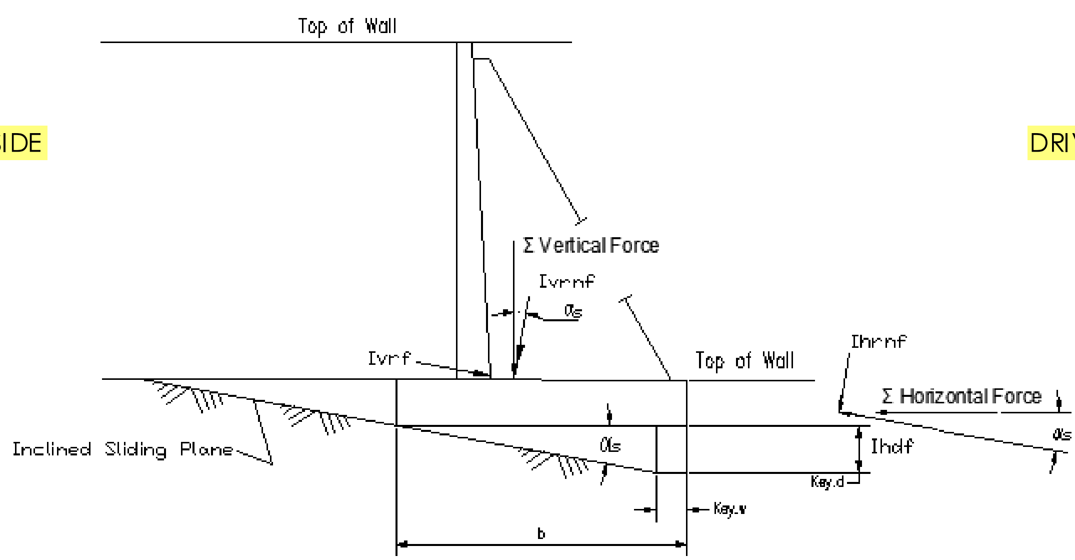
$$FS_{Horiz.SlidingU1} := \frac{\left|\Sigma V_{U1}\right| \cdot \tan\left(\phi_{rock} \cdot \frac{\pi}{180}\right)}{\left|\Sigma H_{U1}\right|} = 0.68$$

$$FS_{Sliding.check1.U1} := \begin{cases} \text{"OKAY "} & \text{if } FS_{Horiz.SlidingU1} > FS_{sliding.reqU1} \\ \text{"Key req'"} & \text{otherwise} \end{cases} = \text{"Key req'"}$$

CHECK FACTOR OF SAFETY SLIDING WITH KEY (INCLINED SLIDING PLANE):

RESISTING SIDE

DRIVING SIDE



TOE

HEEL

Ivrf=Inclined Resisting Force
Ivrnf=Inclined Resisting Normal Force
Ihrnf=Inclined Resisting Normal Force
Ihdf=Inclined Driving Force

$$\alpha s := \text{atan}\left(\frac{-Key_{vdist}}{Key_{hdist}}\right) = 0.322 \qquad \text{as degrees=} \qquad \alpha s \cdot \left(\frac{180}{\pi}\right) = 18.43$$

(With properly engineered reinforced concrete Key, horizontal sliding plane thru Toe is protected, critical sliding plane is relocated to the INCLINED SLIDING PLANE FROM HEEL KEY To TOE, Bedrock Mass above this examing plane is mobilized by reinforced concrete key and combined into Structural Wedge.)

Resolve ΣV_{U1} & ΣH_{U1}

$$\Sigma V_{InclinedU1} := \cos(\alpha s) \cdot \left(\left|\Sigma V_{U1} + V_{rocksection}\right|\right) + \sin(\alpha s) \cdot \left|\Sigma H_{U1}\right| = 3384.3 \cdot kN$$

$$\Sigma H_{InclinedU1} := \cos(\alpha s) \cdot \left|\Sigma H_{U1}\right| - \sin(\alpha s) \cdot \left(\left|\Sigma V_{U1} + V_{rocksection}\right|\right) = 681.4 \cdot kN$$

LOAD CASE U1

Safety Factor for Sliding Inclined Failure Plane

$$FS_{InclinedISlidingU1} := \frac{\Sigma V_{InclinedU1} \cdot \tan(\phi_r)}{\Sigma H_{InclinedU1}} = 2.21$$

$$FS_{Sliding.check2.U1} := \begin{cases} \text{"OKAY "} & \text{if } FS_{InclinedISlidingU1} > FS_{sliding.reqU1} \\ \text{"NG - Revise Structure""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

CHECK FOUNDATION ECCENTRICITY:

Summation of the resisting moments about the toe:

$$\Sigma M_{resU1} := \Sigma M_{conc} + \Sigma M_{VertSoilWaterResistU1} + \Sigma M_{HorizSoilResistU1} + \Sigma M_{rocksection} = 29048 \cdot kN \cdot m$$

Summation of the overturning moments about the toe:

$$\Sigma M_{oU1} := \Sigma M_{LateralSoildriveU1} + \Sigma M_{UpliftU1} = -8972 \cdot kN \cdot m$$

Total moment: $\Sigma M_{U1} := \Sigma M_{resU1} + \Sigma M_{oU1} = 20075.1 \cdot kN \cdot m$

Normal force to base: $\Sigma V_{InclinedU1} = 3384.3 \cdot kN$

Inclined Sliding Plane Length: $L_{incline} := \dfrac{b}{\cos(\alpha s)} = 13.7\ m$

Eccentricity (inclined plane): $ex_{U1} := \dfrac{L_{incline}}{2} - \dfrac{\Sigma M_{U1}}{\Sigma V_{InclinedU1}} = 0.92\ m$ $\qquad Kern := \dfrac{L_{incline}}{6} = 2.284\ m$

Eccentricity Check: $e_{check.U1} := \begin{cases} \text{"Okay"} & \text{if } ex_{U1} \le Kern \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"Okay"}$

CHECK FOUNDATION BEARING CAPACITY:

Base Section Modulus: $S_b := \dfrac{1}{6}\left(B \cdot L_{incline}^{\ 2}\right) = 31.3\ m^3$

Bearing Pressure Under Toe:

$$\sigma_{ToeU1} := \begin{cases} \left[\dfrac{\Sigma V_{InclinedU1}}{L_{incline} \cdot B} + \dfrac{(\Sigma V_{InclinedU1} \cdot ex_{U1})}{S_b}\right] & \text{if } \dfrac{\Sigma V_{InclinedU1}}{L_{incline} \cdot B} \ge \dfrac{\Sigma V_{InclinedU1} \cdot ex_{U1}}{S_b} \\ \dfrac{2 \cdot \Sigma V_{InclinedU1}}{B \cdot 3\left(\dfrac{b}{2} - ex_{U1}\right)} & \text{otherwise} \end{cases} = 346.4 \cdot kPa$$

$$Bearing_{ChecktoeU1} := \begin{cases} \text{"OKAY "} & \text{if } \sigma_{ToeU1} < \sigma_{allowU1} \\ \text{"NG""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

Bearing Pressure Under Heel:

$$\sigma_{HeelU1} := \begin{cases} \left[\dfrac{\Sigma V_{InclinedU1}}{L_{incline} \cdot B} - \dfrac{(\Sigma V_{InclinedU1} \cdot ex_{U1})}{S_b}\right] & \text{if } \dfrac{\Sigma V_{InclinedU1}}{L_{incline} \cdot B} \ge \dfrac{\Sigma V_{InclinedU1} \cdot ex_{U1}}{S_b} \\ 0 & \text{otherwise} \end{cases} = 147.5 \cdot kPa$$

$$Bearing_{CheckheelU1} := \left(\begin{cases} \text{"OKAY "} & \text{if } \sigma_{HeelU1} < \sigma_{allowU1} \wedge \sigma_{HeelU1} > 0 \\ \text{"NG - perform cracked base analysis""} & \text{otherwise} \end{cases}\right) = \text{"OKAY "}$$

CHECK FLOATATION:

Safety Factor for Floatation: $FS_{FloatationU1} := \frac{\Sigma V_{conc} + \Sigma V_{SoilWaterU1}}{\left|\Sigma V_{UpliftU1}\right|} = 4.25$

$FS_{Floatation.U1.check} :=$ "OKAY " if $FS_{FloatationU1} > FS_{req.U1.flt}$ = "OKAY "
"Revise Structure"" otherwise

CHECK OVERTURNING

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.
Assumptions are made in order to compute overturning stablity of indetermine forces on monolith with key;
(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.
(b) The horizontal resisting force acting on the key, P.key, is that required for static equilibrium
(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1

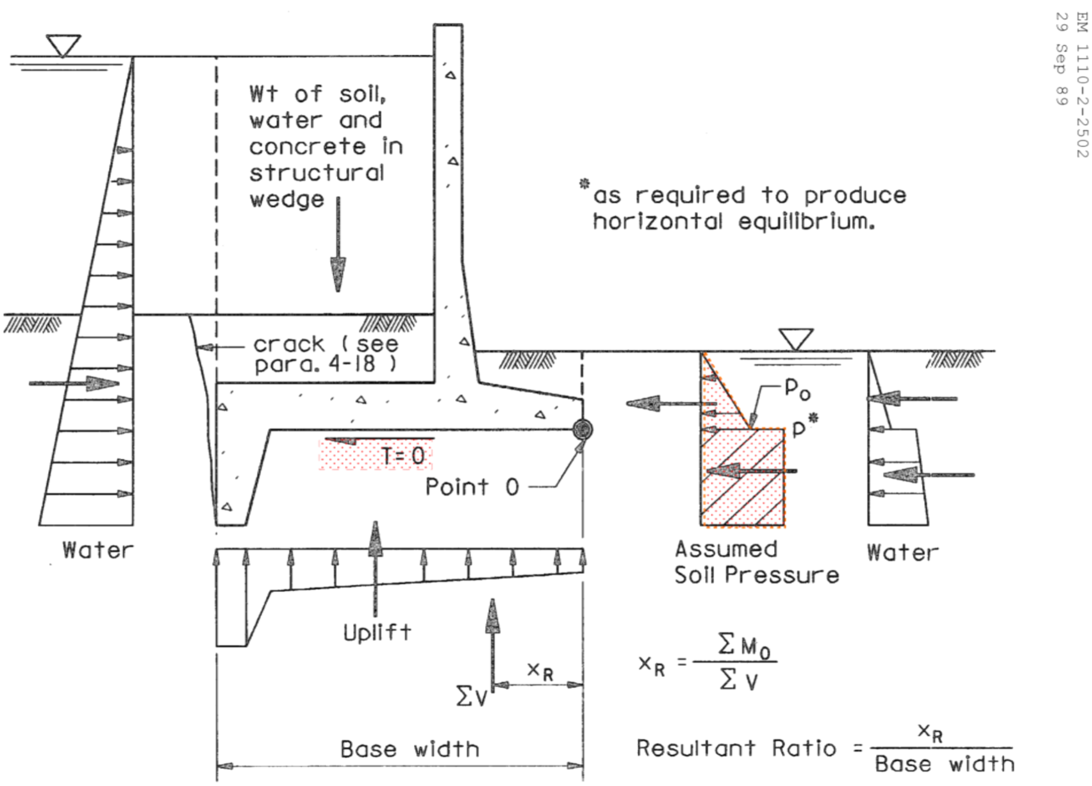


Figure 4-5. Forces for overturning analysis for wall with horizontal base and key

Modify Uplift for Overturning Analysis: **LOAD CASE U1**

(Uplift is calculated along the concrete/rock contact using the Line of Creep method)

Water Pressure at h: $u_{h.U1} := \Delta h_{g.hj.U1} \cdot \gamma_w = 88.20 \cdot kPa$

Water Pressure at o: $u_{o.U1} := \left(\Delta h_{g.no.U1} - \frac{\Delta h_{g.r.U1} \cdot L_{ho.U1}}{L_{ho.U1}}\right) \cdot \gamma_w = 24.5 \cdot kPa$

Head loss between point h and o: $\Delta h_{ho.U1} := \Delta h_{g.r.U1} \cdot \frac{L_{ho.U1}}{L_{ho.U1}} = 2.5\,m$

Length of concrete base (h -> o): $L_{baseho.U1} := Key_{h.w} + Key_{h.d} + Key_{hdist} + Key_{t.d} + Key_{t.w} = 17\,m$

Head loss along h -> j: $\Delta h_{hj.U1} := \Delta h_{ho.U1} \cdot \frac{Key_{h.w}}{L_{baseho.U1}} = 0.147\,m$

Water Pressure at j: $u_{j.U1} := \left(\Delta h_{g.hj.U1} - \Delta h_{hj.U1}\right) \cdot \gamma_w = 86.76 \cdot kPa$

Head loss along h -> k: $\Delta h_{hjk.U1} := \Delta h_{ho.U1} \cdot \left(\frac{Key_{h.w} + Key_{h.d}}{L_{baseho.U1}}\right) = 0.735\,m$

Water Pressure at k: $u_{k.U1} := \left(\Delta h_{g.km.U1} - \Delta h_{hjk.U1}\right) \cdot \gamma_w = 41.79 \cdot kPa$

Head loss along h -> m: $\Delta h_{hjkm.U1} := \Delta h_{ho.U1} \cdot \left(\frac{Key_{h.w} + Key_{h.d} + Key_{hdist}}{L_{baseho.U1}}\right) = 2.5\,m$

Water Pressure at m: $u_{m.U1} := \left(\Delta h_{g.km.U1} - \Delta h_{hjkm.U1}\right) \cdot \gamma_w = 24.50 \cdot kPa$

Head loss along h -> n: $\Delta h_{hjkmn.U1} := \Delta h_{ho.U1} \cdot \left(\frac{Key_{h.w} + Key_{h.d} + Key_{hdist} + Key_{t.d}}{L_{baseho.U1}}\right) = 2.5\,m$

Water Pressure at n: $u_{n.U1} := \left(\Delta h_{g.no.U1} - \Delta h_{hjkmn.U1}\right) \cdot \gamma_w = 24.50 \cdot kPa$

Uplift under key at heel: $V_{ulkeyhU1.OT} := \frac{\left(u_{h.U1} + u_{j.U1}\right) \cdot Key_{h.w}}{2} \cdot B \cdot -1 = -87.479 \cdot kN$

Moment Arm (from Point O): $V_{ulkeyhU1loc.OT} := b - \frac{Key_{h.w} \cdot \left(2 \cdot u_{j.U1} + u_{h.U1}\right)}{3 \cdot \left(u_{j.U1} + u_{h.U1}\right)} = 12.501\,m$

Uplift under base: $V_{ulbaseU1.OT} := \frac{\left(u_{k.U1} + u_{m.U1}\right) \cdot Key_{hdist}}{2} \cdot B \cdot -1 = -397.765 \cdot kN$

Moment Arm (from Point O): $V_{ulbaseU1loc.OT} := b - Key_{h.w} - \frac{Key_{hdist} \cdot \left(2 \cdot u_{m.U1} + u_{k.U1}\right)}{3 \cdot \left(u_{m.U1} + u_{k.U1}\right)} = 6.522\,m$

Uplift under key at toe: $V_{ulkeytU1.OT} := \frac{\left(u_{n.U1} + u_{o.U1}\right) \cdot Key_{t.w}}{2} \cdot B \cdot -1 = 0 \cdot kN$

Moment Arm (from Point O): $V_{ulkeytU1loc.OT} := \frac{Key_{t.w} \cdot \left(2 \cdot u_{n.U1} + u_{o.U1}\right)}{3 \cdot \left(u_{n.U1} + u_{o.U1}\right)} = 0$

$$\Sigma V_{UpliftU1.OT} := V_{ulkeyhU1.OT} + V_{ulbaseU1.OT} + V_{ulkeytU1.OT} = -485 \cdot kN$$

$$U_{U1.loc.OT} := \frac{V_{ulkeyhU1.OT} \cdot V_{ulkeyhU1loc.OT} + V_{ulbaseU1.OT} \cdot V_{ulbaseU1loc.OT} + V_{ulkeytU1.OT} \cdot V_{ulkeytU1loc.OT}}{\Sigma V_{UpliftU1.OT}} = 7.60\,m$$

$$\Sigma M_{UpliftU1.OT} := \Sigma V_{UpliftU1.OT} \cdot U_{U1.loc.OT} = -3687.7 \cdot kN \cdot m$$

Modify Lateral Water Pressure (Resisting) for Overturning Analysis:

(Resisting water pressure is calculated using the Line of Creep method)

Water Load at Key (heel):

$$H_{h2U1.OT} := \frac{\upsilon_{k.U1} + \upsilon_{j.U1}}{2} \cdot Key_{h.d} \cdot B = 257.1 \cdot kN$$

Moment Arm (from Point O):

$$H_{h2locU1.OT} := \frac{Key_{h.d} \cdot \left(2 \cdot \upsilon_{k.U1} + \upsilon_{j.U1}\right)}{3\left(\upsilon_{k.U1} + \upsilon_{j.U1}\right)} + Key_{vdist} = -2.23\ m$$

Water Load at Key (toe):

$$H_{h6U1.OT} := \frac{\upsilon_{o.U1} \cdot \left(UWSEL_{U1} - Bot_{ftg} + Key_{t.d}\right)}{2} \cdot B = 31 \cdot kN$$

Moment Arm (from Point O):

$$H_{h6locU1.OT} := \frac{UWSEL_{U1} - Bot_{ftg} + Key_{t.d}}{3} = 0.83\ m$$

$$\Sigma H_{waterresistU1.OT} := H_{h2U1.OT} + H_{h6U1.OT} = 287.73 \cdot kN$$

$$H_{waterresistlocU1.OT} := \frac{H_{h2U1.OT} \cdot H_{h2locU1.OT} + H_{h6U1.OT} \cdot H_{h6locU1.OT}}{\Sigma H_{waterresistU1.OT}} = -1.907\ m$$

$$\Sigma M_{waterresistU1.OT} := \Sigma H_{waterresistU1.OT} \cdot H_{waterresistlocU1.OT} = -548.64 \cdot kN \cdot m$$

Modify Lateral Soil Loads for Overturning Analysis:

(Lateral soil loads are calculated down to Point O instead of bottom of shear key)

<u>Driving Soil Load (Headwater Side):</u>

Surcharge Load:

$$E_{s1U1.OT} := S1_{U1} \cdot K_o \cdot \left(H_w + Key_{h.d} + Key_{vdist}\right) \cdot B \cdot -1 = 0 \cdot kN$$

Moment Arm (from Point O):

$$E_{s1locU1.OT} := \frac{H_w + Key_{h.d} + Key_{vdist}}{2} = 7.00\ m$$

Moist Soil Load above GWL:

$$E_{h1U1.OT} := \frac{\gamma_m \cdot K_o \cdot h_{1U1}^{\ 2}}{2} \cdot B \cdot -1 = -442.3 \cdot kN$$

Moment Arm (from Point O):

$$E_{h1locU1.OT} := \frac{h_{1U1}}{3} + h_{2U1} + Key_{vdist} = 8.00\ m$$

Saturated Soil Load below GWL:
(rectangular component)

$$E_{h2U1.OT} := \left(\gamma_m \cdot K_o \cdot h_{1U1}\right) \cdot \left(h_{2U1} + Key_{vdist}\right) \cdot B \cdot -1 = -491.4 \cdot kN$$

Moment Arm (from Point O):

$$E_{h2locU1.OT} := \frac{h_{2U1} + Key_{vdist}}{2} = 2.50\ m$$

Saturated Soil Load below GWL:
(triangular component)

$$E_{h2aU1.OT} := \frac{\left(\gamma_{sat} - \gamma_w\right) \cdot K_o \cdot \left(h_{2U1} + Key_{vdist}\right)^2}{2} \cdot B \cdot -1 = -83.3 \cdot kN$$

Moment Arm (from Point O):

$$E_{h2alocU1.OT} := \frac{h_{2U1} + Key_{vdist}}{3} = 1.67\ m$$

Resisting Soil Load (Tailwater Side):

(Determine resisting soil load based on depth variation between the keys (ie. Key_{vdist}). In case where key at heel is deeper than key at toe (ie. $Key_{vdist} < 0$), resisting soil load (p*) is assumed to produce horizontal equilibrium as per Figure 4-5 above. Resisting soil load (p_o) is neglected.)

Total Driving Force: $\Sigma H_{SoildriveU1.OT} := E_{s1U1.OT} + E_{h1U1.OT} + E_{h2U1.OT} + E_{h2aU1.OT} + H_{h2U1} = -1413.8 \cdot kN$

Total Resisting Force: $\Sigma H_{waterresistU1.OT} = 287.7 \cdot kN$

Assumed Soil Load p*: $E_{h8U1a.OT} := \left(\Sigma H_{SoildriveU1.OT} + \Sigma H_{waterresistU1.OT}\right) \cdot -1 = 1126.112 \cdot kN$

Moment Arm (from Point O): $E_{h8U1a.loc.OT} := \dfrac{Key_{vdist}}{2} = -2\,m$

$$E_{h8U1.OT} := \begin{cases} E_{h8U1a.OT} & \text{if } Key_{vdist} < 0 \\ \Sigma H_{SoilresistU1} - H_{h6U1} - H_{h6aU1} & \text{otherwise} \end{cases} = 1126.112 \cdot kN$$

$$\Sigma M_{SoilresistU1.OT} := \begin{cases} E_{h8U1a.OT} \cdot E_{h8U1a.loc.OT} & \text{if } Key_{vdist} < 0 \\ \Sigma M_{HorizSoilResistU1} - H_{h6U1} \cdot H_{h6locU1} - H_{h6aU1} \cdot H_{h6alocU1} & \text{otherwise} \end{cases} = -2252.224 \cdot kN \cdot m$$

Sum of Moment about Point O:

$$\Sigma M_{LateraldriveU1.OT} := E_{s1U1.OT} \cdot E_{s1locU1.OT} + E_{h1U1.OT} \cdot E_{h1locU1.OT} + E_{h2U1.OT} \cdot E_{h2locU1.OT} \dots + E_{h2aU1.OT} \cdot E_{h2alocU1.OT} + H_{h2U1} \cdot H_{h2locU1} = -4508.5 \cdot kN \cdot m$$

$$\Sigma M_{LateralresistU1.OT} := \Sigma M_{waterresistU1.OT} + \Sigma M_{SoilresistU1.OT} = -2800.9 \cdot kN \cdot m$$

Total moment:

$$\Sigma M_{U1.OT} := \Sigma M_{conc} + \Sigma M_{VertSoilWaterResistU1} + \Sigma M_{UpliftU1.OT} + \Sigma M_{LateraldriveU1.OT} + \Sigma M_{LateralresistU1.OT} = 13628.1 \cdot kN \cdot m$$

Total Vertical Force: $\Sigma V_{U1.OT} := \Sigma V_{conc} + \Sigma V_{SoilWaterU1} + \Sigma V_{UpliftU1.OT} = 2628.1 \cdot kN$

Distance X_R: EM 1110-2-2502 Eq.4-1 $X_{R.U1} := \dfrac{\Sigma M_{U1.OT}}{\Sigma V_{U1.OT}} = 5.186\,m$

Overturning Resultant Ratio $Ratio_{U1.OT} := \dfrac{X_{R.U1}}{b} = 0.4$

$$Ratio_{U1.OT.check} := \begin{cases} \text{"OKAY "} & \text{if } Ratio_{U1.OT} > X_{R.reqU1} \\ \text{"Revise Structure""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

CHECK FOUNDATION ECCENTRICITY (HORIZONTAL PLANE):

Eccentricity (horizontal plan): $ex_{U1.OT} := \dfrac{b}{2} - \dfrac{\Sigma M_{U1.OT}}{\Sigma V_{U1.OT}} = 1.31\,m$ $Kern_{OT} := \dfrac{b}{6} = 2.167\,m$

Eccentricity Check: $$e_{check.U1.OT} := \begin{cases} \text{"Okay"} & \text{if } ex_{U1} \le Kern_{OT} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"Okay"}$$

LOAD CASE U1

CHECK FOUNDATION BEARING CAPACITY (HORIZONTAL PLANE):

Base Section Modulus: $S_{b.OT} := \frac{1}{6}\left(B \cdot b^2\right) = 28.17\ m^3$

Bearing Pressure Under Toe:

$$\sigma_{ToeU1.OT} := \begin{cases} \left(\frac{\Sigma V_{U1.OT}}{b \cdot B} + \frac{\Sigma V_{U1.OT} \cdot ex_{U1.OT}}{S_{b.OT}}\right) & \text{if } \frac{\Sigma V_{U1.OT}}{b \cdot B} \geq \frac{\Sigma V_{U1.OT} \cdot ex_{U1.OT}}{S_{b.OT}} \\ \frac{2 \cdot \Sigma V_{U1.OT}}{B \cdot 3\left(\frac{b}{2} - ex_{U1.OT}\right)} & \text{otherwise} \end{cases} = 324.8 \cdot kPa$$

$$Bearing_{ChecktoeU1.OT} := \begin{cases} \text{"OKAY "} & \text{if } \sigma_{ToeU1.OT} < \sigma_{allowU1} \\ \text{"NG - for reference only""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

Bearing Pressure Under Heel:

$$\sigma_{HeelU1.OT} := \begin{cases} \left(\frac{\Sigma V_{U1.OT}}{b \cdot B} - \frac{\Sigma V_{U1.OT} \cdot ex_{U1.OT}}{S_{b.OT}}\right) & \text{if } \frac{\Sigma V_{U1.OT}}{b \cdot B} \geq \frac{\Sigma V_{U1.OT} \cdot ex_{U1.OT}}{S_{b.OT}} \\ 0 & \text{otherwise} \end{cases} = 79.5 \cdot kPa$$

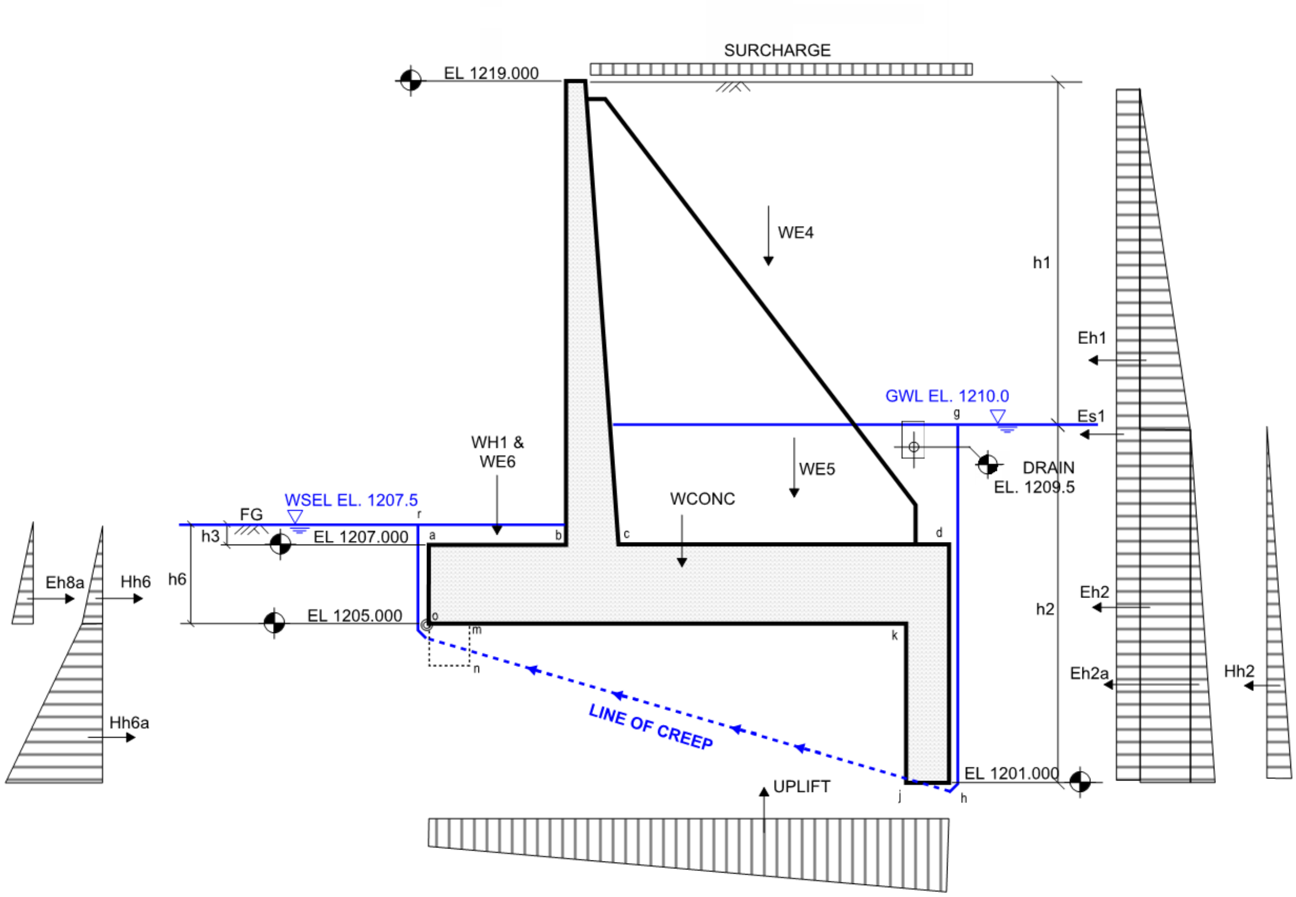
$$Bearing_{CheckheelU1.OT} := \left(\begin{cases} \text{"OKAY "} & \text{if } \sigma_{HeelU1.OT} < \sigma_{allowU1} \wedge \sigma_{HeelU1.OT} > 0 \\ \text{"NG - for reference only""} & \text{otherwise} \end{cases}\right) = \text{"OKAY "}$$

SUMMARY OF STABILITY ASSESSMENT:

LOAD CASE U1

Sliding Factor of Safety: (Horizontal Plane - Ref only)	$FS_{Horiz.SlidingU1} = 0.68$	$FS_{Sliding.check1.U1}$ = "Key req""
Sliding Factor of Safety: (Inclined Plane)	$FS_{InclinedlSlidingU1} = 2.21$	$FS_{Sliding.check2.U1}$ = "OKAY "
Eccentricity: (Inclined Plane)	$ex_{U1} = 0.92\ m$	$e_{check.U1}$ = "Okay"
Bearing Pressure At Heel: (Inclined Plane)	$\sigma_{HeelU1} = 148 \cdot kPa$	$Bearing_{CheckheelU1}$ = "OKAY "
Bearing Pressure At Toe: (Inclined Plane)	$\sigma_{ToeU1} = 346 \cdot kPa$	$Bearing_{ChecktoeU1}$ = "OKAY "
Flotation Factor of Safety (horizontal plane)	$FS_{FloatationU1} = 4.25$	$FS_{Floatation.U1.check}$ = "OKAY "
Overturning Resultant Ratio: (horizontal plane)	$Ratio_{U1.OT} = 0.4$	$Ratio_{U1.OT.check}$ = "OKAY "
Eccentricity: (horizontal plane - Ref only)	$ex_{U1.OT} = 1.31\ m$	$e_{check.U1.OT}$ = "Okay"
Bearing Pressure At Heel: (horizontal plane - Ref only)	$\sigma_{HeelU1.OT} = 80 \cdot kPa$	$Bearing_{CheckheelU1.OT}$ = "OKAY "
Bearing Pressure At Toe: (horizontal plane - Ref only)	$\sigma_{ToeU1.OT} = 325 \cdot kPa$	$Bearing_{ChecktoeU1.OT}$ = "OKAY "

LOAD CASE UN1 - NORMAL OPERATION + SURCHARGE



UN1 DESIGN CASE

LOAD CASE UN1 ACCEPTANCE PARAMETERS

FS sliding:

Unusual (UN) 1.3 (without cohesion) (Table 3-3, USACE EM 1110-2-2100)

Resultant Location:

Unsual (UN) Inside middle third ~100% base in compression

Required Factor of Safety for Sliding: $FS_{sliding.reqUN1} := 1.3$ (Without Cohesion)

Allowable rock bearing pressure: $\sigma_{allowUN1} := 1470kPa$ (Section 5.2, Design Criteria EM 1110-2-2100 Section 3-10)

Overturning Required Resultant Ratio: $X_{R.reqUN1} := 0.333$ (EM 1110-2-2502, Figure 4-4)

Required Factor of Safety for Floatation $FS_{req.UN1.flt} := 1.3$

SOIL HEIGHTS and Water Levels:

LOAD CASE UN1

Heel Conditions:

Groundwater Elevation at Heel: $GWL_{UN1} := 1210.0m$

Distance from Finish Grade to Groundwater at Heel: $h_{1UN1} := \left[T_w - GWL_{UN1} + \left(L_{cd} + t_{wb} - t_{wt}\right) \cdot \tan(\beta)\right] = 9.00\ m$

Distance from Water Surface to Bottom of Footing at Heel: $h_{2UN1} := GWL_{UN1} - Bot_{ftg} + Key_{h.d} = 9.00\ m$

Toe Conditions:

Water Surface Elevation at Toe: $WSEL_{UN1} := 1207.5m$

Water Surface Elevation at Toe for Uplift: $UWSEL_{UN1} := 1207.5 \cdot m$

Finish Grade at Toe providing lateral resistance: $FG_{toeUN1} := 1207.5 \cdot m$

Soil Depth Above top of footing: $h_{3aUN1} := FG_{toeUN1} - Top_{ftg} = 0.5\ m$

$$h_{3UN1} := \begin{vmatrix} h_{3aUN1} & \text{if } FG_{toeUN1} - Top_{ftg} \geq 0 \\ 0 & \text{otherwise} \end{vmatrix} = 0.5$$

Resisting Fill at Toe: $h_{4UN1} := FG_{toeUN1} - Bot_{ftg} + Key_{t.d} = 2.50\ m$

Distance from Water Level to Top of Footing: $h_{5UN1} := WSEL_{UN1} - Top_{ftg} = 0.50\ m$

Distance from Water Surface to Bottom of Toe Key: $h_{6UN1} := WSEL_{UN1} - Bot_{ftg} + Key_{t.d} = 2.50\ m$

Soil Depth Above WSEL: $h_{7aUN1} := FG_{toeUN1} - WSEL_{UN1} = 0\ m$

$$h_{7UN1} := \begin{vmatrix} h_{7aUN1} & \text{if } FG_{toeUN1} - WSEL_{UN1} \geq 0 \\ 0 & \text{otherwise} \end{vmatrix} = 0$$

Soil Depth Below WSEL:

$$h_{8UN1} := \begin{vmatrix} WSEL_{UN1} - Bot_{ftg} + Key_{t.d} & \text{if } FG_{toeUN1} - WSEL_{UN1} \geq 0 \\ h_{4UN1} & \text{otherwise} \end{vmatrix} = 2.5$$

For Line of Creep Method: $L_{ho.UN1} := \sqrt{b^2 + \left(Key_{h.d} - Key_{t.d}\right)^2} = 13.601\ m$

Head Loss from Point g:

$\Delta h_{g.hj.UN1} := h_{2UN1} = 9\ m$ (to point h & j)

$\Delta h_{g.km.UN1} := GWL_{UN1} - Bot_{ftg} = 5\ m$ (to point k & m)

$\Delta h_{g.no.UN1} := GWL_{UN1} - Bot_{ftg} + Key_{t.d} = 5\ m$ (to point n & o)

$\Delta h_{g.p.UN1} := GWL_{UN1} - FG_{toeUN1} = 2.5\ m$ (to point p*)

$\Delta h_{g.r.UN1} := GWL_{UN1} - UWSEL_{UN1} = 2.5\ m$ (to point r)

Surcharge

Surcharge on Heel: $S1_{UN1} := 15.0 \dfrac{kN}{m^2}$

* same as point "r" in this case

Calculate Soil Lateral Pressure Coefficients:

For all load cases except seismic, soil loading to be based on At-Rest Condition.
Calculate at-rest pressure coefficient Ko based on Jaky's (1944) equation.

Soil At Rest Static Coefficient: $K_o := \frac{1 - \sin(\phi)}{1 + \sin(\beta)} = 0.546$ (Eq. 3-6, USACE EM 1110-2-2502)

Lateral - Driving Force

Static At-Rest:

Surcharge Load: $E_{s1UN1} := S1_{UN1} \cdot K_o \cdot \left(H_w + Key_{h.d}\right) \cdot B \cdot -1 = -147.423 \cdot kN$

Moment Arm (from Point O): $E_{s1locUN1} := \frac{H_w + Key_{h.d}}{2} + Key_{vdist} = 5.00\ m$

Moist Soil Load above GWL: $E_{h1UN1} := \frac{\gamma_m \cdot K_o \cdot h_{1UN1}^{\ 2}}{2} \cdot B \cdot -1 = -442.3 \cdot kN$

Moment Arm (from Point O): $E_{h1locUN1} := \frac{h_{1UN1}}{3} + h_{2UN1} + Key_{vdist} = 8.00\ m$

Saturated Soil Load below GWL:
(rectangular component)

$E_{h2UN1} := \left(\gamma_m \cdot K_o \cdot h_{1UN1}\right) \cdot \left(h_{2UN1}\right) \cdot B \cdot -1 = -884.5 \cdot kN$

Moment Arm (from Point O): $E_{h2locUN1} := \frac{h_{2UN1}}{2} + Key_{vdist} = 0.50\ m$

Saturated Soil Load below GWT:
(triangular L

$E_{h2aUN1} := \frac{\left(\gamma_{sat} - \gamma_w\right) \cdot K_o \cdot h_{2UN1}^{\ 2}}{2} \cdot B \cdot -1 = -269.8 \cdot kN$

Moment Arm (from Point O): $E_{h2alocUN1} := \frac{h_{2UN1}}{3} + Key_{vdist} = -1.00\ m$

Lateral Water Load:

Water Load GWL to Bottom of Keys:

$$H_{h2UN1} := \begin{cases} \frac{\gamma_w \cdot h_{2UN1}^{\ 2}}{2} \cdot B \cdot -1 & \text{if } Key_{vdist} < 0 \\ \frac{\gamma_w \cdot \left(h_{2UN1} + Key_{vdist}\right)^2}{2} \cdot B \cdot -1 & \text{otherwise} \end{cases} = -396.9 \cdot kN$$

Moment Arm (from Point O):

$$H_{h2locUN1} := \begin{cases} \frac{h_{2UN1}}{3} + Key_{vdist} & \text{if } Key_{vdist} < 0 \\ \frac{h_{2UN1} + Key_{vdist}}{3} & \text{otherwise} \end{cases} = -1.00 \cdot m$$

$$\Sigma H_{SoildriveUN1} := E_{s1UN1} + E_{h1UN1} + E_{h2UN1} + E_{h2aUN1} + H_{h2UN1} = -2140.9 \cdot kN$$

$$\Sigma M_{LateralSoildriveUN1} := E_{s1UN1} \cdot E_{s1locUN1} + E_{h1UN1} \cdot E_{h1locUN1} + E_{h2UN1} \cdot E_{h2locUN1} \cdots + E_{h2aUN1} \cdot E_{h2alocUN1} + H_{h2UN1} \cdot H_{h2locUN1} = -4050.8\ m \cdot kN$$

Lateral - Resisting Force

LOAD CASE UN1

Lateral Water Load:

Water Load WSEL to Bot. of Toe Key: $H_{h6UN1} := \dfrac{\gamma_w \cdot h_{6UN1}^{\ 2}}{2} \cdot B = 30.6 \cdot kN$

Moment Arm (from Point O): $H_{h6locUN1} := \dfrac{h_{6UN1}}{3} = 0.83\ m$

Water Load between Keys (if any) $H_{h6aUN1} := \begin{cases} \dfrac{\left(h_{6UN1} + h_{2UN1}\right) \cdot -Key_{vdist}}{2} \cdot \gamma_w \cdot B & \text{if } Key_{vdist} < 0 \\ 0 & \text{otherwise} \end{cases} = 225.4 \cdot kN$

Moment Arm (from Point O): $H_{h6alocUN1} := \begin{cases} \dfrac{Key_{vdist} \cdot \left(2 \cdot h_{2UN1} + h_{6UN1}\right)}{3\left(h_{2UN1} + h_{6UN1}\right)} & \text{if } Key_{vdist} < 0 \\ 0 & \text{otherwise} \end{cases} = -2.38 \cdot m$

Lateral Soil Load:

Moist Soil Load above WSEL: $E_{h7UN1} := \dfrac{\gamma_m \cdot K_o \cdot h_{7UN1}^{\ 2}}{2} \cdot B = 0.0 \cdot kN$

Moment Arm (from bot. of toe key): $E_{h7locUN1} := h_{6UN1} + \dfrac{h_{7UN1}}{3} + Key_{vdist} = -1.50\ m$

Saturated Soil Load below WSEL:
(rectangular component) $E_{h8UN1} := \left(\gamma_m \cdot K_o \cdot h_{7UN1}\right) \cdot h_{8UN1} \cdot B = 0.0 \cdot kN$

Moment Arm (from bot. of toe key): $E_{h8locUN1} := \dfrac{h_{8UN1}}{2} = 1.25\ m$

Saturated Soil Load below WSEL:
(triangular component) $E_{h8aUN1} := \dfrac{\left[\left(\gamma_{sat} - \gamma_w\right) \cdot K_o\right] \cdot h_{8UN1}^{\ 2}}{2} \cdot B = 20.8 \cdot kN$

Moment Arm (from bot. of footing): $E_{h8alocUN1} := \dfrac{h_{8UN1}}{3} = 0.83\ m$

$\Sigma H_{SoilresistUN1} := H_{h6UN1} + H_{h6aUN1} + E_{h7UN1} + E_{h8UN1} + E_{h8aUN1} = 276.8 \cdot kN$

$$\Sigma M_{HorizSoilResistUN1} := H_{h6UN1} \cdot H_{h6locUN1} + H_{h6aUN1} \cdot H_{h6alocUN1} + E_{h7UN1} \cdot E_{h7locUN1} \cdots + E_{h8UN1} \cdot E_{h8locUN1} + E_{h8aUN1} \cdot E_{h8alocUN1} = -492.9\ m \cdot kN$$

Vertical Force:

UPLIFT: Linear distribution from water at heel to water at toe:

$$\Sigma V_{UplliftUN1} := \left[\left(UWSEL_{UN1} - Bot_{ftg} + Key_{t.d}\right) + h_{2UN1}\right] \cdot \frac{b}{2} \cdot \gamma_w \cdot B \cdot -1 = -732.55 \cdot kN$$

Moment Arm (from Point O): $V_{UpliftUN1aloc} := \dfrac{b \cdot \left[2 \cdot h_{2UN1} + \left(UWSEL_{UN1} - Bot_{ftg} + Key_{t.d}\right)\right]}{3\left[h_{2UN1} + \left(UWSEL_{UN1} - Bot_{ftg} + Key_{t.d}\right)\right]} = 7.725\ m$

$$\Sigma M_{UpliftUN1} := \Sigma V_{UplliftUN1} \cdot V_{UpliftUN1aloc} = -5658.683 \cdot kN \cdot m$$

Weight of soil and water over toe:

Water Above the Top of Footing: $W_{H1UN1} := \gamma_w \cdot h_{5UN1} \cdot L_{ab} \cdot B = 17.15 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E1locUN1} := \frac{L_{ab}}{2} = 1.75\ m$

Soil above top of footing: $W_{E6UN1} := \gamma_b \cdot h_{3UN1} \cdot L_{ab} \cdot B = 21.4 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E6locUN1} := \frac{L_{ab}}{2} = 1.75\ m$

Vertical Load Due to Surcharge: $S_{UN1} := S1_{UN1} \cdot L_{cd} \cdot B = 120.855 \cdot kN$ $\quad S_{UN1loc} := b - \frac{L_{cd}}{2} = 8.97\ m$

Weight of soil and water over heel:

Moist Soil for sloped grade above top of wall:

Length of sloped portion of soil above top of wall: $L_{E3UN1} := \left(L_{cd} + t_{wb} - t_{wt}\right) = 9.00\ m$

Height of sloped soil above top of wall over heel: $h_{E3locUN1} := \left(L_{E3UN1}\right) \cdot \tan(\beta) = 0.00\ m$

Weight of sloped soil above top of wall: $W_{E3UN1} := \frac{\gamma_m}{2} \cdot h_{E3locUN1} \cdot L_{E3UN1} \cdot B = 0.0 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E3locUN1} := L_{ab} + t_{wt} + \frac{2}{3} \cdot L_{E3UN1} = 10.00\ m$

Moist soil from top of wall to groundwater level:

Height of soil from top of wall and top of GWL: $h_{1UN1} = 9.00\ m$

Length from edge of wall at GWL to edge of heel: $L_{E4UN1} := L_{E3UN1} - \left(h_{1UN1} \cdot S_{batter}\right) = 8.29\ m$

Weight of soil over heel from top of wall to GWL: $W_{E4UN1} := \gamma_m \cdot h_{1UN1} \cdot \frac{\left(L_{E3UN1} + L_{E4UN1}\right)}{2} \cdot B = 1556.3 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E4locUN1} := b - \frac{L_{E3UN1}^2 + L_{E3UN1} \cdot L_{E4UN1} + L_{E4UN1}^2}{3\left(L_{E3UN1} + L_{E4UN1}\right)} = 8.67\ m$

Saturated soil from groundwater to top of footing:

Height of soil from GWL to top of heel: $h_{E4UN1} := h_{2UN1} - t_{ftg} - Key_{h.d} = 3.00\ m$

Weight of soil over heel from GWL to top of heel: $W_{E5UN1} := \left(\gamma_{sat}\right) \cdot h_{E4UN1} \cdot \frac{\left(L_{E4UN1} + L_{cd}\right)}{2} \cdot B = 539.5 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E5locUN1} := b - \frac{L_{E4UN1}^2 + L_{E4UN1} \cdot L_{cd} + L_{cd}^2}{3\left(L_{E4UN1} + L_{cd}\right)} = 8.91\ m$

$$\Sigma V_{SoilWaterUN1} := W_{H1UN1} + W_{E6UN1} + W_{E3UN1} + W_{E4UN1} + W_{E5UN1} + S_{UN1} = 2255.2 \cdot kN$$

$$\Sigma M_{VertSoilWaterResistUN1} := W_{H1UN1} \cdot W_{E1locUN1} + W_{E6UN1} \cdot W_{E6locUN1} \cdots + W_{E3UN1} \cdot W_{E3locUN1} + W_{E4UN1} \cdot W_{E4locUN1} + W_{E5UN1} \cdot W_{E5locUN1} + S_{UN1} \cdot S_{UN1loc} = 19460.6\ m \cdot kN$$

THIS PAGE INTENTIONALLY LEFT BLANK
PLEASE GO TO THE NEXT PAGE

STABILITY ASSESSMENT:

LOAD CASE UN1

CHECK SLIDING ALONG HORIZONTAL SLIDING PLANE:

Summation of the vertical forces:

$$\Sigma V_{UN1} := \Sigma V_{conc} + \Sigma V_{SoilWaterUN1} + \Sigma V_{UpliftUN1} = 2501.7 \cdot kN$$

Summation of the horizontal forces:

$$\Sigma H_{UN1} := \Sigma H_{SoildriveUN1} + \Sigma H_{SoilresistUN1} = -1864.1 \cdot kN$$

Safety Factor for Sliding Horizontal Failure Plane

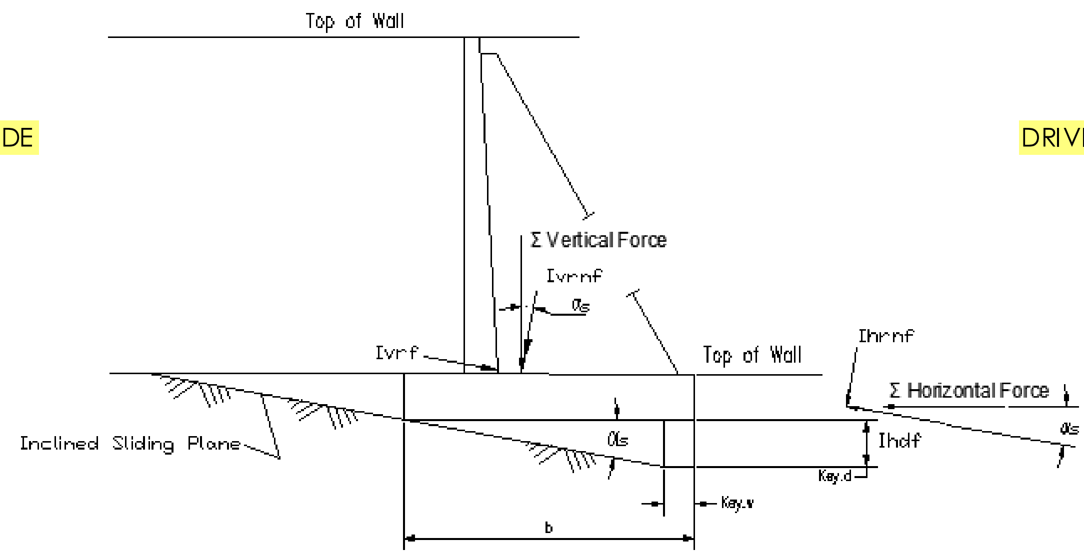
$$FS_{Horiz.SlidingUN1} := \frac{\left|\Sigma V_{UN1}\right| \cdot \tan\left(\phi_{rock} \cdot \frac{\pi}{180}\right)}{\left|\Sigma H_{UN1}\right|} = 0.65$$

$$FS_{Sliding.check1.UN1} := \begin{cases} \text{"OKAY"} & \text{if } FS_{Horiz.SlidingUN1} > FS_{sliding.reqUN1} \\ \text{"NG - key req'"} & \text{otherwise} \end{cases} = \text{"NG - key req'"}$$

CHECK FACTOR OF SAFETY SLIDING WITH KEY (INCLINED SLIDING PLANE):

RESISTING SIDE

DRIVING SIDE



TOE

HEEL

Ivrf=Inclined Resisting Force
Ivrnf=Inclined Resisting Normal Force
Ihrnf=Inclined Resisting Normal Force
Ihdf=Inclined Driving Force

$\alpha s = 0.322$ as degrees= $\alpha s \cdot \left(\frac{180}{\pi}\right) = 18.43$

(With properly engineered reinforced concrete Key, horizontal sliding plane thru Toe is protected, critical sliding plane is relocated to the INCLINED SLIDING PLANE FROM HEEL KEY To TOE, Bedrock Mass above this examing plane is mobilized by reinforced concrete key and combined into Structural Wedge.)

Resolve ΣV_{UN1} & ΣH_{UN1}

$$\Sigma V_{InclinedUN1} := \cos(\alpha s) \cdot \left(\left|\Sigma V_{UN1} + V_{rocksection}\right|\right) + \sin(\alpha s) \cdot \left|\Sigma H_{UN1}\right| = 3545.6 \cdot kN$$

$$\Sigma H_{InclinedUN1} := \cos(\alpha s) \cdot \left|\Sigma H_{UN1}\right| - \sin(\alpha s) \cdot \left(\left|\Sigma V_{UN1} + V_{rocksection}\right|\right) = 783.0 \cdot kN$$

LOAD CASE UN1

Safety Factor for Sliding Inclined Failure Plane

$$FS_{InclinedlSlidingUN1} := \frac{\Sigma V_{InclinedUN1} \cdot \tan(\phi_r)}{\Sigma H_{InclinedUN1}} = 2.02$$

$$FS_{Sliding.check2.UN1} := \begin{cases} \text{"OKAY "} & \text{if } FS_{InclinedlSlidingUN1} > FS_{sliding.reqUN1} \\ \text{"NG - Revise Structure""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

CHECK FOUNDATION ECCENTRICITY:

Summation of the resisting moments about the toe:

$$\Sigma M_{resUN1} := \Sigma M_{conc} + \Sigma M_{VertSoilWaterResistUN1} + \Sigma M_{HorizSoilResistUN1} + \Sigma M_{rocksection} = 30132 \cdot kN \cdot m$$

Summation of the overturning moments about the toe:

$$\Sigma M_{oUN1} := \Sigma M_{LateralSoildriveUN1} + \Sigma M_{UpliftUN1} = -9710 \cdot kN \cdot m$$

Total moment: $\Sigma M_{UN1} := \Sigma M_{resUN1} + \Sigma M_{oUN1} = 20422.3 \cdot kN \cdot m$

Normal force to base: $\Sigma V_{InclinedUN1} = 3545.6 \cdot kN$

Inclined Sliding Plane Length: $L_{incline} = 13.7 \cdot m$

Eccentricity (inclined plane): $ex_{UN1} := \frac{L_{incline}}{2} - \frac{\Sigma M_{UN1}}{\Sigma V_{InclinedUN1}} = 1.09\ m$

Kern = 2.284 m

Eccentricity Check: $e_{check.UN1} := \begin{cases} \text{"Okay"} & \text{if } ex_{UN1} \le Kern \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"Okay"}$

CHECK FOUNDATION BEARING CAPACITY:

Base Section Modulus: $S_b = 31.3\ m^3$

Bearing Pressure Under Toe:

$$\sigma_{ToeUN1} := \begin{cases} \left[\frac{\Sigma V_{InclinedUN1}}{L_{incline} \cdot B} + \frac{(\Sigma V_{InclinedUN1} \cdot ex_{UN1})}{S_b}\right] & \text{if } \frac{\Sigma V_{InclinedUN1}}{L_{incline} \cdot B} \ge \frac{\Sigma V_{InclinedUN1} \cdot ex_{UN1}}{S_b} \\ \frac{2 \cdot \Sigma V_{InclinedUN1}}{B \cdot 3\left(\frac{b}{2} - ex_{UN1}\right)} & \text{otherwise} \end{cases} = 382.4 \cdot kPa$$

$$Bearing_{ChecktoeUN1} := \begin{cases} \text{"OKAY "} & \text{if } \sigma_{ToeUN1} < \sigma_{allowUN1} \\ \text{"NG""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

Bearing Pressure Under Heel:

$$\sigma_{HeelUN1} := \begin{cases} \left[\frac{\Sigma V_{InclinedUN1}}{L_{incline} \cdot B} - \frac{(\Sigma V_{InclinedUN1} \cdot ex_{UN1})}{S_b}\right] & \text{if } \frac{\Sigma V_{InclinedUN1}}{L_{incline} \cdot B} \ge \frac{\Sigma V_{InclinedUN1} \cdot ex_{UN1}}{S_b} \\ 0 & \text{otherwise} \end{cases} = 135.1 \cdot kPa$$

$$Bearing_{CheckheelUN1} := \left(\begin{cases} \text{"OKAY "} & \text{if } \sigma_{HeelUN1} < \sigma_{allowUN1} \wedge \sigma_{HeelUN1} > 0 \\ \text{"NG - perform cracked base analysis""} & \text{otherwise} \end{cases} \right) = \text{"OKAY "}$$

CHECK FLOATATION:

Safety Factor for Floatation:

$$FS_{FloatationUN1} := \frac{\Sigma V_{conc} + \Sigma V_{SoilWaterUN1}}{\left|\Sigma V_{UpliftUN1}\right|} = 4.41$$

$$FS_{Floatation.UN1.check} := \begin{cases} \text{"OKAY "} & \text{if } FS_{FloatationUN1} > FS_{req.UN1.flt} \\ \text{"Revise Structure""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

CHECK OVERTURNING

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.
Assumptions are made in order to compute overturning stablity of indetermine forces on monolith with key;
(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.
(b) The horizontal resisting force acting on the key, P.key, is that required for static equilibrium
(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1

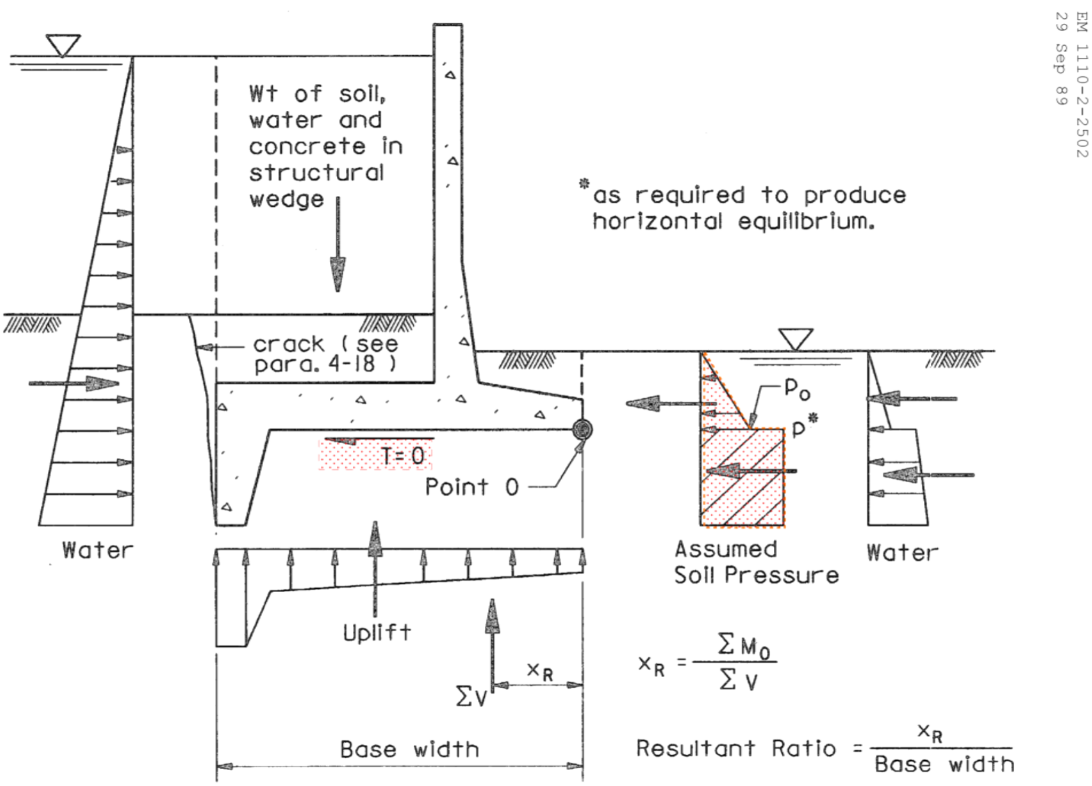


Figure 4-5. Forces for overturning analysis for wall with horizontal base and key

Modify Uplift for Overturning Analysis: **LOAD CASE UN1**

(Uplift is calculated along the concrete/rock contact using the Line of Creep method)

Water Pressure at h: $u_{h.UN1} := \Delta h_{g.hj.UN1} \cdot \gamma_w = 88.20 \cdot kPa$

Water Pressure at o: $u_{o.UN1} := \left(\Delta h_{g.no.UN1} - \frac{\Delta h_{g.r.UN1} \cdot L_{ho.UN1}}{L_{ho.UN1}}\right) \cdot \gamma_w = 24.5 \cdot kPa$

Head loss between point h and o: $\Delta h_{ho.UN1} := \Delta h_{g.r.UN1} \cdot \frac{L_{ho.UN1}}{L_{ho.UN1}} = 2.5\,m$

Length of concrete base (h -> o): $L_{baseho.UN1} := Key_{h.w} + Key_{h.d} + Key_{hdist} + Key_{t.d} + Key_{t.w} = 17\,m$

Head loss along h -> j: $\Delta h_{hj.UN1} := \Delta h_{ho.UN1} \cdot \frac{Key_{h.w}}{L_{baseho.UN1}} = 0.147\,m$

Water Pressure at j: $u_{j.UN1} := \left(\Delta h_{g.hj.UN1} - \Delta h_{hj.UN1}\right) \cdot \gamma_w = 86.76 \cdot kPa$

Head loss along h -> k: $\Delta h_{hjk.UN1} := \Delta h_{ho.UN1} \cdot \left(\frac{Key_{h.w} + Key_{h.d}}{L_{baseho.UN1}}\right) = 0.735\,m$

Water Pressure at k: $u_{k.UN1} := \left(\Delta h_{g.km.UN1} - \Delta h_{hjk.UN1}\right) \cdot \gamma_w = 41.79 \cdot kPa$

Head loss along h -> m: $\Delta h_{hjkm.UN1} := \Delta h_{ho.UN1} \cdot \left(\frac{Key_{h.w} + Key_{h.d} + Key_{hdist}}{L_{baseho.UN1}}\right) = 2.5\,m$

Water Pressure at m: $u_{m.UN1} := \left(\Delta h_{g.km.UN1} - \Delta h_{hjkm.UN1}\right) \cdot \gamma_w = 24.50 \cdot kPa$

Head loss along h -> n: $\Delta h_{hjkmn.UN1} := \Delta h_{ho.UN1} \cdot \left(\frac{Key_{h.w} + Key_{h.d} + Key_{hdist} + Key_{t.d}}{L_{baseho.UN1}}\right) = 2.5\,m$

Water Pressure at n: $u_{n.UN1} := \left(\Delta h_{g.no.UN1} - \Delta h_{hjkmn.UN1}\right) \cdot \gamma_w = 24.50 \cdot kPa$

Uplift under key at heel: $V_{ulkeyhUN1.OT} := \frac{\left(u_{h.UN1} + u_{j.UN1}\right) \cdot Key_{h.w}}{2} \cdot B \cdot -1 = -87.479 \cdot kN$

Moment Arm (from Point O): $V_{ulkeyhUN1loc.OT} := b - \frac{Key_{h.w} \cdot \left(2 \cdot u_{j.UN1} + u_{h.UN1}\right)}{3 \cdot \left(u_{j.UN1} + u_{h.UN1}\right)} = 12.501\,m$

Uplift under base: $V_{ulbaseUN1.OT} := \frac{\left(u_{k.UN1} + u_{m.UN1}\right) \cdot Key_{hdist}}{2} \cdot B \cdot -1 = -397.765 \cdot kN$

Moment Arm (from Point O): $V_{ulbaseUN1loc.OT} := b - Key_{h.w} - \frac{Key_{hdist} \cdot \left(2 \cdot u_{m.UN1} + u_{k.UN1}\right)}{3 \cdot \left(u_{m.UN1} + u_{k.UN1}\right)} = 6.522\,m$

Uplift under key at toe: $V_{ulkeytUN1.OT} := \frac{\left(u_{n.UN1} + u_{o.UN1}\right) \cdot Key_{t.w}}{2} \cdot B \cdot -1 = 0 \cdot kN$

Moment Arm (from Point O): $V_{ulkeytUN1loc.OT} := \frac{Key_{t.w} \cdot \left(2 \cdot u_{n.UN1} + u_{o.UN1}\right)}{3 \cdot \left(u_{n.UN1} + u_{o.UN1}\right)} = 0$

$$\Sigma V_{UpliftUN1.OT} := V_{ulkeyhUN1.OT} + V_{ulbaseUN1.OT} + V_{ulkeytUN1.OT} = -485 \cdot kN$$

$$U_{UN1.loc.OT} := \frac{V_{ulkeyhUN1.OT} \cdot V_{ulkeyhUN1loc.OT} + V_{ulbaseUN1.OT} \cdot V_{ulbaseUN1loc.OT} + V_{ulkeytUN1.OT} \cdot V_{ulkeytUN1loc.OT}}{\Sigma V_{UpliftUN1.OT}} = 7.60\,m$$

$$\Sigma M_{UpliftUN1.OT} := \Sigma V_{UpliftUN1.OT} \cdot U_{UN1.loc.OT} = -3687.7 \cdot kN \cdot m$$

Modify Lateral Water Pressure (Resisting) for Overturning Analysis:

(Resisting water pressure is calculated using the Line of Creep method)

Water Load at Key (heel):
$$H_{h2UN1.OT} := \frac{u_{k.UN1} + u_{j.UN1}}{2} \cdot Key_{h.d} B = 257.1 \cdot kN$$

Moment Arm (from Point O):
$$H_{h2locUN1.OT} := \frac{Key_{h.d} \cdot (2 \cdot u_{k.UN1} + u_{j.UN1})}{3(u_{k.UN1} + u_{j.UN1})} + Key_{vdist} = -2.23\ m$$

Water Load at Key (toe):
$$H_{h6UN1.OT} := \frac{u_{o.UN1} \cdot (UWSEL_{UN1} - Bot_{ftg} + Key_{t.d})}{2} \cdot B = 31 \cdot kN$$

Moment Arm (from Point O):
$$H_{h6locUN1.OT} := \frac{UWSEL_{UN1} - Bot_{ftg} + Key_{t.d}}{3} = 0.83\ m$$

$$\Sigma H_{waterresistUN1.OT} := H_{h2UN1.OT} + H_{h6UN1.OT} = 287.73 \cdot kN$$

$$H_{waterresistlocUN1.OT} := \frac{H_{h2UN1.OT} \cdot H_{h2locUN1.OT} + H_{h6UN1.OT} \cdot H_{h6locUN1.OT}}{\Sigma H_{waterresistUN1.OT}} = -1.907\ m$$

$$\Sigma M_{waterresistUN1.OT} := \Sigma H_{waterresistUN1.OT} \cdot H_{waterresistlocUN1.OT} = -548.64 \cdot kN \cdot m$$

Modify Lateral Soil Loads for Overturning Analysis:

(Lateral soil loads are calculated down to Point O instead of bottom of shear key)

Driving Soil Load (Headwater Side):

Surcharge Load:
$$E_{s1UN1.OT} := S1_{UN1} \cdot K_o \cdot (H_w + Key_{h.d} + Key_{vdist}) \cdot B \cdot -1 = -114.662 \cdot kN$$

Moment Arm (from Point O):
$$E_{s1locUN1.OT} := \frac{H_w + Key_{h.d} + Key_{vdist}}{2} = 7.00\ m$$

Moist Soil Load above GWL:
$$E_{h1UN1.OT} := \frac{\gamma_m \cdot K_o \cdot h_{1UN1}^{\ 2}}{2} B \cdot -1 = -442.3 \cdot kN$$

Moment Arm (from Point O):
$$E_{h1locUN1.OT} := \frac{h_{1UN1}}{3} + h_{2UN1} + Key_{vdist} = 8.00\ m$$

Saturated Soil Load below GWL: (rectangular component)
$$E_{h2UN1.OT} := (\gamma_m \cdot K_o \cdot h_{1UN1}) \cdot (h_{2UN1} + Key_{vdist}) \cdot B \cdot -1 = -491.4 \cdot kN$$

Moment Arm (from Point O):
$$E_{h2locUN1.OT} := \frac{h_{2UN1} + Key_{vdist}}{2} = 2.50\ m$$

Saturated Soil Load below GWL: (triangular component)
$$E_{h2aUN1.OT} := \frac{(\gamma_{sat} - \gamma_w) \cdot K_o \cdot (h_{2UN1} + Key_{vdist})^2}{2} \cdot B \cdot -1 = -83.3 \cdot kN$$

Moment Arm (from Point O):
$$E_{h2alocUN1.OT} := \frac{h_{2UN1} + Key_{vdist}}{3} = 1.67\ m$$

Resisting Soil Load (Tailwater Side):

(Determine resisting soil load based on depth variation between the keys (ie. Key_{vdist}). In case where key at heel is deeper than key at toe (ie. $Key_{vdist} < 0$), resisting soil load (p*) is assumed to produce horizontal equilibrium as per Figure 4-5 above. Resisting soil load (p_o) is neglected.)

Total Driving Force: $\Sigma H_{SoildriveUN1.OT} := E_{s1UN1.OT} + E_{h1UN1.OT} + E_{h2UN1.OT} + E_{h2aUN1.OT} + H_{h2UN1} = -1528.5 \cdot kN$

Total Resisting Force: $\Sigma H_{waterresistUN1.OT} = 287.7 \cdot kN$

Assumed Soil Load p*: $E_{h8UN1a.OT} := \left(\Sigma H_{SoildriveUN1.OT} + \Sigma H_{waterresistU1.OT}\right) \cdot -1 = 1240.774 \cdot kN$

Moment Arm (from Point O): $E_{h8UN1a.loc.OT} := \dfrac{Key_{vdist}}{2} = -2\, m$

$$E_{h8UN1.OT} := \begin{cases} E_{h8UN1a.OT} & \text{if } Key_{vdist} < 0 \\ \Sigma H_{SoilresistUN1} - H_{h6UN1} - H_{h6aUN1} & \text{otherwise} \end{cases} = 1240.774 \cdot kN$$

$$\Sigma M_{SoilresistUN1.OT} := \begin{cases} E_{h8UN1a.OT} \cdot E_{h8UN1a.loc.OT} & \text{if } Key_{vdist} < 0 \\ \Sigma M_{HorizSoilResistUN1} - H_{h6UN1} \cdot H_{h6locUN1} - H_{h6aUN1} \cdot H_{h6alocUN1} & \text{otherwise} \end{cases} = -2481.548 \cdot kN \cdot m$$

Sum of Moment about Point O:

$$\Sigma M_{LateraldriveUN1.OT} := E_{s1UN1.OT} \cdot E_{s1locUN1.OT} + E_{h1UN1.OT} \cdot E_{h1locUN1.OT} + E_{h2UN1.OT} \cdot E_{h2locUN1.OT} \dots + E_{h2aUN1.OT} \cdot E_{h2alocUN1.OT} + H_{h2UN1} \cdot H_{h2locUN1} = -5311.2 \cdot kN \cdot m$$

$$\Sigma M_{LateralresistUN1.OT} := \Sigma M_{waterresistUN1.OT} + \Sigma M_{SoilresistUN1.OT} = -3030.2 \cdot kN \cdot m$$

Total moment:

$$\Sigma M_{UN1.OT} := \Sigma M_{conc} + \Sigma M_{VertSoilWaterResistUN1} + \Sigma M_{UpliftUN1.OT} + \Sigma M_{LateraldriveUN1.OT} + \Sigma M_{LateralresistUN1.OT} = 13680.4 \cdot kN \cdot m$$

Total Vertical Force: $\Sigma V_{UN1.OT} := \Sigma V_{conc} + \Sigma V_{SoilWaterUN1} + \Sigma V_{UplliftUN1.OT} = 2749.0 \cdot kN$

Distance X_R: EM 1110-2-2502 Eq.4-1 $X_{R.UN1} := \dfrac{\Sigma M_{UN1.OT}}{\Sigma V_{UN1.OT}} = 4.977\, m$

Overturning Resultant Ratio $Ratio_{UN1.OT} := \dfrac{X_{R.UN1}}{b} = 0.38$

$$Ratio_{UN1.OT.check} := \begin{cases} \text{"OKAY "} & \text{if } Ratio_{UN1.OT} > X_{R.reqUN1} \\ \text{"Revise Structure""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

CHECK FOUNDATION ECCENTRICITY (HORIZONTAL PLANE):

Eccentricity (horizontal plan): $ex_{UN1.OT} := \dfrac{b}{2} - \dfrac{\Sigma M_{UN1.OT}}{\Sigma V_{UN1.OT}} = 1.52\, m$ $Kern_{OT} = 2.167\, m$

Eccentricity Check: $$e_{check.UN1.OT} := \begin{cases} \text{"Okay"} & \text{if } ex_{UN1} \le Kern_{OT} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"Okay"}$$

LOAD CASE UN1

CHECK FOUNDATION BEARING CAPACITY (HORIZONTAL PLANE):

Base Section Modulus: $S_{b.OT} = 28.17\,m^3$

Bearing Pressure Under Toe:

$$\sigma_{ToeUN1.OT} := \begin{cases} \left(\dfrac{\Sigma V_{UN1.OT}}{b \cdot B} + \dfrac{\Sigma V_{UN1.OT} \cdot ex_{UN1.OT}}{S_{b.OT}}\right) & \text{if } \dfrac{\Sigma V_{UN1.OT}}{b \cdot B} \geq \dfrac{\Sigma V_{UN1.OT} \cdot ex_{UN1.OT}}{S_{b.OT}} \\ \dfrac{2 \cdot \Sigma V_{UN1.OT}}{B \cdot 3\left(\dfrac{b}{2} - ex_{UN1.OT}\right)} & \text{otherwise} \end{cases} = 360.1 \cdot kPa$$

$$Bearing_{ChecktoeUN1.OT} := \begin{cases} \text{"OKAY "} & \text{if } \sigma_{ToeUN1.OT} < \sigma_{allowUN1} \\ \text{"NG - for reference only""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

Bearing Pressure Under Heel:

$$\sigma_{HeelUN1.OT} := \begin{cases} \left(\dfrac{\Sigma V_{UN1.OT}}{b \cdot B} - \dfrac{\Sigma V_{UN1.OT} \cdot ex_{UN1.OT}}{S_{b.OT}}\right) & \text{if } \dfrac{\Sigma V_{UN1.OT}}{b \cdot B} \geq \dfrac{\Sigma V_{UN1.OT} \cdot ex_{UN1.OT}}{S_{b.OT}} \\ 0 & \text{otherwise} \end{cases} = 62.8 \cdot kPa$$

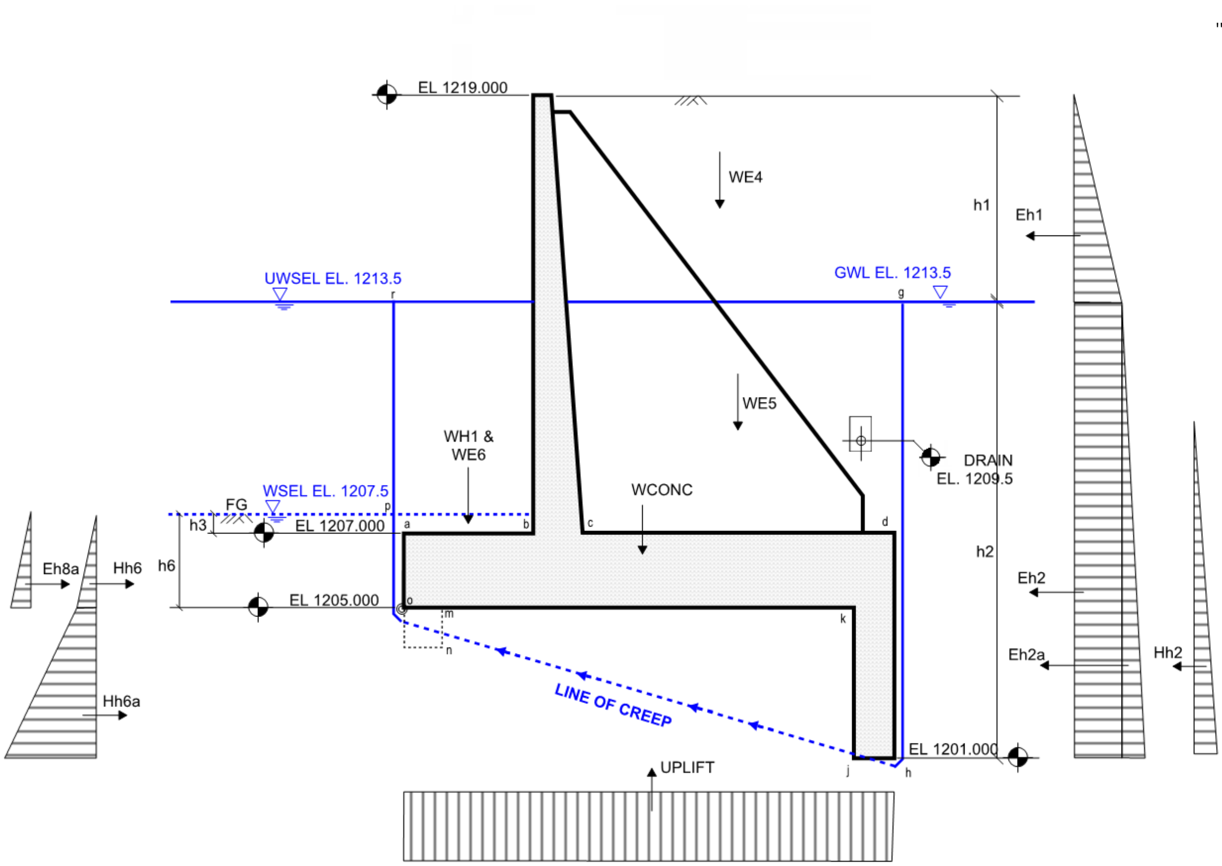
$$Bearing_{CheckheelUN1.OT} := \left(\begin{cases} \text{"OKAY "} & \text{if } \sigma_{HeelUN1.OT} < \sigma_{allowUN1} \wedge \sigma_{HeelUN1.OT} > 0 \\ \text{"NG - for reference only""} & \text{otherwise} \end{cases}\right) = \text{"OKAY "}$$

SUMMARY OF STABILITY ASSESSMENT:

LOAD CASE UN1

Sliding Factor of Safety: (Horizontal Plane - Ref only)	$FS_{Horiz.SlidingUN1} = 0.65$	$FS_{Sliding.check1.UN1}$ = "NG - key req""
Sliding Factor of Safety: (Inclined Plane)	$FS_{InclinedlSlidingUN1} = 2.02$	$FS_{Sliding.check2.UN1}$ = "OKAY "
Eccentricity: (Inclined Plane)	$ex_{UN1} = 1.09\ m$	$e_{check.UN1}$ = "Okay"
Bearing Pressure At Heel: (Inclined Plane)	$\sigma_{HeelUN1} = 135 \cdot kPa$	$Bearing_{CheckheelUN1}$ = "OKAY "
Bearing Pressure At Toe: (Inclined Plane)	$\sigma_{ToeUN1} = 382 \cdot kPa$	$Bearing_{ChecktoeUN1}$ = "OKAY "
Flotation Factor of Safety (horizontal plane)	$FS_{FloatationUN1} = 4.41$	$FS_{Floatation.UN1.check}$ = "OKAY "
Overturning Resultant Ratio: (horizontal plane)	$Ratio_{UN1.OT} = 0.38$	$Ratio_{UN1.OT.check}$ = "OKAY "
Eccentricity: (horizontal plane - Ref only)	$ex_{UN1.OT} = 1.52\ m$	$e_{check.UN1.OT}$ = "Okay"
Bearing Pressure At Heel: (horizontal plane - Ref only)	$\sigma_{HeelUN1.OT} = 63 \cdot kPa$	$Bearing_{CheckheelUN1.OT}$ = "OKAY "
Bearing Pressure At Toe: (horizontal plane - Ref only)	$\sigma_{ToeUN1.OT} = 360 \cdot kPa$	$Bearing_{ChecktoeUN1.OT}$ = "OKAY "

LOAD CASE UN2 - INEFFECTIVE DRAIN



UN2 DESIGN CASE

LOAD CASE UN2 ACCEPTANCE PARAMETERS

FS sliding:

Unusual (UN) 1.3 (without cohesion) (Table 3-3, USACE EM 1110-2-2100)

Resultant Location:

Unsual (UN) Inside middle third ~100% base in compression

Required Factor of Safety for Sliding: $FS_{sliding.reqUN2} := 1.3$ (Without Cohesion)

Allowable rock bearing pressure: $\sigma_{allowUN2} := 1470kPa$ (Section 5.2, Design Criteria EM 1110-2-2100 Section 3-10)

Overturning Required Resultant Ratio: $X_{R.reqUN2} := 0.333$ (EM 1110-2-2502, Figure 4-4)

Required Factor of Safety for Floatation $FS_{req.UN2.flt} := 1.3$

SOIL HEIGHTS and Water Levels:

LOAD CASE UN2

Heel Conditions:

Groundwater Elevation at Heel: $GWL_{UN2} := 1213.5m$

Distance from Finish Grade to Groundwater at Heel: $h_{1UN2} := \left[T_w - GWL_{UN2} + \left(L_{cd} + t_{wb} - t_{wt}\right) \cdot \tan(\beta)\right] = 5.50\ m$

Distance from Water Surface to Bottom of Footing at Heel: $h_{2UN2} := GWL_{UN2} - Bot_{ftg} + Key_{h.d} = 12.50\ m$

Toe Conditions:

Water Surface Elevation at Toe: $WSEL_{UN2} := 1207.5m$

Water Surface Elevation at Toe for Uplift: $UWSEL_{UN2} := 1213.5 \cdot m$

Finish Grade at Toe providing lateral resistance: $FG_{toeUN2} := 1207.5 \cdot m$

Soil Depth Above top of footing: $h_{3aUN2} := FG_{toeUN2} - Top_{ftg} = 0.5\ m$

$$h_{3UN2} := \begin{cases} h_{3aUN2} & \text{if } FG_{toeUN2} - Top_{ftg} \ge 0 \\ 0 & \text{otherwise} \end{cases} = 0.5$$

Resisting Fill at Toe: $h_{4UN2} := FG_{toeUN2} - Bot_{ftg} + Key_{t.d} = 2.50\ m$

Distance from Water Level to Top of Footing: $h_{5UN2} := WSEL_{UN2} - Top_{ftg} = 0.50\ m$

Distance from Water Surface to Bottom of Toe Key: $h_{6UN2} := WSEL_{UN2} - Bot_{ftg} + Key_{t.d} = 2.50\ m$

Soil Depth Above WSEL: $h_{7aUN2} := FG_{toeUN2} - WSEL_{UN2} = 0\ m$

$$h_{7UN2} := \begin{cases} h_{7aUN2} & \text{if } FG_{toeUN2} - WSEL_{UN2} \ge 0 \\ 0 & \text{otherwise} \end{cases} = 0$$

Soil Depth Below WSEL:

$$h_{8UN2} := \begin{cases} WSEL_{UN2} - Bot_{ftg} + Key_{t.d} & \text{if } FG_{toeUN2} - WSEL_{UN2} \ge 0 \\ h_{4UN2} & \text{otherwise} \end{cases} = 2.5$$

For Line of Creep Method: $L_{ho.UN2} := \sqrt{b^2 + \left(Key_{h.d} - Key_{t.d}\right)^2} = 13.601\ m$

Head Loss from Point g:

$\Delta h_{g.hj.UN2} := h_{2UN2} = 12.5\ m$ (to point h & j)

$\Delta h_{g.km.UN2} := GWL_{UN2} - Bot_{ftg} = 8.5\ m$ (to point k & m)

$\Delta h_{g.no.UN2} := GWL_{UN2} - Bot_{ftg} + Key_{t.d} = 8.5\ m$ (to point n & o)

$\Delta h_{g.p.UN2} := GWL_{UN2} - FG_{toeUN2} = 6\ m$ (to point p)

$\Delta h_{g.r.UN2} := GWL_{UN2} - UWSEL_{UN2} = 0\ m$ (to point r)

Surcharge

Surcharge on Heel: $S1_{UN2} := 0.0 \dfrac{kN}{m^2}$

Calculate Soil Lateral Pressure Coefficients:

For all load cases except seismic, soil loading to be based on At-Rest Condition.
Calculate at-rest pressure coefficient Ko based on Jaky's (1944) equation.

Soil At Rest Static Coefficient: $K_o := \frac{1 - \sin(\phi)}{1 + \sin(\beta)} = 0.546$ (Eq. 3-6, USACE EM 1110-2-2502)

Lateral - Driving Force

Static At-Rest:

Surcharge Load: $E_{s1UN2} := S1_{UN2} \cdot K_o \cdot \left(H_w + Key_{h.d}\right) \cdot B \cdot -1 = 0 \cdot kN$

Moment Arm (from Point O): $E_{s1locUN2} := \frac{H_w + Key_{h.d}}{2} + Key_{vdist} = 5.00\ m$

Moist Soil Load above GWL: $E_{h1UN2} := \frac{\gamma_m \cdot K_o \cdot h_{1UN2}^2}{2} B \cdot -1 = -165.2 \cdot kN$

Moment Arm (from Point O): $E_{h1locUN2} := \frac{h_{1UN2}}{3} + h_{2UN2} + Key_{vdist} = 10.33\ m$

Saturated Soil Load below GWL: (rectangular component) $E_{h2UN2} := \left(\gamma_m \cdot K_o \cdot h_{1UN2}\right) \cdot h_{2UN2} \cdot B \cdot -1 = -750.8 \cdot kN$

Moment Arm (from Point O): $E_{h2locUN2} := \frac{h_{2UN2}}{2} + Key_{vdist} = 2.25\ m$

Saturated Soil Load below GWL: (triangular component) $E_{h2aUN2} := \frac{\left(\gamma_{sat} - \gamma_w\right) \cdot K_o \cdot h_{2UN2}^2}{2} \cdot B \cdot -1 = -520.4 \cdot kN$

Moment Arm (from Point O): $E_{h2alocUN2} := \frac{h_{2UN2}}{3} + Key_{vdist} = 0.17\ m$

Lateral Water Load:

Water Load GWL to Bottom of Keys:

$$H_{h2UN2} := \begin{cases} \frac{\gamma_w \cdot h_{2UN2}^2}{2} \cdot B \cdot -1 & \text{if } Key_{vdist} < 0 \\ \frac{\gamma_w \cdot \left(h_{2UN2} + Key_{vdist}\right)^2}{2} \cdot B \cdot -1 & \text{otherwise} \end{cases} = -765.6 \cdot kN$$

Moment Arm (from Point O):

$$H_{h2locUN2} := \begin{cases} \frac{h_{2UN2}}{3} + Key_{vdist} & \text{if } Key_{vdist} < 0 \\ \frac{h_{2UN2} + Key_{vdist}}{3} & \text{otherwise} \end{cases} = 0.17 \cdot m$$

$$\Sigma H_{SoildriveUN2} := E_{s1UN2} + E_{h1UN2} + E_{h2UN2} + E_{h2aUN2} + H_{h2UN2} = -2202.0 \cdot kN$$

$$\Sigma M_{LateralSoildriveUN2} := E_{s1UN2} \cdot E_{s1locUN2} + E_{h1UN2} \cdot E_{h1locUN2} + E_{h2UN2} \cdot E_{h2locUN2} \cdots + E_{h2aUN2} \cdot E_{h2alocUN2} + H_{h2UN2} \cdot H_{h2locUN2} = -3610.3\ m \cdot kN$$

Lateral - Resisting Force

LOAD CASE UN2

Lateral Water Load:

Water Load WSEL to Bot. of Toe Key:
$$H_{h6UN2} := \frac{\gamma_w \cdot h_{6UN2}^2}{2} \cdot B = 30.6 \cdot kN$$

Moment Arm (from Point O):
$$H_{h6locUN2} := \frac{h_{6UN2}}{3} = 0.83\ m$$

Water Load between Keys (if any)
$$H_{h6aUN2} := \begin{cases} \frac{\left(h_{6UN2} + h_{2UN2}\right) \cdot -Key_{vdist}}{2} \cdot \gamma_w \cdot B & \text{if } Key_{vdist} < 0 \\ 0 & \text{otherwise} \end{cases} = 294.0 \cdot kN$$

Moment Arm (from Point O):
$$H_{h6alocUN2} := \begin{cases} \frac{Key_{vdist} \cdot \left(2 \cdot h_{2UN2} + h_{6UN2}\right)}{3\left(h_{2UN2} + h_{6UN2}\right)} & \text{if } Key_{vdist} < 0 \\ 0 & \text{otherwise} \end{cases} = -2.44 \cdot m$$

Lateral Soil Load:

Moist Soil Load above WSEL:
$$E_{h7UN2} := \frac{\gamma_m \cdot K_o \cdot h_{7UN2}^2}{2} B = 0.0 \cdot kN$$

Moment Arm (from bot. of toe key):
$$E_{h7locUN2} := h_{6UN2} + \frac{h_{7UN2}}{3} + Key_{vdist} = -1.50\ m$$

Saturated Soil Load below WSEL:
(rectangular component)
$$E_{h8UN2} := \left(\gamma_m \cdot K_o \cdot h_{7UN2}\right) \cdot h_{8UN2} \cdot B = 0.0 \cdot kN$$

Moment Arm (from bot. of toe key):
$$E_{h8locUN2} := \frac{h_{8UN2}}{2} = 1.25\ m$$

Saturated Soil Load below WSEL:
(triangular component)
$$E_{h8aUN2} := \frac{\left[\left(\gamma_{sat} - \gamma_w\right) \cdot K_o\right] \cdot h_{8UN2}^2}{2} \cdot B = 20.8 \cdot kN$$

Moment Arm (from bot. of footing):
$$E_{h8alocUN2} := \frac{h_{8UN2}}{3} = 0.83\ m$$

$$\Sigma H_{SoilresistUN2} := H_{h6UN2} + H_{h6aUN2} + E_{h7UN2} + E_{h8UN2} + E_{h8aUN2} = 345.4 \cdot kN$$

$$\Sigma M_{HorizSoilResistUN2} := H_{h6UN2} \cdot H_{h6locUN2} + H_{h6aUN2} \cdot H_{h6alocUN2} + E_{h7UN2} \cdot E_{h7locUN2} \cdots + E_{h8UN2} \cdot E_{h8locUN2} + E_{h8aUN2} \cdot E_{h8alocUN2} = -675.8\ m \cdot kN$$

Vertical Force:

UPLIFT: Linear distribution from water at heel to water at toe:

$$\Sigma V_{UpliftUN2} := \left[\left(UWSEL_{UN2} - Bot_{ftg} + Key_{t.d}\right) + h_{2UN2}\right] \cdot \frac{b}{2} \cdot \gamma_w \cdot B \cdot -1 = -1337.7 \cdot kN$$

Moment Arm (from Point O):
$$V_{UpliftUN2aloc} := \frac{b \cdot \left[2 \cdot h_{2UN2} + \left(UWSEL_{UN2} - Bot_{ftg} + Key_{t.d}\right)\right]}{3\left[h_{2UN2} + \left(UWSEL_{UN2} - Bot_{ftg} + Key_{t.d}\right)\right]} = 6.913\ m$$

$$\Sigma M_{UpliftUN2} := \Sigma V_{UpliftUN2} \cdot V_{UpliftUN2aloc} = -9247.117 \cdot kN \cdot m$$

Weight of soil and water over toe:

Water Above the Top of Footing: $W_{H1UN2} := \gamma_w \cdot h_{5UN2} \cdot L_{ab} \cdot B = 17.15 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E1locUN2} := \frac{L_{ab}}{2} = 1.75\ m$

Soil above top of footing: $W_{E6UN2} := \gamma_b \cdot h_{3UN2} \cdot L_{ab} \cdot B = 21.4 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E6locUN2} := \frac{L_{ab}}{2} = 1.75\ m$

Vertical Load Due to Surcharge: $S_{UN2} := S1_{UN2} \cdot L_{cd} \cdot B = 0 \cdot kN$ $\quad S_{UN2loc} := b - \frac{L_{cd}}{2} = 8.97\ m$

Weight of soil and water over heel:

Moist Soil for sloped grade above top of wall:

Length of sloped portion of soil above top of wall: $L_{E3UN2} := \left(L_{cd} + t_{wb} - t_{wt}\right) = 9.00\ m$

Height of sloped soil above top of wall over heel: $h_{E3locUN2} := \left(L_{E3UN2}\right) \cdot \tan(\beta) = 0.00\ m$

Weight of sloped soil above top of wall: $W_{E3UN2} := \frac{\gamma_m}{2} \cdot h_{E3locUN2} \cdot L_{E3UN2} \cdot B = 0.0 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E3locUN2} := L_{ab} + t_{wt} + \frac{2}{3} \cdot L_{E3UN2} = 10.00\ m$

Moist soil from top of wall to groundwater level:

Height of soil from top of wall and top of GWL: $h_{1UN2} = 5.50\ m$

Length from edge of wall at GWL to edge of heel: $L_{E4UN2} := L_{E3UN2} - \left(h_{1UN2} \cdot S_{batter}\right) = 8.57\ m$

Weight of soil over heel from top of wall to GWL: $W_{E4UN2} := \gamma_m \cdot h_{1UN2} \cdot \frac{\left(L_{E3UN2} + L_{E4UN2}\right)}{2} \cdot B = 966.2 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E4locUN2} := b - \frac{L_{E3UN2}^2 + L_{E3UN2} \cdot L_{E4UN2} + L_{E4UN2}^2}{3\left(L_{E3UN2} + L_{E4UN2}\right)} = 8.61\ m$

Saturated soil from groundwater to top of footing:

Height of soil from GWL to top of heel: $h_{E4UN2} := h_{2UN2} - t_{ftg} - Key_{h.d} = 6.50\ m$

Weight of soil over heel from GWL to top of heel: $W_{E5UN2} := \left(\gamma_{sat}\right) \cdot h_{E4UN2} \cdot \frac{\left(L_{E4UN2} + L_{cd}\right)}{2} \cdot B = 1188.7 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E5locUN2} := b - \frac{L_{E4UN2}^2 + L_{E4UN2} \cdot L_{cd} + L_{cd}^2}{3\left(L_{E4UN2} + L_{cd}\right)} = 8.84\ m$

$$\Sigma V_{SoilWaterUN2} := W_{H1UN2} + W_{E6UN2} + W_{E3UN2} + W_{E4UN2} + W_{E5UN2} + S_{UN2} = 2193.4 \cdot kN$$

$$\Sigma M_{VertSoilWaterResistUN2} := W_{H1UN2} \cdot W_{E1locUN2} + W_{E6UN2} \cdot W_{E6locUN2} \cdots + W_{E3UN2} \cdot W_{E3locUN2} + W_{E4UN2} \cdot W_{E4locUN2} + W_{E5UN2} \cdot W_{E5locUN2} + S_{UN2} \cdot S_{UN2loc} = 18894.7\ m \cdot kN$$

THIS PAGE INTENTIONALLY LEFT BLANK
PLEASE GO TO THE NEXT PAGE

STABILITY ASSESSMENT:

LOAD CASE UN2

CHECK SLIDING ALONG HORIZONTAL SLIDING PLANE:

Summation of the vertical forces:

$$\Sigma V_{UN2} := \Sigma V_{conc} + \Sigma V_{SoilWaterUN2} + \Sigma V_{UpliftUN2} = 1834.7 \cdot kN$$

Summation of the horizontal forces:

$$\Sigma H_{UN2} := \Sigma H_{SoildriveUN2} + \Sigma H_{SoilresistUN2} = -1856.5 \cdot kN$$

Safety Factor for Sliding Horizontal Failure Plane

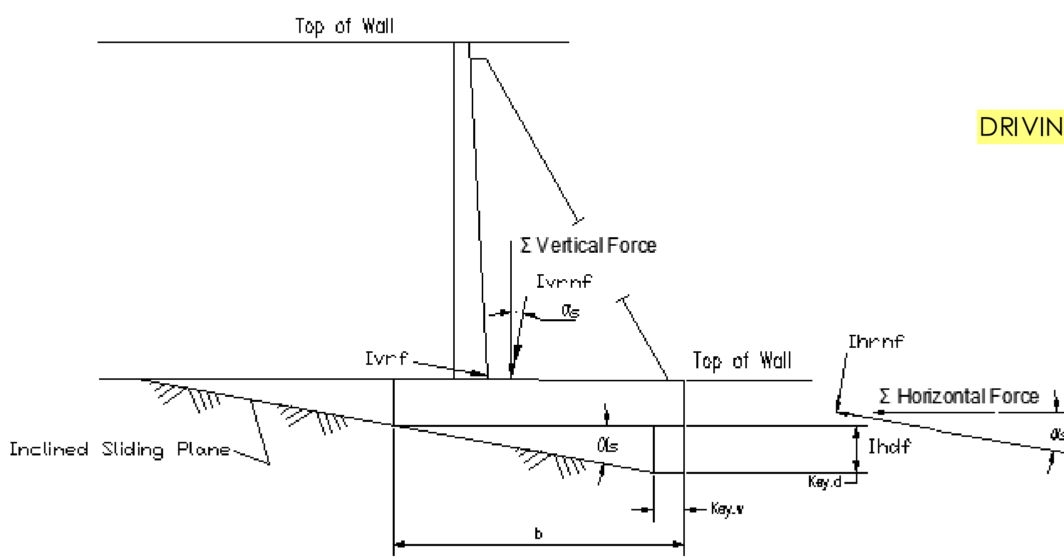
$$FS_{Horiz.SlidingUN2} := \frac{\left|\Sigma V_{UN2}\right| \cdot \tan\left(\phi_{rock} \cdot \frac{\pi}{180}\right)}{\left|\Sigma H_{UN2}\right|} = 0.48$$

$$FS_{Sliding.check1.UN2} := \begin{cases} \text{"OKAY "} & \text{if } FS_{Horiz.SlidingUN2} > FS_{sliding.reqUN2} \\ \text{"NG - key req'"} & \text{otherwise} \end{cases} = \text{"NG - key req'"}$$

CHECK FACTOR OF SAFETY SLIDING WITH KEY (INCLINED SLIDING PLANE):

RESISTING SIDE

DRIVING SIDE



TOE

HEEL

Ivrf=Inclined Resisting Force
Ivrnf=Inclined Resisting Normal Force
Ihrnf=Inclined Resisting Normal Force
Ihdf=Inclined Driving Force

$\alpha s = 0.322$ as degrees= $\alpha s \cdot \left(\frac{180}{\pi}\right) = 18.43$

(With properly engineered reinforced concrete Key, horizontal sliding plane thru Toe is protected, critical sliding plane is relocated to the INCLINED SLIDING PLANE FROM HEEL KEY To TOE, Bedrock Mass above this examing plane is mobilized by reinforced concrete key and combined into Structural Wedge.)

Resolve ΣV_{UN2} & ΣH_{UN2}

$$\Sigma V_{InclinedUN2} := \cos(\alpha s) \cdot \left(\left|\Sigma V_{UN2} + V_{rocksection}\right|\right) + \sin(\alpha s) \cdot \left|\Sigma H_{UN2}\right| = 2910.5 \cdot kN$$

$$\Sigma H_{InclinedUN2} := \cos(\alpha s) \cdot \left|\Sigma H_{UN2}\right| - \sin(\alpha s) \cdot \left(\left|\Sigma V_{UN2} + V_{rocksection}\right|\right) = 986.8 \cdot kN$$

Safety Factor for Sliding Inclined Failure Plane

$$FS_{InclinedISlidingUN2} := \frac{\Sigma V_{InclinedUN2} \cdot \tan(\phi_r)}{\Sigma H_{InclinedUN2}} = 1.31$$

$$FS_{Sliding.check2.UN2} := \begin{cases} \text{"OKAY"} & \text{if } FS_{InclinedISlidingUN2} > FS_{sliding.reqUN2} \\ \text{"NG - Revise Structure"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

CHECK FOUNDATION ECCENTRICITY:

Summation of the resisting moments about the toe:

$$\Sigma M_{resUN2} := \Sigma M_{conc} + \Sigma M_{VertSoilWaterResistUN2} + \Sigma M_{HorizSoilResistUN2} + \Sigma M_{rocksection} = 29383 \cdot kN \cdot m$$

Summation of the overturning moments about the toe:

$$\Sigma M_{oUN2} := \Sigma M_{LateralSoildriveUN2} + \Sigma M_{UpliftUN2} = -12857 \cdot kN \cdot m$$

Total moment: $\Sigma M_{UN2} := \Sigma M_{resUN2} + \Sigma M_{oUN2} = 16525.6\, m \cdot kN$

Normal force to base: $\Sigma V_{InclinedUN2} = 2910.5 \cdot kN$

Inclined Sliding Plane Length: $L_{incline} = 13.7 \cdot m$

Eccentricity (inclined plane): $ex_{UN2} := \frac{L_{incline}}{2} - \frac{\Sigma M_{UN2}}{\Sigma V_{InclinedUN2}} = 1.17\, m$ Kern = 2.284 m

Eccentricity Check: $e_{check.UN2} := \begin{cases} \text{"Okay"} & \text{if } ex_{UN2} \le Kern \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"Okay"}$

CHECK FOUNDATION BEARING CAPACITY:

Base Section Modulus: $S_b = 31.3\, m^3$

Bearing Pressure Under Toe:

$$\sigma_{ToeUN2} := \begin{cases} \left[\frac{\Sigma V_{InclinedUN2}}{L_{incline} \cdot B} + \frac{(\Sigma V_{InclinedUN2} \cdot ex_{UN2})}{S_b}\right] & \text{if } \frac{\Sigma V_{InclinedUN2}}{L_{incline} \cdot B} \ge \frac{\Sigma V_{InclinedUN2} \cdot ex_{UN2}}{S_b} \\ \frac{2 \cdot \Sigma V_{InclinedUN2}}{B \cdot 3\left(\frac{b}{2} - ex_{UN2}\right)} & \text{otherwise} \end{cases} = 321.5 \cdot kPa$$

$$Bearing_{ChecktoeUN2} := \begin{cases} \text{"OKAY"} & \text{if } \sigma_{ToeUN2} < \sigma_{allowUN2} \\ \text{"NG"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

Bearing Pressure Under Heel:

$$\sigma_{HeelUN2} := \begin{cases} \left[\frac{\Sigma V_{InclinedUN2}}{L_{incline} \cdot B} - \frac{(\Sigma V_{InclinedUN2} \cdot ex_{UN2})}{S_b}\right] & \text{if } \frac{\Sigma V_{InclinedUN2}}{L_{incline} \cdot B} \ge \frac{\Sigma V_{InclinedUN2} \cdot ex_{UN2}}{S_b} \\ 0 & \text{otherwise} \end{cases} = 103.2 \cdot kPa$$

$$Bearing_{CheckheelUN2} := \left(\begin{cases} \text{"OKAY"} & \text{if } \sigma_{HeelUN2} < \sigma_{allowUN2} \wedge \sigma_{HeelUN2} > 0 \\ \text{"NG - perform cracked base analysis"} & \text{otherwise} \end{cases}\right) = \text{"OKAY"}$$

CHECK FLOATATION:

Safety Factor for Floatation: $FS_{FloatationUN2} := \dfrac{\Sigma V_{conc} + \Sigma V_{SoilWaterUN2}}{\left|\Sigma V_{UpliftUN2}\right|} = 2.37$

$FS_{Floatation.UN2.check} := \begin{cases} \text{"OKAY "} & \text{if } FS_{FloatationUN2} > FS_{req.UN2.flt} \\ \text{"Revise Structure""} & \text{otherwise} \end{cases} = \text{"OKAY "}$

CHECK OVERTURNING

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.
Assumptions are made in order to compute overturning stablity of indetermine forces on monolith with key;
(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.
(b) The horizontal resisting force acting on the key, P.key, is that required for static equilibrium
(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1

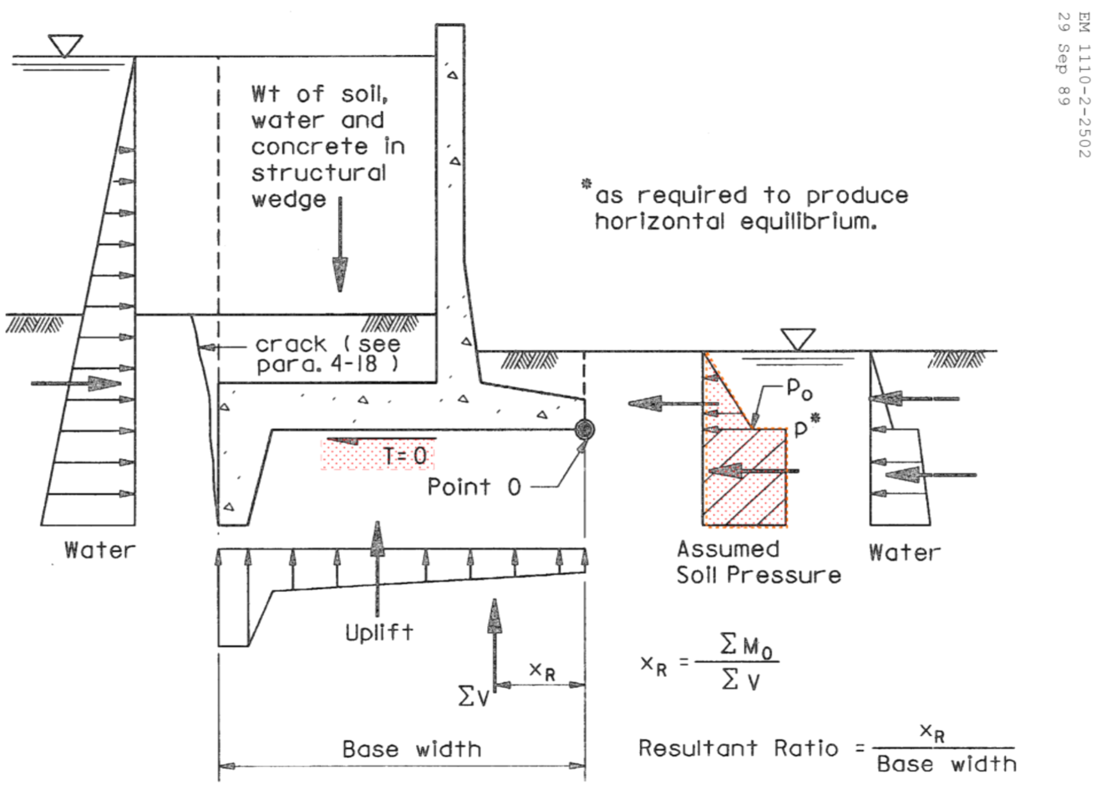


Figure 4-5. Forces for overturning analysis for wall with horizontal base and key

Modify Uplift for Overturning Analysis: **LOAD CASE UN2**

(Uplift is calculated along the concrete/rock contact using the Line of Creep method)

Water Pressure at h: $u_{h.UN2} := \Delta h_{g.hj.UN2} \cdot \gamma_w = 122.50 \cdot kPa$

Water Pressure at o: $u_{o.UN2} := \left(\Delta h_{g.no.UN2} - \frac{\Delta h_{g.r.UN2} \cdot L_{ho.UN2}}{L_{ho.UN2}}\right) \cdot \gamma_w = 83.3 \cdot kPa$

Head loss between point h and o: $\Delta h_{ho.UN2} := \Delta h_{g.r.UN2} \cdot \frac{L_{ho.UN2}}{L_{ho.UN2}} = 0\,m$

Length of concrete base (h -> o): $L_{baseho.UN2} := Key_{h.w} + Key_{h.d} + Key_{hdist} + Key_{t.d} + Key_{t.w} = 17\,m$

Head loss along h -> j: $\Delta h_{hj.UN2} := \Delta h_{ho.UN2} \cdot \frac{Key_{h.w}}{L_{baseho.UN2}} = 0\,m$

Water Pressure at j: $u_{j.UN2} := \left(\Delta h_{g.hj.UN2} - \Delta h_{hj.UN2}\right) \cdot \gamma_w = 122.50 \cdot kPa$

Head loss along h -> k: $\Delta h_{hjk.UN2} := \Delta h_{ho.UN2} \cdot \left(\frac{Key_{h.w} + Key_{h.d}}{L_{baseho.UN2}}\right) = 0\,m$

Water Pressure at k: $u_{k.UN2} := \left(\Delta h_{g.km.UN2} - \Delta h_{hjk.UN2}\right) \cdot \gamma_w = 83.30 \cdot kPa$

Head loss along h -> m: $\Delta h_{hjkm.UN2} := \Delta h_{ho.UN2} \cdot \left(\frac{Key_{h.w} + Key_{h.d} + Key_{hdist}}{L_{baseho.UN2}}\right) = 0\,m$

Water Pressure at m: $u_{m.UN2} := \left(\Delta h_{g.km.UN2} - \Delta h_{hjkm.UN2}\right) \cdot \gamma_w = 83.30 \cdot kPa$

Head loss along h -> n: $\Delta h_{hjkmn.UN2} := \Delta h_{ho.UN2} \cdot \left(\frac{Key_{h.w} + Key_{h.d} + Key_{hdist} + Key_{t.d}}{L_{baseho.UN2}}\right) = 0\,m$

Water Pressure at n: $u_{n.UN2} := \left(\Delta h_{g.no.UN2} - \Delta h_{hjkmn.UN2}\right) \cdot \gamma_w = 83.30 \cdot kPa$

Uplift under key at heel: $V_{ulkeyhUN2.OT} := \frac{\left(u_{h.UN2} + u_{j.UN2}\right) \cdot Key_{h.w}}{2} \cdot B \cdot -1 = -122.5 \cdot kN$

Moment Arm (from Point O): $V_{ulkeyhUN2loc.OT} := b - \frac{Key_{h.w} \cdot \left(2 \cdot u_{j.UN2} + u_{h.UN2}\right)}{3 \cdot \left(u_{j.UN2} + u_{h.UN2}\right)} = 12.5\,m$

Uplift under base: $V_{ulbaseUN2.OT} := \frac{\left(u_{k.UN2} + u_{m.UN2}\right) \cdot Key_{hdist}}{2} \cdot B \cdot -1 = -999.6 \cdot kN$

Moment Arm (from Point O): $V_{ulbaseUN2loc.OT} := b - Key_{h.w} - \frac{Key_{hdist} \cdot \left(2 \cdot u_{m.UN2} + u_{k.UN2}\right)}{3 \cdot \left(u_{m.UN2} + u_{k.UN2}\right)} = 6\,m$

Uplift under key at toe: $V_{ulkeytUN2.OT} := \frac{\left(u_{n.UN2} + u_{o.UN2}\right) \cdot Key_{t.w}}{2} \cdot B \cdot -1 = 0 \cdot kN$

Moment Arm (from Point O): $V_{ulkeytUN2loc.OT} := \frac{Key_{t.w} \cdot \left(2 \cdot u_{n.UN2} + u_{o.UN2}\right)}{3 \cdot \left(u_{n.UN2} + u_{o.UN2}\right)} = 0$

$$\Sigma V_{UpliftUN2.OT} := V_{ulkeyhUN2.OT} + V_{ulbaseUN2.OT} + V_{ulkeytUN2.OT} = -1122 \cdot kN$$

$$U_{UN2.loc.OT} := \frac{V_{ulkeyhUN2.OT} \cdot V_{ulkeyhUN2loc.OT} + V_{ulbaseUN2.OT} \cdot V_{ulbaseUN2loc.OT} + V_{ulkeytUN2.OT} \cdot V_{ulkeytUN2loc.OT}}{\Sigma V_{UpliftUN2.OT}} = 6.71\,m$$

$$\Sigma M_{UpliftUN2.OT} := \Sigma V_{UpliftUN2.OT} \cdot U_{UN2.loc.OT} = -7528.9 \cdot kN \cdot m$$

Modify Lateral Water Pressure (Resisting) for Overturning Analysis:

(Resisting water pressure is calculated using the Line of Creep method)

Water Load at Key (heel):
$$H_{h2UN2.OT} := \frac{u_{k.UN2} + u_{j.UN2}}{2} \cdot Key_{h.d}\, B = 411.6 \cdot kN$$

Moment Arm (from Point O):
$$H_{h2locUN2.OT} := \frac{Key_{h.d} \cdot \left(2 \cdot u_{k.UN2} + u_{j.UN2}\right)}{3\left(u_{k.UN2} + u_{j.UN2}\right)} + Key_{vdist} = -2.13\ m$$

Water Load at Key (toe):
$$H_{h6UN2.OT} := \frac{u_{o.UN2} \cdot \left(UWSEL_{UN2} - Bot_{ftg} + Key_{t.d}\right)}{2} \cdot B = 354 \cdot kN$$

Moment Arm (from Point O):
$$H_{h6locUN2.OT} := \frac{UWSEL_{UN2} - Bot_{ftg} + Key_{t.d}}{3} = 2.83\ m$$

$$\Sigma H_{waterresistUN2.OT} := H_{h2UN2.OT} + H_{h6UN2.OT} = 765.63 \cdot kN$$

$$H_{waterresistlocUN2.OT} := \frac{H_{h2UN2.OT} \cdot H_{h2locUN2.OT} + H_{h6UN2.OT} \cdot H_{h6locUN2.OT}}{\Sigma H_{waterresistUN2.OT}} = 0.167\ m$$

$$\Sigma M_{waterresistUN2.OT} := \Sigma H_{waterresistUN2.OT} \cdot H_{waterresistlocUN2.OT} = 127.6 \cdot kN \cdot m$$

Modify Lateral Soil Loads for Overturning Analysis:

(Lateral soil loads are calculated down to Point O instead of bottom of shear key)

Driving Soil Load (Headwater Side):

Surcharge Load:
$$E_{s1UN2.OT} := S1_{UN2} \cdot K_o \cdot \left(H_w + Key_{h.d} + Key_{vdist}\right) \cdot B \cdot -1 = 0 \cdot kN$$

Moment Arm (from Point O):
$$E_{s1locUN2.OT} := \frac{H_w + Key_{h.d} + Key_{vdist}}{2} = 7.00\ m$$

Moist Soil Load above GWL:
$$E_{h1UN2.OT} := \frac{\gamma_m \cdot K_o \cdot h_{1UN2}^{\ 2}}{2} B \cdot -1 = -165.2 \cdot kN$$

Moment Arm (from Point O):
$$E_{h1locUN2.OT} := \frac{h_{1UN2}}{3} + h_{2UN2} + Key_{vdist} = 10.33\ m$$

Saturated Soil Load below GWL:
(rectangular component)
$$E_{h2UN2.OT} := \left(\gamma_m \cdot K_o \cdot h_{1UN2}\right) \cdot \left(h_{2UN2} + Key_{vdist}\right) \cdot B \cdot -1 = -510.5 \cdot kN$$

Moment Arm (from Point O):
$$E_{h2locUN2.OT} := \frac{h_{2UN2} + Key_{vdist}}{2} = 4.25\ m$$

Saturated Soil Load below GWL:
(triangular component)
$$E_{h2aUN2.OT} := \frac{\left(\gamma_{sat} - \gamma_w\right) \cdot K_o \cdot \left(h_{2UN2} + Key_{vdist}\right)^2}{2} \cdot B \cdot -1 = -240.6 \cdot kN$$

Moment Arm (from Point O):
$$E_{h2alocUN2.OT} := \frac{h_{2UN2} + Key_{vdist}}{3} = 2.83\ m$$

Resisting Soil Load (Tailwater Side):

(Determine resisting soil load based on depth variation between the keys (ie. Key_{vdist}). In case where key at heel is deeper than key at toe (ie. $Key_{vdist} < 0$), resisting soil load (p*) is assumed to produce horizontal equilibrium as per Figure 4-5 above. Resisting soil load (p_o) is neglected.)

Total Driving Force: $\Sigma H_{SoildriveUN2.OT} := E_{s1UN2.OT} + E_{h1UN2.OT} + E_{h2UN2.OT} + E_{h2aUN2.OT} + H_{h2UN2} = -1682.0 \cdot kN$

Total Resisting Force: $\Sigma H_{waterresistUN2.OT} = 765.6 \cdot kN$

Assumed Soil Load p*: $E_{h8UN2a.OT} := \left(\Sigma H_{SoildriveUN2.OT} + \Sigma H_{waterresistUN2.OT}\right) \cdot -1 = 916.327 \cdot kN$

Moment Arm (from Point O): $E_{h8UN2a.loc.OT} := \dfrac{Key_{vdist}}{2} = -2\,m$

$$E_{h8UN2.OT} := \begin{cases} E_{h8UN2a.OT} & \text{if } Key_{vdist} < 0 \\ \Sigma H_{SoilresistUN2} - H_{h6UN2} - H_{h6aUN2} & \text{otherwise} \end{cases} = 916.327 \cdot kN$$

$$\Sigma M_{SoilresistUN2.OT} := \begin{cases} E_{h8UN2a.OT} \cdot E_{h8UN2a.loc.OT} & \text{if } Key_{vdist} < 0 \\ \Sigma M_{HorizSoilResistUN2} - H_{h6UN2} \cdot H_{h6locUN2} - H_{h6aUN2} \cdot H_{h6alocUN2} & \text{otherwise} \end{cases} = -1832.654 \cdot kN \cdot m$$

Sum of Moment about Point O:

$$\Sigma M_{LateraldriveUN2.OT} := E_{s1UN2.OT} \cdot E_{s1locUN2.OT} + E_{h1UN2.OT} \cdot E_{h1locUN2.OT} + E_{h2UN2.OT} \cdot E_{h2locUN2.OT} \cdots + E_{h2aUN2.OT} \cdot E_{h2alocUN2.OT} + H_{h2UN2} \cdot H_{h2locUN2} = -4685.9 \cdot kN \cdot m$$

$$\Sigma M_{LateralresistUN2.OT} := \Sigma M_{waterresistUN2.OT} + \Sigma M_{SoilresistUN2.OT} = -1705.0 \cdot kN \cdot m$$

Total moment:

$$\Sigma M_{UN2.OT} := \Sigma M_{conc} + \Sigma M_{VertSoilWaterResistUN2} + \Sigma M_{UpliftUN2.OT} + \Sigma M_{LateraldriveUN2.OT} + \Sigma M_{LateralresistUN2.OT} = 11223.8 \cdot kN \cdot m$$

Total Vertical Force: $\Sigma V_{UN2.OT} := \Sigma V_{conc} + \Sigma V_{SoilWaterUN2} + \Sigma V_{UplliftUN2.OT} = 2050.3 \cdot kN$

Distance X_R: EM 1110-2-2502 Eq.4-1 $X_{R.UN2} := \dfrac{\Sigma M_{UN2.OT}}{\Sigma V_{UN2.OT}} = 5.474\,m$

Overturning Resultant Ratio $Ratio_{UN2.OT} := \dfrac{X_{R.UN2}}{b} = 0.42$

$$Ratio_{UN2.OT.check} := \begin{cases} \text{"OKAY "} & \text{if } Ratio_{UN2.OT} > X_{R.reqUN2} \\ \text{"Revise Structure""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

CHECK FOUNDATION ECCENTRICITY (HORIZONTAL PLANE):

Eccentricity (horizontal plan): $ex_{UN2.OT} := \dfrac{b}{2} - \dfrac{\Sigma M_{UN2.OT}}{\Sigma V_{UN2.OT}} = 1.03\,m$ $Kern_{OT} = 2.167\,m$

Eccentricity Check:

$$e_{check.UN2.OT} := \begin{cases} \text{"Okay"} & \text{if } ex_{UN2} \le Kern_{OT} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"Okay"}$$

LOAD CASE UN2

CHECK FOUNDATION BEARING CAPACITY (HORIZONTAL PLANE):

Base Section Modulus: $S_{b.OT} = 28.17\,m^3$

Bearing Pressure Under Toe:

$$\sigma_{ToeUN2.OT} := \begin{cases} \left(\dfrac{\Sigma V_{UN2.OT}}{b \cdot B} + \dfrac{\Sigma V_{UN2.OT} \cdot ex_{UN2.OT}}{S_{b.OT}}\right) & \text{if } \dfrac{\Sigma V_{UN2.OT}}{b \cdot B} \geq \dfrac{\Sigma V_{UN2.OT} \cdot ex_{UN2.OT}}{S_{b.OT}} \\ \dfrac{2 \cdot \Sigma V_{UN2.OT}}{B \cdot 3\left(\dfrac{b}{2} - ex_{UN2.OT}\right)} & \text{otherwise} \end{cases} = 232.4 \cdot kPa$$

$$Bearing_{ChecktoeUN2.OT} := \begin{cases} \text{"OKAY "} & \text{if } \sigma_{ToeUN2.OT} < \sigma_{allowUN2} \\ \text{"NG - for reference only""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

Bearing Pressure Under Heel:

$$\sigma_{HeelUN2.OT} := \begin{cases} \left(\dfrac{\Sigma V_{UN2.OT}}{b \cdot B} - \dfrac{\Sigma V_{UN2.OT} \cdot ex_{UN2.OT}}{S_{b.OT}}\right) & \text{if } \dfrac{\Sigma V_{UN2.OT}}{b \cdot B} \geq \dfrac{\Sigma V_{UN2.OT} \cdot ex_{UN2.OT}}{S_{b.OT}} \\ 0 & \text{otherwise} \end{cases} = 83.1 \cdot kPa$$

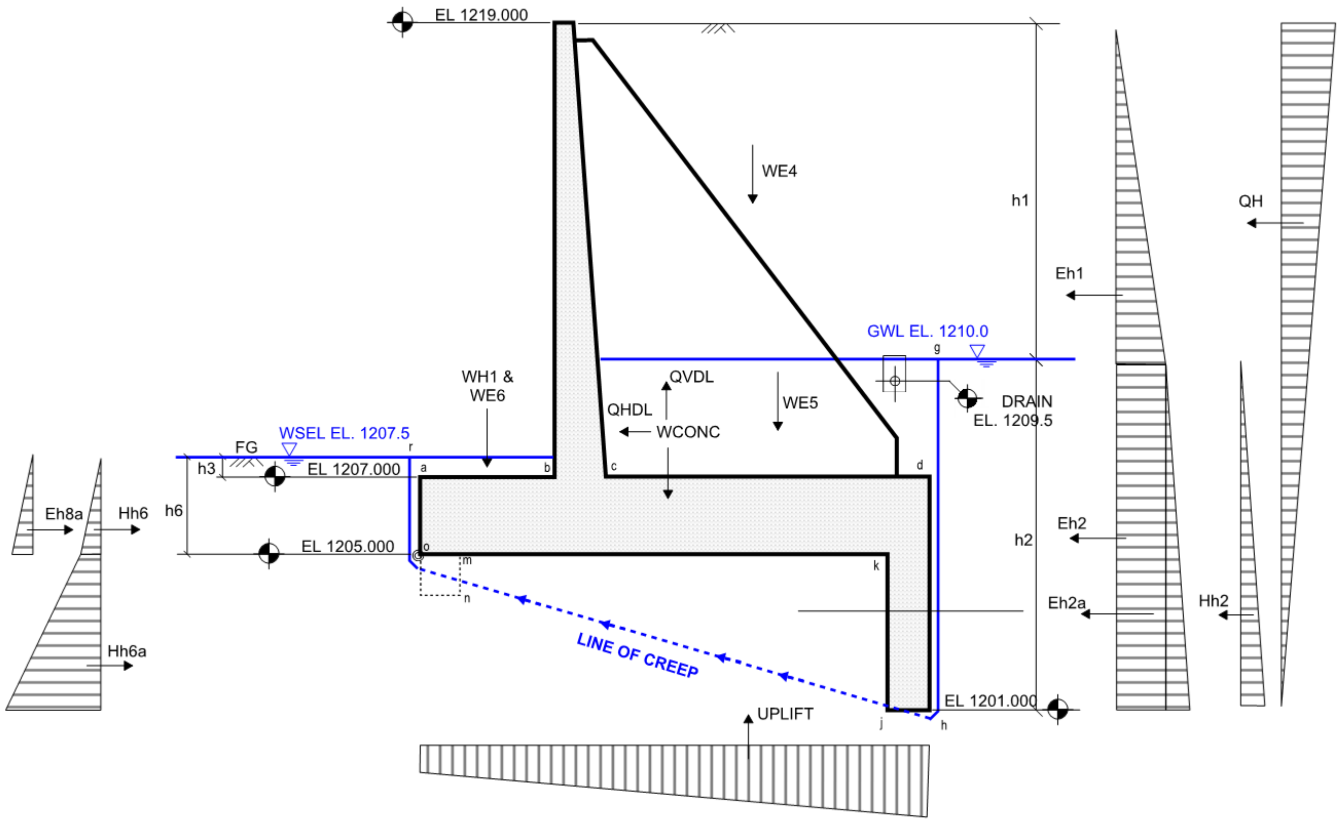
$$Bearing_{CheckheelUN2.OT} := \left(\begin{cases} \text{"OKAY "} & \text{if } \sigma_{HeelUN2.OT} < \sigma_{allowUN2} \wedge \sigma_{HeelUN2.OT} > 0 \\ \text{"NG - for reference only""} & \text{otherwise} \end{cases} \right) = \text{"OKAY "}$$

SUMMARY OF STABILITY ASSESSMENT:

LOAD CASE UN2

Sliding Factor of Safety: (Horizontal Plane - Ref only)	$FS_{Horiz.SlidingUN2} = 0.48$	$FS_{Sliding.check1.UN2}$ = "NG - key req'"
Sliding Factor of Safety: (Inclined Plane)	$FS_{InclinedlSlidingUN2} = 1.31$	$FS_{Sliding.check2.UN2}$ = "OKAY "
Eccentricity: (Inclined Plane)	$ex_{UN2} = 1.17\ m$	$e_{check.UN2}$ = "Okay"
Bearing Pressure At Heel: (Inclined Plane)	$\sigma_{HeelUN2} = 103 \cdot kPa$	$Bearing_{CheckheelUN2}$ = "OKAY "
Bearing Pressure At Toe: (Inclined Plane)	$\sigma_{ToeUN2} = 322 \cdot kPa$	$Bearing_{ChecktoeUN2}$ = "OKAY "
Flotation Factor of Safety (horizontal plane)	$FS_{FloatationUN2} = 2.37$	$FS_{Floatation.UN2.check}$ = "OKAY "
Overturning Resultant Ratio: (horizontal plane)	$Ratio_{UN2.OT} = 0.42$	$Ratio_{UN2.OT.check}$ = "OKAY "
Eccentricity: (horizontal plane - Ref only)	$ex_{UN2.OT} = 1.03\ m$	$e_{check.UN2.OT}$ = "Okay"
Bearing Pressure At Heel: (horizontal plane - Ref only)	$\sigma_{HeelUN2.OT} = 83 \cdot kPa$	$Bearing_{CheckheelUN2.OT}$ = "OKAY "
Bearing Pressure At Toe: (horizontal plane - Ref only)	$\sigma_{ToeUN2.OT} = 232 \cdot kPa$	$Bearing_{ChecktoeUN2.OT}$ = "OKAY "

LOAD CASE E1 - SEISMIC LOADING



E1 DESIGN CASE

LOAD CASE E1 ACCEPTANCE PARAMETERS

FS sliding:

Extreme (E) loading)	1.0 (without cohesion, seismic	(Table 3-3, USACE EM 1110-2-2100)

Resultant Location:

Extremem (E) Inside middle half ~75% base in compression

Required Factor of Safety for Sliding: $FS_{sliding.reqE1} := 1.0$ (Without Cohesion)

Allowable rock bearing pressure: $\sigma_{allowE1} := 1740kPa$ (Section 5.2, Design Criteria EM 1110-2-2100 Section 3-10)

Overturning Required Resultant Ratio: $X_{R.reqE1} := 0.25$ (EM 1110-2-2502, Figure 4-4)

Required Factor of Safety for Floatation $FS_{req.E1.flt} := 1.1$

SOIL HEIGHTS and Water Levels:

LOAD CASE E1

Heel Conditions:

Groundwater Elevation at Heel: $GWL_{E1} := 1210.0m$

Distance from Finish Grade to Groundwater at Heel: $h_{1E1} := \left[T_w - GWL_{E1} + \left(L_{cd} + t_{wb} - t_{wt}\right)\cdot \tan(\beta)\right] = 9.00\ m$

Distance from Water Surface to Bottom of Footing at Heel: $h_{2E1} := GWL_{E1} - Bot_{ftg} + Key_{h.d} = 9.00\ m$

Toe Conditions:

Water Surface Elevation at Toe: $WSEL_{E1} := 1207.5m$

Water Surface Elevation at Toe for Uplift: $UWSEL_{E1} := 1207.5\cdot m$

Finish Grade at Toe providing lateral resistance: $FG_{toeE1} := 1207.5\cdot m$

Soil Depth Above top of footing: $h_{3aE1} := FG_{toeE1} - Top_{ftg} = 0.5\ m$

$$h_{3E1} := \begin{cases} h_{3aE1} & \text{if } FG_{toeE1} - Top_{ftg} \geq 0 \\ 0 & \text{otherwise} \end{cases} = 0.5$$

Resisting Fill at Toe: $h_{4E1} := FG_{toeE1} - Bot_{ftg} + Key_{t.d} = 2.50\ m$

Distance from Water Level to Top of Footing: $h_{5E1} := WSEL_{E1} - Top_{ftg} = 0.50\ m$

Distance from Water Surface to Bottom of Toe Key: $h_{6E1} := WSEL_{E1} - Bot_{ftg} + Key_{t.d} = 2.50\ m$

Soil Depth Above WSEL: $h_{7aE1} := FG_{toeE1} - WSEL_{E1} = 0\ m$

$$h_{7E1} := \begin{cases} h_{7aE1} & \text{if } FG_{toeE1} - WSEL_{E1} \geq 0 \\ 0 & \text{otherwise} \end{cases} = 0$$

Soil Depth Below WSEL:

$$h_{8E1} := \begin{cases} WSEL_{E1} - Bot_{ftg} + Key_{t.d} & \text{if } FG_{toeE1} - WSEL_{E1} \geq 0 \\ h_{4E1} & \text{otherwise} \end{cases} = 2.5$$

For Line of Creep Method: $L_{ho.E1} := \sqrt{b^2 + \left(Key_{h.d} - Key_{t.d}\right)^2} = 13.601\ m$

Head Loss from Point g:

$\Delta h_{g.hj.E1} := h_{2E1} = 9\ m$ (to point h & j)

$\Delta h_{g.km.E1} := GWL_{E1} - Bot_{ftg} = 5\ m$ (to point k & m)

$\Delta h_{g.no.E1} := GWL_{E1} - Bot_{ftg} + Key_{t.d} = 5\ m$ (to point n & o)

$\Delta h_{g.p.E1} := GWL_{E1} - FG_{toeE1} = 2.5\ m$ (to point p*)

$\Delta h_{g.r.E1} := GWL_{E1} - UWSEL_{E1} = 2.5\ m$ (to point r)

Surcharge

Surcharge on Heel: $S1_{E1} := 0.0\ \frac{kN}{m^2}$

* same as point "r" in this case

Calculate Soil Lateral Pressure Coefficients:

LOAD CASE E1

Calculate at-rest pressure coefficient K_o based on Jaky's (1944) equation.

Soil At Rest Static Coefficient:
(apply to resisting soil loads)

$$K_o := \frac{1 - \sin(\phi)}{1 + \sin(\beta)} = 0.546$$

(Eq. 3-6, USACE EM 1110-2-2502)

Calculate active pressure coefficient K_A based on Coulumb equations.

Determine Slope of Active Wedge: (cohesionless backfill with water table)

$$c_1 := 2 \cdot \tan(\phi) = 1.019 \qquad c_2 := 1 - \tan(\phi) \cdot \tan(\beta) - \frac{\tan(\beta)}{\tan(\phi)} = 1$$

(Eq. G-14 / G-15, USACE EM 1110-2-2100)

$$\alpha := \operatorname{atan}\left(\frac{c_1 + \sqrt{c_1^{\,2} + 4 \cdot c_2}}{2}\right) = 1.021 \qquad \alpha_{deg} := \alpha \cdot \frac{180}{\pi} = 58.5$$

degrees (Eq. G-13, USACE EM 1110-2-2100)

Soil Active Coefficient above GWL:

$$K_{Aagwt} := \left(\frac{1 - \tan(\phi) \cdot \cot(\alpha)}{1 + \tan(\phi) \cdot \tan(\alpha)}\right) \cdot \left(\frac{\tan(\alpha)}{\tan(\alpha) - \tan(\beta)}\right) = 0.376$$

Soil Active Coefficient below GWL:

$$K_{Abgwt} := \frac{1 - \tan(\phi) \cdot \cot(\alpha)}{1 + \tan(\phi) \cdot \tan(\alpha)} \cdot \left[1 + \left(\frac{\tan(\alpha)}{\tan(\alpha) - \tan(\beta)} - 1\right) \cdot \left(\frac{\gamma_m}{\gamma_{sat} - \gamma_w}\right)\right] = 0.376$$

Lateral - Driving Force

(Eq. G-29, USACE EM 1110-2-2100)

Static Copmonent : Active Pressure:

Surcharge Load:

$$E_{s1E1} := S1_{E1} \cdot K_{Aagwt} \cdot \left(H_w + Key_{h.d}\right) \cdot B \cdot -1 = 0 \cdot kN$$

Moment Arm (from Point O):

$$E_{s1locE1} := \frac{H_w + Key_{h.d}}{2} + Key_{vdist} = 5.00\ m$$

Moist Soil Load above GWL:

$$E_{h1E1} := \frac{\gamma_m \cdot K_{Aagwt} \cdot h_{1E1}^{\,2}}{2} \cdot B \cdot -1 = -304.2 \cdot kN$$

Moment Arm (from Point O):

$$E_{h1locE1} := \frac{h_{1E1}}{3} + h_{2E1} + Key_{vdist} = 8.00\ m$$

Saturated Soil Load below GWL:
(rectangular component)

$$E_{h2E1} := \left(\gamma_m \cdot K_{Abgwt} \cdot h_{1E1}\right) \cdot h_{2E1} \cdot B \cdot -1 = -608.4 \cdot kN$$

Moment Arm (from Point O):

$$E_{h2locE1} := \frac{h_{2E1}}{2} + Key_{vdist} = 0.50\ m$$

Saturated Soil Load below GWL:
(triangular component)

$$E_{h2aE1} := \frac{\left(\gamma_{sat} - \gamma_w\right) \cdot K_{Abgwt} \cdot h_{2E1}^{\,2}}{2} \cdot B \cdot -1 = -185.5 \cdot kN$$

Moment Arm (from Point O):

$$E_{h2alocE1} := \frac{h_{2E1}}{3} + Key_{vdist} = -1.00\ m$$

Lateral Water Load:

Water Load GWL to Bottom of Keys:

$$H_{h2E1} := \begin{cases} \dfrac{\gamma_w \cdot h_{2E1}^{\,2}}{2} \cdot B \cdot -1 & \text{if } Key_{vdist} < 0 \\ \dfrac{\gamma_w \cdot \left(h_{2E1} + Key_{vdist}\right)^2}{2} \cdot B \cdot -1 & \text{otherwise} \end{cases} = -396.9 \cdot kN$$

Moment Arm (from Point O):

$$H_{h2locE1} := \begin{cases} \dfrac{h_{2E1}}{3} + Key_{vdist} & \text{if } Key_{vdist} < 0 \\ \dfrac{h_{2E1} + Key_{vdist}}{3} & \text{otherwise} \end{cases} = -1.00 \cdot m$$

$$\Sigma H_{SoildriveE1} := E_{s1E1} + E_{h1E1} + E_{h2E1} + E_{h2aE1} + H_{h2E1} = -1495.0 \cdot kN$$

$$\Sigma M_{LateralSoildriveE1} := E_{s1E1} \cdot E_{s1locE1} + E_{h1E1} \cdot E_{h1locE1} + E_{h2E1} \cdot E_{h2locE1} \ldots + E_{h2aE1} \cdot E_{h2alocE1} + H_{h2E1} \cdot H_{h2locE1} = -2155.1\ m \cdot kN$$

Lateral - Resisting Force

LOAD CASE E1

Note: **Due to the relatively shallow depth of resisting soil/rock, a conservative apporach using at-rest coefficient in lieu of a passive wedge is used to calculate resisting forces.**

Lateral Water Load:

Water Load WSEL to Bot. of Toe Key: $H_{h6E1} := H_{h6U1} = 30.6 \cdot kN$

Moment Arm (from Point O): $H_{h6locE1} := H_{h6locU1} = 0.83\ m$

Water Load between Keys (if any)

$$H_{h6aE1} := \begin{cases} \frac{\left(h_{6E1} + h_{2E1}\right) \cdot -Key_{vdist}}{2} \cdot \gamma_w \cdot B & \text{if } Key_{vdist} < 0 \\ 0 & \text{otherwise} \end{cases} = 225.4 \cdot kN$$

Moment Arm (from Point O):

$$H_{h6alocE1} := \begin{cases} \frac{Key_{vdist} \cdot \left(2 \cdot h_{2E1} + h_{6E1}\right)}{3\left(h_{2E1} + h_{6E1}\right)} & \text{if } Key_{vdist} < 0 \\ 0 & \text{otherwise} \end{cases} = -2.38 \cdot m$$

Lateral Soil Load:

Moist Soil Load above WSEL:

$$E_{h7E1} := \frac{\gamma_m \cdot K_o \cdot h_{7E1}^{\ 2}}{2} B = 0.0 \cdot kN$$

Moment Arm (from bot. of toe key):

$$E_{h7locE1} := h_{6E1} + \frac{h_{7E1}}{3} + Key_{vdist} = -1.50\ m$$

Saturated Soil Load below WSEL: (rectangular component)

$$E_{h8E1} := \left(\gamma_m \cdot K_o \cdot h_{7E1}\right) \cdot h_{8E1} \cdot B = 0.0 \cdot kN$$

Moment Arm (from bot. of toe key):

$$E_{h8locE1} := \frac{h_{8E1}}{2} = 1.25\ m$$

Saturated Soil Load below WSEL: (triangular component)

$$E_{h8aE1} := \frac{\left[\left(\gamma_{sat} - \gamma_w\right) \cdot K_o\right] \cdot h_{8E1}^{\ 2}}{2} \cdot B = 20.8 \cdot kN$$

Moment Arm (from bot. of footing):

$$E_{h8alocE1} := \frac{h_{8E1}}{3} = 0.83\ m$$

$$\Sigma H_{SoilresistE1} := H_{h6E1} + H_{h6aE1} + E_{h7E1} + E_{h8E1} + E_{h8aE1} = 276.8 \cdot kN$$

$$\Sigma M_{HorizSoilResistE1} := H_{h6E1} \cdot H_{h6locE1} + H_{h6aE1} \cdot H_{h6alocE1} + E_{h7E1} \cdot E_{h7locE1} \dots + E_{h8E1} \cdot E_{h8locE1} + E_{h8aE1} \cdot E_{h8alocE1} = -492.9\ m \cdot kN$$

Vertical Force:

UPLIFT: Linear distribution from water at heel to water at toe:

$$\Sigma V_{UpliftE1} := \left[\left(UWSEL_{E1} - Bot_{ftg} + Key_{t.d}\right) + h_{2E1}\right] \cdot \frac{b}{2} \cdot \gamma_w \cdot B \cdot -1 = -732.55 \cdot kN$$

Moment Arm (from Point O):

$$V_{UpliftE1aloc} := \frac{b \cdot \left[2 \cdot h_{2E1} + \left(UWSEL_{E1} - Bot_{ftg} + Key_{t.d}\right)\right]}{3\left[h_{2E1} + \left(UWSEL_{E1} - Bot_{ftg} + Key_{t.d}\right)\right]} = 7.725\ m$$

$$\Sigma M_{UpliftE1} := \Sigma V_{UpliftE1} \cdot V_{UpliftE1aloc} = -5658.683 \cdot kN \cdot m$$

Weight of soil and water over toe:

Water Above the Top of Footing: $W_{H1E1} := \gamma_w \cdot h_{5E1} \cdot L_{ab} \cdot B = 17.15 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E1locE1} := \frac{L_{ab}}{2} = 1.75\ m$

Soil above top of footing: $W_{E6E1} := \gamma_b \cdot h_{3E1} \cdot L_{ab} \cdot B = 21.4 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E6locE1} := \frac{L_{ab}}{2} = 1.75\ m$

Vertical Load Due to Surcharge: $S_{E1} := S1_{E1} \cdot L_{cd} \cdot B = 0 \cdot kN$ $\quad S_{E1loc} := b - \frac{L_{cd}}{2} = 8.97\ m$

Weight of soil and water over heel:

Moist Soil for sloped grade above top of wall:

Length of sloped portion of soil above top of wall: $L_{E3E1} := \left(L_{cd} + t_{wb} - t_{wt}\right) = 9.00\ m$

Height of sloped soil above top of wall over heel: $h_{E3locE1} := \left(L_{E3E1}\right) \cdot \tan(\beta) = 0.00\ m$

Weight of sloped soil above top of wall: $W_{E3E1} := \frac{\gamma_m}{2} \cdot h_{E3locE1} \cdot L_{E3E1} \cdot B = 0.0 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E3locE1} := L_{ab} + t_{wt} + \frac{2}{3} \cdot L_{E3E1} = 10.00\ m$

Moist soil from top of wall to groundwater level:

Height of soil from top of wall and top of GWL: $h_{1E1} = 9.00\ m$

Length from edge of wall at GWL to edge of heel: $L_{E4E1} := L_{E3E1} - \left(h_{1E1} \cdot S_{batter}\right) = 8.29\ m$

Weight of soil over heel from top of wall to GWL: $W_{E4E1} := \gamma_m \cdot h_{1E1} \cdot \frac{\left(L_{E3E1} + L_{E4E1}\right)}{2} \cdot B = 1556.3 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E4locE1} := b - \frac{L_{E3E1}^2 + L_{E3E1} \cdot L_{E4U1} + L_{E4E1}^2}{3\left(L_{E3E1} + L_{E4E1}\right)} = 8.67\ m$

Saturated soil from groundwater to top of footing:

Height of soil from GWL to top of heel: $h_{E4E1} := h_{2E1} - t_{ftg} - Key_{h.d} = 3.00\ m$

Weight of soil over heel from GWL to top of heel: $W_{E5E1} := \left(\gamma_{sat}\right) \cdot h_{E4E1} \cdot \frac{\left(L_{E4E1} + L_{cd}\right)}{2} \cdot B = 539.5 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E5locE1} := b - \frac{L_{E4E1}^2 + L_{E4E1} \cdot L_{cd} + L_{cd}^2}{3\left(L_{E4E1} + L_{cd}\right)} = 8.91\ m$

$$\Sigma V_{SoilWaterE1} := W_{H1E1} + W_{E6E1} + W_{E3E1} + W_{E4E1} + W_{E5E1} + S_{E1} = 2134.4 \cdot kN$$

$$\Sigma M_{VertSoilWaterResistE1} := W_{H1E1} \cdot W_{E1locE1} + W_{E6E1} \cdot W_{E6locE1} \cdots + W_{E3E1} \cdot W_{E3locE1} + W_{E4E1} \cdot W_{E4locE1} + W_{E5E1} \cdot W_{E5locE1} + S_{E1} \cdot S_{E1loc} = 18376.3\ m \cdot kN$$

SESIMIC ANALYSIS:

LOAD CASE E1

Seismic coefficient will be applied to dead loads to calculate seismic force and force is applied at center of gravity of the mass. Vertical and Horizontal loads are applied in the "destabilizing direction"

SEISMIC PARAMETERS:

(Section 7.9, Design Criteria)

Peak Ground Acceleration for Seismic Load $PGA_{Horiz} := 0.26$ $PGA_{Vert} := 0.56 \cdot PGA_{Horiz} = 0.146$

In accordance with USACE EM 1110-2-2100 Section 4-7.b, consider 2/3 PGA as seismic coefficient for stabilitiy.

Horizontal Seismic coefficient for stabilty: $K_{hE1} := \frac{2}{3} PGA_{Horiz} = 0.173$

Vertical Seismic coefficient for stabilty: $K_{vE1} := \frac{2}{3} PGA_{Vert} = 0.097$

SEISMIC ACCELERATION OF RIGID MASSES (Q_D):

Vertical Load Application:

$\Sigma V_{conc} = 979 \cdot kN$

$Q_{v.conc} := \Sigma V_{conc} \cdot K_{vE1} \cdot -1 = -95 \cdot kN$ (assume acting upwards for adverse sliding effect)

Moment arm for siesmic load application (From Toe): $H_{cent} = 6.383\,m$

$M_{Qv.conc} := Q_{v.conc} \cdot H_{cent} = -606.6 \cdot kN \cdot m$

Lateral Load Application:

$Q_{h.conc} := \Sigma V_{conc} \cdot K_{hE1} \cdot -1 = -169.7 \cdot kN$

Moment arm for siesmic load application (Above Base of Footing): $V_{Cent} = 2.399\,m$

$M_{Q.conc} := Q_{h.conc} \cdot V_{Cent} = -407.1 \cdot kN \cdot m$

SEISMIC ACCELERATION OF SOIL WEDGE + WATER (Q_{EH}):

Vertical Load Application:

$\Sigma V_{SoilWaterE1} = 2134.4 \cdot kN$

$Q_{v.SoilWaterE1} := \Sigma V_{SoilWaterE1} \cdot K_{vE1} \cdot -1 = -207.2 \cdot kN$ (assume acting upwards for adverse sliding effect)

Moment arm for siesmic load application (From Toe): $e_{QE1} := \frac{\Sigma M_{VertSoilWaterResistE1}}{\Sigma V_{SoilWaterE1}} = 8.61\,m$

$M_{Qv.SoilWaterE1} := Q_{v.SoilWaterE1} \cdot e_{QE1} = -1783.7 \cdot kN \cdot m$

Lateral Load Application:

Seismic soil load is calculated based on Mononobe-Okabe method to determine combined static and dynamic coefficient (K_{AE}). Coulomb's active component (K_A) is subtracted from K_{AE} to obtain the seismic coefficient (ΔK_{AE}) for dynamic component of soil force.

Glacial Till Internal Friction (radians): $\phi = 0.471$

Seismic Inertia Angle (radians): $\psi := atan\left(\frac{K_{hE1}}{1 - K_{vE1}}\right) = 0.190$

Inclination of batter (radians): $\theta := 0.00$ assuming zero is conservative

Slope of retained ground surface: $\beta = 0.00$

$$K_{AE} := \frac{\cos(\phi - \psi - \theta) \cdot \cos(\phi - \psi - \theta)}{\cos(\psi) \cdot \cos(\theta) \cdot \cos(\theta)\, \cos(\psi + \theta) \cdot \left(1 + \sqrt{\frac{\sin(\phi)\, \sin(\phi - \psi - \beta)}{\cos(\beta - \theta) \cdot \cos(\psi + \theta)}}\right)^2} = 0.519$$

$\Delta K_{AE} := K_{AE} - K_{Abgwt} = 0.143$

Dynamic component of active seismic wedge:

$$Q_{h.SoilWaterE1} := \Delta K_{AE} \cdot \left[\frac{\gamma_m \cdot \left(H_w + Key_{h.d}\right)^2}{2 \cdot (\tan(\alpha) - \tan(\beta))} + \frac{\left(\gamma_{sat} - \gamma_m\right) \cdot h_{2E1}{}^2}{2 \cdot \tan(\alpha)}\right] \cdot B \cdot -1 = -291.0 \cdot kN$$

(Eq. G-64, USACE EM 1110-2-2100)

Moment arm for siesmic load application (About Point O): $Q_{h.SoilWaterlocE1} := \frac{2}{3} \cdot \left(H_w + Key_{h.d}\right) + Key_{vdist} = 8.00\,m$

$M_{Q.h.SoilWaterE1} := Q_{h.SoilWaterE1} \cdot Q_{h.SoilWaterlocE1} = -2327.9 \cdot kN \cdot m$

STABILITY ASSESSMENT:

LOAD CASE E1

CHECK SLIDING ALONG HORIZONTAL SLIDING PLANE:

Summation of the vertical forces: $\Sigma V_{E1} := \Sigma V_{conc} + \Sigma V_{SoilWaterE1} + \Sigma V_{UpliftE1} + Q_{v.conc} + Q_{v.SoilWaterE1} = 2078.6 \cdot kN$

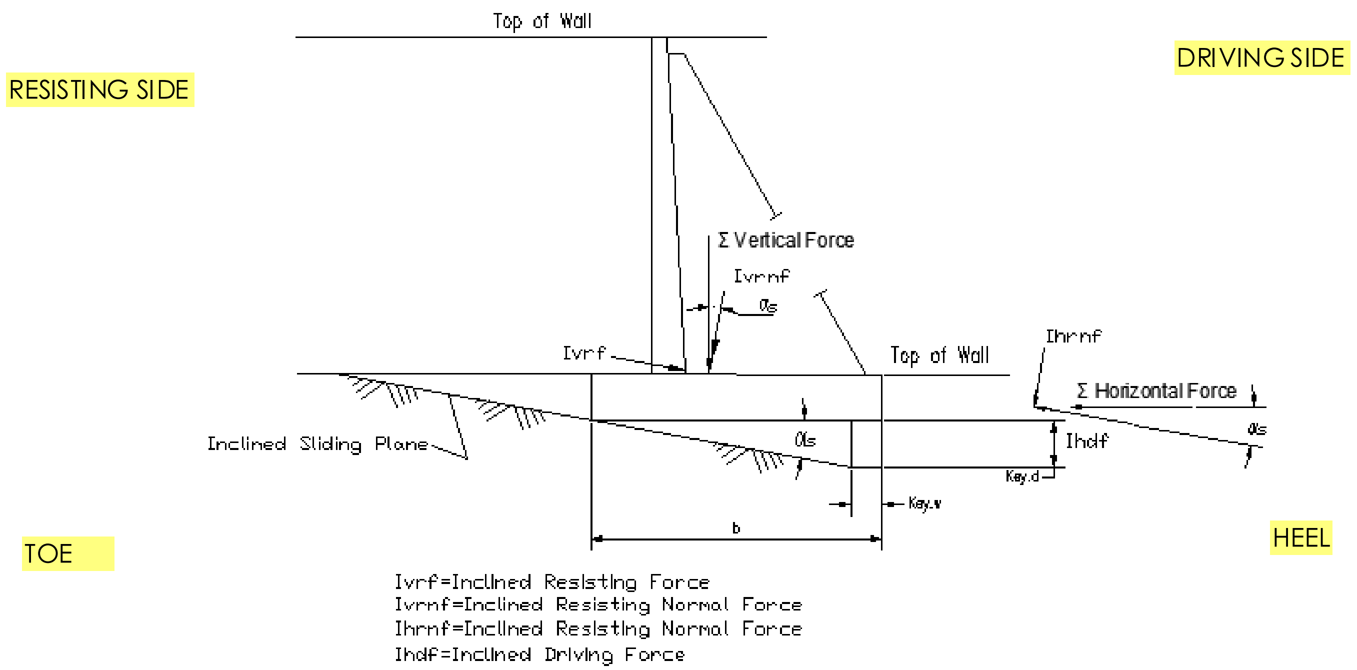
Summation of the horizontal forces: $\Sigma H_{E1} := \Sigma H_{SoildriveE1} + Q_{h.conc} + Q_{h.SoilWaterE1} + \Sigma H_{SoilresistE1} = -1678.8 \cdot kN$

Safety Factor for Sliding Horizontal Failure Plane

$$FS_{Horiz.SlidingE1} := \frac{\left|\Sigma V_{E1}\right| \cdot \tan\left(\phi_{rock} \cdot \frac{\pi}{180}\right)}{\left|\Sigma H_{E1}\right|} = 0.60$$

$$FS_{Sliding.check1.E1} := \begin{vmatrix} \text{"OKAY"} & \text{if } FS_{Horiz.SlidingE1} > FS_{sliding.reqE1} \\ \text{"NG - key req"} & \text{otherwise} \end{vmatrix} = \text{"NG - key req"}$$

CHECK FACTOR OF SAFETY SLIDING WITH KEY (INCLINED SLIDING PLANE):



(With properly engineered reinforced concrete Key, horizontal sliding plane thru Toe is protected, critical sliding plane is relocated to the INCLINED SLIDING PLANE FROM HEEL KEY To TOE, Bedrock Mass above this examing plane is mobilized by reinforced concrete key and combined into Structural Wedge.)

Resolve ΣV_{E1} & ΣH_{E1}

$$\Sigma V_{InclinedE1} := \cos(\alpha s) \cdot \left(\left|\Sigma V_{E1} + V_{rocksection}\right|\right) + \sin(\alpha s) \cdot \left|\Sigma H_{E1}\right| = 3085.7 \cdot kN$$

$$\Sigma H_{InclinedE1} := \cos(\alpha s) \cdot \left|\Sigma H_{E1}\right| - \sin(\alpha s) \cdot \left(\left|\Sigma V_{E1} + V_{rocksection}\right|\right) = 741.1 \cdot kN$$

Safety Factor for Sliding Inclined Failure Plane

$$FS_{InclinedISlidingE1} := \frac{\Sigma V_{InclinedE1} \cdot \tan\left(\phi_r\right)}{\Sigma H_{InclinedE1}} = 1.85$$

$$FS_{Sliding.check2.E1} := \begin{vmatrix} \text{"OKAY"} & \text{if } FS_{InclinedISlidingE1} > FS_{sliding.reqE1} \\ \text{"NG"} & \text{otherwise} \end{vmatrix} = \text{"OKAY"}$$

CHECK FOUNDATION ECCENTRICITY:

LOAD CASE E1

(Vertical seismic loads from concrete, soil and water are assumed acting downwards for adverse bearing effect)

Summation of the vertical forces: $\Sigma V_{seisE1} := \Sigma V_{conc} + \Sigma V_{SoilWaterE1} + \Sigma V_{UpliftE1} - Q_{v.conc} - Q_{v.SoilWaterE1} = 2683.0 \cdot kN$

Summation of the horizontal forces: $\Sigma H_{seisE1} := \Sigma H_{E1} = -1678.8 \cdot kN$

Resolve ΣV_{seisE1} & ΣH_{seisE1}

$$\Sigma V_{InclinedseisE1} := \cos(\alpha s) \cdot \left(\left|\Sigma V_{seisE1} + V_{rocksection}\right|\right) + \sin(\alpha s) \cdot \left|\Sigma H_{seisE1}\right| = 3659.1 \cdot kN$$

$$\Sigma H_{InclinedseisE1} := \cos(\alpha s) \cdot \left|\Sigma H_{seisE1}\right| - \sin(\alpha s) \cdot \left(\left|\Sigma V_{seisE1} + V_{rocksection}\right|\right) = 549.9 \cdot kN$$

Summation of the resisting moments about the toe:

$$\Sigma M_{resE1} := \Sigma M_{conc} + \Sigma M_{VertSoilWaterResistE1} + \Sigma M_{HorizSoilResistE1} + \Sigma M_{rocksection} = 29048 \cdot kN \cdot m$$

Summation of seismic moments about the toe:

$$\Sigma M_{seisE1} := -M_{Qv.conc} + M_{Q.conc} - M_{Qv.SoilWaterE1} + M_{Q.h.SoilWaterE1} = -345 \cdot kN \cdot m$$

Summation of the overturning moments about the toe:

$$\Sigma M_{oE1} := \Sigma M_{LateralSoildriveE1} + \Sigma M_{UpliftE1} = -7814 \cdot kN \cdot m$$

Total moment: $\Sigma M_{E1} := \Sigma M_{resE1} + \Sigma M_{seisE1} + \Sigma M_{oE1} = 20888.9 \cdot kN \cdot m$

Normal force to base: $\Sigma V_{InclinedseisE1} = 3659.1 \cdot kN$

Inclined Sliding Plane Length: $L_{incline} = 13.7 \cdot m$

Eccentricity (inclined plane): $ex_{E1} := \dfrac{L_{incline}}{2} - \dfrac{\Sigma M_{E1}}{\Sigma V_{InclinedseisE1}} = 1.14\,m$ $\qquad Kern_{E1} := \dfrac{L_{incline}}{4} = 3.426\,m$

Eccentricity Check:

$$e_{check.E1} := \begin{cases} \text{"Okay"} & \text{if } ex_{E1} \le Kern_{E1} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"Okay"}$$

CHECK FOUNDATION BEARING CAPACITY:

Base Section Modulus: $S_b = 31.3\,m^3$

Bearing Pressure Under Toe:

$$\sigma_{ToeE1} := \begin{cases} \left[\dfrac{\Sigma V_{InclinedE1}}{L_{incline} \cdot B} + \dfrac{\left(\Sigma V_{InclinedE1} \cdot ex_{E1}\right)}{S_b}\right] & \text{if } \dfrac{\Sigma V_{InclinedE1}}{L_{incline} \cdot B} \ge \dfrac{\Sigma V_{InclinedE1} \cdot ex_{E1}}{S_b} \\ \dfrac{2 \cdot \Sigma V_{InclinedE1}}{B \cdot 3\left(\dfrac{b}{2} - ex_{E1}\right)} & \text{otherwise} \end{cases} = 337.9 \cdot kPa$$

$$Bearing_{CheckToeE1} := \begin{cases} \text{"OKAY "} & \text{if } \sigma_{ToeE1} < \sigma_{allowE1} \\ \text{"NG""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

Bearing Pressure Under Heel:

$$\sigma_{HeelE1} := \begin{cases} \left[\dfrac{\Sigma V_{InclinedE1}}{L_{incline} \cdot B} - \dfrac{\left(\Sigma V_{InclinedE1} \cdot ex_{E1}\right)}{S_b}\right] & \text{if } \dfrac{\Sigma V_{InclinedE1}}{L_{incline} \cdot B} \ge \dfrac{\Sigma V_{InclinedE1} \cdot ex_{E1}}{S_b} \\ 0 & \text{otherwise} \end{cases} = 112.5 \cdot kPa$$

$$Bearing_{CheckheelE1} := \left(\begin{cases} \text{"OKAY "} & \text{if } \sigma_{HeelE1} < \sigma_{allowE1} \wedge \sigma_{HeelE1} > 0 \\ \text{"NG - perform cracked base analysis""} & \text{otherwise} \end{cases}\right) = \text{"OKAY "}$$

CHECK FLOATATION:

Safety Factor for Floatation:

$$FS_{FloatationE1} := \frac{\Sigma V_{conc} + \Sigma V_{SoilWaterE1} + Q_{v.conc} + Q_{v.SoilWaterE1}}{\left|\Sigma V_{UpliftE1}\right|} = 3.84$$

$$FS_{Floatation.E1.check} := \begin{cases} \text{"OKAY "} & \text{if } FS_{FloatationE1} > FS_{req.E1.flt} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

CHECK OVERTURNING

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.
Assumptions are made in order to compute overturning stablity of indetermine forces on monolith with key;
(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.
(b) The horizontal resisting force acting on the key, P.key, is that required for static equilibrium
(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1

EM 1110-2-2502
29 Sep 89

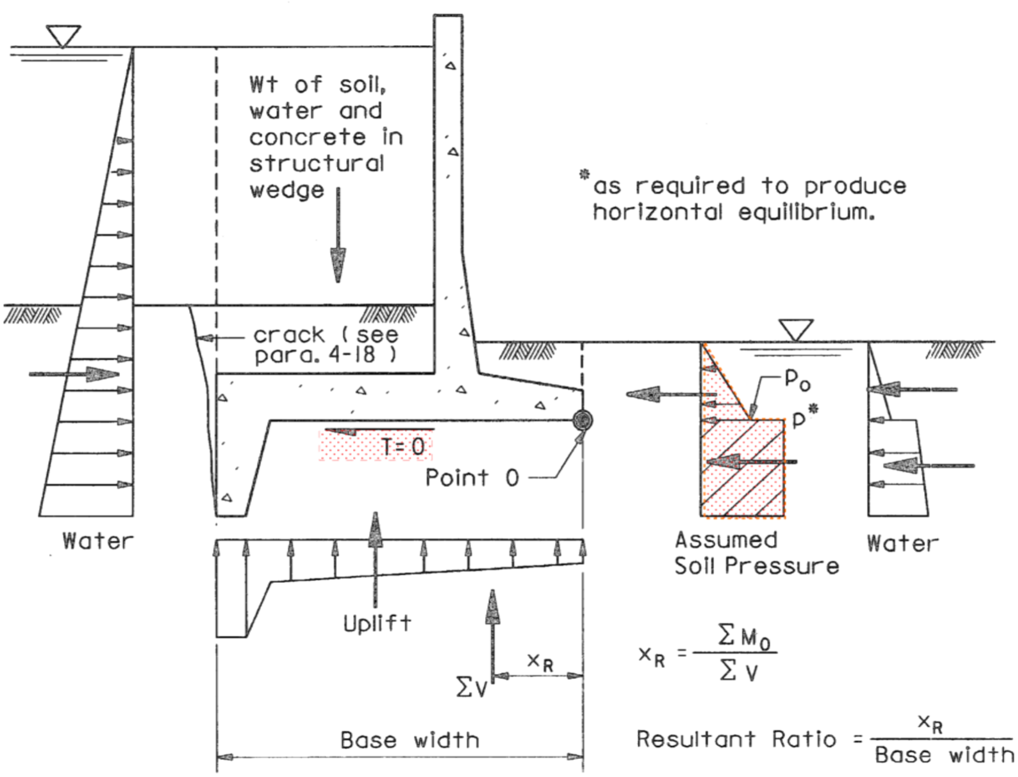


Figure 4-5. Forces for overturning analysis for wall with horizontal base and key

Modify Uplift for Overturning Analysis: **LOAD CASE E1**

(Uplift is calculated along the concrete/rock contact using the Line of Creep method)

Water Pressure at h: $u_{h.E1} := \Delta h_{g.hj.E1} \cdot \gamma_w = 88.20 \cdot kPa$

Water Pressure at o: $u_{o.E1} := \left(\Delta h_{g.no.E1} - \frac{\Delta h_{g.r.E1} \cdot L_{ho.E1}}{L_{ho.E1}}\right) \cdot \gamma_w = 24.5 \cdot kPa$

Head loss between point h and o: $\Delta h_{ho.E1} := \Delta h_{g.r.E1} \cdot \frac{L_{ho.E1}}{L_{ho.E1}} = 2.5\, m$

Length of concrete base (h -> o): $L_{baseho.E1} := Key_{h.w} + Key_{h.d} + Key_{hdist} + Key_{t.d} + Key_{t.w} = 17\, m$

Head loss along h -> j: $\Delta h_{hj.E1} := \Delta h_{ho.E1} \cdot \frac{Key_{h.w}}{L_{baseho.E1}} = 0.147\, m$

Water Pressure at j: $u_{j.E1} := \left(\Delta h_{g.hj.E1} - \Delta h_{hj.E1}\right) \cdot \gamma_w = 86.76 \cdot kPa$

Head loss along h -> k: $\Delta h_{hjk.E1} := \Delta h_{ho.E1} \cdot \left(\frac{Key_{h.w} + Key_{h.d}}{L_{baseho.E1}}\right) = 0.735\, m$

Water Pressure at k: $u_{k.E1} := \left(\Delta h_{g.km.E1} - \Delta h_{hjk.E1}\right) \cdot \gamma_w = 41.79 \cdot kPa$

Head loss along h -> m: $\Delta h_{hjkm.E1} := \Delta h_{ho.E1} \cdot \left(\frac{Key_{h.w} + Key_{h.d} + Key_{hdist}}{L_{baseho.E1}}\right) = 2.5\, m$

Water Pressure at m: $u_{m.E1} := \left(\Delta h_{g.km.E1} - \Delta h_{hjkm.E1}\right) \cdot \gamma_w = 24.50 \cdot kPa$

Head loss along h -> n: $\Delta h_{hjkmn.E1} := \Delta h_{ho.E1} \cdot \left(\frac{Key_{h.w} + Key_{h.d} + Key_{hdist} + Key_{t.d}}{L_{baseho.E1}}\right) = 2.5\, m$

Water Pressure at n: $u_{n.E1} := \left(\Delta h_{g.no.E1} - \Delta h_{hjkmn.E1}\right) \cdot \gamma_w = 24.50 \cdot kPa$

Uplift under key at heel: $V_{ulkeyhE1.OT} := \frac{\left(u_{h.E1} + u_{j.E1}\right) \cdot Key_{h.w}}{2} \cdot B \cdot -1 = -87.479 \cdot kN$

Moment Arm (from Point O): $V_{ulkeyhE1loc.OT} := b - \frac{Key_{h.w} \cdot \left(2 \cdot u_{j.E1} + u_{h.E1}\right)}{3 \cdot \left(u_{j.E1} + u_{h.E1}\right)} = 12.501\, m$

Uplift under base: $V_{ulbaseE1.OT} := \frac{\left(u_{k.E1} + u_{m.E1}\right) \cdot Key_{hdist}}{2} \cdot B \cdot -1 = -397.765 \cdot kN$

Moment Arm (from Point O): $V_{ulbaseE1loc.OT} := b - Key_{h.w} - \frac{Key_{hdist} \cdot \left(2 \cdot u_{m.E1} + u_{k.E1}\right)}{3 \cdot \left(u_{m.E1} + u_{k.E1}\right)} = 6.522\, m$

Uplift under key at toe $V_{ulkeytE1.OT} := \frac{\left(u_{n.E1} + u_{o.E1}\right) \cdot Key_{t.w}}{2} \cdot B \cdot -1 = 0 \cdot kN$

Moment Arm (from Point O): $V_{ulkeytE1loc.OT} := \frac{Key_{t.w} \cdot \left(2 \cdot u_{n.E1} + u_{o.E1}\right)}{3 \cdot \left(u_{n.E1} + u_{o.E1}\right)} = 0$

$$\Sigma V_{UpliftE1.OT} := V_{ulkeyhE1.OT} + V_{ulbaseE1.OT} + V_{ulkeytE1.OT} = -485 \cdot kN$$

$$U_{E1.loc.OT} := \frac{V_{ulkeyhE1.OT} \cdot V_{ulkeyhE1loc.OT} + V_{ulbaseE1.OT} \cdot V_{ulbaseE1loc.OT} + V_{ulkeytE1.OT} \cdot V_{ulkeytE1loc.OT}}{\Sigma V_{UpliftE1.OT}} = 7.60\, m$$

$$\Sigma M_{UpliftE1.OT} := \Sigma V_{UpliftE1.OT} \cdot U_{E1.loc.OT} = -3687.7 \cdot kN \cdot m$$

LOAD CASE E1

Modify Lateral Water Pressure (Resisting) for Overturning Analysis:

(Resisting water pressure is calculated using the Line of Creep method)

Water Load at Key (heel): $H_{h2E1.OT} := \frac{u_{k.E1} + u_{j.E1}}{2} \cdot Key_{h.d} B = 257.1 \cdot kN$

Moment Arm (from Point O): $H_{h2locE1.OT} := \frac{Key_{h.d} \cdot (2 \cdot u_{k.E1} + u_{j.E1})}{3(u_{k.E1} + u_{j.E1})} + Key_{vdist} = -2.23\ m$

Water Load at Key (toe): $H_{h6E1.OT} := \frac{u_{o.E1} \cdot (UWSEL_{E1} - Bot_{ftg} + Key_{t.d})}{2} \cdot B = 31 \cdot kN$

Moment Arm (from Point O): $H_{h6locE1.OT} := \frac{UWSEL_{E1} - Bot_{ftg} + Key_{t.d}}{3} = 0.83\ m$

$$\Sigma H_{waterresistE1.OT} := H_{h2E1.OT} + H_{h6E1.OT} = 287.73 \cdot kN$$

$$H_{waterresistlocE1.OT} := \frac{H_{h2E1.OT} \cdot H_{h2locE1.OT} + H_{h6E1.OT} \cdot H_{h6locE1.OT}}{\Sigma H_{waterresistE1.OT}} = -1.907\ m$$

$$\Sigma M_{waterresistE1.OT} := \Sigma H_{waterresistE1.OT} \cdot H_{waterresistlocE1.OT} = -548.64 \cdot kN \cdot m$$

Modify Lateral Soil Loads for Overturning Analysis:

(Lateral soil loads are calculated down to Point O instead of bottom of shear key)

Driving Soil Load (Headwater Side):

Surcharge Load: $E_{s1E1.OT} := S1_{E1} \cdot K_{Aagwt} \cdot (H_w + Key_{h.d} + Key_{vdist}) \cdot B \cdot -1 = 0 \cdot kN$

Moment Arm (from Point O): $E_{s1locE1.OT} := \frac{H_w + Key_{h.d} + Key_{vdist}}{2} = 7.00\ m$

Moist Soil Load above GWL: $E_{h1E1.OT} := \frac{\gamma_m \cdot K_{Aagwt} \cdot h_{1E1}^{\ 2}}{2} B \cdot -1 = -304.2 \cdot kN$

Moment Arm (from Point O): $E_{h1locE1.OT} := \frac{h_{1E1}}{3} + h_{2E1} + Key_{vdist} = 8.00\ m$

Saturated Soil Load below GWL: (rectangular component) $E_{h2E1.OT} := (\gamma_m \cdot K_{Aagwt} \cdot h_{1E1}) \cdot (h_{2E1} + Key_{vdist}) \cdot B \cdot -1 = -338.0 \cdot kN$

Moment Arm (from Point O): $E_{h2locE1.OT} := \frac{h_{2E1} + Key_{vdist}}{2} = 2.50\ m$

Saturated Soil Load below GWL: (triangular component) $E_{h2aE1.OT} := \frac{(\gamma_{sat} - \gamma_w) \cdot K_{Aagwt} \cdot (h_{2E1} + Key_{vdist})^2}{2} \cdot B \cdot -1 = -57.3 \cdot kN$

Moment Arm (from Point O): $E_{h2alocE1.OT} := \frac{h_{2E1} + Key_{vdist}}{3} = 1.67\ m$

Resisting Soil Load (Tailwater Side):

LOAD CASE E1

(Determine resisting soil load based on depth variation between the keys (ie. Key_{vdist}). In case where key at heel is deeper than key at toe (ie. $Key_{vdist} < 0$), resisting soil load (p*) is assumed to produce horizontal equilibrium as per Figure 4-5 above. Resisting soil load (p_o) is neglected.)

Total Driving Force: $\Sigma H_{SoildriveE1.OT} := E_{s1E1.OT} + E_{h1E1.OT} + E_{h2E1.OT} + E_{h2aE1.OT} + H_{h2E1} \cdots + Q_{h.conc} + Q_{h.SoilWaterE1} = -1557.0 \cdot kN$

Total Resisting Force: $\Sigma H_{waterresistE1.OT} = 287.731 \cdot kN$

Assumed Soil Load p*: $E_{h8E1a.OT} := \left(\Sigma H_{SoildriveE1.OT} + \Sigma H_{waterresistE1.OT}\right) \cdot -1 = 1269.265 \cdot kN$

Moment Arm (from Point O): $E_{h8E1a.loc.OT} := \dfrac{Key_{vdist}}{2} = -2\,m$

$$E_{h8E1.OT} := \begin{cases} E_{h8E1a.OT} & \text{if } Key_{vdist} < 0 \\ \Sigma H_{SoilresistE1} - H_{h6E1} - H_{h6aE1} & \text{otherwise} \end{cases} = 1269.265 \cdot kN$$

$$\Sigma M_{SoilresistE1.OT} := \begin{cases} E_{h8E1a.OT} \cdot E_{h8E1a.loc.OT} & \text{if } Key_{vdist} < 0 \\ \Sigma M_{HorizSoilResistE1} - H_{h6E1} \cdot H_{h6locE1} - H_{h6aE1} \cdot H_{h6alocE1} & \text{otherwise} \end{cases} = -2538.529 \cdot kN \cdot m$$

Sum of Moment about Point O:

$$\Sigma M_{LateraldriveE1.OT} := E_{s1E1.OT} \cdot E_{s1locE1.OT} + E_{h1E1.OT} \cdot E_{h1locE1.OT} + E_{h2E1.OT} \cdot E_{h2locE1.OT} \cdots + E_{h2aE1.OT} \cdot E_{h2alocE1.OT} + H_{h2E1} \cdot H_{h2locE1} = -2976.9 \cdot kN \cdot m$$

$$\Sigma M_{LateralresistE1.OT} := \Sigma M_{waterresistE1.OT} + \Sigma M_{SoilresistE1.OT} = -3087.2 \cdot kN \cdot m$$

$$\Sigma M_{seisE1.OT} := M_{Qv.conc} + M_{Q.conc} + M_{Qv.SoilWaterE1} + M_{Q.h.SoilWaterE1} = -5125 \cdot kN \cdot m$$

(seismic moment modified for the most adverse overturning effect)

Total moment:

$$\Sigma M_{E1.OT} := \Sigma M_{conc} + \Sigma M_{VertSoilWaterResistE1} + \Sigma M_{UpliftE1.OT} + \Sigma M_{LateraldriveE1.OT} + \Sigma M_{LateralresistE1.OT} + \Sigma M_{seisE1.OT} = 9748.1 \cdot kN \cdot m$$

Total Vertical Force: $\Sigma V_{E1.OT} := \Sigma V_{conc} + \Sigma V_{SoilWaterE1} + \Sigma V_{UpliftE1.OT} + Q_{v.conc} + Q_{v.SoilWaterE1} = 2325.9 \cdot kN$

Distance X_R: EM 1110-2-2502 Eq.4-1 $X_{R.E1} := \dfrac{\Sigma M_{E1.OT}}{\Sigma V_{E1.OT}} = 4.191\,m$

Overturning Resultant Ratio $Ratio_{E1.OT} := \dfrac{X_{R.E1}}{b} = 0.32$

$$Ratio_{E1.OT.check} := \begin{cases} \text{"OKAY "} & \text{if } Ratio_{E1.OT} > X_{R.reqE1} \\ \text{"Revise Structure""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

CHECK FOUNDATION ECCENTRICITY (HORIZONTAL PLANE):

Eccentricity (horizontal plan): $ex_{E1.OT} := \dfrac{b}{2} - \dfrac{\Sigma M_{E1.OT}}{\Sigma V_{E1.OT}} = 2.31\,m$ $Kern_{E1.OT} := \dfrac{b}{4} = 3.25\,m$

Eccentricity Check:

$$e_{check.E1.OT} := \begin{cases} \text{"Okay"} & \text{if } ex_{E1.OT} \le Kern_{E1.OT} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"Okay"}$$

LOAD CASE E1

CHECK FOUNDATION BEARING CAPACITY (HORIZONTAL PLANE):

Base Section Modulus: $S_{b.OT} = 28.17\,m^3$

Bearing Pressure Under Toe:

$$\sigma_{ToeE1.OT} := \begin{cases} \left(\frac{\Sigma V_{E1.OT}}{b \cdot B} + \frac{\Sigma V_{E1.OT} \cdot ex_{E1.OT}}{S_{b.OT}}\right) & \text{if } \frac{\Sigma V_{E1.OT}}{b \cdot B} \geq \frac{\Sigma V_{E1.OT} \cdot ex_{E1.OT}}{S_{b.OT}} \\ \frac{2 \cdot \Sigma V_{E1.OT}}{B \cdot 3\left(\frac{b}{2} - ex_{E1.OT}\right)} & \text{otherwise} \end{cases} = 370.0 \cdot kPa$$

$$Bearing_{ChecktoeE1.OT} := \begin{cases} \text{"OKAY "} & \text{if } \sigma_{ToeE1.OT} < \sigma_{allowE1} \\ \text{"NG - for reference only""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

Bearing Pressure Under Heel:

$$\sigma_{HeelE1.OT} := \begin{cases} \left(\frac{\Sigma V_{E1.OT}}{b \cdot B} - \frac{\Sigma V_{E1.OT} \cdot ex_{E1.OT}}{S_{b.OT}}\right) & \text{if } \frac{\Sigma V_{E1.OT}}{b \cdot B} \geq \frac{\Sigma V_{E1.OT} \cdot ex_{E1.OT}}{S_{b.OT}} \\ 0 & \text{otherwise} \end{cases} = 0.0 \cdot kPa$$

$$Bearing_{CheckheelE1.OT} := \left(\begin{cases} \text{"OKAY "} & \text{if } \sigma_{HeelE1.OT} < \sigma_{allowE1} \wedge \sigma_{HeelE1.OT} > 0 \\ \text{"NG - for reference only""} & \text{otherwise} \end{cases}\right) = \text{"NG - for reference only""}$$

SUMMARY OF STABILITY ASSESSMENT:

LOAD CASE E1

Sliding Factor of Safety: (Horizontal Plane - Ref only)	$FS_{Horiz.SlidingE1} = 0.60$	$FS_{Sliding.check1.E1}$ = "NG - key req""
Sliding Factor of Safety: (Inclined Plane)	$FS_{InclinedlSlidingE1} = 1.85$	$FS_{Sliding.check2.E1}$ = "OKAY "
Eccentricity: (Inclined Plane)	$ex_{E1} = 1.14\ m$	$e_{check.E1}$ = "Okay"
Bearing Pressure At Heel: (Inclined Plane)	$\sigma_{HeelE1} = 113 \cdot kPa$	$Bearing_{CheckheelE1}$ = "OKAY "
Bearing Pressure At Toe: (Inclined Plane)	$\sigma_{ToeE1} = 338 \cdot kPa$	$Bearing_{ChecktoeE1}$ = "OKAY "
Flotation Factor of Safety (horizontal plane)	$FS_{FloatationE1} = 3.84$	$FS_{Floatation.E1.check}$ = "OKAY "
Overturning Resultant Ratio: (horizontal plane)	$Ratio_{E1.OT} = 0.32$	$Ratio_{E1.OT.check}$ = "OKAY "
Eccentricity: (horizontal plane - Ref only)	$ex_{E1.OT} = 2.31\ m$	$e_{check.E1.OT}$ = "Okay"
Bearing Pressure At Heel: (horizontal plane - Ref only)	$\sigma_{HeelE1.OT} = 0 \cdot kPa$	$Bearing_{CheckheelE1.OT}$ = "NG - for reference only""
Bearing Pressure At Toe: (horizontal plane - Ref only)	$\sigma_{ToeE1.OT} = 370 \cdot kPa$	$Bearing_{ChecktoeE1.OT}$ = "OKAY "

Appendix E.1-4 PROJECT DRAWINGS

Refer to Preliminary Design Report - Appendix A for drawings.

Springbank Off-Stream Storage Project Structural Design Report

Service Spillway

Prepared for:

Alberta Transportation
3rd Floor – Twin Atria Building
4999 – 98 Avenue
Edmonton, AB T6B 2X3

Prepared by:

Stantec Consulting Ltd
Calgary, AB

Project Number 110773396

September 25, 2020

Stantec

Table of Contents

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

1.0 INTRODUCTION

1.1 PURPOSE

This Structural Design Report (SDR) describes stability assessment, structural analyses and design of the Service Spillway, which is part of the Springbank Off-stream Storage Project (SR1). The SDR consolidates and documents the design philosophy, relevant criteria, primary design parameters, and reference source of data used for design. The Service Spillway was sized to meet stability requirements and major structural members were designed for conformance with structural criteria.

1.2 PROJECT OVERVIEW

SR1 is a flood diversion system comprised of a diversion structure, a diversion channel and off-stream dry storage reservoir (no permanent pool). When in operation, SR1 will divert and temporarily store excess flood water from the Elbow River and release it back into the river system in a controlled manner. SR1 will work in tandem with the downstream Glenmore Reservoir to limit flood flows downstream of Glenmore to less than 170 m^3/s for up to SR1's design event - the 2013 flood or its equivalent.

Elements of the project are:

- Diversion Structure on the Elbow River consisting of, from left to right when looking downstream, gated Diversion Inlet structure leading to a Diversion Channel, gated Service Spillway located on the Elbow River, adjacent Auxiliary Spillway and a Floodplain Berm. A Debris Deflection Barrier is in the headwater of the Diversion Structure to protect the Diversion Inlet from flood debris.

- Diversion Channel leading from the Elbow River at the Diversion Inlet to the Off-stream Storage Reservoir with an Emergency Spillway along the channel and Channel Outlet at end of the channel.

- Off-stream Storage Dam with Low-Level Outlet Works.

1.3 DESIGN OBJECTIVES

The primary objective of the Service Spillway is to regulate river flow and headpond elevation during flood events which is best accomplished with bottom-hinged overflow crest gates. Since the Diversion Inlet gates are not intended for operational control, the headpond water surface elevation immediately upstream of the Diversion Structure. The crest gates are normally in the open (lowered) position at Elevation 1210.0 m to allow "free flow" of the Elbow River. When the operations plan calls for diversion of flood flows, the crest gates are raised to desired position to retain water and control either headpond elevation or discharge flow depending on the operations plan for a given flood scenario.

The Service Spillway left abutment serves as a retaining wall for the left embankment, primary site access road, control building, parking, and work area. The right abutment provides a physical separation between Service Spillway flow and Auxiliary Spillway flow during discharge of extreme floods and acts as a training wall for the Service Spillway stilling basin.

Since the Service Spillway is the primary water conveyance and regulating structure, steps were taken to reduce the potential for debris hang-ups and flow obstruction. For this reason, vehicle and pedestrian access to the left abutment is not included across the Service Spillway. Although there is no river crossing at the site, the right abutment is accessible via an access road upstream of the Auxiliary Spillway under typical river conditions.

The retaining walls retain embankment fill, serve as water barriers to contain the Elbow River, and prevent overtopping during flood events. For this reason, the walls were designed as concrete hydraulic structures to address stability, strength, and serviceability considerations for multiple operating conditions.

1.4 GENERAL ARRANGEMENT

The Service Spillway is a gated concrete structure located on the main channel of the Elbow River serving as the regulating feature for river and diversion flow. The primary elements of the Service Spillway include:

- Left abutment retaining walls and embankment transitions;
- Concrete monoliths with two 24 m wide gate bays with a center pier divider wall and fixed crest at Elevation 1210.0 m;
- Two 24 m wide by 5 m high bottom hinged crest gates with pneumatic bladders for control;
- Stilling basin concrete monoliths with an end sill to provide energy dissipation and reduce channel erosion during gate operations; and
- Right abutment monoliths and training walls.

An isometric view of the Service Spillway is shown in Figure 1. A general arrangement of the Service Spillway is shown on Drawing S-150 and detailed drawings of the monoliths and retaining walls are depicted on Drawings S-200 through S-259.

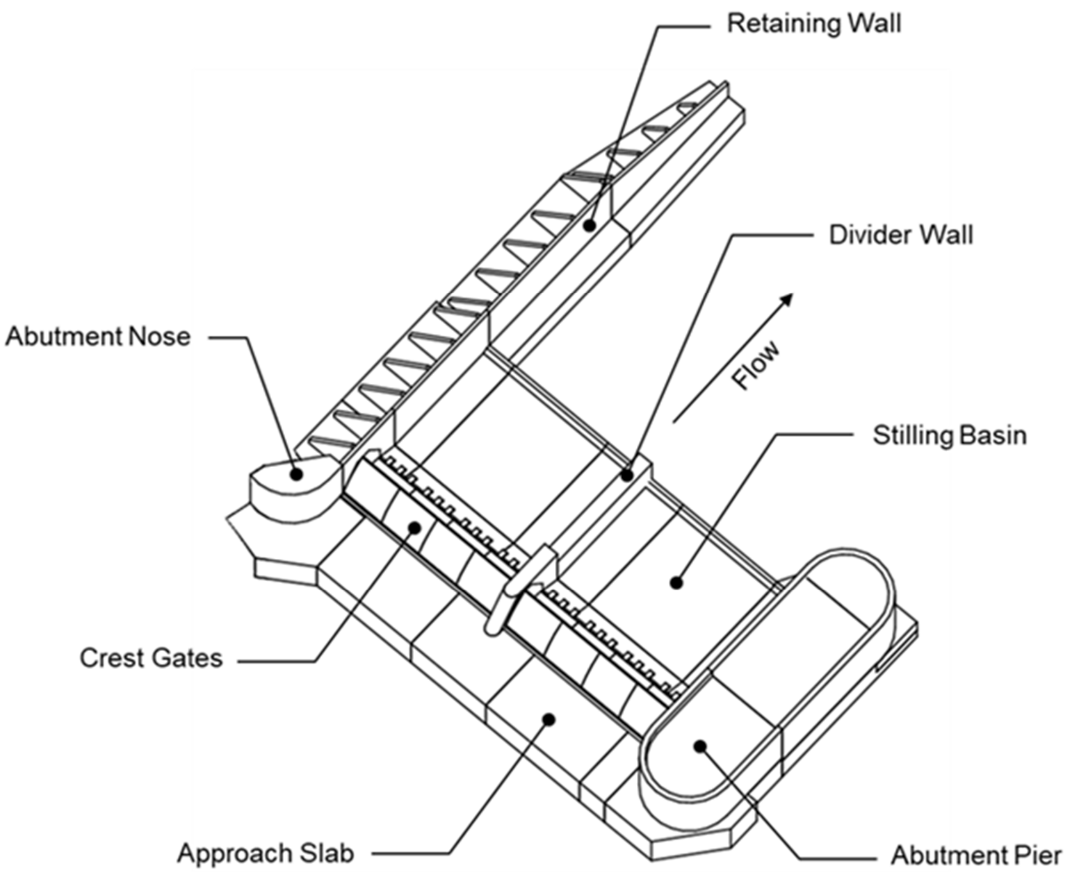


Figure 1. Service Spillway Structural Arrangement

1.5 BASIS FOR STRUCTURE LAYOUT

The Service Spillway layout and sizing were based on hydrotechnical evaluation to establish overall geometry, top of dam elevation, and hydraulic profiles to set crest elevation, stilling basin floors, and sizing of the gates.

The base elevation for each monolith or retaining wall was selected based on existing bedrock profile, stability requirements, and constructability considerations. Along the Service Spillway alignment, geotechnical evaluations identified approximate top of rock below the hydraulic profile and established an upper bound for the concrete/rock interface at or below Elevation 1207.0 m. The actual lower bound was determined based on concrete mass needed to provide stability. The concrete/rock interface was identified as a uniform bench to define the limit of excavation and simplify foundation preparation.

Lateral limits of individual monoliths and possible joint locations were selected to maintain base mat aspect ratios between 1:1 and 1.75:1, provide adequate toe for retaining wall and abutment segments, and satisfy stability requirements.

The abutments, approach walls, and training walls are concrete gravity structures using either counterfort or cantilever retaining walls depending on wall height. In general, walls with stem heights more than 6.5 m required counterforts to provide adequate stiffness and lateral load path.

2.0 CODES AND STANDARDS

In accordance with "Terms of Reference" for this project, the design complies with current Alberta Transportation (AT) Design Standards and current AT Design and Construction Bulletins. By reference in AT Standards, Canadian Dam Association (CDA) Dam Safety Guidelines and Technical Bulletin Nos. 1 through 9 provided primary guidance for design of the project including the hydraulic structures. Other recognized industry standards referenced in the AT/CDA Guidelines were used to supplement aspects of the design that the AT/CDA Guidelines do not address. Such references include the US Army Corps of Engineers (USACE) Engineering Manuals and US Bureau of Reclamation (USBR) Design Standards. In case of conflicting criteria, AT provisions were used unless a "more stringent" requirement was deemed appropriate based on engineering judgement.

Where referenced by AT and CDA, the National Building Code of Canada (NBCC) and Alberta Building Code (ABC) were used to obtain certain design loads (wind, snow, live, vehicle), and develop load combinations associated with strength and serviceability. NBCC and ABC provisions were used primarily for evaluation of individual elements such as gratings, ladders, and other ancillary structures.

The following codes, guidelines, and standards were identified for use on this project:

2.1 PROJECT STANDARDS

- Alberta Government, Terms of Reference (TOR0015997) for "Flood Mitigation Works, Springbank Off-Stream Storage Project (SR1) (WAC0078983), Addendum No. 2," August 1, 2014.
- AT's "Engineering Consultant Guidelines for Highway Bridge and Water Projects, Volume 1- Design & Tender" - 2011.
- AT's "Engineering Consultant Guidelines for Highway Bridge and Water Projects, Volume 2- Design & Tender" - 2011.
- AT's Civil Works Master Specifications for Construction of Provincial Water Management Projects.

2.2 DAM DESIGN AND SAFETY

- Province of Alberta Water Act – Water (Ministerial) Regulation - Regulation 205/98 (consolidated up to 185/2015).
- AT's "Water Control Structures Selected Design Guidelines" – Nov. 2004

- Canadian Dam Association Dam Safety Guidelines (CDA) 2007 with 2013 Revisions.
- CDA – Technical Bulletins:
    1. Inundation, Consequences, and Classification for Dam Safety, 2007
    2. Surveillance of Dam Facilities, 2007
    3. Flow Control Equipment for Dam Safety, 2007
    4. Retracted & Replaced by "Guidelines for Public Safety Around Dams," 2011
    5. Dam Safety Analysis and Assessment, 2007
    6. Hydrotechnical Considerations for Dam Safety, 2007
    7. Seismic Hazard Considerations for Dam Safety, 2007
    8. Geotechnical Considerations for Dam Safety, 2007
    9. Structural Considerations for Dam Safety, 2007
- USACE - Stability Analysis of Concrete Structures - EM 1110-2-2100, December 2005
- USACE – Earthquake Design and Evaluation of Concrete Hydraulic Structures - EM 1110-2-6053, 1 May 2007
- USACE - Gravity Dam Design - EM 1110-2-2200, June 1995
- USACE – Retaining and Flood Walls – EM 1110-2-2502, 29 September 1989
- USBR – Design Standards No. 14, Appurtenant Structures for Dams (Spillways and Outlet Works) Design Standards, Chapters 1 to 3, August 2014
- USBR – Design of Small Dams, 3rd Edition, 1987
- USBR – Design of Gravity Dams, 1976
- FEMA – Best Practices Technical Manuals

2.3 BUILDING CODE & PERSONNEL SAFETY

- Alberta Building Code (ABC) 2014
- National Building Code of Canada (NBCC) 2015
- Alberta Occupational Health and Safety Code (OHS code).

2.4 STRUCTURAL ANALYSIS, DESIGN AND MATERIAL SPECIFICATIONS

- Concrete Materials and Methods of Concrete Construction, CSA A23.1-14 & A23.2 -14
- Design of Concrete Structures, CSA A23.3-14
- Design of Steel Structures, CSA S16-14
- Welded Steel Construction, CSA W59-13
- Canadian Foundation Engineering Manual, Canadian Geotechnical Society – 4th Ed., 2006
- Canadian Highway Bridge Design Code, CSA S6-14
- Alberta Transportation Bridge Design Criteria
- Reinforcing Steel Institute of Canada, Standards Practice Manual

3.0 PROJECT DATA

3.1 LOCATION

The project is located in the Springbank area of Rocky View County, Alberta, CA, southwest of the City of Calgary in Township 24 (Range 04/03, W5M).

Latitude	51.050504 N
Longitude	114.401436 W
Elevation	1180 to 1220 m

3.2 FOUNDATION PARAMETERS

Site characterization is based on geologic assessment of the project site, exploratory borings, laboratory testing of project samples, and geotechnical engineering judgment. The following foundation parameters, derived from Brazeau formation data, are described in Preliminary Design Report (PDR), Appendix D - Geotechnical Assessment Report, Chapter 10.

Rock Classification sandstone/mudstone/shale/claystone

Recommended Concrete/Bedrock Interface	EL. 1207 or lower	
Bedrock Unit Weight	25.6 kN/m^3	
Bedrock Friction Angle (Rock/Rock Interface) (φ)	26 Deg.	
Concrete/Rock Interface Friction Angle (φ)	26 Deg.	
Cross Bed Friction Angle (φ) – Passive Wedge	24 Deg.	
Ultimate Bearing Capacity (σ_{ult})	1915 kPa	
Allowable Bearing Capacity – Usual	1270 kPa	(σ_{ult}/1.5 SF)
Allowable Bearing Capacity – Unusual	1470 kPa	(σ_{ult}/1.3 SF)
Allowable Bearing Capacity – Extreme	1740 kPa	(σ_{ult}/1.1 SF)

Cohesion: In accordance with CDA Guidelines Technical Bulletin No. 7 (Geotechnical) and Technical Bulletin No. 8 (Structural), cohesion was not included in the sliding stability analysis, and acceptance criteria is based on sliding factors for friction only resistance.

3.3 HYDROTECHNICAL PARAMETERS

Performance of the Diversion Structure and Diversion Channel was assessed using numerical and physical modeling. Hydraulic calculations and detailed modeling used in the design of individual hydraulic structures and other components are presented in the Preliminary Design Report, Appendices C and F. The various operating scenarios to be assessed for the Service Spillway were based on a High Hazard Dam Classification with the separation between the Usual and Unusual Conditions being the 50-year frequency flood and the 1000-year frequency flood dividing the Unusual and Extreme conditions.

Table 1 provides a summary of the hydrotechnical parameters for selected operating scenarios used in the design and stability analyses of the Service Spillway.

Table 1. Service Spillway Hydrotechnical Parameters

Operating Scenario	Service Spillway Discharge (m^3/s)	Headwater Elevation (m)	Tailwater Elevation (m)
Usual Condition			
Normal Operation (No Diversion) *160 m^3/s inflow*	160	1212.1	1211.8
Diversion Operation *50-Year Flood*	160	1214.6	1211.8
Unusual Condition			
Diversion Operation *2013 Flood*	640	1215.8	1213.1
Diversion Operation *2013 Flood* *Right Crest Gate Fails to Open*	565	1216.1	1213.0
No Diversion *1000-Year Flood*	1480	1217.0	1214.7
Construction / Maintenance *100-Year Flood*	320 (one bay)	1215.0	1212.5 with flow 1211.9 dewatered
Extreme - Flood			
IDF–DS (No Diversion) 2210 m^3/s inflow	1585	1217.3	1214.9
Extreme – Seismic (Post-Seismic Condition)			
EDGM – Normal Operation *160 m^3/s inflow*	160	1212.1	1211.8
EDGM – Diversion Operation *50-Year Flood*	160	1214.6	1211.8

3.4 CLIMATE DATA

3.4.1 Snow

Snow Load data for this project was obtained from Ontario Climate Centre – Environment Canada.

- Ground snow load, snow component (S_s) =1.7 kPa
- Ground snow load, rain component (S_r) =0.1 kPa
- Snow load, Importance factor I_s =1.25

3.4.2 Frost Considerations

Frost depth was determined in accordance with ABC and is shown in PDR, Appendix D - Geotechnical Assessment Report.

- Minimum design frost depth of 2.0 m
- Non-frost susceptible backfill - Gravel and clean sands

3.4.3 Temperature Variations

Monthly temperature data for use in the evaluation was obtained from the Calgary International Airport records, which is considered representative of typical temperature ranges at project site.

3.4.4 Wind

A wind load of 0.48 kPa was determined for use at the site based on the Alberta Building Code.

4.0 CONSTRUCTION MATERIALS

4.1 CONCRETE AND CONCRETE ACCESSORIES

- **Structural Concrete – Class A1**
  30 MPa @ 28 days, (AT Civil Works Specifications)
  General use reinforced concrete where thermal control and volume change are not a concern.

- **Structural Concrete – Class B1**
  30 MPa @ 90 days, (AT Civil Works Specifications)
  General use reinforced concrete where thermal control and volume change need to be considered (typically thickness > 600 mm)

- **Mass Concrete – Class M**
  20 MPa @ 90 days, 30 MPa @ 180 days (New mixture to be specified)
  Unreinforced concrete for monoliths, slabs, piers and retaining walls where thermal control and volume change need to be considered (typically thickness >1500 mm).

- **Foundation Concrete - Class F**
  15 MPa @ 28 days, (AT Civil Works Specifications)
  For use in foundation preparation such as mud mats and low strength fill.

- **Grout**
  Premixed structural non-shrink grout for equipment bases.

- **Preformed Expansion Joint Filler**
  ASTM D1752, Type I, Closed-cell sponge rubber.

- **Bond Breaker**
  Bituminous paint conforming to CGSB 37.2-88.

- **Waterstops**
  PVC ribbed profile with minimum rated hydrostatic head of 373 KPa based on joint type.

4.2 METALS

- **Steel Reinforcement** - CAN/CSA-G30.18, Grade 400W deformed bars
- **Structural Steel** - CSA-G40.21, Grade 300W or 350W
- **Stainless Steel** - ASTM A276
- **Miscellaneous Metals** (stairs, ladders, handrails) - Galvanized steel
- **Grating** - Galvanized steel – serrated bar grating

4.3 EARTHWORK MATERIALS

The Service Spillway structure will be constructed on a rock foundation. Soil backfill parameters are based on terminology in AT's Civil Works Master Specification 02330 – Earthwork Materials and described in the PDR, Appendix D - Geotechnical Assessment Report.

Design values for specified material include:

Impervious Fill

Unit Weight (-)	21 kN/m^3
Internal Friction Angle (-)	18 deg

Granular Fill

Unit Weight (-)	21 kN/m^3
Internal Friction Angle (-)	34 deg

Glacial Till

Unit Weight (-)	20 kN/m^3
Internal Friction Angle (-)	27 deg

Rock Fill

Unit Weight (-)	22 kN/m^3
Internal Friction Angle (-)	20 deg

Siltation (Equivalent Fluid)

Unit Weight Vertical (-)	19 kN/m^3
Unit Weight Horizontal (-)	13 kN/m^3

5.0 STRUCTURAL ANALYSIS APPROACH

For the purposes of analysis, the Service Spillway was divided into individual monoliths based on geometry, size, joint location, and loading considerations. The monoliths were analyzed as either concrete gravity sections (gate structures, piers and stilling basin) or retaining walls (wing walls, training walls, and abutments). Each monolith was evaluated for global stability, strength, and serviceability.

Global stability was assessed using the rigid body analysis method and application of unfactored loads. This method uses the summation of forces applied to the monolith to determine resultant location, foundation bearing pressures, and sliding resistance along identified potential failure plane(s). Analysis methodology and acceptance criteria are described in further detail in later sections of this report.

Reinforced concrete design of members was performed according to Design of Concrete Structures, CSA A23.3-14 with the additional requirements of the CSA's SEED Document – *Structural Design of Wastewater Treatment Plants-2018* for revisions addressing service load conditions, water tightness, shrinkage and temperature reinforcement, and crack control. The Seed Document contains references to ACI 350M-06 for modifying CSA A23.3-14.

Finite Element Models (FEMs) were used to validate manual calculations, identify potential stress concentrations, and assess additional serviceability concerns such as localized deflection, need for thermal stress relief, and stress redistribution not captured in manual calculations. Mitigation of alkali-aggregate reaction (AAR) potential and thermal crack control for mass concrete placements were addressed through design detailing and material specifications.

5.1 DESIGN TOOLS AND SOFTWARE

Microsoft Excel - 2010 - version: 14.0.7166.5000

Mathcad 15.0 - 2013 - version: MC15_M030_20131216

SAP2000 v21 version: 21.0.2

Revit 2019.2.1 version/build: 19.2.10.7

6.0 LOADS

6.1 DEAD LOADS (D)

Permanent loads on the structure include concrete structure weight, fixed equipment, backfill and water. Unit weights for principal materials are included in Table 2.

Table 2. Dead Load and Unit Weights

Material	Unit Weight	Source
Water	9.81 kN/m^3	CSA S6-14, Table 3.4
Concrete	23.5 kN/m^3	AT WCS Design Guide 4.2
Steel	77.0 kN/m^3	AT WCS Design Guide 4.2
Backfill – Glacial Till	20.0 kN/m^3 (moist unit weight)	4.3 - Earthwork Materials
"	22.0 kN/m^3 (saturated unit weight)	4.3 - Earthwork Materials
"	12.2 kN/m^3 (buoyant unit weight)	4.3 - Earthwork Materials

6.2 HYDROSTATIC LOADS (H)

Both horizontal and vertical components of water load were used based on water surface elevation for the load condition considered. Upstream and downstream water surface elevations are described in Hydrotechnical Parameters, Section 3.3. The water surface elevations were considered to be hydrostatic pressures without kinematic effects. Headwater was considered the water surface elevation at the upstream face of the structure. Tailwater elevation was either maximum tailwater indicated on tailwater rating curves, or a reduced tailwater elevation to account for hydraulic jump depending on load condition considered and which condition produced a more adverse effect on the structure.

6.3 UPLIFT PRESSURE (U)

The following uplift pressures were considered for analysis of sliding, floatation, bearing capacities and resultant location. For overflow weir monoliths and stilling basins, uplift was assumed to vary from 100 percent of headwater pressure at upstream edge of slab to 100 percent of tailwater pressure at downstream edge of slab applied over 100 percent of the base. For retaining walls, the uplift was assumed to vary from 100 percent of water pressure at face of the foundation heel to 100 percent of water pressure at face of the foundation toe applied over 100% of the base.

For analysis of overturning capacity and floatation for gravity structures, stilling basins and retaining walls, uplift pressure was considered to vary proportionally along the length of concrete structure/rock contact surface. For sliding and bearing capacity analysis of gravity structures and retaining walls, uplift was assumed to vary along the length of the linear sliding failure plane under consideration (horizontal concrete/rock contact, or through rock if structure contact with rock was keyed or sloped).

The foundation interface was assumed to have zero tensile capacity. For bases where stability calculations indicated bearing pressures less than zero, the foundation interface was assumed to crack, and 100 percent of the hydrostatic pressure was applied over the area of the cracked foundation, then vary linearly to 100 percent of tailwater pressure. For seismic evaluations, uplift loading remained unchanged from the pre-earthquake condition to the post-earthquake evaluation unless seismic loading resulted in a cracked foundation, in which case full hydrostatic pressure was applied to the entire area of the cracked foundation during the post-earthquake evaluation.

6.3.1 Seepage Reduction Measures

The underlying rock was identified as highly weathered and fractured. To minimize uplift potential, seepage reduction measures included using an upstream apron, cut-off keys, and drainage piping below the basin slab that discharges downstream in the Elbow River.

Where seepage reduction measures were provided, such as drains, a reduced uplift pressure was used for stability analyses for the Usual Load Condition only. For stability analyses of other load conditions, the seepage reduction measures were conservatively neglected.

6.4 EARTH PRESSURE (E)

Soil loads include both vertical and horizontal forces due to backfill, sediment, and siltation. Physical Model Sedimentation Studies indicate there is little accumulation of sediment adjacent to structures so loads associated with Sediment/Siltation were excluded from structural analysis.

Vertical force associated with soil mass above the structure was based on vertical projection of footing or structure below the soil. Soil mass was based on moist unit weight for material above the waterline and buoyant unit weight for material below the waterline. Vertical force associated with water above the structure was calculated separate from the soil mass.

Horizontal force associate with soil are based on at-rest condition represented by the empirical relationship:

$$K_o = 1 - \sin\theta$$

where: K_o = At-rest lateral pressure coefficient(*)
θ = Soil friction angle

In accordance with EM 1110-2-2100 and EM 1110-2-2502 to use At-Rest Coefficient (K_o).

6.5 LIVE LOADS (V)

The principal live loads on the Service Spillway include Vehicle Loads (V) or Heavy Equipment Loads adjacent to retaining walls, and Hoist/Equipment Loads associated with gate operation. Live Loads described in this section were considered transitory loads. Transitory loads were used for strength design of individual structure elements but were not included in stability analyses.

Vehicle Loads were obtained from CSA-S6-14, Section 3.8.3.

Vehicle (Vertical Application): CL-625

Vehicle (Horizontal Application): CL-625

Heavy Equipment Surcharge was applied to retaining wall design as a separate load condition to account for future modifications such as building additions, long-term material storage, or top-of-wall modifications. This load is not applied simultaneously with Vehicle Loads.

Heavy Equipment Surcharge: 15.0 kPa (Equivalent 0.75 m soil)

6.6 HYDRODYNAMIC LOADS (HD)

Hydrodynamic loads include wave action, sub-atmospheric pressure at the fixed crest, and hydraulic dissipater forces. For the Service Spillway, these forces have been excluded from stability analysis since they are considered insignificant or of a localized nature.

- Wave action is not included due to the short-term duration and relatively short fetch.
- Sub-atmospheric pressure is not included since there is insufficient head to develop sub-atmospheric pressure on the fixed crest.
- Hydraulic dissipater forces are localized forces addressed in the hydraulic design of stilling basin and end sill.

6.7 DEBRIS AND IMPACT LOADS

Impact loads associated with debris flows were based on geometry of the Service Spillway operating in conjunction with the Debris Deflection Barrier. Debris impact and drift loads were derived from 2D hydraulic modelling of the Service Spillway based on various flood events as described in PDR, Appendix C – Hydraulics.

6.8 ICE LOAD (I)

Three types of ice load to consider for the Service Spillway structure design include Static Ice Load (I_s), Dynamic Ice Loading (I_d), and Ice Accretion Load (I_v).

Static Ice Load (I_s) is a result of water surface freezing with application of horizontal load as an ice sheet expands and confinement increases. Static Ice Loading has the potential to occur at low flow conditions, particularly within the stilling basin. Static Ice Loading is applied in Usual Load Cases that address winter operating conditions.

Dynamic Ice Loading (I_d) is a result of moving ice floe impacting the structure. Dynamic Ice Loading was not considered as a design load case because the Diversion Structures do not have a permanent pool.

Ice Accretion Load (I_v) occurs when ice bonds to the structure and must be broken as water level rises. Ice Accretion Load associated with water level rise was not considered for the diversion structures due to small order of magnitude relative to hydrostatic loading and low probability of occurring simultaneous with spring and summer flooding.

Frost Heave. Vertical ice loading associated with "frost heave" is a realistic consideration. The structures are normally in a dewatered or low-water state with freeze/thaw action tending to open rock joints and concrete/rock interface and subject the structure to increased uplift potential. To minimize frost heave loading potential and remove this condition from the analysis, foundation interfaces will be located below the identified frost depth of 2.0 m for this site and drainage provided to reduce the formation of ice in the foundation.

Table 3. Ice Loads

Ice Condition	Load	Source
Static Ice (applied to structure)	150 kN/m @ 0.3 m below WS	AT WCS Design Guide 4.5.1.1
Static Ice (applied to gates)	75 kN/m @ 0.3 m below WS	AT WCS Design Guide 4.5.1.1
Ice Accretion	Per requirements of ABC for affected structures	ABC

6.9 SEISMIC - EARTHQUAKE LOADS (Q)

The seismic classification for the Service Spillway is based on Stantec's *Seismic Hazard Assessment - Springbank Off-Stream Dam and Reservoir Report* dated November 28, 2016. Since the hazard classification for this structure is High (Diversion Structure), the seismic parameters are based on an Earthquake Design Ground Motion (EDGM) with an Annual Exceedance Probability (AEP) of

1/10,000 resulting in Peak Ground Acceleration (PGA) of 0.26 g for horizontal application and PGA of 0.15 for vertical application.

This project site is situated in an area of low to moderate seismic activity. Consequently, CDA Guidelines, Section 6.5 allow for the seismic stability analysis of concrete gravity structures to be completed using a pseudo-static approach (coefficient method). This method applies a seismic force to a rigid body with the objective of determining sliding and overturning response of the structure. Since the pseudo-static method does not recognize the oscillatory nature of seismic loads, accepted practice is to perform the stability calculations using sustained acceleration values equivalent to 2/3 of the peak acceleration values.

When performing concrete stress analyses, the objective is to determine the tensile crack length induced by the inertia forces applied to the structure, so peak acceleration is used to calculate seismic coefficients. This approach assumes an instantaneous acceleration spike can induce cracking but is not sustained long enough to develop significant displacement along the crack plane. If no significant displacement occurs, the dynamic stability is maintained.

6.9.1 Seismic Effects on Concrete Mass

The horizontal force required to accelerate the concrete mass is calculated as:

$Q_h = k_h \times W$ where:

Q_h = Horizontal seismic load (kN)
k_h = Horizontal seismic coefficient
W = Structure mass (kg)
PGA = Peak ground acceleration= 0.26g

For Stability Analysis (Table 4): k_h = 2/3 x 0.26 = 0.17
For Member Analysis (Table 5): k_h = 1.0 x 0.26 = 0.26

The vertical force required to accelerate the concrete mass is calculated as:

$Q_v = k_v \times W$ where:

Q_v = Vertical seismic load (kN)
k_v = Horizontal seismic coefficient = 0.56*k_h
W = Structure mass (kg)

For Stability Analysis (Table 4): k_v = 2/3 x (0.56*k_h) = 0.10
For Member Analysis (Table 5): k_v = 1.0 x (0.56*k_h) = 0.15

Since an earthquake produces oscillating forces, the horizontal PGA and vertical PGA cannot occur at the same time. To account for this in the stability calculations, three separate combinations of vertical and horizontal seismic combinations were considered, but only the maximum value was reported. The three combinations of vertical and horizontal seismic load are as follows:

Table 4. Stability Analysis – Seismic Coefficients

Seismic Combination	Horizontal	Vertical
100% Horiz., No Vert.	$1.0*k_h = 0.17$	-
100% Horiz., 30% Vert.	$1.0*k_h = 0.17$	$0.3*k_v = 0.03$
30% Horiz., 100% Vert.	$0.3*k_h = 0.05$	$1.0*k_v = 0.10$

Table 5. Stress Analysis – Seismic Coefficients

Seismic Combination	Horizontal	Vertical
100% Horiz., No Vert.	$1.0*k_h = 0.26$	-
100% Horiz., 30% Vert Horiz.	$1.0*k_h = 0.26$	$0.3*k_v = 0.05$
30% Horiz., 100% Vert.	$0.3*k_h = 0.08$	$1.0*k_v = 0.15$

6.9.2 Seismic Effects on Water (H_E)

Using a pseudo-static method, hydrodynamic effects on water were approximated by using the Westergaard method to calculate the seismic water force (H_E). The calculated hydrodynamic force is additive to the hydrostatic water pressure force. The distribution is parabolic with the line of action for the force H_E at 0.4*h above the base of the water column. Detailed explanation of method can be found in Section 4-7.e, EM 1110-2-2100.

$$H_E = \left(\frac{7}{12}\right) * k_{h/v} * \gamma_w * h^2$$

where:
H_E = Seismic water force (kN)
$k_{h/v}$ = horizontal/vertical seismic coefficient
γ_w = unit weight of water (kN/m^3)
h = depth of water (m)

Note: The Westergaard method assumes an infinite waterbody length in the horizontal direction, which is a reasonable simplifying assumption for most conditions. For the unique case where seismic acceleration of water in the cross-stream direction is considered to evaluate divider walls and training walls, the Westergaard method will conservatively overestimate the hydrodynamic force.

6.9.3 Seismic Effect on Soils

Dynamic soil pressures and associated forces were analyzed assuming non-yielding backfills and an elastic response using the Wood's method. As referenced in Section 5-5.a.1, EM 1110-2-2100, and verified by project specific calculation (Appendix D), this method can be expected to have dynamic soil pressures greater than those predicted by the Mononobe-Okabe method for yielding backfills.

The use of Wood's method is considered reasonable and was used for analysis of gate bays that have relatively short backfills (<4 m) consisting primarily of rock fill for erosion protection. The use of Wood's method may be overly conservative for taller retaining walls with height ranging above 4 m with backfill consisting of granular fills and/or glacial till materials.

For conditions where seismic load cases control the wall design, dynamic soil pressures and associated forces were analyzed assuming yielding backfills and an elastic response using the Mononobe-Okabe method. This method uses active soil pressure during seismic conditions to assess stability.

Mononobe-Okabe Method for Yielding Backfill: This method assumes a wedge of soil bounded by the structure and an assumed soil failure plane moves as a rigid body with the same horizontal acceleration. The driving (active) wedge force is calculated based on a combined static and dynamic pressure coefficient (K_{AE}), but must then be divided into static and dynamic components for cases where the water table is above the backfill. Detailed explanation of this method can be found in Appendix G, EM 1110-2-2100.

$$P_{PE} = \frac{1}{2} K_{PE} \gamma (1 - k_v) h^2 \tag{G-3}$$

$$K_{PE} = \frac{\cos^2(\phi - \psi - \theta)}{\cos\psi \cos^2\theta \cos(\psi - \theta + \delta)\left[1 - \sqrt{\dfrac{\sin(\phi + \delta)\sin(\phi - \psi + \beta)}{\cos(\beta - \theta)\cos(\psi - \theta + \delta)}}\right]^2} \tag{G-4}$$

γ = unit weight of soil
k_v = vertical acceleration in g's
h = height of structure
ϕ = internal friction angle of soil

$$\psi = \tan\left(\frac{k_h}{1-k_v}\right) = \text{seismic inertia angle}$$

k_h = horizontal acceleration in g's
θ = inclination of interface with respect to vertical (this definition of θ is different from θ 1in Coulomb's equations)
δ = soil-structure friction angle
β = inclination of soil surface (upward slopes away from the structure are positive)

(c) Simplifying Conditions. For the usual case where k_v, δ, and θ are taken to be zero, the equations reduce to:

$$K_{AE} = \frac{\cos^2(\phi - \psi)}{\cos^2\psi\left[1 + \sqrt{\frac{\sin\phi\,\sin(\phi - \psi - \beta)}{\cos\beta\,\cos\psi}}\right]^2} \tag{G-5}$$

6.10 CLIMATIC CONDITIONS

6.10.1 Snow Loads (S)

Snow loads were considered insignificant compared to hydrostatic loads and were not considered for the Service Spillway.

6.10.2 Thermal Loads (T)

Temperature changes will influence the overflow weir monoliths and retaining walls. Thermal effects and measures, such as placement of expansion/contraction joints in concrete structures, to relieve thermal loads will be addressed during Final Design.

6.10.3 Wind (W)

Wind loads were considered insignificant compared to hydrostatic loads and were not considered for stability of the Service Spillway. Wind loads during construction (prior to placement of backfill) will be included for design of retaining walls and divider pier components. Wind Load data is listed in Section 3.4.4 above.

7.0 STABILITY ANALYSIS

Representative monoliths were analyzed for bearing and sliding for loading conditions applicable to the Service Spillway as identified in the tables presented in Section 7.3. Analysis methodology is as follows:

7.1 METHODOLOGY

7.1.1 Overturning and Bearing Stress

The Rigid Body Method (conventional gravity method) was used for the analysis of overturning and bearing stresses criteria. Overturning was evaluated as a percentage of base that remains in compression and not a safety factor. This method is outlined in Section 7.2 of CDA Technical Bulletin No. 9. It uses the vector summation of all forces, including uplift, acting on the monolith to determine the vector resultant force (V), resultant force eccentricity (e) within the base, and moment (Ve/S) based on an elastic and homogeneous rectangular beam analogy. Stresses were calculated as indicated below and stability was assured by maintaining the resultant force eccentricity within acceptance criteria limits for various loading conditions.

$$\sigma = \frac{V}{A} \pm \frac{Ve}{S}$$

Where: σ = Applied bearing pressure at each end of base (kN/m^2)
V = Summation of forces normal to base (kN)
A = Base area in compression (m^2)
e = Eccentricity of normal load about centroid of base in compression (m)
S = Section modulus of base area in compression (m^3)

7.1.2 Sliding

The sliding factor of safety was calculated for each load case using the limit equilibrium method as outlined in Section 7.2 of CDA Technical Bulletin No. 9. This method reduces to the equation shown below for a single wedge system with a horizontal sliding plane, along the concrete/rock interface (CRI) or through rock/rock failure plane as identified for each hydraulic structure. For inclined sliding planes projecting from the base of shear key to bottom base slab at the toe, vertical and horizontal forces are resolved into components normal and parallel to the sliding plane. Rock mass between the inclined plane and structure base is included in the dead load summation (EM 1110-2-2100). For this project, cohesion was conservatively assumed to be zero and acceptance criteria for sliding were based only on friction angle.

$$SSF = \frac{(V tan\varphi + c\ A)}{H}$$

Where: SSF = Sliding Safety Factor
V = Summation of vertical loads including uplift (kN)
$tan\ \varphi$ = Coefficient along sliding plane being considered
c = Cohesion at concrete/rock or rock/rock interface (assumed as 0) (kN/m^3)
A = Base area in compression (m^2)
H = Summation of horizontal forces (kN)

7.1.3 Floatation

The floatation factor of safety was determined for components of the project such as stilling basins and apron slabs as outlined in Section 8.5, AT WCS. The factor of safety against floatation is defined as ratio of resisting gravity force to driving uplift force. The possible resistance due to friction between adjacent structures or between structure and backfill was neglected unless shear provisions were provided.

$$FSF = \frac{\Sigma N}{\Sigma U}$$

Where: FSF = Factor of Safety against Floatation
ΣN = Summation of normal forces
ΣU = Summation of uplift forces

7.2 ACCEPTANCE CRITERIA

The following acceptance criteria are based on AT WCS Chapter 8, CDA Table 6-4, and CDA Technical Bulletin No. 8, Section 6.0. The load cases to be evaluated are divided into five categories as listed in Table 6:

Usual Condition: Those conditions under which the structure is intended to serve during normal operations and further defined as a condition that has a high likelihood of occurring within the design life of the structure. For the Service Spillway, this includes flood events up to the 50-year frequency flood (high hazard classified structures).

Unusual Condition: Those conditions that occur infrequently and may stress the structure more, under certain aspects, than normal conditions and may occur within the design life of the structure. Unusual load conditions include construction conditions, maintenance conditions, flood events between the 50-year and 1000-year frequency, infrequent earthquake events other than the MDE, and plugged drain conditions for Usual Load Cases.

Extreme – Flood: Extreme Load Conditions have a very remote likelihood of occurring with the design life of the structure. For the SR1 project, it is defined as those floods that occur from the 1000-year frequency event up to the structure's IDF. For the Service Spillway, it would occur when the IDF is considered with no diversion and the spillway gates open.

Extreme – Earthquake: For the SR1 project, the Extreme - Earthquake load condition to be assessed is the MDE as it has a very remote likelihood of occurring with the design life of the structure. The MDE is applied to the Usual Condition load cases. The Extreme – Earthquake condition is used to establish Post-Earthquake condition of the hydraulic structure. Thus, there are no stability acceptance criteria for this condition.

Post-Earthquake: The Post-Earthquake condition assesses the stability of the hydraulic structure following the applied seismic event based on earthquake induced cracking at the foundation structural interface and within the structure so that it is still capable of resisting the Usual Loading.

Table 6. Acceptance Criteria for Hydraulic Structures

Loading Combination	Position of Resultant Force (Percent of Base in Compression)[1]	Normal Compression Stress[2]	Sliding Safety Factor (Friction Only)	Floatation Safety Factor
Usual	Middle third of the base: 100% compression	<0.3 x f_c	≥1.5	≥1.5
Unusual	Middle third of the base: 100% compression	<0.5 x f_c	≥1.3	≥1.3
Extreme Flood	Within middle half of the base, and all other acceptance criteria must be met	<0.5 x f_c	≥1.1	≥1.1
Extreme Earthquake	Within the base, except where an instantaneous occurrence of resultant outside the base may be acceptable	<0.9 x f_c	Note [3]	
Post-Earthquake	Within middle half of the base	<0.5 x f_c	≥1.0	≥1.1

[1] Foundation bearing stress is compared to allowable stress determined from Geotechnical Investigation

[2] Where f_c = compressive strength of concrete

[3] The earthquake load case is used to establish post-earthquake condition of the structure

7.3 LOAD CONDITIONS

Load conditions varied for various Service Spillway structures based on configuration and location of applied load. The following sections summarize load conditions for various structures.

7.3.1 Service Spillway – Gate Structure

Table 7. Gate Structure – Load Conditions

Usual Load Cases		
U1	Usual Condition - Normal Operation Prior to Initiation of Diversion (Winter Condition) Design inflow 160 m³/s with no diversion + Ice (both crest gates open, EL 1210.0) Headwater: EL 1212.1 Tailwater: EL 1211.8	D+H+E+U+I
U2	Usual Condition - Diversion Operation – 50 Year Frequency Flood Inflow 530 m³/s with diversion of 370 m³/s + Debris Impact Regulating crest gate at EL 1212.1 and guard crest gate closed, EL 1215.0 Headwater: EL 1214.6 Tailwater: EL 1211.8	D+H+E+U
Unusual Load Cases		
UN1	Unusual Condition - Diversion Operation – 2013 Design Flood Inflow 1240 m³/s with diversion of 600 m³/s + Debris Impact Regulating crest gate open, EL 1210.0, and guard crest gate at EL 1213.5 Headwater: EL 1215.8 Tailwater: EL 1213.1	D+H+E+U+I
UN2	Unusual Condition – Crest Gate Failure - Diversion Operation – 2013 Design Flood Inflow 1240 m³/s with diversion of 600 m³/s + Debris Impact Regulating crest gate open, EL 1210.0, and guard crest gate closed, EL 1215.0 Headwater: EL 1216.1 Tailwater: EL 1213.0	D+H+E+U+I
UN3	Unusual Condition – No Diversion - 1000 Year Design Flood – Regulatory - Inflow 1930 m³/s with no diversion (Both crest gates open, EL 1210.0) Headwater: EL 1217.0 Tailwater: EL 1214.7	D+H+E+U
UN4	Unusual Condition – Construction/Maintenance - Single gate bay dewatered 100 Year Frequency Flood – Inflow 765 m³/s with diversion of 600 m³/s Headwater: EL 1215.0 Tailwater: EL 1211.9 dewatered; EL 1212.5 with flow	D+H+E+U
Extreme – Flood		
E1	Extreme Condition - IDF Inflow 2210 m³/s with no diversion, both crest gates open, EL 1210.0 Headwater: EL 1217.3 Tailwater: 1214.9	D+H+E+U+I
Extreme – Earthquake used to develop Post-Seismic Condition		
Post-Seismic		
E2	Extreme Condition – EDGM applied to U1 Load Case If E2 loading results in cracked base, modify structure to prevent cracked base. Headwater: EL 1212.1 Tailwater: EL 1211.8	Load Case$_{U1}$+ Q
E3	Extreme Condition – EDGM applied to U2 Load Case If E3 loading results in cracked base, modify structure to prevent cracked base. Headwater: EL 1214.6 Tailwater: EL 1211.8	Load Case$_{U2}$+ Q
Notes		
D	Dead Load: Includes weight of concrete (C), water (H), and gates (G)	
H	Hydrostatic Loads: See each load case for various Headwater and Tailwater conditions.	
E	Earth / Sediment / Siltation: Include horizontal and vertical loads	
U	Uplift Pressure	
I	Static Ice Load <u>or</u> Impact Load: Apply one or the other depending on load case	
Q	Seismic Load: Design Earthquake load * Seismic evaluation to consider simultaneous vertical and horizontal for three combinations.	

7.3.2 Service Spillway – Stilling Basins

Table 8. Stilling Basins – Load Conditions

F1 Usual	Usual Condition – Spillway Discharge 160 m³/s (crest gates open) Water Weight based on: TWEL = 1211.8 Linear Uplift based on: HWEL = 1212.1 (1211.8 – Drain Effective) TWEL = 1211.8	(D+H) / U
F2 Unusual	Unusual Condition – Flood Condition Spillway Discharge 640 m³/s Water Weight based on: TWEL = 1213.1 Linear Uplift based on: HWEL = 1215.8 TWEL = 1213.1	(D+H) / U
F3 Unusual	Unusual Condition – Construction /Maintenance/ single gate bay dewatered Water Weight: Not Included for this condition Linear Uplift based on: HWEL = 1214.6 TWEL = 1211.8	D / U
F4 Extreme	Extreme Condition – Drain Plugged with Crest Gates Closed and 160 m³/s discharge Water Weight based on: TWEL = 1211.8 Linear Uplift based on: HWEL = 1215.8 TWEL = 1211.8	(D+H) / U
Notes		
D	Dead Load: Includes concrete (C), water (H)	
H	Hydrostatic Loads: See each load case for various Headwater and Tailwater conditions.	
U	Uplift Load	

7.3.3 Service Spillway – Retaining Walls

Table 9. Retaining Walls – Load Conditions

Usual Load Cases		
U1	Usual Condition – At-Rest Soil Loading Groundwater at 0.5 m above drain centerline	D+H+E+U
Unusual Load Cases		
UN1	Unusual Condition – At-Rest Soil Loading + Equipment Surcharge Groundwater at 0.5 m above drain centerline	D+H+E+U+L
UN2	Unusual Condition – At-Rest Soil Loading – Ineffective Drain Groundwater and uplift at 2013 Design Flood HWEL or TWEL depending on location of wall Section being analyzed.	D+H+E+U
Seismic		
E1	Extreme Condition – Seismic Load Groundwater at 0.5 m above drain centerline	D+H+E+U+Q
Notes		
D	Dead Load: Includes concrete (C), backfill (E),	
H	Hydrostatic Load: Groundwater 0.5 m above drain centerline, use buoyant weight of soil on heel.	
E	Earth / Backfill / Sediment / Siltation: Include horizontal and vertical loads	
U	Uplift Load	
L	Live Loads: Equipment Surcharge	
Q	Seismic Load: Design Earthquake load * Seismic evaluation to consider simultaneous vertical and horizontal for three combinations.	

7.4 SUMMARY OF STABILITY ANALYSES

Stability analyses for the Service Spillway gate structures, stilling basins, retaining walls, and abutment / training walls were performed in accordance with criteria and procedures outlined in the CDA Technical Bulletin No. 9, "Structural Considerations for Dam Safety", and the USACE EM 1110-2-2100 "Stability Analysis of Concrete Structures." Each section was evaluated for Usual, Unusual, Extreme, and Post-Seismic loading conditions representing potential conditions the structure will experience during its design life. Summaries of the stability calculation results are presented in the sections that follow. Refer to the Appendices for stability calculations and results.

7.4.1 Gate Structure

The Service Spillway gate structures were analyzed as two distinct monoliths: Gate Crest Blocks (SS-2A & SS-4A) and Center Pier Block (SS-3A).

The Gate Crest Blocks consist of a 4 m thick apron slab at Elevation 1210.0 m with an upstream key extending down to Elevation 1204.0 m. The upstream key provides a seepage cut-off, erosion protection and additional sliding resistance. Downstream of the gate, the Gate Crest Block slopes down to the stilling basin floor, Elevation 1208.0 m. The crest gate is fixed to the apron slab and transfers load vertically but does not transfer load laterally to piers or abutments. The SS-2A and SS-4A Gate Crest Blocks were analyzed separately to account for the assumed operation of guard (right) gate and regulating (left) gate, respectively.

The Center Pier Block is supported on a foundation with the same geometry as the Gate Crest Blocks, but includes a 2.0 m wide center pier extending to Elevation 1216.0 m. The Center Pier divides the left and right spillway bays and acts as an abutment for the crest gates. This center monolith is subjected to the same loads as the gate crest blocks with the addition of lateral loads due to the divider wall. The divider wall was analyzed for lateral load associated with unbalanced water load on one side of wall during dewatered maintenance conditions and peak seismic acceleration in the cross-stream direction with unbalanced water load.

The stability analyses for the structures were performed using a Mathcad spreadsheet. Results of the analyses are summarized in Tables 10, 11, and 12 and calculations are included in Appendix E.2-1.

Stability analyses indicate a relatively light structure sensitive to sliding when crest gates are used to retain water during diversion operation. Stability calculations indicate results within the limits of acceptance criteria utilizing an inclined plane for analysis. For all loading conditions considered, floatation factors of safety were above required, 100 percent of the base was in compression, and sliding factors of safety were above required. Stability results indicate that sliding stability was the primary concern due to the low friction angle of the foundation rock. To ensure an inclined failure plane utilized in the analysis was valid, the upstream shear key was designed as a structural element. The controlling load case was Load Case E3 (EDGM applied during 50-Year Flood).

Table 10. Gate Crest Block 2A – Stability Analysis Summary

Load Case	Headwater Elevation (m)	Tailwater Elevation (m)	Critical Depth at Gate Lip (m)	Uplift Force (kN)	Floatation Safety Factor (FSF)		Sliding Safety Factor (SSF)		Foundation Bearing Stress		% Base in Compression
					Req	Calc	Req	Calc	Upstream (Heel) (kPa)	Downstream (Toe) (Kpa)	
Usual Load Cases											
U1 Normal Operation	1212.1	1211.8	1211.4	18920	1.5	1.6	1.5	43.8	89	34	100
U2 Diversion Operation *50 Yr. Flood*	1214.6	1211.8	1211.8	22323	1.5	1.6	1.5	2.3	60	81	100
Unusual Load Cases											
UN1 Diversion Operation *2013 Flood*	1215.8	1213.1	1215.03	25726	1.3	1.5	1.3	3.2	74	70	100
UN2 Diversion Operation *2013 Flood*	1216.1	1213.0	1215.73	25998	1.3	1.6	1.3	2.8	62	94	100
UN3 No Diversion *1000 Yr. Flood*	1217.0	1214.7	1214.67	29537	1.3	1.4	1.3	5.9	86	46	100
UN4 Construction/ Maintenance *100-Yr. Flood*	1215.0	1212.5 bay with flow	1211.9	23003	1.3	1.5	1.3	3.2	55	75	100
Extreme – Flood											
E1 IDF-DS without Diversion	1217.3	1214.9	1214.7	30217	1.1	1.4	1.1	5.6	86	46	100
Extreme – Earthquake used to determine Post-Seismic Condition											
E2 EDGM applied to U1	1212.1	1211.8	1211.4	18920	1.1	1.5 (E2.3)	1.0	1.4 (E2.2)	77 (E2.3)	38 (E2.3)	100
E3 EDGM applied to U2	1214.6	1211.8	1211.8	19601	1.1	1.4 (E3.3)	1.0	1.0 (E.3.2)	30 (E3.2)	112 (E3.1)	100

Notes:
1. See Appendix E.2-1 for definition of monolith description, analysis methodology, and stability calculations.
2. Analysis assumes inclined sliding plane, interface friction angle Φ = 26 degrees, and no cohesion.
3. Reported seismic results are controlling values for the three combinations of vertical and horizontal seismic load considered.

Table 11. Gate Crest Block 4A – Stability Analysis Summary

Load Case	Headwater Elevation (m)	Tailwater Elevation (m)	Critical Depth at Gate Lip (m)	Uplift Force (kN)	Floatation Safety Factor (FSF)		Sliding Safety Factor (SSF)		Foundation Bearing Stress		% Base in Compression
					Req	Calc	Req	Calc	Upstream (Heel) (kPa)	Downstream (Toe) (Kpa)	
Usual Load Cases											
U1 Normal Operation	1212.1	1211.8	1211.4	18920	1.5	1.6	1.5	43.8	89	34	100
U2 Diversion Operation *50 Yr. Flood*	1214.6	1211.8	1213.76	22323	1.5	1.6	1.5	2.7	69	78	100
Unusual Load Cases											
UN1 Diversion Operation *2013 Flood*	1215.8	1213.1	1213.87	25726	1.3	1.5	1.3	5.5	85	54	100
UN2 Diversion Operation *2013 Flood*	1216.1	1213.0	1214.07	25998	1.3	1.5	1.3	4.9	84	58	100
UN3 No Diversion *1000 Yr. Flood*	1217.0	1214.7	1214.67	29537	1.3	1.4	1.3	5.9	86	46	100
UN4 Construction/ Maintenance *100-Yr. Flood*	1215.0	1211.9 dry bay	1213.63	23003	1.3	1.6	1.3	4.4	67	67	100
Extreme – Flood											
E1 IDF-DS without Diversion	1217.3	1214.9	1214.87	30217	1.1	1.4	1.1	5.6	86	46	100
Extreme – Earthquake used to determine Post-Seismic Condition											
E2 EDGM applied to U1	1212.1	1211.8	1211.4	18920	1.1	1.5 (E2.3)	1.0	1.4 (E2.2)	77 (E2.3)	38 (E2.3)	100
E3 EDGM applied to U2	1214.6	1211.8	1213.76	19601	1.1	1.5 (E3.3)	1.0	1.1 (E.3.2)	38 (E3.2)	109 (E3.1)	100

Notes:
4. See Appendix E.2-1 for definition of monolith description, analysis methodology, and stability calculations.
5. Analysis assumes inclined sliding plane, interface friction angle Φ = 26 degrees, and no cohesion.
6. Reported seismic results are controlling values for the three combinations of vertical and horizontal seismic load considered.

Table 12. Gate Center Pier Block 3A – Stability Analysis Summary

Load Case	Headwater Elevation (m)	Tailwater Elevation (m)	Uplift Force (kN)	Floatation Safety Factor (FSF)		Sliding Safety Factor (SSF)		Foundation Bearing Stress		% Base in Compression
				Req	Calc	Req	Calc	Upstream (Heel) (kPa)	Downstream (Toe) (Kpa)	
Usual Load Cases										
U1 Normal Operation	1212.1	1211.8	15136	1.5	1.8	1.5	40.3	78	66	100
U2 Diversion Operation *50 Yr. Flood*	1214.6	1211.8	17858	1.5	1.7	1.5	2.5	56	77	100
Unusual Load Case										
UN1 Diversion Operation *2013 Flood*	1215.8	1213.1	20580	1.3	1.6	1.3	3.0	61	97	100
UN2 Diversion Operation *2013 Flood*	1216.1	1213.0	20798	1.3	1.6	1.3	3.5	67	98	100
UN3 No Diversion *1000 Yr. Flood*	1217.0	1214.7	23629	1.3	1.5	1.3	6.2	83	64	100
UN4 Construction/ Maintenance *100-Yr. Flood*	1215.0	1212.5 / 1211.9	18403	1.3	1.7	1.3	3.2	55	97	100
Extreme – Flood										
E1 IDF-DS without Diversion	1217.8	1214.9	24174	1.1	1.5	1.1	4.8	78	70	100
Extreme – Earthquake used to determine Post-Seismic Condition										
E2 EDGM applied to U1	1212.1	1211.8	15136	1.1	1.6 (E2.3)	1.0	1.6 (E2.2)	48 (E2.3)	94 (E2.1)	100
E3 EDGM applied to U2	1214.6	1211.8	17858	1.1	1.6 (E3.3)	1.0	1.1 (E3.2)	34 (E3.3)	136 (E3.1)	100

Notes:
7. See Appendix E.2-1 for definition of monolith description, analysis methodology, and stability calculations.
8. Analysis assumes inclined sliding plane, interface friction angle Φ = 26 degrees, and no cohesion.
9. Reported seismic results are controlling values for the three combinations of vertical and horizontal seismic load considered.

7.4.2 Stilling Basin

The Service Spillway Stilling Basins consist of a 2.0 m thick by 18.0 m long concrete slab with 0.6 m high end sill. The stilling basin floor is at Elevation 1208.0 m. A 1.0 m thick downstream cutoff wall extends to Elevation 1204.0 m. The upstream end of the slab supports the downstream end of the gate crest blocks and center pier block.

Where the required Floatation Safety Factor was unable to be met through the dead weight of the structure, the unit area anchor force required to resist the uplift pressure was calculated. The stability analyses for the structure were performed using a Mathcad spreadsheet. Results of the analyses are summarized in Table 13 and calculations are included in Appendix E.2-2.

Table 13. Stilling Basin (2B & 4B) – Floatation Stability Summary

Load Comb.	Σ Vert. Forces (kN)	Σ Uplift Forces (kN)	FS Req'd	FS Calc.	Required Anchor Force (kN/m^2)
F1 Usual Normal Operation	22123	15124	1.5	1.46	2.1
F2 Unusual 2013 Flood	25471	19973	1.3	1.28	1.9
F3 Unusual Constr./Dewatered	12338	14936	1.3	0.83	27.0
F4 Extreme Ineffective Drain	22123	17439	1.1	1.27	0.0

Stability analysis results indicate a need for anchorage of the stilling basin into the bedrock below, however the required anchor force is within the capability of conventional active or passive ground anchors. The controlling Load Case for the stilling basin anchors is F3 (Unusual - Single Bay Dewatered for Maintenance/Construction).

7.4.3 Right Abutment Pier

The Service Spillway Right Abutment Pier, Blocks 1A and 1B, serves as an abutment wall for the crest gate, a face form for the Auxiliary Spillway overflow weir; a retaining wall for the Auxiliary Spillway fuse plug and soil overlay; training wall for Service Spillway and Auxiliary Spillway, and potential hub for dewatering cofferdams during construction. Each block is designed as a gravity monolith that provides separation between Service Spillway and Auxiliary Spillway during operation. During certain phases of construction, the right abutment may be subjected to hydraulic loading during construction activity of the Auxiliary Spillway. The abutment base is monolithic with the gate structure and stilling basin base mats. No gate load is applied to the abutment wall. The top of wall is set at the PMF maximum headpond, Elevation 1218.0 m, with no freeboard since it can be overtopped without consequences. The right abutment pier was designed to resist embankment loads in the cross-stream direction from the Auxiliary Spillway.

Stability analyses were performed in accordance with structural design criteria outlined previously. The stability analyses were performed using a Mathcad spreadsheet. The nose component (Block 1A) was analyzed for Usual, Unusual, and Extreme loading conditions representing the potential range of conditions the structure will be exposed to during the design life. In accordance with guidelines for hydraulic structures, at-rest soil pressures were used for all load case calculations except active soil pressures were used when considering seismic load cases.

Results of the analyses are summarized in Table 14 and calculations are included in Appendix E.2-3.

Table 14. Right Abutment – Stability Analysis Summary

Load Case	Headwater Elevation (m)	Tailwater Elevation (m)	Uplift Force (kN)	Floatation Safety Factor (FSF)		Sliding Safety Factor (SSF)		Foundation Bearing Stress		% Base in Compression
				Req	Calc	Req	Calc	Upstream (Heel) (kPa)	Downstream (Toe) (Kpa)	
Usual Load Cases										
U1 Normal Operation	1212.1	1211.8	16750	1.5	3.4	1.5	5.6	55	224	100
U2 Diversion Operation *50 Yr. Flood*	1214.6	1211.8	20817	1.5	2.8	1.5	5.6	42	225	100
Unusual Load Case										
UN1 Diversion Operation *2013 Flood*	1215.8	1213.1	24298	1.3	2.5	1.3	5.1	52	200	100
UN2 Diversion Operation *2013 Flood*	1216.1	1213.0	24013	1.3	2.6	1.3	4.7	86	175	100
UN3 No Diversion *1000 Yr. Flood*	1217.0	1214.7	26957	1.3	2.3	1.3	4.2	57	185	100
UN4 Construction/ Maintenance	1215.0	1211.9	21575	1.3	2.7	1.3	4.2	16	240	100
Extreme – Flood										
E1 IDF without Diversion	1217.8	1214.9	28858	1.1	2.1	1.1	4.3	73	158	100
Extreme – Earthquake used to determine Post-Seismic Condition										
E2 EDGM applied to U1	1212.1	1211.8	16750	1.1	2.0 (E2.3)	1.0	1.3 (E2.2)	24 (E2.1)	260 (E2.1)	100
E3 EDGM applied to U2	1214.6	1211.8	20817	1.1	1.6 (E3.3)	1.0	1.1 (E3.2)	8 (E3.2)	242 (E3.1)	100

Notes:
10. See Appendix E.1 for definition of monolith description, analysis methodology, and stability calculations.
11. Reported seismic results are controlling values for the three combinations of vertical and horizontal seismic load considered.

The principal factors affecting the abutment pier design include significant seismic force associated with relatively high weight of the structure; poor rock quality along the foundation interface; and relatively weak material (glacial till) anticipated in the backfill zone of influence.

For all loading conditions considered, floatation factors of safety were above required, 100 percent of the base was in compression, and sliding factors of safety were above required. Stability results indicate that sliding stability was the primary concern due to the low friction angle at the rock/rock bedding planes. The controlling load case is Load Case E3 (Seismic Effects applied to Load Case U2 – Diversion Operation).

7.4.4 Left Abutment Retaining Walls

The retaining walls that serve as the left abutment for the Service Spillway consist of counterforted or cantilever retaining walls with varying thickness and a stepped top of footing.

Blocks 5A and 5B retaining walls enclose the Gate Blocks and Stilling Basins and serve as the left abutment for the crest gates. Analysis of Block 5B is considered critical due to the increased upstand height. The Block 5B retaining wall extends from top of footing Elevation 1208.5 m behind the wall and top of footing Elevation 1208.0 m at the front of the wall to top of wall Elevation 1219.0 m. The wall varies in thickness between 0.8 m thick and 0.5 m thick. The footing is 2.5 m thick (at the back of the wall) with a 2.0 m deep heel key. The wall has 0.5 m thick counterforts

Blocks 5C and 5D retaining walls extend 43.0 m downstream of the Service Spillway stilling basin. Block 5C retaining walls extend from top of footing Elevation 1207.0 m to top of wall, Elevation 1219.0 m. The footing is 2.5 m thick with a 3.0 m deep heel key. Block 5D retaining walls extend from top of footing Elevation 1207.0 m with top of wall elevation varying between 1219.0 m to 1216.6 m. The footing is 2.5 m thick with a heel key stepping from 3.0 m deep to 2.5 m deep. The wall has 0.5 m thick counterforts at spacing varying from 3.2 m to 3.7 m. The downstream end of the retaining wall does not require counterforts. Block 5D was analyzed at the downstream end and at midsection.

Three representative sections were identified to capture the range of wall geometry and loading conditions for the left abutment. Representative sections are indicated on Figure 2 and described as follows.

- Section SS-5B: Counterfort wall serving as the stilling basin training wall. Crest gates do not transfer load laterally, so the stem is similar to other wall sections, but the footing is thicker to match the stilling basin concrete profile.

- Section SS-5C: Counterfort training wall downstream of the stilling basin representing the tallest wall in the Service Spillway. This section was considered one of the critical wall sections due to retained soil height, retained groundwater depth, minimal resistance on the toe, and potential for vehicle and equipment surcharge.

- Section SS-5D: Counterfort or cantilever wall serving as a downstream training wall and slope protection. This location downstream of the Service Spillway is subjected to different water loading and increased potential for rock scour along the toe than the upstream Section SS-5C retaining wall. Section SS-5D was analyzed at two sections to account for the geometric variability of the monolith.

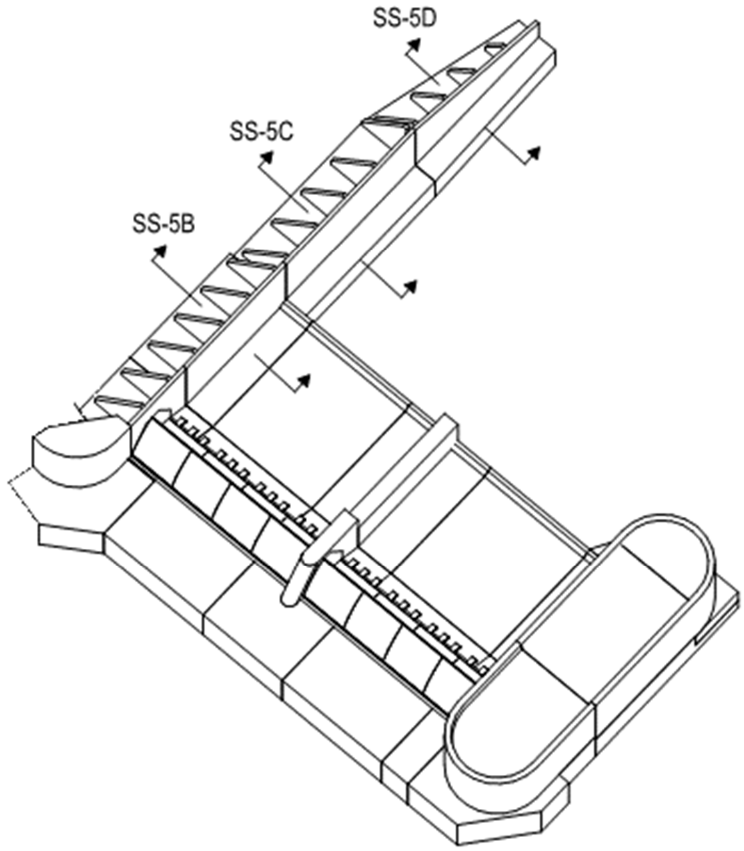


Figure 2. Service Spillway Retaining Wall Key Plan

Stability analyses were performed in accordance with the Structural Design Criteria outlined previously. The stability analyses for the structure were performed using an Excel spreadsheet. Each of the three representative wall sections was evaluated for Usual, Unusual, and Extreme loading conditions representing the potential range of conditions the structure will be exposed to during the design life. In accordance with guidelines for hydraulic structures, at-rest soil pressures were used for all Load Case calculations except active soil pressures were used when considering Seismic Load Cases. Results of the analyses are summarized in Table 15 and calculations are included in Appendix E.2-4.

Table 15. Left Abutment Retaining Walls – Stability Analysis Summary

Load Case	Headwater (Heel) Elevation (m)	Tailwater (Toe) Elevation For Uplift (m)	Uplift Force (kN)	Floatation Safety Factor (FSF)		Sliding Safety Factor (SSF)		Foundation Bearing Stress		% Base in Compression
				Req	Calc	Req	Calc	Upstream (Heel) (kPa)	Downstream (Toe) (kPa)	
WALL BLOCK SS-5B										
U1 Normal Operation	1213.1	1210.0	802	1.5	3.36	1.5	1.67	149	213	100
UN1 Equip. Surcharge	1213.1	1210.0	802	1.3	3.49	1.3	2.01	140	242	100
UN2 Ineffective Drain	1216.2	1216.2	1372	1.3	2.00	1.3	1.30	99	184	100
E1 Seismic	1213.1	1210.0	802	1.1	3.03	1.0	1.79	119	203	100
WALL BLOCK SS-5C										
U1 Normal Operation	1213.0	1210.0	1041	1.5	3.23	1.5	1.64	73	404	100
UN1 Equip. Surcharge	1213.0	1210.0	1041	1.3	3.35	1.3	1.52	56	444	100
UN2 Ineffective Drain	1214.4	1214.4	1397	1.3	2.43	1.3	1.32	49	379	100
E1 Seismic	1213.0	1210.0	1041	1.1	2.92	1.0	1.30	43	386	100
WALL BLOCK SS-5D (Mid-section)										
U1 Normal Operation	1212.5	1210.0	862	1.5	2.78	1.5	1.92	85	272	100
UN1 Equip. Surcharge	1212.5	1210.0	862	1.3	2.90	1.3	1.73	76	304	100
UN2 Ineffective Drain	1214.4	1214.4	1202	1.3	2.02	1.3	1.31	49	258	100
E1 Seismic	1212.5	1210.0	862	1.1	2.51	1.0	1.35	55	266	100
WALL BLOCK SS-5D (Downstream)										
U1 Normal Operation	1212.5	1210.0	722	1.5	2.21	1.5	2.38	71	169	100
UN1 Equip. Surcharge	1212.5	1210.0	722	1.3	2.33	1.3	2.04	70	192	100
UN2 Ineffective Drain	1212.6	1212.6	847	1.3	1.88	1.3	1.31	69	145	100
E1 Seismic	1212.5	1210.0	722	1.1	1.99	1.0	1.28	42	172	100

Notes:
12. See Appendix E.2-3 for definition of wall section description, analysis methodology, and stability calculations.
13. Analysis assumes inclined sliding plane, interface friction angle Φ = 26 degrees, and no cohesion.
14. Seismic results utilize active soil pressure coefficients for stability values reported.

The principal factors affecting the retaining wall design include significant driving force associated with high groundwater conditions; poor rock quality along the foundation interface; relatively weak material (glacial till) anticipated in the backfill zone of influence; and potential for significant uplift pressure when water levels recede faster than pore pressure can dissipate. Preliminary design calculations indicate that retaining walls are most sensitive to groundwater conditions, concrete shear capacity of stem walls, and sliding stability provided by foundation shear keys.

For all loading conditions considered, floatation factors of safety were above required, 100 percent of the base was in compression, and sliding factors of safety were above required. Stability results indicate that sliding stability was the primary concern due to the low friction angle at the rock/rock bedding planes. To achieve stability results within the limits of acceptance criteria, a shear key at the heel of footing, and a wall drain system were required. The structural shear key ensures an inclined base sliding analysis is valid, and the wall drain system significantly reduces load associated with groundwater. The controlling load case is Load Case UN2 (high groundwater due to ineffective drains).

8.0 STRENGTH EVALUATION AND DESIGN

Strength evaluation of individual elements or members of structures and monoliths was used to verify member sizes based on application of factored loads as described in ABC with some adjustments for more severe conditions or loads not considered in the ABC.

Reinforced concrete design was performed according to Design of Concrete Structures, CSA A23.3-14 with the additional requirements of the CSA's SEED Document – *Structural Design of Wastewater Treatment Plants-2018* for revisions addressing service load conditions, water tightness, shrinkage and temperature reinforcement, and crack control. The Seed Document contains references to ACI 350M-06 for modifying CSA A23.3-14.

In general, structural analysis and design was performed manually using Mathcad or Excel spreadsheets. For complex structures, a commercial Three Dimensional- Finite Element Model (FEM) was used to evaluate multiple load combinations, identify stress concentrations, and generate shear and moment values for design of individual elements. The FEM was supplemented with manual calculations to verify/validate model results and where necessary, refine the analysis of individual elements. Based on model output, a combination of manual calculation and commercial software were used for strength design. Additional elements evaluated as part of strength design included joint detailing, equipment anchorage, and embedded parts.

The Service Spillway is designed as a mass concrete gravity structure sized primarily for stability. Most elements exceed 2 m in thickness and are surface reinforced for crack control and durability rather than strength. Each element is checked to ensure calculated stress from factored loads do not exceed member capacity. Some elements which are subjected to higher stress and controlled by strength design include:

- Divider wall pier which is a 6 m high cantilever wall subjected to unbalanced water load and lateral seismic loading in the cross-stream direction;
- Upstream shear keys which are a structural element required for sliding stability; and
- Crest gate hinge anchor bolts.

For each of these elements, preliminary strength calculations were performed to acquire order-of-magnitude stress and establish basis for preliminary member sizing. Strength calculations to develop reinforcement sizing and steel detailing will be performed during Final Design.

The retaining wall monoliths will be detailed during Final Design using commercially available finite element software with beam, shell, and solid elements where appropriate.

Footings were designed as a structural slab on an elastic foundation as the stability analysis concluded that the foundations are in compression based on the value of the subgrade modulus.

The critical sections considered for evaluation of shear and moment were at half the footing thickness as measured from the face of the wall for the toe and at the face of the wall for the heel. In general, footing geometry was dictated by the gate bay limit of excavation, and desired hydraulic profile resulting in footing thicknesses exceeding 1.5 to 2 m with relatively low stress at the critical sections.

Cantilever stem walls were designed as a cantilever beam fixed at the footing interface. The critical sections considered for evaluation were at the base of stem, 1/3 of the stem height, and 2/3 of the stem height. Wall thickness increases from top to bottom with thickness ranging from 0.5 to 2.0 m, respectively. Due to increased thickness and increased load near the base of walls, shear strength becomes a controlling factor, and transverse shear reinforcement (cross ties) will be required.

Counterfort stem walls were designed as continuous beams spanning horizontally between counterforts, with only the lower portions of the stem exhibiting plate action and designed as a cantilever from the footing to a height approximately half of the counterfort spacing.

Counterfort heels were designed with a similar load path as the stem. The portion of footing closest to the stem acts as a cantilever beam, and the portion which is further from the stem by more than half of counterfort spacing, was designed as a continuous beam spanning between counterforts.

Counterforts were designed as cantilever deep beams fixed at the footing interface. The wall serves as the beam flange, and the flange width was calculated as the lesser of 12 times the thickness of the wall or half the distance between the counterforts using equation 10.3.3 of CSA 23.3. The counterfort was considered to act as the stem of a tee beam and is fixed at its base. The tee beam was sized so that the neutral axis of the tee beam was located within the flange. The depth of the tee beam is the perpendicular distance between the sloping face of the counterfort and the vertical face of the retaining wall. Critical sections for evaluation of counterfort shear and moments include the foundation interface and the third points of the counterfort.

9.0 SERVICEABILITY

Serviceability concerns with the Service Spillway relate primarily to concrete durability, shrinkage control, and relief of internal stresses associated with volume changes.

Shrinkage control and volume changes are addressed primarily with placement sequence, mix design, surface reinforcement, and material specifications. The design includes joint locations that define monoliths with balanced aspect ratios and placements less than 12 m to 18 m in any one direction. Expanded guidance related to placement sequence and horizontal joint locations will be addressed during Final Design.

Allowance for thermal expansion/contraction is critical for gate operation. These effects are addressed primarily through clearance between gate and end walls with provisions for side seals and an embedded UHMW-PE (Ultra High Molecular Weight Polyethylene) wall plate to cover the full extent of gate travel.

Protection of the gate leaf is a serviceability concern due the heavy bed load of sand, gravel, and cobbles in the Elbow River. To protect the gate leaf from abrasion and premature deterioration, a surface skin of UHMW-PE is recommended on the crest gate.

Serviceability concerns for the retaining walls relate to concrete durability, shrinkage, crack control, volume changes and wall deflections. Durability, shrinkage, and crack control are achieved primarily through reinforcement placement, high reinforcement ratios, and use of high load factors that account for both strength and serviceability in accordance with the CSA SEED document. Volume changes are addressed primarily with placement sequence, mix design, surface reinforcement, and material specifications. The retaining walls include vertical joints at locations of footing geometry change, and at locations needed to maintain horizontal wall lengths less than 12 to 18 m. Expanded guidance related to placement sequence and horizontal joint locations will be addressed as part of Final Design.

Wall deflections are controlled using counterforts to provide rigidity, by reducing wall and footing spans, and using at-rest soil pressure when sizing wall elements. Locations where wall deflection is critical includes walls serving as gate bay abutments, walls adjacent to access roads and control building foundation, and walls along the upstream face which must maintain tight joints for water retention. Wall deflections will be addressed during Final Design.

10.0 CONSTRUCTION CONSIDERATIONS

Construction specifications and details for the Service Spillway will be furthered during Final Design. The following construction considerations are noted:

- Restricted periods for disturbance within the Elbow River are May 1 to July 16 and September 16 to April 14. This means that construction of a river diversion and the coffer-works for the Service Spillway must take place between April 15 and April 31 or July 15 and September 15.
- Dewatering of excavated areas will be required to sufficiently enable construction of the Service Spillway. The services of a specialist dewatering contractor may be needed.
- Excavation will be to competent bedrock. All soil, including alluvium, talus and other unconsolidated deposits should be removed to expose unweathered or slightly weathered bedrock. Excavation should be performed by mechanical means only; blasting will not be permitted.
- Foundation preparation will require special care in cleaning and preparation of concrete/rock interface. Care must be taken during excavation of the foundation to identify unsuitable rock conditions or weak bedding planes that could impact stability. Loose material and rock overhangs will need to be removed. Small voids will be filled with dental concrete. Once ready, foundation protection will be placed over exposed rock.
- If extensive jointing/fracturing is observed after excavation of the foundation, consolidation grouting may be required.
- Shear keys are required to maintain adequate sliding stability for gate monoliths and retaining walls. Care should be taken during excavation of the shear key trenches to identify unsuitable rock conditions or weak beading planes that could compromise capacity of the shear key.
- Anchors, along with a foundation underdrain to relieve uplift pressures, will be required to maintain adequate factors of safety against floatation in the stilling basin. These are envisioned as static anchors drilled and grouted in a grid pattern prior to placement of the stilling basin concrete.
- Lift joints in the base mats and footings will be required to reduce placement thickness, control heat of hydration, reduce crack potential, and develop hydraulic profile. Changes in mix design will be required to provide lower cement ratio and larger aggregate in mass concrete placements, with higher strength and smaller aggregate mix placed as part of the reinforced "surface skin".

- Vertical joints in gate bays and stilling basins will be spaced and detailed so that "closure grouting" needed to accommodate shrinkage during initial curing is not needed.

- Horizontal joints in the retaining wall stems will be required to reduce placement height to avoid potential for aggregate separation, ensure access for adequate vibration, reduce potential for form bulging, and allow for fill placement to progress in stages with wall construction.

- Joint preparation will require special attention to ensure proper installation of water stops, shear keys, dowels, and reinforcement. Joint alignment and water-tight integrity are critical for minimizing water levels on the back side of retaining walls.

- Hinge anchors, airlines, control lines, restraining strap pockets, and wall plates for Service Spillway crest gates will need to be considered during concrete preparation and placement. Placement tolerance for some of these items are tighter than typical heavy construction tolerance due to fit and operating clearance requirements.

- Procurement lead-time for gate embedments and components will likely be driven by steel availability and fabrication schedules. An allowance of 12 to 18 months is recommended to account for design, shop drawing review/approval, fabrication, testing, and delivery.

- The Service Spillway right abutment or the divider pier may serve as a component of the water control plan during construction. These need to be functional prior to completion of the Service Spillway. Many of these details are at the discretion of the Contractor but will need to be coordinated with the Engineer to ensure appropriate loading conditions have been considered in the water control plan design.

- Placement of free draining backfill, filter material, and drain systems are critical for minimizing groundwater levels behind the walls. Material selection and installation methods will require strict quality control and monitoring.

- Fill placement and compaction methods must be reviewed and monitored to ensure wall movement does not occur during construction.

- Construction sequencing will be required to ensure the Service Spillway and crest gates are fully functional before the Elbow River is diverted back through the Service Spillway.

Appendix E.2-1 GATE BLOCKS AND CENTER PIER

Calculation Section I

Results Summary Table (overview)

Table E2-1.1 – Service Spillway Centre Pier – Stability Analysis Summary

Load Case	Headwater Elevation (m)	Tailwater Elevation (m)	Uplift Force (kN)	Floatation Safety Factor (FSF)		Sliding Safety Factor (SSF)		Foundation Bearing Stress		% Base in Compression
				Req	Calc	Req	Calc	Upstream (Heel) (kPa)	Downstream (Toe) (Kpa)	
Usual Load Cases										
U1 Normal Operation	1212.1	1211.8	15136	1.5	1.8	1.5	40.3	78	66	100
U2 Diversion Operation *50 Yr. Flood*	1214.6	1211.8	17858	1.5	1.7	1.5	2.5	56	77	100
Unusual Load Case										
UN1 Diversion Operation *2013 Flood*	1215.8	1213.1	20580	1.3	1.6	1.3	3.0	61	97	100
UN2 Diversion Operation *2013 Flood*	1216.1	1213.0	20798	1.3	1.6	1.3	3.5	67	98	100
UN3 No Diversion *1000 Yr. Flood*	1217.0	1214.7	23629	1.3	1.5	1.3	6.2	83	64	100
UN4 Construction/ Maintenance	1215.0	1211.9	18403	1.3	1.7	1.3	3.2	55	97	100
Extreme – Flood										
E1 IDF without Diversion	1217.8	1214.9	24174	1.1	1.5	1.1	4.8	78	70	100
Extreme – Earthquake used to determine Post-Seismic Condition										
E2 EDGM applied to U1	1212.1	1211.8	15136	1.1	1.6 (E2.3)	1.0	1.6 (E2.2)	48 (E2.3)	94 (E2.1)	100
E3 EDGM applied to U2	1214.6	1211.8	17858	1.1	1.6 (E3.3)	1.0	1.1 (E3.2)	34 (E3.3)	136 (E3.1)	100

Notes:
1. See Appendix E.2 for definition of monolith description, analysis methodology, and stability calculations.
2. Analysis assumes inclined sliding plane, interface friction angle Φ = 26 degrees, and no cohesion.
3. Reported seismic results are controlling values for the three combinations of vertical and horizontal seismic load considered.

Table E.2-1.2 – Service Spillway Gate (2A) – Stability Analysis Summary

Load Case	Headwater Elevation (m)	Tailwater Elevation (m)	Critical Depth at Gate Lip (m)	Uplift Force (kN)	Floatation Safety Factor (FSF)		Sliding Safety Factor (SSF)		Foundation Bearing Stress		% Base in Compression
					Req	Calc	Req	Calc	Upstream (Heel) (kPa)	Downstream (Toe) (Kpa)	
U1 Normal Operation	1212.1	1211.8	1211.4	18920	1.5	1.6	1.5	43.8	89	34	100
U2 Diversion Operation *50 Yr. Flood*	1214.6	1211.8	1211.8	22323	1.5	1.6	1.5	2.3	60	81	100
UN1 Diversion Operation *2013 Flood*	1215.8	1213.1	1215.03	25726	1.3	1.5	1.3	3.2	74	70	100
UN2 Diversion Operation *2013 Flood*	1216.1	1213.0	1215.73	25998	1.3	1.6	1.3	2.8	62	94	100
UN3 No Diversion *1000 Yr. Flood*	1217.0	1214.7	1214.67	29537	1.3	1.4	1.3	5.9	86	46	100
UN4 Construction/ Maintenance	1215.0	1212.5	1211.9	23003	1.3	1.5	1.3	3.2	55	75	100
E1 IDF without Diversion	1217.3	1214.9	1214.87	30217	1.1	1.4	1.1	5.6	86	46	100
E2 EDGM applied to U1	1212.1	1211.8	1211.4	18920	1.1	1.5 (E2.3)	1.0	1.4 (E2.2)	77 (E2.3)	38 (E2.3)	100
E3 EDGM applied to U2	1214.6	1211.8	1211.8	19601	1.1	1.4 (E3.3)	1.0	1.0 (E.3.2)	30 (E3.2)	112 (E3.1)	100

Notes:
1. See Appendix E.2 for definition of monolith description, analysis methodology, and stability calculations.
2. Analysis assumes inclined sliding plane, interface friction angle Φ = 26 degrees, and no cohesion.
3. Reported seismic results are controlling values for the three combinations of vertical and horizontal seismic load considered.

Table E.2-1.3 – Service Spillway Gate (4A) – Stability Analysis Summary

Load Case	Headwater Elevation (m)	Tailwater Elevation (m)	Critical Depth at Gate Lip (m)	Uplift Force (kN)	Floatation Safety Factor (FSF)		Sliding Safety Factor (SSF)		Foundation Bearing Stress		% Base in Compression
					Req	Calc	Req	Calc	Upstream (Heel) (kPa)	Downstream (Toe) (Kpa)	
U1 Normal Operation	1212.1	1211.8	1211.4	18920	1.5	1.6	1.5	43.8	89	34	100
U2 Diversion Operation *50 Yr. Flood*	1214.6	1211.8	1213.76	22323	1.5	1.6	1.5	2.7	69	78	100
UN1 Diversion Operation *2013 Flood*	1215.8	1213.1	1213.87	25726	1.3	1.7	1.3	1.5	85	54	100
UN2 Diversion Operation *2013 Flood*	1216.1	1213.0	1214.07	25998	1.3	1.7	1.3	1.5	84	58	100
UN3 No Diversion *1000 Yr. Flood*	1217.0	1214.7	1214.67	29537	1.3	1.6	1.3	1.4	86	46	100
UN4 Construction/ Maintenance	1215.0	1211.9	1213.63	23003	1.3	1.8	1.3	1.6	67	67	100
E1 IDF without Diversion	1217.3	1214.9	1214.87	30217	1.1	1.4	1.1	5.6	86	46	100
E2 EDGM applied to U1	1212.1	1211.8	1211.4	18920	1.1	1.5 (E2.3)	1.0	1.4 (E2.2)	77 (E2.3)	38 (E2.3)	100
E3 EDGM applied to U2	1214.6	1211.8	1213.76	19601	1.1	1.5 (E3.3)	1.0	1.1 (E.3.2)	38 (E3.2)	109 (E3.1)	100

Notes:

1. See Appendix E.2 for definition of monolith description, analysis methodology, and stability calculations.
2. Analysis assumes inclined sliding plane, interface friction angle Φ = 26 degrees, and no cohesion.
3. Reported seismic results are controlling values for the three combinations of vertical and horizontal seismic load considered.

Calculation Section II

Results Summary Table (detailed)

SERVICE SPILLWAY CENTER PIER STABILITY SUMMARY (SS-3A)																	
Load Combination	Σ Vertical (kN)	Σ Horizontal (kN)	Σ Vertical Inclined Plane (kN)	Σ Horizontal Inclined Plane (kN)	Σ Moments Inclined (kN*m)	Eccentricity, e Inclined (m)	σ @ Toe (kN/m2) Inclined	σ @ Heel (kN/m2) Inclined	Base in Compression %	FS Sliding Required	Calculated FS Horiz	Calculated FS Inclined	Σ Vertical Without Uplift (kN)	Σ Uplift (kN)	FS Floatation Required	FS Floatation Calculated
U1	11405	2028	16152	195	155528	-0.26	66	79	100	1.5	2.74	40.3	26541	15136	1.5	1.75
U2	13016	5585	18156	3546	151277	0.97	77	56	100	1.5	1.14	2.5	30874	17858	1.5	1.73
UN1	12625	4875	17687	2885	152218	0.70	97	61	100	1.3	1.26	2.99	33205	20580	1.3	1.61
UN2	13326	4604	18352	2536	160062	0.58	98	67	100	1.3	1.41	3.53	34124	20798	1.3	1.64
UN3	11551	3158	16425	1301	159139	-0.38	64	83	100	1.3	1.78	6.16	35180	23629	1.3	1.49
UN4	11958	4501	16982	2589	143596	0.85	97	55	100	1.3	1.3	3.2	30361	18403	1.3	1.65
E1	11517	3540	11784	2860	155716	-0.17	70	78	100	1.1	1.59	4.76	35691	24174	1.1	1.48
E2.1	11405	6730	16686	4867	94971	0.82	94	55	100	1.0	0.83	1.67	26541	15136	1.1	1.75
E2.2	10609	6730	15895	4958	136089	0.74	88	54	100	1.0	0.77	1.56	25745	15136	1.1	1.70
E2.3	8751	3199	13648	1660	126899	0.93	88	47	100	1.0	1.33	4.01	23887	15136	1.1	1.58
E3.1*	13016	10083	18667	8015	137389	1.94	136	31	100	1.0	0.63	1.14	30874	17858	1.1	1.73
E3.2*	12089	10083	17746	8120	128478	2.06	132	27	100	1.0	0.58	1.07	29947	17858	1.1	1.68
E3.3*	9928	6166	15154	4475	117490	1.55	102	34	100	1.0	0.79	1.65	27786	17858	1.1	1.56

SERVICE SPILLWAY GUARD GATE BLOCK STABILITY SUMMARY (SS-2A)																
Load Combination	Σ Vertical (kN)	Σ Horizontal (kN)	Σ Vertical Inclined Plane (kN)	Σ Horizontal Inclined Plane (kN)	Σ Moments Inclined (kN*m)	Eccentricity, e Inclined (m)	σ @ Toe (kN/m2) Inclined	σ @ Heel (kN/m2) Inclined	Base in Compression %	FS Sliding Required	Calculated FS Horiz	Calculated FS Inclined	Σ Vertical Without Uplift (kN)	Σ Uplift (kN)	FS Floatation Required	FS Floatation Calculated
U1	11312	2146	17220	192	184103	-1.39	34	89	100	1.5	2.57	43.82	30232	18920	1.5	1.60
U2	13369	6429	19750	4213	174690	0.46	81	60	100	1.5	1.01	2.29	35692	22323	1.5	1.60
UN1	13824	5290	20073	3031	188601	-0.09	70	74	100	1.3	1.27	3.23	39550	25726	1.3	1.54
UN2	15463	6192	21804	3741	188944	0.64	94	62	100	1.3	1.22	2.84	41461	25998	1.3	1.59
UN3	12392	3617	18461	1531	189178	-0.94	46	86	100	1.3	1.67	5.88	41929	29537	1.3	1.42
UN4	11895	5780	18212	3736	160635	0.48	75	55	100	1.3	1.0	3.2	34898	23003	1.3	1.52
E1	12432	3691	18508	1600	189592	-0.94	46	86	100	1.1	1.64	5.64	42649	30217	1.1	1.41
E2.1	11312	7821	17864	5831	168812	-0.15	61	67	100	1.0	0.71	1.49	30232	18920	1.1	1.60
E2.2	10405	7821	16963	5934	159766	-0.11	59	63	100	1.0	0.65	1.39	29325	18920	1.1	1.55
E2.3	10027	3815	16133	1996	166876	-1.04	38	77	100	1.0	1.28	3.94	28947	18920	1.1	1.53
E3.1*	13369	11661	20344	9412	155550	1.66	112	34	100	1.0	0.56	1.05	35692	22323	1.1	1.60
E3.2*	12462	11661	19443	9515	128478	1.77	109	30	100	1.0	0.52	1.00	34785	22323	1.1	1.56
E3.3*	9800	7173	16289	5359	133216	1.55	80	37	100	1.0	0.67	1.48	32123	22323	1.1	1.44

SERVICE SPILLWAY REGULATING GATE BLOCK STABILITY SUMMARY (SS-4A)																
Load Combination	Σ Vertical (kN)	Σ Horizontal (kN)	Σ Vertical Inclined Plane (kN)	Σ Horizontal Inclined Plane (kN)	Σ Moments Inclined (kN*m)	Eccentricity, e Inclined (m)	σ @ Toe (kN/m2) Inclined	σ @ Heel (kN/m2) Inclined	Base in Compression %	FS Sliding Required	Calculated FS Horiz	Calculated FS Inclined	Σ Vertical Without Uplift (kN)	Σ Uplift (kN)	FS Floatation Required	FS Floatation Calculated
U1	11312	2146	17220	192	184103	-1.39	34	89	100	1.5	2.57	43.82	30232	18920	1.5	1.60
U2	14159	5969	20483	3667	186395	0.20	78	69	100	1.5	1.16	2.7	36482	22323	1.5	1.63
UN1	13274	3912	19370	1723	193328	-0.68	54	85	100	1.3	1.66	5.48	39000	25726	1.3	1.52
UN2	13693	4206	19819	1968	195912	-0.58	58	84	100	1.3	1.59	4.91	39691	25998	1.3	1.53
UN3	12392	3617	18461	1531	189178	-0.94	46	86	100	1.3	1.67	5.88	41929	29537	1.3	1.42
UN4	12626	5780	18212	3736	189178	0.00	67	67	100	1.3	1.46	4.38	35629	23003	1.3	1.55
E1	12432	3691	18508	1600	189592	-0.94	46	86	100	1.1	1.64	5.64	42649	30217	1.1	1.41
E2.1	11312	7821	17864	5831	168812	-0.15	61	67	100	1.0	0.71	1.49	30232	18920	1.1	1.60
E2.2	10405	7821	16963	5934	159766	-0.11	59	63	100	1.0	0.65	1.39	29325	18920	1.1	1.55
E2.3	10027	3815	16133	1996	166876	-1.04	38	77	100	1.0	1.28	3.94	28947	18920	1.1	1.53
E3.1*	14159	11202	21077	8866	167255	1.37	109	42	100	1.0	0.62	1.16	36482	22323	1.1	1.63
E3.2*	13252	11202	19443	9515	158201	1.46	106	38	100	1.0	0.58	1.10	35575	22323	1.1	1.59
E3.3*	10511	6714	16943	4821	144396	0.78	76	45	100	1.0	0.76	1.71	32834	22323	1.1	1.47

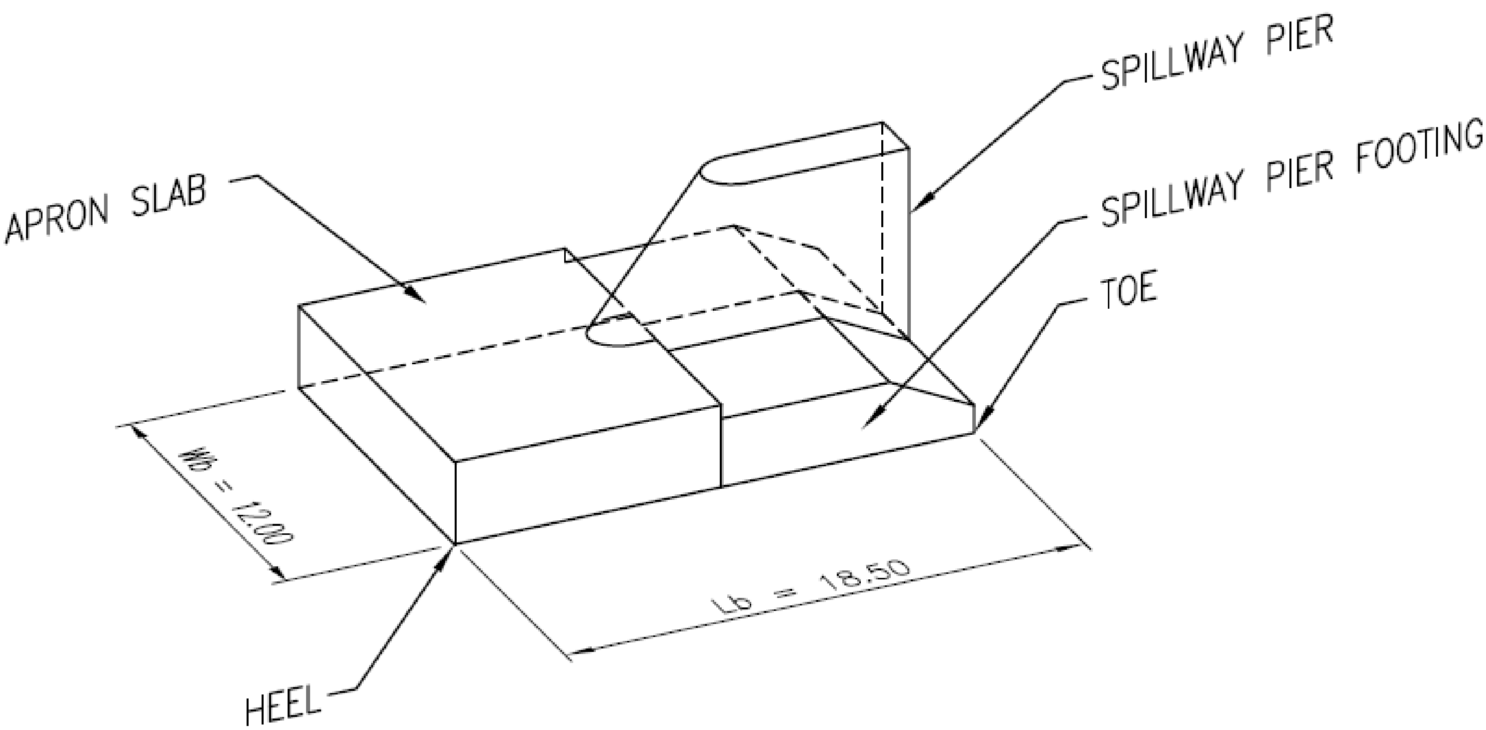
Calculation Section III

SS-3A Center Pier Stability Calculations

Project Number:	110773396
Project Title:	SR1 Project
Client:	Alberta Transportation
Engineer:	Dave Crawford, Derek Cheuk — Date: 12/14/2018
Checker:	Sean Xiao — Date: 01/09/2019

Calculation for: Service Spillway Center Pier Structure

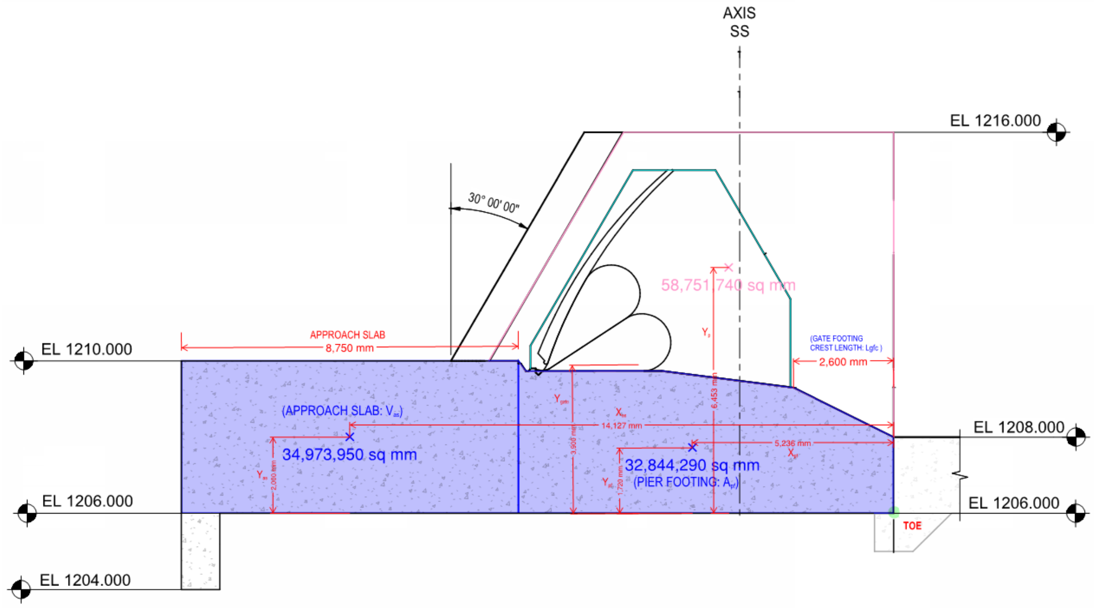
Structure Isometric:



SERVICE SPILLWAY - CENTER PIER - 3A

REGION COLOR CONVENTION User Input | Calculation Highlights | Results

SERVICE SPILLWAY DIMENSIONAL INPUT PARAMETERS



BASE SECTION PROPERTIES

Base Length: $L_b := 18.50\text{m}$ $\quad$ $\text{Kern} := \dfrac{L_b}{6} = 3.08\,\text{m}$

Stilling Basin Length: $L_{sb} := 17.0\text{m}$

Base Width: $W_b := 12.00\text{m}$

Area of Base: $A_b := L_b \cdot W_b = 222\,\text{m}^2$

Section Modulus of Base: $S_b := \dfrac{\left(W_b \cdot L_b^{\,2}\right)}{6} = 684.5\,\text{m}^3$

PIERS

Pier Cross Sectional Area: $Ap := 58.38\text{m}^2$ $\quad$ From Mass Properties ACAD Command

Pier Width: $w_p := 2.00\text{m}$

Volume of Pier Section: $V_p := Ap \cdot w_p = 116.76 \cdot \text{m}^3$

FOOTINGS (fixed crest and approach slab)

Pier Footing Cross Sectional Area: $A_{pf} := 32.84\text{m}^2$ $\quad$ From Mass Properties ACAD Command

Pier/Gate Footing Width/Length: $w_{pf} := W_b = 12.00\,\text{m}$ $\quad$ $L_{pf} := 11.5\text{m}$ $\quad$ $L_{gf} := 9.75\text{m}$

Total Fixed Crest Footing Volume: $V_{pf} := A_{pf} \cdot w_{pf} = 394.1 \cdot \text{m}^3$

Approach Slab Dimensions: $h_{as} := 4.00\text{m}$ $\quad$ $L_{as} := 8.75\text{m}$ $\quad$ $w_{as} := W_b = 12.00\,\text{m}$

Gate Footing Crest Length: $L_{gfc} := 2.6\text{m}$

Total Approach Slab Volume: $V_{as} := h_{as} \cdot w_{as} \cdot L_{as} = 420.0 \cdot \text{m}^3$

FOUNDATION PARAMETERS

Granular Fill Internal Angle of Friction: $\phi := 34 \cdot \dfrac{\pi}{180} = 0.593$ $\quad$ Radians $\quad$ (Section 5.3, Design Criteria)

Friction Angle at Base Concrete / Rock Interface: $\phi_{rock} := 26$ $\quad$ (Section 5.2, Design Criteria)

Base Friction Coefficient: $\tan_\phi := \tan\left(\phi_{rock} \dfrac{\pi}{180}\right) = 0.488$ $\quad$ radians

MATERIAL PROPERTIES

Unit Weight of Concrete: $\gamma_c := 23.5\ \frac{kN}{m^3}$ (Section 7.1, Design Criteria)

Unit Weight of Rock Fill: $\gamma_r := 22.0\ \frac{kN}{m^3}$ (Section 5.3, Design Criteria)

$\phi_{backfill} := \left(20\ \frac{\pi}{180}\right) = 0.35$ radians Assume Rip Rap Backfill

Unit Weight of Water: $\gamma_w := 9.81\ \frac{kN}{m^3}$ (Section 7.2, Design Criteria)

SHEAR KEY PARAMETERS

Key Depth: $d_{key} := 2.00m$

Key Width: $w_{key} := 1.00m$

CONCRETE DEAD LOADS

Pier: $D_p := V_p \cdot \gamma_c = 2743.9 \cdot kN$

Pier Footing (fixed crest): $D_{pf} := V_{pf} \cdot \gamma_c = 9260.88 \cdot kN$

Approach Slab: $D_{as} := V_{as} \cdot \gamma_c + d_{key} \cdot w_{key} \cdot w_{as} \cdot \gamma_c = 10434 \cdot kN$

Total Concrete Dead Loads: $D_{conc} := D_p + D_{pf} + D_{as} = 22438.74 \cdot kN$

Rock Section Mobilized for Inclined Sliding Failure:

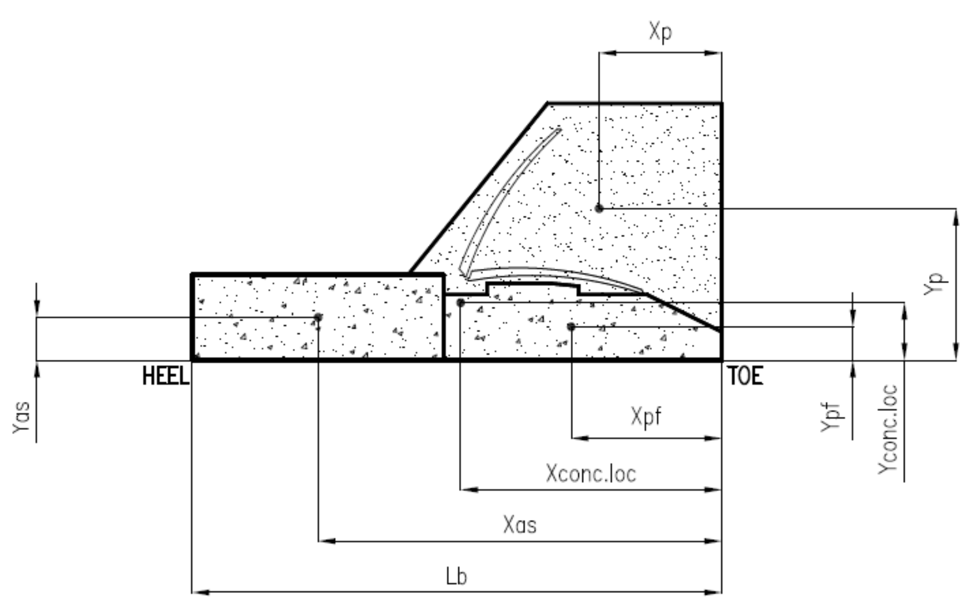
Area of Rock Section Mobilized: $A_{rs} := \frac{\left(L_b - w_{key}\right) \cdot d_{key}}{2} = 17.5\,m^2$

Rock Mass Mobilized: $V_{rs} := A_{rs} \cdot \gamma_r \cdot W_b = 4620 \cdot kN$

(Pore pressure taken along assumed inclined sliding plane)

Distance from Toe to COG of Rock Section: $L_{rs} := \frac{2}{3} \cdot \left(L_b - w_{key}\right) = 11.67\,m$ (From Bluebeam Measurement)

Rock Mass Mobilized Moment: $\Sigma M_{rs} := V_{rs} \cdot L_{rs} = 53900 \cdot kN \cdot m$



MOMENT ARM FROM TOE TO COG OF COMPONENT

Distance from Toe to COG of Pier: $X_p := 4.28\text{m}$ From Bluebeam Measurement

Dist. from Toe to COG of Pier Footing: $X_{pf} := 5.24\text{m}$ From Bluebeam Measurement

Dist. from Toe to COG of Approach Slab: $X_{as} := 14.33\text{m}$ From Bluebeam Measurement

Distance From Toe to COG of Concrete Dead Load :

$$X_{conc.loc} := \frac{\left(X_p \cdot D_p + X_{pf} \cdot D_{pf} + X_{as} \cdot D_{as}\right)}{D_{conc}} = 9.35\,\text{m}$$

MOMENT ARM FROM BASE OF FOOTING TO COG OF COMPONENT

Distance from Base to COG of Pier: $Y_p := 6.45\text{m}$ From Bluebeam Measurement

Dist. from Base to COG of Pier Footing: $Y_{pf} := 1.72\text{m}$ From Bluebeam Measurement

Dist. from Base to COG of Approach Slab: $Y_{as} := 2.00\text{m}$ From Bluebeam Measurement

Distance Above Base to COG of Concrete Dead Load:

$$Y_{conc.loc} := \frac{\left(Y_p \cdot D_p + Y_{pf} \cdot D_{pf} + Y_{as} \cdot D_{as}\right)}{D_{conc}} = 2.43\,\text{m}$$

CREST GATE (OBERMEYER)

Dead Load of Gates: $D_{Gate} := 140\text{kN}$ Vendor dwgs. Q-200 Series

Distance from Toe to COG of Gates: $X_{gate} := 9.50\text{m}$

Distance from Base to COG of Gates: $Y_{gate} := 3.90\text{m}$ Distance from base to top of Pier Footing

DEAD LOAD SUMMATION:

$\Sigma V_{DL} := D_{conc} + D_{Gate} = 22578.7 \cdot \text{kN}$

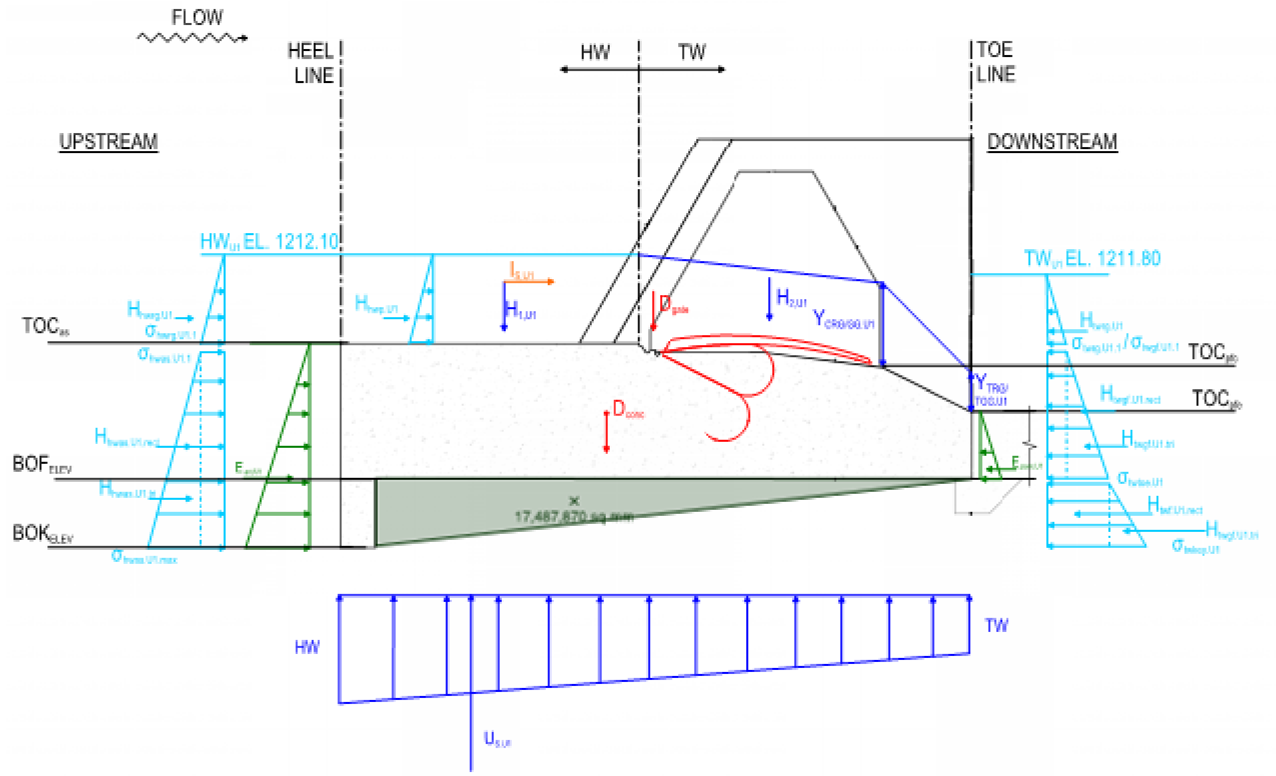
$\Sigma M_{DL} := D_{conc} \cdot X_{conc.loc} + D_{Gate} \cdot X_{gate} = 211119.95 \cdot \text{kN} \cdot \text{m}$

SERVICE SPILLWAY GATE STRUCTURE 2D HYDRAULIC MODEL RESULTS

Applicable or Relevent Scenarios: Service Spillway (SS) - Gate Structure
Prepared: 24 October 2018

Scenario	Total Inflow (m^3/s)	Service Spillway Discharge (m^3/s)			Headwater (m)	Service Spillway Tailwater (m)	Notes	Water Surface Over SS Gate Bays			
		Left Gate	Right Gate	Total				Headwater at gate hinge (m)	Critical depth at gate lip (m)	Depth at Basin Toe (m)	SS Tailwater just passed basin end (m)*
160 m^3/s, No Diversion, **(U1, E2-Q)**	160	91	69	160	1212.1	1211.8	Diversion Inlet gates closed and Service Spillway gates fully open	LG = RG d = 2.1 EL 1212.1	LG = RG y_c = 1.4; EL 1211.4	LG = RG, toe submerged Uplift = Use tailwater d_{toe} = 0.45; EL 1208.46	d_{tw} = 3.8 EL 1211.8
50-yr Event, Diverting up to 600 m^3/s **(U2, E3-Q)**	530	152	0	152	1214.6	1211.8	Diversion Inlet gates open, Service Spillway left crest gate at EL 1212.1 m and right crest gate at EL 1215.0 m	LG = RG d = 4.6 EL 1214.6	LG = y_c = 1.67; EL 1213.76 RG = Closed	LG = d_{toe} = 0.58; EL 1208.58 RG = Use tailwater Uplift = Use tailwater	d_{tw} = 3.8 EL 1211.8
100-yr Event, Service Spillway Construction/Maintenance, **(UN4)**	765	315	0	315	1215.0	1212.5	Diversion Inlet gates open, Service Spillway left crest gate at EL 1210.9 m and right crest gate at EL 1215.0 m	LG = RG d = 5.0 EL 1215.0	LG = y_c = 2.73; EL 1213.63 RG = Closed	LG = d_{toe} = 1.23 super; EL 1209.23 RG = Use tailwater Uplift = Use tailwater	d_{tw} = 3.9 EL 1211.9
2013 Event, Diverting up to 600 m^3/s **(UN1)**	1240	498	137	634	1215.8	1213.1	Diversion Inlet gates open; Service Spillway left crest gate at EL 1210.0 m and right crest gate at EL 1213.5 m	LG = RG d = 5.8 EL 1215.8	LG = y_c = 3.87; EL 1213.87 RG = y_c = 1.53; EL 1215.03	LG = d_{toe} = 1.95 super; EL 1209.95 RG = d_{toe} = 0.48 super; EL 1208.48 Uplift = Use tailwater	d_{tw} = 5.1 EL 1213.1
2013 Event, Diverting with One Service Spillway Crest Gate Failing to Open **(UN2)**	1240	518	44	562	1216.1	1213.0	Diversion Inlet gates open, Service Spillway left crest gate at EL 1210.0 m and right crest gate at EL 1215.0 m	LG = RG d = 6.1 EL 1216.1	LG = y_c = 4.07; EL 1214.07 RG = y_c = 0.73; EL	LG = d_{toe} = 1.97 super; EL 1209.97 RG = Use tailwater	d_{tw} = 5.0 EL 1213.0
1000-yr Event, No Diversion **(UN3)** Auxiliary Spillway cover eroded	1930	759	708	1467	1217.0	1214.7	Diversion Inlet gates closed and Service Spillway gates fully open. Auxilliary Spillway cover layer eroded	LG = RG d = 7.0 EL 1217.0	LG = RG y_c = 4.67; EL 1214.67	LG = RG d_{toe} = 2.89 super; EL 1210.89 Uplift = Use tailwater	d_{tw} = 6.7 EL 1214.7
Diversion Structure IDF Event, 1/3 Between 1000-yr and PMF, **(E1-F)** No Diversion. AS cover eroded.	2210	812	758	1570	1217.3	1214.9	Diversion Inlet gates closed and Service Spillway gates fully open. Auxiliary Spillway cover layer eroded	LG = RG d = 7.3 EL 1217.3	LG = RG y_c = 4.87; EL 1214.87	LG = RG d_{toe} = 3.06 super; EL 1211.06 Uplift = Use tailwater	d_{tw} = 6.9 EL 1214.9

U1 DESIGN CASE



ACCEPTANCE PARAMETERS

Required Factor of Safety for Sliding: $FS_{req.U1.sl} := 1.5$ (Without Cohesion) (Section 8.1, Design Criteria)

Resultant Within Middle Third of Base: $e \le \frac{L_b}{6} \wedge e \ge \frac{-L_b}{6}$

Allowable Rock Bearing Pressure: $\sigma_{allow.U1} := 1270 \cdot \frac{kN}{m^2}$ (Section 5.2, Design Criteria)

INPUT PARAMETERS

Headwater Elevation: $HW_{U1} := 1212.10m$ (Section 8.3, Design Criteria)

Tailwater Elevation: $TW_{U1} := 1211.80m$ (Section 8.3, Design Criteria)

Bottom of Footing Elevation: $BOF_{elev} := 1206.00m$

Approach Slab Top of Concrete Elevation at Upstream Face: $TOC_{as} := 1210.00m$

Pier Footing Top of Concrete Elevation at Stilling Basin: $TOC_{pfe} := 1208.00m$

Pier Footing Top of Concrete Elevation at Center of Footing: $TOC_{pfc} := 1209.30m$

Top of Guard/ Regulating Gate Elevation: $TOP_{rg.U1} := 1210.00m$ $TOP_{gg.U1} := 1210.00m$

Bottom of Key Elevation: $BOK_{elev} := BOF_{elev} - d_{key} = 1204\,m$

Gates are open when top of gate elevation is at 1210.00m

Gates are closed/up when top of gate elevation is at 1215.0m

Crestwater Elevation Guard (Right) Gate: $EL_{CGG.U1} := 1211.4m$

$$Y_{C.gg.U1} := \begin{cases} (EL_{CGG.U1} - TOC_{pfc}) & \text{if } TOP_{gg.U1} \le HW_{U1} \\ (TW_{U1} - TOC_{pfc}) & \text{if } TOP_{gg.U1} > HW_{U1} \end{cases} = 2.1 \cdot m$$

Toewater Elevation Guard (Right) Gate: $EL_{TGG.U1} := 1208.46m$

$$Y_{TOE.gg.U1} := \begin{cases} (EL_{TGG.U1} - TOC_{pfe}) & \text{if } TOP_{gg.U1} \le HW_{U1} \\ (TW_{U1} - TOC_{pfe}) & \text{if } TOP_{gg.U1} > HW_{U1} \end{cases} = 0.46 \cdot m$$

Crestwater Elevation Regulating (Left) Gate:

$EL_{CRG.U1} := 1211.4m$

$$Y_{C.rg.U1} := \begin{cases} \left(EL_{CRG.U1} - TOC_{pfc}\right) & \text{if } TOP_{rg.U1} \le HW_{U1} \\ \left(TW_{U1} - TOC_{pfc}\right) & \text{if } TOP_{rg.U1} > HW_{U1} \end{cases} = 2.1 \cdot m$$

Toewater Elevation Regulating (Left) Gate:

$EL_{TRG.U1} := 1208.46m$

$$Y_{TOE.rg.U1} := \begin{cases} \left(EL_{TRG.U1} - TOC_{pfe}\right) & \text{if } TOP_{rg.U1} \le HW_{U1} \\ \left(TW_{U1} - TOC_{pfe}\right) & \text{if } TOP_{rg.U1} > HW_{U1} \end{cases} = 0.46 \cdot m$$

LATERAL WATER LOADS

HEADWATER (DRIVING):

Headwater Depth on Pier: $D_{hwp.U1} := HW_{U1} - TOC_{as} = 2.10\,m$

Headwater Load Unit Width on Pier: $W_{hwp.U1} := w_p = 2.00\,m$

Total Horizontal Headwater Load on Pier:

$$H_{hwp.U1} := \frac{-\left(\gamma_w \cdot D_{hwp.U1}{}^2\right)}{2} \cdot W_{hwp.U1} = -43.3 \cdot kN$$

Apply Total Pier Headwater Load at:

$$H_{hwp.U1.loc} := \frac{D_{hwp.U1}}{3} + \left(TOC_{as} - BOF_{elev}\right) = 4.70\,m$$

Headwater Depth on Gate Base: $D_{hwg.U1} := HW_{U1} - TOC_{as} = 2.10\,m$

Thickness of Approach Slab (Including Key): $T_{as} := \left(TOC_{as} - BOK_{elev}\right) = 6\,m$

Headwater Depth at Heel (U/S face): $D_{hwas.U1} := HW_{U1} - BOK_{elev} = 8.10\,m$

Headwater Load Unit Width on Approach Slab: $W_{hwas.U1} := W_b = 12.00\,m$

Headwater Unit Load At Top of Approach Slab:

$$H_{hwas.U1.1} := \frac{-\left(\gamma_w \cdot D_{hwg.U1}{}^2\right)}{2} \cdot W_{hwas.U1} = -259.57 \cdot kN$$

Headwater Unit Load At Bottom of Approach Key:

$$H_{hwas.U1.2} := \frac{-\left(\gamma_w \cdot D_{hwas.U1}{}^2\right)}{2} \cdot W_{hwas.U1} = -3861.8 \cdot kN$$

Headwater Line Load At Top of Approach Slab:

$$\sigma_{hwas.U1.1} := -\left(\gamma_w \cdot D_{hwg.U1}\right) = -20.6 \cdot kPa$$

Headwater Line Load At Bottom of Approach Key:

$$\sigma_{hwas.U1.2} := -\left(\gamma_w \cdot D_{hwas.U1}\right) = -79.46 \cdot kPa$$

Triangular Distribution Unit Load on Approach Slab and Key:

$$H_{hwas.U1.2.tri} := \left(\frac{\sigma_{hwas.U1.2} - \sigma_{hwas.U1.1}}{2}\right) \cdot \left(T_{as} \cdot W_{hwas.U1}\right) = -2118.96 \cdot kN$$

Rectangular Distribution Unit Load on Approach Slab and Key:

$$H_{hwas.U1.2.rect} := \sigma_{hwas.U1.1} \cdot \left(T_{as} \cdot W_{hwas.U1}\right) = -1483.27 \cdot kN$$

Total Horizontal Headwater Load on Approach Slab:

$$H_{hwas.U1} := H_{hwas.U1.2.tri} + H_{hwas.U1.2.rect} = -3602.23 \cdot kN$$

Apply Total Footing Headwater Load at:

$$H_{hwas.U1.loc} := \frac{\left[H_{hwas.U1.2.rect} \cdot \frac{\left(T_{as}\right)}{2} + H_{hwas.U1.2.tri} \cdot \frac{\left(T_{as}\right)}{3}\right]}{H_{hwas.U1.2.tri} + H_{hwas.U1.2.rect}} - d_{key} = 0.41\,m$$

LATERAL WATER LOADS (continued)

Regulating Gate (2A) Operating Condition:

Regulating Crest Gate Down/Open Condition: $A1_{U1} := TOP_{rg.U1} \le TOC_{as}$

Regulating Crest Gate Up/Closed, with Top of Gate Higher than HW Elevation: $B1_{U1} := TOP_{rg.U1} \ge HW_{U1} \wedge TOP_{rg.U1} > TOC_{as}$

Regulating Crest Gate Up/Closed, with Top of Gate Lower than HW Elevation: $C1_{U1} := TOP_{rg.U1} > TOC_{as} \wedge HW_{U1} > TOP_{rg.U1}$

Regulating Crest Gate Height: $H_{rg.U1} := TOP_{rg.U1} - TOC_{as} = 0\,m$

Headwater Depth at Regulating Crest Gate: $D_{hwrg.U1} := HW_{U1} - TOC_{as} = 2.10\,m$

Regulating Crest Gate Width: $W_{hwrg.U1} := 5.00m$

Lateral Headwater Pressure at Bottom of Regulating Crest Gate:

$$\sigma_{hwrg.U1.1} := \begin{cases} (0.0kPa) & \text{if } A1_{U1} \\ -(\gamma_w \cdot D_{hwrg.U1}) & \text{if } B1_{U1} \\ -(\gamma_w \cdot D_{hwrg.U1}) & \text{if } C1_{U1} \end{cases} = 0.0 \cdot kPa$$

Lateral Headwater Pressure at Top of Regulating Crest Gate: (Load at HW Elevation On Regulating Crest Gate if HW is below TOG_{rg})

$$\sigma_{hwrg.U1.2} := \begin{cases} (0.0kPa) & \text{if } A1_{U1} \\ 0.0kPa & \text{if } B1_{U1} \\ -\left[\gamma_w \cdot \left(HW_{U1} - TOP_{rg.U1}\right)\right] & \text{if } C1_{U1} \end{cases} = 0.0 \cdot kPa$$

Average Pressure acting on Regulating Gate:

$$\sigma_{hwrg.U1.avg} := \frac{\left(\sigma_{hwrg.U1.1} + \sigma_{hwrg.U1.2}\right)}{2} = 0 \cdot kPa$$

Total Area water acting on Regulating Crest Gate:

$$A_{hwrg.U1} := \begin{cases} D_{hwrg.U1} \cdot W_{hwrg.U1} & \text{if } A1_{U1} \\ D_{hwrg.U1} \cdot W_{hwrg.U1} & \text{if } B1_{U1} \\ H_{rg.U1} \cdot W_{hwrg.U1} & \text{if } C1_{U1} \end{cases} = 10.5 \cdot m^2$$

Total Horizontal Headwater Load on Regulating Crest Gate: $H_{hwrg.U1} := \sigma_{hwrg.U1.avg} \cdot A_{hwrg.U1} = 0.0 \cdot kN$

Apply Total Regulating Crest Gate Headwater Load at:

$$H_{hwrg.U1.loc} := \begin{cases} \left(TOC_{as} - BOF_{elev}\right) & \text{if } A1_{U1} \\ \left[\frac{\left(HW_{U1} - TOC_{as}\right)}{3} + \left(TOC_{as} - BOF_{elev}\right)\right] & \text{if } B1_{U1} \\ \left[\frac{\sigma_{hwrg.U1.2} \cdot A_{hwrg.U1} \cdot \frac{\left(H_{rg.U1}\right)}{2} + \frac{\left(\sigma_{hwrg.U1.1} - \sigma_{hwrg.U1.2}\right)}{2} \cdot A_{hwrg.U1} \cdot \frac{\left(H_{rg.U1}\right)}{3}}{\sigma_{hwrg.U1.2} \cdot A_{hwrg.U1} + \frac{\left(\sigma_{hwrg.U1.1} - \sigma_{hwrg.U1.2}\right)}{2} \cdot A_{hwrg.U1}} \ldots \\ + \left(TOC_{as} - BOF_{elev}\right)\right] & \text{if } C1_{U1} \end{cases} = 4.0 \cdot m$$

Guard Gate (4A) Operating Condition:

Guard Gate Down/Open Condition: $A2_{U1} := TOP_{gg.U1} \le TOC_{as}$

Guard Crest Gate Up/Closed, with Top of Gate Higher than HW Elevation: $B2_{U1} := TOP_{gg.U1} \ge HW_{U1} \wedge TOP_{gg.U1} > TOC_{as}$

Guard Crest Gate Up/Closed, with Top of Gate Lower than HW Elevation: $C2_{U1} := TOP_{gg.U1} > TOC_{as} \wedge HW_{U1} > TOP_{gg.U1}$

Guard Crest Gate Height: $H_{gg.U1} := TOP_{gg.U1} - TOC_{as} = 0\,m$

Headwater Depth at Guard Crest Gate: $D_{hwgg.U1} := HW_{U1} - TOC_{as} = 2.10\,m$

Guard Crest Gate Width: $W_{hwgg.U1} := 5.00m$

Lateral Headwater Pressure at Bottom of Guard Crest Gate:

$$\sigma_{hwgg.U1.1} := \begin{vmatrix} (0.0kPa) \text{ if } A2_{U1} \\ -(\gamma_w \cdot D_{hwgg.U1}) \text{ if } B2_{U1} \\ -(\gamma_w \cdot D_{hwgg.U1}) \text{ if } C2_{U1} \end{vmatrix} = 0.0 \cdot kPa$$

Lateral Headwater Pressure at Top of Guard Crest Gate:
(Load at HW Elevation On Guard Crest Gate if HW is below TOG_{rg})

$$\sigma_{hwgg.U1.2} := \begin{vmatrix} (0.0kPa) \text{ if } A2_{U1} \\ 0.0kPa \text{ if } B2_{U1} \\ -\left[\gamma_w \cdot (HW_{U1} - TOP_{gg.U1})\right] \text{ if } C2_{U1} \end{vmatrix} = 0.0 \cdot kPa$$

Average Pressure acting on Guard Crest Gate:

$$\sigma_{hwgg.U1.avg} := \frac{(\sigma_{hwgg.U1.1} + \sigma_{hwgg.U1.2})}{2} = 0 \cdot kPa$$

Total Area water acting on Crest Gate:

$$A_{hwgg.U1} := \begin{vmatrix} D_{hwgg.U1} \cdot W_{hwgg.U1} \text{ if } A2_{U1} \\ D_{hwgg.U1} \cdot W_{hwgg.U1} \text{ if } B2_{U1} \\ H_{gg.U1} \cdot W_{hwgg.U1} \text{ if } C2_{U1} \end{vmatrix} = 10.5 \cdot m^2$$

Total Horizontal Headwater Load on Guard Crest Gate: $H_{hwgg.U1} := \sigma_{hwgg.U1.avg} \cdot A_{hwgg.U1} = 0.0 \cdot kN$

Apply Total Guard Crest Gate Headwater Load at:

$$H_{hwgg.U1.loc} := \begin{vmatrix} (TOC_{as} - BOF_{elev}) \text{ if } A2_{U1} \\ \left[\frac{(HW_{U1} - TOC_{as})}{3} + (TOC_{as} - BOF_{elev})\right] \text{ if } B2_{U1} \\ \left[\frac{\sigma_{hwgg.U1.2} \cdot A_{hwgg.U1} \cdot \frac{(H_{gg.U1})}{2} + \frac{(\sigma_{hwgg.U1.1} - \sigma_{hwgg.U1.2})}{2} A_{hwgg.U1} \cdot \frac{(H_{gg.U1})}{3}}{\sigma_{hwgg.U1.2} \cdot A_{hwgg.U1} + \frac{(\sigma_{hwgg.U1.1} - \sigma_{hwgg.U1.2})}{2} \cdot A_{hwgg.U1}} \cdots \\ + (TOC_{as} - BOF_{elev}) \right] \text{ if } C2_{U1} \end{vmatrix} = 4.0 \cdot m$$

LATERAL TAILWATER (RESISTING) Applied to Downstream Side of Regulating Crest Gate:

U1 CASE

Regulating Crest Gate Down/Open Condition: $A3_{U1} := TOP_{rg.U1} \le TOC_{as}$

Regulating Crest Gate Up/Closed, with Top of Gate Higher than TW Elevation: $B3_{U1} := TOP_{rg.U1} \ge TW_{U1} \wedge TOP_{rg.U1} > TOC_{as}$

Regulating Crest Gate Up/Closed, with Top of Gate Lower than TW Elevation: $C3_{U1} := TOP_{rg.U1} > TOC_{as} \wedge TW_{U1} > TOP_{rg.U1}$

Regulating Crest Gate Height: $H_{rg.U1} = 0\,m$

Tailwater Depth at Regulating Crest Gate: $D_{twrg.U1} := TW_{U1} - TOC_{as} = 1.80\,m$

Regulating Crest Gate Width: $W_{twrg.U1} := 5m$

Lateral Tailwater Pressure at Bottom of Regulating Crest Gate:

$$\sigma_{twrg.U1.1} := \begin{cases} (0.0kPa) & \text{if } A3_{U1} \\ -(\gamma_w \cdot D_{twrg.U1}) & \text{if } B3_{U1} \\ -(\gamma_w \cdot D_{twrg.U1}) & \text{if } C3_{U1} \end{cases} = 0.0 \cdot kPa$$

Lateral Tailwater Pressure at Top of Regulating Crest Gate: (Load at TW Elevation On Regulating Crest Gate if TW is below TOG_{rg})

$$\sigma_{twrg.U1.2} := \begin{cases} (0.0kPa) & \text{if } A3_{U1} \\ 0.0kPa & \text{if } B3_{U1} \\ -[\gamma_w \cdot (TW_{U1} - TOP_{rg.U1})] & \text{if } C3_{U1} \end{cases} = 0.0 \cdot kPa$$

Average Pressure acting on Regulating Gate:

$$\sigma_{twrg.U1.avg} := \frac{(\sigma_{twrg.U1.1} + \sigma_{twrg.U1.2})}{2} = 0 \cdot kPa$$

Total Area water acting on Regulating Crest Gate:

$$A_{twrg.U1} := \begin{cases} D_{twrg.U1} \cdot W_{twrg.U1} & \text{if } A3_{U1} \\ D_{twrg.U1} \cdot W_{twrg.U1} & \text{if } B3_{U1} \\ H_{rg.U1} \cdot W_{twrg.U1} & \text{if } C3_{U1} \end{cases} = 9 \cdot m^2$$

Total Horizontal Tailwater Load on Regulating Crest Gate: $H_{twrg.U1} := \sigma_{hwrg.U1.avg} \cdot A_{hwrg.U1} = 0.0 \cdot kN$

Apply Total Regulating Crest Gate Tailwater Load at:

$$H_{twrg.U1.loc} := \begin{cases} (TOC_{as} - BOF_{elev}) & \text{if } A3_{U1} \\ \left[\frac{(HW_{U1} - TOC_{as})}{3} + (TOC_{as} - BOF_{elev})\right] & \text{if } B3_{U1} \\ \left[\frac{\sigma_{hwrg.U1.2} \cdot A_{hwrg.U1} \cdot \frac{(H_{rg.U1})}{2} + \frac{(\sigma_{hwrg.U1.1} - \sigma_{hwrg.U1.2})}{2} A_{hwrg.U1} \cdot \frac{(H_{rg.U1})}{3}}{\sigma_{hwrg.U1.2} \cdot A_{hwrg.U1} + \frac{(\sigma_{hwrg.U1.1} - \sigma_{hwrg.U1.2})}{2} \cdot A_{hwrg.U1}} \ldots \\ + (TOC_{as} - BOF_{elev})\right] & \text{if } C3_{U1} \end{cases} = 4.0 \cdot m$$

LATERAL TAILWATER (RESISTING) Applied to Downstream Side of Guard Crest Gate:

U1 CASE

Guard Gate Down/Open Condition: $A4_{U1} := TOP_{gg.U1} \le TOC_{as}$

Guard Crest Gate Up/Closed, with Top of Gate Higher than TW Elevation: $B4_{U1} := TOP_{gg.U1} \ge TW_{U1} \wedge TOP_{gg.U1} > TOC_{as}$

Guard Crest Gate Up/Closed, with Top of Gate Lower than TW Elevation: $C4_{U1} := TOP_{gg.U1} > TOC_{as} \wedge TW_{U1} > TOP_{gg.U1}$

Tailwater Depth at Guard Crest Gate: $D_{twgg.U1} := TW_{U1} - TOC_{as} = 1.80\,m$

Guard Crest Gate Height: $H_{gg.U1} = 0\,m$

Guard Crest Gate Width: $W_{twgg.U1} := 5.00m$

Lateral Water Load at Bottom of Guard Crest Gate:

$$\sigma_{twgg.U1.1} := \begin{vmatrix} (0.0kPa) & \text{if } A4_{U1} \\ (\gamma_w \cdot D_{twgg.U1}) & \text{if } B4_{U1} \\ (\gamma_w \cdot D_{twgg.U1}) & \text{if } C4_{U1} \end{vmatrix} = 0.0 \cdot kPa$$

Lateral Water Load at Top of Guard Crest Gate:
(Load at TW Elevation On Guard Crest Gate if TW is below TOG_{gg})

$$\sigma_{twgg.U1.2} := \begin{vmatrix} (0.0kPa) & \text{if } A4_{U1} \\ 0.0kPa & \text{if } B4_{U1} \\ \left[\gamma_w \cdot (TW_{U1} - TOP_{gg.U1})\right] & \text{if } C4_{U1} \end{vmatrix} = 0.0 \cdot kPa$$

Average Pressure acting on Guard Crest Gate:

$$\sigma_{twgg.U1.avg} := \frac{(\sigma_{twgg.U1.1} + \sigma_{twgg.U1.2})}{2} = 0 \cdot kPa$$

Total Area water acting on Crest Gate:

$$A_{twgg.U1} := \begin{vmatrix} D_{twgg.U1} \cdot W_{twgg.U1} & \text{if } A4_{U1} \\ D_{twgg.U1} \cdot W_{twgg.U1} & \text{if } B4_{U1} \\ H_{gg.U1} \cdot W_{twgg.U1} & \text{if } C4_{U1} \end{vmatrix} = 9 \cdot m^2$$

Total Horizontal Tailwater Load on Guard Crest Gate: $H_{twgg.U1} := \sigma_{twgg.U1.avg} \cdot A_{twgg.U1} = 0.0 \cdot kN$

Apply Total Horiz. TW Load on Guard Gate at:

$$H_{twgg.U1.loc} := \begin{vmatrix} (TOC_{as} - BOF_{elev}) & \text{if } A4_{U1} \\ \left[\frac{(TW_{U1} - TOC_{as})}{3} + (TOC_{as} - BOF_{elev})\right] & \text{if } B4_{U1} \\ \left[\frac{\sigma_{twgg.U1.2} \cdot A_{twgg.U1} \cdot \frac{(H_{gg.U1})}{2} + \frac{(\sigma_{twgg.U1.1} - \sigma_{twgg.U1.2})}{2} A_{twgg.U1} \cdot \frac{(H_{gg.U1})}{3}}{\sigma_{twgg.U1.2} \cdot A_{twgg.U1} + \frac{(\sigma_{twgg.U1.1} - \sigma_{twgg.U1.2})}{2} \cdot A_{twgg.U1}} \ldots \\ + (TOC_{as} - BOF_{elev})\right] & \text{if } C4_{U1} \end{vmatrix} = 4.0 \cdot m$$

LATERAL WATER LOADS (continued)

U1 CASE

TAILWATER (RESISTING) Applied to Concrete Structure:

Tailwater Depth on Pier: $D_{twp.U1} := TW_{U1} - TOC_{as} = 1.80\,m$

Tailwater Load Unit Width on Pier: $W_{twp.U1} := w_p = 2.00\,m$

Total Horizontal Tailwater Load on Pier: $H_{twp.U1} := \frac{\left(\gamma_w \cdot D_{twp.U1}^{\ 2}\right)}{2} \cdot W_{twp.U1} = 31.8 \cdot kN$

Apply Total Pier Tailwater Load at: $H_{twp.U1.loc} := \frac{D_{twp.U1}}{3} + \left(TOC_{as} - BOF_{elev}\right) = 4.60\,m$

Tailwater Depth At top of Gate Base Footing Elevation: $D_{twgf.U1} := TW_{U1} - TOC_{as} = 1.80\,m$

Water Depth at bottom of Gate Base Footing (Excluding Key): $D_{twtoe.U1} := TW_{U1} - BOF_{elev} = 5.80\,m$

Footing Thickness for horizontal at Toe: $h_{toe} := TOC_{as} - BOF_{elev} = 4\,m$

Unit Width of D/S face of crest for application of Tailwater Load: $W_{tw.U1} := W_b = 12.00\,m$

Tailwater Pressure At Top of Gate Footing: $\sigma_{twgf.U1} := \left(\gamma_w \cdot D_{twgf.U1}\right) = 17.66 \cdot kPa$

Tailwater Pressure At Toe: $\sigma_{twtoe.U1} := \left(\gamma_w \cdot D_{twtoe.U1}\right) = 56.9 \cdot kPa$

Triangular Distribution Unit Load on Gate Footing Base: $H_{twgf.U1.tri} := \left(\frac{\sigma_{twtoe.U1} - \sigma_{twgf.U1}}{2}\right) \cdot \left[\left(T_{as} - d_{key}\right) \cdot W_{tw.U1}\right] = 941.76 \cdot kN$

Rectangular Distribution Unit Load on Gate Footing Base: $H_{twgf.U1.rect} := \sigma_{twgf.U1} \cdot \left[\left(T_{as} - d_{key}\right) \cdot W_{tw.U1}\right] = 847.58 \cdot kN$

Tailwater Pressure At Bottom of Sliding Failure Plane: $\sigma_{twbk.U1} := \left(HW_{U1} - BOK_{elev}\right) \cdot \gamma_w = 79.46 \cdot kPa$

Triangular Distribution Unit Load Below Footing: $H_{twbk.U1.tri} := \frac{\left(\sigma_{twbk.U1} - \sigma_{twtoe.U1}\right)}{2} \cdot d_{key} \cdot W_{tw.U1} = 270.76 \cdot kN$

Rectangular Distribution Load Below Footing Base: $H_{twbk.U1.rect} := \sigma_{twtoe.U1} \cdot d_{key} \cdot W_{tw.U1} = 1365.55 \cdot kN$

Total Horizontal Tailwater Headwater Load on Gate Footing (including key): $H_{twgk.U1} := H_{twgf.U1.tri} + H_{twgf.U1.rect} \cdots + \left(H_{twbk.U1.tri} + H_{twbk.U1.rect}\right) = 3425.65 \cdot kN$

Apply Total Gate Footing Tailwater Load at:

$$H_{twgk.U1.loc} := \frac{\left[H_{twgf.U1.rect} \cdot \left(\frac{h_{toe}}{2}\right) + H_{twgf.U1.tri} \cdot \left(\frac{h_{toe}}{3}\right) + H_{twbk.U1.tri} \cdot \left(-d_{key} \cdot \frac{2}{3}\right) + H_{twbk.U1.rect} \cdot \left(\frac{-d_{key}}{2}\right)\right]}{H_{twgf.U1.tri} + H_{twgf.U1.rect} + H_{twbk.U1.tri} + H_{twbk.U1.rect}} = 0.36\,m$$

SUMMATION OF LATERAL WATER LOADS:

$$\Sigma H_{Water.U1} := H_{hwp.U1} + H_{hwas.U1} + H_{hwrg.U1} + H_{hwgg.U1} + H_{twp.U1} + H_{twgk.U1} + H_{twrg.U1} + H_{twgg.U1} = -188.06 \cdot kN$$

$$\Sigma M_{Hwater.U1} := H_{hwp.U1} \cdot H_{hwp.U1.loc} + H_{hwas.U1} \cdot H_{hwas.U1.loc} + H_{hwrg.U1} \cdot H_{hwrg.U1.loc} + H_{hwgg.U1} \cdot H_{hwgg.U1.loc} \cdots + H_{twp.U1} \cdot H_{twp.U1.loc} + H_{twgk.U1} \cdot H_{twgk.U1.loc} + H_{twrg.U1} \cdot H_{twrg.U1.loc} + H_{twgg.U1} \cdot H_{twgg.U1.loc} = -316.11 \cdot kN \cdot m$$

VERTICAL WATER LOADS

U1 CASE

HEADWATER:

Water Depth on top of Approach Slab: $d_{hw.U1} := HW_{U1} - TOC_{as} = 2.10\,m$

Length of Approach Slab: $L_{as} = 8.75\,m$

Width of Approach Slab: $w_{as} = 12.00\,m$

Length from front of Gate to Heel: $L_{hg} := 8.75m$

Vertical Water Weight (H1) on Approach Slab: $H_{1.U1} := \left[w_{as} \cdot d_{hw.U1} \cdot L_{hg} - w_p \cdot d_{hw.U1} \cdot \left(L_{hg} - L_{as}\right)\right] \cdot \gamma_w = 2163.1 \cdot kN$

Moment Arm for Application of Water Weight (H1) from toe: $H_{1.U1.loc} := L_b - \dfrac{L_{hg}}{2} = 14.13\,m$

TAILWATER ABOVE GUARD GATE:

Trapezoid Volume Above Gate Footing from Approach Slab to Crest: $V_{asc.gg.U1} := \left(L_{gf} - L_{gfc}\right) W_{twgg.U1} \dfrac{d_{hw.U1} + Y_{C.gg.U1}}{2} = 75.08 \cdot m^3$

Trapezoid Volume Above Gate Footing Crest to End of Gate Footing: $V_{gfc.gg.U1} := \left(L_{gfc} \cdot W_{twgg.U1}\right) \dfrac{Y_{C.gg.U1} + Y_{TOE.gg.U1}}{2} = 16.64 \cdot m^3$

Load Above Gate Footing from Approach Slab to Crest: $H_{2.U1.asc.gg} := V_{asc.gg.U1} \cdot \gamma_w = 736.49 \cdot kN$

Load Acting Above Footing Crest from Toe: $H_{2.U1.asc.gg.loc} := \dfrac{\left(L_{gf} - L_{gfc}\right) \cdot \left(2 \cdot d_{hw.U1} + Y_{C.gg.U1}\right)}{3 \cdot \left(d_{hw.U1} + Y_{C.gg.U1}\right)} + L_{gfc} = 6.17\,m$

Load Above Gate Footing from Crest to End: $H_{2.U1.gfc.gg} := V_{gfc.gg.U1} \cdot \gamma_w = 163.24 \cdot kN$

Load Acting Above Gate Footing from Crest to End: $H_{2.U1.gfc.gg.loc} := \dfrac{\left(L_{gfc}\right) \cdot \left(2 \cdot Y_{C.gg.U1} + Y_{TOE.gg.U1}\right)}{3 \cdot \left(Y_{C.gg.U1} + Y_{TOE.gg.U1}\right)} = 1.58\,m$

Vertical Water Weight (H2) on Guard Gate Footing: $H_{2.U1.gg} := H_{2.U1.asc.gg} + H_{2.U1.gfc.gg} = 899.72 \cdot kN$

Moment Arm for Application of Water Weight (H2) from toe: $H_{2.U1.gg.loc} := \dfrac{H_{2.U1.asc.gg} \cdot H_{2.U1.asc.gg.loc} + H_{2.U1.gfc.gg} \cdot H_{2.U1.gfc.gg.loc}}{H_{2.U1.gg}} = 5.34\,m$

TAILWATER ABOVE REGULATING GATE:

Trapezoid Volume Above Gate Footing from Approach Slab to Crest: $V_{asc.rg.U1} := \left(L_{gf} - L_{gfc}\right) W_{twrg.U1} \dfrac{d_{hw.U1} + Y_{C.rg.U1}}{2} = 75.08 \cdot m^3$

Trapezoid Volume Above Gate Footing Crest to End of Gate Footing: $V_{gfc.rg.U1} := \left(L_{gfc} \cdot W_{twrg.U1}\right) \dfrac{Y_{C.rg.U1} + Y_{TOE.rg.U1}}{2} = 16.64 \cdot m^3$

Load Above Gate Footing from Approach Slab to Crest: $H_{2.U1.asc.rg} := V_{asc.rg.U1} \cdot \gamma_w = 736.49 \cdot kN$

Load Acting Above Footing Crest from Toe: $H_{2.U1.asc.rg.loc} := \dfrac{\left(L_{gf} - L_{gfc}\right) \cdot \left(2 \cdot d_{hw.U1} + Y_{C.rg.U1}\right)}{3 \cdot \left(d_{hw.U1} + Y_{C.rg.U1}\right)} + L_{gfc} = 6.17\,m$

Load Above Gate Footing from Crest to End: $H_{2.U1.gfc.rg} := V_{gfc.rg.U1} \cdot \gamma_w = 163.24 \cdot kN$

Load Acting Above Gate Footing from Crest to End: $H_{2.U1.gfc.rg.loc} := \dfrac{\left(L_{gfc}\right) \cdot \left(2 \cdot Y_{C.rg.U1} + Y_{TOE.rg.U1}\right)}{3 \cdot \left(Y_{C.rg.U1} + Y_{TOE.rg.U1}\right)} = 1.58\,m$

Vertical Water Weight (H2) on Regulating Gate Footing: $H_{2.U1.rg} := H_{2.U1.asc.rg} + H_{2.U1.gfc.rg} = 899.72 \cdot kN$

Moment Arm for Application of Water Weight (H2) from toe: $H_{2.U1.rg.loc} := \dfrac{H_{2.U1.asc.rg} \cdot H_{2.U1.asc.rg.loc} + H_{2.U1.gfc.rg} \cdot H_{2.U1.gfc.rg.loc}}{H_{2.U1.rg}} = 5.34\,m$

Uplift pressure at U/S Face (heel): $U_{HW.U1} := (D_{hwas.U1}) \cdot \gamma_w = 79.5 \cdot \frac{kN}{m^2}$

Uplift pressure at D/S Face Stilling Basin: $U_{TW.U1} := (D_{twtoe.U1}) \cdot \gamma_w = 56.9 \cdot \frac{kN}{m^2}$

Length from U/S of Gate Structure to U/S of Stilling Basin: $L_{overall.Usual} := L_b = 18.50\,m$

Difference between Uplift pressure at HW and TW: $U_{diff.U1} := U_{HW.U1} - U_{TW.U1} = 22.56 \cdot \frac{kN}{m^2}$

Slope of difference between between Uplift pressure at HW and TW: $U_{slope.U1} := \frac{U_{diff.U1}}{L_{overall.Usual}} = 1.22 \cdot \frac{kN}{m^2 \cdot m}$

Tailwater Pressure at toe of Gate Structure: $U_{press.toe.gs.U1} := U_{TW.U1} + (L_{overall.Usual} - L_b) \cdot U_{slope.U1} = 56.9 \cdot \frac{kN}{m^2}$

Uniform uplift force UA Under Gate Structure due to TW (rectangle): $U_{A.U1} := U_{press.toe.gs.U1} \cdot L_b \cdot W_b \cdot -1 = -12631.36 \cdot kN$

Moment Arm from Toe of Gate Structure for Uplift UA: $L_{A.U1} := \left(\frac{L_b}{2}\right) = 9.25\,m$

Linearly Decreasing Uplift Force U1B Under Gate Structure due to HW-TW Differential (triangle): $U_{B.U1} := \frac{1}{2} \cdot (U_{HW.U1} - U_{press.toe.gs.U1}) \cdot L_b \cdot W_b \cdot -1 = -2504.49 \cdot kN$

Moment Arm from Toe of Gate Structure for Uplift UB: $L_{B.U1} := \frac{2}{3} \cdot L_b = 12.33\,m$

Total Resultant Uplift force: $U_{U1} := U_{A.U1} + U_{B.U1} = -15135.85 \cdot kN$

Resultant Location from Toe: $U_{U1.loc} := \frac{(U_{A.U1} \cdot L_{A.U1} + U_{B.U1} \cdot L_{B.U1})}{(U_{A.U1} + U_{B.U1})} = 9.76\,m$

$\Sigma V_{water.U1} := H_{1.U1} + H_{2.U1.gg} + H_{2.U1.rg} + U_{U1} = -11173.3 \cdot kN$

$\Sigma M_{Vwater.U1} := H_{1.U1} \cdot H_{1.U1.loc} + H_{2.U1.gg} \cdot H_{2.U1.gg.loc} + H_{2.U1.rg} \cdot H_{2.U1.rg.loc} + U_{U1} \cdot U_{U1.loc} = -107564.28 \cdot kN \cdot m$

SOIL LOADS

U1 CASE

Equivalent Fluid Pressure (EFP):

At rest lateral pressure coefficient: $K_{o.U1} := 1 - \sin(\phi_{backfill}) = 0.658$ (Section 5.3, Design Criteria)

Headwater Pier Footing Unit Width: $W_{hwas.U1} = 12.00\,m$

Tailwater Pier Footing Unit Width: $W_{tw.U1} = 12.00\,m$

Pier Footing Thickness at Heel: $t_{hf.U1} := TOC_{as} - BOK_{elev} = 6.00\,m$

Fixed Crest Footing Thickness at Toe: $t_{tf.U1} := TOC_{pfe} - BOF_{elev} = 2.00\,m$

Lateral Driving Force (Headwater Side - at rest condition)

Structure Soil Load:

$$E_{act.U1} := \frac{K_{o.U1} \cdot t_{hf.U1}^{2}}{2} \cdot (\gamma_r - \gamma_w) \cdot W_{hwas.U1} \cdot -1 = -1732.49 \cdot kN$$

Acting at:

$$E_{act.U1.loc} := \frac{t_{hf.U1}}{3} - d_{key} = 0.00\,m$$

Lateral Resisting Force (Tailwater Side - at rest condition)

At-rest Soil Load:

$$E_{pass.U1} := \frac{K_{o.U1} \cdot t_{tf.U1}^{2}}{2} \cdot (\gamma_r - \gamma_w) \cdot W_{tw.U1} = 192.5 \cdot kN$$

Acting at:

$$E_{pass.U1.loc} := \frac{t_{tf.U1}}{3} = 0.67\,m$$

$$\Sigma H_{soil.U1} := E_{act.U1} + E_{pass.U1} = -1539.99 \cdot kN$$

$$\Sigma M_{soil.U1} := E_{act.U1} \cdot E_{act.U1.loc} + E_{pass.U1} \cdot E_{pass.U1.loc} = 128.33 \cdot kN \cdot m$$

ICE / IMPACT LOADS (ASSUME NO ICE LOADING ON TAILWATER SIDE)

Static Ice Loading on Structure: $I_{S.U1} := 150.0 \frac{kN}{m}$ (Section 7.7, Design Criteria)

Ice Loading Unit Width on Structure: $W_{S.U1} := 2.00m$

Static Ice load on Gates: (Section 7.7, Design Criteria)

$$I_{rg.U1} := \begin{cases} 0 \frac{kN}{m} & \text{if } TOP_{rg.U1} \le TOC_{as} \\ 75 \frac{kN}{m} & \text{if } TOP_{rg.U1} > TOC_{as} \end{cases} = 0$$

$$I_{gg.U1} := \begin{cases} 0 \frac{kN}{m} & \text{if } TOP_{gg.U1} \le TOC_{as} \\ 75 \frac{kN}{m} & \text{if } TOP_{gg.U1} > TOC_{as} \end{cases} = 0$$

Ice Loading Unit Width on Crest Gates: $W_{rg.U1} := 5m$ $W_{gg.U1} := 5m$ (Input value for load case)

Total Ice Load on Structure:

$$I_{U1} := (I_{S.U1} \cdot W_{S.U1} + I_{rg.U1} \cdot W_{rg.U1} + I_{gg.U1} \cdot W_{gg.U1}) \cdot -1 = -300 \cdot kN$$

Apply Ice load at:

$$I_{U1.loc} := (HW_{U1} - BOF_{elev} - 0.30m) = 5.80\,m$$

$$\Sigma H_{I.U1} := I_{U1} = -300 \cdot kN$$

$$\Sigma M_{I.U1} := I_{U1} \cdot I_{U1.loc} = -1740 \cdot kN \cdot m$$

SEISMIC LOAD (NOT APPLICABLE FOR THIS LOAD CASE)

U1 CASE

SUMMARY OF LOADS

	Loads	Moment Arm
Dead load of Concrete Structure:	$D_{conc} = 22438.7 \cdot kN$	$X_{conc.loc} = 9.35\,m$
Obermyer Gate Weight:	$D_{Gate} = 140.0 \cdot kN$	$X_{gate} = 9.50\,m$
HW Lateral Load on Pier:	$H_{hwp.U1} = -43.3 \cdot kN$	$H_{hwp.U1.loc} = 4.70\,m$
HW Lateral Load on Approach Slab:	$H_{hwas.U1} = -3602.2 \cdot kN$	$H_{hwas.U1.loc} = 0.41\,m$
HW Lateral Load on Regulating Gate:	$H_{hwrg.U1} = 0.0 \cdot kN$	$H_{hwrg.U1.loc} = 4.00\,m$
HW Lateral Load on Guard Gate:	$H_{hwgg.U1} = 0.0 \cdot kN$	$H_{hwgg.U1.loc} = 4.00\,m$
TW Lateral Load on Pier:	$H_{twp.U1} = 31.8 \cdot kN$	$H_{twp.U1.loc} = 4.60\,m$
TW Lateral Load on Pier Footing (including Key):	$H_{twgk.U1} = 3425.65 \cdot kN$	$H_{twgk.U1.loc} = 0.36\,m$
TW Lateral Load on Regulating Gate:	$H_{twrg.U1} = 0.0 \cdot kN$	$H_{twrg.U1.loc} = 4.00\,m$
TW Lateral Load on Guard Gate:	$H_{twgg.U1} = 0.0 \cdot kN$	$H_{twgg.U1.loc} = 4.00\,m$
Vertical HW Load on Approach Slab:	$H_{1.U1} = 2163.1 \cdot kN$	$H_{1.U1.loc} = 14.13\,m$
Vertical TW Load on Regulating Gate:	$H_{2.U1.rg} = 899.7 \cdot kN$	$H_{2.U1.rg.loc} = 5.34\,m$
Vertical TW Load on Guard Gate:	$H_{2.U1.gg} = 899.7 \cdot kN$	$H_{2.U1.gg.loc} = 5.34\,m$
Uplift:	$U_{U1} = -15135.8 \cdot kN$	$U_{U1.loc} = 9.76\,m$
Lateral Soil Load (driving):	$E_{act.U1} = -1732.5 \cdot kN$	$E_{act.U1.loc} = 0.00\,m$
Lateral Soil Load (resisting):	$E_{pass.U1} = 192.5 \cdot kN$	$E_{pass.U1.loc} = 0.67\,m$
Ice / Impact Load:	$I_{U1} = -300.0 \cdot kN$	$I_{U1.loc} = 5.80\,m$

STABILITY ASSESSMENT (SLIDNG, BEARING, FLOTATION AND OVERTURNING): U1 CASE

CHECK SLIDING ALONG HORIZONTAL PLANE THRU TOE,
IGNORING BEDROCK MOBILIZED BY STRUCTURAL HEEL KEY, OR VOID BEHIND KEY

Sum of Vertical Forces:

$\Sigma V_{U1} := \Sigma V_{DL} + \Sigma V_{water.U1} = 11405.4 \cdot kN$

Sum of Horizontal Forces:

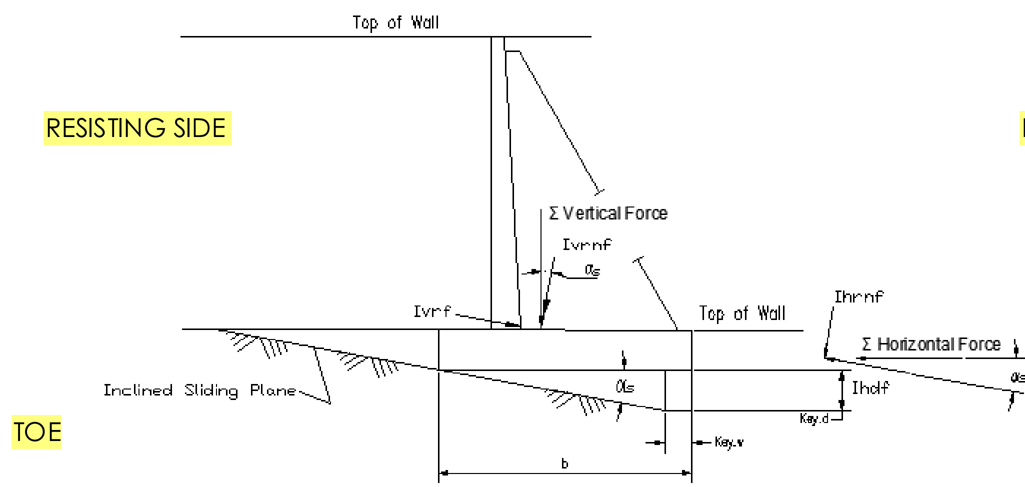
$\Sigma H_{U1} := \Sigma H_{Water.U1} + \Sigma H_{soil.U1} + \Sigma H_{I.U1} = -2028.05 \cdot kN$

Sliding Factor of Safety:

$$FS_{HorizSliding.U1} := \frac{\tan_{\phi} \cdot \Sigma V_{U1}}{|\Sigma H_{U1}|} = 2.74$$

$$FS_{HorizSliding.U1.Check} := \begin{cases} \text{"OKAY"} & \text{if } FS_{HorizSliding.U1} \geq FS_{req.U1.sl} \\ \text{"Check Inclined Sliding with Key"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

CHECK SLIDING ALONG INCLINED SLIDING PLANE FROM HEEL KEY TO TOE,
WITH BEDROCK MASS MOBILIZED BY REINFOCREDE CONCRETE KEY)



$\Sigma V_{U1} = 11405.44 \cdot kN$

$V_{rs} = 4620 \cdot kN$

$$\alpha s := \operatorname{atan}\left(\frac{d_{key}}{L_b - w_{key}}\right) = 0.11$$

Ivrf=Inclined Resisting Force
Ivrnf=Inclined Resisting Normal Force
Ihrnf=Inclined Resisting Normal Force
Ihdf=Inclined Driving Force

as degrees= $\alpha s \cdot \left(\frac{180}{\pi}\right) = 6.52$

Resolve $\Sigma Vert_{U1}$ & $\Sigma Horiz_{U1}$

$$\Sigma V_{InclinedU1} := \cos(\alpha s) \cdot (\Sigma V_{U1} + V_{rs}) + \sin(\alpha s) \cdot |\Sigma H_{U1}| = 16152.1 \cdot kN$$

$$\Sigma H_{InclinedU1} := \cos(\alpha s) \cdot |\Sigma H_{U1}| - \sin(\alpha s) \cdot (\Sigma V_{U1} + V_{rs}) = 195.3 \cdot kN$$

(With properly engineered reinforced concrete Key, horizontal sliding plane thru Toe is protected, critical sliding plane is relocated to the INCLINED SLIDING PLANE FROM HEEL KEY To TOE, Bedrock Mass above this examining plane is mobilized by reinforced concrete key and combined into Structural Wedge.)

Inclined Sliding Plane Length

$$L_{incline} := \left[L_b^{\,2} + (BOF_{elev} - BOK_{elev})^2\right]^{0.5} = 18.61 \, m$$

Safety Factor for Sliding
Inclined Failure Plane

$$FS_{InclinedlSlidingU1} := \frac{\Sigma V_{InclinedU1} \cdot \tan\left(\phi_{rock} \cdot \frac{\pi}{180}\right)}{|\Sigma H_{InclinedU1}|} = 40.34$$

$$FS_{InclinedSliding.check.U1} := \begin{cases} \text{"OKAY "} & \text{if } FS_{InclinedlSlidingU1} > FS_{req.U1.sl} \\ \text{"Revise Structure""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

$FS_{InclinedSliding.check.U1} = \text{"OKAY "}$

OVERTURNING STABILITY CHECK:

U1 CASE

CHECK ECCENTRICITY

Sum of the moments:

$$\Sigma M_{U1} := \Sigma M_{DL} + \Sigma M_{Hwater.U1} + \Sigma M_{Vwater.U1} + \Sigma M_{I.U1} + \Sigma M_{soil.U1} + \Sigma M_{rs} = 155528 \cdot kN \cdot m$$

Eccentricity:

$$e_{U1} := \left(\frac{L_{incline}}{2}\right) - \frac{\left(\Sigma M_{U1}\right)}{\Sigma V_{InclinedU1}} \cdot \cos(\alpha s) = -0.26\,m$$

Eccentricity Check:

$$e_{check.U1} := \begin{cases} \text{"Okay"} & \text{if } |e_{U1}| \le Kern \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$$e_{check.U1} = \text{"Okay"}$$

Foundation Bearing Checks:

Incline Plane Area:

$$A_{b.incline} := L_{incline} \cdot W_b = 223.29\,m^2$$

Incline Plane Section Modulus:

$$S_{b.incline} := \frac{W_b \cdot L_{incline}^2}{6} = 692.5 \cdot m^3$$

Bearing Pressure at Heel:

$$\sigma_{heel.U1} := \frac{\Sigma V_{InclinedU1}}{A_{b.incline}} - \frac{\left(\Sigma V_{InclinedU1} \cdot e_{U1}\right)}{S_{b.incline}} = 78.5 \cdot \frac{kN}{m^2}$$

$$\sigma_{heel.U1.check} := \left(\begin{cases} \text{"Okay"} & \text{if } \sigma_{heel.U1} \le \sigma_{allow.U1} \\ \text{"Revise Structure"} & \text{if } \sigma_{heel.U1} < 0\,\frac{kN}{m^2} \end{cases} \right)$$

$$\sigma_{heel.U1.check} = \text{"Okay"}$$

Bearing Pressure at Toe:

$$\sigma_{toe.U1} := \frac{\Sigma V_{InclinedU1}}{A_{b.incline}} + \frac{\left(\Sigma V_{InclinedU1} \cdot e_{U1}\right)}{S_{b.incline}} = 66.2 \cdot \frac{kN}{m^2}$$

$$\sigma_{toe.U1.1.check} := \begin{cases} \text{"Okay"} & \text{if } \sigma_{toe.U1} \le \sigma_{allow.U1} \\ \text{"Revise Structure"} & \text{if } \sigma_{toe.U1} < 0\,\frac{kN}{m^2} \end{cases}$$

$$\sigma_{toe.U1.1.check} = \text{"Okay"}$$

FLOATATION ANALYSIS:

ACCEPTANCE PARAMETERS

Required Factor of Safety: $FS_{req.FU1} := 1.5$

VERTICAL LOADS RESISTING:

Dead Load: $\Sigma V_{DL} = 22578.74 \cdot kN$

Water Weight H1+H2: $\Sigma V_{H.FU1} := H_{1.U1} + H_{2.U1.gg} + H_{2.U1.rg} = 3962.55 \cdot kN$

Summation Vertical Resisting: $\Sigma V_{FU1} := \Sigma V_{DL} + \Sigma V_{H.FU1} = 26541.3 \cdot kN$

VERTICAL LOADS UPLIFT:

Uplift: $U_{U1} = -15135.85 \cdot kN$

Factor of Safety Floatation:

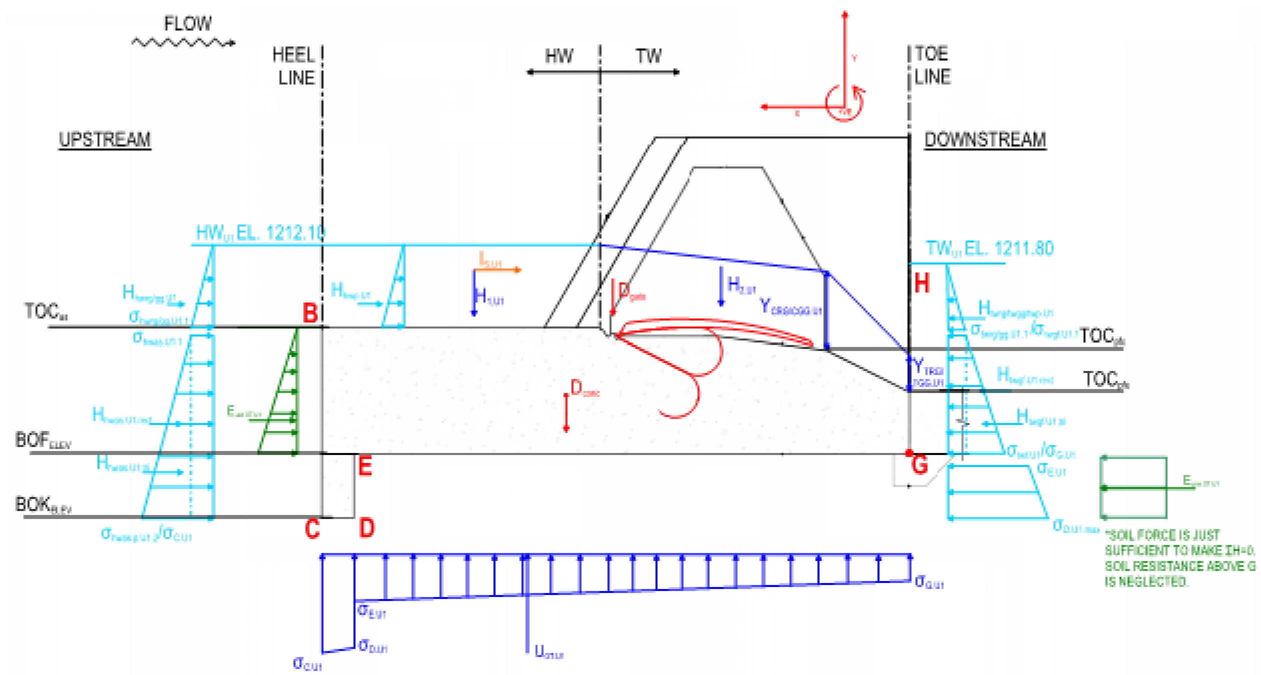
$$FS_{act.FU1} := \frac{\Sigma V_{FU1}}{|U_{U1}|} = 1.75$$

$$FS_{check.FU1} := \begin{cases} \text{"OKAY"} & \text{if } FS_{act.FU1} \ge FS_{req.FU1} \\ \text{"ANCHORS REQUIRED"} & \text{if } FS_{act.FU1} < FS_{req.FU1} \end{cases} = \text{"OKAY"}$$

MONOLITH OVERTURNING STABILITY ANALYSIS

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.
Assumptions are made in order to compute overturning stability of indetermine forces on monolith with key;
(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.
(b) The horizontal resisting force acting on the key, P.key, is that required for static equilibrium
(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1 $Ratio_{OT.U1.min} := 0.33$ at Rock Foundation



Uplift Loads for Overturning Stability Analysis

Line of Creep:

Change in Water Head: $\Delta_{h.U1} := HW_{U1} - TW_{U1} = 0.3\ m$

Length from Point C to Point G: $L_{CG} := \sqrt{d_{key}^{\ 2} + L_b^{\ 2}} = 18.61\ m$

Length from Various Points to Points: $L_{CD} := w_{key} = 1\ m$ $L_{DE} := d_{key} = 2\ m$ $L_{EG} := L_b - L_{CD} = 17.5\ m$

$L_{GH} := TW_{U1} - BOF_{elev} = 5.8\ m$

Length from Point C, D, E to G: $L_{CDEG} := L_{CD} + L_{DE} + L_{EG} = 20.5\ m$ $L_{CDE} := L_{CD} + L_{DE} = 3\ m$

Water Pressure at Point C & G: $\sigma_{C.U1} := \sigma_{hwas.U1.2} = -79.46 \cdot kPa$ $\sigma_{G.U1} := \sigma_{twtoe.U1} \cdot -1 = -56.9 \cdot kPa$

Water Pressure at Point D:
$$\sigma_{D.U1} := -\gamma_w \cdot \left[\left(HW_{U1} - BOK_{elev}\right) - \frac{\Delta_{h.U1} \cdot L_{CD}}{L_{CDEG}}\right] = -79.32 \cdot kPa$$

Water Pressure at Point E:
$$\sigma_{E.U1} := -\gamma_w \cdot \left[\left(HW_{U1} - BOF_{elev}\right) - \frac{\Delta_{h.U1} \cdot L_{CDE}}{L_{CDEG}}\right] = -59.41 \cdot kPa$$

Uplift for Overturning Analysis on Bottom of Key:
$$U_{OT.U1.key} := \frac{\sigma_{C.U1} + \sigma_{D.U1}}{2} \cdot L_{CD} \cdot W_b = -952.67 \cdot kN$$

Acting at:
$$U_{OT.U1.key.loc} := \frac{L_{CD} \cdot \left(2 \cdot \sigma_{C.U1} + \sigma_{D.U1}\right)}{3\left(\sigma_{C.U1} + \sigma_{D.U1}\right)} + L_{EG} = 18\ m$$

Uplift for Overturning Analysis on Bottom of Footing:
$$U_{OT.U1.ftg} := \frac{\sigma_{E.U1} + \sigma_{G.U1}}{2} \cdot L_{EG} \cdot W_b = -12212.37 \cdot kN$$

Acting at:
$$U_{OT.U1.ftg.loc} := \frac{L_{EG} \cdot \left(\sigma_{G.U1} + 2 \cdot \sigma_{E.U1}\right)}{3\left(\sigma_{G.U1} + \sigma_{E.U1}\right)} = 8.81\ m$$

U1 CASE

Uplift Load for Overturning Analysis: $U_{OT.U1} := U_{OT.U1.key} + U_{OT.U1.ftg} = -13165.04 \cdot kN$

Uplift Load Acting from Toe:

$$U_{OT.U1.loc} := \frac{U_{OT.U1.key} \cdot U_{OT.U1.key.loc} + U_{OT.U1.ftg} \cdot U_{OT.U1.ftg.loc}}{U_{OT.U1}} = 9.48\,m$$

All Vertical Loads Applicable to Overturning Stability Analysis

Total Concrete Dead Loads:	$D_{conc} = 22438.74 \cdot kN$	at:	$X_{conc.loc} = 9.35\,m$
Dead Load of Gate:	$D_{Gate} = 140.0 \cdot kN$		$X_{gate} = 9.50\,m$
Water Weight (HW) on Apron Slab:	$H_{1.U1} = 2163.1 \cdot kN$		$H_{1.U1.loc} = 14.13\,m$
Water Weight (TW) on Gate Footing:	$H_{2.U1.rg} = 899.7 \cdot kN$		$H_{2.U1.rg.loc} = 5.34\,m$
Water Weight (TW) on Regulating Gate Footing:	$H_{2.U1.gg} = 899.7 \cdot kN$		$H_{2.U1.gg.loc} = 5.34\,m$
Uplift Load for Overturning Analysis:	$U_{OT.U1} = -13165.04 \cdot kN$		$U_{OT.U1.loc} = 9.48 \cdot m$

Sum of All Overturning Analysis Vertical Load:

$$\Sigma V_{U1.OT} := D_{conc} + D_{Gate} + H_{1.U1} + H_{2.U1.rg} + H_{2.U1.gg} + U_{OT.U1} = 13376.25 \cdot kN$$

Sum of All Overturning Analysis Vertical Load Moments:

$$\Sigma M_{V.U1.OT} := D_{conc} \cdot X_{conc.loc} + D_{Gate} \cdot X_{gate} + H_{1.U1} \cdot H_{1.U1.loc} + H_{2.U1.rg} \cdot H_{2.U1.rg.loc} \ldots = 126508.58 \cdot kN \cdot m$$
$$+ H_{2.U1.gg} \cdot H_{2.U1.gg.loc} + U_{OT.U1} \cdot U_{OT.U1.loc}$$

Lateral Tailwater Loads for Overturning Stability Analysis

TW Lateral Load on Gate Footing (No Key - Overturning Values Adjusted): $H_{twgf.U1} := H_{twgf.U1.tri} + H_{twgf.U1.rect} = 1789.34 \cdot kN$

Acting at:

$$H_{twgf.U1.loc} := \frac{\frac{h_{toe}}{3} \cdot H_{twgf.U1.tri} + \frac{h_{toe}}{2} \cdot H_{twgf.U1.rect}}{H_{twgf.U1}} = 1.65\,m$$

Horizontal Tailwater Pressure Top of Key (Overturning Analysis): $\sigma_{twtk.OT.U1} := \sigma_{E.U1} \cdot -1 = 59.41 \cdot kPa$

Horizontal Tailwater Pressure Bottom of Key (Overturning Analysis): $\sigma_{twbk.OT.U1} := \sigma_{D.U1} \cdot -1 = 79.32 \cdot kPa$

Triangular Distribution Unit Load Acting at Key:

$$H_{twbk.OT.U1.tri} := \frac{(\sigma_{twbk.OT.U1} - \sigma_{twtk.OT.U1})}{2} \cdot d_{key} \cdot W_{tw.U1} = 238.89 \cdot kN$$

Triangular Distribution Unit Load Acting at Key: $H_{twbk.OT.U1.rect} := \sigma_{twtk.OT.U1} \cdot d_{key} \cdot W_{tw.U1} = 1425.85 \cdot kN$

Total Horizontal Tailwater Load on Key (Overturning Values Adjusted): $H_{twkey.OT.U1} := H_{twbk.OT.U1.tri} + H_{twbk.OT.U1.rect} = 1664.73 \cdot kN$

Acting at:

$$H_{twkey.OT.U1.loc} := \frac{H_{twbk.OT.U1.tri} \cdot \frac{-2 \cdot d_{key}}{3} + H_{twbk.OT.U1.rect} \cdot \frac{-d_{key}}{2}}{H_{twkey.OT.U1}} = -1.05 \cdot m$$

Lateral Driving Earth Loads for Overturning Stability Analysis (at rest condition)

Depth of Driving Soil Loads (to top of key): $h_{E.OT.U1} := TOC_{as} - BOF_{elev} = 4\,m$

At-Rest Soil Load:

$$E_{act.OT.U1} := \frac{\left(K_{o.U1} \cdot h_{E.OT.U1}^{\,2}\right)}{2} \cdot (\gamma_r - \gamma_w) \cdot W_{hwas.U1} \cdot -1 = -769.99 \cdot kN$$

At Rest- Soil Load Acting from Toe:

$$E_{act.OT.U1.loc} := \frac{h_{E.OT.U1}}{3} = 1.33\,m$$

All Lateral Loads Applicable to Overturning Stability Analysis

HW Lateral Load on Approach Slab: $H_{hwas.U1} = -3602.2 \cdot kN$ $H_{hwas.U1.loc} = 0.41\,m$

HW Lateral Load on Regulating Gate: $H_{hwrg.U1} = 0.0 \cdot kN$ $H_{hwrg.U1.loc} = 4.00\,m$

HW Lateral Load on Guard Gate: $H_{hwgg.U1} = 0.0 \cdot kN$ $H_{hwgg.U1.loc} = 4.00\,m$

TW Lateral Load on Regulating Gate: $H_{twrg.U1} = 0.0 \cdot kN$ $H_{twrg.U1.loc} = 4.00\,m$

HW Lateral Load on Guard Gate: $H_{twgg.U1} = 0.0 \cdot kN$ $H_{twgg.U1.loc} = 4.00\,m$

TW Lateral Load on Gate Footing (No Key - Overturning Values Adjusted): $H_{twgf.U1} = 1789.34 \cdot kN$ $H_{twgf.U1.loc} = 1.65\,m$

TW Lateral Load on Key: $H_{twkey.OT.U1} = 1664.73 \cdot kN$ $H_{twkey.OT.U1.loc} = -1.05\,m$

Ice / Impact Load: $I_{U1} = -300.0 \cdot kN$ $I_{U1.loc} = 5.80\,m$

Lateral Soil Load (driving): $E_{act.OT.U1} = -770.0 \cdot kN$ $E_{act.OT.U1.loc} = 1.33\,m$

Resisting Lateral Soil Load as required to produce horizontal equilibrium:

$$E_{pas.OT.U1} := -\left(H_{hwas.U1} + H_{hwrg.U1} + H_{hwgg.U1} + H_{twrg.U1} + H_{twgg.U1} \cdots \atop + H_{twgf.U1} + H_{twkey.OT.U1} + I_{U1} + E_{act.OT.U1}\right) = 1218.15 \cdot kN$$

Acting at:

$$E_{pas.OT.U1.loc} := -1 \cdot \frac{d_{key}}{2} = -1\,m$$

Sum of All Overturning Analysis Horizontal Load (ΣH=0):

$$\Sigma H_{U1.OT} := H_{hwas.U1} + H_{hwrg.U1} + H_{hwgg.U1} + H_{twrg.U1} + H_{twgg.U1} + H_{twgf.U1} + H_{twkey.OT.U1} + I_{U1} + E_{act.OT.U1} + E_{pas.OT.U1} = 0 \cdot kN$$

Sum of All Overturning Analysis Horizontal Load Moments:

$$\begin{aligned}\Sigma M_{H.U1.OT} := {} & H_{hwas.U1} \cdot H_{hwas.U1.loc} + H_{hwrg.U1} \cdot H_{hwrg.U1.loc} + H_{hwgg.U1} \cdot H_{hwgg.U1.loc} \cdots \\ & + H_{twrg.U1} \cdot H_{twrg.U1.loc} + H_{twgg.U1} \cdot H_{twgg.U1.loc} + H_{twgf.U1} \cdot H_{twgf.U1.loc} \cdots \\ & + H_{twkey.OT.U1} \cdot H_{twkey.OT.U1.loc} + I_{U1} \cdot I_{U1.loc} + E_{act.OT.U1} \cdot E_{act.OT.U1.loc} + E_{pas.OT.U1} \cdot E_{pas.OT.U1.loc}\end{aligned} = -4261.59 \cdot kN \cdot m$$

Overturning Stability Analysis

$$\Sigma M_{U1.OT} := \Sigma M_{V.U1.OT} + \Sigma M_{H.U1.OT} = 122246.99 \cdot kN \cdot m$$

$$X_{R.U1} := \frac{\Sigma M_{U1.OT}}{\Sigma V_{U1.OT}} = 9.14\,m \qquad x_{OT.U1} := X_{R.U1} - \frac{L_b}{2} = -0.11\,m$$

Overturning Resultant Ratio

$$Ratio_{OT.U1} := \frac{X_{R.U1}}{L_b} = 0.49$$

$$Ratio_{OT.U1.check} := \begin{vmatrix} \text{"OKAY"} \quad \text{if} \quad Ratio_{OT.U1} \geq Ratio_{OT.U1.min} \\ \text{"Revise Structure"} \quad \text{otherwise} \end{vmatrix} = \text{"OKAY"}$$

$$x_{OT.check.U1} := \begin{vmatrix} \text{"OKAY"} \quad \text{if} \quad \left|x_{OT.U1}\right| \leq Kern \\ \text{"Revise Structure"} \quad \text{otherwise} \end{vmatrix} = \text{"OKAY"}$$

U1 CASE

CHECK FOUNDATION BEARING CAPACITY (HORIZONTAL PLANE):

Bearing Pressure Under Toe:

$$\sigma_{ToeU1.OT} := \frac{\Sigma V_{U1.OT}}{L_b \cdot W_b} + \frac{\left(\Sigma V_{U1.OT} \cdot x_{OT.U1}\right)}{S_b} = 58.1 \cdot kPa$$

$$Bearing_{CheckToeU1.OT} := \begin{cases} \text{"OKAY"} & \text{if } \sigma_{ToeU1.OT} < \sigma_{allow.U1} \\ \text{"NG"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

Bearing Pressure Under Heel:

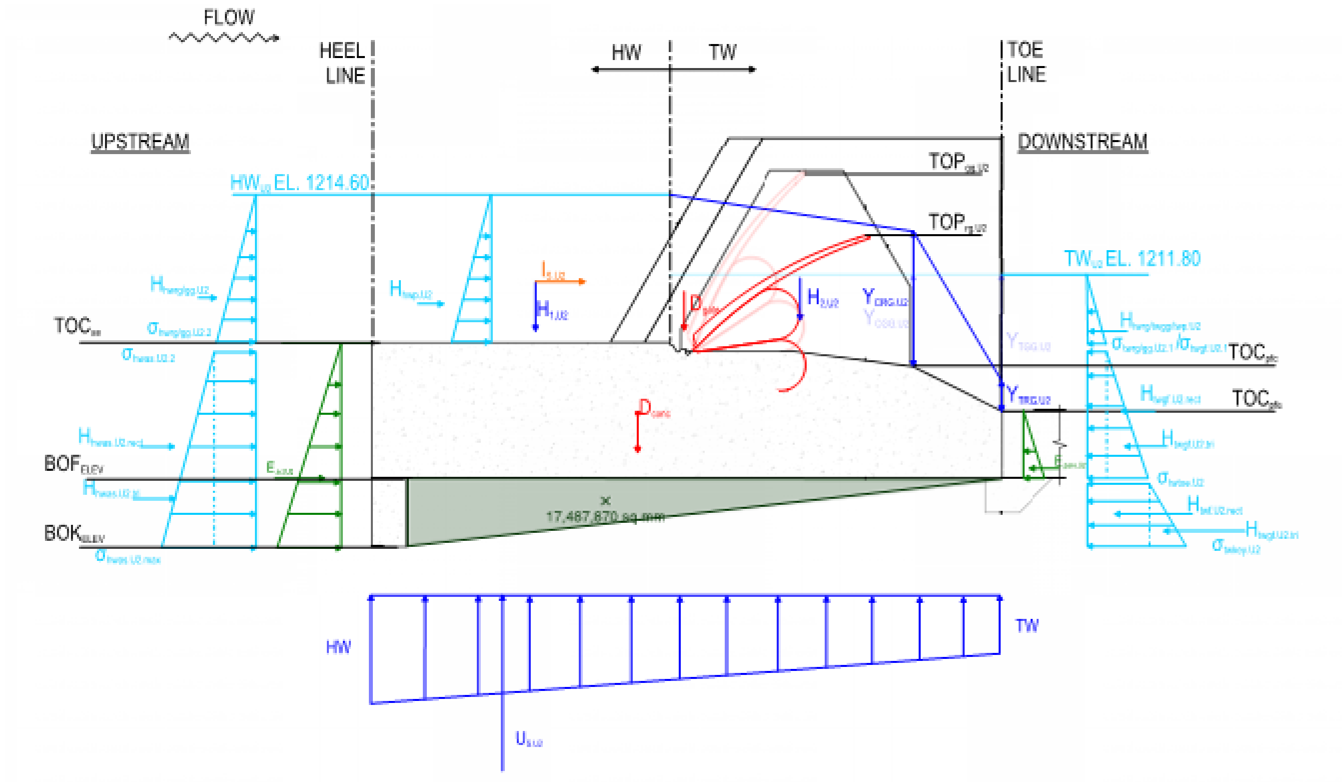
$$\sigma_{HeelU1.OT} := \frac{\Sigma V_{U1.OT}}{L_b \cdot W_b} - \frac{\left(\Sigma V_{U1.OT} \cdot x_{OT.U1}\right)}{S_b} = 62.4 \cdot kPa$$

$$Bearing_{CheckheelU1.OT} := \left(\begin{cases} \text{"OKAY"} & \text{if } \sigma_{HeelU1.OT} < \sigma_{allow.U1} \wedge \sigma_{HeelU1.OT} > 0 \\ \text{"NG"} & \text{otherwise} \end{cases} \right) = \text{"OKAY"}$$

SUMMARY OF STABILITY ASSESSMENT:

Sliding Factor of Safety: (Horizontal Plane)	$FS_{HorizSliding.U1} = 2.74$	$FS_{HorizSliding.U1.Check} = \text{"OKAY"}$
Sliding Factor of Safety: (Inclined Plane)	$FS_{InclinedlSlidingU1} = 40.34$	$FS_{InclinedSliding.check.U1} = \text{"OKAY"}$
Eccentricity: (Inclined Plane)	$e_{U1} = -0.26\,m$	$e_{check.U1} = \text{"Okay"}$
Bearing Pressure At Heel: (Inclined Plane)	$\sigma_{heel.U1} = 78 \cdot kPa$	$\sigma_{heel.U1.check} = \text{"Okay"}$
Bearing Pressure At Toe: (Inclined Plane)	$\sigma_{toe.U1} = 66 \cdot kPa$	$\sigma_{toe.U1.1.check} = \text{"Okay"}$
Flotation Factor of Safety (horizontal plane)	$FS_{act.FU1} = 1.75$	$FS_{check.FU1} = \text{"OKAY"}$
Overturning Resultant Ratio: (horizontal plane)	$Ratio_{OT.U1} = 0.49$	$Ratio_{OT.U1.check} = \text{"OKAY"}$
Eccentricity: (horizontal plane)	$x_{OT.U1} = -0.11\,m$	$x_{OT.check.U1} = \text{"OKAY"}$
Bearing Pressure At Heel: (horizontal plane)	$\sigma_{HeelU1.OT} = 62 \cdot kPa$	$Bearing_{CheckheelU1.OT} = \text{"OKAY"}$
Bearing Pressure At Toe: (horizontal plane)	$\sigma_{ToeU1.OT} = 58 \cdot kPa$	$Bearing_{ChecktoeU1.OT} = \text{"OKAY"}$

U2 DESIGN CASE



ACCEPTANCE PARAMETERS

Required Factor of Safety for Sliding: $FS_{req.U2.sl} := 1.5$ (Without Cohesion) (Section 8.1, Design Criteria)

Resultant Within Middle Third of Base: $e \le \frac{L_b}{6} \wedge e \ge \frac{-L_b}{6}$

Allowable Rock Bearing Pressure: $\sigma_{allow.U2} := 1270 \cdot \frac{kN}{m^2}$ (Section 5.2, Design Criteria)

INPUT PARAMETERS

Headwater Elevation: $HW_{U2} := 1214.60m$ (Section 8.3, Design Criteria)

Tailwater Elevation: $TW_{U2} := 1211.80m$ (Section 8.3, Design Criteria)

Bottom of Footing Elevation: $BOF_{elev} = 1206.00\,m$

Approach Slab Top of Concrete Elevation at Upstream Face: $TOC_{as} = 1210.00\,m$

Pier Footing Top of Concrete Elevation at Stilling Basin: $TOC_{pfe} = 1208.00\,m$

Pier Footing Top of Concrete Elevation at Center of Footing: $TOC_{pfc} = 1209.30\,m$

Top of Guard/ Regulating Gate Elevation: $TOP_{rg.U2} := 1212.10m$ $TOP_{gg.U2} := 1215.00m$

Bottom of Key Elevation: $BOK_{elev} = 1204\,m$

Gates are open when top of gate elevation is at 1210.00m

Gates are closed/up when top of gate elevation is at 1215.0m

Crestwater Elevation (Right) Guard Gate: $EL_{CGG.U2} := 1213.76m$

$$Y_{C.gg.U2} := \begin{cases} (EL_{CGG.U2} - TOC_{pfc}) & \text{if } TOP_{gg.U2} \le HW_{U2} \\ (TW_{U2} - TOC_{pfc}) & \text{if } TOP_{gg.U2} > HW_{U2} \end{cases} = 2.5 \cdot m$$

Toewater Elevation (Right) Guard Gate: $EL_{TGG.U2} := 1211.8m$

$$Y_{TOE.gg.U2} := \begin{cases} (EL_{TGG.U2} - TOC_{pfe}) & \text{if } TOP_{gg.U2} \le HW_{U2} \\ (TW_{U2} - TOC_{pfe}) & \text{if } TOP_{gg.U2} > HW_{U2} \end{cases} = 3.8 \cdot m$$

Crestwater Elevation Regulating (Left) Gate: $EL_{CRG.U2} := 1213.76m$

$$Y_{C.rg.U2} := \begin{cases} (EL_{CRG.U2} - TOC_{pfc}) & \text{if } TOP_{rg.U2} \le HW_{U2} \\ (TW_{U2} - TOC_{pfc}) & \text{if } TOP_{rg.U2} > HW_{U2} \end{cases} = 4.46 \cdot m$$

Toewater Elevation Regulating (Left) Gate: $EL_{TRG.U2} := 1208.58m$

$$Y_{TOE.rg.U2} := \begin{cases} (EL_{TRG.U2} - TOC_{pfe}) & \text{if } TOP_{rg.U2} \le HW_{U2} \\ (TW_{U2} - TOC_{pfe}) & \text{if } TOP_{rg.U2} > HW_{U2} \end{cases} = 0.58 \cdot m$$

LATERAL WATER LOADS

HEADWATER (DRIVING):

Headwater Depth on Pier: $D_{hwp.U2} := HW_{U2} - TOC_{as} = 4.60\,m$

Headwater Load Unit Width on Pier: $W_{hwp.U2} := w_p = 2.00\,m$

Total Horizontal Headwater Load on Pier:

$$H_{hwp.U2} := \frac{-\left(\gamma_w \cdot D_{hwp.U2}^{\;2}\right)}{2} \cdot W_{hwp.U2} = -207.6 \cdot kN$$

Apply Total Pier Headwater Load at:

$$H_{hwp.U2.loc} := \frac{D_{hwp.U2}}{3} + \left(TOC_{as} - BOF_{elev}\right) = 5.53\,m$$

Headwater Depth on Gate Base: $D_{hwg.U2} := HW_{U2} - TOC_{as} = 4.60\,m$

Thickness of Approach Slab (Including Key): $T_{as} = 6\,m$

Headwater Depth at Heel (U/S face): $D_{hwas.U2} := HW_{U2} - BOK_{elev} = 10.60\,m$

Headwater Load Unit Width on Approach Slab: $W_{hwas.U2} := W_b = 12.00\,m$

Headwater Unit Load At Top of Approach Slab:

$$H_{hwas.U2.1} := \frac{-\left(\gamma_w \cdot D_{hwg.U2}^{\;2}\right)}{2} \cdot W_{hwas.U2} = -1245.48 \cdot kN$$

Headwater Unit Load At Bottom of Approach Key:

$$H_{hwas.U2.2} := \frac{-\left(\gamma_w \cdot D_{hwas.U2}^{\;2}\right)}{2} \cdot W_{hwas.U2} = -6613.5 \cdot kN$$

Headwater Line Load At Top of Approach Slab:

$$\sigma_{hwas.U2.1} := -\left(\gamma_w \cdot D_{hwg.U2}\right) = -45.13 \cdot kPa$$

Headwater Line Load At Bottom of Approach Key:

$$\sigma_{hwas.U2.2} := -\left(\gamma_w \cdot D_{hwas.U2}\right) = -103.99 \cdot kPa$$

Triangular Distribution Unit Load on Approach Slab and Key:

$$H_{hwas.U2.2.tri} := \left(\frac{\sigma_{hwas.U2.2} - \sigma_{hwas.U2.1}}{2}\right) \cdot \left(T_{as} \cdot W_{hwas.U2}\right) = -2118.96 \cdot kN$$

Rectangular Distribution Unit Load on Approach Slab and Key:

$$H_{hwas.U2.2.rect} := \sigma_{hwas.U2.1} \cdot \left(T_{as} \cdot W_{hwas.U2}\right) = -3249.07 \cdot kN$$

Total Horizontal Headwater Load on Approach Slab:

$$H_{hwas.U2} := H_{hwas.U2.2.tri} + H_{hwas.U2.2.rect} = -5368.03 \cdot kN$$

Apply Total Footing Headwater Load at:

$$H_{hwas.U2.loc} := \frac{\left[H_{hwas.U2.2.rect} \cdot \frac{(T_{as})}{2} + H_{hwas.U2.2.tri} \cdot \frac{(T_{as})}{3}\right]}{H_{hwas.U2.2.tri} + H_{hwas.U2.2.rect}} - d_{key} = 0.61\,m$$

LATERAL WATER LOADS (continued)

Regulating Gate (2A) Operating Condition:

Regulating Crest Gate Down/Open Condition: $A1_{U2} := TOP_{rg.U2} \le TOC_{as}$

Regulating Crest Gate Up/Closed, with Top of Gate Higher than HW Elevation: $B1_{U2} := TOP_{rg.U2} \ge HW_{U2} \wedge TOP_{rg.U2} > TOC_{as}$

Regulating Crest Gate Up/Closed, with Top of Gate Lower than HW Elevation: $C1_{U2} := TOP_{rg.U2} > TOC_{as} \wedge HW_{U2} > TOP_{rg.U2}$

Regulating Crest Gate Height: $H_{rg.U2} := TOP_{rg.U2} - TOC_{as} = 2.1\ m$

Headwater Depth at Regulating Crest Gate: $D_{hwrg.U2} := HW_{U2} - TOC_{as} = 4.60\,m$

Regulating Crest Gate Width: $W_{hwrg.U2} := 5.00m$

Lateral Headwater Pressure at Bottom of Regulating Crest Gate:

$$\sigma_{hwrg.U2.1} := \begin{cases} (0.0kPa) & \text{if } A1_{U2} \\ -(\gamma_w \cdot D_{hwrg.U2}) & \text{if } B1_{U2} \\ -(\gamma_w \cdot D_{hwrg.U2}) & \text{if } C1_{U2} \end{cases} = -45.1 \cdot kPa$$

Lateral Headwater Pressure at Top of Regulating Crest Gate: (Load at HW Elevation On Regulating Crest Gate if HW is below TOG_{rg})

$$\sigma_{hwrg.U2.2} := \begin{cases} (0.0kPa) & \text{if } A1_{U2} \\ 0.0kPa & \text{if } B1_{U2} \\ -\left[\gamma_w \cdot (HW_{U2} - TOP_{rg.U2})\right] & \text{if } C1_{U2} \end{cases} = -24.5 \cdot kPa$$

Average Pressure acting on Regulating Gate:

$$\sigma_{hwrg.U2.avg} := \frac{(\sigma_{hwrg.U2.1} + \sigma_{hwrg.U2.2})}{2} = -34.83 \cdot kPa$$

Total Area water acting on Regulating Crest Gate:

$$A_{hwrg.U2} := \begin{cases} D_{hwrg.U2} \cdot W_{hwrg.U2} & \text{if } A1_{U2} \\ D_{hwrg.U2} \cdot W_{hwrg.U2} & \text{if } B1_{U2} \\ H_{rg.U2} \cdot W_{hwrg.U2} & \text{if } C1_{U2} \end{cases} = 10.5 \cdot m^2$$

Total Horizontal Headwater Load on Regulating Crest Gate: $H_{hwrg.U2} := \sigma_{hwrg.U2.avg} \cdot A_{hwrg.U2} = -365.7 \cdot kN$

Apply Total Regulating Crest Gate Headwater Load at:

$$H_{hwrg.U2.loc} := \begin{cases} (TOC_{as} - BOF_{elev}) & \text{if } A1_{U2} \\ \left[\frac{(HW_{U2} - TOC_{as})}{3} + (TOC_{as} - BOF_{elev})\right] & \text{if } B1_{U2} \\ \left[\frac{\sigma_{hwrg.U2.2} \cdot A_{hwrg.U2} \cdot \frac{(H_{rg.U2})}{2} + \frac{(\sigma_{hwrg.U2.1} - \sigma_{hwrg.U2.2})}{2} \cdot A_{hwrg.U2} \cdot \frac{(H_{rg.U2})}{3}}{\sigma_{hwrg.U2.2} \cdot A_{hwrg.U2} + \frac{(\sigma_{hwrg.U2.1} - \sigma_{hwrg.U2.2})}{2} \cdot A_{hwrg.U2}} \ldots \\ + (TOC_{as} - BOF_{elev})\right] & \text{if } C1_{U2} \end{cases} = 4.9 \cdot m$$

Guard Gate (4A) Operating Condition:

Guard Gate Down/Open Condition: $A2_{U2} := TOP_{gg.U2} \le TOC_{as}$

Guard Crest Gate Up/Closed, with Top of Gate Higher than HW Elevation: $B2_{U2} := TOP_{gg.U2} \ge HW_{U2} \wedge TOP_{gg.U2} > TOC_{as}$

Guard Crest Gate Up/Closed, with Top of Gate Lower than HW Elevation: $C2_{U2} := TOP_{gg.U2} > TOC_{as} \wedge HW_{U2} > TOP_{gg.U2}$

Guard Crest Gate Height: $H_{gg.U2} := TOP_{gg.U2} - TOC_{as} = 5\,m$

Headwater Depth at Guard Crest Gate: $D_{hwgg.U2} := HW_{U2} - TOC_{as} = 4.60\,m$

Guard Crest Gate Width: $W_{hwgg.U2} := 5.00m$

Lateral Headwater Pressure at Bottom of Guard Crest Gate:

$$\sigma_{hwgg.U2.1} := \begin{cases} (0.0kPa) & \text{if } A2_{U2} \\ -(\gamma_w \cdot D_{hwgg.U2}) & \text{if } B2_{U2} \\ -(\gamma_w \cdot D_{hwgg.U2}) & \text{if } C2_{U2} \end{cases} = -45.1 \cdot kPa$$

Lateral Headwater Pressure at Top of Guard Crest Gate: (Load at HW Elevation On Guard Crest Gate if HW is below TOG_{rg})

$$\sigma_{hwgg.U2.2} := \begin{cases} (0.0kPa) & \text{if } A2_{U2} \\ 0.0kPa & \text{if } B2_{U2} \\ -\left[\gamma_w \cdot (HW_{U2} - TOP_{gg.U2})\right] & \text{if } C2_{U2} \end{cases} = 0.0 \cdot kPa$$

Average Pressure acting on Guard Crest Gate:

$$\sigma_{hwgg.U2.avg} := \frac{(\sigma_{hwgg.U2.1} + \sigma_{hwgg.U2.2})}{2} = -22.56 \cdot kPa$$

Total Area water acting on Crest Gate:

$$A_{hwgg.U2} := \begin{cases} D_{hwgg.U2} \cdot W_{hwgg.U2} & \text{if } A2_{U2} \\ D_{hwgg.U2} \cdot W_{hwgg.U2} & \text{if } B2_{U2} \\ H_{gg.U2} \cdot W_{hwgg.U2} & \text{if } C2_{U2} \end{cases} = 23 \cdot m^2$$

Total Horizontal Headwater Load on Guard Crest Gate: $H_{hwgg.U2} := \sigma_{hwgg.U2.avg} \cdot A_{hwgg.U2} = -518.9 \cdot kN$

Apply Total Guard Crest Gate Headwater Load at:

$$H_{hwgg.U2.loc} := \begin{cases} (TOC_{as} - BOF_{elev}) & \text{if } A2_{U2} \\ \left[\frac{(HW_{U2} - TOC_{as})}{3} + (TOC_{as} - BOF_{elev})\right] & \text{if } B2_{U2} \\ \left[\frac{\sigma_{hwgg.U2.2} \cdot A_{hwgg.U2} \cdot \frac{(H_{gg.U2})}{2} + \frac{(\sigma_{hwgg.U2.1} - \sigma_{hwgg.U2.2})}{2} A_{hwgg.U2} \cdot \frac{(H_{gg.U2})}{3}}{\sigma_{hwgg.U2.2} \cdot A_{hwgg.U2} + \frac{(\sigma_{hwgg.U2.1} - \sigma_{hwgg.U2.2})}{2} \cdot A_{hwgg.U2}} \ldots \\ + (TOC_{as} - BOF_{elev})\right] & \text{if } C2_{U2} \end{cases} = 5.5 \cdot m$$

LATERAL TAILWATER (RESISTING) Applied to Downstream Side of Regulating Crest Gate:

Regulating Crest Gate Down/Open Condition: $A3_{U2} := TOP_{rg.U2} \le TOC_{as}$

Regulating Crest Gate Up/Closed, with Top of Gate Higher than TW Elevation: $B3_{U2} := TOP_{rg.U2} \ge TW_{U2} \wedge TOP_{rg.U2} > TOC_{as}$

Regulating Crest Gate Up/Closed, with Top of Gate Lower than TW Elevation: $C3_{U2} := TOP_{rg.U2} > TOC_{as} \wedge TW_{U2} > TOP_{rg.U2}$

Regulating Crest Gate Height: $H_{rg.U2} = 2.1\ m$

Tailwater Depth at Regulating Crest Gate: $D_{twrg.U2} := TW_{U2} - TOC_{as} = 1.80\,m$

Regulating Crest Gate Width: $W_{twrg.U2} := 5m$

Lateral Tailwater Pressure at Bottom of Regulating Crest Gate:

$$\sigma_{twrg.U2.1} := \begin{cases} (0.0kPa) & \text{if } A3_{U2} \\ -(\gamma_w \cdot D_{twrg.U2}) & \text{if } B3_{U2} \\ -(\gamma_w \cdot D_{twrg.U2}) & \text{if } C3_{U2} \end{cases} = -17.7 \cdot kPa$$

Lateral Tailwater Pressure at Top of Regulating Crest Gate: (Load at TW Elevation On Regulating Crest Gate if TW is below TOG_{rg})

$$\sigma_{twrg.U2.2} := \begin{cases} (0.0kPa) & \text{if } A3_{U2} \\ 0.0kPa & \text{if } B3_{U2} \\ -\left[\gamma_w \cdot (TW_{U2} - TOP_{rg.U2})\right] & \text{if } C3_{U2} \end{cases} = 0.0 \cdot kPa$$

Average Pressure acting on Regulating Gate:

$$\sigma_{twrg.U2.avg} := \frac{(\sigma_{twrg.U2.1} + \sigma_{twrg.U2.2})}{2} = -8.83 \cdot kPa$$

Total Area water acting on Regulating Crest Gate:

$$A_{twrg.U2} := \begin{cases} D_{twrg.U2} \cdot W_{twrg.U2} & \text{if } A3_{U2} \\ D_{twrg.U2} \cdot W_{twrg.U2} & \text{if } B3_{U2} \\ H_{rg.U2} \cdot W_{twrg.U2} & \text{if } C3_{U2} \end{cases} = 9 \cdot m^2$$

Total Horizontal Tailwater Load on Regulating Crest Gate: $H_{twrg.U2} := \sigma_{hwrg.U2.avg} \cdot A_{hwrg.U2} = -365.7 \cdot kN$

Apply Total Regulating Crest Gate Tailwater Load at:

$$H_{twrg.U2.loc} := \begin{cases} (TOC_{as} - BOF_{elev}) & \text{if } A3_{U2} \\ \left[\frac{(HW_{U2} - TOC_{as})}{3} + (TOC_{as} - BOF_{elev})\right] & \text{if } B3_{U2} \\ \left[\frac{\sigma_{hwrg.U2.2} \cdot A_{hwrg.U2} \cdot \frac{(H_{rg.U2})}{2} + \frac{(\sigma_{hwrg.U2.1} - \sigma_{hwrg.U2.2})}{2} A_{hwrg.U2} \cdot \frac{(H_{rg.U2})}{3}}{\sigma_{hwrg.U2.2} \cdot A_{hwrg.U2} + \frac{(\sigma_{hwrg.U2.1} - \sigma_{hwrg.U2.2})}{2} \cdot A_{hwrg.U2}} \ldots \\ + (TOC_{as} - BOF_{elev})\right] & \text{if } C3_{U2} \end{cases} = 5.5 \cdot m$$

LATERAL TAILWATER (RESISTING) Applied to Downstream Side of Guard Crest Gate:

U2 CASE

Guard Gate Down/Open Condition: $A4_{U2} := TOP_{gg.U2} \le TOC_{as}$

Guard Crest Gate Up/Closed, with Top of Gate Higher than TW Elevation: $B4_{U2} := TOP_{gg.U2} \ge TW_{U2} \wedge TOP_{gg.U2} > TOC_{as}$

Guard Crest Gate Up/Closed, with Top of Gate Lower than TW Elevation: $C4_{U2} := TOP_{gg.U2} > TOC_{as} \wedge TW_{U2} > TOP_{gg.U2}$

Tailwater Depth at Guard Crest Gate: $D_{twgg.U2} := TW_{U2} - TOC_{as} = 1.80\,m$

Guard Crest Gate Height: $H_{gg.U2} = 5\,m$

Guard Crest Gate Width: $W_{twgg.U2} := 5.00m$

Lateral Water Load at Bottom of Guard Crest Gate:

$$\sigma_{twgg.U2.1} := \begin{cases} (0.0kPa) & \text{if } A4_{U2} \\ (\gamma_w \cdot D_{twgg.U2}) & \text{if } B4_{U2} \\ (\gamma_w \cdot D_{twgg.U2}) & \text{if } C4_{U2} \end{cases} = 17.7 \cdot kPa$$

Lateral Water Load at Top of Guard Crest Gate:
(Load at TW Elevation On Guard Crest Gate if TW is below TOG_{gg})

$$\sigma_{twgg.U2.2} := \begin{cases} (0.0kPa) & \text{if } A4_{U2} \\ 0.0kPa & \text{if } B4_{U2} \\ \left[\gamma_w \cdot \left(TW_{U2} - TOP_{gg.U2}\right)\right] & \text{if } C4_{U2} \end{cases} = 0.0 \cdot kPa$$

Average Pressure acting on Guard Crest Gate:

$$\sigma_{twgg.U2.avg} := \frac{\left(\sigma_{twgg.U2.1} + \sigma_{twgg.U2.2}\right)}{2} = 8.83 \cdot kPa$$

Total Area water acting on Crest Gate:

$$A_{twgg.U2} := \begin{cases} D_{twgg.U2} \cdot W_{twgg.U2} & \text{if } A4_{U2} \\ D_{twgg.U2} \cdot W_{twgg.U2} & \text{if } B4_{U2} \\ H_{gg.U2} \cdot W_{twgg.U2} & \text{if } C4_{U2} \end{cases} = 9 \cdot m^2$$

Total Horizontal Tailwater Load on Guard Crest Gate:

$$H_{twgg.U2} := \sigma_{twgg.U2.avg} \cdot A_{twgg.U2} = 79.5 \cdot kN$$

Apply Total Horiz. TW Load on Guard Gate at:

$$H_{twgg.U2.loc} := \begin{cases} \left(TOC_{as} - BOF_{elev}\right) & \text{if } A4_{U2} \\ \left[\frac{\left(TW_{U2} - TOC_{as}\right)}{3} + \left(TOC_{as} - BOF_{elev}\right)\right] & \text{if } B4_{U2} \\ \left[\frac{\sigma_{twgg.U2.2} \cdot A_{twgg.U2} \cdot \frac{\left(H_{gg.U2}\right)}{2} + \frac{\left(\sigma_{twgg.U2.1} - \sigma_{twgg.U2.2}\right)}{2} A_{twgg.U2} \cdot \frac{\left(H_{gg.U2}\right)}{3}}{\sigma_{twgg.U2.2} \cdot A_{twgg.U2} + \frac{\left(\sigma_{twgg.U2.1} - \sigma_{twgg.U2.2}\right)}{2} \cdot A_{twgg.U2}} \ldots \\ + \left(TOC_{as} - BOF_{elev}\right) \right] & \text{if } C4_{U2} \end{cases} = 4.6 \cdot m$$

LATERAL WATER LOADS (continued)

U2 CASE

TAILWATER (RESISTING) Applied to Concrete Structure:

Tailwater Depth on Pier: $D_{twp.U2} := TW_{U2} - TOC_{as} = 1.80\,m$

Tailwater Load Unit Width on Pier: $W_{twp.U2} := w_p = 2.00\,m$

Total Horizontal Tailwater Load on Pier: $H_{twp.U2} := \dfrac{\left(\gamma_w \cdot D_{twp.U2}^{\,2}\right)}{2} \cdot W_{twp.U2} = 31.8 \cdot kN$

Apply Total Pier Tailwater Load at: $H_{twp.U2.loc} := \dfrac{D_{twp.U2}}{3} + \left(TOC_{as} - BOF_{elev}\right) = 4.60\,m$

Tailwater Depth At top of Gate Base Footing Elevation: $D_{twgf.U2} := TW_{U2} - TOC_{as} = 1.80\,m$

Water Depth at bottom of Gate Base Footing (Excluding Key): $D_{twtoe.U2} := TW_{U2} - BOF_{elev} = 5.80\,m$

Footing Thickness for horizontal at Toe: $h_{toe} = 4\,m$

Unit Width of D/S face of crest for application of Tailwater Load: $W_{tw.U2} := W_b = 12.00\,m$

Tailwater Pressure At Top of Gate Footing: $\sigma_{twgf.U2} := \left(\gamma_w \cdot D_{twgf.U2}\right) = 17.66 \cdot kPa$

Tailwater Pressure At Toe: $\sigma_{twtoe.U2} := \left(\gamma_w \cdot D_{twtoe.U2}\right) = 56.9 \cdot kPa$

Triangular Distribution Unit Load on Gate Footing Base: $H_{twgf.U2.tri} := \left(\dfrac{\sigma_{twtoe.U2} - \sigma_{twgf.U2}}{2}\right) \cdot \left[\left(T_{as} - d_{key}\right) \cdot W_{tw.U2}\right] = 941.76 \cdot kN$

Rectangular Distribution Unit Load on Gate Footing Base: $H_{twgf.U2.rect} := \sigma_{twgf.U2} \cdot \left[\left(T_{as} - d_{key}\right) \cdot W_{tw.U2}\right] = 847.58 \cdot kN$

Tailwater Pressure At Bottom of Sliding Failure Plane: $\sigma_{twbk.U2} := \left(HW_{U2} - BOK_{elev}\right) \cdot \gamma_w = 103.99 \cdot kPa$

Triangular Distribution Unit Load Below Footing: $H_{twbk.U2.tri} := \dfrac{\left(\sigma_{twbk.U2} - \sigma_{twtoe.U2}\right)}{2} \cdot d_{key} \cdot W_{tw.U2} = 565.06 \cdot kN$

Rectangular Distribution Load Below Footing Base: $H_{twbk.U2.rect} := \sigma_{twtoe.U2} \cdot d_{key} \cdot W_{tw.U2} = 1365.55 \cdot kN$

Total Horizontal Tailwater Headwater Load on Gate Footing (including key): $H_{twgk.U2} := H_{twgf.U2.tri} + H_{twgf.U2.rect} \cdots + H_{twbk.U2.tri} + H_{twbk.U2.rect} = 3719.95 \cdot kN$

Apply Total Gate Footing Tailwater Load at:

$$H_{twgk.U2.loc} := \frac{\left[H_{twgf.U2.rect} \cdot \dfrac{\left(h_{toe}\right)}{2} + H_{twgf.U2.tri} \cdot \dfrac{\left(h_{toe}\right)}{3} + H_{twbk.U2.tri} \cdot \left(-d_{key} \cdot \dfrac{2}{3}\right) + H_{twbk.U2.rect} \cdot \left(\dfrac{-d_{key}}{2}\right)\right]}{H_{twgf.U2.tri} + H_{twgf.U2.rect} + H_{twbk.U2.tri} + H_{twbk.U2.rect}} = 0.22\,m$$

SUMMATION OF LATERAL WATER LOADS:

$$\Sigma H_{Water.U2} := H_{hwp.U2} + H_{hwas.U2} + H_{hwrg.U2} + H_{hwgg.U2} + H_{twp.U2} + H_{twgk.U2} + H_{twrg.U2} + H_{twgg.U2} = -2994.7 \cdot kN$$

$$\Sigma M_{Hwater.U2} := H_{hwp.U2} \cdot H_{hwp.U2.loc} + H_{hwas.U2} \cdot H_{hwas.U2.loc} + H_{hwrg.U2} \cdot H_{hwrg.U2.loc} + H_{hwgg.U2} \cdot H_{hwgg.U2.loc} \cdots + H_{twp.U2} \cdot H_{twp.U2.loc} + H_{twgk.U2} \cdot H_{twgk.U2.loc} + H_{twrg.U2} \cdot H_{twrg.U2.loc} + H_{twgg.U2} \cdot H_{twgg.U2.loc} = -9757.71 \cdot kN \cdot m$$

VERTICAL WATER LOADS

U2 CASE

HEADWATER:

Water Depth on top of Approach Slab: $d_{hw.U2} := HW_{U2} - TOC_{as} = 4.60\,m$

Length of Approach Slab: $L_{as} = 8.75\,m$

Width of Approach Slab: $w_{as} = 12.00\,m$

Length from front of Gate to Heel: $L_{hg} = 8.75\,m$

Vertical Water Weight (H1) on Approach Slab:

$$H_{1.U2} := \left[w_{as} \cdot d_{hw.U2} \cdot L_{hg} - w_p \cdot d_{hw.U2} \cdot \left(L_{hg} - L_{as}\right)\right] \cdot \gamma_w = 4738.2 \cdot kN$$

Moment Arm for Application of Water Weight (H1) from toe:

$$H_{1.U2.loc} := L_b - \frac{L_{hg}}{2} = 14.13\,m$$

TAILWATER ABOVE GUARD GATE:

Trapezoid Volume Above Gate Footing from Approach Slab to Crest:

$$V_{asc.gg.U2} := \left(L_{gf} - L_{gfc}\right) W_{twgg.U2} \frac{d_{hw.U2} + Y_{C.gg.U2}}{2} = 126.91 \cdot m^3$$

Trapezoid Volume Above Gate Footing Crest to End of Gate Footing:

$$V_{gfc.gg.U2} := \left(L_{gfc} \cdot W_{twgg.U2}\right) \frac{Y_{C.gg.U2} + Y_{TOE.gg.U2}}{2} = 40.95 \cdot m^3$$

Load Above Gate Footing from Approach Slab to Crest:

$$H_{2.U2.asc.gg} := V_{asc.gg.U2} \cdot \gamma_w = 1245.01 \cdot kN$$

Load Acting Above Footing Crest from Toe:

$$H_{2.U2.asc.gg.loc} := \frac{\left(L_{gf} - L_{gfc}\right) \cdot \left(2 \cdot d_{hw.U2} + Y_{C.gg.U2}\right)}{3 \cdot \left(d_{hw.U2} + Y_{C.gg.U2}\right)} + L_{gfc} = 6.53\,m$$

Load Above Gate Footing from Crest to End:

$$H_{2.U2.gfc.gg} := V_{gfc.gg.U2} \cdot \gamma_w = 401.72 \cdot kN$$

Load Acting Above Gate Footing from Crest to End:

$$H_{2.U2.gfc.gg.loc} := \frac{\left(L_{gfc}\right) \cdot \left(2 \cdot Y_{C.gg.U2} + Y_{TOE.gg.U2}\right)}{3 \cdot \left(Y_{C.gg.U2} + Y_{TOE.gg.U2}\right)} = 1.21\,m$$

Vertical Water Weight (H2) on Guard Gate Footing:

$$H_{2.U2.gg} := H_{2.U2.asc.gg} + H_{2.U2.gfc.gg} = 1646.73 \cdot kN$$

Moment Arm for Application of Water Weight (H2) from toe:

$$H_{2.U2.gg.loc} := \frac{H_{2.U2.asc.gg} \cdot H_{2.U2.asc.gg.loc} \cdots + H_{2.U2.gfc.gg} \cdot H_{2.U2.gfc.gg.loc}}{H_{2.U2.gg}} = 5.23\,m$$

TAILWATER ABOVE REGULATING GATE:

Trapezoid Volume Above Gate Footing from Approach Slab to Crest:

$$V_{asc.rg.U2} := \left(L_{gf} - L_{gfc}\right) W_{twrg.U2} \frac{d_{hw.U2} + Y_{C.rg.U2}}{2} = 161.95 \cdot m^3$$

Trapezoid Volume Above Gate Footing Crest to End of Gate Footing:

$$V_{gfc.rg.U2} := \left(L_{gfc} \cdot W_{twrg.U2}\right) \frac{Y_{C.rg.U2} + Y_{TOE.rg.U2}}{2} = 32.76 \cdot m^3$$

Load Above Gate Footing from Approach Slab to Crest:

$$H_{2.U2.asc.rg} := V_{asc.rg.U2} \cdot \gamma_w = 1588.7 \cdot kN$$

Load Acting Above Footing Crest from Toe:

$$H_{2.U2.asc.rg.loc} := \frac{\left(L_{gf} - L_{gfc}\right) \cdot \left(2 \cdot d_{hw.U2} + Y_{C.rg.U2}\right)}{3 \cdot \left(d_{hw.U2} + Y_{C.rg.U2}\right)} + L_{gfc} = 6.19\,m$$

Load Above Gate Footing from Crest to End:

$$H_{2.U2.gfc.rg} := V_{gfc.rg.U2} \cdot \gamma_w = 321.38 \cdot kN$$

Load Acting Above Gate Footing from Crest to End:

$$H_{2.U2.gfc.rg.loc} := \frac{\left(L_{gfc}\right) \cdot \left(2 \cdot Y_{C.rg.U2} + Y_{TOE.rg.U2}\right)}{3 \cdot \left(Y_{C.rg.U2} + Y_{TOE.rg.U2}\right)} = 1.63\,m$$

Vertical Water Weight (H2) on Regulating Gate Footing:

$$H_{2.U2.rg} := H_{2.U2.asc.rg} + H_{2.U2.gfc.rg} = 1910.08 \cdot kN$$

Moment Arm for Application of Water Weight (H2) from toe:

$$H_{2.U2.rg.loc} := \frac{H_{2.U2.asc.rg} \cdot H_{2.U2.asc.rg.loc} \cdots + H_{2.U2.gfc.rg} \cdot H_{2.U2.gfc.rg.loc}}{H_{2.U2.rg}} = 5.43\,m$$

UPLIFT **U2 CASE**

Uplift pressure at U/S Face (heel): $U_{HW.U2} := (D_{hwas.U2}) \cdot \gamma_w = 104.0 \cdot \frac{kN}{m^2}$

Uplift pressure at D/S Face Stilling Basin: $U_{TW.U2} := (D_{twtoe.U2}) \cdot \gamma_w = 56.9 \cdot \frac{kN}{m^2}$

Length from U/S of Gate Structure to U/S of Stilling Basin: $L_{overall.Usual} = 18.50\,m$

Difference between Uplift pressure at HW and TW: $U_{diff.U2} := U_{HW.U2} - U_{TW.U2} = 47.09 \cdot \frac{kN}{m^2}$

Slope of difference between between Uplift pressure at HW and TW: $U_{slope.U2} := \frac{U_{diff.U2}}{L_{overall.Usual}} = 2.55 \cdot \frac{kN}{m^2 \cdot m}$

Tailwater Pressure at toe of Gate Structure: $U_{press.toe.gs.U2} := U_{TW.U2} + (L_{overall.Usual} - L_b) \cdot U_{slope.U2} = 56.9 \cdot \frac{kN}{m^2}$

Uniform uplift force UA Under Gate Structure due to TW (rectangle): $U_{A.U2} := U_{press.toe.gs.U2} \cdot L_b \cdot W_b \cdot -1 = -12631.36 \cdot kN$

Moment Arm from Toe of Gate Structure for Uplift UA: $L_{A.U2} := \left(\frac{L_b}{2}\right) = 9.25\,m$

Linearly Decreasing Uplift Force U2B Under Gate Structure due to HW-TW Differential (triangle): $U_{B.U2} := \frac{1}{2} \cdot (U_{HW.U2} - U_{press.toe.gs.U2}) \cdot L_b \cdot W_b \cdot -1 = -5226.77 \cdot kN$

Moment Arm from Toe of Gate Structure for Uplift UB: $L_{B.U2} := \frac{2}{3} \cdot L_b = 12.33\,m$

Total Resultant Uplift force: $U_{U2} := U_{A.U2} + U_{B.U2} = -17858.12 \cdot kN$

Resultant Location from Toe: $U_{U2.loc} := \frac{(U_{A.U2} \cdot L_{A.U2} + U_{B.U2} \cdot L_{B.U2})}{(U_{A.U2} + U_{B.U2})} = 10.15\,m$

$\Sigma V_{water.U2} := H_{1.U2} + H_{2.U2.gg} + H_{2.U2.rg} + U_{U2} = -9563.08 \cdot kN$

$\Sigma M_{Vwater.U2} := H_{1.U2} \cdot H_{1.U2.loc} + H_{2.U2.gg} \cdot H_{2.U2.gg.loc} + H_{2.U2.rg} \cdot H_{2.U2.rg.loc} + U_{U2} \cdot U_{U2.loc} = -95398.43 \cdot kN \cdot m$

SOIL LOADS

U2 CASE

Equivalent Fluid Pressure (EFP):

At rest lateral pressure coefficient: $K_{o.U2} := 1 - \sin(\phi_{backfill}) = 0.658$ (Section 5.3, Design Criteria)

Headwater Pier Footing Unit Width: $W_{hwas.U2} = 12.00\,m$

Tailwater Pier Footing Unit Width: $W_{tw.U2} = 12.00\,m$

Pier Footing Thickness at Heel: $t_{hf.U2} := TOC_{as} - BOK_{elev} = 6.00\,m$

Fixed Crest Footing Thickness at Toe: $t_{tf.U2} := TOC_{pfe} - BOF_{elev} = 2.00\,m$

Lateral Driving Force (Headwater Side - at rest condition)

Structure Soil Load: $E_{act.U2} := \frac{K_{o.U2} \cdot t_{hf.U2}^{2}}{2} \cdot (\gamma_r - \gamma_w) \cdot W_{hwas.U2} \cdot -1 = -1732.49 \cdot kN$

Acting at: $E_{act.U2.loc} := \frac{t_{hf.U2}}{3} - d_{key} = 0.00\,m$

Lateral Resisting Force (Tailwater Side - at rest condition)

At-rest Soil Load: $E_{pass.U2} := \frac{K_{o.U2} \cdot t_{tf.U2}^{2}}{2} \cdot (\gamma_r - \gamma_w) \cdot W_{tw.U2} = 192.5 \cdot kN$

Acting at: $E_{pass.U2.loc} := \frac{t_{tf.U2}}{3} = 0.67\,m$

$\Sigma H_{soil.U2} := E_{act.U2} + E_{pass.U2} = -1539.99 \cdot kN$

$\Sigma M_{soil.U2} := E_{act.U2} \cdot E_{act.U2.loc} + E_{pass.U2} \cdot E_{pass.U2.loc} = 128.33 \cdot kN \cdot m$

ICE / IMPACT LOADS (ASSUME NO ICE LOADING ON TAILWATER SIDE)

Static Ice Loading on Structure: $I_{S.U2} := 150.0 \frac{kN}{m}$

Ice Loading Unit Width on Structure: $W_{S.U2} := 2.00m$ (Section 7.7, Design Criteria)

Static Ice load on Gates: (Section 7.7, Design Criteria)

$$I_{rg.U2} := \begin{cases} 0 \frac{kN}{m} & \text{if } TOP_{rg.U2} \le TOC_{as} \\ 75 \frac{kN}{m} & \text{if } TOP_{rg.U2} > TOC_{as} \end{cases} = 75 \cdot \frac{kN}{m} \qquad I_{gg.U2} := \begin{cases} 0 \frac{kN}{m} & \text{if } TOP_{gg.U2} \le TOC_{as} \\ 75 \frac{kN}{m} & \text{if } TOP_{gg.U2} > TOC_{as} \end{cases} = 75 \cdot \frac{kN}{m}$$

Ice Loading Unit Width on Crest Gates: $W_{rg.U2} := 5m$ $W_{gg.U2} := 5m$ (Input value for load case)

Total Ice Load on Structure: $I_{U2} := (I_{S.U2} \cdot W_{S.U2} + I_{rg.U2} \cdot W_{rg.U2} + I_{gg.U2} \cdot W_{gg.U2}) \cdot -1 = -1050 \cdot kN$

Apply Ice load at: $I_{U2.loc} := (HW_{U2} - BOF_{elev} - 0.30m) = 8.30\,m$

$\Sigma H_{I.U2} := I_{U2} = -1050 \cdot kN$

$\Sigma M_{I.U2} := I_{U2} \cdot I_{U2.loc} = -8715 \cdot kN \cdot m$

SEISMIC LOAD (NOT APPLICABLE FOR THIS LOAD CASE)

U2 CASE

SUMMARY OF LOADS	Loads	Moment Arm
Dead load of Concrete Structure:	$D_{conc} = 22438.7 \cdot kN$	$X_{conc.loc} = 9.35\,m$
Obermyer Gate Weight:	$D_{Gate} = 140.0 \cdot kN$	$X_{gate} = 9.50\,m$
HW Lateral Load on Pier:	$H_{hwp.U2} = -207.6 \cdot kN$	$H_{hwp.U2.loc} = 5.53\,m$
HW Lateral Load on Approach Slab:	$H_{hwas.U2} = -5368.0 \cdot kN$	$H_{hwas.U2.loc} = 0.61\,m$
HW Lateral Load on Regulating Gate:	$H_{hwrg.U2} = -365.7 \cdot kN$	$H_{hwrg.U2.loc} = 4.95\,m$
HW Lateral Load on Guard Gate:	$H_{hwgg.U2} = -518.9 \cdot kN$	$H_{hwgg.U2.loc} = 5.53\,m$
TW Lateral Load on Pier:	$H_{twp.U2} = 31.8 \cdot kN$	$H_{twp.U2.loc} = 4.60\,m$
TW Lateral Load on Pier Footing (including Key):	$H_{twgk.U2} = 3719.95 \cdot kN$	$H_{twgk.U2.loc} = 0.22\,m$
TW Lateral Load on Regulating Gate:	$H_{twrg.U2} = -365.7 \cdot kN$	$H_{twrg.U2.loc} = 5.53\,m$
TW Lateral Load on Guard Gate:	$H_{twgg.U2} = 79.5 \cdot kN$	$H_{twgg.U2.loc} = 4.60\,m$
Vertical HW Load on Approach Slab:	$H_{1.U2} = 4738.2 \cdot kN$	$H_{1.U2.loc} = 14.13\,m$
Vertical TW Load on Regulating Gate:	$H_{2.U2.rg} = 1910.1 \cdot kN$	$H_{2.U2.rg.loc} = 5.43\,m$
Vertical TW Load on Guard Gate:	$H_{2.U2.gg} = 1646.7 \cdot kN$	$H_{2.U2.gg.loc} = 5.23\,m$
Uplift:	$U_{U2} = -17858.1 \cdot kN$	$U_{U2.loc} = 10.15\,m$
Lateral Soil Load (driving):	$E_{act.U2} = -1732.5 \cdot kN$	$E_{act.U2.loc} = 0.00\,m$
Lateral Soil Load (resisting):	$E_{pass.U2} = 192.5 \cdot kN$	$E_{pass.U2.loc} = 0.67\,m$
Ice / Impact Load:	$I_{U2} = -1050.0 \cdot kN$	$I_{U2.loc} = 8.30\,m$

STABILITY ASSESSMENT (SLIDNG, BEARING, FLOTATION AND OVERTURNING): U2 CASE

CHECK SLIDING ALONG HORIZONTAL PLANE THRU TOE, IGNORING BEDROCK MOBILIZED BY STRUCTURAL HEEL KEY, OR VOID BEHIND KEY

Sum of Vertical Forces:

$\Sigma V_{U2} := \Sigma V_{DL} + \Sigma V_{water.U2} = 13015.7 \cdot kN$

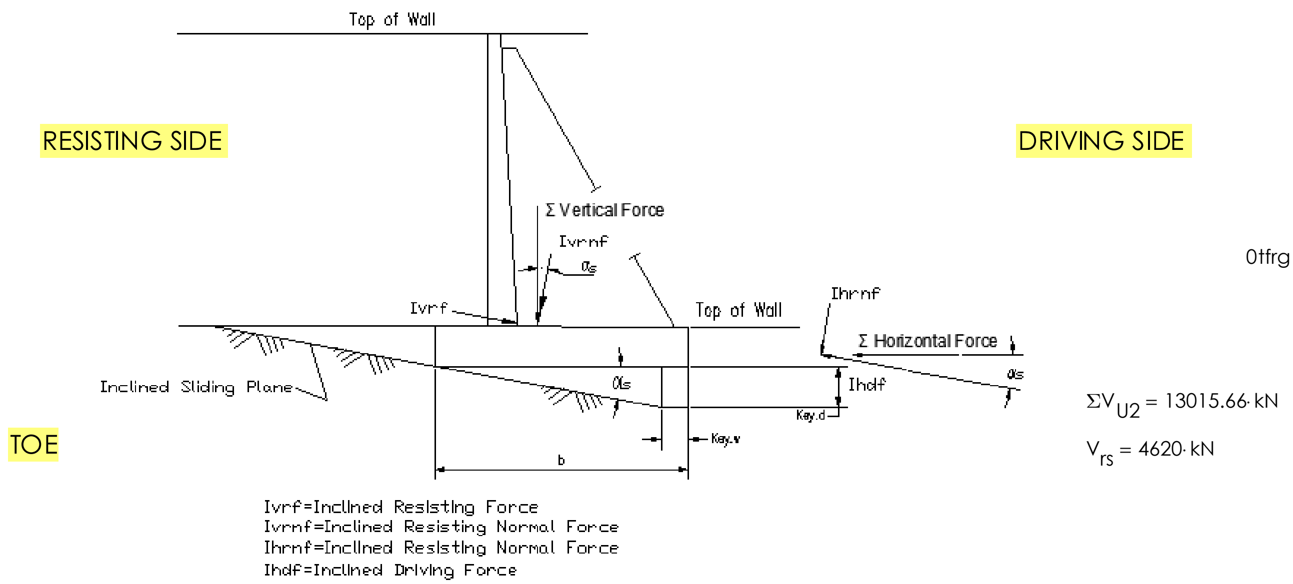
Sum of Horizontal Forces:

$\Sigma H_{U2} := \Sigma H_{Water.U2} + \Sigma H_{soil.U2} + \Sigma H_{I.U2} = -5584.69 \cdot kN$

Sliding Factor of Safety: $FS_{HorizSliding.U2} := \dfrac{\tan_{\phi} \cdot \Sigma V_{U2}}{|\Sigma H_{U2}|} = 1.14$

$FS_{HorizSliding.U2.Check} :=$ | "OKAY" if $FS_{HorizSliding.U2} \geq FS_{req.U2.sl}$; "Check Inclined Sliding with Key" otherwise = "Check Inclined Sliding with Key"

CHECK SLIDING ALONG INCLINED SLIDING PLANE FROM HEEL KEY TO TOE, WITH BEDROCK MASS MOBILIZED BY REINFOCREDE CONCRETE KEY)



$\Sigma V_{U2} = 13015.66 \cdot kN$

$V_{rs} = 4620 \cdot kN$

$\alpha s = 0.11$

as degrees= $\alpha s \cdot \left(\dfrac{180}{\pi}\right) = 6.52$

Resolve $\Sigma Vert_{U2}$ & $\Sigma Horiz_{U2}$

$\Sigma V_{InclinedU2} := \cos(\alpha s) \cdot (\Sigma V_{U2} + V_{rs}) + \sin(\alpha s) \cdot |\Sigma H_{U2}| = 18155.7 \cdot kN$

$\Sigma H_{InclinedU2} := \cos(\alpha s) \cdot |\Sigma H_{U2}| - \sin(\alpha s) \cdot (\Sigma V_{U2} + V_{rs}) = 3546.1 \cdot kN$

(With properly engineered reinforced concrete Key, horizontal sliding plane thru Toe is protected, critical sliding plane is relocated to the INCLINED SLIDING PLANE FROM HEEL KEY To TOE, Bedrock Mass above this examining plane is mobilized by reinforced concrete key and combined into Structural Wedge.)

Inclined Sliding Plane Length

$L_{incline} = 18.61\ m$

Safety Factor for Sliding Inclined Failure Plane

$FS_{InclinedlSlidingU2} := \dfrac{\Sigma V_{InclinedU2} \cdot \tan\left(\phi_{rock} \cdot \dfrac{\pi}{180}\right)}{|\Sigma H_{InclinedU2}|} = 2.50$

$FS_{InclinedSliding.check.U2} :=$ | "OKAY " if $FS_{InclinedlSlidingU2} > FS_{req.U2.sl}$; "Revise Structure"" otherwise = "OKAY "

$FS_{InclinedSliding.check.U2}$ = "OKAY "

U2 CASE

OVERTURNING STABILITY CHECK:

CHECK ECCENTRICITY

Sum of the moments:

$$\Sigma M_{U2} := \Sigma M_{DL} + \Sigma M_{Hwater.U2} + \Sigma M_{Vwater.U2} + \Sigma M_{I.U2} + \Sigma M_{soil.U2} + \Sigma M_{rs} = 151277 \cdot kN \cdot m$$

Eccentricity:

$$e_{U2} := \left(\frac{L_{incline}}{2}\right) - \frac{(\Sigma M_{U2})}{\Sigma V_{InclinedU2}} = 0.97\,m$$

Eccentricity Check:

$$e_{check.U2} := \begin{cases} \text{"Okay"} & \text{if } e_{U2} \le Kern \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$e_{check.U2} = \text{"Okay"}$

Foundation Bearing Checks:

Bearing Pressure at Heel:

$$\sigma_{heel.U2} := \frac{\Sigma V_{InclinedU2}}{A_{b.incline}} - \frac{(\Sigma V_{InclinedU2} \cdot e_{U2})}{S_{b.incline}} = 55.8 \cdot \frac{kN}{m^2}$$

$$\sigma_{heel.U2.check} := \left(\begin{cases} \text{"Okay"} & \text{if } \sigma_{heel.U2} \le \sigma_{allow.U2} \\ \text{"Revise Structure"} & \text{if } \sigma_{heel.U2} < 0\,\frac{kN}{m^2} \end{cases} \right)$$

$\sigma_{heel.U2.check} = \text{"Okay"}$

Bearing Pressure at Toe:

$$\sigma_{toe.U2} := \frac{\Sigma V_{U2}}{A_{b.incline}} + \frac{(\Sigma V_{U2} \cdot e_{U2})}{S_{b.incline}} = 76.6 \cdot \frac{kN}{m^2}$$

$$\sigma_{toe.U2.1.check} := \begin{cases} \text{"Okay"} & \text{if } \sigma_{toe.U2} \le \sigma_{allow.U2} \\ \text{"Revise Structure"} & \text{if } \sigma_{toe.U2} < 0\,\frac{kN}{m^2} \end{cases}$$

$\sigma_{toe.U2.1.check} = \text{"Okay"}$

FLOATATION ANALYSIS:

ACCEPTANCE PARAMETERS

Required Factor of Safety: $FS_{req.FU2} := 1.5$

VERTICAL LOADS RESISTING:

Dead Load: $\Sigma V_{DL} = 22578.74 \cdot kN$

Water Weight H1+H2: $\Sigma V_{H.FU2} := H_{1.U2} + H_{2.U2.gg} + H_{2.U2.rg} = 8295.04 \cdot kN$

Summation Vertical Resisting: $\Sigma V_{FU2} := \Sigma V_{DL} + \Sigma V_{H.FU2} = 30873.8 \cdot kN$

VERTICAL LOADS UPLIFT:

Uplift: $U_{U2} = -17858.12 \cdot kN$

Factor of Safety Floatation:

$$FS_{act.FU2} := \frac{\Sigma V_{FU2}}{|U_{U2}|} = 1.73$$

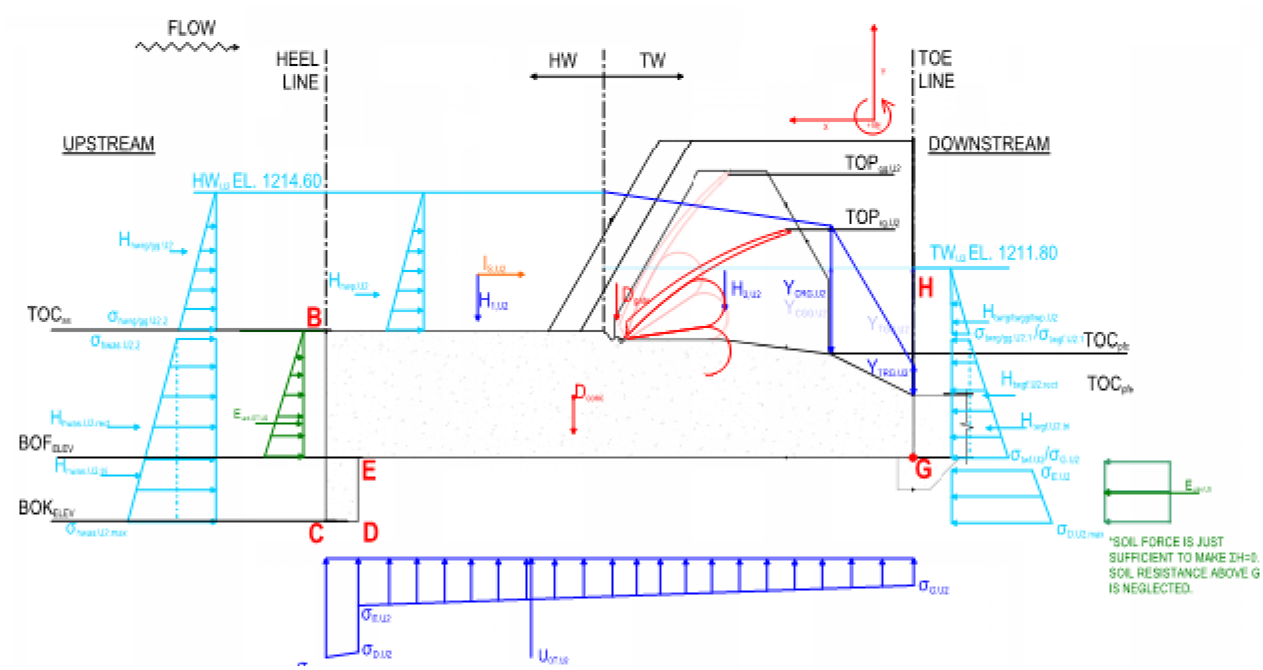
$$FS_{check.FU2} := \begin{cases} \text{"OKAY"} & \text{if } FS_{act.FU2} \ge FS_{req.FU2} \\ \text{"ANCHORS REQUIRED"} & \text{if } FS_{act.FU2} < FS_{req.FU2} \end{cases} = \text{"OKAY"}$$

MONOLITH OVERTURNING STABILITY ANALYSIS

U2 CASE

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.
Assumptions are made in order to compute overturning stability of indetermine forces on monolith with key;
(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.
(b) The horizontal resisting force acting on the key, P.key, is that required for static equilibrium
(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1 $Ratio_{OT.U2.min} := 0.33$ at Rock Foundation



Uplift Loads for Overturning Stability Analysis

Line of Creep:

Change in Water Head: $\Delta_{h.U2} := HW_{U2} - TW_{U2} = 2.8\,m$

Length from Point C to Point G: $L_{CG} = 18.61\,m$

Length from Various Points to Points: $L_{CD} = 1\,m$ $L_{DE} = 2\,m$ $L_{EG} = 17.5\,m$

$L_{GH.U2} := TW_{U2} - BOF_{elev} = 5.8\,m$

Length from Point C, D, E to G: $L_{CDEG} = 20.5\,m$ $L_{CDE} = 3\,m$

Water Pressure at Point C & G: $\sigma_{C.U2} := \sigma_{hwas.U2.2} = -103.99 \cdot kPa$ $\sigma_{G.U2} := \sigma_{twtoe.U2} \cdot -1 = -56.9 \cdot kPa$

Water Pressure at Point D:

$$\sigma_{D.U2} := -\gamma_w \cdot \left[\left(HW_{U2} - BOK_{elev}\right) - \frac{\Delta_{h.U2} \cdot L_{CD}}{L_{CDEG}}\right] = -102.65 \cdot kPa$$

Water Pressure at Point E:

$$\sigma_{E.U2} := -\gamma_w \cdot \left[\left(HW_{U2} - BOF_{elev}\right) - \frac{\Delta_{h.U2} \cdot L_{CDE}}{L_{CDEG}}\right] = -80.35 \cdot kPa$$

Uplift for Overturning Analysis on Bottom of Key:

$$U_{OT.U2.key} := \frac{\sigma_{C.U2} + \sigma_{D.U2}}{2} \cdot L_{CD} \cdot W_b = -1239.79 \cdot kN$$

Acting at:

$$U_{OT.U2.key.loc} := \frac{L_{CD} \cdot \left(2 \cdot \sigma_{C.U2} + \sigma_{D.U2}\right)}{3\left(\sigma_{C.U2} + \sigma_{D.U2}\right)} + L_{EG} = 18\,m$$

Uplift for Overturning Analysis on Bottom of Footing:

$$U_{OT.U2.ftg} := \frac{\sigma_{E.U2} + \sigma_{G.U2}}{2} \cdot L_{EG} \cdot W_b = -14410.65 \cdot kN$$

Acting at:

$$U_{OT.U2.ftg.loc} := \frac{L_{EG} \cdot \left(\sigma_{G.U2} + 2 \cdot \sigma_{E.U2}\right)}{3\left(\sigma_{G.U2} + \sigma_{E.U2}\right)} = 9.25\,m$$

U2 CASE

Uplift Load for Overturning Analysis: $U_{OT.U2} := U_{OT.U2.key} + U_{OT.U2.ftg} = -15650.44 \cdot kN$

Uplift Load Acting from Toe: $U_{OT.U2.loc} := \dfrac{U_{OT.U2.key} \cdot U_{OT.U2.key.loc} + U_{OT.U2.ftg} \cdot U_{OT.U2.ftg.loc}}{U_{OT.U2}} = 9.94\,m$

<u>All Vertical Loads Applicable to Overturning Stability Analysis</u>

Total Concrete Dead Loads:	$D_{conc} = 22438.74 \cdot kN$	at:	$X_{conc.loc} = 9.35\,m$
Dead Load of Gate:	$D_{Gate} = 140.0 \cdot kN$		$X_{gate} = 9.50\,m$
Water Weight (HW) on Apron Slab:	$H_{1.U2} = 4738.2 \cdot kN$		$H_{1.U2.loc} = 14.13\,m$
Water Weight (TW) on Gate Footing:	$H_{2.U2.rg} = 1910.1 \cdot kN$		$H_{2.U2.rg.loc} = 5.43\,m$
Water Weight (TW) on Regulating Gate Footing:	$H_{2.U2.gg} = 1646.7 \cdot kN$		$H_{2.U2.gg.loc} = 5.23\,m$
Uplift Load for Overturning Analysis:	$U_{OT.U2} = -15650.44 \cdot kN$		$U_{OT.U2.loc} = 9.94 \cdot m$

Sum of All Overturning Analysis Vertical Load:

$$\Sigma V_{U2.OT} := D_{conc} + D_{Gate} + H_{1.U2} + H_{2.U2.rg} + H_{2.U2.gg} + U_{OT.U2} = 15223.34 \cdot kN$$

Sum of All Overturning Analysis Vertical Load Moments:

$$\Sigma M_{V.U2.OT} := D_{conc} \cdot X_{conc.loc} + D_{Gate} \cdot X_{gate} + H_{1.U2} \cdot H_{1.U2.loc} + H_{2.U2.rg} \cdot H_{2.U2.rg.loc} \ldots = 141433.2 \cdot kN \cdot m$$
$$+ H_{2.U2.gg} \cdot H_{2.U2.gg.loc} + U_{OT.U2} \cdot U_{OT.U2.loc}$$

<u>Lateral Tailwater Loads for Overturning Stability Analysis</u>

TW Lateral Load on Gate Footing (No Key - Overturning Values Adjusted): $H_{twgf.U2} := H_{twgf.U2.tri} + H_{twgf.U2.rect} = 1789.34 \cdot kN$

Acting at: $H_{twgf.U2.loc} := \dfrac{\frac{h_{toe}}{3} \cdot H_{twgf.U2.tri} + \frac{h_{toe}}{2} \cdot H_{twgf.U2.rect}}{H_{twgf.U2}} = 1.65\,m$

Horizontal Tailwater Pressure Top of Key (Overturning Analysis): $\sigma_{twtk.OT.U2} := \sigma_{E.U2} \cdot -1 = 80.35 \cdot kPa$

Horizontal Tailwater Pressure Bottom of Key (Overturning Analysis): $\sigma_{twbk.OT.U2} := \sigma_{D.U2} \cdot -1 = 102.65 \cdot kPa$

Triangular Distribution Unit Load Acting at Key: $H_{twbk.OT.U2.tri} := \dfrac{(\sigma_{twbk.OT.U2} - \sigma_{twtk.OT.U2})}{2} \cdot d_{key} \cdot W_{tw.U2} = 267.6 \cdot kN$

Triangular Distribution Unit Load Acting at Key: $H_{twbk.OT.U2.rect} := \sigma_{twtk.OT.U2} \cdot d_{key} \cdot W_{tw.U2} = 1928.31 \cdot kN$

Total Horizontal Tailwater Load on Key (Overturning Values Adjusted): $H_{twkey.OT.U2} := H_{twbk.OT.U2.tri} + H_{twbk.OT.U2.rect} = 2195.91 \cdot kN$

Acting at: $H_{twkey.OT.U2.loc} := \dfrac{H_{twbk.OT.U2.tri} \cdot \frac{-2 \cdot d_{key}}{3} + H_{twbk.OT.U2.rect} \cdot \frac{-d_{key}}{2}}{H_{twkey.OT.U2}} = -1.04\,m$

<u>Lateral Driving Earth Loads for Overturning Stability Analysis (at rest condition)</u>

Depth of Driving Soil Loads (to top of key): $h_{E.OT.U2} := TOC_{as} - BOF_{elev} = 4\,m$

At-Rest Soil Load: $E_{act.OT.U2} := \dfrac{\left(K_{o.U2} \cdot h_{E.OT.U2}^{\;2}\right)}{2} \cdot (\gamma_r - \gamma_w) \cdot W_{hwas.U2} \cdot -1 = -769.99 \cdot kN$

At Rest- Soil Load Acting from Toe: $E_{act.OT.U2.loc} := \dfrac{h_{E.OT.U2}}{3} = 1.33\,m$

U2 CASE

All Lateral Loads Applicable to Overturning Stability Analysis

HW Lateral Load on Approach Slab:	$H_{hwas.U2} = -5368.0 \cdot kN$	$H_{hwas.U2.loc} = 0.61\,m$
HW Lateral Load on Regulating Gate:	$H_{hwrg.U2} = -365.7 \cdot kN$	$H_{hwrg.U2.loc} = 4.95\,m$
HW Lateral Load on Guard Gate:	$H_{hwgg.U2} = -518.9 \cdot kN$	$H_{hwgg.U2.loc} = 5.53\,m$
TW Lateral Load on Regulating Gate:	$H_{twrg.U2} = -365.7 \cdot kN$	$H_{twrg.U2.loc} = 5.53\,m$
HW Lateral Load on Guard Gate:	$H_{twgg.U2} = 79.5 \cdot kN$	$H_{twgg.U2.loc} = 4.60\,m$
TW Lateral Load on Gate Footing (No Key - Overturning Values Adjusted):	$H_{twgf.U2} = 1789.34 \cdot kN$	$H_{twgf.U2.loc} = 1.65\,m$
TW Lateral Load on Key:	$H_{twkey.OT.U2} = 2195.91 \cdot kN$	$H_{twkey.OT.U2.loc} = -1.04\,m$
Ice / Impact Load:	$I_{U2} = -1050.0 \cdot kN$	$I_{U2.loc} = 8.30\,m$
Lateral Soil Load (driving):	$E_{act.OT.U2} = -770.0 \cdot kN$	$E_{act.OT.U2.loc} = 1.33\,m$

Resisting Lateral Soil Load as required to produce horizontal equilibrium:

$$E_{pas.OT.U2} := -\left(H_{hwas.U2} + H_{hwrg.U2} + H_{hwgg.U2} + H_{twrg.U2} + H_{twgg.U2} \cdots + H_{twgf.U2} + H_{twkey.OT.U2} + I_{U2} + E_{act.OT.U2}\right) = 4373.6 \cdot kN$$

$$E_{pas.OT.U2.loc} := -1 \cdot \frac{d_{key}}{2} = -1\,m$$

Sum of All Overturning Analysis Horizontal Load (ΣH=0):

$$\Sigma H_{U2.OT} := H_{hwas.U2} + H_{hwrg.U2} + H_{hwgg.U2} + H_{twrg.U2} + H_{twgg.U2} + H_{twgf.U2} + H_{twkey.OT.U2} + I_{U2} + E_{act.OT.U2} + E_{pas.OT.U2} = 0 \cdot kN$$

Sum of All Overturning Analysis Horizontal Load Moments:

$$\Sigma M_{H.U2.OT} := H_{hwas.U2} \cdot H_{hwas.U2.loc} + H_{hwrg.U2} \cdot H_{hwrg.U2.loc} + H_{hwgg.U2} \cdot H_{hwgg.U2.loc} \cdots + H_{twrg.U2} \cdot H_{twrg.U2.loc} + H_{twgg.U2} \cdot H_{twgg.U2.loc} + H_{twgf.U2} \cdot H_{twgf.U2.loc} \cdots + H_{twkey.OT.U2} \cdot H_{twkey.OT.U2.loc} + I_{U2} \cdot I_{U2.loc} + E_{act.OT.U2} \cdot E_{act.OT.U2.loc} + E_{pas.OT.U2} \cdot E_{pas.OT.U2.loc} = -23036.71 \cdot kN \cdot m$$

Overturning Stability Analysis

$$\Sigma M_{U2.OT} := \Sigma M_{V.U2.OT} + \Sigma M_{H.U2.OT} = 118396.49 \cdot kN \cdot m$$

$$X_{R.U2} := \frac{\Sigma M_{U2.OT}}{\Sigma V_{U2.OT}} = 7.78\,m \qquad x_{OT.U2} := X_{R.U2} - \frac{L_b}{2} = -1.47\,m$$

Overturning Resultant Ratio

$$Ratio_{OT.U2} := \frac{X_{R.U2}}{L_b} = 0.42$$

$$Ratio_{OT.U2.check} := \begin{cases} \text{"OKAY"} & \text{if } Ratio_{OT.U2} \ge Ratio_{OT.U2.min} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

$$x_{OT.check.U2} := \begin{cases} \text{"OKAY"} & \text{if } \left|x_{OT.U2}\right| \le Kern \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

CHECK FOUNDATION BEARING CAPACITY (HORIZONTAL PLANE):

U2 CASE

Bearing Pressure Under Toe:

$$\sigma_{ToeU2.OT} := \frac{\Sigma V_{U2.OT}}{L_b \cdot W_b} + \frac{\left(\Sigma V_{U2.OT} \cdot x_{OT.U2}\right)}{S_b} = 35.8 \cdot kPa$$

$$Bearing_{ChecktoeU2.OT} := \begin{vmatrix} \text{"OKAY "} & \text{if } \sigma_{ToeU2.OT} < \sigma_{allow.U2} \\ \text{"NG""} & \text{otherwise} \end{vmatrix} = \text{"OKAY "}$$

Bearing Pressure Under Heel:

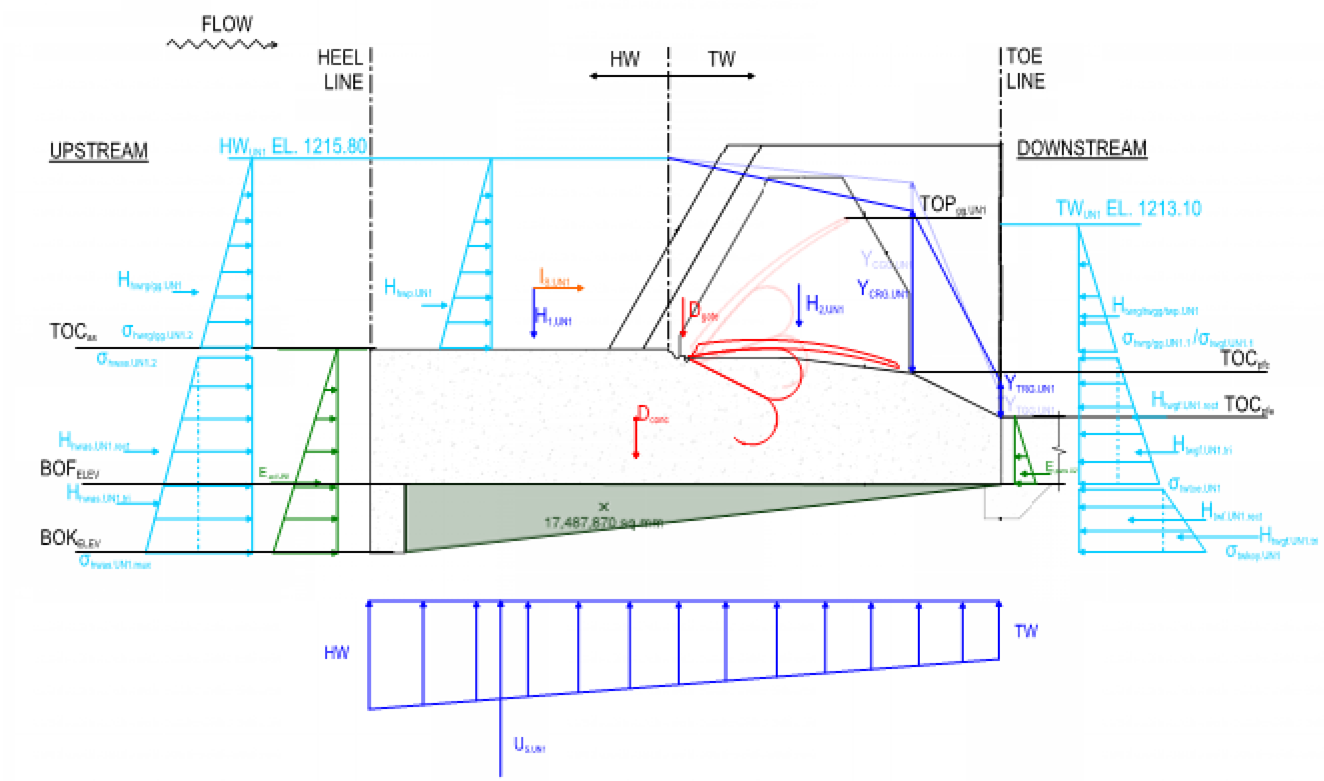
$$\sigma_{HeelU2.OT} := \frac{\Sigma V_{U2.OT}}{L_b \cdot W_b} - \frac{\left(\Sigma V_{U2.OT} \cdot x_{OT.U2}\right)}{S_b} = 101.3 \cdot kPa$$

$$Bearing_{CheckheelU2.OT} := \left(\begin{vmatrix} \text{"OKAY "} & \text{if } \sigma_{HeelU2.OT} < \sigma_{allow.U2} \wedge \sigma_{HeelU2.OT} > 0 \\ \text{"NG""} & \text{otherwise} \end{vmatrix} \right) = \text{"OKAY "}$$

SUMMARY OF STABILITY ASSESSMENT:

Sliding Factor of Safety: (Horizontal Plane)	$FS_{HorizSliding.U2} = 1.14$	$FS_{HorizSliding.U2.Check}$ = "Check Inclined Sliding with Key"
Sliding Factor of Safety: (Inclined Plane)	$FS_{InclinedlSlidingU2} = 2.5$	$FS_{InclinedSliding.check.U2}$ = "OKAY "
Eccentricity: (Inclined Plane)	$e_{U2} = 0.97\,m$	$e_{check.U2}$ = "Okay"
Bearing Pressure At Heel: (Inclined Plane)	$\sigma_{heel.U2} = 56 \cdot kPa$	$\sigma_{heel.U2.check}$ = "Okay"
Bearing Pressure At Toe: (Inclined Plane)	$\sigma_{toe.U2} = 77 \cdot kPa$	$\sigma_{toe.U2.1.check}$ = "Okay"
Flotation Factor of Safety (horizontal plane)	$FS_{act.FU2} = 1.73$	$FS_{check.FU2}$ = "OKAY"
Overturning Resultant Ratio: (horizontal plane)	$Ratio_{OT.U2} = 0.42$	$Ratio_{OT.U2.check}$ = "OKAY"
Eccentricity: (horizontal plane)	$x_{OT.U2} = -1.47\,m$	$x_{OT.check.U2}$ = "OKAY"
Bearing Pressure At Heel: (horizontal plane)	$\sigma_{HeelU2.OT} = 101 \cdot kPa$	$Bearing_{CheckheelU2.OT}$ = "OKAY "
Bearing Pressure At Toe: (horizontal plane)	$\sigma_{ToeU2.OT} = 36 \cdot kPa$	$Bearing_{ChecktoeU2.OT}$ = "OKAY "

UN1 DESIGN CASE



ACCEPTANCE PARAMETERS

Required Factor of Safety for Sliding: $FS_{req.UN1.sl} := 1.3$ (Without Cohesion)

(Section 8.1, Design Criteria)

Resultant Within Middle Third of Base: $e \le \frac{L_b}{6} \wedge e \ge \frac{-L_b}{6}$

Allowable Rock Bearing Pressure: $\sigma_{allow.UN1} := 1470 \cdot \frac{kN}{m^2}$ (Section 5.2, Design Criteria)

INPUT PARAMETERS

Headwater Elevation: $HW_{UN1} := 1215.80m$ (Section 8.3, Design Criteria)

Tailwater Elevation: $TW_{UN1} := 1213.10m$ (Section 8.3, Design Criteria)

Bottom of Footing Elevation: $BOF_{elev} = 1206.00\,m$

Approach Slab Top of Concrete Elevation at Upstream Face: $TOC_{as} = 1210.00\,m$

Pier Footing Top of Concrete Elevation at Stilling Basin: $TOC_{pfe} = 1208.00\,m$

Pier Footing Top of Concrete Elevation at Center of Footing: $TOC_{pfc} = 1209.30\,m$

Top of Guard/ Regulating Gate Elevation: $TOP_{rg.UN1} := 1210.00m$ $TOP_{gg.UN1} := 1213.50m$

Gates are open when top of gate elevation is at 1210.00m

Gates are closed/up when top of gate elevation is at 1215.0m

Bottom of Key Elevation: $BOK_{elev} = 1204\,m$

Crestwater Elevation (Right) Guard Gate: $EL_{CGG.UN1} := 1215.03m$

$$Y_{C.gg.UN1} := \begin{cases} (EL_{CGG.UN1} - TOC_{pfc}) & \text{if } TOP_{gg.UN1} \le HW_{UN1} \\ (TW_{UN1} - TOC_{pfc}) & \text{if } TOP_{gg.UN1} > HW_{UN1} \end{cases} = 5.73 \cdot m$$

Toewater Elevation (Right) Guard Gate: $EL_{TGG.UN1} := 1208.48m$

$$Y_{TOE.gg.UN1} := \begin{cases} (EL_{TGG.UN1} - TOC_{pfe}) & \text{if } TOP_{gg.UN1} \le HW_{UN1} \\ (TW_{UN1} - TOC_{pfe}) & \text{if } TOP_{gg.UN1} > HW_{UN1} \end{cases} = 0.48 \cdot m$$

Crestwater Elevation (Left) Regulating Gate: $EL_{CRG.UN1} := 1213.87m$

$$Y_{C.rg.UN1} := \begin{cases} (EL_{CRG.UN1} - TOC_{pfc}) & \text{if } TOP_{rg.UN1} \le HW_{UN1} \\ (TW_{UN1} - TOC_{pfc}) & \text{if } TOP_{rg.UN1} > HW_{UN1} \end{cases} = 4.57 \cdot m$$

Toewater Elevation (Left) Regulating Gate: $EL_{TRG.UN1} := 1209.95m$

$$Y_{TOE.rg.UN1} := \begin{cases} (EL_{TRG.UN1} - TOC_{pfe}) & \text{if } TOP_{rg.UN1} \le HW_{UN1} \\ (TW_{UN1} - TOC_{pfe}) & \text{if } TOP_{rg.UN1} > HW_{UN1} \end{cases} = 1.95 \cdot m$$

LATERAL WATER LOADS

HEADWATER (DRIVING):

Headwater Depth on Pier: $D_{hwp.UN1} := HW_{UN1} - TOC_{as} = 5.80\,m$

Headwater Load Unit Width on Pier: $W_{hwp.UN1} := w_p = 2.00\,m$

Total Horizontal Headwater Load on Pier:

$$H_{hwp.UN1} := \frac{-\left(\gamma_w \cdot D_{hwp.UN1}^{\;2}\right)}{2} \cdot W_{hwp.UN1} = -330.0 \cdot kN$$

Apply Total Pier Headwater Load at:

$$H_{hwp.UN1.loc} := \frac{D_{hwp.UN1}}{3} + \left(TOC_{as} - BOF_{elev}\right) = 5.93\,m$$

Headwater Depth on Gate Base: $D_{hwg.UN1} := HW_{UN1} - TOC_{as} = 5.80\,m$

Thickness of Approach Slab (Including Key): $T_{as} = 6\,m$

Headwater Depth at Heel (U/S face): $D_{hwas.UN1} := HW_{UN1} - BOK_{elev} = 11.80\,m$

Headwater Load Unit Width on Approach Slab: $W_{hwas.UN1} := W_b = 12.00\,m$

Headwater Unit Load At Top of Approach Slab:

$$H_{hwas.UN1.1} := \frac{-\left(\gamma_w \cdot D_{hwg.UN1}^{\;2}\right)}{2} \cdot W_{hwas.UN1} = -1980.05 \cdot kN$$

Headwater Unit Load At Bottom of Approach Key:

$$H_{hwas.UN1.2} := \frac{-\left(\gamma_w \cdot D_{hwas.UN1}^{\;2}\right)}{2} \cdot W_{hwas.UN1} = -8195.7 \cdot kN$$

Headwater Line Load At Top of Approach Slab: $\sigma_{hwas.UN1.1} := -\left(\gamma_w \cdot D_{hwg.UN1}\right) = -56.9 \cdot kPa$

Headwater Line Load At Bottom of Approach Key: $\sigma_{hwas.UN1.2} := -\left(\gamma_w \cdot D_{hwas.UN1}\right) = -115.76 \cdot kPa$

Triangular Distribution Unit Load on Approach Slab and Key:

$$H_{hwas.UN1.2.tri} := \left(\frac{\sigma_{hwas.UN1.2} - \sigma_{hwas.UN1.1}}{2}\right) \cdot \left(T_{as} \cdot W_{hwas.UN1}\right) = -2118.96 \cdot kN$$

Rectangular Distribution Unit Load on Approach Slab and Key:

$$H_{hwas.UN1.2.rect} := \sigma_{hwas.UN1.1} \cdot \left(T_{as} \cdot W_{hwas.UN1}\right) = -4096.66 \cdot kN$$

Total Horizontal Headwater Load on Approach Slab:

$$H_{hwas.UN1} := H_{hwas.UN1.2.tri} + H_{hwas.UN1.2.rect} = -6215.62 \cdot kN$$

Apply Total Footing Headwater Load at:

$$H_{hwas.UN1.loc} := \frac{\left[H_{hwas.UN1.2.rect} \cdot \frac{\left(T_{as}\right)}{2} + H_{hwas.UN1.2.tri} \cdot \frac{\left(T_{as}\right)}{3}\right]}{H_{hwas.UN1.2.tri} + H_{hwas.UN1.2.rect}} - d_{key} = 0.66\,m$$

LATERAL WATER LOADS (continued)

UN1 CASE

Regulating Gate (2A) Operating Condition:

Regulating Crest Gate Down/Open Condition: $A1_{UN1} := TOP_{rg.UN1} \le TOC_{as}$

Regulating Crest Gate Up/Closed, with Top of Gate Higher than HW Elevation: $B1_{UN1} := TOP_{rg.UN1} \ge HW_{UN1} \wedge TOP_{rg.UN1} > TOC_{as}$

Regulating Crest Gate Up/Closed, with Top of Gate Lower than HW Elevation: $C1_{UN1} := TOP_{rg.UN1} > TOC_{as} \wedge HW_{UN1} > TOP_{rg.UN1}$

Regulating Crest Gate Height: $H_{rg.UN1} := TOP_{rg.UN1} - TOC_{as} = 0\,m$

Headwater Depth at Regulating Crest Gate: $D_{hwrg.UN1} := HW_{UN1} - TOC_{as} = 5.80\,m$

Regulating Crest Gate Width: $W_{hwrg.UN1} := 5.00m$

Lateral Headwater Pressure at Bottom of Regulating Crest Gate:

$$\sigma_{hwrg.UN1.1} := \begin{cases} (0.0kPa) & \text{if } A1_{UN1} \\ -(\gamma_w \cdot D_{hwrg.UN1}) & \text{if } B1_{UN1} \\ -(\gamma_w \cdot D_{hwrg.UN1}) & \text{if } C1_{UN1} \end{cases} = 0.0 \cdot kPa$$

Lateral Headwater Pressure at Top of Regulating Crest Gate: (Load at HW Elevation On Regulating Crest Gate if HW is below TOG_{rg})

$$\sigma_{hwrg.UN1.2} := \begin{cases} (0.0kPa) & \text{if } A1_{UN1} \\ 0.0kPa & \text{if } B1_{UN1} \\ -\left[\gamma_w \cdot (HW_{UN1} - TOP_{rg.UN1})\right] & \text{if } C1_{UN1} \end{cases} = 0.0 \cdot kPa$$

Average Pressure acting on Regulating Gate:

$$\sigma_{hwrg.UN1.avg} := \frac{(\sigma_{hwrg.UN1.1} + \sigma_{hwrg.UN1.2})}{2} = 0 \cdot kPa$$

Total Area water acting on Regulating Crest Gate:

$$A_{hwrg.UN1} := \begin{cases} D_{hwrg.UN1} \cdot W_{hwrg.UN1} & \text{if } A1_{UN1} \\ D_{hwrg.UN1} \cdot W_{hwrg.UN1} & \text{if } B1_{UN1} \\ H_{rg.UN1} \cdot W_{hwrg.UN1} & \text{if } C1_{UN1} \end{cases} = 29 \cdot m^2$$

Total Horizontal Headwater Load on Regulating Crest Gate: $H_{hwrg.UN1} := \sigma_{hwrg.UN1.avg} \cdot A_{hwrg.UN1} = 0.0 \cdot kN$

Apply Total Regulating Crest Gate Headwater Load at:

$$H_{hwrg.UN1.loc} := \begin{cases} (TOC_{as} - BOF_{elev}) & \text{if } A1_{UN1} \\ \left[\frac{(HW_{UN1} - TOC_{as})}{3} + (TOC_{as} - BOF_{elev})\right] & \text{if } B1_{UN1} \\ \left[\frac{\sigma_{hwrg.UN1.2} \cdot A_{hwrg.UN1} \cdot \frac{(H_{rg.UN1})}{2} + \frac{(\sigma_{hwrg.UN1.1} - \sigma_{hwrg.UN1.2})}{2} A_{hwrg.UN1} \cdot \frac{(H_{rg.UN1})}{3}}{\sigma_{hwrg.UN1.2} \cdot A_{hwrg.UN1} + \frac{(\sigma_{hwrg.UN1.1} - \sigma_{hwrg.UN1.2})}{2} \cdot A_{hwrg.UN1}} \ldots \\ + (TOC_{as} - BOF_{elev})\right] & \text{if } C1_{UN1} \end{cases} = 4.0 \cdot m$$

Guard Gate (4A) Operating Condition:

Guard Gate Down/Open Condition: $A2_{UN1} := TOP_{gg.UN1} \le TOC_{as}$

Guard Crest Gate Up/Closed, with Top of Gate Higher than HW Elevation: $B2_{UN1} := TOP_{gg.UN1} \ge HW_{UN1} \wedge TOP_{gg.UN1} > TOC_{as}$

Guard Crest Gate Up/Closed, with Top of Gate Lower than HW Elevation: $C2_{UN1} := TOP_{gg.UN1} > TOC_{as} \wedge HW_{UN1} > TOP_{gg.UN1}$

Guard Crest Gate Height: $H_{gg.UN1} := TOP_{gg.UN1} - TOC_{as} = 3.5\,m$

Headwater Depth at Guard Crest Gate: $D_{hwgg.UN1} := HW_{UN1} - TOC_{as} = 5.80\,m$

Guard Crest Gate Width: $W_{hwgg.UN1} := 5.00m$

Lateral Headwater Pressure at Bottom of Guard Crest Gate:

$$\sigma_{hwgg.UN1.1} := \begin{cases} (0.0kPa) & \text{if } A2_{UN1} \\ -(\gamma_w \cdot D_{hwgg.UN1}) & \text{if } B2_{UN1} \\ -(\gamma_w \cdot D_{hwgg.UN1}) & \text{if } C2_{UN1} \end{cases} = -56.9 \cdot kPa$$

Lateral Headwater Pressure at Top of Guard Crest Gate: (Load at HW Elevation On Guard Crest Gate if HW is below TOG_{rg})

$$\sigma_{hwgg.UN1.2} := \begin{cases} (0.0kPa) & \text{if } A2_{UN1} \\ 0.0kPa & \text{if } B2_{UN1} \\ -\left[\gamma_w \cdot (HW_{UN1} - TOP_{gg.UN1})\right] & \text{if } C2_{UN1} \end{cases} = -22.6 \cdot kPa$$

Average Pressure acting on Guard Crest Gate:

$$\sigma_{hwgg.UN1.avg} := \frac{(\sigma_{hwgg.UN1.1} + \sigma_{hwgg.UN1.2})}{2} = -39.73 \cdot kPa$$

Total Area water acting on Crest Gate:

$$A_{hwgg.UN1} := \begin{cases} D_{hwgg.UN1} \cdot W_{hwgg.UN1} & \text{if } A2_{UN1} \\ D_{hwgg.UN1} \cdot W_{hwgg.UN1} & \text{if } B2_{UN1} \\ H_{gg.UN1} \cdot W_{hwgg.UN1} & \text{if } C2_{UN1} \end{cases} = 17.5 \cdot m^2$$

Total Horizontal Headwater Load on Guard Crest Gate: $H_{hwgg.UN1} := \sigma_{hwgg.UN1.avg} \cdot A_{hwgg.UN1} = -695.3 \cdot kN$

Apply Total Guard Crest Gate Headwater Load at:

$$H_{hwgg.UN1.loc} := \begin{cases} (TOC_{as} - BOF_{elev}) & \text{if } A2_{UN1} \\ \left[\frac{(HW_{UN1} - TOC_{as})}{3} + (TOC_{as} - BOF_{elev})\right] & \text{if } B2_{UN1} \\ \left[\frac{\sigma_{hwgg.UN1.2} \cdot A_{hwgg.UN1} \cdot \frac{(H_{gg.UN1})}{2} + \frac{(\sigma_{hwgg.UN1.1} - \sigma_{hwgg.UN1.2})}{2} \cdot A_{hwgg.UN1} \cdot \frac{(H_{gg.UN1})}{3}}{\sigma_{hwgg.UN1.2} \cdot A_{hwgg.UN1} + \frac{(\sigma_{hwgg.UN1.1} - \sigma_{hwgg.UN1.2})}{2} \cdot A_{hwgg.UN1}} \ldots \\ + (TOC_{as} - BOF_{elev})\right] & \text{if } C2_{UN1} \end{cases} = 5.5 \cdot m$$

LATERAL TAILWATER (RESISTING) Applied to Downstream Side of Regulating Crest Gate: UN1 CASE

Regulating Crest Gate Down/Open Condition: $A3_{UN1} := TOP_{rg.UN1} \le TOC_{as}$

Regulating Crest Gate Up/Closed, with Top of Gate Higher than TW Elevation: $B3_{UN1} := TOP_{rg.UN1} \ge TW_{UN1} \wedge TOP_{rg.UN1} > TOC_{as}$

Regulating Crest Gate Up/Closed, with Top of Gate Lower than TW Elevation: $C3_{UN1} := TOP_{rg.UN1} > TOC_{as} \wedge TW_{UN1} > TOP_{rg.UN1}$

Regulating Crest Gate Height: $H_{rg.UN1} = 0\,m$

Tailwater Depth at Regulating Crest Gate: $D_{twrg.UN1} := TW_{UN1} - TOC_{as} = 3.10\,m$

Regulating Crest Gate Width: $W_{twrg.UN1} := 5m$

Lateral Tailwater Pressure at Bottom of Regulating Crest Gate:

$$\sigma_{twrg.UN1.1} := \left| \begin{array}{ll} (0.0kPa) & \text{if } A3_{UN1} \\ -(\gamma_w \cdot D_{twrg.UN1}) & \text{if } B3_{UN1} \\ -(\gamma_w \cdot D_{twrg.UN1}) & \text{if } C3_{UN1} \end{array} \right. = 0.0 \cdot kPa$$

Lateral Tailwater Pressure at Top of Regulating Crest Gate: (Load at TW Elevation On Regulating Crest Gate if TW is below TOG_{rg})

$$\sigma_{twrg.UN1.2} := \left| \begin{array}{ll} (0.0kPa) & \text{if } A3_{UN1} \\ 0.0kPa & \text{if } B3_{UN1} \\ -\left[\gamma_w \cdot (TW_{UN1} - TOP_{rg.UN1})\right] & \text{if } C3_{UN1} \end{array} \right. = 0.0 \cdot kPa$$

Average Pressure acting on Regulating Gate:

$$\sigma_{twrg.UN1.avg} := \frac{(\sigma_{twrg.UN1.1} + \sigma_{twrg.UN1.2})}{2} = 0 \cdot kPa$$

Total Area water acting on Regulating Crest Gate:

$$A_{twrg.UN1} := \left| \begin{array}{ll} D_{twrg.UN1} \cdot W_{twrg.UN1} & \text{if } A3_{UN1} \\ D_{twrg.UN1} \cdot W_{twrg.UN1} & \text{if } B3_{UN1} \\ H_{rg.UN1} \cdot W_{twrg.UN1} & \text{if } C3_{UN1} \end{array} \right. = 15.5 \cdot m^2$$

Total Horizontal Tailwater Load on Regulating Crest Gate: $H_{twrg.UN1} := \sigma_{hwrg.UN1.avg} \cdot A_{hwrg.UN1} = 0.0 \cdot kN$

Apply Total Regulating Crest Gate Tailwater Load at:

$$H_{twrg.UN1.loc} := \left| \begin{array}{ll} (TOC_{as} - BOF_{elev}) & \text{if } A3_{UN1} \\ \left[\frac{(HW_{UN1} - TOC_{as})}{3} + (TOC_{as} - BOF_{elev})\right] & \text{if } B3_{UN1} \\ \left[\frac{\sigma_{hwrg.UN1.2} \cdot A_{hwrg.UN1} \cdot \frac{(H_{rg.UN1})}{2} + \frac{(\sigma_{hwrg.UN1.1} - \sigma_{hwrg.UN1.2})}{2} A_{hwrg.UN1} \cdot \frac{(H_{rg.UN1})}{3}}{\sigma_{hwrg.UN1.2} \cdot A_{hwrg.UN1} + \frac{(\sigma_{hwrg.UN1.1} - \sigma_{hwrg.UN1.2})}{2} \cdot A_{hwrg.UN1}} \ldots \\ + (TOC_{as} - BOF_{elev}) \right] & \text{if } C3_{UN1} \end{array} \right. = 4.0 \cdot m$$

LATERAL TAILWATER (RESISTING) Applied to Downstream Side of Guard Crest Gate:

UN1 CASE

Guard Gate Down/Open Condition: $A4_{UN1} := TOP_{gg.UN1} \le TOC_{as}$

Guard Crest Gate Up/Closed, with Top of Gate Higher than TW Elevation: $B4_{UN1} := TOP_{gg.UN1} \ge TW_{UN1} \wedge TOP_{gg.UN1} > TOC_{as}$

Guard Crest Gate Up/Closed, with Top of Gate Lower than TW Elevation: $C4_{UN1} := TOP_{gg.UN1} > TOC_{as} \wedge TW_{UN1} > TOP_{gg.UN1}$

Tailwater Depth at Guard Crest Gate: $D_{twgg.UN1} := TW_{UN1} - TOC_{as} = 3.10\,m$

Guard Crest Gate Height: $H_{gg.UN1} = 3.5\,m$

Guard Crest Gate Width: $W_{twgg.UN1} := 5.00m$

Lateral Water Load at Bottom of Guard Crest Gate:

$$\sigma_{twgg.UN1.1} := \begin{cases} (0.0kPa) & \text{if } A4_{UN1} \\ (\gamma_w \cdot D_{twgg.UN1}) & \text{if } B4_{UN1} \\ (\gamma_w \cdot D_{twgg.UN1}) & \text{if } C4_{UN1} \end{cases} = 30.4 \cdot kPa$$

Lateral Water Load at Top of Guard Crest Gate:
(Load at TW Elevation On Guard Crest Gate if TW is below TOG_{gg})

$$\sigma_{twgg.UN1.2} := \begin{cases} (0.0kPa) & \text{if } A4_{UN1} \\ 0.0kPa & \text{if } B4_{UN1} \\ \left[\gamma_w \cdot (TW_{UN1} - TOP_{gg.UN1})\right] & \text{if } C4_{UN1} \end{cases} = 0.0 \cdot kPa$$

Average Pressure acting on Guard Crest Gate:

$$\sigma_{twgg.UN1.avg} := \frac{(\sigma_{twgg.UN1.1} + \sigma_{twgg.UN1.2})}{2} = 15.21 \cdot kPa$$

Total Area water acting on Crest Gate:

$$A_{twgg.UN1} := \begin{cases} D_{twgg.UN1} \cdot W_{twgg.UN1} & \text{if } A4_{UN1} \\ D_{twgg.UN1} \cdot W_{twgg.UN1} & \text{if } B4_{UN1} \\ H_{gg.UN1} \cdot W_{twgg.UN1} & \text{if } C4_{UN1} \end{cases} = 15.5 \cdot m^2$$

Total Horizontal Tailwater Load on Guard Crest Gate: $H_{twgg.UN1} := \sigma_{twgg.UN1.avg} \cdot A_{twgg.UN1} = 235.7 \cdot kN$

Apply Total Horiz. TW Load on Guard Gate at:

$$H_{twgg.UN1.loc} := \begin{cases} (TOC_{as} - BOF_{elev}) & \text{if } A4_{UN1} \\ \left[\frac{(TW_{UN1} - TOC_{as})}{3} + (TOC_{as} - BOF_{elev})\right] & \text{if } B4_{UN1} \\ \left[\frac{\sigma_{twgg.UN1.2} \cdot A_{twgg.UN1} \cdot \frac{(H_{gg.UN1})}{2} + \frac{(\sigma_{twgg.UN1.1} - \sigma_{twgg.UN1.2})}{2} A_{twgg.UN1} \cdot \frac{(H_{gg.UN1})}{3}}{\sigma_{twgg.UN1.2} \cdot A_{twgg.UN1} + \frac{(\sigma_{twgg.UN1.1} - \sigma_{twgg.UN1.2})}{2} \cdot A_{twgg.UN1}} \ldots + (TOC_{as} - BOF_{elev})\right] & \text{if } C4_{UN1} \end{cases} = 5.0 \cdot m$$

LATERAL WATER LOADS (continued)

UN1 CASE

TAILWATER (RESISTING) Applied to Concrete Structure:

Tailwater Depth on Pier: $D_{twp.UN1} := TW_{UN1} - TOC_{as} = 3.10\,m$

Tailwater Load Unit Width on Pier: $W_{twp.UN1} := w_p = 2.00\,m$

Total Horizontal Tailwater Load on Pier: $H_{twp.UN1} := \frac{\left(\gamma_w \cdot D_{twp.UN1}^{\ 2}\right)}{2} \cdot W_{twp.UN1} = 94.3 \cdot kN$

Apply Total Pier Tailwater Load at: $H_{twp.UN1.loc} := \frac{D_{twp.UN1}}{3} + \left(TOC_{as} - BOF_{elev}\right) = 5.03\,m$

Tailwater Depth At top of Gate Base Footing Elevation: $D_{twgf.UN1} := TW_{UN1} - TOC_{as} = 3.10\,m$

Water Depth at bottom of Gate Base Footing (Excluding Key): $D_{twtoe.UN1} := TW_{UN1} - BOF_{elev} = 7.10\,m$

Footing Thickness for horizontal at Toe: $h_{toe} = 4\,m$

Unit Width of D/S face of crest for application of Tailwater Load: $W_{tw.UN1} := W_b = 12.00\,m$

Tailwater Pressure At Top of Gate Footing: $\sigma_{twgf.UN1} := \left(\gamma_w \cdot D_{twgf.UN1}\right) = 30.41 \cdot kPa$

Tailwater Pressure At Toe: $\sigma_{twtoe.UN1} := \left(\gamma_w \cdot D_{twtoe.UN1}\right) = 69.65 \cdot kPa$

Triangular Distribution Unit Load on Gate Footing Base (including key): $H_{twgf.UN1.tri} := \left(\frac{\sigma_{twtoe.UN1} - \sigma_{twgf.UN1}}{2}\right) \cdot \left[\left(T_{as} - d_{key}\right) \cdot W_{tw.UN1}\right] = 941.76 \cdot kN$

Rectangular Distribution Unit Load on Gate Footing Base (including key): $H_{twgf.UN1.rect} := \sigma_{twgf.UN1} \cdot \left[\left(T_{as} - d_{key}\right) \cdot W_{tw.UN1}\right] = 1459.73 \cdot kN$

Tailwater Pressure At Bottom of Sliding Failure Plane: $\sigma_{twbk.UN1} := \left(HW_{UN1} - BOK_{elev}\right) \cdot \gamma_w = 115.76 \cdot kPa$

Triangular Distribution Unit Load Below Footing: $H_{twbk.UN1.tri} := \frac{\left(\sigma_{twbk.UN1} - \sigma_{twtoe.UN1}\right)}{2} \cdot d_{key} \cdot W_{tw.UN1} = 553.28 \cdot kN$

Rectangular Distribution Load Below Footing Base: $H_{twbk.UN1.rect} := \sigma_{twtoe.UN1} \cdot d_{key} \cdot W_{tw.UN1} = 1671.62 \cdot kN$

Total Horizontal Tailwater Headwater Load on Gate Footing (including key):

$$H_{twgk.UN1} := H_{twgf.UN1.tri} + H_{twgf.UN1.rect} \cdots + H_{twbk.UN1.tri} + H_{twbk.UN1.rect} = 4626.4 \cdot kN$$

Apply Total Gate Footing Tailwater Load at:

$$H_{twgk.UN1.loc} := \frac{\left[H_{twgf.UN1.rect} \cdot \frac{\left(h_{toe}\right)}{2} + H_{twgf.UN1.tri} \cdot \frac{\left(h_{toe}\right)}{3} + H_{twbk.UN1.tri} \cdot \left(-d_{key} \cdot \frac{2}{3}\right) + H_{twbk.UN1.rect} \cdot \left(\frac{-d_{key}}{2}\right)\right]}{H_{twgf.UN1.tri} + H_{twgf.UN1.rect} + H_{twbk.UN1.tri} + H_{twbk.UN1.rect}} = 0.38\,m$$

SUMMATION OF LATERAL WATER LOADS:

$$\Sigma H_{Water.UN1} := H_{hwp.UN1} + H_{hwas.UN1} + H_{hwrg.UN1} + H_{hwgg.UN1} + H_{twp.UN1} + H_{twgk.UN1} + H_{twrg.UN1} + H_{twgg.UN1} = -2284.55 \cdot kN$$

$$\Sigma M_{Hwater.UN1} := H_{hwp.UN1} \cdot H_{hwp.UN1.loc} + H_{hwas.UN1} \cdot H_{hwas.UN1.loc} + H_{hwrg.UN1} \cdot H_{hwrg.UN1.loc} \cdots + H_{hwgg.UN1} \cdot H_{hwgg.UN1.loc} + H_{twp.UN1} \cdot H_{twp.UN1.loc} + H_{twgk.UN1} \cdot H_{twgk.UN1.loc} \cdots + H_{twrg.UN1} \cdot H_{twrg.UN1.loc} + H_{twgg.UN1} \cdot H_{twgg.UN1.loc} = -6450.74 \cdot kN \cdot m$$

VERTICAL WATER LOADS

UN1 CASE

HEADWATER:

Water Depth on top of Approach Slab: $d_{hw.UN1} := HW_{UN1} - TOC_{as} = 5.80\,m$

Length of Approach Slab: $L_{as} = 8.75\,m$

Width of Approach Slab: $w_{as} = 12.00\,m$

Length from front of Gate to Heel: $L_{hg} = 8.75\,m$

Vertical Water Weight (H1) on Approach Slab:

$$H_{1.UN1} := \left[w_{as} \cdot d_{hw.UN1} \cdot L_{hg} - w_p \cdot d_{hw.UN1} \cdot \left(L_{hg} - L_{as}\right)\right] \cdot \gamma_w = 5974.3 \cdot kN$$

Moment Arm for Application of Water Weight (H1) from toe:

$$H_{1.UN1.loc} := L_b - \frac{L_{hg}}{2} = 14.13\,m$$

TAILWATER ABOVE GUARD GATE:

Trapezoid Volume Above Gate Footing from Approach Slab to Crest:

$$V_{asc.gg.UN1} := \left(L_{gf} - L_{gfc}\right) W_{twgg.UN1} \frac{d_{hw.UN1} + Y_{C.gg.UN1}}{2} = 206.1 \cdot m^3$$

Trapezoid Volume Above Gate Footing Crest to End of Gate Footing:

$$V_{gfc.gg.UN1} := \left(L_{gfc} \cdot W_{twgg.UN1}\right) \frac{Y_{C.gg.UN1} + Y_{TOE.gg.UN1}}{2} = 40.37 \cdot m^3$$

Load Above Gate Footing from Approach Slab to Crest:

$$H_{2.UN1.asc.gg} := V_{asc.gg.UN1} \cdot \gamma_w = 2021.83 \cdot kN$$

Load Acting Above Footing Crest from Toe:

$$H_{2.UN1.asc.gg.loc} := \frac{\left(L_{gf} - L_{gfc}\right) \cdot \left(2 \cdot d_{hw.UN1} + Y_{C.gg.UN1}\right)}{3 \cdot \left(d_{hw.UN1} + Y_{C.gg.UN1}\right)} + L_{gfc} = 6.18\,m$$

Load Above Gate Footing from Crest to End:

$$H_{2.UN1.gfc.gg} := V_{gfc.gg.UN1} \cdot \gamma_w = 395.98 \cdot kN$$

Load Acting Above Gate Footing from Crest to End:

$$H_{2.UN1.gfc.gg.loc} := \frac{\left(L_{gfc}\right) \cdot \left(2 \cdot Y_{C.gg.UN1} + Y_{TOE.gg.UN1}\right)}{3 \cdot \left(Y_{C.gg.UN1} + Y_{TOE.gg.UN1}\right)} = 1.67\,m$$

Vertical Water Weight (H2) on Guard Gate Footing:

$$H_{2.UN1.gg} := H_{2.UN1.asc.gg} + H_{2.UN1.gfc.gg} = 2417.81 \cdot kN$$

Moment Arm for Application of Water Weight (H2) from toe:

$$H_{2.UN1.gg.loc} := \frac{H_{2.UN1.asc.gg} \cdot H_{2.UN1.asc.gg.loc} \cdots + H_{2.UN1.gfc.gg} \cdot H_{2.UN1.gfc.gg.loc}}{H_{2.UN1.gg}} = 5.44\,m$$

TAILWATER ABOVE REGULATING GATE:

Trapezoid Volume Above Gate Footing from Approach Slab to Crest:

$$V_{asc.rg.UN1} := \left(L_{gf} - L_{gfc}\right) W_{twrg.UN1} \frac{d_{hw.UN1} + Y_{C.rg.UN1}}{2} = 185.36 \cdot m^3$$

Trapezoid Volume Above Gate Footing Crest to End of Gate Footing:

$$V_{gfc.rg.UN1} := \left(L_{gfc} \cdot W_{twrg.UN1}\right) \frac{Y_{C.rg.UN1} + Y_{TOE.rg.UN1}}{2} = 42.38 \cdot m^3$$

Load Above Gate Footing from Approach Slab to Crest:

$$H_{2.UN1.asc.rg} := V_{asc.rg.UN1} \cdot \gamma_w = 1818.42 \cdot kN$$

Load Acting Above Footing Crest from Toe:

$$H_{2.UN1.asc.rg.loc} := \frac{\left(L_{gf} - L_{gfc}\right) \cdot \left(2 \cdot d_{hw.UN1} + Y_{C.rg.UN1}\right)}{3 \cdot \left(d_{hw.UN1} + Y_{C.rg.UN1}\right)} + L_{gfc} = 6.32\,m$$

Load Above Gate Footing from Crest to End:

$$H_{2.UN1.gfc.rg} := V_{gfc.rg.UN1} \cdot \gamma_w = 415.75 \cdot kN$$

Load Acting Above Gate Footing from Crest to End:

$$H_{2.UN1.gfc.rg.loc} := \frac{\left(L_{gfc}\right) \cdot \left(2 \cdot Y_{C.rg.UN1} + Y_{TOE.rg.UN1}\right)}{3 \cdot \left(Y_{C.rg.UN1} + Y_{TOE.rg.UN1}\right)} = 1.47\,m$$

Vertical Water Weight (H2) on Regulating Gate Footing:

$$H_{2.UN1.rg} := H_{2.UN1.asc.rg} + H_{2.UN1.gfc.rg} = 2234.17 \cdot kN$$

Moment Arm for Application of Water Weight (H2) from toe:

$$H_{2.UN1.rg.loc} := \frac{H_{2.UN1.asc.rg} \cdot H_{2.UN1.asc.rg.loc} \cdots + H_{2.UN1.gfc.rg} \cdot H_{2.UN1.gfc.rg.loc}}{H_{2.UN1.rg}} = 5.42\,m$$

UPLIFT **UN1 CASE**

Uplift pressure at U/S Face (heel): $U_{HW.UN1} := \left(D_{hwas.UN1}\right)\cdot\gamma_w = 115.8\cdot\frac{kN}{m^2}$

Uplift pressure at D/S Face Stilling Basin: $U_{TW.UN1} := \left(D_{twtoe.UN1}\right)\cdot\gamma_w = 69.65\cdot\frac{kN}{m^2}$

Length from U/S of Gate Structure to D/S of Stilling Basin: $L_{overall} := L_b = 18.50\,m$

Difference between Uplift pressure at HW and TW: $U_{diff.UN1} := U_{HW.UN1} - U_{TW.UN1} = 46.11\cdot\frac{kN}{m^2}$

Slope of difference between between Uplift pressure at HW and TW: $U_{slope.UN1} := \frac{U_{diff.UN1}}{L_{overall}} = 2.49\cdot\frac{kN}{m^2\cdot m}$

Tailwater Pressure at toe of Gate Structure: $U_{press.toe.gs.UN1} := U_{TW.UN1} + \left(L_{overall} - L_b\right)\cdot U_{slope.UN1} = 69.65\cdot\frac{kN}{m^2}$

Uniform uplift force UA Under Gate Structure due to TW (rectangle): $U_{A.UN1} := U_{press.toe.gs.UN1}\cdot L_b\cdot W_b\cdot -1 = -15462.52\cdot kN$

Moment Arm from Toe of Gate Structure for Uplift UA: $L_{A.UN1} := \left(\frac{L_b}{2}\right) = 9.25\,m$

Linearly Decreasing Uplift Force UN1B Under Gate Structure due to HW-TW Differential (triangle): $U_{B.UN1} := \frac{1}{2}\cdot\left(U_{HW.UN1} - U_{press.toe.gs.UN1}\right)\cdot L_b\cdot W_b\cdot -1 = -5117.88\cdot kN$

Moment Arm from Toe of Gate Structure for Uplift UB: $L_{B.UN1} := \frac{2}{3}\cdot L_b = 12.33\,m$

Total Resultant Uplift force: $U_{UN1} := U_{A.UN1} + U_{B.UN1} = -20580.4\cdot kN$

Resultant Location from Toe: $U_{UN1.loc} := \frac{\left(U_{A.UN1}\cdot L_{A.UN1} + U_{B.UN1}\cdot L_{B.UN1}\right)}{\left(U_{A.UN1} + U_{B.UN1}\right)} = 10.02\,m$

$\Sigma V_{water.UN1} := H_{1.UN1} + H_{2.UN1.gg} + H_{2.UN1.rg} + U_{UN1} = -9954.13\cdot kN$

$\Sigma M_{Vwater.UN1} := H_{1.UN1}\cdot H_{1.UN1.loc} + H_{2.UN1.gg}\cdot H_{2.UN1.gg.loc} + H_{2.UN1.rg}\cdot H_{2.UN1.rg.loc} + U_{UN1}\cdot U_{UN1.loc} = -96504.08\cdot kN\cdot m$

SOIL LOADS

UN1 CASE

Equivalent Fluid Pressure (EFP):

At rest lateral pressure coefficient: $K_{o.UN1} := 1 - \sin(\phi_{backfill}) = 0.658$ (Section 5.3, Design Criteria)

Headwater Pier Footing Unit Width: $W_{hwas.UN1} = 12.00\,m$

Tailwater Pier Footing Unit Width: $W_{tw.UN1} = 12.00\,m$

Pier Footing Thickness at Heel: $t_{hf.UN1} := TOC_{as} - BOK_{elev} = 6.00\,m$

Fixed Crest Footing Thickness at Toe: $t_{tf.UN1} := TOC_{pfe} - BOF_{elev} = 2.00\,m$

Lateral Driving Force (Headwater Side - at rest condition)

Structure Soil Load: $E_{act.UN1} := \dfrac{\left(K_{o.UN1} \cdot t_{hf.UN1}^{\,2}\right)}{2} \cdot (\gamma_r - \gamma_w) \cdot W_{hwas.UN1} \cdot -1 = -1732.49 \cdot kN$

Acting at: $E_{act.UN1.loc} := \dfrac{t_{hf.UN1}}{3} - d_{key} = 0.00\,m$

Lateral Resisting Force (Tailwater Side - at rest condition)

At-rest Soil Load: $E_{pass.UN1} := \dfrac{\left(K_{o.UN1} \cdot t_{tf.UN1}^{\,2}\right)}{2} \cdot (\gamma_r - \gamma_w) \cdot W_{tw.UN1} = 192.5 \cdot kN$

Acting at: $E_{pass.UN1.loc} := \dfrac{t_{tf.UN1}}{3} = 0.67\,m$

$\Sigma H_{soil.UN1} := E_{act.UN1} + E_{pass.UN1} = -1539.99 \cdot kN$

$\Sigma M_{soil.UN1} := E_{act.UN1} \cdot E_{act.UN1.loc} + E_{pass.UN1} \cdot E_{pass.UN1.loc} = 128.33 \cdot kN \cdot m$

ICE / IMPACT LOADS (ASSUME NO ICE LOADING ON TAILWATER SIDE)

Static Ice Loading on Structure: $I_{S.UN1} := 150.0 \dfrac{kN}{m}$

Ice Loading Unit Width on Structure: $W_{S.UN1} := 2.00m$ (Section 7.7, Design Criteria)

Static Ice load on Gates: (Section 7.7, Design Criteria)

$$I_{rg.UN1} := \begin{cases} 0 \dfrac{kN}{m} & \text{if } TOP_{rg.UN1} \le TOC_{as} \\ 150 \dfrac{kN}{m} & \text{if } TOP_{rg.UN1} > TOC_{as} \end{cases} = 0 \cdot \dfrac{kN}{m}$$

$$I_{gg.UN1} := \begin{cases} 0 \dfrac{kN}{m} & \text{if } TOP_{gg.UN1} \le TOC_{as} \\ 150 \dfrac{kN}{m} & \text{if } TOP_{gg.UN1} > TOC_{as} \end{cases} = 150 \cdot \dfrac{kN}{m}$$

Ice Loading Unit Width on Crest Gates: $W_{rg.UN1} := 5m$ $W_{gg.UN1} := 5m$ (Input value for load case)

Total Ice Load on Structure: $I_{UN1} := \left(I_{S.UN1} \cdot W_{S.UN1} + I_{rg.UN1} \cdot W_{rg.UN1} + I_{gg.UN1} \cdot W_{gg.UN1}\right) \cdot -1 = -1050 \cdot kN$

Apply Ice load at: $I_{UN1.loc} := \left(HW_{UN1} - BOF_{elev} - 0.30m\right) = 9.50\,m$

$\Sigma H_{I.UN1} := I_{UN1} = -1050 \cdot kN$

$\Sigma M_{I.UN1} := I_{UN1} \cdot I_{UN1.loc} = -9975 \cdot kN \cdot m$

SEISMIC LOAD (NOT APPLICABLE FOR THIS LOAD CASE)

UN1 CASE

SUMMARY OF LOADS	**Loads**	**Moment Arm**
Dead load of Concrete Structure:	$D_{conc} = 22438.7 \cdot kN$	$X_{conc.loc} = 9.35\,m$
Obermyer Gate Weight:	$D_{Gate} = 140.0 \cdot kN$	$X_{gate} = 9.50\,m$
HW Lateral Load on Pier:	$H_{hwp.UN1} = -330.0 \cdot kN$	$H_{hwp.UN1.loc} = 5.93\,m$
HW Lateral Load on Approach Slab:	$H_{hwas.UN1} = -6215.6 \cdot kN$	$H_{hwas.UN1.loc} = 0.66\,m$
HW Lateral Load on Regulating Gate:	$H_{hwrg.UN1} = 0.0 \cdot kN$	$H_{hwrg.UN1.loc} = 4.00\,m$
HW Lateral Load on Guard Gate:	$H_{hwgg.UN1} = -695.3 \cdot kN$	$H_{hwgg.UN1.loc} = 5.50\,m$
TW Lateral Load on Pier:	$H_{twp.UN1} = 94.3 \cdot kN$	$H_{twp.UN1.loc} = 5.03\,m$
TW Lateral Load on Pier Footing (including Key):	$H_{twgk.UN1} = 4626.4 \cdot kN$	$H_{twgk.UN1.loc} = 0.38\,m$
TW Lateral Load on Regulating Gate:	$H_{twrg.UN1} = 0.0 \cdot kN$	$H_{twrg.UN1.loc} = 4.00\,m$
TW Lateral Load on Guard Gate:	$H_{twgg.UN1} = 235.7 \cdot kN$	$H_{twgg.UN1.loc} = 5.03\,m$
Vertical HW Load on Approach Slab:	$H_{1.UN1} = 5974.3 \cdot kN$	$H_{1.UN1.loc} = 14.13\,m$
Vertical TW Load on Regulating Gate:	$H_{2.UN1.rg} = 2234.2 \cdot kN$	$H_{2.UN1.rg.loc} = 5.42\,m$
Vertical TW Load on Guard Gate:	$H_{2.UN1.gg} = 2417.8 \cdot kN$	$H_{2.UN1.gg.loc} = 5.44\,m$
Uplift:	$U_{UN1} = -20580.4 \cdot kN$	$U_{UN1.loc} = 10.02\,m$
Lateral Soil Load (driving):	$E_{act.UN1} = -1732.5 \cdot kN$	$E_{act.UN1.loc} = 0.00\,m$
Lateral Soil Load (resisting):	$E_{pass.UN1} = 192.5 \cdot kN$	$E_{pass.UN1.loc} = 0.67\,m$
Ice / Impact Load:	$I_{UN1} = -1050.0 \cdot kN$	$I_{UN1.loc} = 9.50\,m$

STABILITY ASSESSMENT (SLIDNG, BEARING, FLOTATION AND OVERTURNING): UN1 CASE

CHECK SLIDING ALONG HORIZONTAL PLANE THRU TOE,
IGNORING BEDROCK MOBILIZED BY STRUCTURAL HEEL KEY, OR VOID BEHIND KEY

Sum of Vertical Forces:

$\Sigma V_{UN1} := \Sigma V_{DL} + \Sigma V_{water.UN1} = 12624.6 \cdot kN$

Sum of Horizontal Forces:

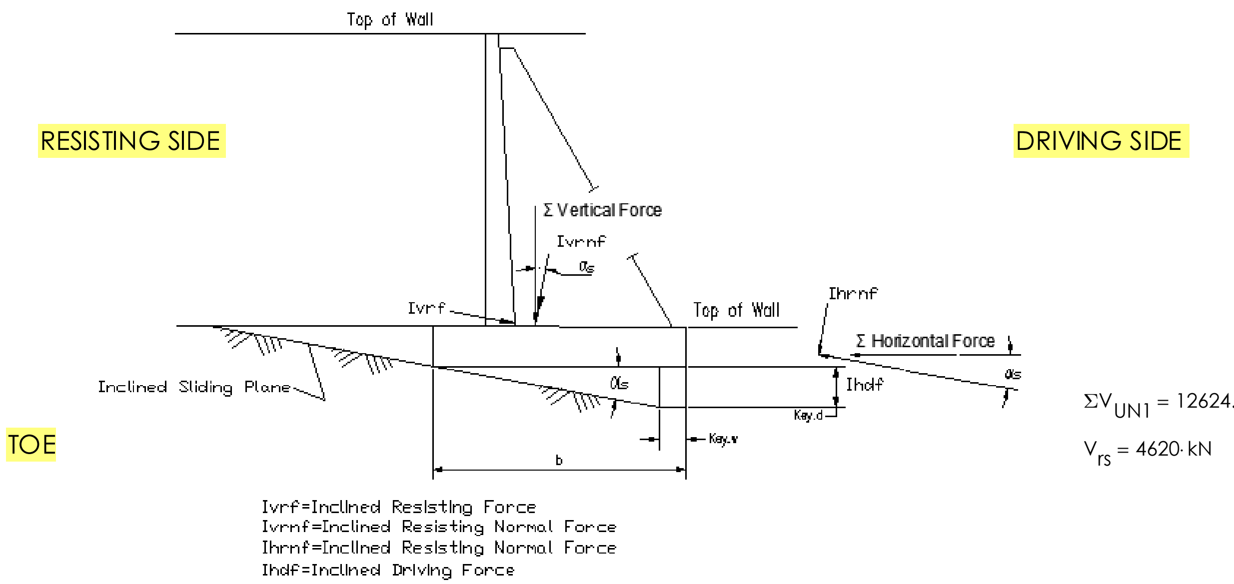
$\Sigma H_{UN1} := \Sigma H_{Water.UN1} + \Sigma H_{soil.UN1} + \Sigma H_{I.UN1} = -4874.54 \cdot kN$

Sliding Factor of Safety:

$$FS_{HorizSliding.UN1} := \frac{\tan_{\phi} \cdot \Sigma V_{UN1}}{\left|\Sigma H_{UN1}\right|} = 1.26$$

$$FS_{HorizSliding.UN1.Check} := \begin{cases} \text{"OKAY"} & \text{if } FS_{HorizSliding.UN1} \geq FS_{req.UN1.sl} \\ \text{"Check Inclined Sliding with Key"} & \text{otherwise} \end{cases} = \text{"Check Inclined Sliding with Key"}$$

CHECK SLIDING ALONG INCLINED SLIDING PLANE FROM HEEL KEY TO TOE,
WITH BEDROCK MASS MOBILIZED BY REINFOCREDE CONCRETE KEY)



$\Sigma V_{UN1} = 12624.61 \cdot kN$

$V_{rs} = 4620 \cdot kN$

$\alpha s = 0.11$

as degrees= $\alpha s \cdot \left(\frac{180}{\pi}\right) = 6.52$

Resolve $\Sigma Vert_{UN1}$ & $\Sigma Horiz_{UN1}$

$$\Sigma V_{InclinedUN1} := \cos(\alpha s) \cdot \left(\Sigma V_{UN1} + V_{rs}\right) + \sin(\alpha s) \cdot \left|\Sigma H_{UN1}\right| = 17686.6 \cdot kN$$

$$\Sigma H_{InclinedUN1} := \cos(\alpha s) \cdot \left|\Sigma H_{UN1}\right| - \sin(\alpha s) \cdot \left(\Sigma V_{UN1} + V_{rs}\right) = 2884.9 \cdot kN$$

(With properly engineered reinforced concrete Key, horizontal sliding plane thru Toe is protected, critical sliding plane is relocated to the INCLINED SLIDING PLANE FROM HEEL KEY To TOE, Bedrock Mass above this examined plane is mobilized by reinforced concrete key and combined into Structural Wedge.)

Inclined Sliding Plane Length

$L_{incline} = 18.61 \text{ m}$

Safety Factor for Sliding
Inclined Failure Plane

$$FS_{InclinedISlidingUN1} := \frac{\Sigma V_{InclinedUN1} \cdot \tan\left(\phi_{rock} \cdot \frac{\pi}{180}\right)}{\left|\Sigma H_{InclinedUN1}\right|} = 2.99$$

$$FS_{InclinedSliding.check.UN1} := \begin{cases} \text{"OKAY "} & \text{if } FS_{InclinedISlidingUN1} > FS_{req.UN1.sl} \\ \text{"Revise Structure""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

$FS_{InclinedSliding.check.UN1} = \text{"OKAY "}$

UN1 CASE

OVERTURNING STABILITY CHECK:

CHECK ECCENTRICITY

Sum of the moments:

$$\Sigma M_{UN1} := \Sigma M_{DL} + \Sigma M_{Hwater.UN1} + \Sigma M_{Vwater.UN1} + \Sigma M_{I.UN1} + \Sigma M_{soil.UN1} + \Sigma M_{rs} = 152218 \cdot kN \cdot m$$

Eccentricity:

$$e_{UN1} := \left(\frac{L_{incline}}{2}\right) - \frac{(\Sigma M_{UN1})}{\Sigma V_{InclinedUN1}} = 0.70\,m$$

Eccentricity Check:

$$e_{check.UN1} := \begin{cases} \text{"Okay"} & \text{if } e_{UN1} \le Kern \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$$e_{check.UN1} = \text{"Okay"}$$

Foundation Bearing Checks:

Bearing Pressure at Heel:

$$\sigma_{heel.UN1} := \frac{\Sigma V_{InclinedUN1}}{A_{b.incline}} - \frac{(\Sigma V_{InclinedUN1} \cdot e_{UN1})}{S_{b.incline}} = 61.4 \cdot \frac{kN}{m^2}$$

$$\sigma_{heel.UN1.check} := \left(\begin{cases} \text{"Okay"} & \text{if } \sigma_{heel.UN1} \le \sigma_{allow.UN1} \\ \text{"Revise Structure"} & \text{if } \sigma_{heel.UN1} < 0 \frac{kN}{m^2} \end{cases} \right)$$

$$\sigma_{heel.UN1.check} = \text{"Okay"}$$

Bearing Pressure at Toe:

$$\sigma_{toe.UN1} := \frac{\Sigma V_{InclinedUN1}}{A_{b.incline}} + \frac{(\Sigma V_{InclinedUN1} \cdot e_{UN1})}{S_{b.incline}} = 97.0 \cdot \frac{kN}{m^2}$$

$$\sigma_{toe.UN1.1.check} := \begin{cases} \text{"Okay"} & \text{if } \sigma_{toe.UN1} \le \sigma_{allow.UN1} \\ \text{"Revise Structure"} & \text{if } \sigma_{toe.UN1} < 0 \frac{kN}{m^2} \end{cases}$$

$$\sigma_{toe.UN1.1.check} = \text{"Okay"}$$

FLOATATION ANALYSIS:

ACCEPTANCE PARAMETERS

Required Factor of Safety: $FS_{req.FUN1} := 1.3$

VERTICAL LOADS RESISTING:

Dead Load: $\Sigma V_{DL} = 22578.74 \cdot kN$

Water Weight H1+H2: $\Sigma V_{H.FUN1} := H_{1.UN1} + H_{2.UN1.gg} + H_{2.UN1.rg} = 10626.27 \cdot kN$

Summation Vertical Resisting: $\Sigma V_{FUN1} := \Sigma V_{DL} + \Sigma V_{H.FUN1} = 33205.0 \cdot kN$

VERTICAL LOADS UPLIFT:

Uplift: $U_{UN1} = -20580.4 \cdot kN$

Factor of Safety Floatation:

$$FS_{act.FUN1} := \frac{\Sigma V_{FUN1}}{|U_{UN1}|} = 1.61$$

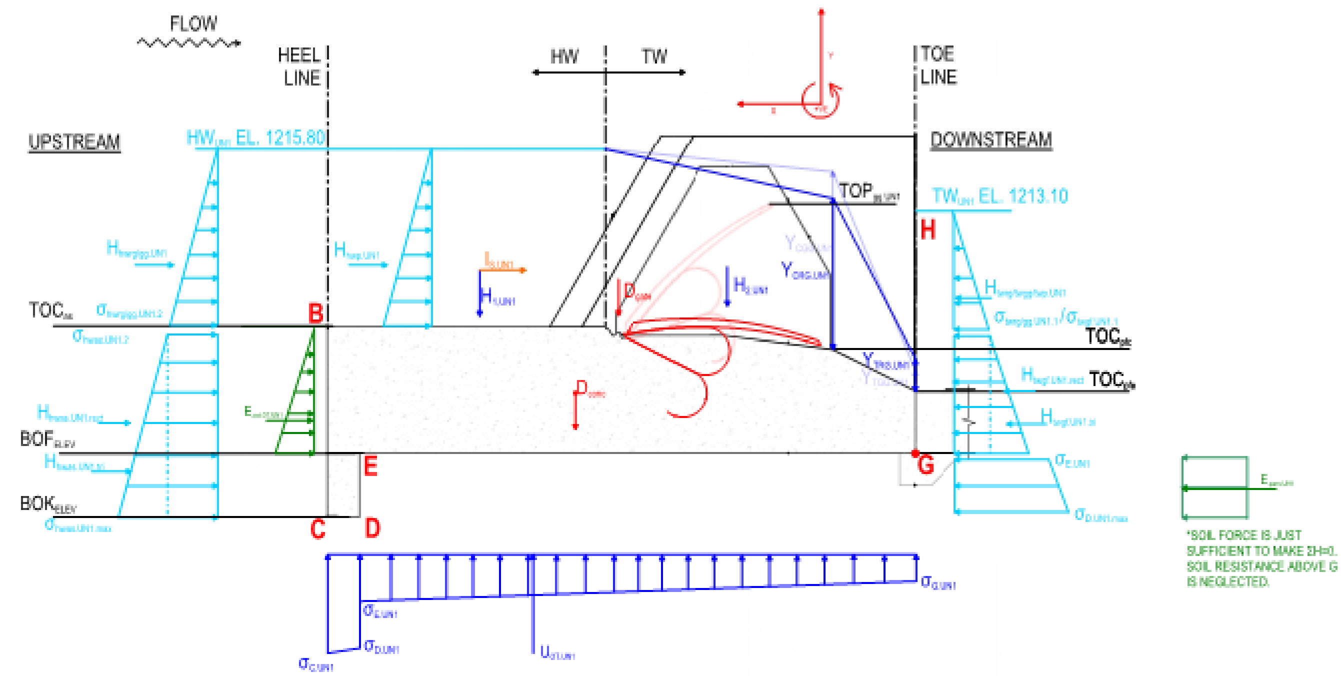
$$FS_{check.FUN1} := \begin{cases} \text{"OKAY"} & \text{if } FS_{act.FUN1} \ge FS_{req.FUN1} \\ \text{"ANCHORS REQUIRED"} & \text{if } FS_{act.FUN1} < FS_{req.FUN1} \end{cases} = \text{"OKAY"}$$

MONOLITH OVERTURNING STABILITY ANALYSIS

UN1 CASE

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.
Assumptions are made in order to compute overturning stability of indeterminate forces on monolith with key;
(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.
(b) The horizontal resisting force acting on the key, P.key, is that required for static equilibrium
(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1 $Ratio_{OT.UN1.min} := 0.33$ at Rock Foundation



Uplift Loads for Overturning Stability Analysis

Line of Creep:

Change in Water Head: $\Delta_{h.UN1} := HW_{UN1} - TW_{UN1} = 2.7\,m$

Length from Point C to Point G: $L_{CG} = 18.61\,m$

Length from Various Points to Points: $L_{CD} = 1\,m$ $L_{DE} = 2\,m$ $L_{EG} = 17.5\,m$

$L_{GH.UN1} := TW_{UN1} - BOF_{elev} = 7.1\,m$

Length from Point C, D, E to G: $L_{CDEG} = 20.5\,m$ $L_{CDE} = 3\,m$

Water Pressure at Point C & G: $\sigma_{C.UN1} := \sigma_{hwas.UN1.2} = -115.76\cdot kPa$ $\sigma_{G.UN1} := \sigma_{twtoe.UN1}\cdot -1 = -69.65\cdot kPa$

Water Pressure at Point D: $$\sigma_{D.UN1} := -\gamma_w \cdot \left[\left(HW_{UN1} - BOK_{elev}\right) - \frac{\Delta_{h.UN1}\cdot L_{CD}}{L_{CDEG}}\right] = -114.47\cdot kPa$$

Water Pressure at Point E: $$\sigma_{E.UN1} := -\gamma_w \cdot \left[\left(HW_{UN1} - BOF_{elev}\right) - \frac{\Delta_{h.UN1}\cdot L_{CDE}}{L_{CDEG}}\right] = -92.26\cdot kPa$$

Uplift for Overturning Analysis on Bottom of Key: $$U_{OT.UN1.key} := \frac{\sigma_{C.UN1} + \sigma_{D.UN1}}{2}\cdot L_{CD}\cdot W_b = -1381.34\cdot kN$$

Acting at: $$U_{OT.UN1.key.loc} := \frac{L_{CD}\cdot\left(2\cdot\sigma_{C.UN1} + \sigma_{D.UN1}\right)}{3\left(\sigma_{C.UN1} + \sigma_{D.UN1}\right)} + L_{EG} = 18\,m$$

Uplift for Overturning Analysis on Bottom of Footing: $$U_{OT.UN1.ftg} := \frac{\sigma_{E.UN1} + \sigma_{G.UN1}}{2}\cdot L_{EG}\cdot W_b = -17000.85\cdot kN$$

Acting at: $$U_{OT.UN1.ftg.loc} := \frac{L_{EG}\cdot\left(\sigma_{G.UN1} + 2\cdot\sigma_{E.UN1}\right)}{3\left(\sigma_{G.UN1} + \sigma_{E.UN1}\right)} = 9.16\,m$$

UN1 CASE

Uplift Load for Overturning Analysis: $U_{OT.UN1} := U_{OT.UN1.key} + U_{OT.UN1.ftg} = -18382.19 \cdot kN$

Uplift Load Acting from Toe: $U_{OT.UN1.loc} := \dfrac{U_{OT.UN1.key} \cdot U_{OT.UN1.key.loc} + U_{OT.UN1.ftg} \cdot U_{OT.UN1.ftg.loc}}{U_{OT.UN1}} = 9.82\,m$

All Vertical Loads Applicable to Overturning Stability Analysis

		at:	
Total Concrete Dead Loads:	$D_{conc} = 22438.74 \cdot kN$		$X_{conc.loc} = 9.35\,m$
Dead Load of Gate:	$D_{Gate} = 140.0 \cdot kN$		$X_{gate} = 9.50\,m$
Water Weight (HW) on Apron Slab:	$H_{1.UN1} = 5974.3 \cdot kN$		$H_{1.UN1.loc} = 14.13\,m$
Water Weight (TW) on Gate Footing:	$H_{2.UN1.rg} = 2234.2 \cdot kN$		$H_{2.UN1.rg.loc} = 5.42\,m$
Water Weight (TW) on Regulating Gate Footing:	$H_{2.UN1.gg} = 2417.8 \cdot kN$		$H_{2.UN1.gg.loc} = 5.44\,m$
Uplift Load for Overturning Analysis:	$U_{OT.UN1} = -18382.19 \cdot kN$		$U_{OT.UN1.loc} = 9.82 \cdot m$

Sum of All Overturning Analysis Vertical Load:

$$\Sigma V_{UN1.OT} := D_{conc} + D_{Gate} + H_{1.UN1} + H_{2.UN1.rg} + H_{2.UN1.gg} + U_{OT.UN1} = 14822.81 \cdot kN$$

Sum of All Overturning Analysis Vertical Load Moments:

$$\Sigma M_{V.UN1.OT} := D_{conc} \cdot X_{conc.loc} + D_{Gate} \cdot X_{gate} + H_{1.UN1} \cdot H_{1.UN1.loc} + H_{2.UN1.rg} \cdot H_{2.UN1.rg.loc} \ldots = 140217.2 \cdot kN \cdot m$$
$$+ H_{2.UN1.gg} \cdot H_{2.UN1.gg.loc} + U_{OT.UN1} \cdot U_{OT.UN1.loc}$$

Lateral Tailwater Loads for Overturning Stability Analysis

TW Lateral Load on Gate Footing (No Key - Overturning Values Adjusted): $H_{twgf.UN1} := H_{twgf.UN1.tri} + H_{twgf.UN1.rect} = 2401.49 \cdot kN$

Acting at: $H_{twgf.UN1.loc} := \dfrac{\frac{h_{toe}}{3} \cdot H_{twgf.UN1.tri} + \frac{h_{toe}}{2} \cdot H_{twgf.UN1.rect}}{H_{twgf.UN1}} = 1.74\,m$

Horizontal Tailwater Pressure Top of Key (Overturning Analysis): $\sigma_{twtk.OT.UN1} := \sigma_{E.UN1} \cdot -1 = 92.26 \cdot kPa$

Horizontal Tailwater Pressure Bottom of Key (Overturning Analysis): $\sigma_{twbk.OT.UN1} := \sigma_{D.UN1} \cdot -1 = 114.47 \cdot kPa$

Triangular Distribution Unit Load Acting at Key: $H_{twbk.OT.UN1.tri} := \dfrac{\left(\sigma_{twbk.OT.UN1} - \sigma_{twtk.OT.UN1}\right)}{2} \cdot d_{key} \cdot W_{tw.UN1} = 266.45 \cdot kN$

Triangular Distribution Unit Load Acting at Key: $H_{twbk.OT.UN1.rect} := \sigma_{twtk.OT.UN1} \cdot d_{key} \cdot W_{tw.UN1} = 2214.28 \cdot kN$

Total Horizontal Tailwater Load on Key (Overturning Values Adjusted): $H_{twkey.OT.UN1} := H_{twbk.OT.UN1.tri} + H_{twbk.OT.UN1.rect} = 2480.73 \cdot kN$

Acting at: $H_{twkey.OT.UN1.loc} := \dfrac{H_{twbk.OT.UN1.tri} \cdot \frac{-2 \cdot d_{key}}{3} + H_{twbk.OT.UN1.rect} \cdot \frac{-d_{key}}{2}}{H_{twkey.OT.UN1}} = -1.04 \cdot m$

Lateral Driving Earth Loads for Overturning Stability Analysis (at rest condition)

Depth of Driving Soil Loads (to top of key): $h_{E.OT.UN1} := TOC_{as} - BOF_{elev} = 4\,m$

At-Rest Soil Load: $E_{act.OT.UN1} := \dfrac{\left(K_{o.UN1} \cdot h_{E.OT.UN1}{}^{2}\right)}{2} \cdot \left(\gamma_r - \gamma_w\right) \cdot W_{hwas.UN1} \cdot -1 = -769.99 \cdot kN$

At Rest- Soil Load Acting from Toe: $E_{act.OT.UN1.loc} := \dfrac{h_{E.OT.UN1}}{3} = 1.33\,m$

All Lateral Loads Applicable to Overturning Stability Analysis

HW Lateral Load on Approach Slab:	$H_{hwas.UN1} = -6215.6 \cdot kN$	$H_{hwas.UN1.loc} = 0.66\,m$
HW Lateral Load on Regulating Gate:	$H_{hwrg.UN1} = 0.0 \cdot kN$	$H_{hwrg.UN1.loc} = 4.00\,m$
HW Lateral Load on Guard Gate:	$H_{hwgg.UN1} = -695.3 \cdot kN$	$H_{hwgg.UN1.loc} = 5.50\,m$
TW Lateral Load on Regulating Gate:	$H_{twrg.UN1} = 0.0 \cdot kN$	$H_{twrg.UN1.loc} = 4.00\,m$
HW Lateral Load on Guard Gate:	$H_{twgg.UN1} = 235.7 \cdot kN$	$H_{twgg.UN1.loc} = 5.03\,m$
TW Lateral Load on Gate Footing (No Key - Overturning Values Adjusted):	$H_{twgf.UN1} = 2401.49 \cdot kN$	$H_{twgf.UN1.loc} = 1.74\,m$
TW Lateral Load on Key:	$H_{twkey.OT.UN1} = 2480.73 \cdot kN$	$H_{twkey.OT.UN1.loc} = -1.04\,m$
Ice / Impact Load:	$I_{UN1} = -1050.0 \cdot kN$	$I_{UN1.loc} = 9.50\,m$
Lateral Soil Load (driving):	$E_{act.OT.UN1} = -770.0 \cdot kN$	$E_{act.OT.UN1.loc} = 1.33\,m$

Resisting Lateral Soil Load as required to produce horizontal equilibrium:

$$E_{pas.OT.UN1} := -\left(H_{hwas.UN1} + H_{hwrg.UN1} + H_{hwgg.UN1} + H_{twrg.UN1} + H_{twgg.UN1} \cdots \atop + H_{twgf.UN1} + H_{twkey.OT.UN1} + I_{UN1} + E_{act.OT.UN1}\right) = 3612.99 \cdot kN$$

$$E_{pas.OT.UN1.loc} := -1 \cdot \frac{d_{key}}{2} = -1\,m$$

Sum of All Overturning Analysis Horizontal Load (ΣH=0):

$$\Sigma H_{UN1.OT} := H_{hwas.UN1} + H_{hwrg.UN1} + H_{hwgg.UN1} + H_{twrg.UN1} + H_{twgg.UN1} \cdots + H_{twgf.UN1} + H_{twkey.OT.UN1} + I_{UN1} + E_{act.OT.UN1} + E_{pas.OT.UN1} = 0 \cdot kN$$

Sum of All Overturning Analysis Horizontal Load Moments:

$$\Sigma M_{H.UN1.OT} := H_{hwas.UN1} \cdot H_{hwas.UN1.loc} + H_{hwrg.UN1} \cdot H_{hwrg.UN1.loc} + H_{hwgg.UN1} \cdot H_{hwgg.UN1.loc} \cdots + H_{twrg.UN1} \cdot H_{twrg.UN1.loc} + H_{twgg.UN1} \cdot H_{twgg.UN1.loc} + H_{twgf.UN1} \cdot H_{twgf.UN1.loc} \cdots + H_{twkey.OT.UN1} \cdot H_{twkey.OT.UN1.loc} + I_{UN1} \cdot I_{UN1.loc} + E_{act.OT.UN1} \cdot E_{act.OT.UN1.loc} \cdots + E_{pas.OT.UN1} \cdot E_{pas.OT.UN1.loc} = -19742.06 \cdot kN \cdot m$$

Overturning Stability Analysis

$$\Sigma M_{UN1.OT} := \Sigma M_{V.UN1.OT} + \Sigma M_{H.UN1.OT} = 120475.13 \cdot kN \cdot m$$

$$X_{R.UN1} := \frac{\Sigma M_{UN1.OT}}{\Sigma V_{UN1.OT}} = 8.13\,m \qquad x_{OT.UN1} := X_{R.UN1} - \frac{L_b}{2} = -1.12\,m$$

Overturning Resultant Ratio

$$Ratio_{OT.UN1} := \frac{X_{R.UN1}}{L_b} = 0.44$$

$$Ratio_{OT.UN1.check} := \begin{cases} \text{"OKAY"} & \text{if } Ratio_{OT.UN1} \geq Ratio_{OT.UN1.min} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

$$x_{OT.check.UN1} := \begin{cases} \text{"OKAY"} & \text{if } \left|x_{OT.UN1}\right| \leq Kern \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

CHECK FOUNDATION BEARING CAPACITY (HORIZONTAL PLANE):

UN1 CASE

Bearing Pressure Under Toe:

$$\sigma_{ToeUN1.OT} := \frac{\Sigma V_{UN1.OT}}{L_b \cdot W_b} + \frac{\left(\Sigma V_{UN1.OT} \cdot x_{OT.UN1}\right)}{S_b} = 42.5 \cdot kPa$$

$$Bearing_{ChecktoeUN1.OT} := \begin{array}{|l} \text{"OKAY "} \quad \text{if} \quad \sigma_{ToeUN1.OT} < \sigma_{allow.UN1} \\ \text{"NG""} \quad \text{otherwise} \end{array} = \text{"OKAY "}$$

Bearing Pressure Under Heel:

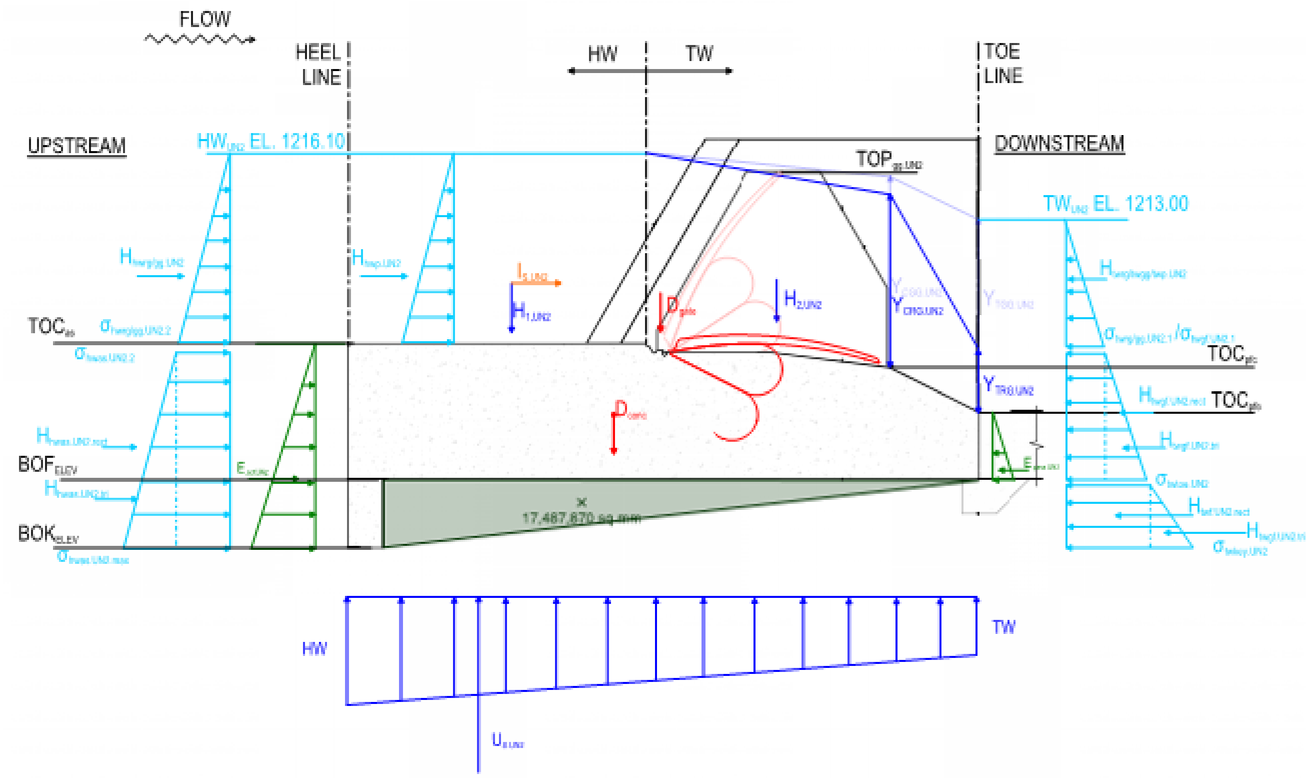
$$\sigma_{HeelUN1.OT} := \frac{\Sigma V_{UN1.OT}}{L_b \cdot W_b} - \frac{\left(\Sigma V_{UN1.OT} \cdot x_{OT.UN1}\right)}{S_b} = 91.1 \cdot kPa$$

$$Bearing_{CheckheelUN1.OT} := \left(\begin{array}{|l} \text{"OKAY "} \quad \text{if} \quad \sigma_{HeelUN1.OT} < \sigma_{allow.UN1} \wedge \sigma_{HeelUN1.OT} > 0 \\ \text{"NG""} \quad \text{otherwise} \end{array} \right) = \text{"OKAY "}$$

SUMMARY OF STABILITY ASSESSMENT:

Sliding Factor of Safety: (Horizontal Plane)	$FS_{HorizSliding.UN1} = 1.26$	$FS_{HorizSliding.UN1.Check}$ = "Check Inclined Sliding wi
Sliding Factor of Safety: (Inclined Plane)	$FS_{InclinedlSlidingUN1} = 2.99$	$FS_{InclinedSliding.check.UN1}$ = "OKAY "
Eccentricity: (Inclined Plane)	$e_{UN1} = 0.70\,m$	$e_{check.UN1}$ = "Okay"
Bearing Pressure At Heel: (Inclined Plane)	$\sigma_{heel.UN1} = 61 \cdot kPa$	$\sigma_{heel.UN1.check}$ = "Okay"
Bearing Pressure At Toe: (Inclined Plane)	$\sigma_{toe.UN1} = 97 \cdot kPa$	$\sigma_{toe.UN1.1.check}$ = "Okay"
Flotation Factor of Safety (horizontal plane)	$FS_{act.FUN1} = 1.61$	$FS_{check.FUN1}$ = "OKAY"
Overturning Resultant Ratio: (horizontal plane)	$Ratio_{OT.UN1} = 0.44$	$Ratio_{OT.UN1.check}$ = "OKAY"
Eccentricity: (horizontal plane)	$x_{OT.UN1} = -1.12\,m$	$x_{OT.check.UN1}$ = "OKAY"
Bearing Pressure At Heel: (horizontal plane)	$\sigma_{HeelUN1.OT} = 91 \cdot kPa$	$Bearing_{CheckheelUN1.OT}$ = "OKAY "
Bearing Pressure At Toe: (horizontal plane)	$\sigma_{ToeUN1.OT} = 42 \cdot kPa$	$Bearing_{ChecktoeUN1.OT}$ = "OKAY "

UN2 DESIGN CASE



ACCEPTANCE PARAMETERS

(Without Cohesion)

Required Factor of Safety for Sliding: $FS_{req.UN2.sl} := 1.3$ (Section 8.1, Design Criteria)

Resultant Within Middle Third of Base: $e \le \frac{L_b}{6} \wedge e \ge \frac{-L_b}{6}$

Allowable Rock Bearing Pressure: $\sigma_{allow.UN2} := 1470 \cdot \frac{kN}{m^2}$ (Section 5.2, Design Criteria)

INPUT PARAMETERS

Headwater Elevation: $HW_{UN2} := 1216.10m$ (Section 8.3, Design Criteria)

Tailwater Elevation: $TW_{UN2} := 1213.00m$ (Section 8.3, Design Criteria)

Bottom of Footing Elevation: $BOF_{elev} = 1206.00\,m$

Approach Slab Top of Concrete Elevation at Upstream Face: $TOC_{as} = 1210.00\,m$

Pier Footing Top of Concrete Elevation at Stilling Basin: $TOC_{pfe} = 1208.00\,m$

Pier Footing Top of Concrete Elevation at Center of Footing: $TOC_{pfc} = 1209.30\,m$

Gates are open when top of gate elevation is at 1210.00m

Top of Guard/ Regulating Gate Elevation: $TOP_{rg.UN2} := 1210.00m$ $TOP_{gg.UN2} := 1215.00m$

Gates are closed/up when top of gate elevation is at 1215.0m

Bottom of Key Elevation: $BOK_{elev} = 1204\,m$

Crestwater Elevation (Right) Guard Gate: $EL_{CGG.UN2} := 1215.73m$

$$Y_{C.gg.UN2} := \begin{cases} (EL_{CGG.UN2} - TOC_{pfc}) & \text{if } TOP_{gg.UN2} \le HW_{UN2} \\ (TW_{UN2} - TOC_{pfc}) & \text{if } TOP_{gg.UN2} > HW_{UN2} \end{cases} = 6.43 \cdot m$$

Toewater Elevation (Right) Guard Gate: $EL_{TGG.UN2} := 1213.00m$

$$Y_{TOE.gg.UN2} := \begin{cases} (EL_{TGG.UN2} - TOC_{pfe}) & \text{if } TOP_{gg.UN2} \le HW_{UN2} \\ (TW_{UN2} - TOC_{pfe}) & \text{if } TOP_{gg.UN2} > HW_{UN2} \end{cases} = 5 \cdot m$$

UN2 CASE

Crestwater Elevation Regulating (Left) Gate: $EL_{CRG.UN2} := 1214.07m$

$$Y_{C.rg.UN2} := \begin{cases} (EL_{CRG.UN2} - TOC_{pfc}) & \text{if } TOP_{rg.UN2} \le HW_{UN2} \\ (TW_{UN2} - TOC_{pfc}) & \text{if } TOP_{rg.UN2} > HW_{UN2} \end{cases} = 4.77 \cdot m$$

Toewater Elevation Regulating (Left) Gate: $EL_{TRG.UN2} := 1209.97m$

$$Y_{TOE.rg.UN2} := \begin{cases} (EL_{TRG.UN2} - TOC_{pfe}) & \text{if } TOP_{rg.UN2} \le HW_{UN2} \\ (TW_{UN2} - TOC_{pfe}) & \text{if } TOP_{rg.UN2} > HW_{UN2} \end{cases} = 1.97 \cdot m$$

LATERAL WATER LOADS

HEADWATER (DRIVING):

Headwater Depth on Pier: $D_{hwp.UN2} := HW_{UN2} - TOC_{as} = 6.10\,m$

Headwater Load Unit Width on Pier: $W_{hwp.UN2} := w_p = 2.00\,m$

Total Horizontal Headwater Load on Pier:

$$H_{hwp.UN2} := \frac{-\left(\gamma_w \cdot D_{hwp.UN2}^{\;2}\right)}{2} \cdot W_{hwp.UN2} = -365.0 \cdot kN$$

Apply Total Pier Headwater Load at:

$$H_{hwp.UN2.loc} := \frac{D_{hwp.UN2}}{3} + \left(TOC_{as} - BOF_{elev}\right) = 6.03\,m$$

Headwater Depth on Gate Base: $D_{hwg.UN2} := HW_{UN2} - TOC_{as} = 6.10\,m$

Thickness of Approach Slab (Including Key): $T_{as} = 6\,m$

Headwater Depth at Heel (U/S face): $D_{hwas.UN2} := HW_{UN2} - BOK_{elev} = 12.10\,m$

Headwater Load Unit Width on Approach Slab: $W_{hwas.UN2} := W_b = 12.00\,m$

Headwater Unit Load At Top of Approach Slab:

$$H_{hwas.UN2.1} := \frac{-\left(\gamma_w \cdot D_{hwg.UN2}^{\;2}\right)}{2} \cdot W_{hwas.UN2} = -2190.18 \cdot kN$$

Headwater Unit Load At Bottom of Approach Key:

$$H_{hwas.UN2.2} := \frac{-\left(\gamma_w \cdot D_{hwas.UN2}^{\;2}\right)}{2} \cdot W_{hwas.UN2} = -8617.7 \cdot kN$$

Headwater Line Load At Top of Approach Slab:

$$\sigma_{hwas.UN2.1} := -\left(\gamma_w \cdot D_{hwg.UN2}\right) = -59.84 \cdot kPa$$

Headwater Line Load At Bottom of Approach Key:

$$\sigma_{hwas.UN2.2} := -\left(\gamma_w \cdot D_{hwas.UN2}\right) = -118.7 \cdot kPa$$

Triangular Distribution Unit Load on Approach Slab and Key:

$$H_{hwas.UN2.2.tri} := \left(\frac{\sigma_{hwas.UN2.2} - \sigma_{hwas.UN2.1}}{2}\right) \cdot \left(T_{as} \cdot W_{hwas.UN2}\right) = -2118.96 \cdot kN$$

Rectangular Distribution Unit Load on Approach Slab and Key:

$$H_{hwas.UN2.2.rect} := \sigma_{hwas.UN2.1} \cdot \left(T_{as} \cdot W_{hwas.UN2}\right) = -4308.55 \cdot kN$$

Total Horizontal Headwater Load on Approach Slab:

$$H_{hwas.UN2} := H_{hwas.UN2.2.tri} + H_{hwas.UN2.2.rect} = -6427.51 \cdot kN$$

Apply Total Footing Headwater Load at:

$$H_{hwas.UN2.loc} := \frac{\left[H_{hwas.UN2.2.rect} \cdot \frac{\left(T_{as}\right)}{2} + H_{hwas.UN2.2.tri} \cdot \frac{\left(T_{as}\right)}{3}\right]}{H_{hwas.UN2.2.tri} + H_{hwas.UN2.2.rect}} - d_{key} = 0.67\,m$$

LATERAL WATER LOADS (continued)

UN2 CASE

Regulating Gate (2A) Operating Condition:

Regulating Crest Gate Down/Open Condition: $A1_{UN2} := TOP_{rg.UN2} \le TOC_{as}$

Regulating Crest Gate Up/Closed, with Top of Gate Higher than HW Elevation: $B1_{UN2} := TOP_{rg.UN2} \ge HW_{UN2} \wedge TOP_{rg.UN2} > TOC_{as}$

Regulating Crest Gate Up/Closed, with Top of Gate Lower than HW Elevation: $C1_{UN2} := TOP_{rg.UN2} > TOC_{as} \wedge HW_{UN2} > TOP_{rg.UN2}$

Regulating Crest Gate Height: $H_{rg.UN2} := TOP_{rg.UN2} - TOC_{as} = 0\,m$

Headwater Depth at Regulating Crest Gate: $D_{hwrg.UN2} := HW_{UN2} - TOC_{as} = 6.10\,m$

Regulating Crest Gate Width: $W_{hwrg.UN2} := 5.00m$

Lateral Headwater Pressure at Bottom of Regulating Crest Gate:

$$\sigma_{hwrg.UN2.1} := \begin{cases} (0.0kPa) & \text{if } A1_{UN2} \\ -(\gamma_w \cdot D_{hwrg.UN2}) & \text{if } B1_{UN2} \\ -(\gamma_w \cdot D_{hwrg.UN2}) & \text{if } C1_{UN2} \end{cases} = 0.0 \cdot kPa$$

Lateral Headwater Pressure at Top of Regulating Crest Gate: (Load at HW Elevation On Regulating Crest Gate if HW is below TOG_{rg})

$$\sigma_{hwrg.UN2.2} := \begin{cases} (0.0kPa) & \text{if } A1_{UN2} \\ 0.0kPa & \text{if } B1_{UN2} \\ -\left[\gamma_w \cdot (HW_{UN2} - TOP_{rg.UN2})\right] & \text{if } C1_{UN2} \end{cases} = 0.0 \cdot kPa$$

Average Pressure acting on Regulating Gate:

$$\sigma_{hwrg.UN2.avg} := \frac{(\sigma_{hwrg.UN2.1} + \sigma_{hwrg.UN2.2})}{2} = 0 \cdot kPa$$

Total Area water acting on Regulating Crest Gate:

$$A_{hwrg.UN2} := \begin{cases} D_{hwrg.UN2} \cdot W_{hwrg.UN2} & \text{if } A1_{UN2} \\ D_{hwrg.UN2} \cdot W_{hwrg.UN2} & \text{if } B1_{UN2} \\ H_{rg.UN2} \cdot W_{hwrg.UN2} & \text{if } C1_{UN2} \end{cases} = 30.5 \cdot m^2$$

Total Horizontal Headwater Load on Regulating Crest Gate: $H_{hwrg.UN2} := \sigma_{hwrg.UN2.avg} \cdot A_{hwrg.UN2} = 0.0 \cdot kN$

Apply Total Regulating Crest Gate Headwater Load at:

$$H_{hwrg.UN2.loc} := \begin{cases} (TOC_{as} - BOF_{elev}) & \text{if } A1_{UN2} \\ \left[\frac{(HW_{UN2} - TOC_{as})}{3} + (TOC_{as} - BOF_{elev})\right] & \text{if } B1_{UN2} \\ \left[\frac{\sigma_{hwrg.UN2.2} \cdot A_{hwrg.UN2} \cdot \frac{(H_{rg.UN2})}{2} + \frac{(\sigma_{hwrg.UN2.1} - \sigma_{hwrg.UN2.2})}{2} \cdot A_{hwrg.UN2} \cdot \frac{(H_{rg.UN2})}{3}}{\sigma_{hwrg.UN2.2} \cdot A_{hwrg.UN2} + \frac{(\sigma_{hwrg.UN2.1} - \sigma_{hwrg.UN2.2})}{2} \cdot A_{hwrg.UN2}} \ldots \\ + (TOC_{as} - BOF_{elev})\right] & \text{if } C1_{UN2} \end{cases} = 4.0 \cdot m$$

LATERAL WATER LOADS (continued) UN2 CASE

Guard Gate (4A) Operating Condition:

Guard Gate Down/Open Condition: $A2_{UN2} := TOP_{gg.UN2} \le TOC_{as}$

Guard Crest Gate Up/Closed, with Top of Gate Higher than HW Elevation: $B2_{UN2} := TOP_{gg.UN2} \ge HW_{UN2} \wedge TOP_{gg.UN2} > TOC_{as}$

Guard Crest Gate Up/Closed, with Top of Gate Lower than HW Elevation: $C2_{UN2} := TOP_{gg.UN2} > TOC_{as} \wedge HW_{UN2} > TOP_{gg.UN2}$

Guard Crest Gate Height: $H_{gg.UN2} := TOP_{gg.UN2} - TOC_{as} = 5\,m$

Headwater Depth at Guard Crest Gate: $D_{hwgg.UN2} := HW_{UN2} - TOC_{as} = 6.10\,m$

Guard Crest Gate Width: $W_{hwgg.UN2} := 5.00m$

Lateral Headwater Pressure at Bottom of Guard Crest Gate:

$$\sigma_{hwgg.UN2.1} := \begin{cases} (0.0kPa) & \text{if } A2_{UN2} \\ -(\gamma_w \cdot D_{hwgg.UN2}) & \text{if } B2_{UN2} \\ -(\gamma_w \cdot D_{hwgg.UN2}) & \text{if } C2_{UN2} \end{cases} = -59.8 \cdot kPa$$

Lateral Headwater Pressure at Top of Guard Crest Gate: (Load at HW Elevation On Guard Crest Gate if HW is below TOG_{rg})

$$\sigma_{hwgg.UN2.2} := \begin{cases} (0.0kPa) & \text{if } A2_{UN2} \\ 0.0kPa & \text{if } B2_{UN2} \\ -\left[\gamma_w \cdot (HW_{UN2} - TOP_{gg.UN2})\right] & \text{if } C2_{UN2} \end{cases} = -10.8 \cdot kPa$$

Average Pressure acting on Guard Crest Gate:

$$\sigma_{hwgg.UN2.avg} := \frac{(\sigma_{hwgg.UN2.1} + \sigma_{hwgg.UN2.2})}{2} = -35.32 \cdot kPa$$

Total Area water acting on Crest Gate:

$$A_{hwgg.UN2} := \begin{cases} D_{hwgg.UN2} \cdot W_{hwgg.UN2} & \text{if } A2_{UN2} \\ D_{hwgg.UN2} \cdot W_{hwgg.UN2} & \text{if } B2_{UN2} \\ H_{gg.UN2} \cdot W_{hwgg.UN2} & \text{if } C2_{UN2} \end{cases} = 25 \cdot m^2$$

Total Horizontal Headwater Load on Guard Crest Gate: $H_{hwgg.UN2} := \sigma_{hwgg.UN2.avg} \cdot A_{hwgg.UN2} = -882.9 \cdot kN$

Apply Total Guard Crest Gate Headwater Load at:

$$H_{hwgg.UN2.loc} := \begin{cases} (TOC_{as} - BOF_{elev}) & \text{if } A2_{UN2} \\ \left[\frac{(HW_{UN2} - TOC_{as})}{3} + (TOC_{as} - BOF_{elev})\right] & \text{if } B2_{UN2} \\ \left[\frac{\sigma_{hwgg.UN2.2} \cdot A_{hwgg.UN2} \cdot \frac{(H_{gg.UN2})}{2} + \frac{(\sigma_{hwgg.UN2.1} - \sigma_{hwgg.UN2.2})}{2} A_{hwgg.UN2} \cdot \frac{(H_{gg.UN2})}{3}}{\sigma_{hwgg.UN2.2} \cdot A_{hwgg.UN2} + \frac{(\sigma_{hwgg.UN2.1} - \sigma_{hwgg.UN2.2})}{2} \cdot A_{hwgg.UN2}} \ldots \\ + (TOC_{as} - BOF_{elev})\right] & \text{if } C2_{UN2} \end{cases} = 5.9 \cdot m$$

LATERAL TAILWATER (RESISTING) Applied to Downstream Side of Regulating Crest Gate:

UN2 CASE

Regulating Crest Gate Down/Open Condition: $A3_{UN2} := TOP_{rg.UN2} \le TOC_{as}$

Regulating Crest Gate Up/Closed, with Top of Gate Higher than TW Elevation: $B3_{UN2} := TOP_{rg.UN2} \ge TW_{UN2} \wedge TOP_{rg.UN2} > TOC_{as}$

Regulating Crest Gate Up/Closed, with Top of Gate Lower than TW Elevation: $C3_{UN2} := TOP_{rg.UN2} > TOC_{as} \wedge TW_{UN2} > TOP_{rg.UN2}$

Regulating Crest Gate Height: $H_{rg.UN2} = 0\,m$

Tailwater Depth at Regulating Crest Gate: $D_{twrg.UN2} := TW_{UN2} - TOC_{as} = 3.00\,m$

Regulating Crest Gate Width: $W_{twrg.UN2} := 5m$

Lateral Tailwater Pressure at Bottom of Regulating Crest Gate:

$$\sigma_{twrg.UN2.1} := \begin{cases} (0.0kPa) & \text{if } A3_{UN2} \\ -(\gamma_w \cdot D_{twrg.UN2}) & \text{if } B3_{UN2} \\ -(\gamma_w \cdot D_{twrg.UN2}) & \text{if } C3_{UN2} \end{cases} = 0.0 \cdot kPa$$

Lateral Tailwater Pressure at Top of Regulating Crest Gate: (Load at TW Elevation On Regulating Crest Gate if TW is below TOG_{rg})

$$\sigma_{twrg.UN2.2} := \begin{cases} (0.0kPa) & \text{if } A3_{UN2} \\ 0.0kPa & \text{if } B3_{UN2} \\ -[\gamma_w \cdot (TW_{UN2} - TOP_{rg.UN2})] & \text{if } C3_{UN2} \end{cases} = 0.0 \cdot kPa$$

Average Pressure acting on Regulating Gate:

$$\sigma_{twrg.UN2.avg} := \frac{(\sigma_{twrg.UN2.1} + \sigma_{twrg.UN2.2})}{2} = 0 \cdot kPa$$

Total Area water acting on Regulating Crest Gate:

$$A_{twrg.UN2} := \begin{cases} D_{twrg.UN2} \cdot W_{twrg.UN2} & \text{if } A3_{UN2} \\ D_{twrg.UN2} \cdot W_{twrg.UN2} & \text{if } B3_{UN2} \\ H_{rg.UN2} \cdot W_{twrg.UN2} & \text{if } C3_{UN2} \end{cases} = 15 \cdot m^2$$

Total Horizontal Tailwater Load on Regulating Crest Gate: $H_{twrg.UN2} := \sigma_{hwrg.UN2.avg} \cdot A_{hwrg.UN2} = 0.0 \cdot kN$

Apply Total Regulating Crest Gate Tailwater Load at:

$$H_{twrg.UN2.loc} := \begin{cases} (TOC_{as} - BOF_{elev}) & \text{if } A3_{UN2} \\ \left[\frac{(HW_{UN2} - TOC_{as})}{3} + (TOC_{as} - BOF_{elev})\right] & \text{if } B3_{UN2} \\ \left[\frac{\sigma_{hwrg.UN2.2} \cdot A_{hwrg.UN2} \cdot \frac{(H_{rg.UN2})}{2} + \frac{(\sigma_{hwrg.UN2.1} - \sigma_{hwrg.UN2.2})}{2} A_{hwrg.UN2} \cdot \frac{(H_{rg.UN2})}{3}}{\sigma_{hwrg.UN2.2} \cdot A_{hwrg.UN2} + \frac{(\sigma_{hwrg.UN2.1} - \sigma_{hwrg.UN2.2})}{2} \cdot A_{hwrg.UN2}} \ldots \\ + (TOC_{as} - BOF_{elev})\right] & \text{if } C3_{UN2} \end{cases} = 4.0 \cdot m$$

LATERAL TAILWATER (RESISTING) Applied to Downstream Side of Guard Crest Gate:

UN2 CASE

Guard Gate Down/Open Condition: $A4_{UN2} := TOP_{gg.UN2} \le TOC_{as}$

Guard Crest Gate Up/Closed, with Top of Gate Higher than TW Elevation: $B4_{UN2} := TOP_{gg.UN2} \ge TW_{UN2} \wedge TOP_{gg.UN2} > TOC_{as}$

Guard Crest Gate Up/Closed, with Top of Gate Lower than TW Elevation: $C4_{UN2} := TOP_{gg.UN2} > TOC_{as} \wedge TW_{UN2} > TOP_{gg.UN2}$

Tailwater Depth at Guard Crest Gate: $D_{twgg.UN2} := TW_{UN2} - TOC_{as} = 3.00\,m$

Guard Crest Gate Height: $H_{gg.UN2} = 5\,m$

Guard Crest Gate Width: $W_{twgg.UN2} := 5.00m$

Lateral Water Load at Bottom of Guard Crest Gate:

$$\sigma_{twgg.UN2.1} := \begin{cases} (0.0kPa) & \text{if } A4_{UN2} \\ (\gamma_w \cdot D_{twgg.UN2}) & \text{if } B4_{UN2} \\ (\gamma_w \cdot D_{twgg.UN2}) & \text{if } C4_{UN2} \end{cases} = 29.4 \cdot kPa$$

Lateral Water Load at Top of Guard Crest Gate:
(Load at TW Elevation On Guard Crest Gate if TW is below TOG_{gg})

$$\sigma_{twgg.UN2.2} := \begin{cases} (0.0kPa) & \text{if } A4_{UN2} \\ 0.0kPa & \text{if } B4_{UN2} \\ \left[\gamma_w \cdot (TW_{UN2} - TOP_{gg.UN2})\right] & \text{if } C4_{UN2} \end{cases} = 0.0 \cdot kPa$$

Average Pressure acting on Guard Crest Gate:

$$\sigma_{twgg.UN2.avg} := \frac{(\sigma_{twgg.UN2.1} + \sigma_{twgg.UN2.2})}{2} = 14.71 \cdot kPa$$

Total Area water acting on Crest Gate:

$$A_{twgg.UN2} := \begin{cases} D_{twgg.UN2} \cdot W_{twgg.UN2} & \text{if } A4_{UN2} \\ D_{twgg.UN2} \cdot W_{twgg.UN2} & \text{if } B4_{UN2} \\ H_{gg.UN2} \cdot W_{twgg.UN2} & \text{if } C4_{UN2} \end{cases} = 15 \cdot m^2$$

Total Horizontal Tailwater Load on Guard Crest Gate:

$$H_{twgg.UN2} := \sigma_{twgg.UN2.avg} \cdot A_{twgg.UN2} = 220.7 \cdot kN$$

Apply Total Horiz. TW Load on Guard Gate at:

$$H_{twgg.UN2.loc} := \begin{cases} (TOC_{as} - BOF_{elev}) & \text{if } A4_{UN2} \\ \left[\frac{(TW_{UN2} - TOC_{as})}{3} + (TOC_{as} - BOF_{elev})\right] & \text{if } B4_{UN2} \\ \left[\frac{\sigma_{twgg.UN2.2} \cdot A_{twgg.UN2} \cdot \frac{(H_{gg.UN2})}{2} + \frac{(\sigma_{twgg.UN2.1} - \sigma_{twgg.UN2.2})}{2} A_{twgg.UN2} \cdot \frac{(H_{gg.UN2})}{3}}{\sigma_{twgg.UN2.2} \cdot A_{twgg.UN2} + \frac{(\sigma_{twgg.UN2.1} - \sigma_{twgg.UN2.2})}{2} \cdot A_{twgg.UN2}} \ldots \\ + (TOC_{as} - BOF_{elev})\right] & \text{if } C4_{UN2} \end{cases} = 5.0 \cdot m$$

LATERAL WATER LOADS (continued) UN2 CASE

TAILWATER (RESISTING) Applied to Concrete Structure:

Tailwater Depth on Pier: $D_{twp.UN2} := TW_{UN2} - TOC_{as} = 3.00\,m$

Tailwater Load Unit Width on Pier: $W_{twp.UN2} := w_p = 2.00\,m$

Total Horizontal Tailwater Load on Pier: $H_{twp.UN2} := \frac{\left(\gamma_w \cdot D_{twp.UN2}^{\ 2}\right)}{2} \cdot W_{twp.UN2} = 88.3 \cdot kN$

Apply Total Pier Tailwater Load at: $H_{twp.UN2.loc} := \frac{D_{twp.UN2}}{3} + \left(TOC_{as} - BOF_{elev}\right) = 5.00\,m$

Tailwater Depth At top of Gate Base Footing Elevation: $D_{twgf.UN2} := TW_{UN2} - TOC_{as} = 3.00\,m$

Water Depth at bottom of Gate Base Footing (Excluding Key): $D_{twtoe.UN2} := TW_{UN2} - BOF_{elev} = 7.00\,m$

Footing Thickness for horizontal at Toe: $h_{toe} = 4\,m$

Unit Width of D/S face of crest for application of Tailwater Load: $W_{tw.UN2} := W_b = 12.00\,m$

Tailwater Pressure At Top of Gate Footing: $\sigma_{twgf.UN2} := \left(\gamma_w \cdot D_{twgf.UN2}\right) = 29.43 \cdot kPa$

Tailwater Pressure At Toe: $\sigma_{twtoe.UN2} := \left(\gamma_w \cdot D_{twtoe.UN2}\right) = 68.67 \cdot kPa$

Triangular Distribution Unit Load on Gate Footing Base (including key): $H_{twgf.UN2.tri} := \left(\frac{\sigma_{twtoe.UN2} - \sigma_{twgf.UN2}}{2}\right) \cdot \left[\left(T_{as} - d_{key}\right) \cdot W_{tw.UN2}\right] = 941.76 \cdot kN$

Rectangular Distribution Unit Load on Gate Footing Base (including key): $H_{twgf.UN2.rect} := \sigma_{twgf.UN2} \cdot \left[\left(T_{as} - d_{key}\right) \cdot W_{tw.UN2}\right] = 1412.64 \cdot kN$

Tailwater Pressure At Bottom of Sliding Failure Plane: $\sigma_{twbk.UN2} := \left(HW_{UN2} - BOK_{elev}\right) \cdot \gamma_w = 118.7 \cdot kPa$

Triangular Distribution Unit Load Below Footing: $H_{twbk.UN2.tri} := \frac{\left(\sigma_{twbk.UN2} - \sigma_{twtoe.UN2}\right)}{2} \cdot d_{key} \cdot W_{tw.UN2} = 600.37 \cdot kN$

Rectangular Distribution Load Below Footing Base: $H_{twbk.UN2.rect} := \sigma_{twtoe.UN2} \cdot d_{key} \cdot W_{tw.UN2} = 1648.08 \cdot kN$

Total Horizontal Tailwater Headwater Load on Gate Footing (including key): $H_{twgk.UN2} := H_{twgf.UN2.tri} + H_{twgf.UN2.rect} + H_{twbk.UN2.tri} + H_{twbk.UN2.rect} = 4602.85 \cdot kN$

Apply Total Gate Footing Tailwater Load at:

$$H_{twgk.UN2.loc} := \frac{\left[H_{twgf.UN2.rect} \cdot \frac{\left(h_{toe}\right)}{2} + H_{twgf.UN2.tri} \cdot \frac{\left(h_{toe}\right)}{3} + H_{twbk.UN2.tri} \cdot \left(-d_{key} \cdot \frac{2}{3}\right) + H_{twbk.UN2.rect} \cdot \left(\frac{-d_{key}}{2}\right)\right]}{H_{twgf.UN2.tri} + H_{twgf.UN2.rect} + H_{twbk.UN2.tri} + H_{twbk.UN2.rect}} = 0.35\,m$$

SUMMATION OF LATERAL WATER LOADS:

$$\Sigma H_{Water.UN2} := H_{hwp.UN2} + H_{hwas.UN2} + H_{hwrg.UN2} + H_{hwgg.UN2} + H_{twp.UN2} + H_{twgk.UN2} + H_{twrg.UN2} + H_{twgg.UN2} = -2763.58 \cdot kN$$

$$\Sigma M_{Hwater.UN2} := H_{hwp.UN2} \cdot H_{hwp.UN2.loc} + H_{hwas.UN2} \cdot H_{hwas.UN2.loc} + H_{hwrg.UN2} \cdot H_{hwrg.UN2.loc} + H_{hwgg.UN2} \cdot H_{hwgg.UN2.loc} + H_{twp.UN2} \cdot H_{twp.UN2.loc} + H_{twgk.UN2} \cdot H_{twgk.UN2.loc} + H_{twrg.UN2} \cdot H_{twrg.UN2.loc} + H_{twgg.UN2} \cdot H_{twgg.UN2.loc} = -8561.35 \cdot kN \cdot m$$

VERTICAL WATER LOADS

UN2 CASE

HEADWATER:

Water Depth on top of Approach Slab: $d_{hw.UN2} := HW_{UN2} - TOC_{as} = 6.10\,m$

Length of Approach Slab: $L_{as} = 8.75\,m$

Width of Approach Slab: $w_{as} = 12.00\,m$

Length from front of Gate to Heel: $L_{hg} = 8.75\,m$

Vertical Water Weight (H1) on Approach Slab:

$$H_{1.UN2} := \left[w_{as} \cdot d_{hw.UN2} \cdot L_{hg} - w_p \cdot d_{hw.UN2} \cdot \left(L_{hg} - L_{as}\right)\right] \cdot \gamma_w = 6283.3 \cdot kN$$

Moment Arm for Application of Water Weight (H1) from toe:

$$H_{1.UN2.loc} := L_b - \frac{L_{hg}}{2} = 14.13\,m$$

TAILWATER ABOVE GUARD GATE:

Trapezoid Volume Above Gate Footing from Approach Slab to Crest:

$$V_{asc.gg.UN2} := \left(L_{gf} - L_{gfc}\right) W_{twgg.UN2} \frac{d_{hw.UN2} + Y_{C.gg.UN2}}{2} = 223.97 \cdot m^3$$

Trapezoid Volume Above Gate Footing Crest to End of Gate Footing:

$$V_{gfc.gg.UN2} := \left(L_{gfc} \cdot W_{twgg.UN2}\right) \frac{Y_{C.gg.UN2} + Y_{TOE.gg.UN2}}{2} = 74.3\,m^3$$

Load Above Gate Footing from Approach Slab to Crest:

$$H_{2.UN2.asc.gg} := V_{asc.gg.UN2} \cdot \gamma_w = 2197.18 \cdot kN$$

Load Acting Above Footing Crest from Toe:

$$H_{2.UN2.asc.gg.loc} := \frac{\left(L_{gf} - L_{gfc}\right) \cdot \left(2 \cdot d_{hw.UN2} + Y_{C.gg.UN2}\right)}{3 \cdot \left(d_{hw.UN2} + Y_{C.gg.UN2}\right)} + L_{gfc} = 6.14\,m$$

Load Above Gate Footing from Crest to End:

$$H_{2.UN2.gfc.gg} := V_{gfc.gg.UN2} \cdot \gamma_w = 728.83 \cdot kN$$

Load Acting Above Gate Footing from Crest to End:

$$H_{2.UN2.gfc.gg.loc} := \frac{\left(L_{gfc}\right) \cdot \left(2 \cdot Y_{C.gg.UN2} + Y_{TOE.gg.UN2}\right)}{3 \cdot \left(Y_{C.gg.UN2} + Y_{TOE.gg.UN2}\right)} = 1.35\,m$$

Vertical Water Weight (H2) on Guard Gate Footing:

$$H_{2.UN2.gg} := H_{2.UN2.asc.gg} + H_{2.UN2.gfc.gg} = 2926.02 \cdot kN$$

Moment Arm for Application of Water Weight (H2) from toe:

$$H_{2.UN2.gg.loc} := \frac{H_{2.UN2.asc.gg} \cdot H_{2.UN2.asc.gg.loc} + H_{2.UN2.gfc.gg} \cdot H_{2.UN2.gfc.gg.loc}}{H_{2.UN2.gg}} = 4.95\,m$$

TAILWATER ABOVE REGULATING GATE:

Trapezoid Volume Above Gate Footing from Approach Slab to Crest:

$$V_{asc.rg.UN2} := \left(L_{gf} - L_{gfc}\right) W_{twrg.UN2} \frac{d_{hw.UN2} + Y_{C.rg.UN2}}{2} = 194.3 \cdot m^3$$

Trapezoid Volume Above Gate Footing Crest to End of Gate Footing:

$$V_{gfc.rg.UN2} := \left(L_{gfc} \cdot W_{twrg.UN2}\right) \frac{Y_{C.rg.UN2} + Y_{TOE.rg.UN2}}{2} = 43.81 \cdot m^3$$

Load Above Gate Footing from Approach Slab to Crest:

$$H_{2.UN2.asc.rg} := V_{asc.rg.UN2} \cdot \gamma_w = 1906.1 \cdot kN$$

Load Acting Above Footing Crest from Toe:

$$H_{2.UN2.asc.rg.loc} := \frac{\left(L_{gf} - L_{gfc}\right) \cdot \left(2 \cdot d_{hw.UN2} + Y_{C.rg.UN2}\right)}{3 \cdot \left(d_{hw.UN2} + Y_{C.rg.UN2}\right)} + L_{gfc} = 6.32\,m$$

Load Above Gate Footing from Crest to End:

$$H_{2.UN2.gfc.rg} := V_{gfc.rg.UN2} \cdot \gamma_w = 429.78 \cdot kN$$

Load Acting Above Gate Footing from Crest to End:

$$H_{2.UN2.gfc.rg.loc} := \frac{\left(L_{gfc}\right) \cdot \left(2 \cdot Y_{C.rg.UN2} + Y_{TOE.rg.UN2}\right)}{3 \cdot \left(Y_{C.rg.UN2} + Y_{TOE.rg.UN2}\right)} = 1.48\,m$$

Vertical Water Weight (H2) on Regulating Gate Footing:

$$H_{2.UN2.rg} := H_{2.UN2.asc.rg} + H_{2.UN2.gfc.rg} = 2335.87 \cdot kN$$

Moment Arm for Application of Water Weight (H2) from toe:

$$H_{2.UN2.rg.loc} := \frac{H_{2.UN2.asc.rg} \cdot H_{2.UN2.asc.rg.loc} + H_{2.UN2.gfc.rg} \cdot H_{2.UN2.gfc.rg.loc}}{H_{2.UN2.rg}} = 5.43\,m$$

UPLIFT

UN2 CASE

Uplift pressure at U/S Face (heel): $U_{HW.UN2} := \left(D_{hwas.UN2}\right)\cdot\gamma_w = 118.7\cdot\frac{kN}{m^2}$

Uplift pressure at D/S Face Stilling Basin: $U_{TW.UN2} := \left(D_{twtoe.UN2}\right)\cdot\gamma_w = 68.67\cdot\frac{kN}{m^2}$

Difference between Uplift pressure at HW and TW: $U_{diff.UN2} := U_{HW.UN2} - U_{TW.UN2} = 50.03\cdot\frac{kN}{m^2}$

Slope of difference between between Uplift pressure at HW and TW: $U_{slope.UN2} := \frac{U_{diff.UN2}}{L_{overall}} = 2.70\cdot\frac{kN}{m^2\cdot m}$

Tailwater Pressure at toe of Gate Structure: $U_{press.toe.gs.UN2} := U_{TW.UN2} + \left(L_{overall} - L_b\right)\cdot U_{slope.UN2} = 68.67\cdot\frac{kN}{m^2}$

Uniform uplift force UA Under Gate Structure due to TW (rectangle): $U_{A.UN2} := U_{press.toe.gs.UN2}\cdot L_b\cdot W_b\cdot -1 = -15244.74\cdot kN$

Moment Arm from Toe of Gate Structure for Uplift UA: $L_{A.UN2} := \left(\frac{L_b}{2}\right) = 9.25\,m$

Linearly Decreasing Uplift Force UN2B Under Gate Structure due to HW-TW Differential (triangle): $U_{B.UN2} := \frac{1}{2}\cdot\left(U_{HW.UN2} - U_{press.toe.gs.UN2}\right)\cdot L_b\cdot W_b\cdot -1 = -5553.44\cdot kN$

Moment Arm from Toe of Gate Structure for Uplift UB: $L_{B.UN2} := \frac{2}{3}\cdot L_b = 12.33\,m$

Total Resultant Uplift force: $U_{UN2} := U_{A.UN2} + U_{B.UN2} = -20798.18\cdot kN$

Resultant Location from Toe: $U_{UN2.loc} := \frac{\left(U_{A.UN2}\cdot L_{A.UN2} + U_{B.UN2}\cdot L_{B.UN2}\right)}{\left(U_{A.UN2} + U_{B.UN2}\right)} = 10.07\,m$

$\Sigma V_{water.UN2} := H_{1.UN2} + H_{2.UN2.gg} + H_{2.UN2.rg} + U_{UN2} = -9252.99\cdot kN$

$\Sigma M_{Vwater.UN2} := H_{1.UN2}\cdot H_{1.UN2.loc} + H_{2.UN2.gg}\cdot H_{2.UN2.gg.loc} + H_{2.UN2.rg}\cdot H_{2.UN2.rg.loc} + U_{UN2}\cdot U_{UN2.loc} = -93584.82\cdot kN\cdot m$

SOIL LOADS

UN2 CASE

Equivalent Fluid Pressure (EFP):

At rest lateral pressure coefficient: $K_{o.UN2} := 1 - \sin(\phi_{backfill}) = 0.658$ (Section 5.3, Design Criteria)

Headwater Pier Footing Unit Width: $W_{hwas.UN2} = 12.00\,m$

Tailwater Pier Footing Unit Width: $W_{tw.UN2} = 12.00\,m$

Pier Footing Thickness at Heel: $t_{hf.UN2} := TOC_{as} - BOK_{elev} = 6.00\,m$

Fixed Crest Footing Thickness at Toe: $t_{tf.UN2} := TOC_{pfe} - BOF_{elev} = 2.00\,m$

Lateral Driving Force (Headwater Side - at rest condition)

Structure Soil Load:

$$E_{act.UN2} := \frac{\left(K_{o.UN2} \cdot t_{hf.UN2}^{\ 2}\right)}{2} \cdot \left(\gamma_r - \gamma_w\right) \cdot W_{hwas.UN2} \cdot -1 = -1732.49 \cdot kN$$

Acting at:

$$E_{act.UN2.loc} := \frac{t_{hf.UN2}}{3} - d_{key} = 0.00\,m$$

Lateral Resisting Force (Tailwater Side - at rest condition)

At-rest Soil Load:

$$E_{pass.UN2} := \frac{\left(K_{o.UN2} \cdot t_{tf.UN2}^{\ 2}\right)}{2} \cdot \left(\gamma_r - \gamma_w\right) \cdot W_{tw.UN2} = 192.5 \cdot kN$$

Acting at:

$$E_{pass.UN2.loc} := \frac{t_{tf.UN2}}{3} = 0.67\,m$$

$$\Sigma H_{soil.UN2} := E_{act.UN2} + E_{pass.UN2} = -1539.99 \cdot kN$$

$$\Sigma M_{soil.UN2} := E_{act.UN2} \cdot E_{act.UN2.loc} + E_{pass.UN2} \cdot E_{pass.UN2.loc} = 128.33 \cdot kN \cdot m$$

ICE / IMPACT LOADS (ASSUME NO ICE LOADING ON TAILWATER SIDE)

Static Ice Loading on Structure: $I_{S.UN2} := 150.0 \frac{kN}{m}$

Ice Loading Unit Width on Structure: $W_{S.UN2} := 2.00m$ (Section 7.7, Design Criteria)

Static Ice load on Gates: (Section 7.7, Design Criteria)

$$I_{rg.UN2} := \begin{cases} 0 \frac{kN}{m} & \text{if } TOP_{rg.UN2} \le TOC_{as} \\ 150 \frac{kN}{m} & \text{if } TOP_{rg.UN2} > TOC_{as} \end{cases} = 0 \cdot \frac{kN}{m}$$

$$I_{gg.UN2} := \begin{cases} 0 \frac{kN}{m} & \text{if } TOP_{rg.UN2} \le TOC_{as} \\ 150 \frac{kN}{m} & \text{if } TOP_{rg.UN2} > TOC_{as} \end{cases} = 0 \cdot \frac{kN}{m}$$

Ice Loading Unit Width on Crest Gates: $W_{rg.UN2} := 5m$ $W_{gg.UN2} := 5m$ (Input value for load case)

Total Ice Load on Structure: $I_{UN2} := \left(I_{S.UN2} \cdot W_{S.UN2} + I_{rg.UN2} \cdot W_{rg.UN2} + I_{gg.UN2} \cdot W_{gg.UN2}\right) \cdot -1 = -300 \cdot kN$

Apply Ice load at: $I_{UN2.loc} := \left(HW_{UN2} - BOF_{elev} - 0.30m\right) = 9.80\,m$

$$\Sigma H_{I.UN2} := I_{UN2} = -300 \cdot kN$$

$$\Sigma M_{I.UN2} := I_{UN2} \cdot I_{UN2.loc} = -2940 \cdot kN \cdot m$$

SEISMIC LOAD (NOT APPLICABLE FOR THIS LOAD CASE)

UN2 CASE

SUMMARY OF LOADS

	Loads	Moment Arm
Dead load of Concrete Structure:	$D_{conc} = 22438.7 \cdot kN$	$X_{conc.loc} = 9.35\,m$
Obermyer Gate Weight:	$D_{Gate} = 140.0 \cdot kN$	$X_{gate} = 9.50\,m$
HW Lateral Load on Pier:	$H_{hwp.UN2} = -365.0 \cdot kN$	$H_{hwp.UN2.loc} = 6.03\,m$
HW Lateral Load on Approach Slab:	$H_{hwas.UN2} = -6427.5 \cdot kN$	$H_{hwas.UN2.loc} = 0.67\,m$
HW Lateral Load on Regulating Gate:	$H_{hwrg.UN2} = 0.0 \cdot kN$	$H_{hwrg.UN2.loc} = 4.00\,m$
HW Lateral Load on Guard Gate:	$H_{hwgg.UN2} = -882.9 \cdot kN$	$H_{hwgg.UN2.loc} = 5.92\,m$
TW Lateral Load on Pier:	$H_{twp.UN2} = 88.3 \cdot kN$	$H_{twp.UN2.loc} = 5.00\,m$
TW Lateral Load on Pier Footing (including Key):	$H_{twgk.UN2} = 4602.85 \cdot kN$	$H_{twgk.UN2.loc} = 0.35\,m$
TW Lateral Load on Regulating Gate:	$H_{twrg.UN2} = 0.0 \cdot kN$	$H_{twrg.UN2.loc} = 4.00\,m$
TW Lateral Load on Guard Gate:	$H_{twgg.UN2} = 220.7 \cdot kN$	$H_{twgg.UN2.loc} = 5.00\,m$
Vertical HW Load on Approach Slab:	$H_{1.UN2} = 6283.3 \cdot kN$	$H_{1.UN2.loc} = 14.13\,m$
Vertical TW Load on Regulating Gate:	$H_{2.UN2.rg} = 2335.9 \cdot kN$	$H_{2.UN2.rg.loc} = 5.43\,m$
Vertical TW Load on Guard Gate:	$H_{2.UN2.gg} = 2926.0 \cdot kN$	$H_{2.UN2.gg.loc} = 4.95\,m$
Uplift:	$U_{UN2} = -20798.2 \cdot kN$	$U_{UN2.loc} = 10.07\,m$
Lateral Soil Load (driving):	$E_{act.UN2} = -1732.5 \cdot kN$	$E_{act.UN2.loc} = 0.00\,m$
Lateral Soil Load (resisting):	$E_{pass.UN2} = 192.5 \cdot kN$	$E_{pass.UN2.loc} = 0.67\,m$
Ice / Impact Load:	$I_{UN2} = -300.0 \cdot kN$	$I_{UN2.loc} = 9.80\,m$

STABILITY ASSESSMENT (SLIDNG, BEARING, FLOTATION AND OVERTURNING): UN2 CASE

CHECK SLIDING ALONG HORIZONTAL PLANE THRU TOE,
IGNORING BEDROCK MOBILIZED BY STRUCTURAL HEEL KEY, OR VOID BEHIND KEY

Sum of Vertical Forces:

$\Sigma V_{UN2} := \Sigma V_{DL} + \Sigma V_{water.UN2} = 13325.8 \cdot kN$

Sum of Horizontal Forces:

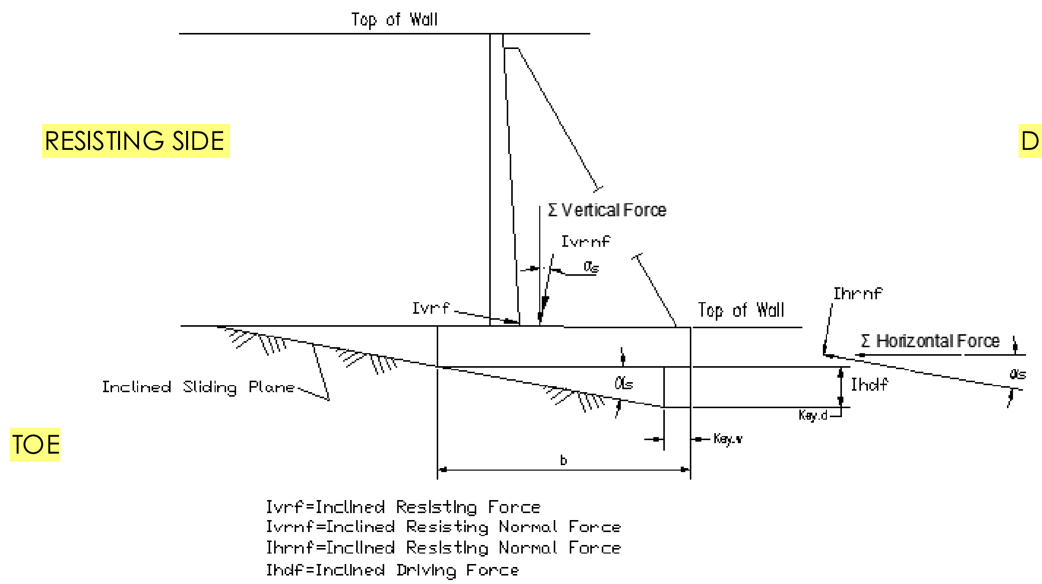
$\Sigma H_{UN2} := \Sigma H_{Water.UN2} + \Sigma H_{soil.UN2} + \Sigma H_{I.UN2} = -4603.56 \cdot kN$

Sliding Factor of Safety:

$$FS_{HorizSliding.UN2} := \frac{\tan_{\phi} \cdot \Sigma V_{UN2}}{\left|\Sigma H_{UN2}\right|} = 1.41$$

$FS_{HorizSliding.UN2.Check} :=$ | "OKAY" if $FS_{HorizSliding.UN2} \geq FS_{req.UN2.sl}$ = "OKAY"
| "Check Inclined Sliding with Key" otherwise

CHECK SLIDING ALONG INCLINED SLIDING PLANE FROM HEEL KEY TO TOE,
WITH BEDROCK MASS MOBILIZED BY REINFOCREDE CONCRETE KEY)



$\Sigma V_{UN2} = 13325.75 \cdot kN$

$V_{rs} = 4620 \cdot kN$

$\alpha s = 0.11$ as degrees= $\alpha s \cdot \left(\frac{180}{\pi}\right) = 6.52$

Resolve $\Sigma Vert_{UN2}$ & $\Sigma Horiz_{UN2}$

$$\Sigma V_{InclinedUN2} := \cos(\alpha s) \cdot \left(\Sigma V_{UN2} + V_{rs}\right) + \sin(\alpha s) \cdot \left|\Sigma H_{UN2}\right| = 18352.4 \cdot kN$$

$$\Sigma H_{InclinedUN2} := \cos(\alpha s) \cdot \left|\Sigma H_{UN2}\right| - \sin(\alpha s) \cdot \left(\Sigma V_{UN2} + V_{rs}\right) = 2536.1 \cdot kN$$

(With properly engineered reinforced concrete Key, horizontal sliding plane thru Toe is protected, critical sliding plane is relocated to the INCLINED SLIDING PLANE FROM HEEL KEY To TOE, Bedrock Mass above this examined plane is mobilized by reinforced concrete key and combined into Structural Wedge.)

Inclined Sliding Plane Length

$L_{incline} = 18.61 \, m$

Safety Factor for Sliding
Inclined Failure Plane

$$FS_{InclinedlSlidingUN2} := \frac{\Sigma V_{InclinedUN2} \cdot \tan\left(\phi_{rock} \cdot \frac{\pi}{180}\right)}{\left|\Sigma H_{InclinedUN2}\right|} = 3.53$$

$FS_{InclinedSliding.check.UN2} :=$ | "OKAY " if $FS_{InclinedlSlidingUN2} > FS_{req.UN2.sl}$ = "OKAY "
| "Revise Structure"" otherwise

$FS_{InclinedSliding.check.UN2}$ = "OKAY "

UN2 CASE

OVERTURNING STABILITY CHECK:

CHECK ECCENTRICITY

Sum of the moments:

$$\Sigma M_{UN2} := \Sigma M_{DL} + \Sigma M_{Hwater.UN2} + \Sigma M_{Vwater.UN2} + \Sigma M_{I.UN2} + \Sigma M_{soil.UN2} + \Sigma M_{rs} = 160062 \cdot kN \cdot m$$

Eccentricity:

$$e_{UN2} := \left(\frac{L_{incline}}{2}\right) - \frac{\left(\Sigma M_{UN2}\right)}{\Sigma V_{InclinedUN2}} = 0.58\,m$$

Eccentricity Check:

$$e_{check.UN2} := \begin{cases} \text{"Okay"} & \text{if } e_{UN2} \le Kern \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$$e_{check.UN2} = \text{"Okay"}$$

Foundation Bearing Checks:

Bearing Pressure at Heel:

$$\sigma_{heel.UN2} := \frac{\Sigma V_{InclinedUN2}}{A_{b.incline}} - \frac{\left(\Sigma V_{InclinedUN2} \cdot e_{UN2}\right)}{S_{b.incline}} = 66.8 \cdot \frac{kN}{m^2}$$

$$\sigma_{heel.UN2.check} := \left(\begin{cases} \text{"Okay"} & \text{if } \sigma_{heel.UN2} \le \sigma_{allow.UN2} \\ \text{"Revise Structure"} & \text{if } \sigma_{heel.UN2} < 0 \frac{kN}{m^2} \end{cases} \right)$$

$$\sigma_{heel.UN2.check} = \text{"Okay"}$$

Bearing Pressure at Toe:

$$\sigma_{toe.UN2} := \frac{\Sigma V_{InclinedUN2}}{A_{b.incline}} + \frac{\left(\Sigma V_{InclinedUN2} \cdot e_{UN2}\right)}{S_{b.incline}} = 97.6 \cdot \frac{kN}{m^2}$$

$$\sigma_{toe.UN2.1.check} := \begin{cases} \text{"Okay"} & \text{if } \sigma_{toe.UN2} \le \sigma_{allow.UN2} \\ \text{"Revise Structure"} & \text{if } \sigma_{toe.UN2} < 0 \frac{kN}{m^2} \end{cases}$$

$$\sigma_{toe.UN2.1.check} = \text{"Okay"}$$

FLOATATION ANALYSIS:

ACCEPTANCE PARAMETERS

Required Factor of Safety: $FS_{req.FUN2} := 1.3$

VERTICAL LOADS RESISTING:

Dead Load: $\Sigma V_{DL} = 22578.74 \cdot kN$

Water Weight H1+H2: $\Sigma V_{H.FUN2} := H_{1.UN2} + H_{2.UN2.gg} + H_{2.UN2.rg} = 11545.19 \cdot kN$

Summation Vertical Resisting: $\Sigma V_{FUN2} := \Sigma V_{DL} + \Sigma V_{H.FUN2} = 34123.9 \cdot kN$

VERTICAL LOADS UPLIFT:

Uplift: $U_{UN2} = -20798.18 \cdot kN$

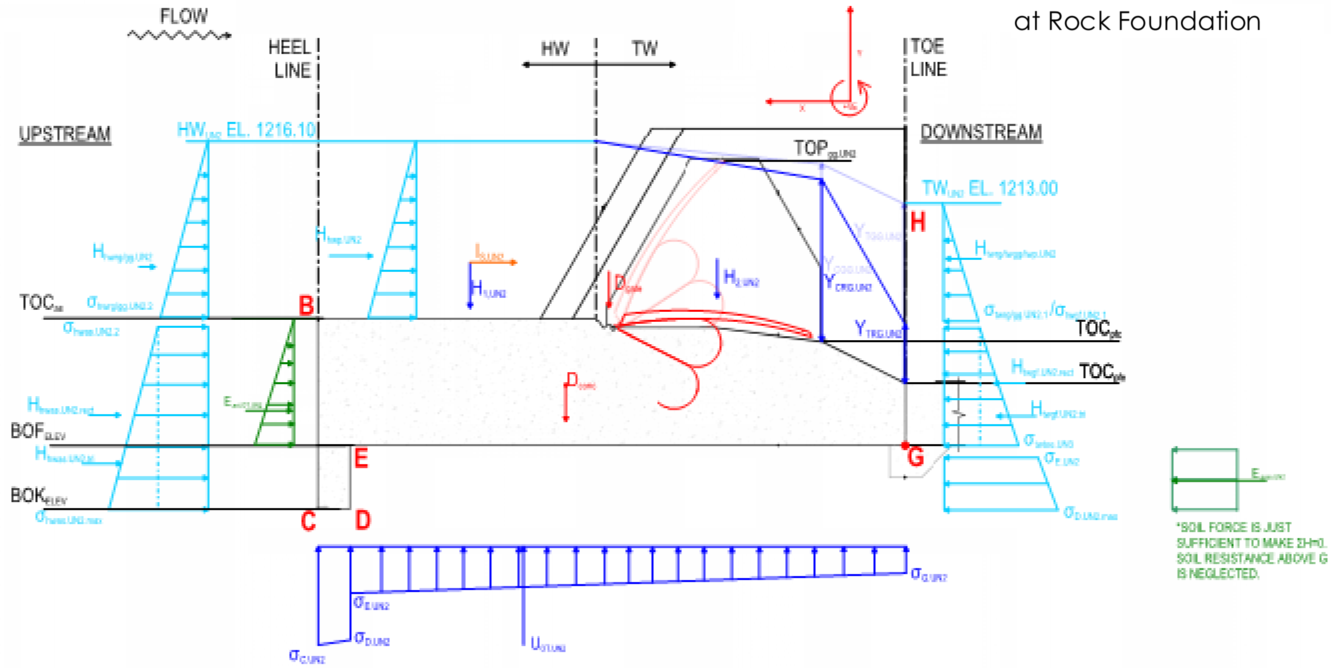
Factor of Safety Floatation:

$$FS_{act.FUN2} := \frac{\Sigma V_{FUN2}}{\left|U_{UN2}\right|} = 1.64$$

$$FS_{check.FUN2} := \begin{cases} \text{"OKAY"} & \text{if } FS_{act.FUN2} \ge FS_{req.FUN2} \\ \text{"ANCHORS REQUIRED"} & \text{if } FS_{act.FUN2} < FS_{req.FUN2} \end{cases} = \text{"OKAY"}$$

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.
Assumptions are made in order to compute overturning stability of indetermine forces on monolith with key;
(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.
(b) The horizontal resisting force acting on the key, P.key, is that required for static equilibrium
(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1 $Ratio_{OT.UN2.min} := 0.33$



Uplift Loads for Overturning Stability Analysis

Line of Creep:

Change in Water Head: $\Delta_{h.UN2} := HW_{UN2} - TW_{UN2} = 3.1\ m$

Length from Point C to Point G: $L_{CG} = 18.61\ m$

Length from Various Points to Points: $L_{CD} = 1\ m$ $L_{DE} = 2\ m$ $L_{EG} = 17.5\ m$

$L_{GH.UN2} := TW_{UN2} - BOF_{elev} = 7\ m$

Length from Point C, D, E to G: $L_{CDEG} = 20.5\ m$ $L_{CDE} = 3\ m$

Water Pressure at Point C & G: $\sigma_{C.UN2} := \sigma_{hwas.UN2.2} = -118.7 \cdot kPa$ $\sigma_{G.UN2} := \sigma_{twtoe.UN2} \cdot -1 = -68.67 \cdot kPa$

Water Pressure at Point D:

$$\sigma_{D.UN2} := -\gamma_w \cdot \left[\left(HW_{UN2} - BOK_{elev} \right) - \frac{\Delta_{h.UN2} \cdot L_{CD}}{L_{CDEG}} \right] = -117.22 \cdot kPa$$

Water Pressure at Point E:

$$\sigma_{E.UN2} := -\gamma_w \cdot \left[\left(HW_{UN2} - BOF_{elev} \right) - \frac{\Delta_{h.UN2} \cdot L_{CDE}}{L_{CDEG}} \right] = -94.63 \cdot kPa$$

Uplift for Overturning Analysis on Bottom of Key:

$$U_{OT.UN2.key} := \frac{\sigma_{C.UN2} + \sigma_{D.UN2}}{2} \cdot L_{CD} \cdot W_b = -1415.51 \cdot kN$$

Acting at:

$$U_{OT.UN2.key.loc} := \frac{L_{CD} \cdot \left(2 \cdot \sigma_{C.UN2} + \sigma_{D.UN2} \right)}{3 \left(\sigma_{C.UN2} + \sigma_{D.UN2} \right)} + L_{EG} = 18\ m$$

Uplift for Overturning Analysis on Bottom of Footing:

$$U_{OT.UN2.ftg} := \frac{\sigma_{E.UN2} + \sigma_{G.UN2}}{2} \cdot L_{EG} \cdot W_b = -17146.56 \cdot kN$$

Acting at:

$$U_{OT.UN2.ftg.loc} := \frac{L_{EG} \cdot \left(\sigma_{G.UN2} + 2 \cdot \sigma_{E.UN2} \right)}{3 \left(\sigma_{G.UN2} + \sigma_{E.UN2} \right)} = 9.21\ m$$

UN2 CASE

Uplift Load for Overturning Analysis: $U_{OT.UN2} := U_{OT.UN2.key} + U_{OT.UN2.ftg} = -18562.08 \cdot kN$

Uplift Load Acting from Toe: $U_{OT.UN2.loc} := \dfrac{U_{OT.UN2.key} \cdot U_{OT.UN2.key.loc} + U_{OT.UN2.ftg} \cdot U_{OT.UN2.ftg.loc}}{U_{OT.UN2}} = 9.88\, m$

All Vertical Loads Applicable to Overturning Stability Analysis

Total Concrete Dead Loads:	$D_{conc} = 22438.74 \cdot kN$	at: $X_{conc.loc} = 9.35\, m$
Dead Load of Gate:	$D_{Gate} = 140.0 \cdot kN$	$X_{gate} = 9.50\, m$
Water Weight (HW) on Apron Slab:	$H_{1.UN2} = 6283.3 \cdot kN$	$H_{1.UN2.loc} = 14.13\, m$
Water Weight (TW) on Gate Footing:	$H_{2.UN2.rg} = 2335.9 \cdot kN$	$H_{2.UN2.rg.loc} = 5.43\, m$
Water Weight (TW) on Regulating Gate Footing:	$H_{2.UN2.gg} = 2926.0 \cdot kN$	$H_{2.UN2.gg.loc} = 4.95\, m$
Uplift Load for Overturning Analysis:	$U_{OT.UN2} = -18562.08 \cdot kN$	$U_{OT.UN2.loc} = 9.88 \cdot m$

Sum of All Overtuming Analysis Vertical Load:

$$\Sigma V_{UN2.OT} := D_{conc} + D_{Gate} + H_{1.UN2} + H_{2.UN2.rg} + H_{2.UN2.gg} + U_{OT.UN2} = 15561.86 \cdot kN$$

Sum of All Overtuming Analysis Vertical Load Moments:

$$\Sigma M_{V.UN2.OT} := D_{conc} \cdot X_{conc.loc} + D_{Gate} \cdot X_{gate} + H_{1.UN2} \cdot H_{1.UN2.loc} + H_{2.UN2.rg} \cdot H_{2.UN2.rg.loc} \dots + H_{2.UN2.gg} \cdot H_{2.UN2.gg.loc} + U_{OT.UN2} \cdot U_{OT.UN2.loc} = 143577.86 \cdot kN \cdot m$$

Lateral Tailwater Loads for Overturning Stability Analysis

TW Lateral Load on Gate Footing (No Key - Overturning Values Adjusted): $H_{twgf.UN2} := H_{twgf.UN2.tri} + H_{twgf.UN2.rect} = 2354.4 \cdot kN$

Acting at: $H_{twgf.UN2.loc} := \dfrac{\frac{h_{toe}}{3} \cdot H_{twgf.UN2.tri} + \frac{h_{toe}}{2} \cdot H_{twgf.UN2.rect}}{H_{twgf.UN2}} = 1.73\, m$

Horizontal Tailwater Pressure Top of Key (Overturning Analysis): $\sigma_{twtk.OT.UN2} := \sigma_{E.UN2} \cdot -1 = 94.63 \cdot kPa$

Horizontal Tailwater Pressure Bottom of Key (Overturning Analysis): $\sigma_{twbk.OT.UN2} := \sigma_{D.UN2} \cdot -1 = 117.22 \cdot kPa$

Triangular Distribution Unit Load Acting at Key: $H_{twbk.OT.UN2.tri} := \dfrac{(\sigma_{twbk.OT.UN2} - \sigma_{twtk.OT.UN2})}{2} \cdot d_{key} \cdot W_{tw.UN2} = 271.04 \cdot kN$

Triangular Distribution Unit Load Acting at Key: $H_{twbk.OT.UN2.rect} := \sigma_{twtk.OT.UN2} \cdot d_{key} \cdot W_{tw.UN2} = 2271.13 \cdot kN$

Total Horizontal Tailwater Load on Key (Overturning Values Adjusted): $H_{twkey.OT.UN2} := H_{twbk.OT.UN2.tri} + H_{twbk.OT.UN2.rect} = 2542.18 \cdot kN$

Acting at: $H_{twkey.OT.UN2.loc} := \dfrac{H_{twbk.OT.UN2.tri} \cdot \frac{-2 \cdot d_{key}}{3} + H_{twbk.OT.UN2.rect} \cdot \frac{-d_{key}}{2}}{H_{twkey.OT.UN2}} = -1.04 \cdot m$

Lateral Driving Earth Loads for Overturning Stability Analysis (at rest condition)

Depth of Driving Soil Loads (to top of key): $h_{E.OT.UN2} := TOC_{as} - BOF_{elev} = 4\, m$

At-Rest Soil Load: $E_{act.OT.UN2} := \dfrac{\left(K_{o.UN2} \cdot h_{E.OT.UN2}^{\,2}\right)}{2} \cdot (\gamma_r - \gamma_w) \cdot W_{hwas.UN2} \cdot -1 = -769.99 \cdot kN$

At Rest- Soil Load Acting from Toe: $E_{act.OT.UN2.loc} := \dfrac{h_{E.OT.UN2}}{3} = 1.33\, m$

All Lateral Loads Applicable to Overturning Stability Analysis

HW Lateral Load on Approach Slab:	$H_{hwas.UN2} = -6427.5 \cdot kN$	$H_{hwas.UN2.loc} = 0.67\,m$
HW Lateral Load on Regulating Gate:	$H_{hwrg.UN2} = 0.0 \cdot kN$	$H_{hwrg.UN2.loc} = 4.00\,m$
HW Lateral Load on Guard Gate:	$H_{hwgg.UN2} = -882.9 \cdot kN$	$H_{hwgg.UN2.loc} = 5.92\,m$
TW Lateral Load on Regulating Gate:	$H_{twrg.UN2} = 0.0 \cdot kN$	$H_{twrg.UN2.loc} = 4.00\,m$
HW Lateral Load on Guard Gate:	$H_{twgg.UN2} = 220.7 \cdot kN$	$H_{twgg.UN2.loc} = 5.00\,m$
TW Lateral Load on Gate Footing (No Key - Overturning Values Adjusted):	$H_{twgf.UN2} = 2354.4 \cdot kN$	$H_{twgf.UN2.loc} = 1.73\,m$
TW Lateral Load on Key:	$H_{twkey.OT.UN2} = 2542.18 \cdot kN$	$H_{twkey.OT.UN2.loc} = -1.04\,m$
Ice / Impact Load:	$I_{UN2} = -300.0 \cdot kN$	$I_{UN2.loc} = 9.80\,m$
Lateral Soil Load (driving):	$E_{act.OT.UN2} = -770.0 \cdot kN$	$E_{act.OT.UN2.loc} = 1.33\,m$

Resisting Lateral Soil Load as required to produce horizontal equilibrium:

$$E_{pas.OT.UN2} := -\left(H_{hwas.UN2} + H_{hwrg.UN2} + H_{hwgg.UN2} + H_{twrg.UN2} + H_{twgg.UN2} \cdots + H_{twgf.UN2} + H_{twkey.OT.UN2} + I_{UN2} + E_{act.OT.UN2}\right) = 3263.1 \cdot kN$$

$$E_{pas.OT.UN2.loc} := -1 \cdot \frac{d_{key}}{2} = -1\,m$$

Sum of All Overturning Analysis Horizontal Load (ΣH=0):

$$\Sigma H_{UN2.OT} := H_{hwas.UN2} + H_{hwrg.UN2} + H_{hwgg.UN2} + H_{twrg.UN2} + H_{twgg.UN2} \cdots + H_{twgf.UN2} + H_{twkey.OT.UN2} + I_{UN2} + E_{act.OT.UN2} + E_{pas.OT.UN2} = 0 \cdot kN$$

Sum of All Overturning Analysis Horizontal Load Moments:

$$\Sigma M_{H.UN2.OT} := H_{hwas.UN2} \cdot H_{hwas.UN2.loc} + H_{hwrg.UN2} \cdot H_{hwrg.UN2.loc} + H_{hwgg.UN2} \cdot H_{hwgg.UN2.loc} \cdots + H_{twrg.UN2} \cdot H_{twrg.UN2.loc} + H_{twgg.UN2} \cdot H_{twgg.UN2.loc} + H_{twgf.UN2} \cdot H_{twgf.UN2.loc} \cdots + H_{twkey.OT.UN2} \cdot H_{twkey.OT.UN2.loc} + I_{UN2} \cdot I_{UN2.loc} + E_{act.OT.UN2} \cdot E_{act.OT.UN2.loc} \cdots + E_{pas.OT.UN2} \cdot E_{pas.OT.UN2.loc} = -14214.17 \cdot kN \cdot m$$

Overturning Stability Analysis

$$\Sigma M_{UN2.OT} := \Sigma M_{V.UN2.OT} + \Sigma M_{H.UN2.OT} = 129363.69 \cdot kN \cdot m$$

$$X_{R.UN2} := \frac{\Sigma M_{UN2.OT}}{\Sigma V_{UN2.OT}} = 8.31\,m \qquad x_{OT.UN2} := X_{R.UN2} - \frac{L_b}{2} = -0.94\,m$$

Overturning Resultant Ratio

$$Ratio_{OT.UN2} := \frac{X_{R.UN2}}{L_b} = 0.45$$

$$Ratio_{OT.UN2.check} := \begin{cases} \text{"OKAY"} & \text{if } Ratio_{OT.UN2} \ge Ratio_{OT.UN2.min} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

$$x_{OT.check.UN2} := \begin{cases} \text{"OKAY"} & \text{if } \left|x_{OT.UN2}\right| \le Kern \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

CHECK FOUNDATION BEARING CAPACITY (HORIZONTAL PLANE):

UN2 CASE

Bearing Pressure Under Toe:

$$\sigma_{ToeUN2.OT} := \frac{\Sigma V_{UN2.OT}}{L_b \cdot W_b} + \frac{\left(\Sigma V_{UN2.OT} \cdot x_{OT.UN2}\right)}{S_b} = 48.8 \cdot kPa$$

$$Bearing_{ChecktoeUN2.OT} := \begin{vmatrix} \text{"OKAY "} & \text{if } \sigma_{ToeUN2.OT} < \sigma_{allow.UN2} \\ \text{"NG""} & \text{otherwise} \end{vmatrix} = \text{"OKAY "}$$

Bearing Pressure Under Heel:

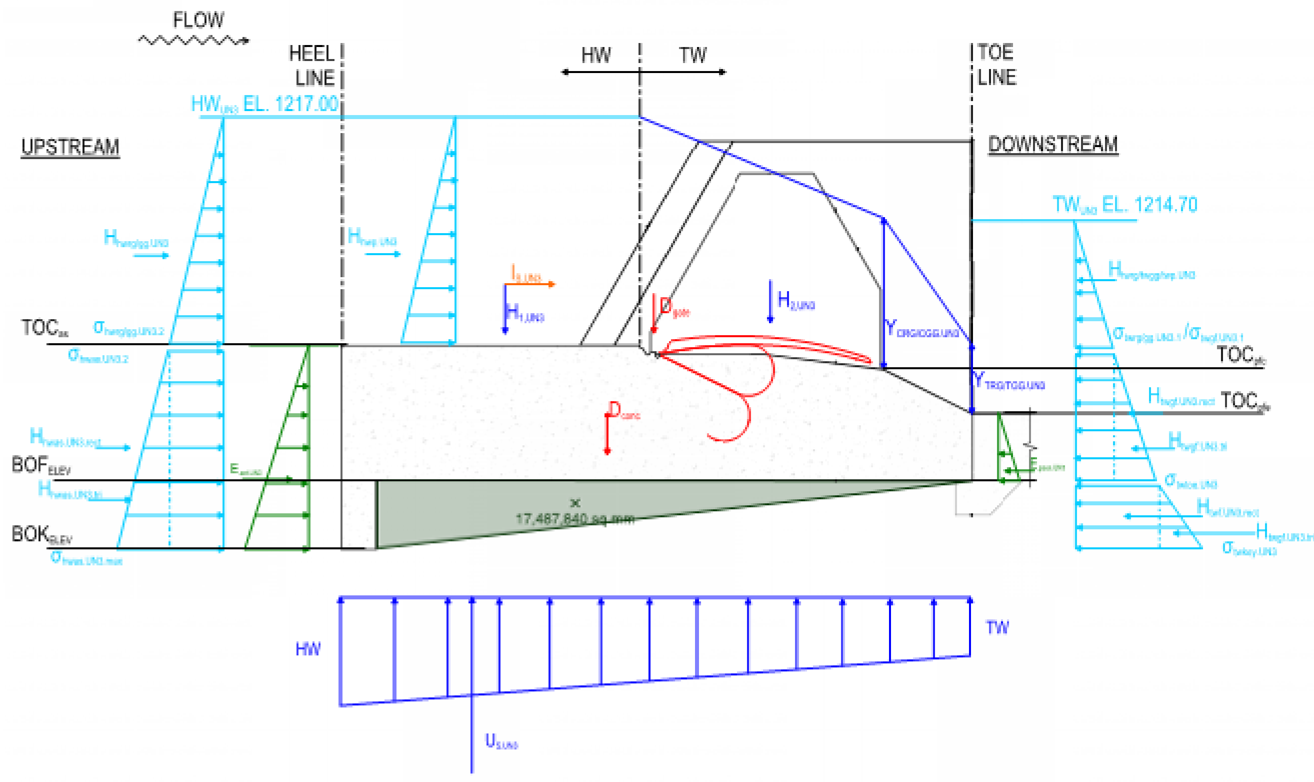
$$\sigma_{HeelUN2.OT} := \frac{\Sigma V_{UN2.OT}}{L_b \cdot W_b} - \frac{\left(\Sigma V_{UN2.OT} \cdot x_{OT.UN2}\right)}{S_b} = 91.4 \cdot kPa$$

$$Bearing_{CheckheelUN2.OT} := \left(\begin{vmatrix} \text{"OKAY "} & \text{if } \sigma_{HeelUN2.OT} < \sigma_{allow.UN2} \wedge \sigma_{HeelUN2.OT} > 0 \\ \text{"NG""} & \text{otherwise} \end{vmatrix} \right) = \text{"OKAY "}$$

SUMMARY OF STABILITY ASSESSMENT:

th Key"	Sliding Factor of Safety: (Horizontal Plane)	$FS_{HorizSliding.UN2} = 1.41$	$FS_{HorizSliding.UN2.Check} =$ "OKAY"
	Sliding Factor of Safety: (Inclined Plane)	$FS_{InclinedlSlidingUN2} = 3.53$	$FS_{InclinedSliding.check.UN2} =$ "OKAY "
	Eccentricity: (Inclined Plane)	$e_{UN2} = 0.58\,m$	$e_{check.UN2} =$ "Okay"
	Bearing Pressure At Heel: (Inclined Plane)	$\sigma_{heel.UN2} = 67 \cdot kPa$	$\sigma_{heel.UN2.check} =$ "Okay"
	Bearing Pressure At Toe: (Inclined Plane)	$\sigma_{toe.UN2} = 98 \cdot kPa$	$\sigma_{toe.UN2.1.check} =$ "Okay"
	Flotation Factor of Safety (horizontal plane)	$FS_{act.FUN2} = 1.64$	$FS_{check.FUN2} =$ "OKAY"
	Overturning Resultant Ratio: (horizontal plane)	$Ratio_{OT.UN2} = 0.45$	$Ratio_{OT.UN2.check} =$ "OKAY"
	Eccentricity: (horizontal plane)	$x_{OT.UN2} = -0.94\,m$	$x_{OT.check.UN2} =$ "OKAY"
	Bearing Pressure At Heel: (horizontal plane)	$\sigma_{HeelUN2.OT} = 91 \cdot kPa$	$Bearing_{CheckheelUN2.OT} =$ "OKAY "
	Bearing Pressure At Toe: (horizontal plane)	$\sigma_{ToeUN2.OT} = 49 \cdot kPa$	$Bearing_{ChecktoeUN2.OT} =$ "OKAY "

UN3 DESIGN CASE



ACCEPTANCE PARAMETERS

Required Factor of Safety for Sliding:	$FS_{req.UN3.sl} := 1.3$	(Without Cohesion) (Section 8.1, Design Criteria)
Resultant Within Middle Third of Base:	$e \le \frac{L_b}{6} \wedge e \ge \frac{-L_b}{6}$	
Allowable Rock Bearing Pressure:	$\sigma_{allow.UN3} := 1470 \cdot \frac{kN}{m^2}$	(Section 5.2, Design Criteria)

INPUT PARAMETERS

Headwater Elevation:	$HW_{UN3} := 1217.00m$	(Section 8.3, Design Criteria)
Tailwater Elevation:	$TW_{UN3} := 1214.70m$	(Section 8.3, Design Criteria)
Bottom of Footing Elevation:	$BOF_{elev} = 1206.00\,m$	
Approach Slab Top of Concrete Elevation at Upstream Face:	$TOC_{as} = 1210.00\,m$	
Pier Footing Top of Concrete Elevation at Stilling Basin:	$TOC_{pfe} = 1208.00\,m$	
Pier Footing Top of Concrete Elevation at Center of Footing:	$TOC_{pfc} = 1209.30\,m$	
Top of Guard/ Regulating Gate Elevation:	$TOP_{rg.UN3} := 1210.00m$ $\quad TOP_{gg.UN3} := 1210.00m$	
Bottom of Key Elevation:	$BOK_{elev} = 1204\,m$	

Gates are open when top of gate elevation is at 1210.00m

Gates are closed/up when top of gate elevation is at 1215.0m

Crestwater Elevation (Right) Guard Gate: $EL_{CGG.UN3} := 1214.67m$

$$Y_{C.gg.UN3} := \begin{cases} \left(EL_{CGG.UN3} - TOC_{pfc}\right) & \text{if } TOP_{gg.UN3} \le HW_{UN3} \\ \left(TW_{UN3} - TOC_{pfc}\right) & \text{if } TOP_{gg.UN3} > HW_{UN3} \end{cases} = 5.37 \cdot m$$

Toewater Elevation (Right) Guard Gate: $EL_{TGG.UN3} := 1210.89m$

$$Y_{TOE.gg.UN3} := \begin{cases} \left(EL_{TGG.UN3} - TOC_{pfe}\right) & \text{if } TOP_{gg.UN3} \le HW_{UN3} \\ \left(TW_{UN3} - TOC_{pfe}\right) & \text{if } TOP_{gg.UN3} > HW_{UN3} \end{cases} = 2.89 \cdot m$$

UN3 CASE

Crestwater Elevation Regulating (Left) Gate: $EL_{CRG.UN3} := 1214.67m$

$$Y_{C.rg.UN3} := \begin{cases} (EL_{CRG.UN3} - TOC_{pfc}) & \text{if } TOP_{rg.UN3} \le HW_{UN3} \\ (TW_{UN3} - TOC_{pfc}) & \text{if } TOP_{rg.UN3} > HW_{UN3} \end{cases} = 5.37 \cdot m$$

Toewater Elevation Regulating (Left) Gate: $EL_{TRG.UN3} := 1210.89m$

$$Y_{TOE.rg.UN3} := \begin{cases} (EL_{TRG.UN3} - TOC_{pfe}) & \text{if } TOP_{rg.UN3} \le HW_{UN3} \\ (TW_{UN3} - TOC_{pfe}) & \text{if } TOP_{rg.UN3} > HW_{UN3} \end{cases} = 2.89 \cdot m$$

LATERAL WATER LOADS

HEADWATER (DRIVING):

Headwater Depth on Pier: $D_{hwp.UN3} := HW_{UN3} - TOC_{as} = 7.00\,m$

Headwater Load Unit Width on Pier: $w_{hwp.UN3} := w_p = 2.00\,m$

Total Horizontal Headwater Load on Pier:

$$H_{hwp.UN3} := \frac{-\left(\gamma_w \cdot D_{hwp.UN3}^{\,2}\right)}{2} \cdot w_{hwp.UN3} = -480.7 \cdot kN$$

Apply Total Pier Headwater Load at:

$$H_{hwp.UN3.loc} := \frac{D_{hwp.UN3}}{3} + (TOC_{as} - BOF_{elev}) = 6.33\,m$$

Headwater Depth on Gate base: $D_{hwg.UN3} := HW_{UN3} - TOC_{as} = 7.00\,m$

Thickness of Approach Slab (Including Key): $T_{as} = 6\,m$

Headwater Depth at Heel (U/S face): $D_{hwas.UN3} := HW_{UN3} - BOK_{elev} = 13.00\,m$

Headwater Load Unit Width on Approach Slab: $w_{hwas.UN3} := w_b = 12.00\,m$

Headwater Unit Load At Top of Approach Slab:

$$H_{hwas.UN3.1} := \frac{-\left(\gamma_w \cdot D_{hwg.UN3}^{\,2}\right)}{2} \cdot w_{hwas.UN3} = -2884.14 \cdot kN$$

Headwater Unit Load At Bottom of Approach Key:

$$H_{hwas.UN3.2} := \frac{-\left(\gamma_w \cdot D_{hwas.UN3}^{\,2}\right)}{2} \cdot w_{hwas.UN3} = -9947.3 \cdot kN$$

Headwater Line Load At Top of Approach Slab:

$$\sigma_{hwas.UN3.1} := -\left(\gamma_w \cdot D_{hwg.UN3}\right) = -68.67 \cdot kPa$$

Headwater Line Load At Bottom of Approach Key:

$$\sigma_{hwas.UN3.2} := -\left(\gamma_w \cdot D_{hwas.UN3}\right) = -127.53 \cdot kPa$$

Triangular Distribution Unit Load on Approach Slab and Key:

$$H_{hwas.UN3.2.tri} := \left(\frac{\sigma_{hwas.UN3.2} - \sigma_{hwas.UN3.1}}{2}\right) \cdot \left(T_{as} \cdot w_{hwas.UN3}\right) = -2118.96 \cdot kN$$

Rectangular Distribution Unit Load on Approach Slab and Key:

$$H_{hwas.UN3.2.rect} := \sigma_{hwas.UN3.1} \cdot \left(T_{as} \cdot w_{hwas.UN3}\right) = -4944.24 \cdot kN$$

Total Horizontal Headwater Load on Approach Slab:

$$H_{hwas.UN3} := H_{hwas.UN3.2.tri} + H_{hwas.UN3.2.rect} = -7063.2 \cdot kN$$

Apply Total Footing Headwater Load at:

$$H_{hwas.UN3.loc} := \frac{\left[H_{hwas.UN3.2.rect} \cdot \frac{(T_{as})}{2} + H_{hwas.UN3.2.tri} \cdot \frac{(T_{as})}{3}\right]}{H_{hwas.UN3.2.tri} + H_{hwas.UN3.2.rect}} - d_{key} = 0.70\,m$$

LATERAL WATER LOADS (continued)

Regulating Gate (2A) Operating Condition:

Regulating Crest Gate Down/Open Condition: $A1_{UN3} := TOP_{rg.UN3} \le TOC_{as}$

Regulating Crest Gate Up/Closed, with Top of Gate Higher than HW Elevation: $B1_{UN3} := TOP_{rg.UN3} \ge HW_{UN3} \wedge TOP_{rg.UN3} > TOC_{as}$

Regulating Crest Gate Up/Closed, with Top of Gate Lower than HW Elevation: $C1_{UN3} := TOP_{rg.UN3} > TOC_{as} \wedge HW_{UN3} > TOP_{rg.UN3}$

Regulating Crest Gate Height: $H_{rg.UN3} := TOP_{rg.UN3} - TOC_{as} = 0\,m$

Headwater Depth at Regulating Crest Gate: $D_{hwrg.UN3} := HW_{UN3} - TOC_{as} = 7.00\,m$

Regulating Crest Gate Width: $W_{hwrg.UN3} := 5.00m$

Lateral Headwater Pressure at Bottom of Regulating Crest Gate:

$$\sigma_{hwrg.UN3.1} := \begin{vmatrix} (0.0kPa) & \text{if } A1_{UN3} \\ -(\gamma_w \cdot D_{hwrg.UN3}) & \text{if } B1_{UN3} \\ -(\gamma_w \cdot D_{hwrg.UN3}) & \text{if } C1_{UN3} \end{vmatrix} = 0.0 \cdot kPa$$

Lateral Headwater Pressure at Top of Regulating Crest Gate:
(Load at HW Elevation On Regulating Crest Gate if HW is below TOG_{rg})

$$\sigma_{hwrg.UN3.2} := \begin{vmatrix} (0.0kPa) & \text{if } A1_{UN3} \\ 0.0kPa & \text{if } B1_{UN3} \\ -\left[\gamma_w \cdot (HW_{UN3} - TOP_{rg.UN3})\right] & \text{if } C1_{UN3} \end{vmatrix} = 0.0 \cdot kPa$$

Average Pressure acting on Regulating Gate:

$$\sigma_{hwrg.UN3.avg} := \frac{(\sigma_{hwrg.UN3.1} + \sigma_{hwrg.UN3.2})}{2} = 0 \cdot kPa$$

Total Area water acting on Regulating Crest Gate:

$$A_{hwrg.UN3} := \begin{vmatrix} D_{hwrg.UN3} \cdot W_{hwrg.UN3} & \text{if } A1_{UN3} \\ D_{hwrg.UN3} \cdot W_{hwrg.UN3} & \text{if } B1_{UN3} \\ H_{rg.UN3} \cdot W_{hwrg.UN3} & \text{if } C1_{UN3} \end{vmatrix} = 35 \cdot m^2$$

Total Horizontal Headwater Load on Regulating Crest Gate:

$$H_{hwrg.UN3} := \sigma_{hwrg.UN3.avg} \cdot A_{hwrg.UN3} = 0.0 \cdot kN$$

Apply Total Regulating Crest Gate Headwater Load at:

$$H_{hwrg.UN3.loc} := \begin{vmatrix} (TOC_{as} - BOF_{elev}) & \text{if } A1_{UN3} \\ \left[\frac{(HW_{UN3} - TOC_{as})}{3} + (TOC_{as} - BOF_{elev})\right] & \text{if } B1_{UN3} \\ \left[\frac{\sigma_{hwrg.UN3.2} \cdot A_{hwrg.UN3} \cdot \frac{(H_{rg.UN3})}{2} + \frac{(\sigma_{hwrg.UN3.1} - \sigma_{hwrg.UN3.2})}{2} A_{hwrg.UN3} \cdot \frac{(H_{rg.UN3})}{3}}{\sigma_{hwrg.UN3.2} \cdot A_{hwrg.UN3} + \frac{(\sigma_{hwrg.UN3.1} - \sigma_{hwrg.UN3.2})}{2} \cdot A_{hwrg.UN3}} \ldots \\ + (TOC_{as} - BOF_{elev})\right] & \text{if } C1_{UN3} \end{vmatrix} = 4.0 \cdot m$$

Guard Gate (4A) Operating Condition:

Guard Gate Down/Open Condition: $A2_{UN3} := TOP_{gg.UN3} \le TOC_{as}$

Guard Crest Gate Up/Closed, with Top of Gate Higher than HW Elevation: $B2_{UN3} := TOP_{gg.UN3} \ge HW_{UN3} \wedge TOP_{gg.UN3} > TOC_{as}$

Guard Crest Gate Up/Closed, with Top of Gate Lower than HW Elevation: $C2_{UN3} := TOP_{gg.UN3} > TOC_{as} \wedge HW_{UN3} > TOP_{gg.UN3}$

Guard Crest Gate Height: $H_{gg.UN3} := TOP_{gg.UN3} - TOC_{as} = 0\,m$

Headwater Depth at Guard Crest Gate: $D_{hwgg.UN3} := HW_{UN3} - TOC_{as} = 7.00\,m$

Guard Crest Gate Width: $W_{hwgg.UN3} := 5.00m$

Lateral Headwater Pressure at Bottom of Guard Crest Gate:

$$\sigma_{hwgg.UN3.1} := \begin{cases} (0.0kPa) & \text{if } A2_{UN3} \\ -(\gamma_w \cdot D_{hwgg.UN3}) & \text{if } B2_{UN3} \\ -(\gamma_w \cdot D_{hwgg.UN3}) & \text{if } C2_{UN3} \end{cases} = 0.0 \cdot kPa$$

Lateral Headwater Pressure at Top of Guard Crest Gate: (Load at HW Elevation On Guard Crest Gate if HW is below TOG_{rg})

$$\sigma_{hwgg.UN3.2} := \begin{cases} (0.0kPa) & \text{if } A2_{UN3} \\ 0.0kPa & \text{if } B2_{UN3} \\ -\left[\gamma_w \cdot (HW_{UN3} - TOP_{gg.UN3})\right] & \text{if } C2_{UN3} \end{cases} = 0.0 \cdot kPa$$

Average Pressure acting on Guard Crest Gate:

$$\sigma_{hwgg.UN3.avg} := \frac{(\sigma_{hwgg.UN3.1} + \sigma_{hwgg.UN3.2})}{2} = 0 \cdot kPa$$

Total Area water acting on Crest Gate:

$$A_{hwgg.UN3} := \begin{cases} D_{hwgg.UN3} \cdot W_{hwgg.UN3} & \text{if } A2_{UN3} \\ D_{hwgg.UN3} \cdot W_{hwgg.UN3} & \text{if } B2_{UN3} \\ H_{gg.UN3} \cdot W_{hwgg.UN3} & \text{if } C2_{UN3} \end{cases} = 35 \cdot m^2$$

Total Horizontal Headwater Load on Guard Crest Gate: $H_{hwgg.UN3} := \sigma_{hwgg.UN3.avg} \cdot A_{hwgg.UN3} = 0.0 \cdot kN$

Apply Total Guard Crest Gate Headwater Load at:

$$H_{hwgg.UN3.loc} := \begin{cases} (TOC_{as} - BOF_{elev}) & \text{if } A2_{UN3} \\ \left[\frac{(HW_{UN3} - TOC_{as})}{3} + (TOC_{as} - BOF_{elev})\right] & \text{if } B2_{UN3} \\ \left[\frac{\sigma_{hwgg.UN3.2} \cdot A_{hwgg.UN3} \cdot \frac{(H_{gg.UN3})}{2} + \frac{(\sigma_{hwgg.UN3.1} - \sigma_{hwgg.UN3.2})}{2} A_{hwgg.UN3} \cdot \frac{(H_{gg.UN3})}{3}}{\sigma_{hwgg.UN3.2} \cdot A_{hwgg.UN3} + \frac{(\sigma_{hwgg.UN3.1} - \sigma_{hwgg.UN3.2})}{2} \cdot A_{hwgg.UN3}} \ldots \\ + (TOC_{as} - BOF_{elev})\right] & \text{if } C2_{UN3} \end{cases} = 4.0 \cdot m$$

LATERAL TAILWATER (RESISTING) Applied to Downstream Side of Regulating Crest Gate:

UN3 CASE

Regulating Crest Gate Down/Open Condition: $A3_{UN3} := TOP_{rg.UN3} \le TOC_{as}$

Regulating Crest Gate Up/Closed, with Top of Gate Higher than TW Elevation: $B3_{UN3} := TOP_{rg.UN3} \ge TW_{UN3} \wedge TOP_{rg.UN3} > TOC_{as}$

Regulating Crest Gate Up/Closed, with Top of Gate Lower than TW Elevation: $C3_{UN3} := TOP_{rg.UN3} > TOC_{as} \wedge TW_{UN3} > TOP_{rg.UN3}$

Regulating Crest Gate Height: $H_{rg.UN3} = 0\,m$

Tailwater Depth at Regulating Crest Gate: $D_{twrg.UN3} := TW_{UN3} - TOC_{as} = 4.70\,m$

Regulating Crest Gate Width: $W_{twrg.UN3} := 5m$

Lateral Tailwater Pressure at Bottom of Regulating Crest Gate:

$$\sigma_{twrg.UN3.1} := \begin{cases} (0.0kPa) & \text{if } A3_{UN3} \\ -\left(\gamma_w \cdot D_{twrg.UN3}\right) & \text{if } B3_{UN3} \\ -\left(\gamma_w \cdot D_{twrg.UN3}\right) & \text{if } C3_{UN3} \end{cases} = 0.0 \cdot kPa$$

Lateral Tailwater Pressure at Top of Regulating Crest Gate: (Load at TW Elevation On Regulating Crest Gate if TW is below TOG_{rg})

$$\sigma_{twrg.UN3.2} := \begin{cases} (0.0kPa) & \text{if } A3_{UN3} \\ 0.0kPa & \text{if } B3_{UN3} \\ -\left[\gamma_w \cdot \left(TW_{UN3} - TOP_{rg.UN3}\right)\right] & \text{if } C3_{UN3} \end{cases} = 0.0 \cdot kPa$$

Average Pressure acting on Regulating Gate:

$$\sigma_{twrg.UN3.avg} := \frac{\left(\sigma_{twrg.UN3.1} + \sigma_{twrg.UN3.2}\right)}{2} = 0 \cdot kPa$$

Total Area water acting on Regulating Crest Gate:

$$A_{twrg.UN3} := \begin{cases} D_{twrg.UN3} \cdot W_{twrg.UN3} & \text{if } A3_{UN3} \\ D_{twrg.UN3} \cdot W_{twrg.UN3} & \text{if } B3_{UN3} \\ H_{rg.UN3} \cdot W_{twrg.UN3} & \text{if } C3_{UN3} \end{cases} = 23.5 \cdot m^2$$

Total Horizontal Tailwater Load on Regulating Crest Gate:

$$H_{twrg.UN3} := \sigma_{hwrg.UN3.avg} \cdot A_{hwrg.UN3} = 0.0 \cdot kN$$

Apply Total Regulating Crest Gate Tailwater Load at:

$$H_{twrg.UN3.loc} := \begin{cases} \left(TOC_{as} - BOF_{elev}\right) & \text{if } A3_{UN3} \\ \left[\dfrac{\left(HW_{UN3} - TOC_{as}\right)}{3} + \left(TOC_{as} - BOF_{elev}\right)\right] & \text{if } B3_{UN3} \\ \left[\dfrac{\sigma_{hwrg.UN3.2} \cdot A_{hwrg.UN3} \cdot \dfrac{\left(H_{rg.UN3}\right)}{2} + \dfrac{\left(\sigma_{hwrg.UN3.1} - \sigma_{hwrg.UN3.2}\right)}{2} A_{hwrg.UN3} \cdot \dfrac{\left(H_{rg.UN3}\right)}{3}}{\sigma_{hwrg.UN3.2} \cdot A_{hwrg.UN3} + \dfrac{\left(\sigma_{hwrg.UN3.1} - \sigma_{hwrg.UN3.2}\right)}{2} \cdot A_{hwrg.UN3}} \ldots \\ + \left(TOC_{as} - BOF_{elev}\right)\right] & \text{if } C3_{UN3} \end{cases} = 4.0 \cdot m$$

LATERAL TAILWATER (RESISTING) Applied to Downstream Side of Guard Crest Gate:

UN3 CASE

Guard Gate Down/Open Condition: $A4_{UN3} := TOP_{gg.UN3} \le TOC_{as}$

Guard Crest Gate Up/Closed, with Top of Gate Higher than TW Elevation: $B4_{UN3} := TOP_{gg.UN3} \ge TW_{UN3} \wedge TOP_{gg.UN3} > TOC_{as}$

Guard Crest Gate Up/Closed, with Top of Gate Lower than TW Elevation: $C4_{UN3} := TOP_{gg.UN3} > TOC_{as} \wedge TW_{UN3} > TOP_{gg.UN3}$

Tailwater Depth at Guard Crest Gate: $D_{twgg.UN3} := TW_{UN3} - TOC_{as} = 4.70\,m$

Guard Crest Gate Height: $H_{gg.UN3} = 0\,m$

Guard Crest Gate Width: $W_{twgg.UN3} := 5.00m$

Lateral Water Load at Bottom of Guard Crest Gate:

$$\sigma_{twgg.UN3.1} := \begin{cases} (0.0kPa) & \text{if } A4_{UN3} \\ (\gamma_w \cdot D_{twgg.UN3}) & \text{if } B4_{UN3} \\ (\gamma_w \cdot D_{twgg.UN3}) & \text{if } C4_{UN3} \end{cases} = 0.0 \cdot kPa$$

Lateral Water Load at Top of Guard Crest Gate:
(Load at TW Elevation On Guard Crest Gate if TW is below TOG_{gg})

$$\sigma_{twgg.UN3.2} := \begin{cases} (0.0kPa) & \text{if } A4_{UN3} \\ 0.0kPa & \text{if } B4_{UN3} \\ \left[\gamma_w \cdot (TW_{UN3} - TOP_{gg.UN3})\right] & \text{if } C4_{UN3} \end{cases} = 0.0 \cdot kPa$$

Average Pressure acting on Guard Crest Gate:

$$\sigma_{twgg.UN3.avg} := \frac{(\sigma_{twgg.UN3.1} + \sigma_{twgg.UN3.2})}{2} = 0 \cdot kPa$$

Total Area water acting on Crest Gate:

$$A_{twgg.UN3} := \begin{cases} D_{twgg.UN3} \cdot W_{twgg.UN3} & \text{if } A4_{UN3} \\ D_{twgg.UN3} \cdot W_{twgg.UN3} & \text{if } B4_{UN3} \\ H_{gg.UN3} \cdot W_{twgg.UN3} & \text{if } C4_{UN3} \end{cases} = 23.5 \cdot m^2$$

Total Horizontal Tailwater Load on Guard Crest Gate: $H_{twgg.UN3} := \sigma_{twgg.UN3.avg} \cdot A_{twgg.UN3} = 0.0 \cdot kN$

Apply Total Horiz. TW Load on Guard Gate at:

$$H_{twgg.UN3.loc} := \begin{cases} (TOC_{as} - BOF_{elev}) & \text{if } A4_{UN3} \\ \left[\frac{(TW_{UN3} - TOC_{as})}{3} + (TOC_{as} - BOF_{elev})\right] & \text{if } B4_{UN3} \\ \left[\frac{\sigma_{twgg.UN3.2} \cdot A_{twgg.UN3} \cdot \frac{(H_{gg.UN3})}{2} + \frac{(\sigma_{twgg.UN3.1} - \sigma_{twgg.UN3.2})}{2} A_{twgg.UN3} \cdot \frac{(H_{gg.UN3})}{3}}{\sigma_{twgg.UN3.2} \cdot A_{twgg.UN3} + \frac{(\sigma_{twgg.UN3.1} - \sigma_{twgg.UN3.2})}{2} \cdot A_{twgg.UN3}} \ldots \\ + (TOC_{as} - BOF_{elev})\right] & \text{if } C4_{UN3} \end{cases} = 4.0 \cdot m$$

LATERAL WATER LOADS (continued)

UN3 CASE

TAILWATER (RESISTING) Applied to Concrete Structure:

Tailwater Depth on Pier: $D_{twp.UN3} := TW_{UN3} - TOC_{as} = 4.70\,m$

Tailwater Load Unit Width on Pier: $w_{twp.UN3} := w_p = 2.00\,m$

Total Horizontal Tailwater Load on Pier: $H_{twp.UN3} := \frac{\left(\gamma_w \cdot D_{twp.UN3}{}^2\right)}{2} \cdot w_{twp.UN3} = 216.7 \cdot kN$

Apply Total Pier Tailwater Load at: $H_{twp.UN3.loc} := \frac{D_{twp.UN3}}{3} + \left(TOC_{as} - BOF_{elev}\right) = 5.57\,m$

Tailwater Depth At top of Gate Base Footing Elevation: $D_{twgf.UN3} := TW_{UN3} - TOC_{as} = 4.70\,m$

Water Depth at bottom of Gate Base Footing (Excluding Key): $D_{twtoe.UN3} := TW_{UN3} - BOF_{elev} = 8.70\,m$

Footing Thickness for horizontal at Toe: $h_{toe} = 4\,m$

Unit Width of D/S face of crest for application of Tailwater Load: $w_{tw.UN3} := w_b = 12.00\,m$

Tailwater Pressure At Top of Gate Footing: $\sigma_{twgf.UN3} := \left(\gamma_w \cdot D_{twgf.UN3}\right) = 46.11 \cdot kPa$

Tailwater Pressure At Toe: $\sigma_{twtoe.UN3} := \left(\gamma_w \cdot D_{twtoe.UN3}\right) = 85.35 \cdot kPa$

Triangular Distribution Unit Load on Gate Footing Base (including key): $H_{twgf.UN3.tri} := \left(\frac{\sigma_{twtoe.UN3} - \sigma_{twgf.UN3}}{2}\right) \cdot \left[\left(T_{as} - d_{key}\right) \cdot w_{tw.UN3}\right] = 941.76 \cdot kN$

Rectangular Distribution Unit Load on Gate Footing Base (including key): $H_{twgf.UN3.rect} := \sigma_{twgf.UN3} \cdot \left[\left(T_{as} - d_{key}\right) \cdot w_{tw.UN3}\right] = 2213.14 \cdot kN$

Tailwater Pressure At Bottom of Sliding Failure Plane: $\sigma_{twbk.UN3} := \left(HW_{UN3} - BOK_{elev}\right) \cdot \gamma_w = 127.53 \cdot kPa$

Triangular Distribution Unit Load Below Footing: $H_{twbk.UN3.tri} := \frac{\left(\sigma_{twbk.UN3} - \sigma_{twtoe.UN3}\right)}{2} \cdot d_{key} \cdot w_{tw.UN3} = 506.2 \cdot kN$

Rectangular Distribution Load Below Footing Base: $H_{twbk.UN3.rect} := \sigma_{twtoe.UN3} \cdot d_{key} \cdot w_{tw.UN3} = 2048.33 \cdot kN$

Total Horizontal Tailwater Headwater Load on Gate Footing (including key):

$$H_{twgk.UN3} := H_{twgf.UN3.tri} + H_{twgf.UN3.rect} \cdots + H_{twbk.UN3.tri} + H_{twbk.UN3.rect} = 5709.42 \cdot kN$$

Apply Total Gate Footing Tailwater Load at:

$$H_{twgk.UN3.loc} := \frac{\left[H_{twgf.UN3.rect} \cdot \frac{\left(h_{toe}\right)}{2} + H_{twgf.UN3.tri} \cdot \frac{\left(h_{toe}\right)}{3} + H_{twbk.UN3.tri} \cdot \left(-d_{key} \cdot \frac{2}{3}\right) + H_{twbk.UN3.rect} \cdot \left(\frac{-d_{key}}{2}\right)\right]}{H_{twgf.UN3.tri} + H_{twgf.UN3.rect} + H_{twbk.UN3.tri} + H_{twbk.UN3.rect}} = 0.52\,m$$

SUMMATION OF LATERAL WATER LOADS:

$$\Sigma H_{Water.UN3} := H_{hwp.UN3} + H_{hwas.UN3} + H_{hwrg.UN3} + H_{hwgg.UN3} + H_{twp.UN3} + H_{twgk.UN3} + H_{twrg.UN3} + H_{twgg.UN3} = -1617.77 \cdot kN$$

$$\Sigma M_{Hwater.UN3} := H_{hwp.UN3} \cdot H_{hwp.UN3.loc} + H_{hwas.UN3} \cdot H_{hwas.UN3.loc} + H_{hwrg.UN3} \cdot H_{hwrg.UN3.loc} \cdots + H_{hwgg.UN3} \cdot H_{hwgg.UN3.loc} + H_{twp.UN3} \cdot H_{twp.UN3.loc} + H_{twgk.UN3} \cdot H_{twgk.UN3.loc} \cdots + H_{twrg.UN3} \cdot H_{twrg.UN3.loc} + H_{twgg.UN3} \cdot H_{twgg.UN3.loc} = -3823.6 \cdot kN \cdot m$$

VERTICAL WATER LOADS

UN3 CASE

HEADWATER:

Water Depth on top of Approach Slab: $d_{hw.UN3} := HW_{UN3} - TOC_{as} = 7.00\,m$

Length of Approach Slab: $L_{as} = 8.75\,m$

Width of Approach Slab: $w_{as} = 12.00\,m$

Length from front of Gate to Heel: $L_{hg} = 8.75\,m$

Vertical Water Weight (H1) on Approach Slab:

$$H_{1.UN3} := \left[w_{as} \cdot d_{hw.UN3} \cdot L_{hg} - w_p \cdot d_{hw.UN3} \cdot \left(L_{hg} - L_{as}\right)\right] \cdot \gamma_w = 7210.4 \cdot kN$$

Moment Arm for Application of Water Weight (H1) from toe:

$$H_{1.UN3.loc} := L_b - \frac{L_{hg}}{2} = 14.13\,m$$

TAILWATER ABOVE GUARD GATE:

Trapezoid Volume Above Gate Footing from Approach Slab to Crest:

$$V_{asc.gg.UN3} := \left(L_{gf} - L_{gfc}\right) W_{twgg.UN3} \frac{d_{hw.UN3} + Y_{C.gg.UN3}}{2} = 221.11 \cdot m^3$$

Trapezoid Volume Above Gate Footing Crest to End of Gate Footing:

$$V_{gfc.gg.UN3} := \left(L_{gfc} \cdot W_{twgg.UN3}\right) \frac{Y_{C.gg.UN3} + Y_{TOE.gg.UN3}}{2} = 53.69 \cdot m^3$$

Load Above Gate Footing from Approach Slab to Crest:

$$H_{2.UN3.asc.gg} := V_{asc.gg.UN3} \cdot \gamma_w = 2169.13 \cdot kN$$

Load Acting Above Footing Crest from Toe:

$$H_{2.UN3.asc.gg.loc} := \frac{\left(L_{gf} - L_{gfc}\right) \cdot \left(2 \cdot d_{hw.UN3} + Y_{C.gg.UN3}\right)}{3 \cdot \left(d_{hw.UN3} + Y_{C.gg.UN3}\right)} + L_{gfc} = 6.33\,m$$

Load Above Gate Footing from Crest to End:

$$H_{2.UN3.gfc.gg} := V_{gfc.gg.UN3} \cdot \gamma_w = 526.7 \cdot kN$$

Load Acting Above Gate Footing from Crest to End:

$$H_{2.UN3.gfc.gg.loc} := \frac{\left(L_{gfc}\right) \cdot \left(2 \cdot Y_{C.gg.UN3} + Y_{TOE.gg.UN3}\right)}{3 \cdot \left(Y_{C.gg.UN3} + Y_{TOE.gg.UN3}\right)} = 1.43\,m$$

Vertical Water Weight (H2) on Guard Gate Footing:

$$H_{2.UN3.gg} := H_{2.UN3.asc.gg} + H_{2.UN3.gfc.gg} = 2695.82 \cdot kN$$

Moment Arm for Application of Water Weight (H2) from toe:

$$H_{2.UN3.gg.loc} := \frac{H_{2.UN3.asc.gg} \cdot H_{2.UN3.asc.gg.loc} \cdots + H_{2.UN3.gfc.gg} \cdot H_{2.UN3.gfc.gg.loc}}{H_{2.UN3.gg}} = 5.37\,m$$

TAILWATER ABOVE REGULATING GATE:

Trapezoid Volume Above Gate Footing from Approach Slab to Crest:

$$V_{asc.rg.UN3} := \left(L_{gf} - L_{gfc}\right) W_{twrg.UN3} \frac{d_{hw.UN3} + Y_{C.rg.UN3}}{2} = 221.11 \cdot m^3$$

Trapezoid Volume Above Gate Footing Crest to End of Gate Footing:

$$V_{gfc.rg.UN3} := \left(L_{gfc} \cdot W_{twrg.UN3}\right) \frac{Y_{C.rg.UN3} + Y_{TOE.rg.UN3}}{2} = 53.69 \cdot m^3$$

Load Above Gate Footing from Approach Slab to Crest:

$$H_{2.UN3.asc.rg} := V_{asc.rg.UN3} \cdot \gamma_w = 2169.13 \cdot kN$$

Load Acting Above Footing Crest from Toe:

$$H_{2.UN3.asc.rg.loc} := \frac{\left(L_{gf} - L_{gfc}\right) \cdot \left(2 \cdot d_{hw.UN3} + Y_{C.rg.UN3}\right)}{3 \cdot \left(d_{hw.UN3} + Y_{C.rg.UN3}\right)} + L_{gfc} = 6.33\,m$$

Load Above Gate Footing from Crest to End:

$$H_{2.UN3.gfc.rg} := V_{gfc.rg.UN3} \cdot \gamma_w = 526.7 \cdot kN$$

Load Acting Above Gate Footing from Crest to End:

$$H_{2.UN3.gfc.rg.loc} := \frac{\left(L_{gfc}\right) \cdot \left(2 \cdot Y_{C.rg.UN3} + Y_{TOE.rg.UN3}\right)}{3 \cdot \left(Y_{C.rg.UN3} + Y_{TOE.rg.UN3}\right)} = 1.43\,m$$

Vertical Water Weight (H2) on Regulating Gate Footing:

$$H_{2.UN3.rg} := H_{2.UN3.asc.rg} + H_{2.UN3.gfc.rg} = 2695.82 \cdot kN$$

Moment Arm for Application of Water Weight (H2) from toe:

$$H_{2.UN3.rg.loc} := \frac{H_{2.UN3.asc.rg} \cdot H_{2.UN3.asc.rg.loc} \cdots + H_{2.UN3.gfc.rg} \cdot H_{2.UN3.gfc.rg.loc}}{H_{2.UN3.rg}} = 5.37\,m$$

UPLIFT

UN3 CASE

Uplift pressure at U/S Face (heel): $U_{HW.UN3} := \left(D_{hwas.UN3}\right)\cdot\gamma_w = 127.5\cdot\frac{kN}{m^2}$

Uplift pressure at D/S Face Stilling Basin: $U_{TW.UN3} := \left(D_{twtoe.UN3}\right)\cdot\gamma_w = 85.35\cdot\frac{kN}{m^2}$

$L_{overall} = 18.50\,m$

Difference between Uplift pressure at HW and TW: $U_{diff.UN3} := U_{HW.UN3} - U_{TW.UN3} = 42.18\cdot\frac{kN}{m^2}$

Slope of difference between between Uplift pressure at HW and TW: $U_{slope.UN3} := \frac{U_{diff.UN3}}{L_{overall}} = 2.28\cdot\frac{kN}{m^2\cdot m}$

Tailwater Pressure at toe of Gate Structure: $U_{press.toe.gs.UN3} := U_{TW.UN3} + \left(L_{overall} - L_b\right)\cdot U_{slope.UN3} = 85.35\cdot\frac{kN}{m^2}$

Uniform uplift force UA Under Gate Structure due to TW (rectangle): $U_{A.UN3} := U_{press.toe.gs.UN3}\cdot L_b\cdot W_b\cdot -1 = -18947.03\cdot kN$

Moment Arm from Toe of Gate Structure for Uplift UA: $L_{A.UN3} := \left(\frac{L_b}{2}\right) = 9.25\,m$

Linearly Decreasing Uplift Force UN3B Under Gate Structure due to HW-TW Differential (triangle): $U_{B.UN3} := \frac{1}{2}\cdot\left(U_{HW.UN3} - U_{press.toe.gs.UN3}\right)\cdot L_b\cdot W_b\cdot -1 = -4682.31\cdot kN$

Moment Arm from Toe of Gate Structure for Uplift UB: $L_{B.UN3} := \frac{2}{3}\cdot L_b = 12.33\,m$

Total Resultant Uplift force: $U_{UN3} := U_{A.UN3} + U_{B.UN3} = -23629.35\cdot kN$

Resultant Location from Toe: $U_{UN3.loc} := \frac{\left(U_{A.UN3}\cdot L_{A.UN3} + U_{B.UN3}\cdot L_{B.UN3}\right)}{\left(U_{A.UN3} + U_{B.UN3}\right)} = 9.86\,m$

$\Sigma V_{water.UN3} := H_{1.UN3} + H_{2.UN3.gg} + H_{2.UN3.rg} + U_{UN3} = -11027.35\cdot kN$

$\Sigma M_{Vwater.UN3} := H_{1.UN3}\cdot H_{1.UN3.loc} + H_{2.UN3.gg}\cdot H_{2.UN3.gg.loc} + H_{2.UN3.rg}\cdot H_{2.UN3.rg.loc} + U_{UN3}\cdot U_{UN3.loc} = -102186\cdot kN\cdot m$

SOIL LOADS

UN3 CASE

Equivalent Fluid Pressure (EFP):

At rest lateral pressure coefficient: $K_{o.UN3} := 1 - \sin(\phi_{backfill}) = 0.658$ (Section 5.3, Design Criteria)

Headwater Pier Footing Unit Width: $W_{hwas.UN3} = 12.00\,m$

Tailwater Pier Footing Unit Width: $W_{tw.UN3} = 12.00\,m$

Pier Footing Thickness at Heel: $t_{hf.UN3} := TOC_{as} - BOK_{elev} = 6.00\,m$

Fixed Crest Footing Thickness at Toe: $t_{tf.UN3} := TOC_{pfe} - BOF_{elev} = 2.00\,m$

Lateral Driving Force (Headwater Side - at rest condition)

Structure Soil Load:

$$E_{act.UN3} := \frac{\left(K_{o.UN3} \cdot t_{hf.UN3}^{\ 2}\right)}{2} \cdot \left(\gamma_r - \gamma_w\right) \cdot W_{hwas.UN3} \cdot -1 = -1732.49 \cdot kN$$

Acting at:

$$E_{act.UN3.loc} := \frac{t_{hf.UN3}}{3} - d_{key} = 0.00\,m$$

Lateral Resisting Force (Tailwater Side - at rest condition)

At-rest Soil Load:

$$E_{pass.UN3} := \frac{\left(K_{o.UN3} \cdot t_{tf.UN3}^{\ 2}\right)}{2} \cdot \left(\gamma_r - \gamma_w\right) \cdot W_{tw.UN3} = 192.5 \cdot kN$$

Acting at:

$$E_{pass.UN3.loc} := \frac{t_{tf.UN3}}{3} = 0.67\,m$$

$$\Sigma H_{soil.UN3} := E_{act.UN3} + E_{pass.UN3} = -1539.99 \cdot kN$$

$$\Sigma M_{soil.UN3} := E_{act.UN3} \cdot E_{act.UN3.loc} + E_{pass.UN3} \cdot E_{pass.UN3.loc} = 128.33 \cdot kN \cdot m$$

ICE / IMPACT LOADS (ASSUME NO ICE LOADING ON TAILWATER SIDE)

ICE & IMPACT LOADS DO NOT APPLY FOR THIS LOAD CASE

Static Ice Loading on Structure: $I_{S.UN3} := 0 \frac{kN}{m}$ (Section 7.7, Design Criteria)

Static Ice load on Gates: $I_{G.UN3} := 0 \frac{kN}{m}$ (Section 7.7, Design Criteria)

Ice Loading Unit Width on Structure: $W_{S.UN3} := 2.00m$

Ice Loading Unit Width on Regulating Gate: $W_{rg.UN3} := 0m$ (Input value for load case)

Ice Loading Unit Width on Guard Gate: $W_{gg.UN3} := 0m$ (Input value for load case)

Total Ice Load on Structure:

$$I_{UN3} := \left(I_{S.UN3} \cdot W_{S.UN3} + I_{G.UN3} \cdot W_{rg.UN3} + I_{G.UN3} \cdot W_{gg.UN3}\right) \cdot -1 = 0 \cdot kN$$

Apply Ice load at:

$$I_{UN3.loc} := \left(HW_{UN3} - BOF_{elev} - 0.30m\right) = 10.70\,m$$

$$\Sigma H_{I.UN3} := I_{UN3} = 0 \cdot kN$$

$$\Sigma M_{I.UN3} := I_{UN3} \cdot I_{UN3.loc} = 0 \cdot kN \cdot m$$

SEISMIC LOAD (NOT APPLICABLE FOR THIS LOAD CASE)

UN3 CASE

SUMMARY OF LOADS

	Loads	Moment Arm
Dead load of Concrete Structure:	$D_{conc} = 22438.7 \cdot kN$	$X_{conc.loc} = 9.35\,m$
Obermyer Gate Weight:	$D_{Gate} = 140.0 \cdot kN$	$X_{gate} = 9.50\,m$
HW Lateral Load on Pier:	$H_{hwp.UN3} = -480.7 \cdot kN$	$H_{hwp.UN3.loc} = 6.33\,m$
HW Lateral Load on Approach Slab:	$H_{hwas.UN3} = -7063.2 \cdot kN$	$H_{hwas.UN3.loc} = 0.70\,m$
HW Lateral Load on Regulating Gate:	$H_{hwrg.UN3} = 0.0 \cdot kN$	$H_{hwrg.UN3.loc} = 4.00\,m$
HW Lateral Load on Guard Gate:	$H_{hwgg.UN3} = 0.0 \cdot kN$	$H_{hwgg.UN3.loc} = 4.00\,m$
TW Lateral Load on Pier:	$H_{twp.UN3} = 216.7 \cdot kN$	$H_{twp.UN3.loc} = 5.57\,m$
TW Lateral Load on Pier Footing (including Key):	$H_{twgk.UN3} = 5709.42 \cdot kN$	$H_{twgk.UN3.loc} = 0.52\,m$
TW Lateral Load on Regulating Gate:	$H_{twrg.UN3} = 0.0 \cdot kN$	$H_{twrg.UN3.loc} = 4.00\,m$
TW Lateral Load on Guard Gate:	$H_{twgg.UN3} = 0.0 \cdot kN$	$H_{twgg.UN3.loc} = 4.00\,m$
Vertical HW Load on Approach Slab:	$H_{1.UN3} = 7210.4 \cdot kN$	$H_{1.UN3.loc} = 14.13\,m$
Vertical TW Load on Regulating Gate:	$H_{2.UN3.rg} = 2695.8 \cdot kN$	$H_{2.UN3.rg.loc} = 5.37\,m$
Vertical TW Load on Guard Gate:	$H_{2.UN3.gg} = 2695.8 \cdot kN$	$H_{2.UN3.gg.loc} = 5.37\,m$
Uplift:	$U_{UN3} = -23629.3 \cdot kN$	$U_{UN3.loc} = 9.86\,m$
Lateral Soil Load (driving):	$E_{act.UN3} = -1732.5 \cdot kN$	$E_{act.UN3.loc} = 0.00\,m$
Lateral Soil Load (resisting):	$E_{pass.UN3} = 192.5 \cdot kN$	$E_{pass.UN3.loc} = 0.67\,m$
Ice / Impact Load:	$I_{UN3} = 0.0 \cdot kN$	$I_{UN3.loc} = 10.70\,m$

STABILITY ASSESSMENT (SLIDNG, BEARING, FLOTATION AND OVERTURNING): UN3 CASE

CHECK SLIDING ALONG HORIZONTAL PLANE THRU TOE,
IGNORING BEDROCK MOBILIZED BY STRUCTURAL HEEL KEY, OR VOID BEHIND KEY

Sum of Vertical Forces:

$\Sigma V_{UN3} := \Sigma V_{DL} + \Sigma V_{water.UN3} = 11551.4 \cdot kN$

Sum of Horizontal Forces:

$\Sigma H_{UN3} := \Sigma H_{Water.UN3} + \Sigma H_{soil.UN3} + \Sigma H_{I.UN3} = -3157.76 \cdot kN$

Sliding Factor of Safety:

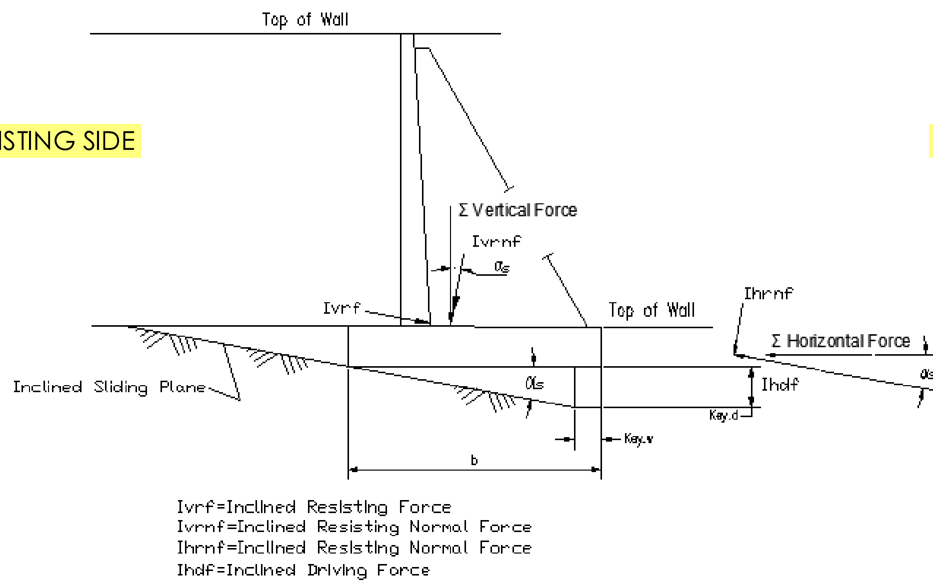
$$FS_{HorizSliding.UN3} := \frac{\tan_{\phi} \cdot \Sigma V_{UN3}}{\left|\Sigma H_{UN3}\right|} = 1.78$$

$$FS_{HorizSliding.UN3.Check} := \begin{array}{|l} \text{"OKAY"} \quad \text{if} \quad FS_{HorizSliding.UN3} \geq FS_{req.UN3.sl} \\ \text{"Check Inclined Sliding with Key"} \end{array} = \text{"Check Inclined Sliding with Key"}$$

CHECK SLIDING ALONG INCLINED SLIDING PLANE FROM HEEL KEY TO TOE,
WITH BEDROCK MASS MOBILIZED BY REINFOCREDE CONCRETE KEY)

RESISTING SIDE

DRIVING SIDE



TOE

$\Sigma V_{UN3} = 11551.39 \cdot kN$

$V_{rs} = 4620 \cdot kN$

$\alpha s = 0.11$

as degrees= $\alpha s \cdot \left(\frac{180}{\pi}\right) = 6.52$

Resolve $\Sigma Vert_{UN3}$ & $\Sigma Horiz_{UN3}$

$$\Sigma V_{InclinedUN3} := \cos(\alpha s) \cdot \left(\Sigma V_{UN3} + V_{rs}\right) + \sin(\alpha s) \cdot \left|\Sigma H_{UN3}\right| = 16425.4 \cdot kN$$

$$\Sigma H_{InclinedUN3} := \cos(\alpha s) \cdot \left|\Sigma H_{UN3}\right| - \sin(\alpha s) \cdot \left(\Sigma V_{UN3} + V_{rs}\right) = 1301.1 \cdot kN$$

(With properly engineered reinforced concrete Key, horizontal sliding plane thru Toe is protected, critical sliding plane is relocated to the INCLINED SLIDING PLANE FROM HEEL KEY To TOE, Bedrock Mass above this examined plane is mobilized by reinforced concrete key and combined into Structural Wedge.)

Inclined Sliding Plane Length

$L_{incline} = 18.61 \, m$

Safety Factor for Sliding
Inclined Failure Plane

$$FS_{InclinedlSlidingUN3} := \frac{\Sigma V_{InclinedUN3} \cdot \tan\left(\phi_{rock} \cdot \frac{\pi}{180}\right)}{\left|\Sigma H_{InclinedUN3}\right|} = 6.16$$

$$FS_{InclinedSliding.check.UN3} := \begin{array}{|l} \text{"OKAY "} \quad \text{if} \quad FS_{InclinedlSlidingUN3} > FS_{req.UN3.sl} \\ \text{"Revise Structure"} \quad \text{otherwise} \end{array} = \text{"OKAY "}$$

$FS_{InclinedSliding.check.UN3} = \text{"OKAY "}$

UN3 CASE

OVERTURNING STABILITY CHECK:

CHECK ECCENTRICITY

Sum of the moments:

$$\Sigma M_{UN3} := \Sigma M_{DL} + \Sigma M_{Hwater.UN3} + \Sigma M_{Vwater.UN3} + \Sigma M_{I.UN3} + \Sigma M_{soil.UN3} + \Sigma M_{rs} = 159139 \cdot kN \cdot m$$

Eccentricity:

$$e_{UN3} := \left(\frac{L_{incline}}{2}\right) - \frac{(\Sigma M_{UN3})}{\Sigma V_{InclinedUN3}} = -0.38\,m$$

Eccentricity Check:

$$e_{check.UN3} := \begin{cases} \text{"Okay"} & \text{if } e_{UN3} \le Kern \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$$e_{check.UN3} = \text{"Okay"}$$

Foundation Bearing Checks:

Bearing Pressure at Heel:

$$\sigma_{heel.UN3} := \frac{\Sigma V_{InclinedUN3}}{A_{b.incline}} - \frac{(\Sigma V_{InclinedUN3} \cdot e_{UN3})}{S_{b.incline}} = 82.7 \cdot \frac{kN}{m^2}$$

$$\sigma_{heel.UN3.check} := \left(\begin{cases} \text{"Okay"} & \text{if } \sigma_{heel.UN3} \le \sigma_{allow.UN3} \\ \text{"Revise Structure"} & \text{if } \sigma_{heel.UN3} < 0\frac{kN}{m^2} \end{cases}\right)$$

$$\sigma_{heel.UN3.check} = \text{"Okay"}$$

Bearing Pressure at Toe:

$$\sigma_{toe.UN3} := \frac{\Sigma V_{InclinedUN3}}{A_{b.incline}} + \frac{(\Sigma V_{InclinedUN3} \cdot e_{UN3})}{S_{b.incline}} = 64.4 \cdot \frac{kN}{m^2}$$

$$\sigma_{toe.UN3.1.check} := \begin{cases} \text{"Okay"} & \text{if } \sigma_{toe.UN3} \le \sigma_{allow.UN3} \\ \text{"Revise Structure"} & \text{if } \sigma_{toe.UN3} < 0\frac{kN}{m^2} \end{cases}$$

$$\sigma_{toe.UN3.1.check} = \text{"Okay"}$$

FLOATATION ANALYSIS:

ACCEPTANCE PARAMETERS

Required Factor of Safety: $FS_{req.FUN3} := 1.3$

VERTICAL LOADS RESISTING:

Dead Load: $\Sigma V_{DL} = 22578.74 \cdot kN$

Water Weight H1+H2: $\Sigma V_{H.FUN3} := H_{1.UN3} + H_{2.UN3.gg} + H_{2.UN3.rg} = 12602 \cdot kN$

Summation Vertical Resisting: $\Sigma V_{FUN3} := \Sigma V_{DL} + \Sigma V_{H.FUN3} = 35180.7 \cdot kN$

VERTICAL LOADS UPLIFT:

Uplift: $U_{UN3} = -23629.35 \cdot kN$

Factor of Safety Floatation:

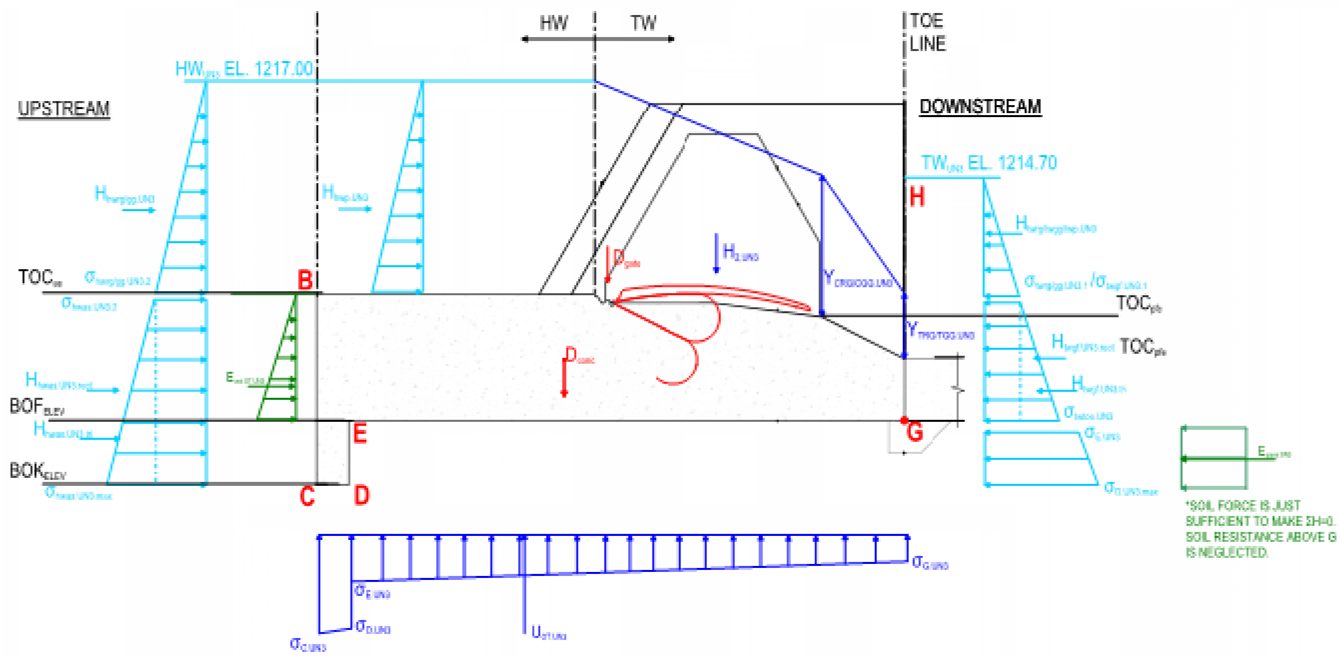
$$FS_{act.FUN3} := \frac{\Sigma V_{FUN3}}{|U_{UN3}|} = 1.49$$

$$FS_{check.FUN3} := \begin{cases} \text{"OKAY"} & \text{if } FS_{act.FUN3} \ge FS_{req.FUN3} \\ \text{"ANCHORS REQUIRED"} & \text{if } FS_{act.FUN3} < FS_{req.FUN3} \end{cases} = \text{"OKAY"}$$

MONOLITH OVERTURNING STABILITY ANALYSIS

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.
Assumptions are made in order to compute overturning stability of indetermine forces on monolith with key;
(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.
(b) The horizontal resisting force acting on the key, P.key, is that required for static equilibrium
(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1 $Ratio_{OT.UN3.min} := 0.33$



Uplift Loads for Overturning Stability Analysis

Line of Creep:

Change in Water Head: $\Delta_{h.UN3} := HW_{UN3} - TW_{UN3} = 2.3\,m$

Length from Point C to Point G: $L_{CG} = 18.61\,m$

Length from Various Points to Points: $L_{CD} = 1\,m$ $L_{DE} = 2\,m$ $L_{EG} = 17.5\,m$

$L_{GH.UN3} := TW_{UN3} - BOF_{elev} = 8.7\,m$

Length from Point C, D, E to G: $L_{CDEG} = 20.5\,m$ $L_{CDE} = 3\,m$

Water Pressure at Point C & G: $\sigma_{C.UN3} := \sigma_{hwas.UN3.2} = -127.53 \cdot kPa$ $\sigma_{G.UN3} := \sigma_{twtoe.UN3} \cdot -1 = -85.35 \cdot kPa$

Water Pressure at Point D: $$\sigma_{D.UN3} := -\gamma_w \cdot \left[\left(HW_{UN3} - BOK_{elev}\right) - \frac{\Delta_{h.UN3} \cdot L_{CD}}{L_{CDEG}}\right] = -126.43 \cdot kPa$$

Water Pressure at Point E: $$\sigma_{E.UN3} := -\gamma_w \cdot \left[\left(HW_{UN3} - BOF_{elev}\right) - \frac{\Delta_{h.UN3} \cdot L_{CDE}}{L_{CDEG}}\right] = -104.61 \cdot kPa$$

Uplift for Overturning Analysis on Bottom of Key: $$U_{OT.UN3.key} := \frac{\sigma_{C.UN3} + \sigma_{D.UN3}}{2} \cdot L_{CD} \cdot W_b = -1523.76 \cdot kN$$

Acting at: $$U_{OT.UN3.key.loc} := \frac{L_{CD} \cdot \left(2 \cdot \sigma_{C.UN3} + \sigma_{D.UN3}\right)}{3\left(\sigma_{C.UN3} + \sigma_{D.UN3}\right)} + L_{EG} = 18\,m$$

Uplift for Overturning Analysis on Bottom of Footing: $$U_{OT.UN3.ftg} := \frac{\sigma_{E.UN3} + \sigma_{G.UN3}}{2} \cdot L_{EG} \cdot W_b = -19945.29 \cdot kN$$

Acting at: $$U_{OT.UN3.ftg.loc} := \frac{L_{EG} \cdot \left(\sigma_{G.UN3} + 2 \cdot \sigma_{E.UN3}\right)}{3\left(\sigma_{G.UN3} + \sigma_{E.UN3}\right)} = 9.05\,m$$

UN3 CASE

Uplift Load for Overturning Analysis: $U_{OT.UN3} := U_{OT.UN3.key} + U_{OT.UN3.ftg} = -21469.04 \cdot kN$

Uplift Load Acting from Toe: $U_{OT.UN3.loc} := \dfrac{U_{OT.UN3.key} \cdot U_{OT.UN3.key.loc} + U_{OT.UN3.ftg} \cdot U_{OT.UN3.ftg.loc}}{U_{OT.UN3}} = 9.68\,m$

All Vertical Loads Applicable to Overturning Stability Analysis

		at:	
Total Concrete Dead Loads:	$D_{conc} = 22438.74 \cdot kN$		$X_{conc.loc} = 9.35\,m$
Dead Load of Gate:	$D_{Gate} = 140.0 \cdot kN$		$X_{gate} = 9.50\,m$
Water Weight (HW) on Apron Slab:	$H_{1.UN3} = 7210.4 \cdot kN$		$H_{1.UN3.loc} = 14.13\,m$
Water Weight (TW) on Gate Footing:	$H_{2.UN3.rg} = 2695.8 \cdot kN$		$H_{2.UN3.rg.loc} = 5.37\,m$
Water Weight (TW) on Regulating Gate Footing:	$H_{2.UN3.gg} = 2695.8 \cdot kN$		$H_{2.UN3.gg.loc} = 5.37\,m$
Uplift Load for Overturning Analysis:	$U_{OT.UN3} = -21469.04 \cdot kN$		$U_{OT.UN3.loc} = 9.68 \cdot m$

Sum of All Overturning Analysis Vertical Load:

$$\Sigma V_{UN3.OT} := D_{conc} + D_{Gate} + H_{1.UN3} + H_{2.UN3.rg} + H_{2.UN3.gg} + U_{OT.UN3} = 13711.7 \cdot kN$$

Sum of All Overturning Analysis Vertical Load Moments:

$$\Sigma M_{V.UN3.OT} := D_{conc} \cdot X_{conc.loc} + D_{Gate} \cdot X_{gate} + H_{1.UN3} \cdot H_{1.UN3.loc} + H_{2.UN3.rg} \cdot H_{2.UN3.rg.loc} \ldots + H_{2.UN3.gg} \cdot H_{2.UN3.gg.loc} + U_{OT.UN3} \cdot U_{OT.UN3.loc} = 134093.87 \cdot kN \cdot m$$

Lateral Tailwater Loads for Overturning Stability Analysis

TW Lateral Load on Gate Footing (No Key - Overturning Values Adjusted): $H_{twgf.UN3} := H_{twgf.UN3.tri} + H_{twgf.UN3.rect} = 3154.9 \cdot kN$

Acting at: $H_{twgf.UN3.loc} := \dfrac{\frac{h_{toe}}{3} \cdot H_{twgf.UN3.tri} + \frac{h_{toe}}{2} \cdot H_{twgf.UN3.rect}}{H_{twgf.UN3}} = 1.8\,m$

Horizontal Tailwater Pressure Top of Key (Overturning Analysis): $\sigma_{twtk.OT.UN3} := \sigma_{E.UN3} \cdot -1 = 104.61 \cdot kPa$

Horizontal Tailwater Pressure Bottom of Key (Overturning Analysis): $\sigma_{twbk.OT.UN3} := \sigma_{D.UN3} \cdot -1 = 126.43 \cdot kPa$

Triangular Distribution Unit Load Acting at Key: $H_{twbk.OT.UN3.tri} := \dfrac{\left(\sigma_{twbk.OT.UN3} - \sigma_{twtk.OT.UN3}\right)}{2} \cdot d_{key} \cdot W_{tw.UN3} = 261.86 \cdot kN$

Triangular Distribution Unit Load Acting at Key: $H_{twbk.OT.UN3.rect} := \sigma_{twtk.OT.UN3} \cdot d_{key} \cdot W_{tw.UN3} = 2510.59 \cdot kN$

Total Horizontal Tailwater Load on Key (Overturning Values Adjusted): $H_{twkey.OT.UN3} := H_{twbk.OT.UN3.tri} + H_{twbk.OT.UN3.rect} = 2772.45 \cdot kN$

Acting at: $H_{twkey.OT.UN3.loc} := \dfrac{H_{twbk.OT.UN3.tri} \cdot \frac{-2 \cdot d_{key}}{3} + H_{twbk.OT.UN3.rect} \cdot \frac{-d_{key}}{2}}{H_{twkey.OT.UN3}} = -1.03 \cdot m$

Lateral Driving Earth Loads for Overturning Stability Analysis (at rest condition)

Depth of Driving Soil Loads (to top of key): $h_{E.OT.UN3} := TOC_{as} - BOF_{elev} = 4\,m$

At-Rest Soil Load: $E_{act.OT.UN3} := \dfrac{\left(K_{o.UN3} \cdot h_{E.OT.UN3}^{\;2}\right)}{2} \cdot \left(\gamma_r - \gamma_w\right) \cdot W_{hwas.UN3} \cdot -1 = -769.99 \cdot kN$

At Rest- Soil Load Acting from Toe: $E_{act.OT.UN3.loc} := \dfrac{h_{E.OT.UN3}}{3} = 1.33\,m$

All Lateral Loads Applicable to Overturning Stability Analysis

HW Lateral Load on Approach Slab:	$H_{hwas.UN3} = -7063.2 \cdot kN$	$H_{hwas.UN3.loc} = 0.70\,m$
HW Lateral Load on Regulating Gate:	$H_{hwrg.UN3} = 0.0 \cdot kN$	$H_{hwrg.UN3.loc} = 4.00\,m$
HW Lateral Load on Guard Gate:	$H_{hwgg.UN3} = 0.0 \cdot kN$	$H_{hwgg.UN3.loc} = 4.00\,m$
TW Lateral Load on Regulating Gate:	$H_{twrg.UN3} = 0.0 \cdot kN$	$H_{twrg.UN3.loc} = 4.00\,m$
HW Lateral Load on Guard Gate:	$H_{twgg.UN3} = 0.0 \cdot kN$	$H_{twgg.UN3.loc} = 4.00\,m$
TW Lateral Load on Gate Footing (No Key - Overturning Values Adjusted):	$H_{twgf.UN3} = 3154.9 \cdot kN$	$H_{twgf.UN3.loc} = 1.8\,m$
TW Lateral Load on Key:	$H_{twkey.OT.UN3} = 2772.45 \cdot kN$	$H_{twkey.OT.UN3.loc} = -1.03\,m$
Ice / Impact Load:	$I_{UN3} = 0.0 \cdot kN$	$I_{UN3.loc} = 10.70\,m$
Lateral Soil Load (driving):	$E_{act.OT.UN3} = -770.0 \cdot kN$	$E_{act.OT.UN3.loc} = 1.33\,m$

Resisting Lateral Soil Load as required to produce horizontal equilibrium:

$$E_{pas.OT.UN3} := -\left(H_{hwas.UN3} + H_{hwrg.UN3} + H_{hwgg.UN3} + H_{twrg.UN3} + H_{twgg.UN3} \cdots + H_{twgf.UN3} + H_{twkey.OT.UN3} + I_{UN3} + E_{act.OT.UN3}\right) = 1905.85 \cdot kN$$

$$E_{pas.OT.UN3.loc} := -1 \cdot \frac{d_{key}}{2} = -1\ m$$

Sum of All Overturning Analysis Horizontal Load (ΣH=0):

$$\Sigma H_{UN3.OT} := H_{hwas.UN3} + H_{hwrg.UN3} + H_{hwgg.UN3} + H_{twrg.UN3} + H_{twgg.UN3} \cdots + H_{twgf.UN3} + H_{twkey.OT.UN3} + I_{UN3} + E_{act.OT.UN3} + E_{pas.OT.UN3} = 0 \cdot kN$$

Sum of All Overturning Analysis Horizontal Load Moments:

$$\Sigma M_{H.UN3.OT} := H_{hwas.UN3} \cdot H_{hwas.UN3.loc} + H_{hwrg.UN3} \cdot H_{hwrg.UN3.loc} + H_{hwgg.UN3} \cdot H_{hwgg.UN3.loc} \cdots + H_{twrg.UN3} \cdot H_{twrg.UN3.loc} + H_{twgg.UN3} \cdot H_{twgg.UN3.loc} + H_{twgf.UN3} \cdot H_{twgf.UN3.loc} \cdots + H_{twkey.OT.UN3} \cdot H_{twkey.OT.UN3.loc} + I_{UN3} \cdot I_{UN3.loc} + E_{act.OT.UN3} \cdot E_{act.OT.UN3.loc} \cdots + E_{pas.OT.UN3} \cdot E_{pas.OT.UN3.loc} = -5054.53 \cdot kN \cdot m$$

Overturning Stability Analysis

$$\Sigma M_{UN3.OT} := \Sigma M_{V.UN3.OT} + \Sigma M_{H.UN3.OT} = 129039.34 \cdot kN \cdot m$$

$$X_{R.UN3} := \frac{\Sigma M_{UN3.OT}}{\Sigma V_{UN3.OT}} = 9.41\,m \qquad x_{OT.UN3} := X_{R.UN3} - \frac{L_b}{2} = 0.16\,m$$

Overturning Resultant Ratio

$$Ratio_{OT.UN3} := \frac{X_{R.UN3}}{L_b} = 0.51$$

$$Ratio_{OT.UN3.check} := \begin{cases} \text{"OKAY"} & \text{if } Ratio_{OT.UN3} \ge Ratio_{OT.UN3.min} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

$$x_{OT.check.UN3} := \begin{cases} \text{"OKAY"} & \text{if } \left|x_{OT.UN3}\right| \le Kern \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

UN3 CASE

CHECK FOUNDATION BEARING CAPACITY (HORIZONTAL PLANE):

Bearing Pressure Under Toe:

$$\sigma_{ToeUN3.OT} := \frac{\Sigma V_{UN3.OT}}{L_b \cdot W_b} + \frac{\left(\Sigma V_{UN3.OT} \cdot x_{OT.UN3}\right)}{S_b} = 65.0 \cdot kPa$$

$$Bearing_{ChecktoeUN3.OT} := \begin{cases} \text{"OKAY "} & \text{if } \sigma_{ToeUN3.OT} < \sigma_{allow.UN3} \\ \text{"NG""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

Bearing Pressure Under Heel:

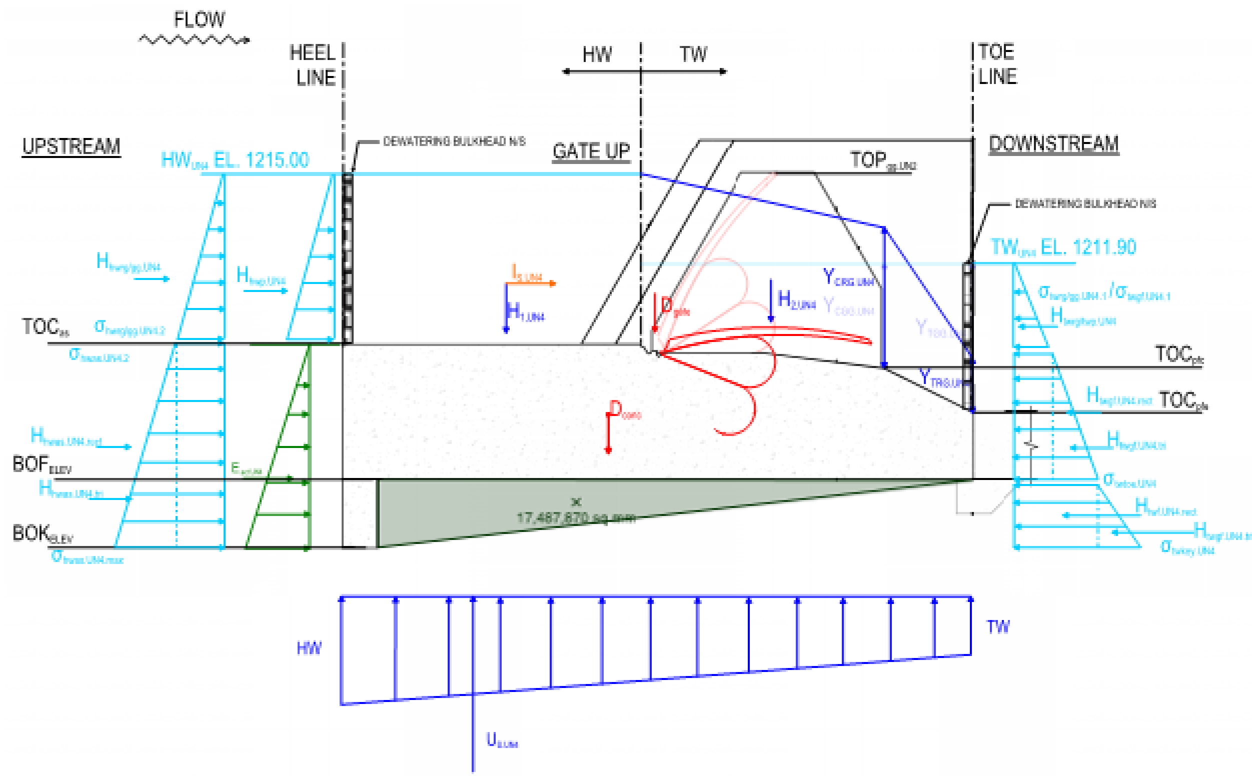
$$\sigma_{HeelUN3.OT} := \frac{\Sigma V_{UN3.OT}}{L_b \cdot W_b} - \frac{\left(\Sigma V_{UN3.OT} \cdot x_{OT.UN3}\right)}{S_b} = 58.5 \cdot kPa$$

$$Bearing_{CheckheelUN3.OT} := \left(\begin{cases} \text{"OKAY "} & \text{if } \sigma_{HeelUN3.OT} < \sigma_{allow.UN3} \wedge \sigma_{HeelUN3.OT} > 0 \\ \text{"NG""} & \text{otherwise} \end{cases} \right) = \text{"OKAY "}$$

SUMMARY OF STABILITY ASSESSMENT:

Sliding Factor of Safety: (Horizontal Plane)	$FS_{HorizSliding.UN3} = 1.78$	$FS_{HorizSliding.UN3.Check}$ = "Check Inclined Sliding with
Sliding Factor of Safety: (Inclined Plane)	$FS_{InclinedlSlidingUN3} = 6.16$	$FS_{InclinedSliding.check.UN3}$ = "OKAY "
Eccentricity: (Inclined Plane)	$e_{UN3} = -0.38\,m$	$e_{check.UN3}$ = "Okay"
Bearing Pressure At Heel: (Inclined Plane)	$\sigma_{heel.UN3} = 83 \cdot kPa$	$\sigma_{heel.UN3.check}$ = "Okay"
Bearing Pressure At Toe: (Inclined Plane)	$\sigma_{toe.UN3} = 64 \cdot kPa$	$\sigma_{toe.UN3.1.check}$ = "Okay"
Flotation Factor of Safety (horizontal plane)	$FS_{act.FUN3} = 1.49$	$FS_{check.FUN3}$ = "OKAY"
Overturning Resultant Ratio: (horizontal plane)	$Ratio_{OT.UN3} = 0.51$	$Ratio_{OT.UN3.check}$ = "OKAY"
Eccentricity: (horizontal plane)	$x_{OT.UN3} = 0.16\,m$	$x_{OT.check.UN3}$ = "OKAY"
Bearing Pressure At Heel: (horizontal plane)	$\sigma_{HeelUN3.OT} = 59 \cdot kPa$	$Bearing_{CheckheelUN3.OT}$ = "OKAY "
Bearing Pressure At Toe: (horizontal plane)	$\sigma_{ToeUN3.OT} = 65 \cdot kPa$	$Bearing_{ChecktoeUN3.OT}$ = "OKAY "

UN4 DESIGN CASE



ACCEPTANCE PARAMETERS

Required Factor of Safety for Sliding: $FS_{req.UN4.sl} := 1.3$ (Without Cohesion) (Section 8.1, Design Criteria)

Resultant Within Middle Third of Base: $e \le \frac{L_b}{6} \wedge e \ge \frac{-L_b}{6}$

Allowable Rock Bearing Pressure: $\sigma_{allow.UN4} := 1470 \cdot \frac{kN}{m^2}$ (Section 5.2, Design Criteria)

INPUT PARAMETERS

Headwater Elevation: $HW_{UN4} := 1215.00m$ (Section 8.3, Design Criteria)

Tailwater Elevation: $TW_{UN4} := 1211.9m$ (Section 8.3, Design Criteria)

Bottom of Footing Elevation: $BOF_{elev} = 1206.00\,m$

Approach Slab Top of Concrete Elevation at Upstream Face: $TOC_{as} = 1210.00\,m$

Pier Footing Top of Concrete Elevation at Stilling Basin: $TOC_{pfe} = 1208.00\,m$

Pier Footing Top of Concrete Elevation at Center of Footing: $TOC_{pfc} = 1209.30\,m$

Top of Guard/ Regulating Gate Elevation: $TOP_{rg.UN4} := 1210.90m$ $TOP_{gg.UN4} := 1215.00m$

Bottom of Key Elevation: $BOK_{elev} = 1204\,m$

Gates are open when top of gate elevation is at 1210.00m

Gates are closed/up when top of gate elevation is at 1215.0m

Crestwater Elevation (Right) Guard Gate: $EL_{CGG.UN4} := 1212.5m$

$$Y_{C.gg.UN4} := \begin{cases} (EL_{CGG.UN4} - TOC_{pfc}) & \text{if } TOP_{gg.UN4} \le HW_{UN4} \\ (TW_{UN4} - TOC_{pfc}) & \text{if } TOP_{gg.UN4} > HW_{UN4} \end{cases} = 3.2 \cdot m$$

Toewater Elevation (Right) Guard Gate: $EL_{TGG.UN4} := 1212.5m$

$$Y_{TOE.gg.UN4} := \begin{cases} (EL_{TGG.UN4} - TOC_{pfe}) & \text{if } TOP_{gg.UN4} \le HW_{UN4} \\ (TW_{UN4} - TOC_{pfe}) & \text{if } TOP_{gg.UN4} > HW_{UN4} \end{cases} = 4.5 \cdot m$$

UN4 CASE

Crestwater Elevation (Left) Regulating Gate: $EL_{CRG.UN4} := 1213.63m$

$$Y_{C.rg.UN4} := \begin{cases} (EL_{CRG.UN4} - TOC_{pfc}) & \text{if } TOP_{rg.UN4} \le HW_{UN4} \\ (TW_{UN4} - TOC_{pfc}) & \text{if } TOP_{rg.UN4} > HW_{UN4} \end{cases} = 4.33 \cdot m$$

Toewater Elevation (Left) Regulating Gate: $EL_{TRG.UN4} := 1209.23m$

$$Y_{TOE.rg.UN4} := \begin{cases} (EL_{TRG.UN4} - TOC_{pfe}) & \text{if } TOP_{rg.UN4} \le HW_{UN4} \\ (TW_{UN4} - TOC_{pfe}) & \text{if } TOP_{rg.UN4} > HW_{UN4} \end{cases} = 1.23 \cdot m$$

This load case is the Construction / Maintenance / Single Gate Bay Dewatered Load Case. One bay is open, while the other has been blocked off for gate maintenance.

CREST GATE (OBERMEYER)

Dead Load of Gates: $D_{Gate.UN4} := 70kN$ Vendor dwgs. Q-200 Series

DEAD LOAD SUMMATION:

$\Sigma V_{DL.UN4} := D_{conc} + D_{Gate.UN4} = 22508.7 \cdot kN$

$\Sigma M_{DL.UN4} := D_{conc} \cdot X_{conc.loc} + D_{Gate.UN4} \cdot X_{gate} = 210454.95 \cdot kN \cdot m$

LATERAL WATER LOADS

HEADWATER (DRIVING):

Headwater Depth on Pier: $D_{hwp.UN4} := HW_{UN4} - TOC_{as} = 5.00\,m$

Headwater Load Unit Width on Pier: $W_{hwp.UN4} := w_p = 2.00\,m$

Total Horizontal Headwater Load on Pier:

$$H_{hwp.UN4} := \frac{-(\gamma_w \cdot D_{hwp.UN4}^{\ 2})}{2} \cdot W_{hwp.UN4} = -245.3 \cdot kN$$

Apply Total Pier Headwater Load at:

$$H_{hwp.UN4.loc} := \frac{D_{hwp.UN4}}{3} + (TOC_{as} - BOF_{elev}) = 5.67\,m$$

Gate Width: $Gate_{width} := 5.00m$

Headwater Depth on Gate base: $D_{hwg.UN4} := HW_{UN4} - TOC_{as} = 5.00\,m$

Thickness of Approach Slab (Including Key): $T_{as} = 6\,m$

Headwater Depth at Heel (U/S face): $D_{hwas.UN4} := HW_{UN4} - BOK_{elev} = 11.00\,m$

Headwater Load Unit Width on Approach Slab: $W_{hwas.UN4} := W_b = 12.00\,m$

Headwater Line Load At Top of Approach Slab: $\sigma_{hwas.UN4.1} := -(\gamma_w \cdot D_{hwg.UN4}) = -49.05 \cdot kPa$

Headwater Line Load At Bottom of Approach Key: $\sigma_{hwas.UN4.2} := -(\gamma_w \cdot D_{hwas.UN4}) = -107.91 \cdot kPa$

Triangular Distribution Unit Load on Approach Slab and Key:

$$H_{hwas.UN4.2.tri} := \left(\frac{\sigma_{hwas.UN4.2} - \sigma_{hwas.UN4.1}}{2}\right) \cdot (T_{as} \cdot W_{hwas.UN4}) = -2118.96 \cdot kN$$

Rectangular Distribution Unit Load on Approach Slab and Key:

$$H_{hwas.UN4.2.rect} := \sigma_{hwas.UN4.1} \cdot (T_{as} \cdot W_{hwas.UN4}) = -3531.6 \cdot kN$$

Total Horizontal Headwater Load on Approach Slab:

$$H_{hwas.UN4} := H_{hwas.UN4.2.tri} + H_{hwas.UN4.2.rect} = -5650.56 \cdot kN$$

Apply Total Footing Headwater Load at:

$$H_{hwas.UN4.loc} := \frac{\left[H_{hwas.UN4.2.rect} \cdot \frac{(T_{as})}{2} + H_{hwas.UN4.2.tri} \cdot \frac{(T_{as})}{3}\right]}{H_{hwas.UN4.2.tri} + H_{hwas.UN4.2.rect}} - d_{key} = 0.63\,m$$

LATERAL WATER LOADS (continued)

UN4 CASE

Regulating Gate (2A) Operating Condition:

Regulating Crest Gate Down/Open Condition: $A1_{UN4} := TOP_{rg.UN4} \le TOC_{as}$

Regulating Crest Gate Up/Closed, with Top of Gate Higher than HW Elevation: $B1_{UN4} := TOP_{rg.UN4} \ge HW_{UN4} \wedge TOP_{rg.UN4} > TOC_{as}$

Regulating Crest Gate Up/Closed, with Top of Gate Lower than HW Elevation: $C1_{UN4} := TOP_{rg.UN4} > TOC_{as} \wedge HW_{UN4} > TOP_{rg.UN4}$

Regulating Crest Gate Height: $H_{rg.UN4} := TOP_{rg.UN4} - TOC_{as} = 0.9\,m$

Headwater Depth at Regulating Crest Gate: $D_{hwrg.UN4} := HW_{UN4} - TOC_{as} = 5.00\,m$

Regulating Crest Gate Width: $W_{hwrg.UN4} := 5.00m$

Lateral Headwater Pressure at Bottom of Regulating Crest Gate:

$$\sigma_{hwrg.UN4.1} := \begin{cases} (0.0kPa) & \text{if } A1_{UN4} \\ -(\gamma_w \cdot D_{hwrg.UN4}) & \text{if } B1_{UN4} \\ -(\gamma_w \cdot D_{hwrg.UN4}) & \text{if } C1_{UN4} \end{cases} = -49.0 \cdot kPa$$

Lateral Headwater Pressure at Top of Regulating Crest Gate:
(Load at HW Elevation On Regulating Crest Gate if HW is below TOG_{rg})

$$\sigma_{hwrg.UN4.2} := \begin{cases} (0.0kPa) & \text{if } A1_{UN4} \\ 0.0kPa & \text{if } B1_{UN4} \\ -\left[\gamma_w \cdot (HW_{UN4} - TOP_{rg.UN4})\right] & \text{if } C1_{UN4} \end{cases} = -40.2 \cdot kPa$$

Average Pressure acting on Regulating Gate:

$$\sigma_{hwrg.UN4.avg} := \frac{(\sigma_{hwrg.UN4.1} + \sigma_{hwrg.UN4.2})}{2} = -44.64 \cdot kPa$$

Total Area water acting on Regulating Crest Gate:

$$A_{hwrg.UN4} := \begin{cases} D_{hwrg.UN4} \cdot W_{hwrg.UN4} & \text{if } A1_{UN4} \\ D_{hwrg.UN4} \cdot W_{hwrg.UN4} & \text{if } B1_{UN4} \\ H_{rg.UN4} \cdot W_{hwrg.UN4} & \text{if } C1_{UN4} \end{cases} = 4.5 \cdot m^2$$

Total Horizontal Headwater Load on Regulating Crest Gate: $H_{hwrg.UN4} := \sigma_{hwrg.UN4.avg} \cdot A_{hwrg.UN4} = -200.9 \cdot kN$

Apply Total Regulating Crest Gate Headwater Load at:

$$H_{hwrg.UN4.loc} := \begin{cases} (TOC_{as} - BOF_{elev}) & \text{if } A1_{UN4} \\ \left[\frac{(HW_{UN4} - TOC_{as})}{3} + (TOC_{as} - BOF_{elev})\right] & \text{if } B1_{UN4} \\ \left[\frac{\sigma_{hwrg.UN4.2} \cdot A_{hwrg.UN4} \cdot \frac{(H_{rg.UN4})}{2} + \frac{(\sigma_{hwrg.UN4.1} - \sigma_{hwrg.UN4.2})}{2} A_{hwrg.UN4} \cdot \frac{(H_{rg.UN4})}{3}}{\sigma_{hwrg.UN4.2} \cdot A_{hwrg.UN4} + \frac{(\sigma_{hwrg.UN4.1} - \sigma_{hwrg.UN4.2})}{2} \cdot A_{hwrg.UN4}} \ldots \\ + (TOC_{as} - BOF_{elev})\right] & \text{if } C1_{UN4} \end{cases} = 4.4 \cdot m$$

Guard Gate (4A) Operating Condition:

Guard Gate Down/Open Condition: $A2_{UN4} := TOP_{gg.UN4} \le TOC_{as}$

Guard Crest Gate Up/Closed, with Top of Gate Higher than HW Elevation: $B2_{UN4} := TOP_{gg.UN4} \ge HW_{UN4} \wedge TOP_{gg.UN4} > TOC_{as}$

Guard Crest Gate Up/Closed, with Top of Gate Lower than HW Elevation: $C2_{UN4} := TOP_{gg.UN4} > TOC_{as} \wedge HW_{UN4} > TOP_{gg.UN4}$

Guard Crest Gate Height: $H_{gg.UN4} := TOP_{gg.UN4} - TOC_{as} = 5\,m$

Headwater Depth at Guard Crest Gate: $D_{hwgg.UN4} := HW_{UN4} - TOC_{as} = 5.00\,m$

Guard Crest Gate Width: $W_{hwgg.UN4} := 5.00m$

Lateral Headwater Pressure at Bottom of Guard Crest Gate:

$$\sigma_{hwgg.UN4.1} := \begin{cases} (0.0kPa) & \text{if } A2_{UN4} \\ -(\gamma_w \cdot D_{hwgg.UN4}) & \text{if } B2_{UN4} \\ -(\gamma_w \cdot D_{hwgg.UN4}) & \text{if } C2_{UN4} \end{cases} = -49.0 \cdot kPa$$

Lateral Headwater Pressure at Top of Guard Crest Gate: (Load at HW Elevation On Guard Crest Gate if HW is below TOG_{rg})

$$\sigma_{hwgg.UN4.2} := \begin{cases} (0.0kPa) & \text{if } A2_{UN4} \\ 0.0kPa & \text{if } B2_{UN4} \\ -\left[\gamma_w \cdot (HW_{UN4} - TOP_{gg.UN4})\right] & \text{if } C2_{UN4} \end{cases} = 0.0 \cdot kPa$$

Average Pressure acting on Guard Crest Gate:

$$\sigma_{hwgg.UN4.avg} := \frac{(\sigma_{hwgg.UN4.1} + \sigma_{hwgg.UN4.2})}{2} = -24.52 \cdot kPa$$

Total Area water acting on Crest Gate:

$$A_{hwgg.UN4} := \begin{cases} D_{hwgg.UN4} \cdot W_{hwgg.UN4} & \text{if } A2_{UN4} \\ D_{hwgg.UN4} \cdot W_{hwgg.UN4} & \text{if } B2_{UN4} \\ H_{gg.UN4} \cdot W_{hwgg.UN4} & \text{if } C2_{UN4} \end{cases} = 25 \cdot m^2$$

Total Horizontal Headwater Load on Guard Crest Gate: $H_{hwgg.UN4} := \sigma_{hwgg.UN4.avg} \cdot A_{hwgg.UN4} = -613.1 \cdot kN$

Apply Total Guard Crest Gate Headwater Load at:

$$H_{hwgg.UN4.loc} := \begin{cases} (TOC_{as} - BOF_{elev}) & \text{if } A2_{UN4} \\ \left[\frac{(HW_{UN4} - TOC_{as})}{3} + (TOC_{as} - BOF_{elev})\right] & \text{if } B2_{UN4} \\ \left[\frac{\sigma_{hwgg.UN4.2} \cdot A_{hwgg.UN4} \cdot \frac{(H_{gg.UN4})}{2} + \frac{(\sigma_{hwgg.UN4.1} - \sigma_{hwgg.UN4.2})}{2} \cdot A_{hwgg.UN4} \cdot \frac{(H_{gg.UN4})}{3}}{\sigma_{hwgg.UN4.2} \cdot A_{hwgg.UN4} + \frac{(\sigma_{hwgg.UN4.1} - \sigma_{hwgg.UN4.2})}{2} \cdot A_{hwgg.UN4}} \ldots \\ + (TOC_{as} - BOF_{elev})\right] & \text{if } C2_{UN4} \end{cases} = 5.7 \cdot m$$

LATERAL TAILWATER (RESISTING) Applied to Downstream Side of Regulating Crest Gate:

UN4 CASE

Regulating Crest Gate Down/Open Condition: $A3_{UN4} := TOP_{rg.UN4} \le TOC_{as}$

Regulating Crest Gate Up/Closed, with Top of Gate Higher than TW Elevation: $B3_{UN4} := TOP_{rg.UN4} \ge TW_{UN4} \wedge TOP_{rg.UN4} > TOC_{as}$

Regulating Crest Gate Up/Closed, with Top of Gate Lower than TW Elevation: $C3_{UN4} := TOP_{rg.UN4} > TOC_{as} \wedge TW_{UN4} > TOP_{rg.UN4}$

Regulating Crest Gate Height: $H_{rg.UN4} = 0.9\,m$

$TW_{UN4} = 1211.9\,m$

$HW_{UN4} = 1215\,m$

$TOP_{rg.UN4} = 1210.9\,m$

Tailwater Depth at Regulating Crest Gate: $D_{twrg.UN4} := TW_{UN4} - TOC_{as} = 1.90\,m$

Regulating Crest Gate Width: $W_{twrg.UN4} := 5m$

Lateral Tailwater Pressure at Bottom of Regulating Crest Gate:

$$\sigma_{twrg.UN4.1} := \begin{cases} (0.0kPa) & \text{if } A3_{UN4} \\ -(\gamma_w \cdot D_{twrg.UN4}) & \text{if } B3_{UN4} \\ -(\gamma_w \cdot D_{twrg.UN4}) & \text{if } C3_{UN4} \end{cases} = -18.6 \cdot kPa$$

Lateral Tailwater Pressure at Top of Regulating Crest Gate: (Load at TW Elevation On Regulating Crest Gate if TW is below TOG_{rg})

$$\sigma_{twrg.UN4.2} := \begin{cases} (0.0kPa) & \text{if } A3_{UN4} \\ 0.0kPa & \text{if } B3_{UN4} \\ -\left[\gamma_w \cdot (TW_{UN4} - TOP_{rg.UN4})\right] & \text{if } C3_{UN4} \end{cases} = -9.8 \cdot kPa$$

Average Pressure acting on Regulating Gate:

$$\sigma_{twrg.UN4.avg} := \frac{(\sigma_{twrg.UN4.1} + \sigma_{twrg.UN4.2})}{2} = -14.22 \cdot kPa$$

Total Area water acting on Regulating Crest Gate:

$$A_{twrg.UN4} := \begin{cases} D_{twrg.UN4} \cdot W_{twrg.UN4} & \text{if } A3_{UN4} \\ D_{twrg.UN4} \cdot W_{twrg.UN4} & \text{if } B3_{UN4} \\ H_{rg.UN4} \cdot W_{twrg.UN4} & \text{if } C3_{UN4} \end{cases} = 4.5 \cdot m^2$$

Total Horizontal Tailwater Load on Regulating Crest Gate:

$$H_{twrg.UN4} := \sigma_{hwrg.UN4.avg} \cdot A_{hwrg.UN4} = -200.9 \cdot kN$$

Apply Total Regulating Crest Gate Tailwater Load at:

$$H_{twrg.UN4.loc} := \begin{cases} (TOC_{as} - BOF_{elev}) & \text{if } A3_{UN4} \\ \left[\frac{(HW_{UN4} - TOC_{as})}{3} + (TOC_{as} - BOF_{elev})\right] & \text{if } B3_{UN4} \\ \left[\frac{\sigma_{hwrg.UN4.2} \cdot A_{hwrg.UN4} \cdot \frac{(H_{rg.UN4})}{2} + \frac{(\sigma_{hwrg.UN4.1} - \sigma_{hwrg.UN4.2})}{2} \cdot A_{hwrg.UN4} \cdot \frac{(H_{rg.UN4})}{3}}{\sigma_{hwrg.UN4.2} \cdot A_{hwrg.UN4} + \frac{(\sigma_{hwrg.UN4.1} - \sigma_{hwrg.UN4.2})}{2} \cdot A_{hwrg.UN4}} \ldots \\ + (TOC_{as} - BOF_{elev})\right] & \text{if } C3_{UN4} \end{cases} = 4.4 \cdot m$$

LATERAL TAILWATER (RESISTING) Applied to Downstream Side of Guard Crest Gate:

Guard Gate Down/Open Condition: $A4_{UN4} := TOP_{gg.UN4} \le TOC_{as}$

Guard Crest Gate Up/Closed, with Top of Gate Higher than TW Elevation: $B4_{UN4} := TOP_{gg.UN4} \ge TW_{UN4} \wedge TOP_{gg.UN4} > TOC_{as}$

Guard Crest Gate Up/Closed, with Top of Gate Lower than TW Elevation: $C4_{UN4} := TOP_{gg.UN4} > TOC_{as} \wedge TW_{UN4} > TOP_{gg.UN4}$

Tailwater Depth at Guard Crest Gate: $D_{twgg.UN4} := TW_{UN4} - TOC_{as} = 1.90\,m$

Guard Crest Gate Height: $H_{gg.UN4} = 5\,m$

Guard Crest Gate Width: $W_{twgg.UN4} := 5.00m$

Lateral Water Load at Bottom of Guard Crest Gate:

$$\sigma_{twgg.UN4.1} := \begin{cases} (0.0kPa) & \text{if } A4_{UN4} \\ (\gamma_w \cdot D_{twgg.UN4}) & \text{if } B4_{UN4} \\ (\gamma_w \cdot D_{twgg.UN4}) & \text{if } C4_{UN4} \end{cases} = 18.6 \cdot kPa$$

Lateral Water Load at Top of Guard Crest Gate:
(Load at TW Elevation On Guard Crest Gate if TW is below TOG_{gg})

$$\sigma_{twgg.UN4.2} := \begin{cases} (0.0kPa) & \text{if } A4_{UN4} \\ 0.0kPa & \text{if } B4_{UN4} \\ \left[\gamma_w \cdot (TW_{UN4} - TOP_{gg.UN4})\right] & \text{if } C4_{UN4} \end{cases} = 0.0 \cdot kPa$$

Average Pressure acting on Guard Crest Gate:

$$\sigma_{twgg.UN4.avg} := \frac{(\sigma_{twgg.UN4.1} + \sigma_{twgg.UN4.2})}{2} = 9.32 \cdot kPa$$

Total Area water acting on Crest Gate:

$$A_{twgg.UN4} := \begin{cases} D_{twgg.UN4} \cdot W_{twgg.UN4} & \text{if } A4_{UN4} \\ D_{twgg.UN4} \cdot W_{twgg.UN4} & \text{if } B4_{UN4} \\ H_{gg.UN4} \cdot W_{twgg.UN4} & \text{if } C4_{UN4} \end{cases} = 9.5 \cdot m^2$$

Total Horizontal Tailwater Load on Guard Crest Gate: $H_{twgg.UN4} := \sigma_{twgg.UN4.avg} \cdot A_{twgg.UN4} = 88.5 \cdot kN$

Apply Total Horiz. TW Load on Guard Gate at:

$$H_{twgg.UN4.loc} := \begin{cases} (TOC_{as} - BOF_{elev}) & \text{if } A4_{UN4} \\ \left[\frac{(TW_{UN4} - TOC_{as})}{3} + (TOC_{as} - BOF_{elev})\right] & \text{if } B4_{UN4} \\ \left[\frac{\sigma_{twgg.UN4.2} \cdot A_{twgg.UN4} \cdot \frac{(H_{gg.UN4})}{2} + \frac{(\sigma_{twgg.UN4.1} - \sigma_{twgg.UN4.2})}{2} A_{twgg.UN4} \cdot \frac{(H_{gg.UN4})}{3}}{\sigma_{twgg.UN4.2} \cdot A_{twgg.UN4} + \frac{(\sigma_{twgg.UN4.1} - \sigma_{twgg.UN4.2})}{2} \cdot A_{twgg.UN4}} \cdots \\ + (TOC_{as} - BOF_{elev})\right] & \text{if } C4_{UN4} \end{cases} = 4.6 \cdot m$$

LATERAL WATER LOADS (continued)

UN4 CASE

TAILWATER (RESISTING) Applied to Concrete Structure:

Tailwater Depth on Pier: $D_{twp.UN4} := TW_{UN4} - TOC_{as} = 1.90\,m$

Tailwater Load Unit Width on Pier: $W_{twp.UN4} := W_{hwp.UN4} = 2.00\,m$

Total Horizontal Tailwater Load on Pier: $H_{twp.UN4} := \frac{\left(\gamma_w \cdot D_{twp.UN4}{}^2\right)}{2} \cdot W_{twp.UN4} = 35.4 \cdot kN$

Apply Total Pier Tailwater Load at: $H_{twp.UN4.loc} := \frac{D_{twp.UN4}}{3} + \left(TOC_{as} - BOF_{elev}\right) = 4.63\,m$

Tailwater Depth At top of Gate Base Footing Elevation: $D_{twgf.UN4} := TW_{UN4} - TOC_{as} = 1.90\,m$

Water Depth at bottom of Gate Base Footing (Excluding Key): $D_{twtoe.UN4} := TW_{UN4} - BOF_{elev} = 5.90\,m$

Footing Thickness for horizontal at Toe: $h_{toe} = 4\,m$

Unit Width of D/S face of crest for application of Tailwater Load: $W_{tw.UN4} := W_b = 12.00\,m$

Tailwater Pressure At Top of Gate Footing: $\sigma_{twgf.UN4} := \left(\gamma_w \cdot D_{twgf.UN4}\right) = 18.64 \cdot kPa$

Tailwater Pressure At Toe: $\sigma_{twtoe.UN4} := \left(\gamma_w \cdot D_{twtoe.UN4}\right) = 57.88 \cdot kPa$

Triangular Distribution Unit Load on Gate Footing Base (including key): $H_{twgf.UN4.tri} := \left(\frac{\sigma_{twtoe.UN4} - \sigma_{twgf.UN4}}{2}\right) \cdot \left[\left(T_{as} - d_{key}\right) \cdot W_{tw.UN4}\right] = 941.76 \cdot kN$

Rectangular Distribution Unit Load on Gate Footing Base (including key): $H_{twgf.UN4.rect} := \sigma_{twgf.UN4} \cdot \left[\left(T_{as} - d_{key}\right) \cdot W_{tw.UN4}\right] = 894.67 \cdot kN$

Tailwater Pressure At Bottom of Sliding Failure Plane: $\sigma_{twbk.UN4} := \left(HW_{UN4} - BOK_{elev}\right) \cdot \gamma_w = 107.91 \cdot kPa$

Triangular Distribution Unit Load Below Footing: $H_{twbk.UN4.tri} := \frac{\left(\sigma_{twbk.UN4} - \sigma_{twtoe.UN4}\right)}{2} \cdot d_{key} \cdot W_{tw.UN4} = 600.37 \cdot kN$

Rectangular Distribution Load Below Footing Base: $H_{twbk.UN4.rect} := \sigma_{twtoe.UN4} \cdot d_{key} \cdot W_{tw.UN4} = 1389.1 \cdot kN$

Total Horizontal Tailwater Headwater Load on Gate Footing (including key):

$$H_{twgk.UN4} := H_{twgf.UN4.tri} + H_{twgf.UN4.rect} \cdots + H_{twbk.UN4.tri} + H_{twbk.UN4.rect} = 3825.9 \cdot kN$$

Apply Total Gate Footing Tailwater Load at:

$$H_{twgk.UN4.loc} := \frac{\left[H_{twgf.UN4.rect} \cdot \frac{\left(h_{toe}\right)}{2} + H_{twgf.UN4.tri} \cdot \frac{\left(h_{toe}\right)}{3} + H_{twbk.UN4.tri} \cdot \left(-d_{key} \cdot \frac{2}{3}\right) + H_{twbk.UN4.rect} \cdot \left(\frac{-d_{key}}{2}\right)\right]}{H_{twgf.UN4.tri} + H_{twgf.UN4.rect} + H_{twbk.UN4.tri} + H_{twbk.UN4.rect}} = 0.22\,m$$

SUMMATION OF LATERAL WATER LOADS:

$$\Sigma H_{Water.UN4} := H_{hwp.UN4} + H_{hwas.UN4} + H_{hwrg.UN4} + H_{hwgg.UN4} + H_{twp.UN4} + H_{twgk.UN4} + H_{twrg.UN4} + H_{twgg.UN4} = -2960.81 \cdot kN$$

$$\Sigma M_{Hwater.UN4} := H_{hwp.UN4} \cdot H_{hwp.UN4.loc} + H_{hwas.UN4} \cdot H_{hwas.UN4.loc} + H_{hwrg.UN4} \cdot H_{hwrg.UN4.loc} \cdots + H_{hwgg.UN4} \cdot H_{hwgg.UN4.loc} + H_{twp.UN4} \cdot H_{twp.UN4.loc} + H_{twgk.UN4} \cdot H_{twgk.UN4.loc} \cdots + H_{twrg.UN4} \cdot H_{twrg.UN4.loc} + H_{twgg.UN4} \cdot H_{twgg.UN4.loc} = -8747.69 \cdot kN \cdot m$$

VERTICAL WATER LOADS

UN4 CASE

HEADWATER:

Water Depth on top of Approach Slab: $d_{hw.UN4} := HW_{UN4} - TOC_{as} = 5.00\,m$

Length of Approach Slab: $L_{as} = 8.75\,m$

Width of Approach Slab: $w_{as} = 12.00\,m$

Length from front of Gate to Heel: $L_{hg} = 8.75\,m$

Weight on Apron is req for stability. Coffer U/S of pier nose must include fill to offset reduced water load.

Vertical Water Weight (H1) on Approach Slab:

$$H_{1.UN4} := \left[w_{as} \cdot d_{hw.UN4} \cdot L_{as} - w_p \cdot d_{hw.UN4} \cdot \left(L_{hg} - L_{as}\right)\right] \cdot \gamma_w \cdot \frac{3}{4} = 3862.7 \cdot kN$$

Moment Arm for Application of Water Weight (H1) from toe:

$$H_{1.UN4.loc} := L_b - \frac{L_{as}}{2} = 14.13\,m$$

TAILWATER ABOVE GUARD GATE:

Trapezoid Volume Above Gate Footing from Approach Slab to Crest:

$$V_{asc.gg.UN4} := \left(L_{gf} - L_{gfc}\right) W_{twgg.UN4} \frac{d_{hw.UN4} + Y_{C.gg.UN4}}{2} = 146.58 \cdot m^3$$

Trapezoid Volume Above Gate Footing Crest to End of Gate Footing:

$$V_{gfc.gg.UN4} := \left(L_{gfc} \cdot W_{twgg.UN4}\right) \frac{Y_{C.gg.UN4} + Y_{TOE.gg.UN4}}{2} = 50.05 \cdot m^3$$

Load Above Gate Footing from Approach Slab to Crest:

$$H_{2.UN4.asc.gg} := V_{asc.gg.UN4} \cdot \gamma_w = 1437.9 \cdot kN$$

Load Acting Above Footing Crest from Toe:

$$H_{2.UN4.asc.gg.loc} := \frac{\left(L_{gf} - L_{gfc}\right) \cdot \left(2 \cdot d_{hw.UN4} + Y_{C.gg.UN4}\right)}{3 \cdot \left(d_{hw.UN4} + Y_{C.gg.UN4}\right)} + L_{gfc} = 6.44\,m$$

Load Above Gate Footing from Crest to End:

$$H_{2.UN4.gfc.gg} := V_{gfc.gg.UN4} \cdot \gamma_w = 490.99 \cdot kN$$

Load Acting Above Gate Footing from Crest to End:

$$H_{2.UN4.gfc.gg.loc} := \frac{\left(L_{gfc}\right) \cdot \left(2 \cdot Y_{C.gg.UN4} + Y_{TOE.gg.UN4}\right)}{3 \cdot \left(Y_{C.gg.UN4} + Y_{TOE.gg.UN4}\right)} = 1.23\,m$$

Vertical Water Weight (H2) on Guard Gate Footing:

$$H_{2.UN4.gg} := H_{2.UN4.asc.gg} + H_{2.UN4.gfc.gg} = 1928.89 \cdot kN$$

Moment Arm for Application of Water Weight (H2) from toe:

$$H_{2.UN4.gg.loc} := \frac{H_{2.UN4.asc.gg} \cdot H_{2.UN4.asc.gg.loc} \cdots + H_{2.UN4.gfc.gg} \cdot H_{2.UN4.gfc.gg.loc}}{H_{2.UN4.gg}} = 5.11\,m$$

TAILWATER ABOVE REGULATING GATE:

Trapezoid Volume Above Gate Footing from Approach Slab to Crest:

$$V_{asc.rg.UN4} := \left(L_{gf} - L_{gfc}\right) W_{twrg.UN4} \frac{d_{hw.UN4} + Y_{C.rg.UN4}}{2} = 166.77 \cdot m^3$$

Trapezoid Volume Above Gate Footing Crest to End of Gate Footing:

$$V_{gfc.rg.UN4} := \left(L_{gfc} \cdot W_{twrg.UN4}\right) \frac{Y_{C.rg.UN4} + Y_{TOE.rg.UN4}}{2} = 36.14 \cdot m^3$$

Load Above Gate Footing from Approach Slab to Crest:

$$H_{2.UN4.asc.rg} := V_{asc.rg.UN4} \cdot \gamma_w = 1636.05 \cdot kN$$

Load Acting Above Footing Crest from Toe:

$$H_{2.UN4.asc.rg.loc} := \frac{\left(L_{gf} - L_{gfc}\right) \cdot \left(2 \cdot d_{hw.UN4} + Y_{C.rg.UN4}\right)}{3 \cdot \left(d_{hw.UN4} + Y_{C.rg.UN4}\right)} + L_{gfc} = 6.26\,m$$

Load Above Gate Footing from Crest to End:

$$H_{2.UN4.gfc.rg} := V_{gfc.rg.UN4} \cdot \gamma_w = 354.53 \cdot kN$$

Load Acting Above Gate Footing from Crest to End:

$$H_{2.UN4.gfc.rg.loc} := \frac{\left(L_{gfc}\right) \cdot \left(2 \cdot Y_{C.rg.UN4} + Y_{TOE.rg.UN4}\right)}{3 \cdot \left(Y_{C.rg.UN4} + Y_{TOE.rg.UN4}\right)} = 1.54\,m$$

Vertical Water Weight (H2) on Regulating Gate Footing:

$$H_{2.UN4.rg} := H_{2.UN4.asc.rg} + H_{2.UN4.gfc.rg} = 1990.58 \cdot kN$$

Moment Arm for Application of Water Weight (H2) from toe:

$$H_{2.UN4.rg.loc} := \frac{H_{2.UN4.asc.rg} \cdot H_{2.UN4.asc.rg.loc} \cdots + H_{2.UN4.gfc.rg} \cdot H_{2.UN4.gfc.rg.loc}}{H_{2.UN4.rg}} = 5.42\,m$$

UPLIFT **UN4 CASE**

Uplift pressure at U/S Face (heel):	$U_{HW.UN4} := \left(D_{hwas.UN4}\right)\cdot\gamma_w = 107.9\cdot\frac{kN}{m^2}$
Uplift pressure at D/S Face Stilling Basin:	$U_{TW.UN4} := \left(D_{twtoe.UN4}\right)\cdot\gamma_w = 57.88\cdot\frac{kN}{m^2}$
Length from U/S of Gate Structure to D/S of Stilling Basin:	$L_{overall} = 18.50\,m$
Difference between Uplift pressure at HW and TW:	$U_{diff.UN4} := U_{HW.UN4} - U_{TW.UN4} = 50.03\cdot\frac{kN}{m^2}$
Slope of difference between between Uplift pressure at HW and TW:	$U_{slope.UN4} := \frac{U_{diff.UN4}}{L_{overall}} = 2.70\cdot\frac{kN}{m^2\cdot m}$
Tailwater Pressure at toe of Gate Structure:	$U_{press.toe.gs.UN4} := U_{TW.UN4} + \left(L_{overall} - L_b\right)\cdot U_{slope.UN4} = 57.88\cdot\frac{kN}{m^2}$
Uniform uplift force UA Under Gate Structure due to TW (rectangle):	$U_{A.UN4} := U_{press.toe.gs.UN4}\cdot L_b\cdot W_b\cdot -1 = -12849.14\cdot kN$
Moment Arm from Toe of Gate Structure for Uplift UA:	$L_{A.UN4} := \left(\frac{L_b}{2}\right) = 9.25\,m$
Linearly Decreasing Uplift Force UN4B Under Gate Structure due to HW-TW Differential (triangle):	$U_{B.UN4} := \frac{1}{2}\cdot\left(U_{HW.UN4} - U_{press.toe.gs.UN4}\right)\cdot L_b\cdot W_b\cdot -1 = -5553.44\cdot kN$
Moment Arm from Toe of Gate Structure for Uplift UB:	$L_{B.UN4} := \frac{2}{3}\cdot L_b = 12.33\,m$
Total Resultant Uplift force:	$U_{UN4} := U_{A.UN4} + U_{B.UN4} = -18402.58\cdot kN$
Resultant Location from Toe:	$U_{UN4.loc} := \frac{\left(U_{A.UN4}\cdot L_{A.UN4} + U_{B.UN4}\cdot L_{B.UN4}\right)}{\left(U_{A.UN4} + U_{B.UN4}\right)} = 10.18\,m$

$$\Sigma V_{water.UN4} := H_{1.UN4} + H_{2.UN4.gg} + H_{2.UN4.rg} + U_{UN4} = -10620.42\cdot kN$$

$$\Sigma M_{Vwater.UN4} := H_{1.UN4}\cdot H_{1.UN4.loc} + H_{2.UN4.gg}\cdot H_{2.UN4.gg.loc} + H_{2.UN4.rg}\cdot H_{2.UN4.rg.loc} + U_{UN4}\cdot U_{UN4.loc} = -112139.8\cdot kN\cdot m$$

SOIL LOADS

UN4 CASE

Equivalent Fluid Pressure (EFP):

At rest lateral pressure coefficient: $K_{o.UN4} := 1 - \sin(\phi_{backfill}) = 0.658$ (Section 5.3, Design Criteria)

Headwater Pier Footing Unit Width: $W_{hwas.UN4} = 12.00\,m$

Tailwater Pier Footing Unit Width: $W_{tw.UN4} = 12.00\,m$

Pier Footing Thickness at Heel: $t_{hf.UN4} := TOC_{as} - BOK_{elev} = 6.00\,m$

Fixed Crest Footing Thickness at Toe: $t_{tf.UN4} := TOC_{pfe} - BOF_{elev} = 2.00\,m$

Lateral Driving Force (Headwater Side - at rest condition)

Structure Soil Load:

$$E_{act.UN4} := \frac{\left(K_{o.UN4} \cdot t_{hf.UN4}{}^2\right)}{2} \cdot \left(\gamma_r - \gamma_w\right) \cdot W_{hwas.UN4} \cdot -1 = -1732.49 \cdot kN$$

Acting at:

$$E_{act.UN4.loc} := \frac{t_{hf.UN4}}{3} - d_{key} = 0.00\,m$$

Lateral Resisting Force (Tailwater Side - at rest condition)

At-rest Soil Load:

$$E_{pass.UN4} := \frac{\left(K_{o.UN4} \cdot t_{tf.UN4}{}^2\right)}{2} \cdot \left(\gamma_r - \gamma_w\right) \cdot W_{tw.UN4} = 192.5 \cdot kN$$

Acting at:

$$E_{pass.UN4.loc} := \frac{t_{tf.UN4}}{3} = 0.67\,m$$

$$\Sigma H_{soil.UN4} := E_{act.UN4} + E_{pass.UN4} = -1539.99 \cdot kN$$

$$\Sigma M_{soil.UN4} := E_{act.UN4} \cdot E_{act.UN4.loc} + E_{pass.UN4} \cdot E_{pass.UN4.loc} = 128.33 \cdot kN \cdot m$$

ICE / IMPACT LOADS (ASSUME NO ICE LOADING ON TAILWATER SIDE)

ICE & IMPACT LOADS DO NOT APPLY FOR THIS LOAD CASE

Static Ice Loading on Structure: $I_{S.UN4} := 0 \frac{kN}{m}$ (Section 7.7, Design Criteria)

Static Ice load on Gates: $I_{G.UN4} := 0 \frac{kN}{m}$ (Section 7.7, Design Criteria)

Ice Loading Unit Width on Structure: $W_{S.UN4} := 2.00m$

Ice Loading Unit Width on Regulating Gate: $W_{rg.UN4} := 0m$ (Input value for load case)

Ice Loading Unit Width on Guard Gate: $W_{gg.UN4} := 5m$ (Input value for load case)

Total Ice Load on Structure:

$$I_{UN4} := \left(I_{S.UN4} \cdot W_{S.UN4} + I_{G.UN4} \cdot W_{rg.UN4} + I_{G.UN4} \cdot W_{gg.UN4}\right) \cdot -1 = 0 \cdot kN$$

Apply Ice load at:

$$I_{UN4.loc} := \left(HW_{UN4} - BOF_{elev} - 0.30m\right) = 8.70\,m$$

$$\Sigma H_{I.UN4} := I_{UN4} = 0 \cdot kN$$

$$\Sigma M_{I.UN4} := I_{UN4} \cdot I_{UN4.loc} = 0 \cdot kN \cdot m$$

SEISMIC LOAD (NOT APPLICABLE FOR THIS LOAD CASE)

UN4 CASE

SUMMARY OF LOADS	Loads	Moment Arm
Dead load of Concrete Structure:	$D_{conc} = 22438.7 \cdot kN$	$X_{conc.loc} = 9.35\,m$
Obermyer Gate Weight:	$D_{Gate.UN4} = 70.0 \cdot kN$	$X_{gate} = 9.50\,m$
HW Lateral Load on Pier:	$H_{hwp.UN4} = -245.3 \cdot kN$	$H_{hwp.UN4.loc} = 5.67\,m$
HW Lateral Load on Approach Slab:	$H_{hwas.UN4} = -5650.6 \cdot kN$	$H_{hwas.UN4.loc} = 0.63\,m$
HW Lateral Load on Regulating Gate:	$H_{hwrg.UN4} = -200.9 \cdot kN$	$H_{hwrg.UN4.loc} = 4.44\,m$
HW Lateral Load on Guard Gate:	$H_{hwgg.UN4} = -613.1 \cdot kN$	$H_{hwgg.UN4.loc} = 5.67\,m$
TW Lateral Load on Pier:	$H_{twp.UN4} = 35.4 \cdot kN$	$H_{twp.UN4.loc} = 4.63\,m$
TW Lateral Load on Pier Footing (including Key):	$H_{twgk.UN4} = 3825.9 \cdot kN$	$H_{twgk.UN4.loc} = 0.22\,m$
TW Lateral Load on Regulating Gate:	$H_{twrg.UN4} = -200.9 \cdot kN$	$H_{twrg.UN4.loc} = 4.44\,m$
TW Lateral Load on Guard Gate:	$H_{twgg.UN4} = 88.5 \cdot kN$	$H_{twgg.UN4.loc} = 4.63\,m$
Vertical HW Load on Approach Slab:	$H_{1.UN4} = 3862.7 \cdot kN$	$H_{1.UN4.loc} = 14.13\,m$
Vertical TW Load on Regulating Gate:	$H_{2.UN4.rg} = 1990.6 \cdot kN$	$H_{2.UN4.rg.loc} = 5.42\,m$
Vertical TW Load on Guard Gate:	$H_{2.UN4.gg} = 1928.9 \cdot kN$	$H_{2.UN4.gg.loc} = 5.11\,m$
Uplift:	$U_{UN4} = -18402.6 \cdot kN$	$U_{UN4.loc} = 10.18\,m$
Lateral Soil Load (driving):	$E_{act.UN4} = -1732.5 \cdot kN$	$E_{act.UN4.loc} = 0.00\,m$
Lateral Soil Load (resisting):	$E_{pass.UN4} = 192.5 \cdot kN$	$E_{pass.UN4.loc} = 0.67\,m$
Ice / Impact Load:	$I_{UN4} = 0.0 \cdot kN$	$I_{UN4.loc} = 8.70\,m$

STABILITY ASSESSMENT (SLIDNG, BEARING, FLOTATION AND OVERTURNING): UN4 CASE

CHECK SLIDING ALONG HORIZONTAL PLANE THRU TOE,
IGNORING BEDROCK MOBILIZED BY STRUCTURAL HEEL KEY, OR VOID BEHIND KEY

Sum of Vertical Forces:

$\Sigma V_{UN4} := \Sigma V_{DL} + \Sigma V_{water.UN4} = 11958.3 \cdot kN$

Sum of Horizontal Forces:

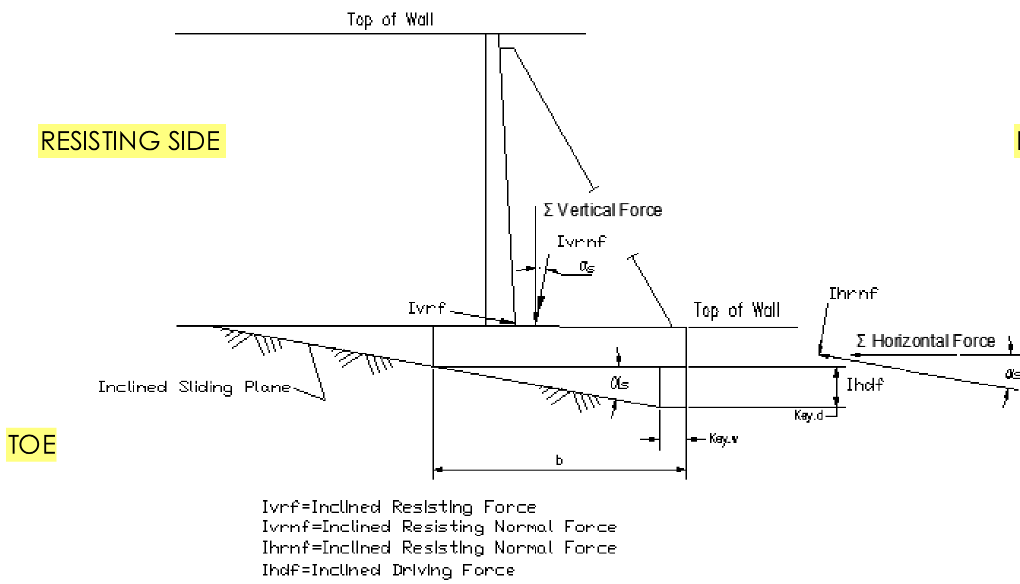
$\Sigma H_{UN4} := \Sigma H_{Water.UN4} + \Sigma H_{soil.UN4} + \Sigma H_{I.UN4} = -4500.79 \cdot kN$

Sliding Factor of Safety:

$$FS_{HorizSliding.UN4} := \frac{\tan_{\phi} \cdot \Sigma V_{UN4}}{|\Sigma H_{UN4}|} = 1.30$$

$$FS_{HorizSliding.UN4.Check} := \begin{vmatrix} \text{"OKAY"} & \text{if } FS_{HorizSliding.UN4} \geq FS_{req.UN4.sl} \\ \text{"Check Inclined Sliding with Key"} & \text{otherwise} \end{vmatrix} = \text{"Check Inclined Sliding with Key"}$$

CHECK SLIDING ALONG INCLINED SLIDING PLANE FROM HEEL KEY TO TOE,
WITH BEDROCK MASS MOBILIZED BY REINFOCREDE CONCRETE KEY)



$\Sigma V_{UN4} = 11958.32 \cdot kN$

$V_{rs} = 4620 \cdot kN$

$\alpha s = 0.11$

as degrees= $\alpha s \cdot \left(\frac{180}{\pi}\right) = 6.52$

Resolve $\Sigma Vert_{UN4}$ & $\Sigma Horiz_{UN4}$

$$\Sigma V_{InclinedUN4} := \cos(\alpha s) \cdot (\Sigma V_{UN4} + V_{rs}) + \sin(\alpha s) \cdot |\Sigma H_{UN4}| = 16982.2 \cdot kN$$

$$\Sigma H_{InclinedUN4} := \cos(\alpha s) \cdot |\Sigma H_{UN4}| - \sin(\alpha s) \cdot (\Sigma V_{UN4} + V_{rs}) = 2589.3 \cdot kN$$

(With properly engineered reinforced concrete Key, horizontal sliding plane thru Toe is protected, critical sliding plane is relocated to the INCLINED SLIDING PLANE FROM HEEL KEY To TOE, Bedrock Mass above this examined plane is mobilized by reinforced concrete key and combined into Structural Wedge.)

Inclined Sliding Plane Length

$L_{incline} = 18.61\ m$

Safety Factor for Sliding
Inclined Failure Plane

$$FS_{InclinedlSlidingUN4} := \frac{\Sigma V_{InclinedUN4} \cdot \tan\left(\phi_{rock} \cdot \frac{\pi}{180}\right)}{|\Sigma H_{InclinedUN4}|} = 3.20$$

$$FS_{InclinedSliding.check.UN4} := \begin{vmatrix} \text{"OKAY "} & \text{if } FS_{InclinedlSlidingUN4} > FS_{req.UN4.sl} \\ \text{"Revise Structure""} & \text{otherwise} \end{vmatrix} = \text{"OKAY "}$$

$FS_{InclinedSliding.check.UN4} = \text{"OKAY "}$

OVERTURNING STABILITY CHECK:

CHECK ECCENTRICITY

Sum of the moments:

$$\Sigma M_{UN4} := \Sigma M_{DL.UN4} + \Sigma M_{Hwater.UN4} + \Sigma M_{Vwater.UN4} + \Sigma M_{I.UN4} + \Sigma M_{soil.UN4} + \Sigma M_{rs} = 143596 \cdot kN \cdot m$$

Eccentricity:

$$e_{UN4} := \left(\frac{L_{incline}}{2}\right) - \frac{(\Sigma M_{UN4})}{\Sigma V_{InclinedUN4}} = 0.85\,m$$

Eccentricity Check:

$$e_{check.UN4} := \begin{cases} \text{"Okay"} & \text{if } e_{UN4} \le Kern \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$$e_{check.UN4} = \text{"Okay"}$$

Foundation Bearing Checks:

Bearing Pressure at Heel:

$$\sigma_{heel.UN4} := \frac{\Sigma V_{InclinedUN4}}{A_{b.incline}} - \frac{(\Sigma V_{InclinedUN4} \cdot e_{UN4})}{S_{b.incline}} = 55.3 \cdot \frac{kN}{m^2}$$

$$\sigma_{heel.UN4.check} := \left(\begin{cases} \text{"Okay"} & \text{if } \sigma_{heel.UN4} \le \sigma_{allow.UN4} \\ \text{"Revise Structure"} & \text{if } \sigma_{heel.UN4} < 0 \frac{kN}{m^2} \end{cases} \right)$$

$$\sigma_{heel.UN4.check} = \text{"Okay"}$$

Bearing Pressure at Toe:

$$\sigma_{toe.UN4} := \frac{\Sigma V_{InclinedUN4}}{A_{b.incline}} + \frac{(\Sigma V_{InclinedUN4} \cdot e_{UN4})}{S_{b.incline}} = 96.9 \cdot \frac{kN}{m^2}$$

$$\sigma_{toe.UN4.1.check} := \begin{cases} \text{"Okay"} & \text{if } \sigma_{toe.UN4} \le \sigma_{allow.UN4} \\ \text{"Revise Structure"} & \text{if } \sigma_{toe.UN4} < 0 \frac{kN}{m^2} \end{cases}$$

$$\sigma_{toe.UN4.1.check} = \text{"Okay"}$$

FLOATATION ANALYSIS:

ACCEPTANCE PARAMETERS

Required Factor of Safety: $FS_{req.FUN4} := 1.3$

VERTICAL LOADS RESISTING:

Dead Load: $\Sigma V_{DL} = 22578.74 \cdot kN$

Water Weight H1+H2: $\Sigma V_{H.FUN4} := H_{1.UN4} + H_{2.UN4.gg} + H_{2.UN4.rg} = 7782.16 \cdot kN$

Summation Vertical Resisting: $\Sigma V_{FUN4} := \Sigma V_{DL} + \Sigma V_{H.FUN4} = 30360.9 \cdot kN$

VERTICAL LOADS UPLIFT:

Uplift: $U_{UN4} = -18402.58 \cdot kN$

Factor of Safety Floatation:

$$FS_{act.FUN4} := \frac{\Sigma V_{FUN4}}{|U_{UN4}|} = 1.65$$

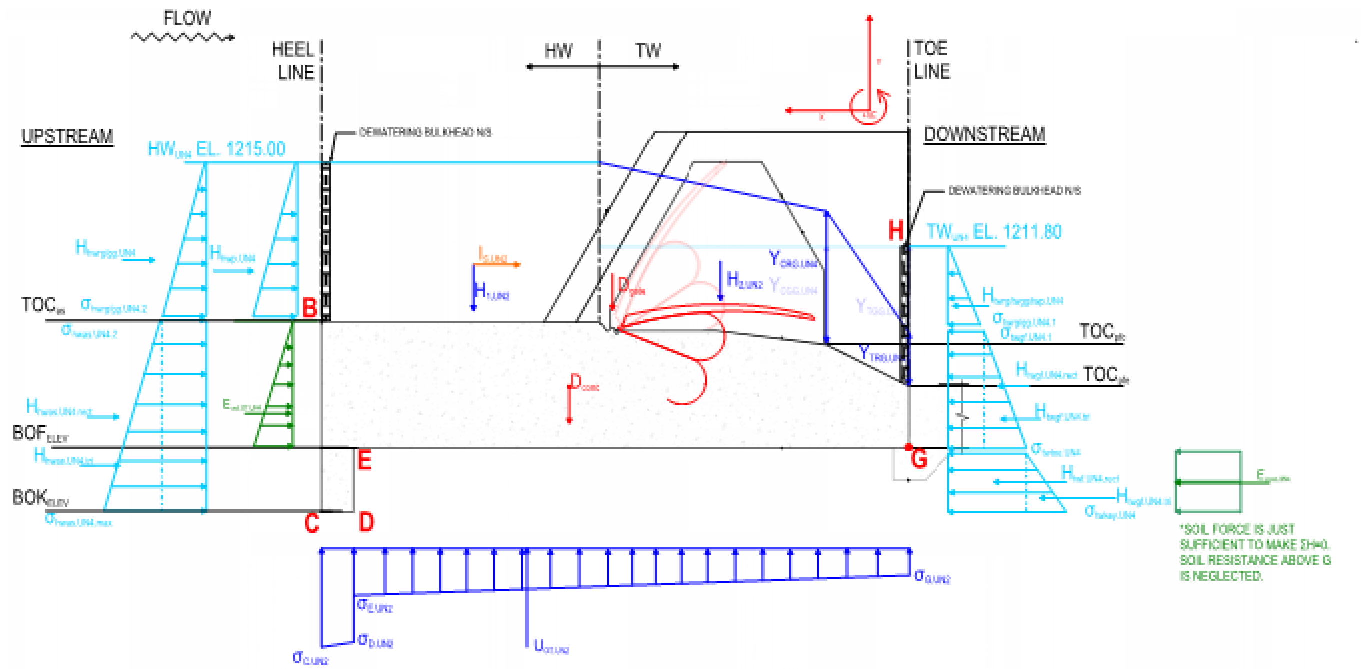
$$FS_{check.FUN4} := \begin{cases} \text{"OKAY"} & \text{if } FS_{act.FUN4} \ge FS_{req.FUN4} \\ \text{"ANCHORS REQUIRED"} & \text{if } FS_{act.FUN4} < FS_{req.FUN4} \end{cases} = \text{"OKAY"}$$

MONOLITH OVERTURNING STABILITY ANALYSIS

UN4 CASE

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.
Assumptions are made in order to compute overturning stability of indetermine forces on monolith with key;
(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.
(b) The horizontal resisting force acting on the key, P.key, is that required for static equilibrium
(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1 $Ratio_{OT.UN4.min} := 0.33$



Uplift Loads for Overturning Stability Analysis

Line of Creep:

Change in Water Head: $\Delta_{h.UN4} := HW_{UN4} - TW_{UN4} = 3.1\ m$

Length from Point C to Point G: $L_{CG} = 18.61\ m$

Length from Various Points to Points: $L_{CD} = 1\ m$ $\quad L_{DE} = 2\ m$ $\quad L_{EG} = 17.5\ m$

$L_{GH.UN4} := TW_{UN4} - BOF_{elev} = 5.9\ m$

Length from Point C, D, E to G: $L_{CDEG} = 20.5\ m$ $\quad L_{CDE} = 3\ m$

Water Pressure at Point C & G: $\sigma_{C.UN4} := \sigma_{hwas.UN4.2} = -107.91 \cdot kPa$ $\quad \sigma_{G.UN4} := \sigma_{twtoe.UN4} \cdot -1 = -57.88 \cdot kPa$

Water Pressure at Point D:

$$\sigma_{D.UN4} := -\gamma_w \cdot \left[\left(HW_{UN4} - BOK_{elev} \right) - \frac{\Delta_{h.UN4} \cdot L_{CD}}{L_{CDEG}} \right] = -106.43 \cdot kPa$$

Water Pressure at Point E:

$$\sigma_{E.UN4} := -\gamma_w \cdot \left[\left(HW_{UN4} - BOF_{elev} \right) - \frac{\Delta_{h.UN4} \cdot L_{CDE}}{L_{CDEG}} \right] = -83.84 \cdot kPa$$

Uplift for Overturning Analysis on Bottom of Key:

$$U_{OT.UN4.key} := \frac{\sigma_{C.UN4} + \sigma_{D.UN4}}{2} \cdot L_{CD} \cdot W_b = -1286.02 \cdot kN$$

Acting at:

$$U_{OT.UN4.key.loc} := \frac{L_{CD} \cdot \left(2 \cdot \sigma_{C.UN4} + \sigma_{D.UN4} \right)}{3 \left(\sigma_{C.UN4} + \sigma_{D.UN4} \right)} + L_{EG} = 18\ m$$

Uplift for Overturning Analysis on Bottom of Footing:

$$U_{OT.UN4.ftg} := \frac{\sigma_{E.UN4} + \sigma_{G.UN4}}{2} \cdot L_{EG} \cdot W_b = -14880.45 \cdot kN$$

Acting at:

$$U_{OT.UN4.ftg.loc} := \frac{L_{EG} \cdot \left(\sigma_{G.UN4} + 2 \cdot \sigma_{E.UN4} \right)}{3 \left(\sigma_{G.UN4} + \sigma_{E.UN4} \right)} = 9.28\ m$$

UN4 CASE

Uplift Load for Overturning Analysis: $U_{OT.UN4} := U_{OT.UN4.key} + U_{OT.UN4.ftg} = -16166.47 \cdot kN$

Uplift Load Acting from Toe: $U_{OT.UN4.loc} := \dfrac{U_{OT.UN4.key} \cdot U_{OT.UN4.key.loc} + U_{OT.UN4.ftg} \cdot U_{OT.UN4.ftg.loc}}{U_{OT.UN4}} = 9.98\,m$

<u>All Vertical Loads Applicable to Overturning Stability Analysis</u>

		at:	
Total Concrete Dead Loads:	$D_{conc} = 22438.74 \cdot kN$		$X_{conc.loc} = 9.35\,m$
Dead Load of Gate:	$D_{Gate} = 140.0 \cdot kN$		$X_{gate} = 9.50\,m$
Water Weight (HW) on Apron Slab:	$H_{1.UN4} = 3862.7 \cdot kN$		$H_{1.UN4.loc} = 14.13\,m$
Water Weight (TW) on Gate Footing:	$H_{2.UN4.rg} = 1990.6 \cdot kN$		$H_{2.UN4.rg.loc} = 5.42\,m$
Water Weight (TW) on Regulating Gate Footing:	$H_{2.UN4.gg} = 1928.9 \cdot kN$		$H_{2.UN4.gg.loc} = 5.11\,m$
Uplift Load for Overturning Analysis:	$U_{OT.UN4} = -16166.47 \cdot kN$		$U_{OT.UN4.loc} = 9.98 \cdot m$

Sum of All Overturning Analysis Vertical Load:

$$\Sigma V_{UN4.OT} := D_{conc} + D_{Gate} + H_{1.UN4} + H_{2.UN4.rg} + H_{2.UN4.gg} + U_{OT.UN4} = 14194.43 \cdot kN$$

Sum of All Overturning Analysis Vertical Load Moments:

$$\Sigma M_{V.UN4.OT} := D_{conc} \cdot X_{conc.loc} + D_{Gate} \cdot X_{gate} + H_{1.UN4} \cdot H_{1.UN4.loc} + H_{2.UN4.rg} \cdot H_{2.UN4.rg.loc} \ldots + H_{2.UN4.gg} \cdot H_{2.UN4.gg.loc} + U_{OT.UN4} \cdot U_{OT.UN4.loc} = 125022.88 \cdot kN \cdot m$$

<u>Lateral Tailwater Loads for Overturning Stability Analysis</u>

TW Lateral Load on Gate Footing (No Key - Overturning Values Adjusted): $H_{twgf.UN4} := H_{twgf.UN4.tri} + H_{twgf.UN4.rect} = 1836.43 \cdot kN$

Acting at: $H_{twgf.UN4.loc} := \dfrac{\frac{h_{toe}}{3} \cdot H_{twgf.UN4.tri} + \frac{h_{toe}}{2} \cdot H_{twgf.UN4.rect}}{H_{twgf.UN4}} = 1.66\,m$

Horizontal Tailwater Pressure Top of Key (Overturning Analysis): $\sigma_{twtk.OT.UN4} := \sigma_{E.UN4} \cdot -1 = 83.84 \cdot kPa$

Horizontal Tailwater Pressure Bottom of Key (Overturning Analysis): $\sigma_{twbk.OT.UN4} := \sigma_{D.UN4} \cdot -1 = 106.43 \cdot kPa$

Triangular Distribution Unit Load Acting at Key: $H_{twbk.OT.UN4.tri} := \dfrac{\left(\sigma_{twbk.OT.UN4} - \sigma_{twtk.OT.UN4}\right)}{2} \cdot d_{key} \cdot W_{tw.UN4} = 271.04 \cdot kN$

Triangular Distribution Unit Load Acting at Key: $H_{twbk.OT.UN4.rect} := \sigma_{twtk.OT.UN4} \cdot d_{key} \cdot W_{tw.UN4} = 2012.15 \cdot kN$

Total Horizontal Tailwater Load on Key (Overturning Values Adjusted): $H_{twkey.OT.UN4} := H_{twbk.OT.UN4.tri} + H_{twbk.OT.UN4.rect} = 2283.19 \cdot kN$

Acting at: $H_{twkey.OT.UN4.loc} := \dfrac{H_{twbk.OT.UN4.tri} \cdot \frac{-2 \cdot d_{key}}{3} + H_{twbk.OT.UN4.rect} \cdot \frac{-d_{key}}{2}}{H_{twkey.OT.UN4}} = -1.04 \cdot m$

<u>Lateral Driving Earth Loads for Overturning Stability Analysis (at rest condition)</u>

Depth of Driving Soil Loads (to top of key): $h_{E.OT.UN4} := TOC_{as} - BOF_{elev} = 4\,m$

At-Rest Soil Load: $E_{act.OT.UN4} := \dfrac{\left(K_{o.UN4} \cdot h_{E.OT.UN4}^{\;2}\right)}{2} \cdot \left(\gamma_r - \gamma_w\right) \cdot W_{hwas.UN4} \cdot -1 = -769.99 \cdot kN$

At Rest- Soil Load Acting from Toe: $E_{act.OT.UN4.loc} := \dfrac{h_{E.OT.UN4}}{3} = 1.33\,m$

All Lateral Loads Applicable to Overturning Stability Analysis

HW Lateral Load on Approach Slab:	$H_{hwas.UN4} = -5650.6 \cdot kN$	$H_{hwas.UN4.loc} = 0.63\,m$
HW Lateral Load on Regulating Gate:	$H_{hwrg.UN4} = -200.9 \cdot kN$	$H_{hwrg.UN4.loc} = 4.44\,m$
HW Lateral Load on Guard Gate:	$H_{hwgg.UN4} = -613.1 \cdot kN$	$H_{hwgg.UN4.loc} = 5.67\,m$
TW Lateral Load on Regulating Gate:	$H_{twrg.UN4} = -200.9 \cdot kN$	$H_{twrg.UN4.loc} = 4.44\,m$
HW Lateral Load on Guard Gate:	$H_{twgg.UN4} = 88.5 \cdot kN$	$H_{twgg.UN4.loc} = 4.63\,m$
TW Lateral Load on Gate Footing (No Key - Overturning Values Adjusted):	$H_{twgf.UN4} = 1836.43 \cdot kN$	$H_{twgf.UN4.loc} = 1.66\,m$
TW Lateral Load on Key:	$H_{twkey.OT.UN4} = 2283.19 \cdot kN$	$H_{twkey.OT.UN4.loc} = -1.04\,m$
Ice / Impact Load:	$I_{UN4} = 0.0 \cdot kN$	$I_{UN4.loc} = 8.70\,m$
Lateral Soil Load (driving):	$E_{act.OT.UN4} = -770.0 \cdot kN$	$E_{act.OT.UN4.loc} = 1.33\,m$

Resisting Lateral Soil Load as required to produce horizontal equilibrium:

$$E_{pas.OT.UN4} := -\left(H_{hwas.UN4} + H_{hwrg.UN4} + H_{hwgg.UN4} + H_{twrg.UN4} + H_{twgg.UN4} \cdots + H_{twgf.UN4} + H_{twkey.OT.UN4} + I_{UN4} + E_{act.OT.UN4}\right) = 3227.24 \cdot kN$$

$$E_{pas.OT.UN4.loc} := -1 \cdot \frac{d_{key}}{2} = -1\,m$$

Sum of All Overturning Analysis Horizontal Load (ΣH=0):

$$\Sigma H_{UN4.OT} := H_{hwas.UN4} + H_{hwrg.UN4} + H_{hwgg.UN4} + H_{twrg.UN4} + H_{twgg.UN4} \cdots + H_{twgf.UN4} + H_{twkey.OT.UN4} + I_{UN4} + E_{act.OT.UN4} + E_{pas.OT.UN4} = 0 \cdot kN$$

Sum of All Overturning Analysis Horizontal Load Moments:

$$\Sigma M_{H.UN4.OT} := H_{hwas.UN4} \cdot H_{hwas.UN4.loc} + H_{hwrg.UN4} \cdot H_{hwrg.UN4.loc} + H_{hwgg.UN4} \cdot H_{hwgg.UN4.loc} \cdots + H_{twrg.UN4} \cdot H_{twrg.UN4.loc} + H_{twgg.UN4} \cdot H_{twgg.UN4.loc} + H_{twgf.UN4} \cdot H_{twgf.UN4.loc} \cdots + H_{twkey.OT.UN4} \cdot H_{twkey.OT.UN4.loc} + I_{UN4} \cdot I_{UN4.loc} + E_{act.OT.UN4} \cdot E_{act.OT.UN4.loc} \cdots + E_{pas.OT.UN4} \cdot E_{pas.OT.UN4.loc} = -11959.87 \cdot kN \cdot m$$

Overturning Stability Analysis

$$\Sigma M_{UN4.OT} := \Sigma M_{V.UN4.OT} + \Sigma M_{H.UN4.OT} = 113063.01 \cdot kN \cdot m$$

$$X_{R.UN4} := \frac{\Sigma M_{UN4.OT}}{\Sigma V_{UN4.OT}} = 7.97\,m \qquad x_{OT.UN4} := X_{R.UN4} - \frac{L_b}{2} = -1.28\,m$$

Overturning Resultant Ratio

$$Ratio_{OT.UN4} := \frac{X_{R.UN4}}{L_b} = 0.43$$

$$Ratio_{OT.UN4.check} := \begin{cases} \text{"OKAY"} & \text{if } Ratio_{OT.UN4} \geq Ratio_{OT.UN4.min} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

$$x_{OT.check.UN4} := \begin{cases} \text{"OKAY"} & \text{if } \left|x_{OT.UN4}\right| \leq Kern \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

CHECK FOUNDATION BEARING CAPACITY (HORIZONTAL PLANE):

UN4 CASE

Bearing Pressure Under Toe:

$$\sigma_{ToeUN4.OT} := \frac{\Sigma V_{UN4.OT}}{L_b \cdot W_b} + \frac{\left(\Sigma V_{UN4.OT} \cdot x_{OT.UN4}\right)}{S_b} = 37.3 \cdot kPa$$

$$Bearing_{ChecktoeUN4.OT} := \begin{vmatrix} \text{"OKAY "} & \text{if } \sigma_{ToeUN4.OT} < \sigma_{allow.UN4} \\ \text{"NG""} & \text{otherwise} \end{vmatrix} = \text{"OKAY "}$$

Bearing Pressure Under Heel:

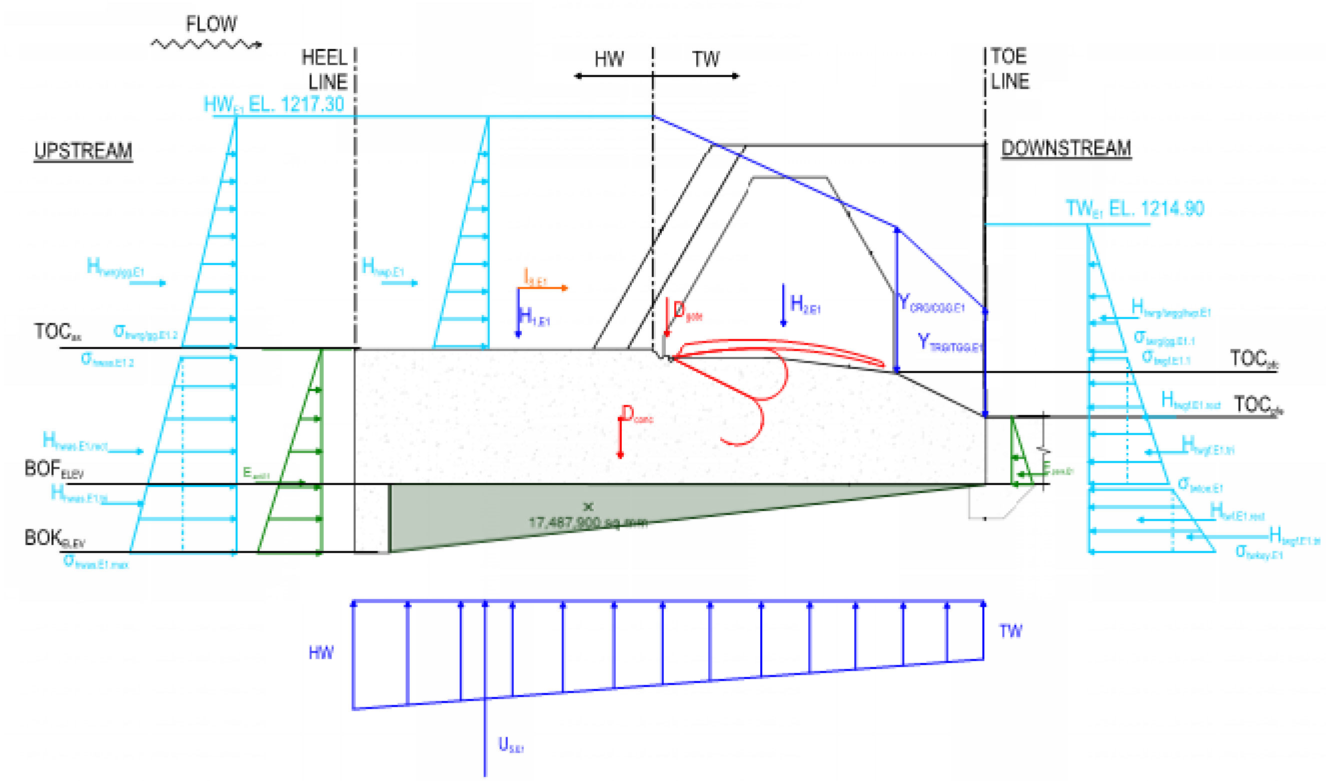
$$\sigma_{HeelUN4.OT} := \frac{\Sigma V_{UN4.OT}}{L_b \cdot W_b} - \frac{\left(\Sigma V_{UN4.OT} \cdot x_{OT.UN4}\right)}{S_b} = 90.6 \cdot kPa$$

$$Bearing_{CheckheelUN4.OT} := \left(\begin{vmatrix} \text{"OKAY "} & \text{if } \sigma_{HeelUN4.OT} < \sigma_{allow.UN4} \wedge \sigma_{HeelUN4.OT} > 0 \\ \text{"NG""} & \text{otherwise} \end{vmatrix} \right) = \text{"OKAY "}$$

SUMMARY OF STABILITY ASSESSMENT:

Key"	Sliding Factor of Safety: (Horizontal Plane)	$FS_{HorizSliding.UN4} = 1.30$	$FS_{HorizSliding.UN4.Check}$ = "Check Inclined Sliding with Key"
	Sliding Factor of Safety: (Inclined Plane)	$FS_{InclinedlSlidingUN4} = 3.2$	$FS_{InclinedSliding.check.UN4}$ = "OKAY "
	Eccentricity: (Inclined Plane)	$e_{UN4} = 0.85\,m$	$e_{check.UN4}$ = "Okay"
	Bearing Pressure At Heel: (Inclined Plane)	$\sigma_{heel.UN4} = 55 \cdot kPa$	$\sigma_{heel.UN4.check}$ = "Okay"
	Bearing Pressure At Toe: (Inclined Plane)	$\sigma_{toe.UN4} = 97 \cdot kPa$	$\sigma_{toe.UN4.1.check}$ = "Okay"
	Flotation Factor of Safety (horizontal plane)	$FS_{act.FUN4} = 1.65$	$FS_{check.FUN4}$ = "OKAY"
	Overturning Resultant Ratio: (horizontal plane)	$Ratio_{OT.UN4} = 0.43$	$Ratio_{OT.UN4.check}$ = "OKAY"
	Eccentricity: (horizontal plane)	$x_{OT.UN4} = -1.28\,m$	$x_{OT.check.UN4}$ = "OKAY"
	Bearing Pressure At Heel: (horizontal plane)	$\sigma_{HeelUN4.OT} = 91 \cdot kPa$	$Bearing_{CheckheelUN4.OT}$ = "OKAY "
	Bearing Pressure At Toe: (horizontal plane)	$\sigma_{ToeUN4.OT} = 37 \cdot kPa$	$Bearing_{ChecktoeUN4.OT}$ = "OKAY "

E1 DESIGN CASE



ACCEPTANCE PARAMETERS

Required Factor of Safety for Sliding: $FS_{req.E1.sl} := 1.1$ (Without Cohesion)

(Section 8.1, Design Criteria)

Resultant Within Middle Third of Base: $e \le \frac{L_b}{6} \wedge e \ge \frac{-L_b}{6}$

Allowable Rock Bearing Pressure: $\sigma_{allow.E1} := 1740 \cdot \frac{kN}{m^2}$ (Section 5.2, Design Criteria)

INPUT PARAMETERS

Headwater Elevation: $HW_{E1} := 1217.30m$ (Section 8.3, Design Criteria)

Tailwater Elevation: $TW_{E1} := 1214.90m$ (Section 8.3, Design Criteria)

Bottom of Footing Elevation: $BOF_{elev} = 1206.00\,m$

Approach Slab Top of Concrete Elevation at Upstream Face: $TOC_{as} = 1210.00\,m$

Pier Footing Top of Concrete Elevation at Stilling Basin: $TOC_{pfe} = 1208.00\,m$

Pier Footing Top of Concrete Elevation at Center of Footing: $TOC_{pfc} = 1209.30\,m$

Top of Guard/ Regulating Gate Elevation: $TOP_{rg.E1} := 1210.00m$ $TOP_{gg.E1} := 1210.00m$

Bottom of Key Elevation: $BOK_{elev} = 1204\,m$

Gates are open when top of gate elevation is at 1210.00m

Gates are closed/up when top of gate elevation is at 1215.0m

Crestwater Elevation (Right) Guard Gate: $EL_{CGG.E1} := 1214.87m$

$$Y_{C.gg.E1} := \begin{cases} (EL_{CGG.E1} - TOC_{pfc}) & \text{if } TOP_{gg.E1} \le HW_{E1} \\ (TW_{E1} - TOC_{pfc}) & \text{if } TOP_{gg.E1} > HW_{E1} \end{cases} = 5.57 \cdot m$$

Toewater Elevation (Right) Guard Gate: $EL_{TGG.E1} := 1210.89m$

$$Y_{TOE.gg.E1} := \begin{cases} (EL_{TGG.E1} - TOC_{pfe}) & \text{if } TOP_{gg.E1} \le HW_{E1} \\ (TW_{E1} - TOC_{pfe}) & \text{if } TOP_{gg.E1} > HW_{E1} \end{cases} = 2.89 \cdot m$$

E1 CASE

Crestwater Elevation (Left) Regulating Gate: $EL_{CRG.E1} := 1214.87m$

$$Y_{C.rg.E1} := \begin{vmatrix} (EL_{CRG.E1} - TOC_{pfc}) & \text{if } TOP_{rg.E1} \le HW_{E1} \\ (TW_{E1} - TOC_{pfc}) & \text{if } TOP_{rg.E1} > HW_{E1} \end{vmatrix} = 5.57 \cdot m$$

Toewater Elevation (Left) Regulating Gate: $EL_{TRG.E1} := 1210.89m$

$$Y_{TOE.rg.E1} := \begin{vmatrix} (EL_{TRG.E1} - TOC_{pfe}) & \text{if } TOP_{rg.E1} \le HW_{E1} \\ (TW_{E1} - TOC_{pfe}) & \text{if } TOP_{rg.E1} > HW_{E1} \end{vmatrix} = 2.89 \cdot m$$

LATERAL WATER LOADS

HEADWATER (DRIVING):

Headwater Depth on Pier: $D_{hwp.E1} := HW_{E1} - TOC_{as} = 7.30\,m$

Headwater Load Unit Width on Pier: $W_{hwp.E1} := w_p = 2.00\,m$

Total Horizontal Headwater Load on Pier:

$$H_{hwp.E1} := \frac{-\left(\gamma_w \cdot D_{hwp.E1}^{\ 2}\right)}{2} \cdot W_{hwp.E1} = -522.8 \cdot kN$$

Apply Total Pier Headwater Load at:

$$H_{hwp.E1.loc} := \frac{D_{hwp.E1}}{3} + \left(TOC_{as} - BOF_{elev}\right) = 6.43\,m$$

Headwater Depth on Gate base: $D_{hwg.E1} := HW_{E1} - TOC_{as} = 7.30\,m$

Thickness of Approach Slab (Including Key): $T_{as} = 6\,m$

Headwater Depth at Heel (U/S face): $D_{hwas.E1} := HW_{E1} - BOK_{elev} = 13.30\,m$

Headwater Load Unit Width on Approach Slab: $W_{hwas.E1} := W_b = 12.00\,m$

Headwater Unit Load At Top of Approach Slab:

$$H_{hwas.E1.1} := \frac{-\left(\gamma_w \cdot D_{hwg.E1}^{\ 2}\right)}{2} \cdot W_{hwas.E1} = -3136.65 \cdot kN$$

Headwater Unit Load At Bottom of Approach Key:

$$H_{hwas.E1.2} := \frac{-\left(\gamma_w \cdot D_{hwas.E1}^{\ 2}\right)}{2} \cdot W_{hwas.E1} = -10411.7 \cdot kN$$

Headwater Line Load At Top of Approach Slab:

$$\sigma_{hwas.E1.1} := -\left(\gamma_w \cdot D_{hwg.E1}\right) = -71.61 \cdot kPa$$

Headwater Line Load At Bottom of Approach Key:

$$\sigma_{hwas.E1.2} := -\left(\gamma_w \cdot D_{hwas.E1}\right) = -130.47 \cdot kPa$$

Triangular Distribution Unit Load on Approach Slab and Key:

$$H_{hwas.E1.2.tri} := \left(\frac{\sigma_{hwas.E1.2} - \sigma_{hwas.E1.1}}{2}\right) \cdot \left(T_{as} \cdot W_{hwas.E1}\right) = -2118.96 \cdot kN$$

Rectangular Distribution Unit Load on Approach Slab and Key:

$$H_{hwas.E1.2.rect} := \sigma_{hwas.E1.1} \cdot \left(T_{as} \cdot W_{hwas.E1}\right) = -5156.14 \cdot kN$$

Total Horizontal Headwater Load on Approach Slab:

$$H_{hwas.E1} := H_{hwas.E1.2.tri} + H_{hwas.E1.2.rect} = -7275.1 \cdot kN$$

Apply Total Footing Headwater Load at:

$$H_{hwas.E1.loc} := \frac{\left[H_{hwas.E1.2.rect} \cdot \left(\frac{T_{as}}{2}\right) + H_{hwas.E1.2.tri} \cdot \left(\frac{T_{as}}{3}\right)\right]}{H_{hwas.E1.2.tri} + H_{hwas.E1.2.rect}} - d_{key} = 0.71\,m$$

LATERAL WATER LOADS (continued)

Regulating Gate (2A) Operating Condition:

Regulating Crest Gate Down/Open Condition: $A1_{E1} := TOP_{rg.E1} \le TOC_{as}$

Regulating Crest Gate Up/Closed, with Top of Gate Higher than HW Elevation: $B1_{E1} := TOP_{rg.E1} \ge HW_{E1} \wedge TOP_{rg.E1} > TOC_{as}$

Regulating Crest Gate Up/Closed, with Top of Gate Lower than HW Elevation: $C1_{E1} := TOP_{rg.E1} > TOC_{as} \wedge HW_{E1} > TOP_{rg.E1}$

Regulating Crest Gate Height: $H_{rg.E1} := TOP_{rg.E1} - TOC_{as} = 0\,m$

Headwater Depth at Regulating Crest Gate: $D_{hwrg.E1} := HW_{E1} - TOC_{as} = 7.30\,m$

Regulating Crest Gate Width: $W_{hwrg.E1} := 5.00m$

Lateral Headwater Pressure at Bottom of Regulating Crest Gate:

$$\sigma_{hwrg.E1.1} := \begin{vmatrix} (0.0kPa) & \text{if } A1_{E1} \\ -(\gamma_w \cdot D_{hwrg.E1}) & \text{if } B1_{E1} \\ -(\gamma_w \cdot D_{hwrg.E1}) & \text{if } C1_{E1} \end{vmatrix} = 0.0 \cdot kPa$$

Lateral Headwater Pressure at Top of Regulating Crest Gate: (Load at HW Elevation On Regulating Crest Gate if HW is below TOG_{rg})

$$\sigma_{hwrg.E1.2} := \begin{vmatrix} (0.0kPa) & \text{if } A1_{E1} \\ 0.0kPa & \text{if } B1_{E1} \\ -\left[\gamma_w \cdot (HW_{E1} - TOP_{rg.E1})\right] & \text{if } C1_{E1} \end{vmatrix} = 0.0 \cdot kPa$$

Average Pressure acting on Regulating Gate:

$$\sigma_{hwrg.E1.avg} := \frac{(\sigma_{hwrg.E1.1} + \sigma_{hwrg.E1.2})}{2} = 0 \cdot kPa$$

Total Area water acting on Regulating Crest Gate:

$$A_{hwrg.E1} := \begin{vmatrix} D_{hwrg.E1} \cdot W_{hwrg.E1} & \text{if } A1_{E1} \\ D_{hwrg.E1} \cdot W_{hwrg.E1} & \text{if } B1_{E1} \\ H_{rg.E1} \cdot W_{hwrg.E1} & \text{if } C1_{E1} \end{vmatrix} = 36.5 \cdot m^2$$

Total Horizontal Headwater Load on Regulating Crest Gate: $H_{hwrg.E1} := \sigma_{hwrg.E1.avg} \cdot A_{hwrg.E1} = 0.0 \cdot kN$

Apply Total Regulating Crest Gate Headwater Load at:

$$H_{hwrg.E1.loc} := \begin{vmatrix} (TOC_{as} - BOF_{elev}) & \text{if } A1_{E1} \\ \left[\frac{(HW_{E1} - TOC_{as})}{3} + (TOC_{as} - BOF_{elev})\right] & \text{if } B1_{E1} \\ \left[\frac{\sigma_{hwrg.E1.2} \cdot A_{hwrg.E1} \cdot \frac{(H_{rg.E1})}{2} + \frac{(\sigma_{hwrg.E1.1} - \sigma_{hwrg.E1.2})}{2} A_{hwrg.E1} \cdot \frac{(H_{rg.E1})}{3}}{\sigma_{hwrg.E1.2} \cdot A_{hwrg.E1} + \frac{(\sigma_{hwrg.E1.1} - \sigma_{hwrg.E1.2})}{2} \cdot A_{hwrg.E1}} \ldots \\ + (TOC_{as} - BOF_{elev})\right] & \text{if } C1_{E1} \end{vmatrix} = 4.0 \cdot m$$

Guard Gate (4A) Operating Condition:

Guard Gate Down/Open Condition: $A2_{E1} := TOP_{gg.E1} \le TOC_{as}$

Guard Crest Gate Up/Closed, with Top of Gate Higher than HW Elevation: $B2_{E1} := TOP_{gg.E1} \ge HW_{E1} \wedge TOP_{gg.E1} > TOC_{as}$

Guard Crest Gate Up/Closed, with Top of Gate Lower than HW Elevation: $C2_{E1} := TOP_{gg.E1} > TOC_{as} \wedge HW_{E1} > TOP_{gg.E1}$

Guard Crest Gate Height: $H_{gg.E1} := TOP_{gg.E1} - TOC_{as} = 0\,m$

Headwater Depth at Guard Crest Gate: $D_{hwgg.E1} := HW_{E1} - TOC_{as} = 7.30\,m$

Guard Crest Gate Width: $W_{hwgg.E1} := 5.00m$

Lateral Headwater Pressure at Bottom of Guard Crest Gate:

$$\sigma_{hwgg.E1.1} := \begin{vmatrix} (0.0kPa) & \text{if } A2_{E1} \\ -(\gamma_w \cdot D_{hwgg.E1}) & \text{if } B2_{E1} \\ -(\gamma_w \cdot D_{hwgg.E1}) & \text{if } C2_{E1} \end{vmatrix} = 0.0 \cdot kPa$$

Lateral Headwater Pressure at Top of Guard Crest Gate: (Load at HW Elevation On Guard Crest Gate if HW is below TOG_{rg})

$$\sigma_{hwgg.E1.2} := \begin{vmatrix} (0.0kPa) & \text{if } A2_{E1} \\ 0.0kPa & \text{if } B2_{E1} \\ -\left[\gamma_w \cdot (HW_{E1} - TOP_{gg.E1})\right] & \text{if } C2_{E1} \end{vmatrix} = 0.0 \cdot kPa$$

Average Pressure acting on Guard Crest Gate:

$$\sigma_{hwgg.E1.avg} := \frac{(\sigma_{hwgg.E1.1} + \sigma_{hwgg.E1.2})}{2} = 0 \cdot kPa$$

Total Area water acting on Crest Gate:

$$A_{hwgg.E1} := \begin{vmatrix} D_{hwgg.E1} \cdot W_{hwgg.E1} & \text{if } A2_{E1} \\ D_{hwgg.E1} \cdot W_{hwgg.E1} & \text{if } B2_{E1} \\ H_{gg.E1} \cdot W_{hwgg.E1} & \text{if } C2_{E1} \end{vmatrix} = 36.5 \cdot m^2$$

Total Horizontal Headwater Load on Guard Crest Gate: $H_{hwgg.E1} := \sigma_{hwgg.E1.avg} \cdot A_{hwgg.E1} = 0.0 \cdot kN$

Apply Total Guard Crest Gate Headwater Load at:

$$H_{hwgg.E1.loc} := \begin{vmatrix} (TOC_{as} - BOF_{elev}) & \text{if } A2_{E1} \\ \left[\frac{(HW_{E1} - TOC_{as})}{3} + (TOC_{as} - BOF_{elev})\right] & \text{if } B2_{E1} \\ \left[\dfrac{\sigma_{hwgg.E1.2} \cdot A_{hwgg.E1} \cdot \frac{(H_{gg.E1})}{2} + \frac{(\sigma_{hwgg.E1.1} - \sigma_{hwgg.E1.2})}{2} A_{hwgg.E1} \cdot \frac{(H_{gg.E1})}{3}}{\sigma_{hwgg.E1.2} \cdot A_{hwgg.E1} + \frac{(\sigma_{hwgg.E1.1} - \sigma_{hwgg.E1.2})}{2} \cdot A_{hwgg.E1}} \ldots \\ + (TOC_{as} - BOF_{elev})\right] & \text{if } C2_{E1} \end{vmatrix} = 4.0 \cdot m$$

LATERAL TAILWATER (RESISTING) Applied to Downstream Side of Regulating Crest Gate:

E1 CASE

Regulating Crest Gate Down/Open Condition: $A3_{E1} := TOP_{rg.E1} \le TOC_{as}$

Regulating Crest Gate Up/Closed, with Top of Gate Higher than TW Elevation: $B3_{E1} := TOP_{rg.E1} \ge TW_{E1} \wedge TOP_{rg.E1} > TOC_{as}$

Regulating Crest Gate Up/Closed, with Top of Gate Lower than TW Elevation: $C3_{E1} := TOP_{rg.E1} > TOC_{as} \wedge TW_{E1} > TOP_{rg.E1}$

Regulating Crest Gate Height: $H_{rg.E1} = 0\,m$

Tailwater Depth at Regulating Crest Gate: $D_{twrg.E1} := TW_{E1} - TOC_{as} = 4.90\,m$

Regulating Crest Gate Width: $W_{twrg.E1} := 5m$

Lateral Tailwater Pressure at Bottom of Regulating Crest Gate:

$$\sigma_{twrg.E1.1} := \begin{cases} (0.0kPa) & \text{if } A3_{E1} \\ -(\gamma_w \cdot D_{twrg.E1}) & \text{if } B3_{E1} \\ -(\gamma_w \cdot D_{twrg.E1}) & \text{if } C3_{E1} \end{cases} = 0.0 \cdot kPa$$

Lateral Tailwater Pressure at Top of Regulating Crest Gate: (Load at TW Elevation On Regulating Crest Gate if TW is below TOG_{rg})

$$\sigma_{twrg.E1.2} := \begin{cases} (0.0kPa) & \text{if } A3_{E1} \\ 0.0kPa & \text{if } B3_{E1} \\ -\left[\gamma_w \cdot \left(TW_{E1} - TOP_{rg.E1}\right)\right] & \text{if } C3_{E1} \end{cases} = 0.0 \cdot kPa$$

Average Pressure acting on Regulating Gate:

$$\sigma_{twrg.E1.avg} := \frac{\left(\sigma_{twrg.E1.1} + \sigma_{twrg.E1.2}\right)}{2} = 0 \cdot kPa$$

Total Area water acting on Regulating Crest Gate:

$$A_{twrg.E1} := \begin{cases} D_{twrg.E1} \cdot W_{twrg.E1} & \text{if } A3_{E1} \\ D_{twrg.E1} \cdot W_{twrg.E1} & \text{if } B3_{E1} \\ H_{rg.E1} \cdot W_{twrg.E1} & \text{if } C3_{E1} \end{cases} = 24.5 \cdot m^2$$

Total Horizontal Tailwater Load on Regulating Crest Gate:

$$H_{twrg.E1} := \sigma_{hwrg.E1.avg} \cdot A_{hwrg.E1} = 0.0 \cdot kN$$

Apply Total Regulating Crest Gate Tailwater Load at:

$$H_{twrg.E1.loc} := \begin{cases} \left(TOC_{as} - BOF_{elev}\right) & \text{if } A3_{E1} \\ \left[\frac{\left(HW_{E1} - TOC_{as}\right)}{3} + \left(TOC_{as} - BOF_{elev}\right)\right] & \text{if } B3_{E1} \\ \left[\frac{\sigma_{hwrg.E1.2} \cdot A_{hwrg.E1} \cdot \frac{\left(H_{rg.E1}\right)}{2} + \frac{\left(\sigma_{hwrg.E1.1} - \sigma_{hwrg.E1.2}\right)}{2} \cdot A_{hwrg.E1} \cdot \frac{\left(H_{rg.E1}\right)}{3}}{\sigma_{hwrg.E1.2} \cdot A_{hwrg.E1} + \frac{\left(\sigma_{hwrg.E1.1} - \sigma_{hwrg.E1.2}\right)}{2} \cdot A_{hwrg.E1}} \ldots \\ + \left(TOC_{as} - BOF_{elev}\right)\right] & \text{if } C3_{E1} \end{cases} = 4.0 \cdot m$$

LATERAL TAILWATER (RESISTING) Applied to Downstream Side of Guard Crest Gate:

E1 CASE

Guard Gate Down/Open Condition: $A4_{E1} := TOP_{gg.E1} \le TOC_{as}$

Guard Crest Gate Up/Closed, with Top of Gate Higher than TW Elevation: $B4_{E1} := TOP_{gg.E1} \ge TW_{E1} \wedge TOP_{gg.E1} > TOC_{as}$

Guard Crest Gate Up/Closed, with Top of Gate Lower than TW Elevation: $C4_{E1} := TOP_{gg.E1} > TOC_{as} \wedge TW_{E1} > TOP_{gg.E1}$

Tailwater Depth at Guard Crest Gate: $D_{twgg.E1} := TW_{E1} - TOC_{as} = 4.90\,m$

Guard Crest Gate Height: $H_{gg.E1} = 0\,m$

Guard Crest Gate Width: $W_{twgg.E1} := 5.00m$

Lateral Water Load at Bottom of Guard Crest Gate:

$$\sigma_{twgg.E1.1} := \begin{vmatrix} (0.0kPa) & \text{if} & A4_{E1} \\ (\gamma_w \cdot D_{twgg.E1}) & \text{if} & B4_{E1} \\ (\gamma_w \cdot D_{twgg.E1}) & \text{if} & C4_{E1} \end{vmatrix} = 0.0 \cdot kPa$$

Lateral Water Load at Top of Guard Crest Gate:
(Load at TW Elevation On Guard Crest Gate if TW is below TOG_{gg})

$$\sigma_{twgg.E1.2} := \begin{vmatrix} (0.0kPa) & \text{if} & A4_{E1} \\ 0.0kPa & \text{if} & B4_{E1} \\ \left[\gamma_w \cdot (TW_{E1} - TOP_{gg.E1})\right] & \text{if} & C4_{E1} \end{vmatrix} = 0.0 \cdot kPa$$

Average Pressure acting on Guard Crest Gate:

$$\sigma_{twgg.E1.avg} := \frac{(\sigma_{twgg.E1.1} + \sigma_{twgg.E1.2})}{2} = 0 \cdot kPa$$

Total Area water acting on Crest Gate:

$$A_{twgg.E1} := \begin{vmatrix} D_{twgg.E1} \cdot W_{twgg.E1} & \text{if} & A4_{E1} \\ D_{twgg.E1} \cdot W_{twgg.E1} & \text{if} & B4_{E1} \\ H_{gg.E1} \cdot W_{twgg.E1} & \text{if} & C4_{E1} \end{vmatrix} = 24.5 \cdot m^2$$

Total Horizontal Tailwater Load on Guard Crest Gate: $H_{twgg.E1} := \sigma_{twgg.E1.avg} \cdot A_{twgg.E1} = 0.0 \cdot kN$

Apply Total Horiz. TW Load on Guard Gate at:

$$H_{twgg.E1.loc} := \begin{vmatrix} (TOC_{as} - BOF_{elev}) \quad \text{if} \quad A4_{E1} \\ \left[\frac{(TW_{E1} - TOC_{as})}{3} + (TOC_{as} - BOF_{elev})\right] \quad \text{if} \quad B4_{E1} \\ \left[\frac{\sigma_{twgg.E1.2} \cdot A_{twgg.E1} \cdot \frac{(H_{gg.E1})}{2} + \frac{(\sigma_{twgg.E1.1} - \sigma_{twgg.E1.2})}{2} A_{twgg.E1} \cdot \frac{(H_{gg.E1})}{3}}{\sigma_{twgg.E1.2} \cdot A_{twgg.E1} + \frac{(\sigma_{twgg.E1.1} - \sigma_{twgg.E1.2})}{2} \cdot A_{twgg.E1}} \ldots \\ + (TOC_{as} - BOF_{elev}) \right] \quad \text{if} \quad C4_{E1} \end{vmatrix} = 4.0 \cdot m$$

LATERAL WATER LOADS (continued)

TAILWATER (RESISTING) Applied to Concrete Structure:

Tailwater Depth on Pier: $D_{twp.E1} := TW_{E1} - TOC_{as} = 4.90\,m$

Tailwater Load Unit Width on Pier: $W_{twp.E1} := w_p = 2.00\,m$

Total Horizontal Tailwater Load on Pier: $H_{twp.E1} := \frac{\left(\gamma_w \cdot D_{twp.E1}{}^2\right)}{2} \cdot W_{twp.E1} = 235.5 \cdot kN$

Apply Total Pier Tailwater Load at: $H_{twp.E1.loc} := \frac{D_{twp.E1}}{3} + \left(TOC_{as} - BOF_{elev}\right) = 5.63\,m$

Tailwater Depth At top of Gate Base Footing Elevation: $D_{twgf.E1} := TW_{E1} - TOC_{as}$

Water Depth at bottom of Gate Base Footing (Excluding Key): $D_{twtoe.E1} := TW_{E1} - BOF_{elev} = 8.90\,m$

Footing Thickness for horizontal at Toe: $h_{toe} = 4\,m$

Unit Width of D/S face of crest for application of Tailwater Load: $W_{tw.E1} := W_b = 12.00\,m$

Tailwater Pressure At Top of Gate Footing: $\sigma_{twgf.E1} := \left(\gamma_w \cdot D_{twgf.E1}\right) = 48.07 \cdot kPa$

Tailwater Pressure At Toe: $\sigma_{twtoe.E1} := \left(\gamma_w \cdot D_{twtoe.E1}\right) = 87.31 \cdot kPa$

Triangular Distribution Unit Load on Gate Footing Base (including key): $H_{twgf.E1.tri} := \left(\frac{\sigma_{twtoe.E1} - \sigma_{twgf.E1}}{2}\right) \cdot \left[\left(T_{as} - d_{key}\right) \cdot W_{tw.E1}\right] = 941.76 \cdot kN$

Rectangular Distribution Unit Load on Gate Footing Base (including key): $H_{twgf.E1.rect} := \sigma_{twgf.E1} \cdot \left[\left(T_{as} - d_{key}\right) \cdot W_{tw.E1}\right] = 2307.31 \cdot kN$

Tailwater Pressure At Bottom of Sliding Failure Plane: $\sigma_{twbk.E1} := \left(HW_{E1} - BOK_{elev}\right) \cdot \gamma_w = 130.47 \cdot kPa$

Triangular Distribution Unit Load Below Footing: $H_{twbk.E1.tri} := \frac{\left(\sigma_{twbk.E1} - \sigma_{twtoe.E1}\right)}{2} \cdot d_{key} \cdot W_{tw.E1} = 517.97 \cdot kN$

Rectangular Distribution Load Below Footing Base: $H_{twbk.E1.rect} := \sigma_{twtoe.E1} \cdot d_{key} \cdot W_{tw.E1} = 2095.42 \cdot kN$

Total Horizontal Tailwater Headwater Load on Gate Footing (including key): $H_{twgk.E1} := H_{twgf.E1.tri} + H_{twgf.E1.rect} + H_{twbk.E1.tri} + H_{twbk.E1.rect} = 5862.46 \cdot kN$

Apply Total Gate Footing Tailwater Load at:

$$H_{twgk.E1.loc} := \frac{\left[H_{twgf.E1.rect} \cdot \frac{\left(h_{toe}\right)}{2} + H_{twgf.E1.tri} \cdot \frac{\left(h_{toe}\right)}{3} + H_{twbk.E1.tri} \cdot \left(-d_{key} \cdot \frac{2}{3}\right) + H_{twbk.E1.rect} \cdot \left(\frac{-d_{key}}{2}\right)\right]}{H_{twgf.E1.tri} + H_{twgf.E1.rect} + H_{twbk.E1.tri} + H_{twbk.E1.rect}} = 0.53\,m$$

SUMMATION OF LATERAL WATER LOADS:

$$\Sigma H_{Water.E1} := H_{hwp.E1} + H_{hwas.E1} + H_{hwrg.E1} + H_{hwgg.E1} + H_{twp.E1} + H_{twgk.E1} + H_{twrg.E1} + H_{twgg.E1} = -1699.88 \cdot kN$$

$$\Sigma M_{Hwater.E1} := H_{hwp.E1} \cdot H_{hwp.E1.loc} + H_{hwas.E1} \cdot H_{hwas.E1.loc} + H_{hwrg.E1} \cdot H_{hwrg.E1.loc} + H_{hwgg.E1} \cdot H_{hwgg.E1.loc} + H_{twp.E1} \cdot H_{twp.E1.loc} + H_{twgk.E1} \cdot H_{twgk.E1.loc} + H_{twrg.E1} \cdot H_{twrg.E1.loc} + H_{twgg.E1} \cdot H_{twgg.E1.loc} = -4108.19 \cdot kN \cdot m$$

VERTICAL WATER LOADS

E1 CASE

HEADWATER:

Water Depth on top of Approach Slab: $d_{hw.E1} := HW_{E1} - TOC_{as} = 7.30\,m$

Length of Approach Slab: $L_{as} = 8.75\,m$

Width of Approach Slab: $w_{as} = 12.00\,m$

Length from front of Gate to Heel: $L_{hg} = 8.75\,m$

Vertical Water Weight (H1) on Approach Slab:

$$H_{1.E1} := \left[w_{as} \cdot d_{hw.E1} \cdot L_{hg} - w_p \cdot d_{hw.E1} \cdot \left(L_{hg} - L_{as}\right)\right] \cdot \gamma_w = 7519.4 \cdot kN$$

Moment Arm for Application of Water Weight (H1) from toe:

$$H_{1.E1.loc} := L_b - \frac{L_{hg}}{2} = 14.13\,m$$

TAILWATER ABOVE GUARD GATE:

Trapezoid Volume Above Gate Footing from Approach Slab to Crest:

$$V_{asc.gg.E1} := \left(L_{gf} - L_{gfc}\right) W_{twgg.E1} \frac{d_{hw.E1} + Y_{C.gg.E1}}{2} = 230.05 \cdot m^3$$

Trapezoid Volume Above Gate Footing Crest to End of Gate Footing:

$$V_{gfc.gg.E1} := \left(L_{gfc} \cdot W_{twgg.E1}\right) \frac{Y_{C.gg.E1} + Y_{TOE.gg.E1}}{2} = 54.99 \cdot m^3$$

Load Above Gate Footing from Approach Slab to Crest:

$$H_{2.E1.asc.gg} := V_{asc.gg.E1} \cdot \gamma_w = 2256.8 \cdot kN$$

Load Acting Above Footing Crest from Toe:

$$H_{2.E1.asc.gg.loc} := \frac{\left(L_{gf} - L_{gfc}\right) \cdot \left(2 \cdot d_{hw.E1} + Y_{C.gg.E1}\right)}{3 \cdot \left(d_{hw.E1} + Y_{C.gg.E1}\right)} + L_{gfc} = 6.34\,m$$

Load Above Gate Footing from Crest to End:

$$H_{2.E1.gfc.gg} := V_{gfc.gg.E1} \cdot \gamma_w = 539.45 \cdot kN$$

Load Acting Above Gate Footing from Crest to End:

$$H_{2.E1.gfc.gg.loc} := \frac{\left(L_{gfc}\right) \cdot \left(2 \cdot Y_{C.gg.E1} + Y_{TOE.gg.E1}\right)}{3 \cdot \left(Y_{C.gg.E1} + Y_{TOE.gg.E1}\right)} = 1.44\,m$$

Vertical Water Weight (H2) on Guard Gate Footing:

$$H_{2.E1.gg} := H_{2.E1.asc.gg} + H_{2.E1.gfc.gg} = 2796.25 \cdot kN$$

Moment Arm for Application of Water Weight (H2) from toe:

$$H_{2.E1.gg.loc} := \frac{H_{2.E1.asc.gg} \cdot H_{2.E1.asc.gg.loc} + H_{2.E1.gfc.gg} \cdot H_{2.E1.gfc.gg.loc}}{H_{2.E1.gg}} = 5.39\,m$$

TAILWATER ABOVE REGULATING GATE:

Trapezoid Volume Above Gate Footing from Approach Slab to Crest:

$$V_{asc.rg.E1} := \left(L_{gf} - L_{gfc}\right) W_{twrg.E1} \frac{d_{hw.E1} + Y_{C.rg.E1}}{2} = 230.05 \cdot m^3$$

Trapezoid Volume Above Gate Footing Crest to End of Gate Footing:

$$V_{gfc.rg.E1} := \left(L_{gfc} \cdot W_{twrg.E1}\right) \frac{Y_{C.rg.E1} + Y_{TOE.rg.E1}}{2} = 54.99 \cdot m^3$$

Load Above Gate Footing from Approach Slab to Crest:

$$H_{2.E1.asc.rg} := V_{asc.rg.E1} \cdot \gamma_w = 2256.8 \cdot kN$$

Load Acting Above Footing Crest from Toe:

$$H_{2.E1.asc.rg.loc} := \frac{\left(L_{gf} - L_{gfc}\right) \cdot \left(2 \cdot d_{hw.E1} + Y_{C.rg.E1}\right)}{3 \cdot \left(d_{hw.E1} + Y_{C.rg.E1}\right)} + L_{gfc} = 6.34\,m$$

Load Above Gate Footing from Crest to End:

$$H_{2.E1.gfc.rg} := V_{gfc.rg.E1} \cdot \gamma_w = 539.45 \cdot kN$$

Load Acting Above Gate Footing from Crest to End:

$$H_{2.E1.gfc.rg.loc} := \frac{\left(L_{gfc}\right) \cdot \left(2 \cdot Y_{C.rg.E1} + Y_{TOE.rg.E1}\right)}{3 \cdot \left(Y_{C.rg.E1} + Y_{TOE.rg.E1}\right)} = 1.44\,m$$

Vertical Water Weight (H2) on Regulating Gate Footing:

$$H_{2.E1.rg} := H_{2.E1.asc.rg} + H_{2.E1.gfc.rg} = 2796.25 \cdot kN$$

Moment Arm for Application of Water Weight (H2) from toe:

$$H_{2.E1.rg.loc} := \frac{H_{2.E1.asc.rg} \cdot H_{2.E1.asc.rg.loc} + H_{2.E1.gfc.rg} \cdot H_{2.E1.gfc.rg.loc}}{H_{2.E1.rg}} = 5.39\,m$$

UPLIFT **E1 CASE**

Uplift pressure at U/S Face (heel): $U_{HW.E1} := \left(D_{hwas.E1}\right)\cdot\gamma_w = 130.5\cdot\frac{kN}{m^2}$

Uplift pressure at D/S Face Stilling Basin: $U_{TW.E1} := \left(D_{twtoe.E1}\right)\cdot\gamma_w = 87.31\cdot\frac{kN}{m^2}$

Length from U/S of Gate Structure to D/S of Stilling Basin: $L_{overall} = 18.50\,m$

Difference between Uplift pressure at HW and TW: $U_{diff.E1} := U_{HW.E1} - U_{TW.E1} = 43.16\cdot\frac{kN}{m^2}$

Slope of difference between between Uplift pressure at HW and TW: $U_{slope.E1} := \frac{U_{diff.E1}}{L_{overall}} = 2.33\cdot\frac{kN}{m^2\cdot m}$

Tailwater Pressure at toe of Gate Structure: $U_{press.toe.gs.E1} := U_{TW.E1} + \left(L_{overall} - L_b\right)\cdot U_{slope.E1} = 87.31\cdot\frac{kN}{m^2}$

Uniform uplift force UA Under Gate Structure due to TW (rectangle): $U_{A.E1} := U_{press.toe.gs.E1}\cdot L_b\cdot W_b\cdot -1 = -19382.6\cdot kN$

Moment Arm from Toe of Gate Structure for Uplift UA: $L_{A.E1} := \left(\frac{L_b}{2}\right) = 9.25\,m$

Linearly Decreasing Uplift Force E1B Under Gate Structure due to HW-TW Differential (triangle): $U_{B.E1} := \frac{1}{2}\cdot\left(U_{HW.E1} - U_{press.toe.gs.E1}\right)\cdot L_b\cdot W_b\cdot -1 = -4791.2\cdot kN$

Moment Arm from Toe of Gate Structure for Uplift UB: $L_{B.E1} := \frac{2}{3}\cdot L_b = 12.33\,m$

Total Resultant Uplift force: $U_{E1} := U_{A.E1} + U_{B.E1} = -24173.8\cdot kN$

Resultant Location from Toe: $U_{E1.loc} := \frac{\left(U_{A.E1}\cdot L_{A.E1} + U_{B.E1}\cdot L_{B.E1}\right)}{\left(U_{A.E1} + U_{B.E1}\right)} = 9.86\,m$

$\Sigma V_{water.E1} := H_{1.E1} + H_{2.E1.gg} + H_{2.E1.rg} + U_{E1} = -11061.93\cdot kN$

$\Sigma M_{Vwater.E1} := H_{1.E1}\cdot H_{1.E1.loc} + H_{2.E1.gg}\cdot H_{2.E1.gg.loc} + H_{2.E1.rg}\cdot H_{2.E1.rg.loc} + U_{E1}\cdot U_{E1.loc} = -102024.31\cdot kN\cdot m$

SOIL LOADS

E1 CASE

Equivalent Fluid Pressure (EFP):

At rest lateral pressure coefficient: $K_{o.E1} := 1 - \sin(\phi_{backfill}) = 0.658$ (Section 5.3, Design Criteria)

Headwater Pier Footing Unit Width: $W_{hwas.E1} = 12.00\,m$

Tailwater Pier Footing Unit Width: $W_{tw.E1} = 12.00\,m$

Pier Footing Thickness at Heel: $t_{hf.E1} := TOC_{as} - BOK_{elev} = 6.00\,m$

Fixed Crest Footing Thickness at Toe: $t_{tf.E1} := TOC_{pfe} - BOF_{elev} = 2.00\,m$

Lateral Driving Force (Headwater Side - at rest condition)

Structure Soil Load: $E_{act.E1} := \dfrac{\left(K_{o.E1} \cdot t_{hf.E1}{}^2\right)}{2} \cdot (\gamma_r - \gamma_w) \cdot W_{hwas.E1} \cdot -1 = -1732.49 \cdot kN$

Acting at: $E_{act.E1.loc} := \dfrac{t_{hf.E1}}{3} - d_{key} = 0.00\,m$

Lateral Resisting Force (Tailwater Side - at rest condition)

At-rest Soil Load: $E_{pass.E1} := \dfrac{\left(K_{o.E1} \cdot t_{tf.E1}{}^2\right)}{2} \cdot (\gamma_r - \gamma_w) \cdot W_{tw.E1} = 192.5 \cdot kN$

Acting at: $E_{pass.E1.loc} := \dfrac{t_{tf.E1}}{3} = 0.67\,m$

$\Sigma H_{soil.E1} := E_{act.E1} + E_{pass.E1} = -1539.99 \cdot kN$

$\Sigma M_{soil.E1} := E_{act.E1} \cdot E_{act.E1.loc} + E_{pass.E1} \cdot E_{pass.E1.loc} = 128.33 \cdot kN \cdot m$

ICE / IMPACT LOADS (ASSUME NO ICE LOADING ON TAILWATER SIDE)

Static Ice Loading on Structure: $I_{S.E1} := 150.0 \dfrac{kN}{m}$ (Section 7.7, Design Criteria)

Static Ice load on Gates: $I_{G.E1} := 75 \dfrac{kN}{m}$ (Section 7.7, Design Criteria)

Ice Loading Unit Width on Structure: $W_{S.E1} := 2.00m$

Ice Loading Unit Width on Regulating Gate: $W_{rg.E1} := 0m$ (Input value for load case)

Ice Loading Unit Width on Guard Gate: $W_{gg.E1} := 0m$ (Input value for load case)

Total Ice Load on Structure: $I_{E1} := \left(I_{S.E1} \cdot W_{S.E1} + I_{G.E1} \cdot W_{rg.E1} + I_{G.E1} \cdot W_{gg.E1}\right) \cdot -1 = -300 \cdot kN$

Apply Ice load at: $I_{E1.loc} := \left(HW_{E1} - BOF_{elev} - 0.30m\right) = 11.00\,m$

$\Sigma H_{I.E1} := I_{E1} = -300 \cdot kN$

$\Sigma M_{I.E1} := I_{E1} \cdot I_{E1.loc} = -3300 \cdot kN \cdot m$

SEISMIC LOAD (NOT APPLICABLE FOR THIS LOAD CASE)

E1 CASE

SUMMARY OF LOADS	Loads	Moment Arm
Dead load of Concrete Structure:	$D_{conc} = 22438.7 \cdot kN$	$X_{conc.loc} = 9.35\,m$
Obermyer Gate Weight:	$D_{Gate} = 140.0 \cdot kN$	$X_{gate} = 9.50\,m$
HW Lateral Load on Pier:	$H_{hwp.E1} = -522.8 \cdot kN$	$H_{hwp.E1.loc} = 6.43\,m$
HW Lateral Load on Approach Slab:	$H_{hwas.E1} = -7275.1 \cdot kN$	$H_{hwas.E1.loc} = 0.71\,m$
HW Lateral Load on Regulating Gate:	$H_{hwrg.E1} = 0.0 \cdot kN$	$H_{hwrg.E1.loc} = 4.00\,m$
HW Lateral Load on Guard Gate:	$H_{hwgg.E1} = 0.0 \cdot kN$	$H_{hwgg.E1.loc} = 4.00\,m$
TW Lateral Load on Pier:	$H_{twp.E1} = 235.5 \cdot kN$	$H_{twp.E1.loc} = 5.63\,m$
TW Lateral Load on Pier Footing (including Key):	$H_{twgk.E1} = 5862.46 \cdot kN$	$H_{twgk.E1.loc} = 0.53\,m$
TW Lateral Load on Regulating Gate:	$H_{twrg.E1} = 0.0 \cdot kN$	$H_{twrg.E1.loc} = 4.00\,m$
TW Lateral Load on Guard Gate:	$H_{twgg.E1} = 0.0 \cdot kN$	$H_{twgg.E1.loc} = 4.00\,m$
Vertical HW Load on Approach Slab:	$H_{1.E1} = 7519.4 \cdot kN$	$H_{1.E1.loc} = 14.13\,m$
Vertical TW Load on Regulating Gate:	$H_{2.E1.rg} = 2796.3 \cdot kN$	$H_{2.E1.rg.loc} = 5.39\,m$
Vertical TW Load on Guard Gate:	$H_{2.E1.gg} = 2796.3 \cdot kN$	$H_{2.E1.gg.loc} = 5.39\,m$
Uplift:	$U_{E1} = -24173.8 \cdot kN$	$U_{E1.loc} = 9.86\,m$
Lateral Soil Load (driving):	$E_{act.E1} = -1732.5 \cdot kN$	$E_{act.E1.loc} = 0.00\,m$
Lateral Soil Load (resisting):	$E_{pass.E1} = 192.5 \cdot kN$	$E_{pass.E1.loc} = 0.67\,m$
Ice / Impact Load:	$I_{E1} = -300.0 \cdot kN$	$I_{E1.loc} = 11.00\,m$

STABILITY ASSESSMENT (SLIDNG, BEARING, FLOTATION AND OVERTURNING): E1 CASE

CHECK SLIDING ALONG HORIZONTAL PLANE THRU TOE, IGNORING BEDROCK MOBILIZED BY STRUCTURAL HEEL KEY, OR VOID BEHIND KEY

Sum of Vertical Forces:

$\Sigma V_{E1} := \Sigma V_{DL} + \Sigma V_{water.E1} = 11516.8 \cdot kN$

Sum of Horizontal Forces:

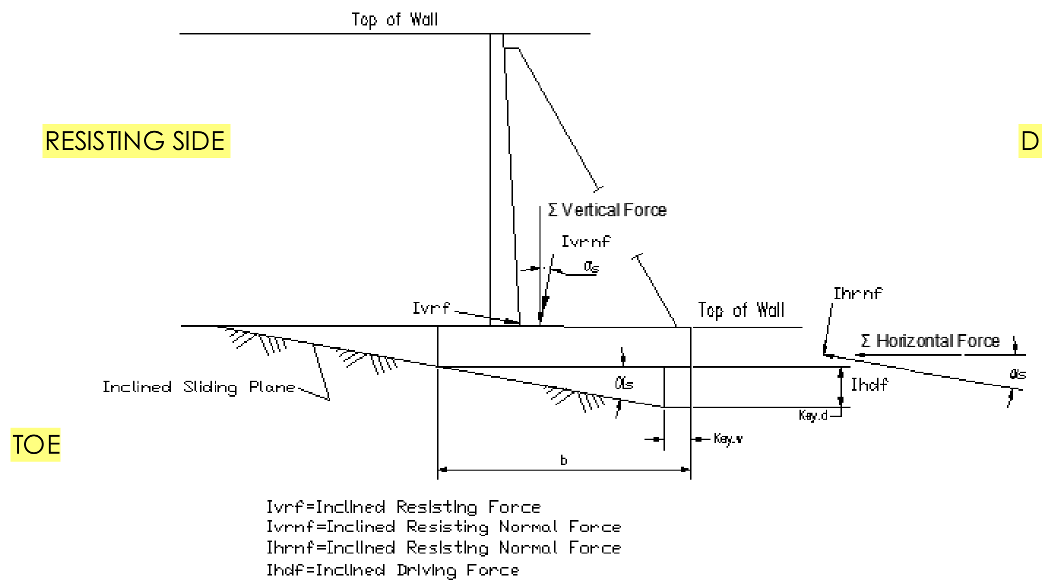
$\Sigma H_{E1} := \Sigma H_{Water.E1} + \Sigma H_{soil.E1} + \Sigma H_{I.E1} = -3539.87 \cdot kN$

Sliding Factor of Safety:

$$FS_{HorizSliding.E1} := \frac{\tan_{\phi} \cdot \Sigma V_{E1}}{\left|\Sigma H_{E1}\right|} = 1.59$$

$FS_{HorizSliding.E1.Check} :=$ | "OKAY" if $FS_{HorizSliding.E1} \geq FS_{req.E1.sl}$ = "OKAY"
"Check Inclined Sliding with Key" otherwise

CHECK SLIDING ALONG INCLINED SLIDING PLANE FROM HEEL KEY TO TOE, WITH BEDROCK MASS MOBILIZED BY REINFOCREDE CONCRETE KEY)



$\alpha s = 0.11$

as degrees= $\alpha s \cdot \left(\frac{180}{\pi}\right) = 6.52$

Resolve $\Sigma Vert_{E1}$ & $\Sigma Horiz_{E1}$

$\Sigma V_{InclinedE1} := \cos(\alpha s) \cdot \left(\Sigma V_{E1} + V_{rs}\right) + \sin(\alpha s) \cdot \left|\Sigma H_{E1}\right| = 16434.4 \cdot kN$

$\Sigma H_{InclinedE1} := \cos(\alpha s) \cdot \left|\Sigma H_{E1}\right| - \sin(\alpha s) \cdot \left(\Sigma V_{E1} + V_{rs}\right) = 1684.7 \cdot kN$

(With properly engineered reinforced concrete Key, horizontal sliding plane thru Toe is protected, critical sliding plane is relocated to the INCLINED SLIDING PLANE FROM HEEL KEY To TOE, Bedrock Mass above this examined plane is mobilized by reinforced concrete key and combined into Structural Wedge.)

Inclined Sliding Plane Length

$L_{incline} = 18.61 \, m$

Safety Factor for Sliding Inclined Failure Plane

$$FS_{InclinedISlidingE1} := \frac{\Sigma V_{InclinedE1} \cdot \tan\left(\phi_{rock} \cdot \frac{\pi}{180}\right)}{\left|\Sigma H_{InclinedE1}\right|} = 4.76$$

$FS_{InclinedSliding.check.E1} :=$ | "OKAY " if $FS_{InclinedISlidingE1} > FS_{req.E1.sl}$ = "OKAY "
"Revise Structure"" otherwise

$FS_{InclinedSliding.check.E1}$ = "OKAY "

E1 CASE

OVERTURNING STABILITY CHECK:

CHECK ECCENTRICITY

Sum of the moments:

$$\Sigma M_{E1} := \Sigma M_{DL} + \Sigma M_{Hwater.E1} + \Sigma M_{Vwater.E1} + \Sigma M_{I.E1} + \Sigma M_{soil.E1} + \Sigma M_{rs} = 155716 \cdot kN \cdot m$$

Eccentricity:

$$e_{E1} := \left(\frac{L_{incline}}{2}\right) - \frac{\left(\Sigma M_{E1}\right)}{\Sigma V_{InclinedE1}} = -0.17\,m$$

Eccentricity Check:

$$e_{check.E1} := \begin{cases} \text{"Okay"} & \text{if } \left|e_{E1}\right| \le Kern \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$$e_{check.E1} = \text{"Okay"}$$

Foundation Bearing Checks:

Bearing Pressure at Heel:

$$\sigma_{heel.E1} := \frac{\Sigma V_{InclinedE1}}{A_{b.incline}} - \frac{\left(\Sigma V_{InclinedE1} \cdot e_{E1}\right)}{S_{b.incline}} = 77.7 \cdot \frac{kN}{m^2}$$

$$\sigma_{heel.E1.check} := \left(\begin{cases} \text{"Okay"} & \text{if } \sigma_{heel.E1} \le \sigma_{allow.E1} \\ \text{"Revise Structure"} & \text{if } \sigma_{heel.E1} < 0\,\frac{kN}{m^2} \end{cases}\right)$$

$$\sigma_{heel.E1.check} = \text{"Okay"}$$

Bearing Pressure at Toe:

$$\sigma_{toe.E1} := \frac{\Sigma V_{InclinedE1}}{A_{b.incline}} + \frac{\left(\Sigma V_{InclinedE1} \cdot e_{E1}\right)}{S_{b.incline}} = 69.5 \cdot \frac{kN}{m^2}$$

$$\sigma_{toe.E1.1.check} := \begin{cases} \text{"Okay"} & \text{if } \sigma_{toe.E1} \le \sigma_{allow.E1} \\ \text{"Revise Structure"} & \text{if } \sigma_{toe.E1} < 0\,\frac{kN}{m^2} \end{cases}$$

$$\sigma_{toe.E1.1.check} = \text{"Okay"}$$

FLOATATION ANALYSIS:

ACCEPTANCE PARAMETERS

Required Factor of Safety: $FS_{req.FE1} := 1.1$

VERTICAL LOADS RESISTING:

Dead Load: $\Sigma V_{DL} = 22578.74 \cdot kN$

Water Weight H1+H2: $\Sigma V_{H.FE1} := H_{1.E1} + H_{2.E1.gg} + H_{2.E1.rg} = 13111.87 \cdot kN$

Summation Vertical Resisting: $\Sigma V_{FE1} := \Sigma V_{DL} + \Sigma V_{H.FE1} = 35690.6 \cdot kN$

VERTICAL LOADS UPLIFT:

Uplift: $U_{E1} = -24173.8 \cdot kN$

Factor of Safety Floatation:

$$FS_{act.FE1} := \frac{\Sigma V_{FE1}}{\left|U_{E1}\right|} = 1.48$$

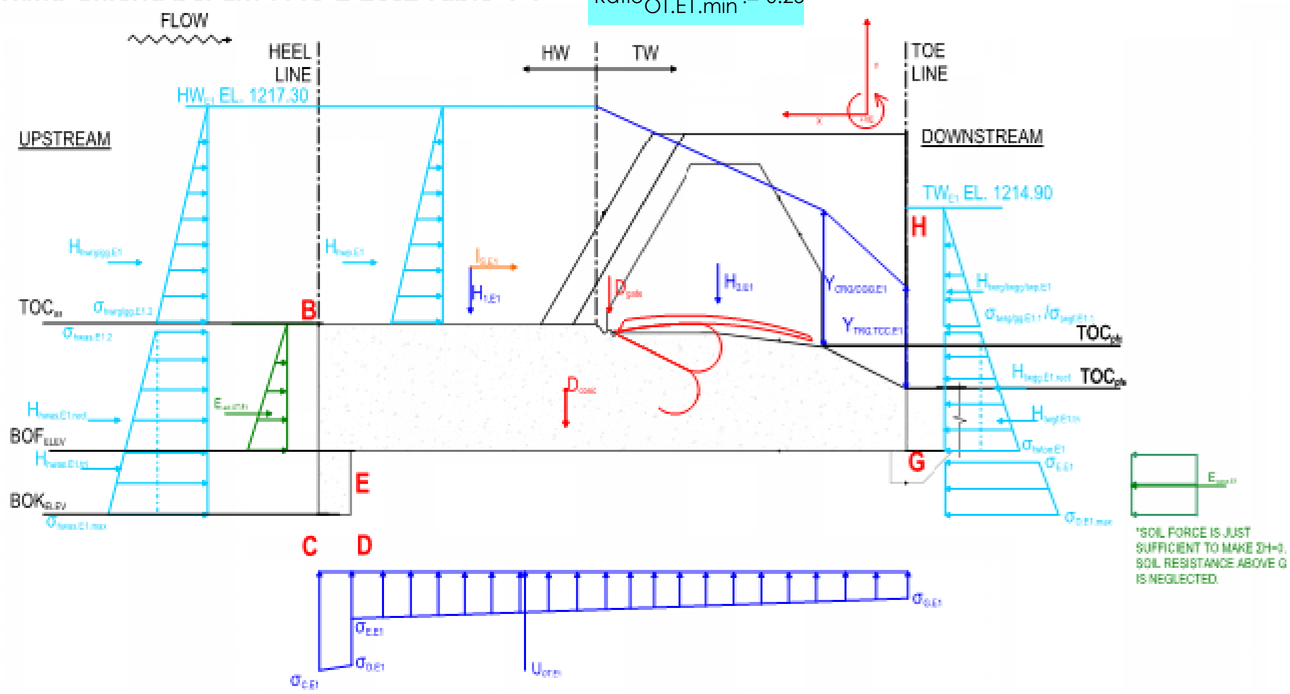
$$FS_{check.FE1} := \begin{cases} \text{"OKAY"} & \text{if } FS_{act.FE1} \ge FS_{req.FE1} \\ \text{"ANCHORS REQUIRED"} & \text{if } FS_{act.FE1} < FS_{req.FE1} \end{cases} = \text{"OKAY"}$$

MONOLITH OVERTURNING STABILITY ANALYSIS

E1 CASE

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.
Assumptions are made in order to compute overturning stability of indeterminate forces on monolith with key;
(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.
(b) The horizontal resisting force acting on the key, P.key, is that required for static equilibrium
(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1 $Ratio_{OT.E1.min} := 0.25$



Uplift Loads for Overturning Stability Analysis

Line of Creep:

Change in Water Head: $\Delta_{h.E1} := HW_{E1} - TW_{E1} = 2.4\,m$

Length from Point C to Point G: $L_{CG} = 18.61\,m$

Length from Various Points to Points: $L_{CD} = 1\,m$ $L_{DE} = 2\,m$ $L_{EG} = 17.5\,m$

$L_{GH.E1} := TW_{E1} - BOF_{elev} = 8.9\,m$

Length from Point C, D, E to G: $L_{CDEG} = 20.5\,m$ $L_{CDE} = 3\,m$

Water Pressure at Point C & G: $\sigma_{C.E1} := \sigma_{hwas.E1.2} = -130.47 \cdot kPa$ $\sigma_{G.E1} := \sigma_{twtoe.E1} \cdot -1 = -87.31 \cdot kPa$

Water Pressure at Point D:

$$\sigma_{D.E1} := -\gamma_w \cdot \left[\left(HW_{E1} - BOK_{elev}\right) - \frac{\Delta_{h.E1} \cdot L_{CD}}{L_{CDEG}}\right] = -129.32 \cdot kPa$$

Water Pressure at Point E:

$$\sigma_{E.E1} := -\gamma_w \cdot \left[\left(HW_{E1} - BOF_{elev}\right) - \frac{\Delta_{h.E1} \cdot L_{CDE}}{L_{CDEG}}\right] = -107.41 \cdot kPa$$

Uplift for Overturning Analysis on Bottom of Key:

$$U_{OT.E1.key} := \frac{\sigma_{C.E1} + \sigma_{D.E1}}{2} \cdot L_{CD} \cdot W_b = -1558.79 \cdot kN$$

Acting at:

$$U_{OT.E1.key.loc} := \frac{L_{CD} \cdot \left(2 \cdot \sigma_{C.E1} + \sigma_{D.E1}\right)}{3\left(\sigma_{C.E1} + \sigma_{D.E1}\right)} + L_{EG} = 18\,m$$

Uplift for Overturning Analysis on Bottom of Footing:

$$U_{OT.E1.ftg} := \frac{\sigma_{E.E1} + \sigma_{G.E1}}{2} \cdot L_{EG} \cdot W_b = -20445.24 \cdot kN$$

Acting at:

$$U_{OT.E1.ftg.loc} := \frac{L_{EG} \cdot \left(\sigma_{G.E1} + 2 \cdot \sigma_{E.E1}\right)}{3\left(\sigma_{G.E1} + \sigma_{E.E1}\right)} = 9.05\,m$$

E1 CASE

Uplift Load for Overturning Analysis: $U_{OT.E1} := U_{OT.E1.key} + U_{OT.E1.ftg} = -22004.02 \cdot kN$

Uplift Load Acting from Toe: $U_{OT.E1.loc} := \dfrac{U_{OT.E1.key} \cdot U_{OT.E1.key.loc} + U_{OT.E1.ftg} \cdot U_{OT.E1.ftg.loc}}{U_{OT.E1}} = 9.69\,m$

All Vertical Loads Applicable to Overturning Stability Analysis

		at:	
Total Concrete Dead Loads:	$D_{conc} = 22438.74 \cdot kN$		$X_{conc.loc} = 9.35\,m$
Dead Load of Gate:	$D_{Gate} = 140.0 \cdot kN$		$X_{gate} = 9.50\,m$
Water Weight (HW) on Apron Slab:	$H_{1.E1} = 7519.4 \cdot kN$		$H_{1.E1.loc} = 14.13\,m$
Water Weight (TW) on Gate Footing:	$H_{2.E1.rg} = 2796.3 \cdot kN$		$H_{2.E1.rg.loc} = 5.39\,m$
Water Weight (TW) on Regulating Gate Footing:	$H_{2.E1.gg} = 2796.3 \cdot kN$		$H_{2.E1.gg.loc} = 5.39\,m$
Uplift Load for Overturning Analysis:	$U_{OT.E1} = -22004.02 \cdot kN$		$U_{OT.E1.loc} = 9.69 \cdot m$

Sum of All Overturning Analysis Vertical Load:

$$\Sigma V_{E1.OT} := D_{conc} + D_{Gate} + H_{1.E1} + H_{2.E1.rg} + H_{2.E1.gg} + U_{OT.E1} = 13686.59 \cdot kN$$

Sum of All Overturning Analysis Vertical Load Moments:

$$\Sigma M_{V.E1.OT} := D_{conc} \cdot X_{conc.loc} + D_{Gate} \cdot X_{gate} + H_{1.E1} \cdot H_{1.E1.loc} + H_{2.E1.rg} \cdot H_{2.E1.rg.loc} \cdots + H_{2.E1.gg} \cdot H_{2.E1.gg.loc} + U_{OT.E1} \cdot U_{OT.E1.loc} = 134365.91 \cdot kN \cdot m$$

Lateral Tailwater Loads for Overturning Stability Analysis

TW Lateral Load on Gate Footing (No Key - Overturning Values Adjusted): $H_{twgf.E1} := H_{twgf.E1.tri} + H_{twgf.E1.rect} = 3249.07 \cdot kN$

Acting at: $H_{twgf.E1.loc} := \dfrac{\frac{h_{toe}}{3} \cdot H_{twgf.E1.tri} + \frac{h_{toe}}{2} \cdot H_{twgf.E1.rect}}{H_{twgf.E1}} = 1.81\,m$

Horizontal Tailwater Pressure Top of Key (Overturning Analysis): $\sigma_{twtk.OT.E1} := \sigma_{E.E1} \cdot -1 = 107.41 \cdot kPa$

Horizontal Tailwater Pressure Bottom of Key (Overturning Analysis): $\sigma_{twbk.OT.E1} := \sigma_{D.E1} \cdot -1 = 129.32 \cdot kPa$

Triangular Distribution Unit Load Acting at Key: $H_{twbk.OT.E1.tri} := \dfrac{(\sigma_{twbk.OT.E1} - \sigma_{twtk.OT.E1})}{2} \cdot d_{key} \cdot W_{tw.E1} = 263 \cdot kN$

Triangular Distribution Unit Load Acting at Key: $H_{twbk.OT.E1.rect} := \sigma_{twtk.OT.E1} \cdot d_{key} \cdot W_{tw.E1} = 2577.78 \cdot kN$

Total Horizontal Tailwater Load on Key (Overturning Values Adjusted): $H_{twkey.OT.E1} := H_{twbk.OT.E1.tri} + H_{twbk.OT.E1.rect} = 2840.78 \cdot kN$

Acting at: $H_{twkey.OT.E1.loc} := \dfrac{H_{twbk.OT.E1.tri} \cdot \frac{-2 \cdot d_{key}}{3} + H_{twbk.OT.E1.rect} \cdot \frac{-d_{key}}{2}}{H_{twkey.OT.E1}} = -1.03 \cdot m$

Lateral Driving Earth Loads for Overturning Stability Analysis (at rest condition)

Depth of Driving Soil Loads (to top of key): $h_{E.OT.E1} := TOC_{as} - BOF_{elev} = 4\,m$

At-Rest Soil Load: $E_{act.OT.E1} := \dfrac{(K_{o.E1} \cdot h_{E.OT.E1}{}^2)}{2} \cdot (\gamma_r - \gamma_w) \cdot W_{hwas.E1} \cdot -1 = -769.99 \cdot kN$

At Rest- Soil Load Acting from Toe: $E_{act.OT.E1.loc} := \dfrac{h_{E.OT.E1}}{3} = 1.33\,m$

All Lateral Loads Applicable to Overturning Stability Analysis

HW Lateral Load on Approach Slab:	$H_{hwas.E1} = -7275.1 \cdot kN$	$H_{hwas.E1.loc} = 0.71\,m$
HW Lateral Load on Regulating Gate:	$H_{hwrg.E1} = 0.0 \cdot kN$	$H_{hwrg.E1.loc} = 4.00\,m$
HW Lateral Load on Guard Gate:	$H_{hwgg.E1} = 0.0 \cdot kN$	$H_{hwgg.E1.loc} = 4.00\,m$
TW Lateral Load on Regulating Gate:	$H_{twrg.E1} = 0.0 \cdot kN$	$H_{twrg.E1.loc} = 4.00\,m$
HW Lateral Load on Guard Gate:	$H_{twgg.E1} = 0.0 \cdot kN$	$H_{twgg.E1.loc} = 4.00\,m$
TW Lateral Load on Gate Footing (No Key - Overturning Values Adjusted):	$H_{twgf.E1} = 3249.07 \cdot kN$	$H_{twgf.E1.loc} = 1.81\,m$
TW Lateral Load on Key:	$H_{twkey.OT.E1} = 2840.78 \cdot kN$	$H_{twkey.OT.E1.loc} = -1.03\,m$
Ice / Impact Load:	$I_{E1} = -300.0 \cdot kN$	$I_{E1.loc} = 11.00\,m$
Lateral Soil Load (driving):	$E_{act.OT.E1} = -770.0 \cdot kN$	$E_{act.OT.E1.loc} = 1.33\,m$

Resisting Lateral Soil Load as required to produce horizontal equilibrium:

$$E_{pas.OT.E1} := -\left(H_{hwas.E1} + H_{hwrg.E1} + H_{hwgg.E1} + H_{twrg.E1} + H_{twgg.E1} \cdots + H_{twgf.E1} + H_{twkey.OT.E1} + I_{E1} + E_{act.OT.E1}\right) = 2255.23 \cdot kN$$

$$E_{pas.OT.E1.loc} := -1 \cdot \frac{d_{key}}{2} = -1\,m$$

Sum of All Overturning Analysis Horizontal Load (ΣH=0):

$$\Sigma H_{E1.OT} := H_{hwas.E1} + H_{hwrg.E1} + H_{hwgg.E1} + H_{twrg.E1} + H_{twgg.E1} \cdots + H_{twgf.E1} + H_{twkey.OT.E1} + I_{E1} + E_{act.OT.E1} + E_{pas.OT.E1} = 0 \cdot kN$$

Sum of All Overturning Analysis Horizontal Load Moments:

$$\Sigma M_{H.E1.OT} := H_{hwas.E1} \cdot H_{hwas.E1.loc} + H_{hwrg.E1} \cdot H_{hwrg.E1.loc} + H_{hwgg.E1} \cdot H_{hwgg.E1.loc} \cdots + H_{twrg.E1} \cdot H_{twrg.E1.loc} + H_{twgg.E1} \cdot H_{twgg.E1.loc} + H_{twgf.E1} \cdot H_{twgf.E1.loc} \cdots + H_{twkey.OT.E1} \cdot H_{twkey.OT.E1.loc} + I_{E1} \cdot I_{E1.loc} + E_{act.OT.E1} \cdot E_{act.OT.E1.loc} \cdots + E_{pas.OT.E1} \cdot E_{pas.OT.E1.loc} = -8796.18 \cdot kN \cdot m$$

Overturning Stability Analysis

$$\Sigma M_{E1.OT} := \Sigma M_{V.E1.OT} + \Sigma M_{H.E1.OT} = 125569.74 \cdot kN \cdot m$$

$$X_{R.E1} := \frac{\Sigma M_{E1.OT}}{\Sigma V_{E1.OT}} = 9.17\,m \qquad x_{OT.E1} := X_{R.E1} - \frac{L_b}{2} = -0.08\,m$$

Overturning Resultant Ratio

$$Ratio_{OT.E1} := \frac{X_{R.E1}}{L_b} = 0.5$$

$$Ratio_{OT.E1.check} := \begin{cases} \text{"OKAY"} & \text{if } Ratio_{OT.E1} \geq Ratio_{OT.E1.min} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

$$x_{OT.check.E1} := \begin{cases} \text{"OKAY"} & \text{if } \left|x_{OT.E1}\right| \leq Kern \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

E1 CASE

CHECK FOUNDATION BEARING CAPACITY (HORIZONTAL PLANE):

Bearing Pressure Under Toe:

$$\sigma_{ToeE1.OT} := \frac{\Sigma V_{E1.OT}}{L_b \cdot W_b} + \frac{\left(\Sigma V_{E1.OT} \cdot x_{OT.E1}\right)}{S_b} = 60.1 \cdot kPa$$

$$Bearing_{CheckToeE1.OT} := \begin{cases} \text{"OKAY"} & \text{if } \sigma_{ToeE1.OT} < \sigma_{allow.E1} \\ \text{"NG"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

Bearing Pressure Under Heel:

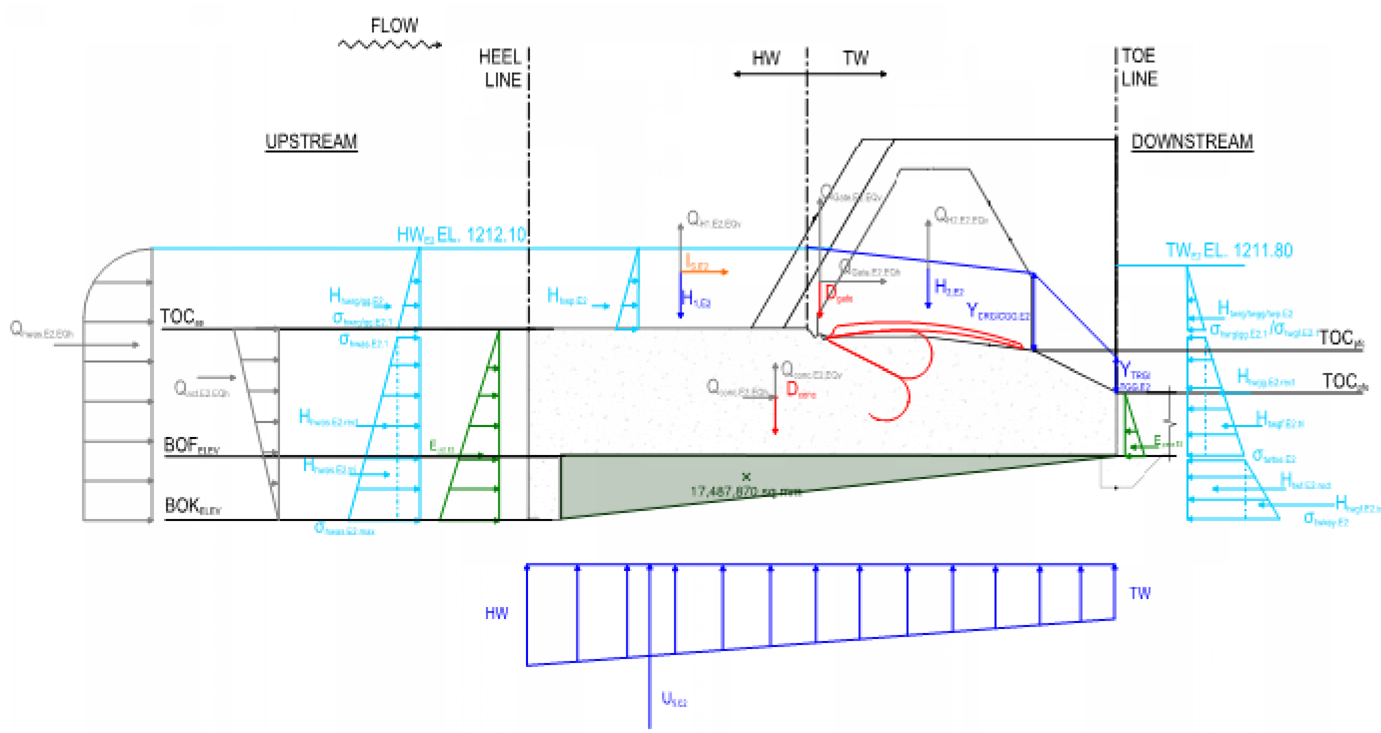
$$\sigma_{HeelE1.OT} := \frac{\Sigma V_{E1.OT}}{L_b \cdot W_b} - \frac{\left(\Sigma V_{E1.OT} \cdot x_{OT.E1}\right)}{S_b} = 63.2 \cdot kPa$$

$$Bearing_{CheckheelE1.OT} := \left(\begin{cases} \text{"OKAY"} & \text{if } \sigma_{HeelE1.OT} < \sigma_{allow.E1} \wedge \sigma_{HeelE1.OT} > 0 \\ \text{"NG"} & \text{otherwise} \end{cases} \right) = \text{"OKAY"}$$

SUMMARY OF STABILITY ASSESSMENT:

Sliding Factor of Safety: (Horizontal Plane)	$FS_{HorizSliding.E1} = 1.59$	$FS_{HorizSliding.E1.Check} = \text{"OKAY"}$
Sliding Factor of Safety: (Inclined Plane)	$FS_{InclinedlSlidingE1} = 4.76$	$FS_{InclinedSliding.check.E1} = \text{"OKAY"}$
Eccentricity: (Inclined Plane)	$e_{E1} = -0.17\,m$	$e_{check.E1} = \text{"Okay"}$
Bearing Pressure At Heel: (Inclined Plane)	$\sigma_{heel.E1} = 78 \cdot kPa$	$\sigma_{heel.E1.check} = \text{"Okay"}$
Bearing Pressure At Toe: (Inclined Plane)	$\sigma_{toe.E1} = 70 \cdot kPa$	$\sigma_{toe.E1.1.check} = \text{"Okay"}$
Flotation Factor of Safety (horizontal plane)	$FS_{act.FE1} = 1.48$	$FS_{check.FE1} = \text{"OKAY"}$
Overturning Resultant Ratio: (horizontal plane)	$Ratio_{OT.E1} = 0.5$	$Ratio_{OT.E1.check} = \text{"OKAY"}$
Eccentricity: (horizontal plane)	$x_{OT.E1} = -0.08\,m$	$x_{OT.check.E1} = \text{"OKAY"}$
Bearing Pressure At Heel: (horizontal plane)	$\sigma_{HeelE1.OT} = 63 \cdot kPa$	$Bearing_{CheckheelE1.OT} = \text{"OKAY"}$
Bearing Pressure At Toe: (horizontal plane)	$\sigma_{ToeE1.OT} = 60 \cdot kPa$	$Bearing_{ChecktoeE1.OT} = \text{"OKAY"}$

E2 DESIGN CASE



U1 CASE PLUS SEISMIC

ACCEPTANCE PARAMETERS

Required Factor of Safety for Sliding: $FS_{req.E2.sl} := 1.0$ (Without Cohesion)

(Section 8.1, Design Criteria)

Resultant Within Middle Half of Base: $e \le \frac{L_b}{4} \wedge e \ge \frac{-L_b}{4}$

Allowable Rock Bearing Pressure: $\sigma_{allow.E2} := 1740 \cdot \frac{kN}{m^2}$ (Section 5.2, Design Criteria)

INPUT PARAMETERS

Headwater Elevation: $HW_{E2} := 1212.10m$ (Section 8.3, Design Criteria)

Tailwater Elevation: $TW_{E2} := 1211.80m$ (Section 8.3, Design Criteria)

Bottom of Footing Elevation: $BOF_{elev} = 1206.00\,m$

Approach Slab Top of Concrete Elevation at Upstream Face: $TOC_{as} = 1210.00\,m$

Pier Footing Top of Concrete Elevation at Stilling Basin: $TOC_{pfe} = 1208.00\,m$

Pier Footing Top of Concrete Elevation at Center of Footing: $TOC_{pfc} = 1209.30\,m$

Top of Regulating Gate Elevation: $TOP_{rg.U1} = 1210.00\,m$

Gates are open when top of gate elevation is at 1210.00m

Top of Guard Gate Elevation: $TOP_{gg.U1} = 1210.00\,m$

Gates are closed/up when top of gate elevation is at 1215.0m

Bottom of Key Elevation: $BOK_{elev} = 1204\,m$

SEISMIC LOAD (Three combinations of E_h and E_v considered)

E2.1 CASE

Seismic Case $Q_{E2.1}$ - 100% Horizontal Seismic Force, No Vertical

Include Seismic Load in Analysis? $Eq_{E2.1} := 1$ 0 = No, 1 = Yes

Horizontal Seismic Coefficient: $K_{h.E2.1} := -0.17$

Vertical Seismic Coefficient: $K_{v.E2.1} := -0.00$

Vertical Tailwater on Approach Slab: $H_{2.U1} := H_{2.U1.gg} + H_{2.U1.rg} = 1799.45 \cdot kN$

Acting At: $H_{2.U1.loc} := \dfrac{H_{2.U1.gg} \cdot H_{2.U1.gg.loc} + H_{2.U1.rg} \cdot H_{2.U1.rg.loc}}{H_{2.U1}} = 5.34 \cdot m$

HORIZONTAL SEISMIC LOADS	**Loads**	**Moment Arm**
Horiz Seismic Component of Concrete:	$Q_{conc.E2.EQh.1} := D_{conc} \cdot K_{h.E2.1} \cdot Eq_{E2.1} = -3814.6 \cdot kN$	$Y_{conc.loc} = 2.43\,m$
Horiz Seismic Component of Gates:	$Q_{Gate.E2.EQh.1} := D_{Gate} \cdot K_{h.E2.1} \cdot Eq_{E2.1} = -23.8 \cdot kN$	$Y_{gate} = 3.90\,m$
Horizontal Seismic Component of Headwater - Sliding:	$Q_{hwas.E2.EQh.1} := \left(\frac{7}{12}\right) \cdot K_{h.E2.1} \cdot \gamma_w \cdot \left(HW_{U1} - BOK_{elev}\right)^2 \cdot W_{hwas.U1} \cdot Eq_{E2.1} = -765.9 \cdot kN$	$Y_{HWg.E2} := 0.4 \cdot \left(HW_{U1} - BOK_{elev}\right) - d_{key} = 1.24\,m$
Horizontal Seismic Component of Soil (Woods Method) - Overturning:	$Q_{act.E2.EQh.1.OT} := \left(\gamma_r - \gamma_w\right) \cdot \left(TOC_{as} - BOK_{elev}\right)^2 \cdot K_{h.E2.1} \cdot W_{hwas.U1} \cdot Eq_{E2.1} = -895.2 \cdot kN$	$Y_{E.act.E2.OT} := 0.63 \cdot \left(TOC_{as} - BOK_{elev}\right) - d_{key} = 1.78\,m$
Horizontal Seismic Component of Soil (Woods Method)	$Q_{act.E2.EQh.1} := \left(\gamma_r - \gamma_w\right) \cdot \left(TOC_{as} - BOF_{elev}\right)^2 \cdot K_{h.E2.1} \cdot W_{hwas.U1} \cdot Eq_{E2.1} = -397.9 \cdot kN$	$Y_{E.act.E2} := 0.63 \cdot \left(TOC_{as} - BOF_{elev}\right) = 2.52\,m$

VERTICAL SEISMIC LOADS	**Loads**	**Moment Arm**
Vertical Component of Concrete:	$Q_{conc.E2.EQv.1} := D_{conc} \cdot K_{v.E2.1} \cdot Eq_{E2.1} = 0.0 \cdot kN$	$X_{conc.loc} = 9.35\,m$
Vertical Component of Gate:	$Q_{Gate.E2.EQv.1} := D_{Gate} \cdot K_{v.E2.1} \cdot Eq_{E2.1} = 0.0 \cdot kN$	$X_{gate} = 9.50\,m$
Vertical Seismic Component of Headwater over Apron Slab:	$Q_{H1.E2.EQv.1} := K_{v.E2.1} \cdot H_{1.U1} \cdot Eq_{E2.1} = 0.0 \cdot kN$	$H_{1.U1.loc} = 14.13\,m$
Vertical Seismic Component of Tailwater over Pier Footing:	$Q_{H2.E2.EQv.1} := K_{v.E2.1} \cdot H_{2.U1} \cdot Eq_{E2.1} = 0.0 \cdot kN$	$H_{2.U1.loc} = 5.34\,m$

$$\Sigma H_{Q.E2.EQh.1} := Q_{conc.E2.EQh.1} + Q_{Gate.E2.EQh.1} + Q_{hwas.E2.EQh.1} + Q_{act.E2.EQh.1} = -5002.19 \cdot kN$$

$$\Sigma H_{Q.E2.EQh.1.OT} := Q_{conc.E2.EQh.1} + Q_{Gate.E2.EQh.1} + Q_{hwas.E2.EQh.1} + Q_{act.E2.EQh.1.OT} = -5499.54 \cdot kN$$

$$\Sigma V_{Q.E2.EQv.1} := Q_{conc.E2.EQv.1} + Q_{Gate.E2.EQv.1} + Q_{H1.E2.EQv.1} + Q_{H2.E2.EQv.1} = 0.0 \cdot kN$$

$$\begin{aligned}\Sigma M_{Q.E2.1} := {} & Q_{conc.E2.EQh.1} \cdot Y_{conc.loc} + Q_{Gate.E2.EQh.1} \cdot Y_{gate} + Q_{hwas.E2.EQh.1} \cdot Y_{HWg.E2} \cdots \\ & + Q_{act.E2.EQh.1.OT} \cdot Y_{E.act.E2.OT} + Q_{conc.E2.EQv.1} \cdot X_{conc.loc} + Q_{Gate.E2.EQv.1} \cdot X_{gate} \cdots \\ & + Q_{H1.E2.EQv.1} \cdot H_{1.U1.loc} + Q_{H2.E2.EQv.1} \cdot H_{2.U1.loc} \end{aligned} = -11900.17 \cdot kN \cdot m$$

STABILITY ASSESSMENT (SLIDNG, BEARING, FLOTATION AND OVERTURNING):

E2.1 CASE

CHECK SLIDING ALONG HORIZONTAL PLANE THRU TOE,
IGNORING BEDROCK MOBILIZED BY STRUCTURAL HEEL KEY, OR VOID BEHIND KEY

Sum of Vertical Forces:

$\Sigma V_{E2.1} := \Sigma V_{U1} + \Sigma V_{Q.E2.EQv.1} = 11405.4 \cdot kN$

Sum of Horizontal Forces:

$\Sigma H_{E2.1} := \Sigma H_{U1} - I_{U1} + \Sigma H_{Q.E2.EQh.1} = -6730.24 \cdot kN$

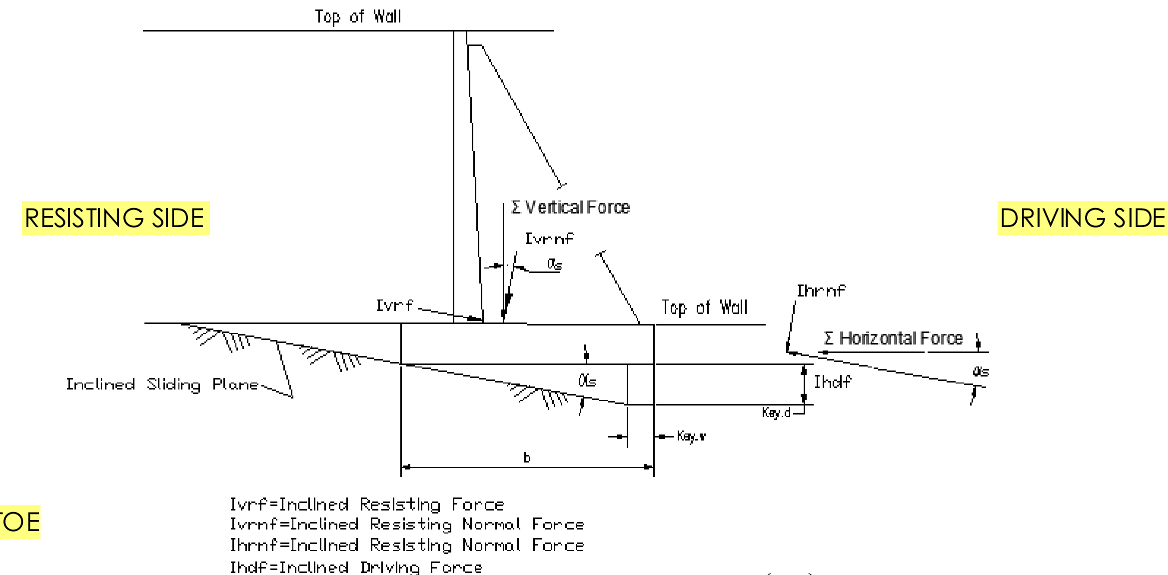
Sliding Factor of Safety:

$$FS_{HorizSliding.E2.1} := \frac{\tan_{\phi} \cdot \Sigma V_{E2.1}}{\left|\Sigma H_{E2.1}\right|} = 0.83$$

$FS_{HorizSliding.E2.1.Check} :=$ "OKAY" if $FS_{HorizSliding.E2.1} \geq FS_{req.E2.sl}$ = "Horizontal Sliding (No Key or Void Behin

"Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !" otherwise

CHECK SLIDING ALONG INCLINED SLIDING PLANE FROM HEEL KEY TO TOE,
WITH BEDROCK MASS MOBILIZED BY REINFOCREDE CONCRETE KEY)



$\alpha s = 0.11$

as degrees= $\alpha s \cdot \left(\frac{180}{\pi}\right) = 6.52$

$V_{rs} = 4620 \cdot kN$

Resolve $\Sigma Vert_{E2.1}$ & $\Sigma Horiz_{E2.1}$

$$\Sigma V_{InclinedE2.1} := \cos(\alpha s) \cdot \left(\Sigma V_{E2.1} + V_{rs}\right) + \sin(\alpha s) \cdot \left|\Sigma H_{E2.1}\right| = 16686.0 \cdot kN$$

$$\Sigma H_{InclinedE2.1} := \cos(\alpha s) \cdot \left|\Sigma H_{E2.1}\right| - \sin(\alpha s) \cdot \left(\Sigma V_{E2.1} + V_{rs}\right) = 4867.1 \cdot kN$$

Inclined Sliding Plane Length

$L_{incline} = 18.61\ m$

Safety Factor for Sliding
Inclined Failure Plane

$$FS_{InclinedlSlidingE2.1} := \frac{\Sigma V_{InclinedE2.1} \cdot \tan\left(\phi_{rock} \cdot \frac{\pi}{180}\right)}{\left|\Sigma H_{InclinedE2.1}\right|} = 1.67$$

$FS_{InclinedSliding.check.E2.1} :=$ "OKAY " if $FS_{InclinedlSlidingE2.1} > FS_{req.E2.sl}$ = "OKAY "

"Revise Structure"" otherwise

$FS_{InclinedSliding.check.E2.1} =$ "OKAY "

OVERTURNING STABILITY CHECK:

E2.1 CASE

CHECK ECCENTRICITY

Sum of the moments:

$$\Sigma M_{E2.1} := \left(\Sigma M_{U1} + \Sigma M_{Q.E3.1}\right) = 141639 \cdot kN \cdot m$$

Eccentricity:

$$e_{E2.1} := \left(\frac{L_{incline}}{2}\right) - \frac{\left(\Sigma M_{E2.1}\right)}{\Sigma V_{InclinedE2.1}} = 0.82\,m$$

Eccentricity Check:

$$e_{check.E2.1} := \begin{cases} \text{"Okay"} & \text{if } e_{E2.1} \le Kern \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$$e_{check.E2.1} = \text{"Okay"}$$

Foundation Bearing Checks:

Bearing Pressure at Heel:

$$\sigma_{heel.E2.1} := \frac{\Sigma V_{InclinedE2.1}}{A_{b.incline}} - \frac{\left(\Sigma V_{InclinedE2.1} \cdot e_{E2.1}\right)}{S_{b.incline}} = 55.1 \cdot \frac{kN}{m^2}$$

$$\sigma_{heel.E2.1.check} := \left(\begin{cases} \text{"Okay"} & \text{if } \sigma_{heel.E2.1} \le \sigma_{allow.E2} \\ \text{"Revise Structure"} & \text{if } \sigma_{heel.E2.1} < 0\,\frac{kN}{m^2} \end{cases}\right)$$

$$\sigma_{heel.E2.1.check} = \text{"Okay"}$$

Bearing Pressure at Toe:

$$\sigma_{toe.E2.1} := \frac{\Sigma V_{InclinedE2.1}}{A_{b.incline}} + \frac{\left(\Sigma V_{InclinedE2.1} \cdot e_{E2.1}\right)}{S_{b.incline}} = 94.4 \cdot \frac{kN}{m^2}$$

$$\sigma_{toe.E2.1.check.1} := \begin{cases} \text{"Okay"} & \text{if } \sigma_{toe.E2.1} \le \sigma_{allow.E2} \\ \text{"Revise Structure"} & \text{if } \sigma_{toe.E2.1} < 0\,\frac{kN}{m^2} \end{cases}$$

$$\sigma_{toe.E2.1.check.1} = \text{"Okay"}$$

FLOATATION ANALYSIS:

ACCEPTANCE PARAMETERS

Required Factor of Safety: $FS_{req.FE2.1} := 1.1$

VERTICAL LOADS RESISTING:

$\Sigma V_{DL} = 22578.74 \cdot kN$

Dead Load:

Water Weight H1+H2: $\Sigma V_{H.FE2.1} := \Sigma V_{H.FU1} + \Sigma V_{Q.E2.EQv.1} = 3962.55 \cdot kN$

Summation Vertical Resisting: $\Sigma V_{FE2.1} := \Sigma V_{DL} + \Sigma V_{H.FE2.1} = 26541.3 \cdot kN$

VERTICAL LOADS UPLIFT:

Uplift: $U_{U1} = -15135.85 \cdot kN$

Factor of Safety Floatation:

$$FS_{act.FE2.1} := \frac{\Sigma V_{FE2.1}}{\left|U_{U1}\right|} = 1.75$$

$$FS_{check.FE2.1} := \begin{cases} \text{"OKAY"} & \text{if } FS_{act.FE2.1} \ge FS_{req.FE2.1} \\ \text{"ANCHORS REQUIRED"} & \text{if } FS_{act.FE2.1} < FS_{req.FE2.1} \end{cases} = \text{"OKAY"}$$

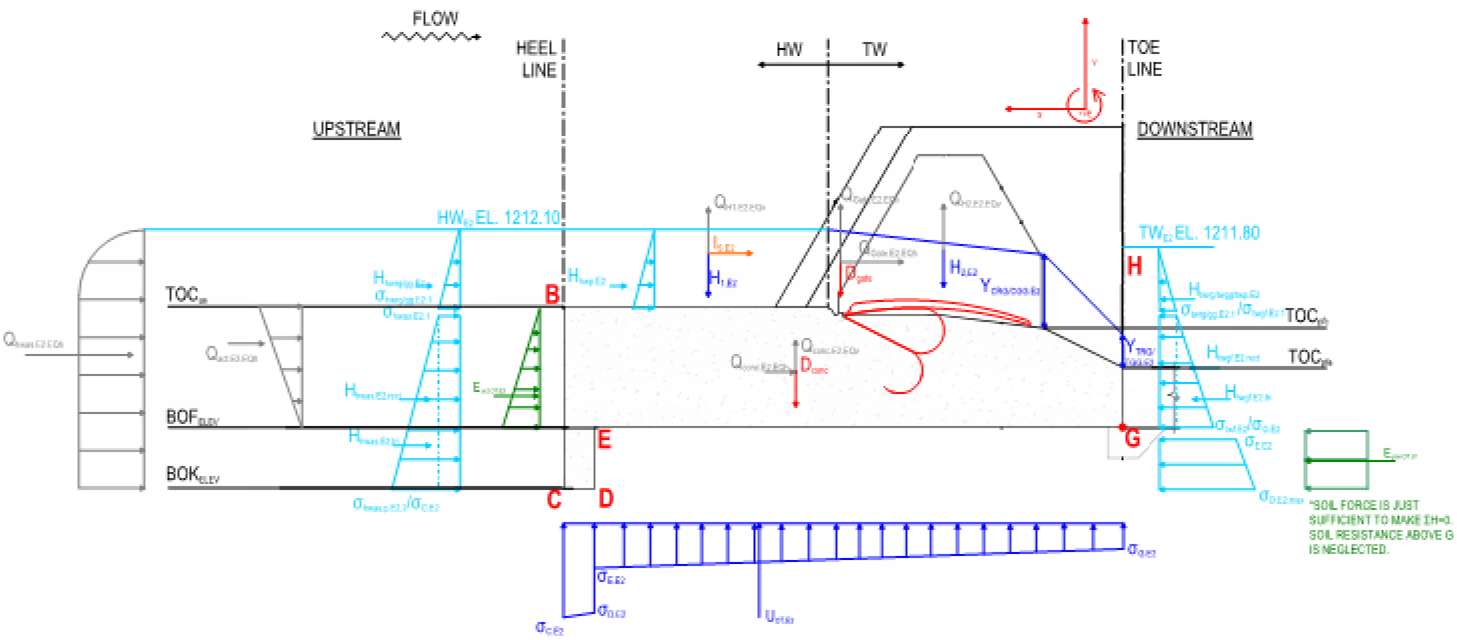
E2.1 CASE

MONOLITH OVERTURNING STABILITY ANALYSIS

Seismic Case $Q_{E2.1}$: 100% Horizontal Seismic Force, No Vertical

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.
Assumptions are made in order to compute overturning stability of indetermine forces on monolith with key;
(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.
(b) The horizontal resisting force acting on the key, P.key, is that required for static equilibrium
(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1 $Ratio_{overturning.allow.Extreme} := 0.0$ Resultant within Base



<u>All Vertical Loads Applicable to Overturning Stability Analysis</u>

		at:	
Total Concrete Dead Loads:	$D_{conc} = 22438.74 \cdot kN$		$X_{conc.loc} = 9.35\,m$
Dead Load of Gate:	$D_{Gate} = 140.0 \cdot kN$		$X_{gate} = 9.50\,m$
Water Weight (HW) on Apron Slab:	$H_{1.U1} = 2163.1 \cdot kN$		$H_{1.U1.loc} = 14.13\,m$
Water Weight (TW) on Gate Footing:	$H_{2.U1} = 1799.4 \cdot kN$		$H_{2.U1.loc} = 5.34\,m$
Uplift Load for Overturning Analysis:	$U_{OT.U1} = -13165.04 \cdot kN$		$U_{OT.U1.loc} = 9.48 \cdot m$
Vertical Seismic Component of Concrete Structure:	$Q_{conc.E2.EQv.1} = 0$		$X_{conc.loc} = 9.35\,m$
Vertical Seismic Component of Crest Gate:	$Q_{Gate.E2.EQv.1} = 0$		$X_{gate} = 9.50\,m$
Vertical Seismic Component of Headwater over Apron Slab:	$Q_{H1.E2.EQv.1} = 0$		$H_{1.U1.loc} = 14.13\,m$
Vertical Seismic Component of Headwater over Fixed Crest Slab:	$Q_{H2.E2.EQv.1} = 0$		$H_{2.U1.loc} = 5.34\,m$

Sum of All Overturning Analysis Vertical Load:

$$\Sigma V_{E2.OT.1} := D_{conc} + D_{Gate} + H_{1.U1} + H_{2.U1} + U_{OT.U1} + \Sigma V_{Q.E2.EQv.1} = 13376.25 \cdot kN$$

Sum of All Overturning Analysis Vertical Load Moments:

$$\Sigma M_{V.E2.OT.1} := D_{conc} \cdot X_{conc.loc} + D_{Gate} \cdot X_{gate} + H_{1.U1} \cdot H_{1.U1.loc} + H_{2.U1} \cdot H_{2.U1.loc} + U_{OT.U1} \cdot U_{OT.U1.loc} = 126508.58 \cdot kN \cdot m$$

Lateral Driving Earth Loads for Overturning Stability Analysis (at rest condition)

E2.1 CASE

Depth of Driving Soil Loads (to top of key): $h_{E.OT.E2.1} := TOC_{as} - BOF_{elev} = 4\,m$

Applicable Soil Load: $E_{act.OT.E2.1} := \frac{\left(K_{o.U1} \cdot h_{E.OT.U1}^{\ 2}\right)}{2} \cdot \left(\gamma_r - \gamma_w\right) \cdot W_{hwas.U1} \cdot -1 = -769.99 \cdot kN$

At Rest- Soil Load Acting from Toe: $E_{act.OT.E2.1.loc} := \frac{h_{E.OT.U1}}{3} = 1.33\,m$

All Lateral Loads Applicable to Overturning Stability Analysis

HW Lateral Load on Approach Slab:	$H_{hwas.U1} = -3602.2 \cdot kN$	$H_{hwas.U1.loc} = 0.41\,m$
HW Lateral Load on Guard Gate:	$H_{hwgg.U1} = 0.0 \cdot kN$	$H_{hwgg.U1.loc} = 4.00\,m$
TW Lateral Load on Guard Gate:	$H_{twgg.U1} = 0.0 \cdot kN$	$H_{twgg.U1.loc} = 4.00\,m$
TW Lateral Load on Gate Footing (No Key - Overturning Values Adjusted):	$H_{twgf.U1} = 1789.34 \cdot kN$	$H_{twgf.U1.loc} = 1.65\,m$
TW Lateral Load on Key:	$H_{twkey.OT.U1} = 1664.73 \cdot kN$	$H_{twkey.OT.U1.loc} = -1.05\,m$
Ice / Impact Load:	$I_{U1} = -300.0 \cdot kN$	$I_{U1.loc} = 5.80\,m$
Lateral Soil Load (driving):	$E_{act.OT.U1} = -770.0 \cdot kN$	$E_{act.OT.U1.loc} = 1.33\,m$
Horizontal Seismic Component of Concrete Structure:	$Q_{conc.E2.EQh.1} = -3814.59 \cdot kN$	$Y_{conc.loc} = 2.43\,m$
Horizontal Seismic Component of Vertical Lift Gate:	$Q_{Gate.E2.EQh.1} = -23.8 \cdot kN$	$Y_{gate} = 3.90\,m$
Horizontal Seismic Component of Headwater on Slab Footing:	$Q_{hwas.E2.EQh.1} = -765.92 \cdot kN$	$Y_{HWg.E2} = 1.24\,m$
Horizontal Seismic Component of Active Soil: (Section 5-5, USACE EM_1110-2-2100)	$Q_{act.E2.EQh.1} = -397.88 \cdot kN$	$Y_{E.act.E2} = 2.52\,m$

Resisting Lateral Soil Load as required to produce horizontal equilibrium:

$$E_{pas.OT.E2.1} := -\left(H_{hwas.U1} + H_{hwgg.U1} + H_{twgg.U1} + H_{twgf.U1} + H_{twkey.OT.U1} + I_{U1} + E_{act.OT.U1} + \Sigma H_{Q.E2.EQh.1.OT}\right) = 6717.69 \cdot kN$$

Acting at: $E_{pas.OT.E2.1.loc} := -1 \cdot \frac{d_{key}}{2} = -1\,m$

Sum of All Overturning Analysis Horizontal Load (ΣH=0):

$$\Sigma H_{E2.OT.1} := H_{hwas.U1} + H_{hwgg.U1} + H_{twgg.U1} + H_{twgf.U1} + H_{twkey.OT.U1} + I_{U1} + E_{act.OT.U1} + E_{pas.OT.E2.1} + \Sigma H_{Q.E2.EQh.1.OT} = 0 \cdot kN$$

Sum of All Overturning Analysis Horizontal Load Moments:

$$\begin{aligned}\Sigma M_{H.E2.OT.1} := {} & H_{hwas.U1} \cdot H_{hwas.U1.loc} + H_{hwgg.U1} \cdot H_{hwgg.U1.loc} + H_{twgg.U1} \cdot H_{twgg.U1.loc} \cdots = -16161.76 \cdot kN \cdot m \\ & + H_{twgf.U1} \cdot H_{twgf.U1.loc} + H_{twkey.OT.U1} \cdot H_{twkey.OT.U1.loc} + I_{U1} \cdot I_{U1.loc} \cdots \\ & + E_{act.OT.U1} \cdot E_{act.OT.U1.loc} + E_{pas.OT.U1} \cdot E_{pas.OT.U1.loc} + \Sigma M_{Q.E2.1}\end{aligned}$$

Overturning Stability Analysis

$\Sigma M_{E2.OT.1} := \Sigma M_{V.E2.OT.1} + \Sigma M_{H.E2.OT.1} = 110346.82 \cdot kN \cdot m$

$X_{R.E2.1} := \frac{\Sigma M_{E2.OT.1}}{\Sigma V_{E2.OT.1}} = 8.25\,m$ $\qquad x_{OT.E2.1} := X_{R.E2.1} - \frac{L_b}{2} = -1\,m$

Overturning Resultant Ratio

$Ratio_{OT.E2.1} := \frac{X_{R.E2.1}}{L_b} = 0.45$

$Ratio_{OT.E2.1.check} := \begin{cases} \text{"OKAY"} & \text{if } Ratio_{OT.E2.1} \geq Ratio_{overturning.allow.Extreme} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"OKAY"}$

$x_{OT.check.E2.1} := \begin{cases} \text{"OKAY"} & \text{if } \left|x_{OT.E2.1}\right| \leq Kern \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"OKAY"}$

Seismic Case $Q_{E2.2}$ - 100% Horizontal Seismic Force, 30% Vertical

E2.2 CASE

0 = No, 1 = Yes

Include Seismic Load in Analysis? $Eq_{E2.2} := 1$

Horizontal Seismic Coefficient: $K_{h.E2.2} := -0.17$

Vertical Seismic Coefficient: $K_{v.E2.2} := -0.03$

HORIZONTAL SEISMIC LOADS	**Loads**	**Moment Arm**
Horiz Seismic Component of Concrete:	$Q_{conc.E2.EQh.2} := D_{conc} \cdot K_{h.E2.2} \cdot Eq_{E2.2} = -3814.6 \cdot kN$	$Y_{conc.loc} = 2.43\,m$
Horiz Seismic Component of Gates:	$Q_{Gate.E2.EQh.2} := D_{Gate} \cdot K_{h.E2.2} \cdot Eq_{E2.2} = -23.8 \cdot kN$	$Y_{gate} = 3.90\,m$
Horizontal Seismic Component of Headwater - Sliding:	$Q_{hwas.E2.EQh.2} := \left(\frac{7}{12}\right) \cdot K_{h.E2.2} \cdot \gamma_w \cdot \left(HW_{U1} - BOK_{elev}\right)^2 \cdot W_{hwas.U1} \cdot Eq_{E2.2} = -765.9 \cdot kN$	$Y_{HWg.E2} = 1.24\,m$
Horizontal Seismic Component of Soil (Woods Method) - Overturning:	$Q_{act.E2.EQh.2.OT} := \left(\gamma_r - \gamma_w\right) \cdot \left(TOC_{as} - BOK_{elev}\right)^2 \cdot K_{h.E2.2} \cdot W_{hwas.U1} \cdot Eq_{E2.2} = -895.2 \cdot kN$	$Y_{E.act.E2.OT} = 1.78\,m$
Horizontal Seismic Component of Soil (Woods Method):	$Q_{act.E2.EQh.2} := \left(\gamma_r - \gamma_w\right) \cdot \left(TOC_{as} - BOF_{elev}\right)^2 \cdot K_{h.E2.2} \cdot W_{hwas.U1} \cdot Eq_{E2.2} = -397.9 \cdot kN$	$Y_{E.act.E2} = 2.52\,m$

VERTICAL SEISMIC LOADS	**Loads**	**Moment Arm**
Vertical Component of Concrete:	$Q_{conc.E2.EQv.2} := D_{conc} \cdot K_{v.E2.2} \cdot Eq_{E2.2} = -673.2 \cdot kN$	$X_{conc.loc} = 9.35\,m$
Vertical Component of Gate:	$Q_{Gate.E2.EQv.2} := D_{Gate} \cdot K_{v.E2.2} \cdot Eq_{E2.2} = -4.2 \cdot kN$	$X_{gate} = 9.50\,m$
Vertical Seismic Component of Headwater over Apron Slab:	$Q_{H1.E2.EQv.2} := K_{v.E2.2} \cdot H_{1.U1} \cdot Eq_{E2.2} = -64.9 \cdot kN$	$H_{1.U1.loc} = 14.13\,m$
Vertical Seismic Component of Headwater over Pier Footing:	$Q_{H2.E2.EQv.2} := K_{v.E2.2} \cdot H_{2.U1} \cdot Eq_{E2.2} = -54.0 \cdot kN$	$H_{2.U1.loc} = 5.34\,m$

$$\Sigma H_{Q.E2.EQh.2} := Q_{conc.E2.EQh.2} + Q_{Gate.E2.EQh.2} + Q_{hwas.E2.EQh.2} + Q_{act.E2.EQh.2} = -5002.19 \cdot kN$$

$$\Sigma H_{Q.E2.EQh.2.OT} := Q_{conc.E2.EQh.2} + Q_{Gate.E2.EQh.2} + Q_{hwas.E2.EQh.2} + Q_{act.E2.EQh.2.OT} = -5499.54 \cdot kN$$

$$\Sigma V_{Q.E2.EQv.2} := Q_{conc.E2.EQv.2} + Q_{Gate.E2.EQv.2} + Q_{H1.E2.EQv.2} + Q_{H2.E2.EQv.2} = -796.2 \cdot kN$$

$$\begin{aligned}\Sigma M_{Q.E2.2} := {} & Q_{conc.E2.EQh.2} \cdot Y_{conc.loc} + Q_{Gate.E2.EQh.2} \cdot Y_{gate} + Q_{hwas.E2.EQh.2} \cdot Y_{HWg.E2} \cdots \\ & + Q_{act.E2.EQh.2.OT} \cdot Y_{E.act.E2.OT} + Q_{conc.E2.EQv.2} \cdot X_{conc.loc} + Q_{Gate.E2.EQv.2} \cdot X_{gate} \cdots \\ & + Q_{H1.E2.EQv.2} \cdot H_{1.U1.loc} + Q_{H2.E2.EQv.2} \cdot H_{2.U1.loc} \end{aligned} = -19438.7 \cdot kN \cdot m$$

STABILITY ASSESSMENT (SLIDNG, BEARING, FLOTATION AND OVERTURNING):

E2.2 CASE

CHECK SLIDING ALONG HORIZONTAL PLANE THRU TOE,
IGNORING BEDROCK MOBILIZED BY STRUCTURAL HEEL KEY, OR VOID BEHIND KEY

Sum of Vertical Forces:

$\Sigma V_{E2.2} := \Sigma V_{U1} + \Sigma V_{Q.E2.EQv.2} = 10609.2 \cdot kN$

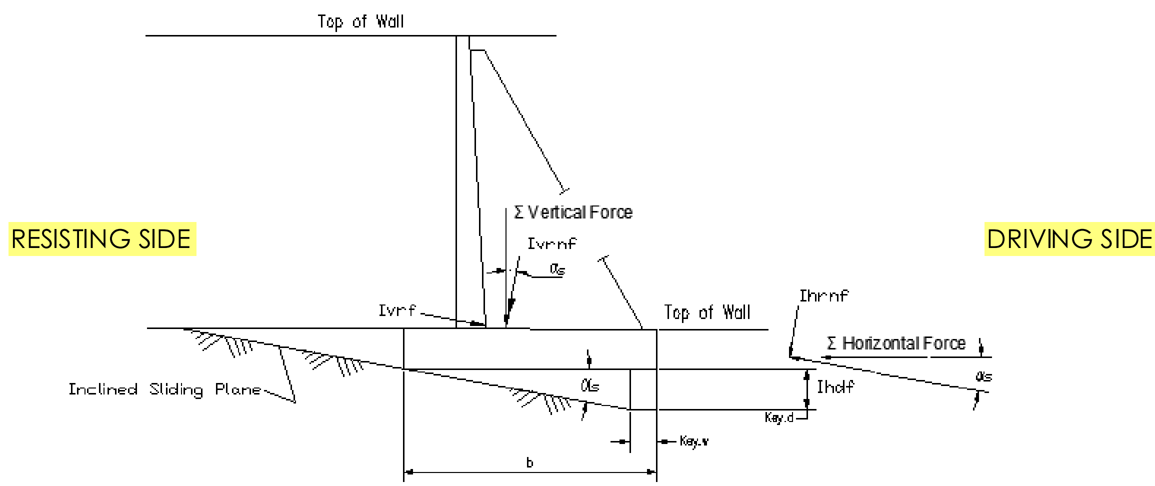
Sum of Horizontal Forces:

$\Sigma H_{E2.2} := \Sigma H_{U1} - I_{U1} + \Sigma H_{Q.E2.EQh.2} = -6730.24 \cdot kN$

Sliding Factor of Safety: $FS_{HorizSliding.E2.2} := \dfrac{\tan_{\phi} \cdot \Sigma V_{E2.2}}{\left|\Sigma H_{E2.2}\right|} = 0.77$

$FS_{HorizSliding.E2.2.Check} :=$ | "OKAY" if $FS_{HorizSliding.E2.2} \geq FS_{req.E2.sl}$ / "Check Inclined Sliding Plane!" otherwise $=$ "Check Inclined Sliding Plane!"

CHECK SLIDING ALONG INCLINED SLIDING PLANE FROM HEEL KEY TO TOE,
WITH BEDROCK MASS MOBILIZED BY REINFOCREDE CONCRETE KEY)



TOE

Ivrf=Inclined Resisting Force
Ivrnf=Inclined Resisting Normal Force
Ihrnf=Inclined Resisting Normal Force
Ihdf=Inclined Driving Force

$\Sigma V_{E2.2} = 10609.21 \cdot kN$

$V_{rs} = 4620 \cdot kN$

$\alpha s = 0.11$

as degrees= $\alpha s \cdot \left(\dfrac{180}{\pi}\right) = 6.52$

Resolve $\Sigma Vert_{E2.2}$ & $\Sigma Horiz_{E2.2}$

$\Sigma V_{InclinedE2.2} := \cos(\alpha s) \cdot \left(\Sigma V_{E2.2} + V_{rs}\right) + \sin(\alpha s) \cdot \left|\Sigma H_{E2.2}\right| = 15894.9 \cdot kN$

$\Sigma H_{InclinedE2.2} := \cos(\alpha s) \cdot \left|\Sigma H_{E2.2}\right| - \sin(\alpha s) \cdot \left(\Sigma V_{E2.2} + V_{rs}\right) = 4957.5 \cdot kN$

(With properly engineered reinforced concrete Key, horizontal sliding plane thru Toe is protected, critical sliding plane is relocated to the INCLINED SLIDING PLANE FROM HEEL KEY To TOE, Bedrock Mass above this examined plane is mobilized by reinforced concrete key and combined into Structural Wedge.)

Inclined Sliding Plane Length $L_{incline} = 18.61 \, m$

Safety Factor for Sliding Inclined Failure Plane

$FS_{InclinedlSlidingE2.2} := \dfrac{\Sigma V_{InclinedE2.2} \cdot \tan\left(\phi_{rock} \cdot \dfrac{\pi}{180}\right)}{\left|\Sigma H_{InclinedE2.2}\right|} = 1.56$

$FS_{InclinedSliding.check.E2.2} :=$ | "OKAY " if $FS_{InclinedlSlidingE2.2} > FS_{req.E2.sl}$ / "Revise Structure"" otherwise $=$ "OKAY "

$FS_{InclinedSliding.check.E2.2} =$ "OKAY "

OVERTURNING STABILITY CHECK:

CHECK ECCENTRICITY

Sum of the moments:

$$\Sigma M_{E2.2} := \left(\Sigma M_{U1} + \Sigma M_{Q.E2.2}\right) = 136089 \cdot kN \cdot m$$

Eccentricity:

$$e_{E2.2} := \left(\frac{L_{incline}}{2}\right) - \frac{\left(\Sigma M_{E2.2}\right)}{\Sigma V_{InclinedE2.2}} = 0.74\,m$$

Eccentricity Check:

$$e_{check.E2.2} := \begin{array}{|l} \text{"Okay"} \quad \text{if} \quad e_{E2.2} \le Kern \\ \text{"Revise Structure"} \quad \text{otherwise} \end{array}$$

$$e_{check.E2.2} = \text{"Okay"}$$

Foundation Bearing Checks:

Bearing Pressure at Heel:

$$\sigma_{heel.E2.2} := \frac{\Sigma V_{InclinedE2.2}}{A_{b.incline}} - \frac{\left(\Sigma V_{InclinedE2.2} \cdot e_{E2.2}\right)}{S_{b.incline}} = 54.2 \cdot \frac{kN}{m^2}$$

$$\sigma_{heel.E2.2.check} := \left(\begin{array}{|l} \text{"Okay"} \quad \text{if} \quad \sigma_{heel.E2.2} \le \sigma_{allow.E2} \\ \text{"Revise Structure"} \quad \text{if} \quad \sigma_{heel.E2.2} < 0 \frac{kN}{m^2} \end{array}\right)$$

$$\sigma_{heel.E2.2.check} = \text{"Okay"}$$

Bearing Pressure at Toe:

$$\sigma_{toe.E2.2} := \frac{\Sigma V_{InclinedE2.2}}{A_{b.incline}} + \frac{\left(\Sigma V_{InclinedE2.2} \cdot e_{E2.2}\right)}{S_{b.incline}} = 88.2 \cdot \frac{kN}{m^2}$$

$$\sigma_{toe.E2.2.check.1} := \begin{array}{|l} \text{"Okay"} \quad \text{if} \quad \sigma_{toe.E2.2} \le \sigma_{allow.E2} \\ \text{"Revise Structure"} \quad \text{if} \quad \sigma_{toe.E2.2} < 0 \frac{kN}{m^2} \end{array}$$

$$\sigma_{toe.E2.2.check.1} = \text{"Okay"}$$

FLOATATION ANALYSIS:

ACCEPTANCE PARAMETERS

Required Factor of Safety: $FS_{req.FE2.2} := 1.1$

VERTICAL LOADS RESISTING:

Dead Load: $\Sigma V_{DL} = 22578.74 \cdot kN$

Water Weight H1+H2: $\Sigma V_{H.FE2.2} := \Sigma V_{H.FU1} + \Sigma V_{Q.E2.EQv.2} = 3166.31 \cdot kN$

Summation Vertical Resisting: $\Sigma V_{FE2.2} := \Sigma V_{DL} + \Sigma V_{H.FE2.2} = 25745.1 \cdot kN$

VERTICAL LOADS UPLIFT:

Uplift: $U_{U1} = -15135.85 \cdot kN$

Factor of Safety Floatation:

$$FS_{act.FE2.2} := \frac{\Sigma V_{FE2.2}}{\left|U_{U1}\right|} = 1.70$$

$$FS_{check.FE2.2} := \begin{array}{|l} \text{"OKAY"} \quad \text{if} \quad FS_{act.FE2.2} \ge FS_{req.FE2.2} \\ \text{"ANCHORS REQUIRED"} \quad \text{if} \quad FS_{act.FE2.2} < FS_{req.FE2.2} \end{array} = \text{"OKAY"}$$

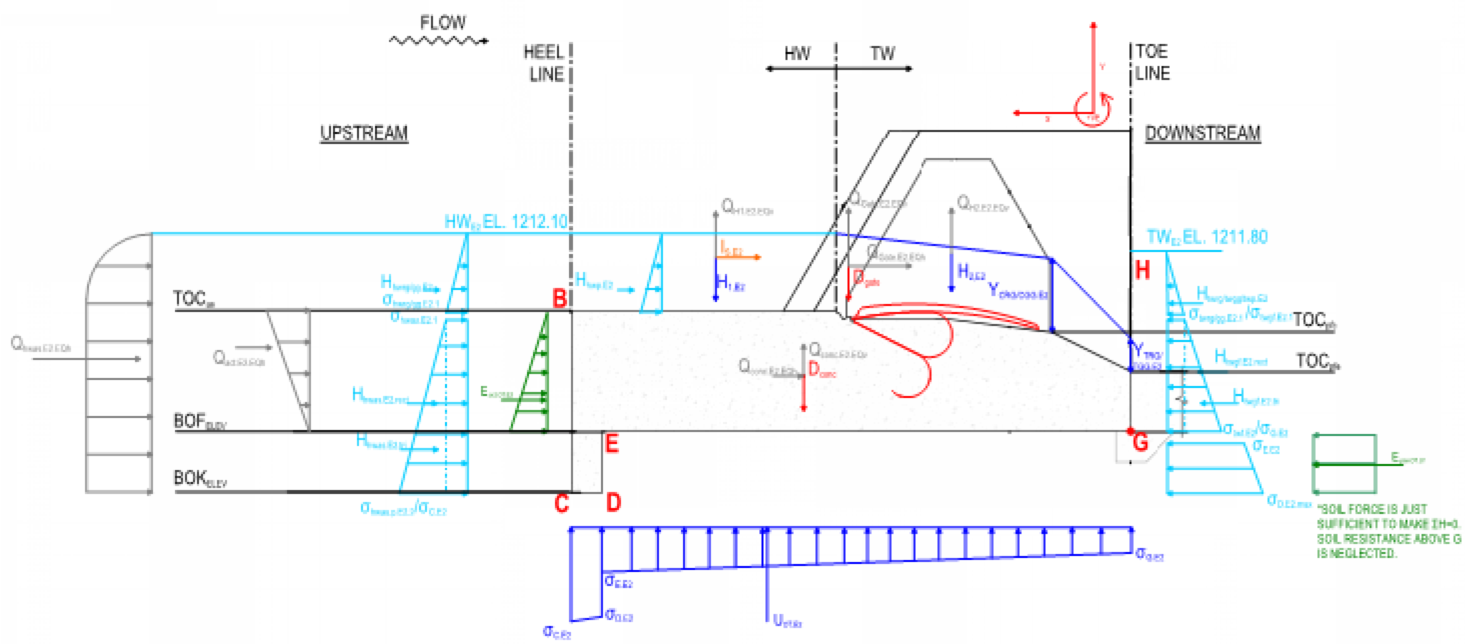
E2.2 CASE

MONOLITH OVERTURNING STABILITY ANALYSIS

Seismic Case $Q_{E2.2}$: 100% Horizontal Seismic Force, 30% Vertical

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.
Assumptions are made in order to compute overturning stability of indetermine forces on monolith with key;
(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.
(b) The horizontal resisting force acting on the key, P.key, is that required for static equilibrium
(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1 $Ratio_{overturning.allow.Extreme} = 0$ Resultant within Base



All Vertical Loads Appliable to Overturning Stability Analysis

Total Concrete Dead Loads:	$D_{conc} = 22438.74 \cdot kN$	at:	$X_{conc.loc} = 9.35\,m$
Dead Load of Gate:	$D_{Gate} = 140.0 \cdot kN$		$X_{gate} = 9.50\,m$
Water Weight (HW) on Apron Slab:	$H_{1.U1} = 2163.1 \cdot kN$		$H_{1.U1.loc} = 14.13\,m$
Water Weight (TW) on Gate Footing:	$H_{2.U1} = 1799.4 \cdot kN$		$H_{2.U1.loc} = 5.34\,m$
Uplift Load for Overturning Analysis:	$U_{OT.U1} = -13165.04 \cdot kN$		$U_{OT.U1.loc} = 9.48 \cdot m$
Vertical Seismic Component of Concrete Structure:	$Q_{conc.E2.EQv.2} = -673.16 \cdot kN$		$X_{conc.loc} = 9.35\,m$
Vertical Seismic Component of Crest Gate:	$Q_{Gate.E2.EQv.2} = -4.2 \cdot kN$		$X_{gate} = 9.50\,m$
Vertical Seismic Component of Headwater over Apron Slab:	$Q_{H1.E2.EQv.2} = -64.89 \cdot kN$		$H_{1.U1.loc} = 14.13\,m$
Vertical Seismic Component of Headwater over Fixed Crest Slab:	$Q_{H2.E2.EQv.2} = -53.98 \cdot kN$		$H_{2.U1.loc} = 5.34\,m$

Sum of All Overturning Analysis Vertical Load:

$$\Sigma V_{E2.OT.2} := D_{conc} + D_{Gate} + H_{1.U1} + H_{2.U1} + U_{OT.U1} + \Sigma V_{Q.E2.EQv.2} = 12580.01 \cdot kN$$

Sum of All Overturning Analysis Vertical Load Moments:

$$\Sigma M_{V.E2.OT.2} := D_{conc} \cdot X_{conc.loc} + D_{Gate} \cdot X_{gate} + H_{1.U1} \cdot H_{1.U1.loc} + H_{2.U1} \cdot H_{2.U1.loc} + U_{OT.U1} \cdot U_{OT.U1.loc} = 126508.58 \cdot kN \cdot m$$

Lateral Driving Earth Loads for Overturning Stability Analysis (at rest condition)

E2.2 CASE

Depth of Driving Soil Loads (to top of key): $h_{E.OT.E2.2} := TOC_{as} - BOF_{elev} = 4\,m$

Applicable Soil Load: $E_{act.OT.E2.2} := \frac{\left(K_{o.U1} \cdot h_{E.OT.U1}\right)^2}{2} \cdot \left(\gamma_r - \gamma_w\right) \cdot W_{hwas.U1} \cdot -1 = -769.99 \cdot kN$

At Rest- Soil Load Acting from Toe: $E_{act.OT.E2.2.loc} := \frac{h_{E.OT.U1}}{3} = 1.33\,m$

All Lateral Loads Applicable to Overturning Stability Analysis

HW Lateral Load on Approach Slab:	$H_{hwas.U1} = -3602.2 \cdot kN$	$H_{hwas.U1.loc} = 0.41\,m$
HW Lateral Load on Guard Gate:	$H_{hwgg.U1} = 0.0 \cdot kN$	$H_{hwgg.U1.loc} = 4.00\,m$
TW Lateral Load on Guard Gate:	$H_{twgg.U1} = 0.0 \cdot kN$	$H_{twgg.U1.loc} = 4.00\,m$
TW Lateral Load on Gate Footing (No Key - Overturning Values Adjusted):	$H_{twgf.U1} = 1789.34 \cdot kN$	$H_{twgf.U1.loc} = 1.65\,m$
TW Lateral Load on Key:	$H_{twkey.OT.U1} = 1664.73 \cdot kN$	$H_{twkey.OT.U1.loc} = -1.05\,m$
Ice / Impact Load:	$I_{U1} = -300.0 \cdot kN$	$I_{U1.loc} = 5.80\,m$
Lateral Soil Load (driving):	$E_{act.OT.U1} = -770.0 \cdot kN$	$E_{act.OT.U1.loc} = 1.33\,m$
Horizontal Seismic Component of Concrete Structure:	$Q_{conc.E2.EQh.2} = -3814.59 \cdot kN$	$Y_{conc.loc} = 2.43\,m$
Horizontal Seismic Component of Vertical Lift Gate:	$Q_{Gate.E2.EQh.2} = -23.8 \cdot kN$	$Y_{gate} = 3.90\,m$
Horizontal Seismic Component of Headwater on Slab Footing:	$Q_{hwas.E2.EQh.2} = -765.92 \cdot kN$	$Y_{HWg.E2} = 1.24\,m$
Horizontal Seismic Component of Active Soil: (Section 5-5, USACE EM_1110-2-2100)	$Q_{act.E2.EQh.2} = -397.88 \cdot kN$	$Y_{E.act.E2} = 2.52\,m$

Resisting Lateral Soil Load as required to produce horizontal equilibrium:

$$E_{pas.OT.E2.2} := -\left(H_{hwas.U1} + H_{hwgg.U1} + H_{twgg.U1} + H_{twgf.U1} + H_{twkey.OT.U1} + I_{U1} + E_{act.OT.U1} + \Sigma H_{Q.E2.EQh.2.OT}\right) = 6717.69 \cdot kN$$

Acting at: $E_{pas.OT.E2.2.loc} := -1 \cdot \frac{d_{key}}{2} = -1\,m$

Sum of All Overturning Analysis Horizontal Load (ΣH=0):

$$\Sigma H_{E2.OT.2} := H_{hwas.U1} + H_{hwgg.U1} + H_{twgg.U1} + H_{twgf.U1} + H_{twkey.OT.U1} + I_{U1} + E_{act.OT.U1} + E_{pas.OT.E2.2} + \Sigma H_{Q.E2.EQh.2.OT} = 0 \cdot kN$$

Sum of All Overturning Analysis Horizontal Load Moments:

$$\Sigma M_{H.E2.OT.2} := H_{hwas.U1} \cdot H_{hwas.U1.loc} + H_{hwgg.U1} \cdot H_{hwgg.U1.loc} + H_{twgg.U1} \cdot H_{twgg.U1.loc} \cdots + H_{twgf.U1} \cdot H_{twgf.U1.loc} + H_{twkey.OT.U1} \cdot H_{twkey.OT.U1.loc} + I_{U1} \cdot I_{U1.loc} \cdots + E_{act.OT.U1} \cdot E_{act.OT.U1.loc} + E_{pas.OT.U1} \cdot E_{pas.OT.U1.loc} + \Sigma M_{Q.E2.2} = -23700.29 \cdot kN \cdot m$$

Overturning Stability Analysis

$\Sigma M_{E2.OT.2} := \Sigma M_{V.E2.OT.2} + \Sigma M_{H.E2.OT.2} = 102808.29 \cdot kN \cdot m$

$X_{R.E2.2} := \frac{\Sigma M_{E2.OT.2}}{\Sigma V_{E2.OT.2}} = 8.17\,m$ $\quad x_{OT.E2.2} := X_{R.E2.2} - \frac{L_b}{2} = -1.08\,m$

Overturning Resultant Ratio

$Ratio_{OT.E2.2} := \frac{X_{R.E2.2}}{L_b} = 0.44$

$Ratio_{OT.E2.2.check} := \begin{cases} \text{"OKAY"} & \text{if } Ratio_{OT.E2.2} \geq Ratio_{overturning.allow.Extreme} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"OKAY"}$

$x_{OT.check.E2.2} := \begin{cases} \text{"OKAY"} & \text{if } \left|x_{OT.E2.2}\right| \leq Kern \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"OKAY"}$

Seismic Case $Q_{E2.3}$ - 30% Horizontal Seismic Force, 100% Vertical

E2.3 CASE

Include Seismic Load in Analysis? $Eq_{E2.3} := 1$ 0 = No, 1 = Yes

Horizontal Seismic Coefficient: $K_{h.E2.3} := -0.05$

Vertical Seismic Coefficient: $K_{v.E2.3} := -0.10$

HORIZONTAL SEISMIC LOADS	**Loads**	**Moment Arm**
Horiz Seismic Component of Concrete:	$Q_{conc.E2.EQh.3} := D_{conc} \cdot K_{h.E2.3} \cdot Eq_{E2.3} = -1121.9 \cdot kN$	$Y_{conc.loc} = 2.43\,m$
Horiz Seismic Component of Gates:	$Q_{Gate.E2.EQh.3} := D_{Gate} \cdot K_{h.E2.3} \cdot Eq_{E2.3} = -7.0 \cdot kN$	$Y_{gate} = 3.90\,m$
Horizontal Seismic Component of Headwater - Sliding:	$Q_{hwas.E2.EQh.3} := \left(\frac{7}{12}\right) \cdot K_{h.E2.3} \cdot \gamma_w \cdot \left(HW_{U1} - BOK_{elev}\right)^2 \cdot W_{hwas.U1} \cdot Eq_{E2.3} = -225.3 \cdot kN$	$Y_{HWg.E2} = 1.24\,m$
Horizontal Seismic Component of Soil (Woods Method) - Overturning:	$Q_{act.E2.EQh.3.OT} := \left(\gamma_r - \gamma_w\right) \cdot \left(TOC_{as} - BOK_{elev}\right)^2 \cdot K_{h.E2.3} \cdot W_{hwas.U1} \cdot Eq_{E2.3} = -263.3 \cdot kN$	$Y_{E.act.E2.OT} = 1.78\,m$
Horizontal Seismic Component of Soil (Woods Method):	$Q_{act.E2.EQh.3} := \left(\gamma_r - \gamma_w\right) \cdot \left(TOC_{as} - BOF_{elev}\right)^2 \cdot K_{h.E2.3} \cdot W_{hwas.U1} \cdot Eq_{E2.3} = -117.0 \cdot kN$	$Y_{E.act.E2} = 2.52\,m$

VERTICAL SEISMIC LOADS	**Loads**	**Moment Arm**
Vertical Component of Concrete:	$Q_{conc.E2.EQv.3} := D_{conc} \cdot K_{v.E2.3} \cdot Eq_{E2.3} = -2243.9 \cdot kN$	$X_{conc.loc} = 9.35\,m$
Vertical Component of Gate:	$Q_{Gate.E2.EQv.3} := D_{Gate} \cdot K_{v.E2.3} \cdot Eq_{E2.3} = -14.0 \cdot kN$	$X_{gate} = 9.50\,m$
Vertical Seismic Component of Headwater over Apron Slab:	$Q_{H1.E2.EQv.3} := K_{v.E2.3} \cdot H_{1.U1} \cdot Eq_{E2.3} = -216.3 \cdot kN$	$H_{1.U1.loc} = 14.13\,m$
Vertical Seismic Component of Headwater over Pier Footing:	$Q_{H2.E2.EQv.3} := K_{v.E2.3} \cdot H_{2.U1} \cdot Eq_{E2.3} = -179.9 \cdot kN$	$H_{2.U1.loc} = 5.34\,m$

$$\Sigma H_{Q.E2.EQh.3} := Q_{conc.E2.EQh.3} + Q_{Gate.E2.EQh.3} + Q_{hwas.E2.EQh.3} + Q_{act.E2.EQh.3} = -1471.23 \cdot kN$$

$$\Sigma H_{Q.E2.EQh.3.OT} := Q_{conc.E2.EQh.3} + Q_{Gate.E2.EQh.3} + Q_{hwas.E2.EQh.3} + Q_{act.E2.EQh.3.OT} = -1617.51 \cdot kN$$

$$\Sigma V_{Q.E2.EQv.3} := Q_{conc.E2.EQv.3} + Q_{Gate.E2.EQv.3} + Q_{H1.E2.EQv.3} + Q_{H2.E2.EQv.3} = -2654.1 \cdot kN$$

$$\begin{aligned}\Sigma M_{Q.E2.3} := {} & Q_{conc.E2.EQh.3} \cdot Y_{conc.loc} + Q_{Gate.E2.EQh.3} \cdot Y_{gate} + Q_{hwas.E2.EQh.3} \cdot Y_{HWg.E2} \cdots \\ & + Q_{act.E2.EQh.3.OT} \cdot Y_{E.act.E2.OT} + Q_{conc.E2.EQv.3} \cdot X_{conc.loc} + Q_{Gate.E2.EQv.3} \cdot X_{gate} \cdots \\ & + Q_{H1.E2.EQv.3} \cdot H_{1.U1.loc} + Q_{H2.E2.EQv.3} \cdot H_{2.U1.loc}\end{aligned} = -28628.49 \cdot kN \cdot m$$

STABILITY ASSESSMENT (SLIDNG, BEARING, FLOTATION AND OVERTURNING):

E2.3 CASE

CHECK SLIDING ALONG HORIZONTAL PLANE THRU TOE,
IGNORING BEDROCK MOBILIZED BY STRUCTURAL HEEL KEY, OR VOID BEHIND KEY

Sum of Vertical Forces:

$\Sigma V_{E2.3} := \Sigma V_{U1} + \Sigma V_{Q.E2.EQv.3} = 8751.3 \cdot kN$

Sum of Horizontal Forces:

$\Sigma H_{E2.3} := \Sigma H_{U1} - I_{U1} + \Sigma H_{Q.E2.EQh.3} = -3199.28 \cdot kN$

Sliding Factor of Safety:

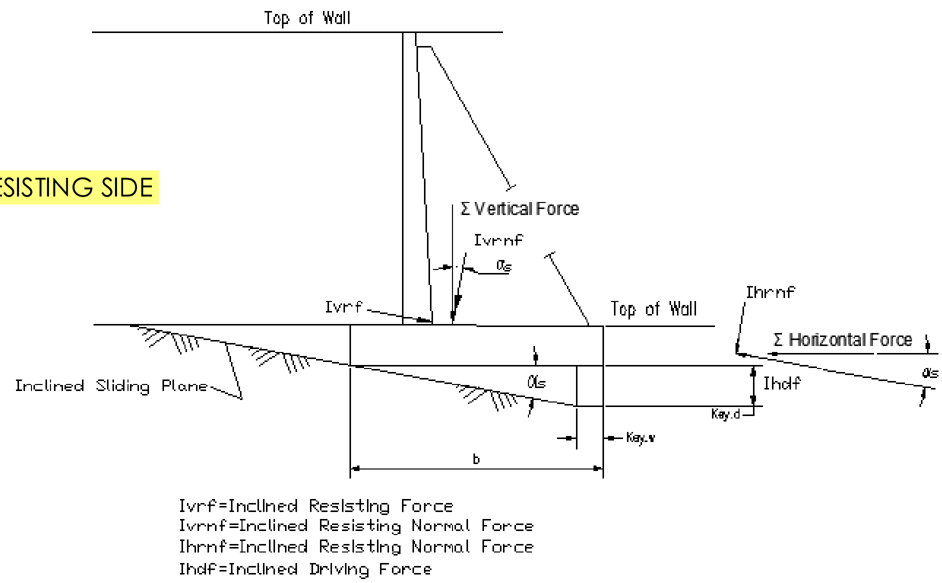
$$FS_{HorizSliding.E2.3} := \frac{\tan_{\phi} \cdot \Sigma V_{E2.3}}{\left|\Sigma H_{E2.3}\right|} = 1.33$$

$FS_{HorizSliding.E2.3.Check} :=$ | "OKAY" if $FS_{HorizSliding.E2.3} \geq FS_{req.E2.sl}$ = "OKAY"
"Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !" otherwise

CHECK SLIDING ALONG INCLINED SLIDING PLANE FROM HEEL KEY TO TOE,
WITH BEDROCK MASS MOBILIZED BY REINFOCREDE CONCRETE KEY)

RESISTING SIDE

DRIVING SIDE



TOE

$\Sigma V_{E2.3} = 8751.31 \cdot kN$

$V_{rs} = 4620 \cdot kN$

$\alpha s = 0.11$

as degrees= $\alpha s \cdot \left(\frac{180}{\pi}\right) = 6.52$

Resolve $\Sigma Vert_{E2.3}$ & $\Sigma Horiz_{E2.3}$

$\Sigma V_{InclinedE2.3} := \cos(\alpha s) \cdot \left(\Sigma V_{E2.3} + V_{rs}\right) + \sin(\alpha s) \cdot \left|\Sigma H_{E2.3}\right| = 13648.1 \cdot kN$

$\Sigma H_{InclinedE2.3} := \cos(\alpha s) \cdot \left|\Sigma H_{E2.3}\right| - \sin(\alpha s) \cdot \left(\Sigma V_{E2.3} + V_{rs}\right) = 1660.3 \cdot kN$

(With properly engineered reinforced concrete Key, horizontal sliding plane thru Toe is protected, critical sliding plane is relocated to the INCLINED SLIDING PLANE FROM HEEL KEY To TOE, Bedrock Mass above this examined plane is mobilized by reinforced concrete key and combined into Structural Wedge.)

Inclined Sliding Plane Length

$L_{incline} = 18.61 \, m$

Safety Factor for Sliding
Inclined Failure Plane

$$FS_{InclinedlSlidingE2.3} := \frac{\Sigma V_{InclinedE2.3} \cdot \tan\left(\phi_{rock} \cdot \frac{\pi}{180}\right)}{\left|\Sigma H_{InclinedE2.3}\right|} = 4.01$$

$FS_{InclinedSliding.check.E2.3} :=$ | "OKAY " if $FS_{InclinedlSlidingE2.3} > FS_{req.E2.sl}$ = "OKAY "
"Revise Structure"" otherwise

$FS_{InclinedSliding.check.E2.3} =$ "OKAY "

E2.3 CASE

OVERTURNING STABILITY CHECK:

CHECK ECCENTRICITY

Sum of the moments:

$$\Sigma M_{E2.3} := \left(\Sigma M_{U1} + \Sigma M_{Q.E2.3}\right) = 126899 \cdot kN \cdot m$$

Eccentricity:

$$e_{E2.3} := \left(\frac{L_{incline}}{2}\right) - \frac{\left(\Sigma M_{E2.3}\right)}{\Sigma V_{InclinedE3.3}} = 0.93\,m$$

Eccentricity Check:

$$e_{check.E2.3} := \begin{cases} \text{"Okay"} & \text{if } e_{E2.3} \le Kern \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$$e_{check.E2.3} = \text{"Okay"}$$

Foundation Bearing Checks:

Bearing Pressure at Heel:

$$\sigma_{heel.E2.3} := \frac{\Sigma V_{InclinedE3.3}}{A_{b.incline}} - \frac{\left(\Sigma V_{InclinedE3.3} \cdot e_{E2.3}\right)}{S_{b.incline}} = 47.5 \cdot \frac{kN}{m^2}$$

$$\sigma_{heel.E2.3.check} := \left(\begin{cases} \text{"Okay"} & \text{if } \sigma_{heel.E2.3} \le \sigma_{allow.E2} \\ \text{"Revise Structure"} & \text{if } \sigma_{heel.E2.3} < 0\,\frac{kN}{m^2} \end{cases}\right)$$

$$\sigma_{heel.E2.3.check} = \text{"Okay"}$$

Bearing Pressure at Toe:

$$\sigma_{toe.E2.3} := \frac{\Sigma V_{InclinedE3.3}}{A_{b.incline}} + \frac{\left(\Sigma V_{InclinedE3.3} \cdot e_{E2.3}\right)}{S_{b.incline}} = 88.2 \cdot \frac{kN}{m^2}$$

$$\sigma_{toe.E2.3.check.1} := \begin{cases} \text{"Okay"} & \text{if } \sigma_{toe.E2.3} \le \sigma_{allow.E2} \\ \text{"Revise Structure"} & \text{if } \sigma_{toe.E2.3} < 0\,\frac{kN}{m^2} \end{cases}$$

$$\sigma_{toe.E2.3.check.1} = \text{"Okay"}$$

FLOATATION ANALYSIS:

ACCEPTANCE PARAMETERS

Required Factor of Safety: $FS_{req.FE2.3} := 1.1$

VERTICAL LOADS RESISTING:

Dead Load: $\Sigma V_{DL} = 22578.74 \cdot kN$

Water Weight H1+H2: $\Sigma V_{H.FE2.3} := \Sigma V_{H.FU1} + \Sigma V_{Q.E2.EQv.3} = 1308.42 \cdot kN$

Summation Vertical Resisting: $\Sigma V_{FE2.3} := \Sigma V_{DL} + \Sigma V_{H.FE2.3} = 23887.2 \cdot kN$

VERTICAL LOADS UPLIFT:

Uplift: $U_{U1} = -15135.85 \cdot kN$

Factor of Safety Floatation:

$$FS_{act.FE2.3} := \frac{\Sigma V_{FE2.3}}{\left|U_{U1}\right|} = 1.58$$

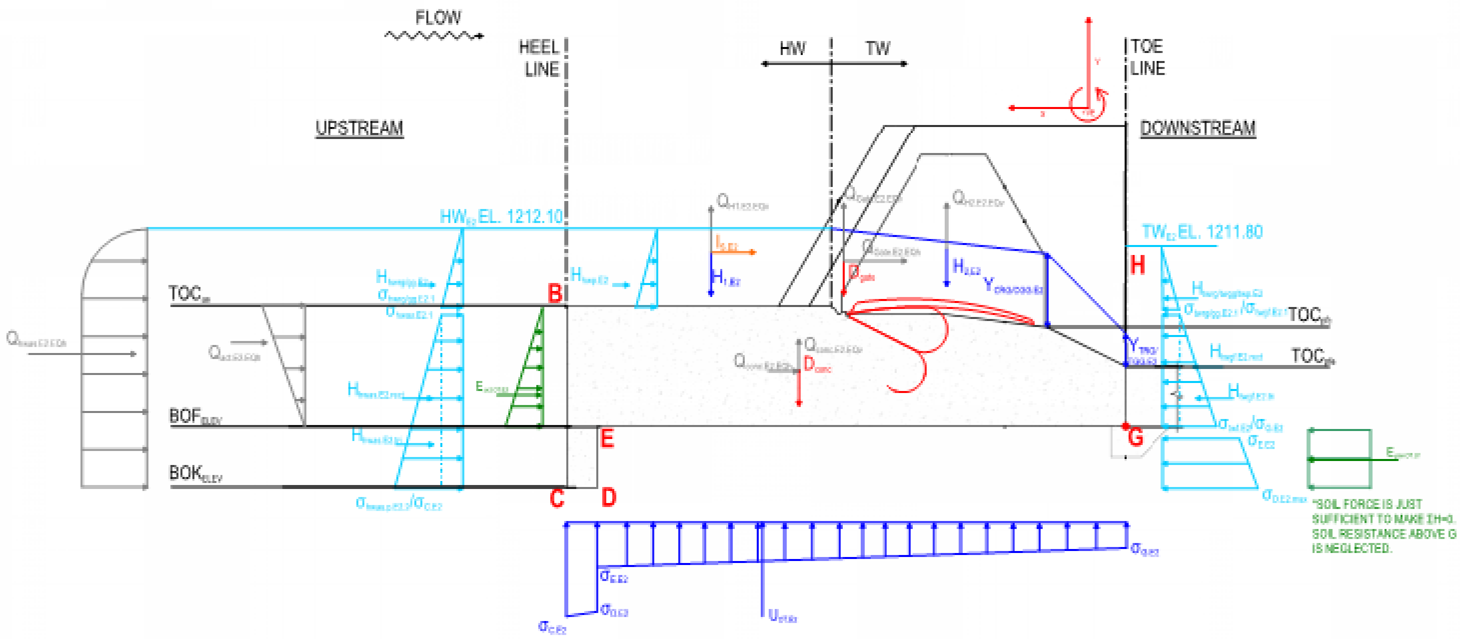
$$FS_{check.FE2.3} := \begin{cases} \text{"OKAY"} & \text{if } FS_{act.FE2.3} \ge FS_{req.FE2.3} \\ \text{"ANCHORS REQUIRED"} & \text{if } FS_{act.FE2.3} < FS_{req.FE2.3} \end{cases} = \text{"OKAY"}$$

MONOLITH OVERTURNING STABILITY ANALYSIS

Seismic Case $Q_{E2.3}$: 30% Horizontal Seismic Force, 100% Vertical

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.
Assumptions are made in order to compute overturning stability of indetermine forces on monolith with key;
(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.
(b) The horizontal resisting force acting on the key, P.key, is that required for static equilibrium
(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1 $Ratio_{overturning.allow.Extreme} = 0$ Resultant within Base



All Vertical Loads Applicable to Overturning Stability Analysis

Total Concrete Dead Loads:	$D_{conc} = 22438.74 \cdot kN$	at:	$X_{conc.loc} = 9.35\,m$
Dead Load of Gate:	$D_{Gate} = 140.0 \cdot kN$		$X_{gate} = 9.50\,m$
Water Weight (HW) on Apron Slab:	$H_{1.U1} = 2163.1 \cdot kN$		$H_{1.U1.loc} = 14.13\,m$
Water Weight (TW) on Gate Footing:	$H_{2.U1} = 1799.4 \cdot kN$		$H_{2.U1.loc} = 5.34\,m$
Uplift Load for Overturning Analysis:	$U_{OT.U1} = -13165.04 \cdot kN$		$U_{OT.U1.loc} = 9.48 \cdot m$
Vertical Seismic Component of Concrete Structure:	$Q_{conc.E2.EQv.3} = -2243.87 \cdot kN$		$X_{conc.loc} = 9.35\,m$
Vertical Seismic Component of Crest Gate:	$Q_{Gate.E2.EQv.3} = -14 \cdot kN$		$X_{gate} = 9.50\,m$
Vertical Seismic Component of Headwater over Apron Slab:	$Q_{H1.E2.EQv.3} = -216.31 \cdot kN$		$H_{1.U1.loc} = 14.13\,m$
Vertical Seismic Component of Headwater over Fixed Crest Slab:	$Q_{H2.E2.EQv.3} = -179.94 \cdot kN$		$H_{2.U1.loc} = 5.34\,m$

Sum of All Overtuming Analysis Vertical Load:

$$\Sigma V_{E2.OT.3} := D_{conc} + D_{Gate} + H_{1.U1} + H_{2.U1} + U_{OT.U1} + \Sigma V_{Q.E2.EQv.3} = 10722.12 \cdot kN$$

Sum of All Overtuming Analysis Vertical Load Moments:

$$\Sigma M_{V.E2.OT.3} := D_{conc} \cdot X_{conc.loc} + D_{Gate} \cdot X_{gate} + H_{1.U1} \cdot H_{1.U1.loc} + H_{2.U1} \cdot H_{2.U1.loc} + U_{OT.U1} \cdot U_{OT.U1.loc} = 126508.58 \cdot kN \cdot m$$

Lateral Driving Earth Loads for Overturning Stability Analysis (at rest condition)

E2.3 CASE

Depth of Driving Soil Loads (to top of key): $h_{E.OT.E2.3} := TOC_{as} - BOF_{elev} = 4\,m$

Applicable Soil Load: $E_{act.OT.E2.3} := \frac{\left(K_{o.U1} \cdot h_{E.OT.U1}^{2}\right)}{2} \cdot \left(\gamma_r - \gamma_w\right) \cdot W_{hwas.U1} \cdot -1 = -769.99 \cdot kN$

At Rest- Soil Load Acting from Toe: $E_{act.OT.E2.3.loc} := \frac{h_{E.OT.U1}}{3} = 1.33\,m$

All Lateral Loads Applicable to Overturning Stability Analysis

HW Lateral Load on Approach Slab:	$H_{hwas.U1} = -3602.2 \cdot kN$	$H_{hwas.U1.loc} = 0.41\,m$
HW Lateral Load on Guard Gate:	$H_{hwgg.U1} = 0.0 \cdot kN$	$H_{hwgg.U1.loc} = 4.00\,m$
TW Lateral Load on Guard Gate:	$H_{twgg.U1} = 0.0 \cdot kN$	$H_{twgg.U1.loc} = 4.00\,m$
TW Lateral Load on Gate Footing (No Key - Overturning Values Adjusted):	$H_{twgf.U1} = 1789.34 \cdot kN$	$H_{twgf.U1.loc} = 1.65\,m$
TW Lateral Load on Key:	$H_{twkey.OT.U1} = 1664.73 \cdot kN$	$H_{twkey.OT.U1.loc} = -1.05\,m$
Ice / Impact Load:	$I_{U1} = -300.0 \cdot kN$	$I_{U1.loc} = 5.80\,m$
Lateral Soil Load (driving):	$E_{act.OT.U1} = -770.0 \cdot kN$	$E_{act.OT.U1.loc} = 1.33\,m$
Horizontal Seismic Component of Concrete Structure:	$Q_{conc.E2.EQh.3} = -1121.94 \cdot kN$	$Y_{conc.loc} = 2.43\,m$
Horizontal Seismic Component of Vertical Lift Gate:	$Q_{Gate.E2.EQh.3} = -7 \cdot kN$	$Y_{gate} = 3.90\,m$
Horizontal Seismic Component of Headwater on Slab Footing:	$Q_{hwas.E2.EQh.3} = -225.27 \cdot kN$	$Y_{HWg.E2} = 1.24\,m$
Horizontal Seismic Component of Active Soil: (Section 5-5, USACE EM_1110-2-2100)	$Q_{act.E2.EQh.3} = -117.02 \cdot kN$	$Y_{E.act.E2} = 2.52\,m$

Resisting Lateral Soil Load as required to produce horizontal equilibrium:

$$E_{pas.OT.E2.3} := -\left(H_{hwas.U1} + H_{hwgg.U1} + H_{twgg.U1} + H_{twgf.U1} + H_{twkey.OT.U1} + I_{U1} + E_{act.OT.U1} + \Sigma H_{Q.E2.EQh.3.OT}\right) = 2835.66 \cdot kN$$

Acting at: $E_{pas.OT.E2.3.loc} := -1 \cdot \frac{d_{key}}{2} = -1\,m$

Sum of All Overtuming Analysis Horizontal Load (ΣH=0):

$$\Sigma H_{E2.OT.3} := H_{hwas.U1} + H_{hwgg.U1} + H_{twgg.U1} + H_{twgf.U1} + H_{twkey.OT.U1} + I_{U1} + E_{act.OT.U1} + E_{pas.OT.E2.3} + \Sigma H_{Q.E2.EQh.3.OT} = 0 \cdot kN$$

Sum of All Overtuming Analysis Horizontal Load Moments:

$$\Sigma M_{H.E2.OT.3} := H_{hwas.U1} \cdot H_{hwas.U1.loc} + H_{hwgg.U1} \cdot H_{hwgg.U1.loc} + H_{twgg.U1} \cdot H_{twgg.U1.loc} \cdots + H_{twgf.U1} \cdot H_{twgf.U1.loc} + H_{twkey.OT.U1} \cdot H_{twkey.OT.U1.loc} + I_{U1} \cdot I_{U1.loc} \cdots + E_{act.OT.U1} \cdot E_{act.OT.U1.loc} + E_{pas.OT.U1} \cdot E_{pas.OT.U1.loc} + \Sigma M_{Q.E2.3} = -32890.09 \cdot kN \cdot m$$

Overturning Stability Analysis

$\Sigma M_{E2.OT.3} := \Sigma M_{V.E2.OT.3} + \Sigma M_{H.E2.OT.3} = 93618.49 \cdot kN \cdot m$

$X_{R.E2.3} := \frac{\Sigma M_{E2.OT.3}}{\Sigma V_{E2.OT.3}} = 8.73\,m$ $\quad x_{OT.E2.3} := X_{R.E2.3} - \frac{L_b}{2} = -0.52\,m$

Overturning Resultant Ratio

$Ratio_{OT.E2.3} := \frac{X_{R.E2.3}}{L_b} = 0.47$

$Ratio_{OT.E2.3.check} := \begin{cases} \text{"OKAY"} & \text{if } Ratio_{OT.E2.3} \ge Ratio_{overturning.allow.Extreme} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"OKAY"}$

$x_{OT.check.E2.3} := \begin{cases} \text{"OKAY"} & \text{if } \left|x_{OT.E2.3}\right| \le Kern \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"OKAY"}$

Summary of Results

E2 CASE

E2.1 Case

Sliding Factor of Safety: (Horizontal Plane)	$FS_{HorizSliding.E2.1} = 0.83$	
	$FS_{HorizSliding.E2.1.Check}$ = "Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !"	
Sliding Factor of Safety: (Inclined Plane)	$FS_{InclinedlSlidingE2.1} = 1.67$	$FS_{InclinedSliding.check.E2.1}$ = "OKAY "
Eccentricity: (Inclined Plane)	$e_{E2.1} = 0.82\,m$	$e_{check.E2.1}$ = "Okay"
Bearing Pressure At Heel: (Inclined Plane)	$\sigma_{heel.E2.1} = 55\cdot kPa$	$\sigma_{heel.E2.1.check}$ = "Okay"
Bearing Pressure At Toe: (Inclined Plane)	$\sigma_{toe.E2.1} = 94\cdot kPa$	$\sigma_{toe.E2.1.check.1}$ = "Okay"
Flotation Factor of Safety (horizontal plane)	$FS_{act.FE2.1} = 1.75$	$FS_{check.FE2.1}$ = "OKAY"
Overturning Resultant Ratio: (horizontal plane)	$Ratio_{OT.E2.1} = 0.45$	$Ratio_{OT.E2.1.check}$ = "OKAY"
Eccentricity: (horizontal plane)	$x_{OT.E2.1} = -1.00\,m$	$x_{OT.check.E2.1}$ = "OKAY"

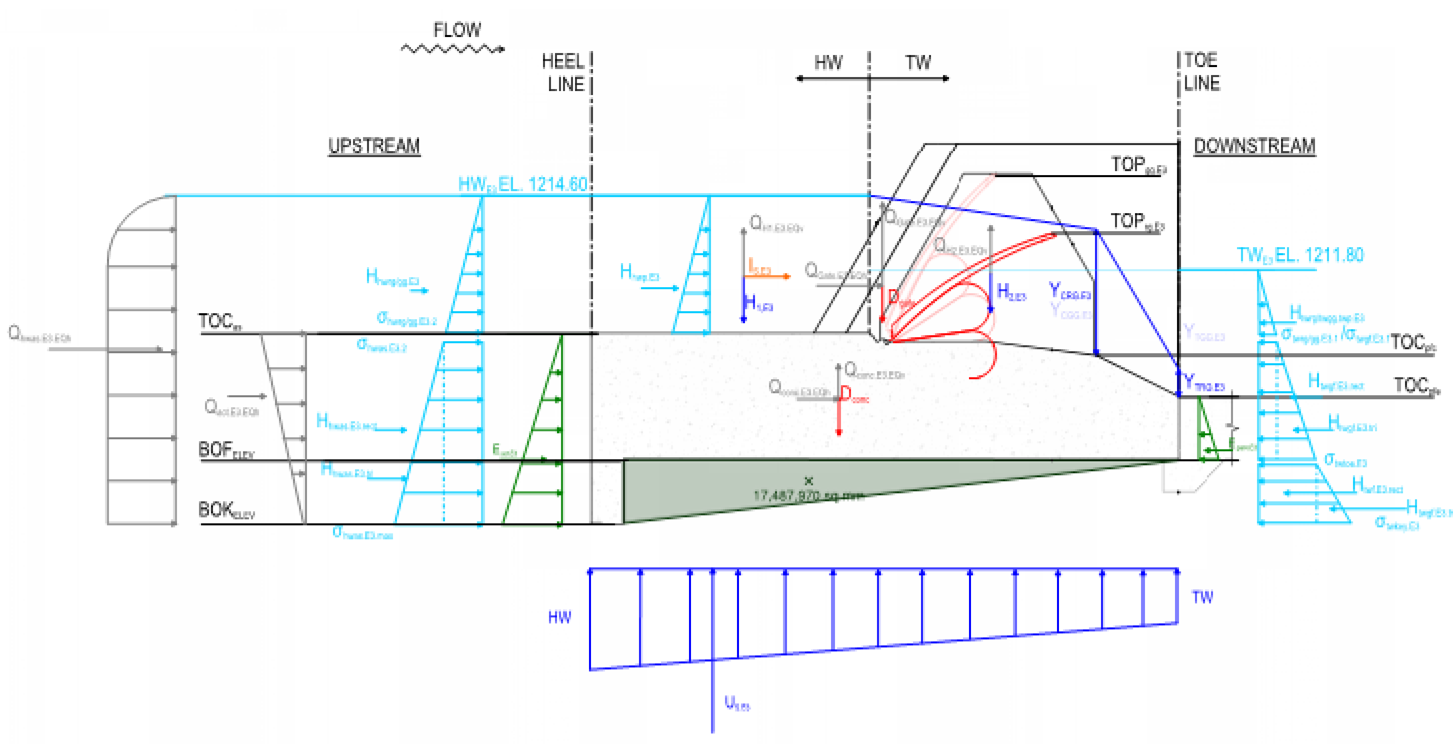
E2.2 Case

Sliding Factor of Safety: (Horizontal Plane)	$FS_{HorizSliding.E2.2} = 0.77$	
	$FS_{HorizSliding.E2.2.Check}$ = "Check Inclined Sliding Plane!"	
Sliding Factor of Safety: (Inclined Plane)	$FS_{InclinedlSlidingE2.2} = 1.56$	$FS_{InclinedSliding.check.E2.2}$ = "OKAY "
Eccentricity: (Inclined Plane)	$e_{E2.2} = 0.74\,m$	$e_{check.E2.2}$ = "Okay"
Bearing Pressure At Heel: (Inclined Plane)	$\sigma_{heel.E2.2} = 54\cdot kPa$	$\sigma_{heel.E2.2.check}$ = "Okay"
Bearing Pressure At Toe: (Inclined Plane)	$\sigma_{toe.E2.2} = 88\cdot kPa$	$\sigma_{toe.E2.2.check.1}$ = "Okay"
Flotation Factor of Safety (horizontal plane)	$FS_{act.FE2.2} = 1.7$	$FS_{check.FE2.2}$ = "OKAY"
Overturning Resultant Ratio: (horizontal plane)	$Ratio_{OT.E2.2} = 0.44$	$Ratio_{OT.E2.2.check}$ = "OKAY"
Eccentricity: (horizontal plane)	$x_{OT.E2.2} = -1.08\,m$	$x_{OT.check.E2.2}$ = "OKAY"

E2.3 Case

Sliding Factor of Safety: (Horizontal Plane)	$FS_{HorizSliding.E2.3} = 1.33$ $FS_{HorizSliding.E2.3.Check} = \text{"OKAY"}$	
Sliding Factor of Safety: (Inclined Plane)	$FS_{InclinedlSlidingE2.3} = 4.01$	$FS_{InclinedSliding.check.E2.3} = \text{"OKAY "}$
Eccentricity: (Inclined Plane)	$e_{E2.3} = 0.93\,m$	$e_{check.E2.3} = \text{"Okay"}$
Bearing Pressure At Heel: (Inclined Plane)	$\sigma_{heel.E2.3} = 48 \cdot kPa$	$\sigma_{heel.E2.3.check} = \text{"Okay"}$
Bearing Pressure At Toe: (Inclined Plane)	$\sigma_{toe.E2.3} = 88 \cdot kPa$	$\sigma_{toe.E2.3.check.1} = \text{"Okay"}$
Flotation Factor of Safety (horizontal plane)	$FS_{act.FE2.3} = 1.58$	$FS_{check.FE2.3} = \text{"OKAY"}$
Overturning Resultant Ratio: (horizontal plane)	$Ratio_{OT.E2.3} = 0.47$	$Ratio_{OT.E2.3.check} = \text{"OKAY"}$
Eccentricity: (horizontal plane)	$x_{OT.E2.3} = -0.52\,m$	$x_{OT.check.E2.3} = \text{"OKAY"}$

E3 DESIGN CASE



U2 CASE PLUS SEISMIC

ACCEPTANCE PARAMETERS

Required Factor of Safety for Sliding:	$FS_{req.E3.sl} := 1.0$	(Without Cohesion) (Section 8.1, Design Criteria)
Resultant Within Middle Half of Base:	$e \le \frac{L_b}{4} \wedge e \ge \frac{-L_b}{4}$	
Allowable Rock Bearing Pressure:	$\sigma_{allow.E3} := 1740 \cdot \frac{kN}{m^2}$	(Section 5.2, Design Criteria)

INPUT PARAMETERS

Headwater Elevation:	$HW_{E3} := 1214.60m$	(Section 8.3, Design Criteria)
Tailwater Elevation:	$TW_{E3} := 1211.80m$	(Section 8.3, Design Criteria)
Bottom of Footing Elevation:	$BOF_{elev} = 1206.00\,m$	
Approach Slab Top of Concrete Elevation at Upstream Face:	$TOC_{as} = 1210.00\,m$	
Pier Footing Top of Concrete Elevation at Stilling Basin:	$TOC_{pfe} = 1208.00\,m$	
Pier Footing Top of Concrete Elevation at Center of Footing:	$TOC_{pfc} = 1209.30\,m$	
Top of Regulating Gate Elevation:	$TOP_{rg.U2} = 1212.10\,m$	Gates are open when top of gate elevation is at 1210.00m
Top of Guard Gate Elevation:	$TOP_{gg.U2} = 1215.00\,m$	Gates are closed/up when top of gate elevation is at 1215.0m
Bottom of Key Elevation:	$BOK_{elev} = 1204\,m$	

SEISMIC LOAD (Three combinations of E_h and E_v considered)

E3.1 CASE

Seismic Case $Q_{E3.1}$ - 100% Horizontal Seismic Force, No Vertical

Include Seismic Load in Analysis? $Eq_{E3.1} := 1$ 0 = No, 1 = Yes

Horizontal Seismic Coefficient: $K_{h.E3.1} := -0.17$

Vertical Seismic Coefficient: $K_{v.E3.1} := -0.00$

Vertical Tailwater on Approach Slab: $H_{2.U2} := H_{2.U2.gg} + H_{2.U2.rg} = 3556.81 \cdot kN$

Acting At: $H_{2.U2.loc} := \dfrac{H_{2.U2.gg} \cdot H_{2.U2.gg.loc} + H_{2.U2.rg} \cdot H_{2.U2.rg.loc}}{H_{2.U2}} = 5.34 \cdot m$

HORIZONTAL SEISMIC LOADS	**Loads**	**Moment Arm**
Horiz Seismic Component of Concrete:	$Q_{conc.E3.EQh.1} := D_{conc} \cdot K_{h.E3.1} \cdot Eq_{E3.1} = -3814.6 \cdot kN$	$Y_{conc.loc} = 2.43\,m$
Horiz Seismic Component of Gates:	$Q_{Gate.E3.EQh.1} := D_{Gate} \cdot K_{h.E3.1} \cdot Eq_{E3.1} = -23.8 \cdot kN$	$Y_{gate} = 3.90\,m$
Horizontal Seismic Component of Headwater - Sliding:	$Q_{hwas.E3.EQh.1} := \left(\frac{7}{12}\right) \cdot K_{h.E3.1} \cdot \gamma_w \cdot \left(HW_{U2} - BOK_{elev}\right)^2 \cdot W_{hwas.U2} \cdot Eq_{E3.1} = -1311.7 \cdot kN$	$Y_{HWg.E3} := 0.4 \cdot \left(HW_{U2} - BOK_{elev}\right) - d_{key} = 2.24\,m$
Horizontal Seismic Component of Soil (Woods Method) - Overturning:	$Q_{act.E3.EQh.1.OT} := \left(\gamma_r - \gamma_w\right) \cdot \left(TOC_{as} - BOK_{elev}\right)^2 \cdot K_{h.E3.1} \cdot W_{hwas.U2} \cdot Eq_{E3.1} = -895.2 \cdot kN$	$Y_{E.act.E3.OT} := 0.63 \cdot \left(TOC_{as} - BOK_{elev}\right) - d_{key} = 1.78\,m$
Horizontal Seismic Component of Soil (Woods Method)	$Q_{act.E3.EQh.1} := \left(\gamma_r - \gamma_w\right) \cdot \left(TOC_{as} - BOF_{elev}\right)^2 \cdot K_{h.E3.1} \cdot W_{hwas.U2} \cdot Eq_{E3.1} = -397.9 \cdot kN$	$Y_{E.act.E3} := 0.63 \cdot \left(TOC_{as} - BOF_{elev}\right) = 2.52\,m$

VERTICAL SEISMIC LOADS	**Loads**	**Moment Arm**
Vertical Component of Concrete:	$Q_{conc.E3.EQv.1} := D_{conc} \cdot K_{v.E3.1} \cdot Eq_{E3.1} = 0.0 \cdot kN$	$X_{conc.loc} = 9.35\,m$
Vertical Component of Gate:	$Q_{Gate.E3.EQv.1} := D_{Gate} \cdot K_{v.E3.1} \cdot Eq_{E3.1} = 0.0 \cdot kN$	$X_{gate} = 9.50\,m$
Vertical Seismic Component of Headwater over Apron Slab:	$Q_{H1.E3.EQv.1} := K_{v.E3.1} \cdot H_{1.U2} \cdot Eq_{E3.1} = 0.0 \cdot kN$	$H_{1.U2.loc} = 14.13\,m$
Vertical Seismic Component of Headwater over Pier Footing:	$Q_{H2.E3.EQv.1} := K_{v.E3.1} \cdot H_{2.U2} \cdot Eq_{E3.1} = 0.0 \cdot kN$	$H_{2.U2.loc} = 5.34\,m$

$$\Sigma H_{Q.E3.EQh.1} := Q_{conc.E3.EQh.1} + Q_{Gate.E3.EQh.1} + Q_{hwas.E3.EQh.1} + Q_{act.E3.EQh.1} = -5547.95 \cdot kN$$

$$\Sigma H_{Q.E3.EQh.1.OT} := Q_{conc.E3.EQh.1} + Q_{Gate.E3.EQh.1} + Q_{hwas.E3.EQh.1} + Q_{act.E3.EQh.1.OT} = -6045.3 \cdot kN$$

$$\Sigma V_{Q.E3.EQv.1} := Q_{conc.E3.EQv.1} + Q_{Gate.E3.EQv.1} + Q_{H1.E3.EQv.1} + Q_{H2.E3.EQv.1} = 0.0 \cdot kN$$

$$\begin{aligned}\Sigma M_{Q.E3.1} := {} & Q_{conc.E3.EQh.1} \cdot Y_{conc.loc} + Q_{Gate.E3.EQh.1} \cdot Y_{gate} + Q_{hwas.E3.EQh.1} \cdot Y_{HWg.E3} \cdots \\ & + Q_{act.E3.EQh.1.OT} \cdot Y_{E.act.E3.OT} + Q_{conc.E3.EQv.1} \cdot X_{conc.loc} + Q_{Gate.E3.EQv.1} \cdot X_{gate} \cdots \\ & + Q_{H1.E3.EQv.1} \cdot H_{1.U2.loc} + Q_{H2.E3.EQv.1} \cdot H_{2.U2.loc} = -13888.58 \cdot kN \cdot m\end{aligned}$$

E3.1 CASE

STABILITY ASSESSMENT (SLIDNG, BEARING, FLOTATION AND OVERTURNING):

CHECK SLIDING ALONG HORIZONTAL PLANE THRU TOE,
IGNORING BEDROCK MOBILIZED BY STRUCTURAL HEEL KEY, OR VOID BEHIND KEY

Sum of Vertical Forces:

$\Sigma V_{E3.1} := \Sigma V_{U2} + \Sigma V_{Q.E3.EQv.1} = 13015.7 \cdot kN$

Sum of Horizontal Forces:

$\Sigma H_{E3.1} := \Sigma H_{U2} - I_{U2} + \Sigma H_{Q.E3.EQh.1} = -10082.63 \cdot kN$

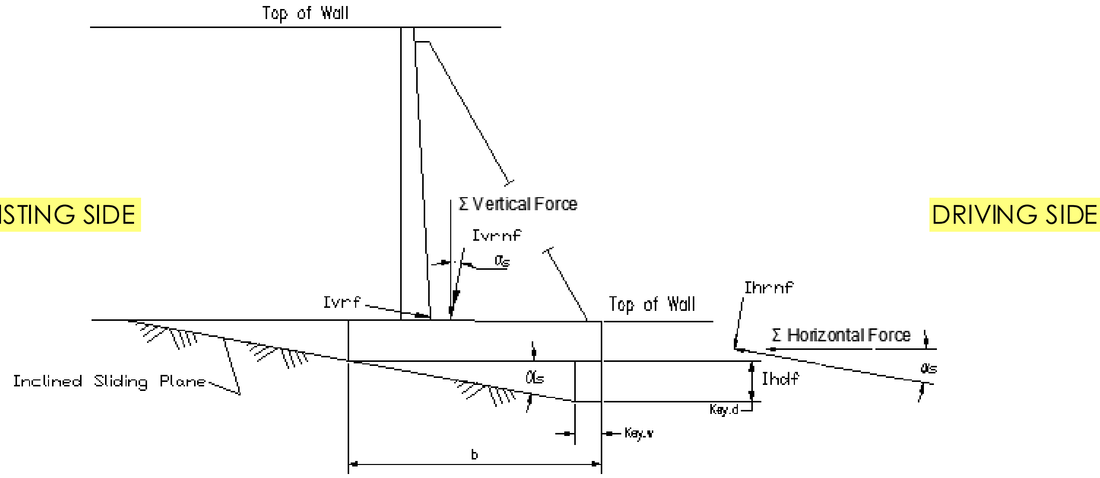
Sliding Factor of Safety:

$$FS_{HorizSliding.E3.1} := \frac{\tan_{\phi} \cdot \Sigma V_{E3.1}}{\left|\Sigma H_{E3.1}\right|} = 0.63$$

d Key) F $FS_{HorizSliding.E3.1.Check} :=$ | "OKAY" if $FS_{HorizSliding.E3.1} \geq FS_{req.E3.sl}$
"Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !" otherwise

$FS_{HorizSliding.E3.1.Check}$ = "Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !"

CHECK SLIDING ALONG INCLINED SLIDING PLANE FROM HEEL KEY TO TOE,
WITH BEDROCK MASS MOBILIZED BY REINFOCREDE CONCRETE KEY)



$\alpha s = 0.11$

as degrees= $\alpha s \cdot \left(\frac{180}{\pi}\right) = 6.52$

$V_{rs} = 4620 \cdot kN$

Resolve $\Sigma Vert_{E3.1}$ & $\Sigma Horiz_{E3.1}$

$$\Sigma V_{InclinedE3.1} := \cos(\alpha s) \cdot \left(\Sigma V_{E3.1} + V_{rs}\right) + \sin(\alpha s) \cdot \left|\Sigma H_{E3.1}\right| = 18666.5 \cdot kN$$

$$\Sigma H_{InclinedE3.1} := \cos(\alpha s) \cdot \left|\Sigma H_{E3.1}\right| - \sin(\alpha s) \cdot \left(\Sigma V_{E3.1} + V_{rs}\right) = 8015.0 \cdot kN$$

Inclined Sliding Plane Length

$L_{incline} = 18.61\ m$

Safety Factor for Sliding
Inclined Failure Plane

$$FS_{InclinedlSlidingE3.1} := \frac{\Sigma V_{InclinedE3.1} \cdot \tan\left(\phi_{rock} \cdot \frac{\pi}{180}\right)}{\left|\Sigma H_{InclinedE3.1}\right|} = 1.14$$

$FS_{InclinedSliding.check.E3.1} :=$ | "OKAY " if $FS_{InclinedlSlidingE3.1} > FS_{req.E3.sl}$ = "OKAY "
"Revise Structure"" otherwise

$FS_{InclinedSliding.check.E3.1}$ = "OKAY "

E3.1 CASE

OVERTURNING STABILITY CHECK:

CHECK ECCENTRICITY

Sum of the moments:

$$\Sigma M_{E3.1} := \left(\Sigma M_{U2} + \Sigma M_{Q.E3.1}\right) = 137389 \cdot kN \cdot m$$

Eccentricity:

$$e_{E3.1} := \left(\frac{L_{incline}}{2}\right) - \frac{\left(\Sigma M_{E3.1}\right)}{\Sigma V_{InclinedE3.1}} = 1.94\,m$$

Eccentricity Check:

$$e_{check.E3.1} := \begin{cases} \text{"Okay"} & \text{if } e_{E3.1} \le Kern \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$$e_{check.E3.1} = \text{"Okay"}$$

Foundation Bearing Checks:

Bearing Pressure at Heel:

$$\sigma_{heel.E3.1} := \frac{\Sigma V_{InclinedE3.1}}{A_{b.incline}} - \frac{\left(\Sigma V_{InclinedE3.1} \cdot e_{E3.1}\right)}{S_{b.incline}} = 31.2 \cdot \frac{kN}{m^2}$$

$$\sigma_{heel.E3.1.check} := \left(\begin{cases} \text{"Okay"} & \text{if } \sigma_{heel.E3.1} \le \sigma_{allow.E3} \\ \text{"Revise Structure"} & \text{if } \sigma_{heel.E3.1} < 0\,\frac{kN}{m^2} \end{cases}\right)$$

$$\sigma_{heel.E3.1.check} = \text{"Okay"}$$

Bearing Pressure at Toe:

$$\sigma_{toe.E3.1} := \frac{\Sigma V_{InclinedE3.1}}{A_{b.incline}} + \frac{\left(\Sigma V_{InclinedE3.1} \cdot e_{E3.1}\right)}{S_{b.incline}} = 136.0 \cdot \frac{kN}{m^2}$$

$$\sigma_{toe.E3.1.check.1} := \begin{cases} \text{"Okay"} & \text{if } \sigma_{toe.E3.1} \le \sigma_{allow.E3} \\ \text{"Revise Structure"} & \text{if } \sigma_{toe.E3.1} < 0\,\frac{kN}{m^2} \end{cases}$$

$$\sigma_{toe.E3.1.check.1} = \text{"Okay"}$$

FLOATATION ANALYSIS:

ACCEPTANCE PARAMETERS

Required Factor of Safety: $FS_{req.FE3.1} := 1.1$

VERTICAL LOADS RESISTING:

Dead Load: $\Sigma V_{DL} = 22578.74 \cdot kN$

Water Weight H1+H2: $\Sigma V_{H.FE3.1} := \Sigma V_{H.FU2} + \Sigma V_{Q.E3.EQv.1} = 8295.04 \cdot kN$

Summation Vertical Resisting: $\Sigma V_{FE3.1} := \Sigma V_{DL} + \Sigma V_{H.FE3.1} = 30873.8 \cdot kN$

VERTICAL LOADS UPLIFT:

Uplift: $U_{U2} = -17858.12 \cdot kN$

Factor of Safety Floatation:

$$FS_{act.FE3.1} := \frac{\Sigma V_{FE3.1}}{\left|U_{U2}\right|} = 1.73$$

$$FS_{check.FE3.1} := \begin{cases} \text{"OKAY"} & \text{if } FS_{act.FE3.1} \ge FS_{req.FE3.1} \\ \text{"ANCHORS REQUIRED"} & \text{if } FS_{act.FE3.1} < FS_{req.FE3.1} \end{cases} = \text{"OKAY"}$$

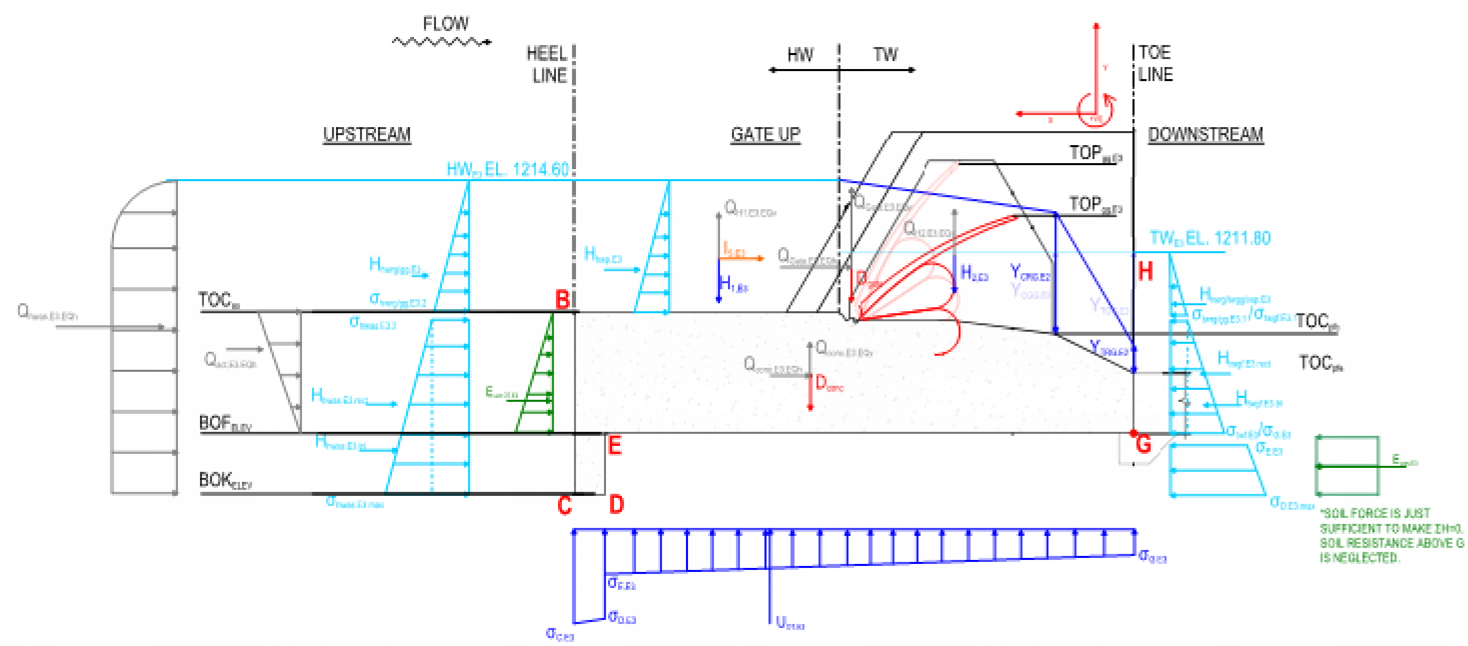
MONOLITH OVERTURNING STABILITY ANALYSIS

E3.1 CASE

Seismic Case $Q_{E3.1}$: 100% Horizontal Seismic Force, No Vertical

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.
Assumptions are made in order to compute overturning stability of indetermine forces on monolith with key;
(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.
(b) The horizontal resisting force acting on the key, P.key, is that required for static equilibrium
(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1 $Ratio_{overturning.allow.Extreme} = 0$ Resultant within Base



All Vertical Loads Applicable to Overturning Stability Analysis

Total Concrete Dead Loads:	$D_{conc} = 22438.74 \cdot kN$	at:	$X_{conc.loc} = 9.35\,m$
Dead Load of Gate:	$D_{Gate} = 140.0 \cdot kN$		$X_{gate} = 9.50\,m$
Water Weight (HW) on Apron Slab:	$H_{1.U2} = 4738.2 \cdot kN$		$H_{1.U2.loc} = 14.13\,m$
Water Weight (TW) on Gate Footing:	$H_{2.U2} = 3556.8 \cdot kN$		$H_{2.U2.loc} = 5.34\,m$
Uplift Load for Overturning Analysis:	$U_{OT.U2} = -15650.44 \cdot kN$		$U_{OT.U2.loc} = 9.94 \cdot m$
Vertical Seismic Component of Concrete Structure:	$Q_{conc.E3.EQv.1} = 0$		$X_{conc.loc} = 9.35\,m$
Vertical Seismic Component of Crest Gate:	$Q_{Gate.E3.EQv.1} = 0$		$X_{gate} = 9.50\,m$
Vertical Seismic Component of Headwater over Apron Slab:	$Q_{H1.E3.EQv.1} = 0$		$H_{1.U2.loc} = 14.13\,m$
Vertical Seismic Component of Headwater over Fixed Crest Slab:	$Q_{H2.E3.EQv.1} = 0$		$H_{2.U2.loc} = 5.34\,m$

Sum of All Overturning Analysis Vertical Load:

$$\Sigma V_{E3.OT.1} := D_{conc} + D_{Gate} + H_{1.U2} + H_{2.U2} + U_{OT.U2} + \Sigma V_{Q.E3.EQv.1} = 15223.34 \cdot kN$$

Sum of All Overturning Analysis Vertical Load Moments:

$$\Sigma M_{V.E3.OT.1} := D_{conc} \cdot X_{conc.loc} + D_{Gate} \cdot X_{gate} + H_{1.U2} \cdot H_{1.U2.loc} + H_{2.U2} \cdot H_{2.U2.loc} + U_{OT.U2} \cdot U_{OT.U2.loc} = 141433.2 \cdot kN \cdot m$$

Lateral Driving Earth Loads for Overturning Stability Analysis (at rest condition)

E3.1 CASE

Depth of Driving Soil Loads (to top of key): $h_{E.OT.E3.1} := TOC_{as} - BOF_{elev} = 4\ m$

Applicable Soil Load: $E_{act.OT.E3.1} := \frac{\left(K_{o.U2} \cdot h_{E.OT.U2}^{\ 2}\right)}{2} \cdot \left(\gamma_r - \gamma_w\right) \cdot W_{hwas.U2} \cdot -1 = -769.99 \cdot kN$

At Rest- Soil Load Acting from Toe: $E_{act.OT.E3.1.loc} := \frac{h_{E.OT.U2}}{3} = 1.33\ m$

All Lateral Loads Applicable to Overturning Stability Analysis

HW Lateral Load on Approach Slab:	$H_{hwas.U2} = -5368.0 \cdot kN$	$H_{hwas.U2.loc} = 0.61\ m$
HW Lateral Load on Guard Gate:	$H_{hwgg.U2} = -518.9 \cdot kN$	$H_{hwgg.U2.loc} = 5.53\ m$
TW Lateral Load on Guard Gate:	$H_{twgg.U2} = 79.5 \cdot kN$	$H_{twgg.U2.loc} = 4.60\ m$
TW Lateral Load on Gate Footing (No Key - Overturning Values Adjusted):	$H_{twgf.U2} = 1789.34 \cdot kN$	$H_{twgf.U2.loc} = 1.65\ m$
TW Lateral Load on Key:	$H_{twkey.OT.U2} = 2195.91 \cdot kN$	$H_{twkey.OT.U2.loc} = -1.04\ m$
Ice / Impact Load:	$I_{U2} = -1050.0 \cdot kN$	$I_{U2.loc} = 8.30\ m$
Lateral Soil Load (driving):	$E_{act.OT.U2} = -770.0 \cdot kN$	$E_{act.OT.U2.loc} = 1.33\ m$
Horizontal Seismic Component of Concrete Structure:	$Q_{conc.E3.EQh.1} = -3814.59 \cdot kN$	$Y_{conc.loc} = 2.43\ m$
Horizontal Seismic Component of Vertical Lift Gate:	$Q_{Gate.E3.EQh.1} = -23.8 \cdot kN$	$Y_{gate} = 3.90\ m$
Horizontal Seismic Component of Headwater on Slab Footing:	$Q_{hwas.E3.EQh.1} = -1311.68 \cdot kN$	$Y_{HWg.E3} = 2.24\ m$
Horizontal Seismic Component of Active Soil: (Section 5-5, USACE EM_1110-2-2100)	$Q_{act.E3.EQh.1} = -397.88 \cdot kN$	$Y_{E.act.E3} = 2.52\ m$

Resisting Lateral Soil Load as required to produce horizontal equilibrium:

$$E_{pas.OT.E3.1} := -\left(H_{hwas.U2} + H_{hwgg.U2} + H_{twgg.U2} + H_{twgf.U2} + H_{twkey.OT.U2} + I_{U2} + E_{act.OT.U2} + \Sigma H_{Q.E3.EQh.1}\right) = 9190.21 \cdot kN$$

Acting at: $E_{pas.OT.E3.1.loc} := -1 \cdot \frac{d_{key}}{2} = -1\ m$

Sum of All Overturning Analysis Horizontal Load (ΣH=0):

$$\Sigma H_{E3.OT.1} := H_{hwas.U2} + H_{hwgg.U2} + H_{twgg.U2} + H_{twgf.U2} + H_{twkey.OT.U2} + I_{U2} + E_{act.OT.U2} + E_{pas.OT.E3.1} + \Sigma H_{Q.E3.EQh.1} = 0 \cdot kN$$

Sum of All Overturning Analysis Horizontal Load Moments:

$$\Sigma M_{H.E3.OT.1} := H_{hwas.U2} \cdot H_{hwas.U2.loc} + H_{hwgg.U2} \cdot H_{hwgg.U2.loc} + H_{twgg.U2} \cdot H_{twgg.U2.loc} \ldots + H_{twgf.U2} \cdot H_{twgf.U2.loc} + H_{twkey.OT.U2} \cdot H_{twkey.OT.U2.loc} + I_{U2} \cdot I_{U2.loc} \ldots + E_{act.OT.U2} \cdot E_{act.OT.U2.loc} + E_{pas.OT.U2} \cdot E_{pas.OT.U2.loc} + \Sigma M_{Q.E3.1} = -33093.17 \cdot kN \cdot m$$

Overturning Stability Analysis

$\Sigma M_{E3.OT.1} := \Sigma M_{V.E1.OT} + \Sigma M_{H.E1.OT} = 125569.74 \cdot kN \cdot m$

$X_{R.E3.1} := \frac{\Sigma M_{E3.OT.1}}{\Sigma V_{E3.OT.1}} = 8.25\ m$ $\qquad x_{OT.E3.1} := X_{R.E3.1} - \frac{L_b}{2} = -1\ m$

Overturning Resultant Ratio

$Ratio_{OT.E3.1} := \frac{X_{R.E3.1}}{L_b} = 0.45$

$Ratio_{OT.E3.1.check} :=$ | "OKAY" if $Ratio_{OT.E3.1} \geq Ratio_{overturning.allow.Extreme}$ = "OKAY"
| "Revise Structure" otherwise

$x_{OT.check.E3.1} :=$ | "OKAY" if $\left|x_{OT.E3.1}\right| \leq Kern$ = "OKAY"
| "Revise Structure" otherwise

Seismic Case $Q_{E3.2}$ - 100% Horizontal Seismic Force, 30% Vertical

E3.2 CASE

Include Seismic Load in Analysis? $Eq_{E3.2} := 1$ 0 = No, 1 = Yes

Horizontal Seismic Coefficient: $K_{h.E3.2} := -0.17$

Vertical Seismic Coefficient: $K_{v.E3.2} := -0.03$

HORIZONTAL SEISMIC LOADS	Loads	Moment Arm
Horiz Seismic Component of Concrete:	$Q_{conc.E3.EQh.2} := D_{conc} \cdot K_{h.E3.2} \cdot Eq_{E3.2} = -3814.6 \cdot kN$	$Y_{conc.loc} = 2.43\,m$
Horiz Seismic Component of Gates:	$Q_{Gate.E3.EQh.2} := D_{Gate} \cdot K_{h.E3.2} \cdot Eq_{E3.2} = -23.8 \cdot kN$	$Y_{gate} = 3.90\,m$
Horizontal Seismic Component of Headwater - Sliding:	$Q_{hwas.E3.EQh.2} := \left(\frac{7}{12}\right) \cdot K_{h.E3.2} \cdot \gamma_w \cdot \left(HW_{U2} - BOK_{elev}\right)^2 \cdot W_{hwas.U2} \cdot Eq_{E3.2} = -1311.7 \cdot kN$	$Y_{HWg.E3} = 2.24\,m$
Horizontal Seismic Component of Soil (Woods Method) - Overturning:	$Q_{act.E3.EQh.2.OT} := \left(\gamma_r - \gamma_w\right) \cdot \left(TOC_{as} - BOK_{elev}\right)^2 \cdot K_{h.E3.2} \cdot W_{hwas.U2} \cdot Eq_{E3.2} = -895.2 \cdot kN$	$Y_{E.act.E3.OT} = 1.78\,m$
Horizontal Seismic Component of Soil (Woods Method)	$Q_{act.E3.EQh.2} := \left(\gamma_r - \gamma_w\right) \cdot \left(TOC_{as} - BOF_{elev}\right)^2 \cdot K_{h.E3.2} \cdot W_{hwas.U2} \cdot Eq_{E3.2} = -397.9 \cdot kN$	$Y_{E.act.E3} = 2.52\,m$

VERTICAL SEISMIC LOADS	Loads	Moment Arm
Vertical Component of Concrete:	$Q_{conc.E3.EQv.2} := D_{conc} \cdot K_{v.E3.2} \cdot Eq_{E3.2} = -673.2 \cdot kN$	$X_{conc.loc} = 9.35\,m$
Vertical Component of Gate:	$Q_{Gate.E3.EQv.2} := D_{Gate} \cdot K_{v.E3.2} \cdot Eq_{E3.2} = -4.2 \cdot kN$	$X_{gate} = 9.50\,m$
Vertical Seismic Component of Headwater over Apron Slab:	$Q_{H1.E3.EQv.2} := K_{v.E3.2} \cdot H_{1.U2} \cdot Eq_{E3.2} = -142.1 \cdot kN$	$H_{1.U2.loc} = 14.13\,m$
Vertical Seismic Component of Headwater over Pier Footing:	$Q_{H2.E3.EQv.2} := K_{v.E3.2} \cdot H_{2.U2} \cdot Eq_{E3.2} = -106.7 \cdot kN$	$H_{2.U2.loc} = 5.34\,m$

$$\Sigma H_{Q.E3.EQh.2} := Q_{conc.E3.EQh.2} + Q_{Gate.E3.EQh.2} + Q_{hwas.E3.EQh.2} + Q_{act.E2.EQh.2} = -5547.95 \cdot kN$$

$$\Sigma H_{Q.E3.EQh.2.OT} := Q_{conc.E3.EQh.2} + Q_{Gate.E3.EQh.2} + Q_{hwas.E3.EQh.2} + Q_{act.E3.EQh.2.OT} = -6045.3 \cdot kN$$

$$\Sigma V_{Q.E3.EQv.2} := Q_{conc.E3.EQv.2} + Q_{Gate.E3.EQv.2} + Q_{H1.E3.EQv.2} + Q_{H2.E3.EQv.2} = -926.2 \cdot kN$$

$$\begin{aligned}\Sigma M_{Q.E3.2} := {} & Q_{conc.E3.EQh.2} \cdot Y_{conc.loc} + Q_{Gate.E3.EQh.2} \cdot Y_{gate} + Q_{hwas.E3.EQh.2} \cdot Y_{HWg.E3} \cdots \\ & + Q_{act.E3.EQh.2.OT} \cdot Y_{E.act.E3.OT} + Q_{conc.E3.EQv.2} \cdot X_{conc.loc} + Q_{Gate.E3.EQv.2} \cdot X_{gate} \cdots \\ & + Q_{H1.E3.EQv.2} \cdot H_{1.U2.loc} + Q_{H2.E3.EQv.2} \cdot H_{2.U2.loc} \end{aligned} = -22799.33 \cdot kN \cdot m$$

STABILITY ASSESSMENT (SLIDNG, BEARING, FLOTATION AND OVERTURNING):

E3.2 CASE

CHECK SLIDING ALONG HORIZONTAL PLANE THRU TOE,
IGNORING BEDROCK MOBILIZED BY STRUCTURAL HEEL KEY, OR VOID BEHIND KEY

Sum of Vertical Forces:

$\Sigma V_{E3.2} := \Sigma V_{U2} + \Sigma V_{Q.E3.EQv.2} = 12089.4 \cdot kN$

Sum of Horizontal Forces:

$\Sigma H_{E3.2} := \Sigma H_{U2} - I_{U2} + \Sigma H_{Q.E3.EQh.2} = -10082.63 \cdot kN$

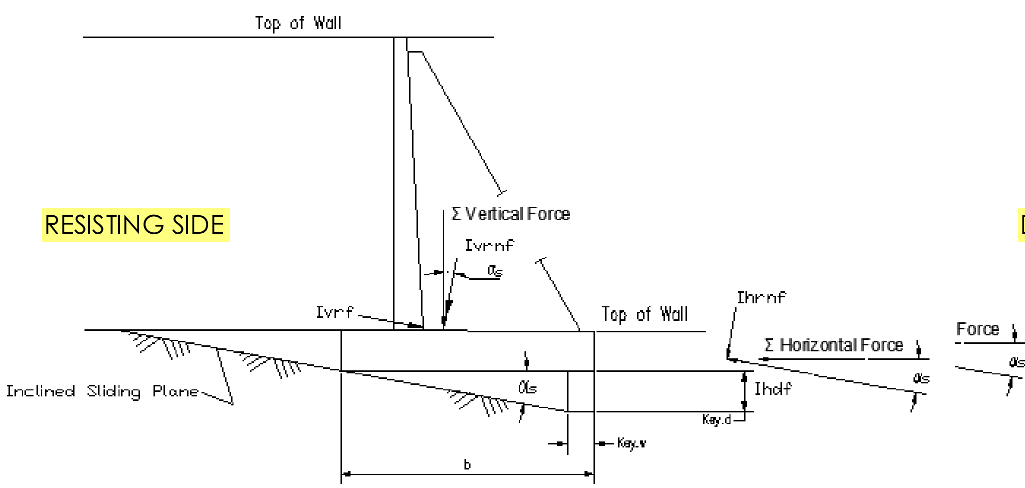
Sliding Factor of Safety:

$$FS_{HorizSliding.E3.2} := \frac{\tan_{\phi} \cdot \Sigma V_{E3.2}}{\left|\Sigma H_{E3.2}\right|} = 0.58$$

$$FS_{HorizSliding.E3.2.Check} := \begin{array}{|l} \text{"OKAY"} \quad \text{if} \quad FS_{HorizSliding.E3.2} \geq FS_{req.E3.sl} \\ \text{"Check Inclined Sliding Plane!"} \quad \text{otherwise} \end{array}$$

$FS_{HorizSliding.E3.2.Check} =$ "Check Inclined Sliding Plane!"

CHECK SLIDING ALONG INCLINED SLIDING PLANE FROM HEEL KEY TO TOE,
WITH BEDROCK MASS MOBILIZED BY REINFOCREDE CONCRETE KEY)



$\Sigma V_{E3.2} = 12089.44 \cdot kN$

$V_{rs} = 4620 \cdot kN$

TOE

Ivrf=Inclined Resisting Force
Ivrnf=Inclined Resisting Normal Force
Ihrnf=Inclined Resisting Normal Force
Ihdf=Inclined Driving Force

$\alpha s = 0.11$

as degrees= $\alpha s \cdot \left(\frac{180}{\pi}\right) = 6.52$

Resolve $\Sigma Vert_{E3.2}$ & $\Sigma Horiz_{E3.2}$

$$\Sigma V_{InclinedE3.2} := \cos(\alpha s) \cdot \left(\Sigma V_{E3.2} + V_{rs}\right) + \sin(\alpha s) \cdot \left|\Sigma H_{E3.2}\right| = 17746.2 \cdot kN$$

$$\Sigma H_{InclinedE3.2} := \cos(\alpha s) \cdot \left|\Sigma H_{E3.2}\right| - \sin(\alpha s) \cdot \left(\Sigma V_{E3.2} + V_{rs}\right) = 8120.1 \cdot kN$$

(With properly engineered reinforced concrete Key, horizontal sliding plane thru Toe is protected, critical sliding plane is relocated to the INCLINED SLIDING PLANE FROM HEEL KEY To TOE, Bedrock Mass above this examined plane is mobilized by reinforced concrete key and combined into Structural Wedge.)

Inclined Sliding Plane Length $L_{incline} = 18.61\ m$

Safety Factor for Sliding
Inclined Failure Plane

$$FS_{InclinedISlidingE3.2} := \frac{\Sigma V_{InclinedE3.2} \cdot \tan\left(\phi_{rock} \cdot \frac{\pi}{180}\right)}{\left|\Sigma H_{InclinedE3.2}\right|} = 1.07$$

$$FS_{InclinedSliding.check.E3.2} := \begin{array}{|l} \text{"OKAY "} \quad \text{if} \quad FS_{InclinedISlidingE3.2} > FS_{req.E3.sl} \\ \text{"Revise Structure""} \quad \text{otherwise} \end{array} = \text{"OKAY "}$$

$FS_{InclinedSliding.check.E3.2} =$ "OKAY "

E3.2 CASE

OVERTURNING STABILITY CHECK:

CHECK ECCENTRICITY

Sum of the moments:

$$\Sigma M_{E3.2} := \left(\Sigma M_{U2} + \Sigma M_{Q.E3.2}\right) = 128478 \cdot kN \cdot m$$

Eccentricity:

$$e_{E3.2} := \left(\frac{L_{incline}}{2}\right) - \frac{\left(\Sigma M_{E3.2}\right)}{\Sigma V_{InclinedE3.2}} = 2.06\,m$$

Eccentricity Check:

$$e_{check.E3.2} := \begin{cases} \text{"Okay"} & \text{if } e_{E3.2} \le Kern \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$$e_{check.E3.2} = \text{"Okay"}$$

Foundation Bearing Checks:

Bearing Pressure at Heel:

$$\sigma_{heel.E3.2} := \frac{\Sigma V_{InclinedE3.2}}{A_{b.incline}} - \frac{\left(\Sigma V_{InclinedE3.2} \cdot e_{E3.2}\right)}{S_{b.incline}} = 26.6 \cdot \frac{kN}{m^2}$$

$$\sigma_{heel.E3.2.check} := \left(\begin{cases} \text{"Okay"} & \text{if } \sigma_{heel.E3.2} \le \sigma_{allow.E3} \\ \text{"Revise Structure"} & \text{if } \sigma_{heel.E3.2} < 0\,\frac{kN}{m^2} \end{cases}\right)$$

$$\sigma_{heel.E3.2.check} = \text{"Okay"}$$

Bearing Pressure at Toe:

$$\sigma_{toe.E3.2} := \frac{\Sigma V_{InclinedE3.2}}{A_{b.incline}} + \frac{\left(\Sigma V_{InclinedE3.2} \cdot e_{E3.2}\right)}{S_{b.incline}} = 132.4 \cdot \frac{kN}{m^2}$$

$$\sigma_{toe.E3.2.check.1} := \begin{cases} \text{"Okay"} & \text{if } \sigma_{toe.E3.2} \le \sigma_{allow.E3} \\ \text{"Revise Structure"} & \text{if } \sigma_{toe.E3.2} < 0\,\frac{kN}{m^2} \end{cases}$$

$$\sigma_{toe.E3.2.check.1} = \text{"Okay"}$$

FLOATATION ANALYSIS:

ACCEPTANCE PARAMETERS

Required Factor of Safety: $FS_{req.FE3.2} := 1.1$

VERTICAL LOADS RESISTING:

Dead Load: $\Sigma V_{DL} = 22578.74 \cdot kN$

Water Weight H1+H2: $\Sigma V_{H.FE3.2} := \Sigma V_{H.FU2} + \Sigma V_{Q.E3.EQv.2} = 7368.83 \cdot kN$

Summation Vertical Resisting: $\Sigma V_{FE3.2} := \Sigma V_{DL} + \Sigma V_{H.FE3.2} = 29947.6 \cdot kN$

VERTICAL LOADS UPLIFT:

Uplift: $U_{U2} = -17858.12 \cdot kN$

Factor of Safety Floatation:

$$FS_{act.FE3.2} := \frac{\Sigma V_{FE3.2}}{\left|U_{U2}\right|} = 1.68$$

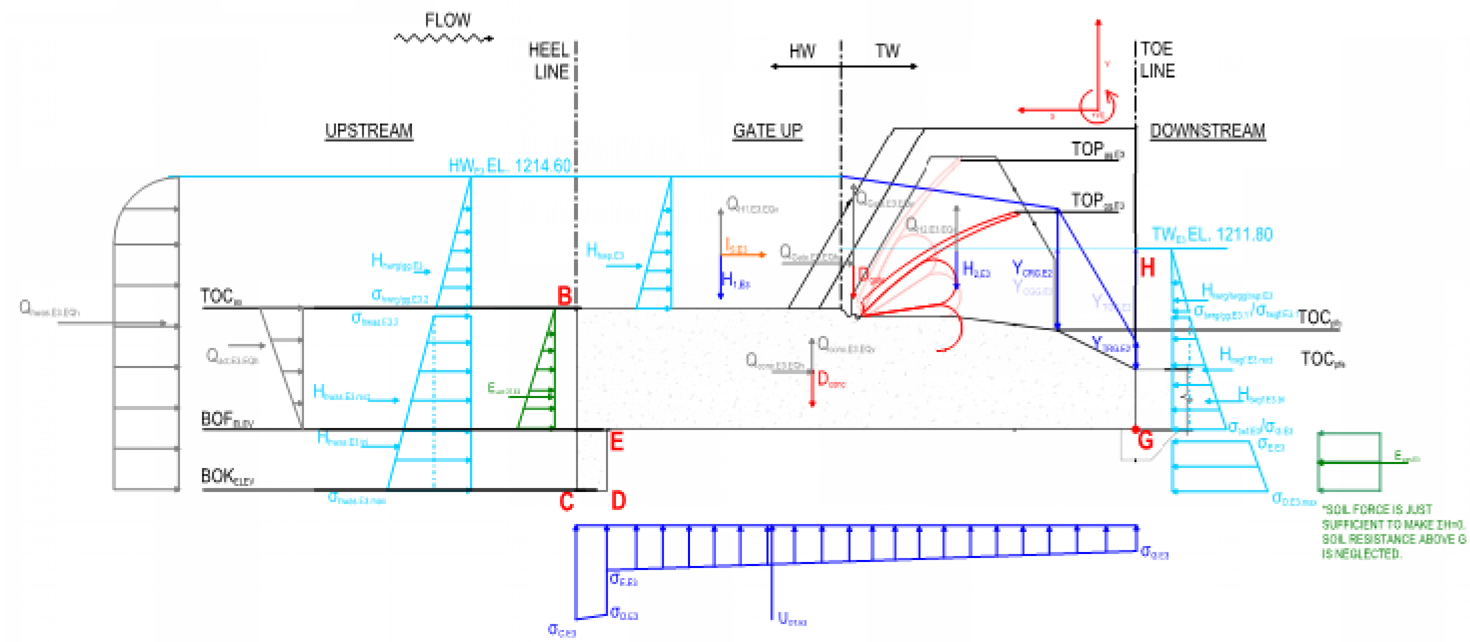
$$FS_{check.FE3.2} := \begin{cases} \text{"OKAY"} & \text{if } FS_{act.FE3.2} \ge FS_{req.FE3.2} \\ \text{"ANCHORS REQUIRED"} & \text{if } FS_{act.FE3.2} < FS_{req.FE3.2} \end{cases} = \text{"OKAY"}$$

MONOLITH OVERTURNING STABILITY ANALYSIS

Seismic Case $Q_{E3.2}$: 100% Horizontal Seismic Force, 30% Vertical

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.
Assumptions are made in order to compute overturning stability of indetermine forces on monolith with key;
(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.
(b) The horizontal resisting force acting on the key, P.key, is that required for static equilibrium
(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1 $\quad Ratio_{overturning.allow.Extreme} = 0 \quad$ Resultant within Base



All Vertical Loads Applicable to Overturning Stability Analysis

Total Concrete Dead Loads:	$D_{conc} = 22438.74 \cdot kN$	at:	$X_{conc.loc} = 9.35\,m$
Dead Load of Gate:	$D_{Gate} = 140.0 \cdot kN$		$X_{gate} = 9.50\,m$
Water Weight (HW) on Apron Slab:	$H_{1.U2} = 4738.2 \cdot kN$		$H_{1.U2.loc} = 14.13\,m$
Water Weight (TW) on Gate Footing:	$H_{2.U2} = 3556.8 \cdot kN$		$H_{2.U2.loc} = 5.34\,m$
Uplift Load for Overturning Analysis:	$U_{OT.U2} = -15650.44 \cdot kN$		$U_{OT.U2.loc} = 9.94 \cdot m$
Vertical Seismic Component of Concrete Structure:	$Q_{conc.E3.EQv.2} = -673.16 \cdot kN$		$X_{conc.loc} = 9.35\,m$
Vertical Seismic Component of Crest Gate:	$Q_{Gate.E3.EQv.2} = -4.2 \cdot kN$		$X_{gate} = 9.50\,m$
Vertical Seismic Component of Headwater over Apron Slab:	$Q_{H1.E3.EQv.2} = -142.15 \cdot kN$		$H_{1.U2.loc} = 14.13\,m$
Vertical Seismic Component of Headwater over Fixed Crest Slab:	$Q_{H2.E3.EQv.2} = -106.7 \cdot kN$		$H_{2.U2.loc} = 5.34\,m$

Sum of All Overturning Analysis Vertical Load:

$$\Sigma V_{E3.OT.2} := D_{conc} + D_{Gate} + H_{1.U2} + H_{2.U2} + U_{OT.U2} + \Sigma V_{Q.E3.EQv.2} = 14297.12 \cdot kN$$

Sum of All Overturning Analysis Vertical Load Moments:

$$\Sigma M_{V.E3.OT.2} := D_{conc} \cdot X_{conc.loc} + D_{Gate} \cdot X_{gate} + H_{1.U2} \cdot H_{1.U2.loc} + H_{2.U2} \cdot H_{2.U2.loc} + U_{OT.U2} \cdot U_{OT.U2.loc} = 141433.2 \cdot kN \cdot m$$

Lateral Driving Earth Loads for Overturning Stability Analysis (at rest condition)

E3.2 CASE

Depth of Driving Soil Loads (to top of key): $h_{E.OT.E3.2} := TOC_{as} - BOF_{elev} = 4\,m$

Applicable Soil Load: $E_{act.OT.E3.2} := \dfrac{\left(K_{o.U1} \cdot h_{E.OT.U2}^{\;2}\right)}{2} \cdot \left(\gamma_r - \gamma_w\right) \cdot W_{hwas.U2} \cdot -1 = -769.99 \cdot kN$

At Rest- Soil Load Acting from Toe: $E_{act.OT.E3..loc} := \dfrac{h_{E.OT.U2}}{3} = 1.33\,m$

All Lateral Loads Applicable to Overturning Stability Analysis

HW Lateral Load on Approach Slab:	$H_{hwas.U2} = -5368.0 \cdot kN$	$H_{hwas.U2.loc} = 0.61\,m$
HW Lateral Load on Guard Gate:	$H_{hwgg.U2} = -518.9 \cdot kN$	$H_{hwgg.U2.loc} = 5.53\,m$
TW Lateral Load on Guard Gate:	$H_{twgg.U2} = 79.5 \cdot kN$	$H_{twgg.U2.loc} = 4.60\,m$
TW Lateral Load on Gate Footing (No Key - Overturning Values Adjusted):	$H_{twgf.U2} = 1789.34 \cdot kN$	$H_{twgf.U2.loc} = 1.65\,m$
TW Lateral Load on Key:	$H_{twkey.OT.U2} = 2195.91 \cdot kN$	$H_{twkey.OT.U2.loc} = -1.04\,m$
Ice / Impact Load:	$I_{U2} = -1050.0 \cdot kN$	$I_{U2.loc} = 8.30\,m$
Lateral Soil Load (driving):	$E_{act.OT.U2} = -770.0 \cdot kN$	$E_{act.OT.U2.loc} = 1.33\,m$
Horizontal Seismic Component of Concrete Structure:	$Q_{conc.E3.EQh.2} = -3814.59 \cdot kN$	$Y_{conc.loc} = 2.43\,m$
Horizontal Seismic Component of Vertical Lift Gate:	$Q_{Gate.E3.EQh.2} = -23.8 \cdot kN$	$Y_{gate} = 3.90\,m$
Horizontal Seismic Component of Headwater on Slab Footing:	$Q_{hwas.E3.EQh.2} = -1311.68 \cdot kN$	$Y_{HWg.E3} = 2.24\,m$
Horizontal Seismic Component of Active Soil: (Section 5-5, USACE EM_1110-2-2100)	$Q_{act.E3.EQh.2} = -397.88 \cdot kN$	$Y_{E.act.E3} = 2.52\,m$

Resisting Lateral Soil Load as required to produce horizontal equilibrium:

$$E_{pas.OT.E3.2} := -\left(H_{hwas.U2} + H_{hwgg.U2} + H_{twgg.U2} + H_{twgf.U2} + H_{twkey.OT.U2} + I_{U2} + E_{act.OT.U2} + \Sigma H_{Q.E3.EQh.2.OT}\right) = 9687.56 \cdot kN$$

Acting at: $E_{pas.OT.E3.2.loc} := -1 \cdot \dfrac{d_{key}}{2} = -1\,m$

Sum of All Overturning Analysis Horizontal Load (ΣH=0):

$$\Sigma H_{E3.OT.2} := H_{hwas.U2} + H_{hwgg.U2} + H_{twgg.U2} + H_{twgf.U2} + H_{twkey.OT.U2} + I_{U2} + E_{act.OT.U2} + E_{pas.OT.E3.2} + \Sigma H_{Q.E3.EQh.2.OT} = 0 \cdot kN$$

Sum of All Overturning Analysis Horizontal Load Moments:

$$\begin{aligned}\Sigma M_{H.E3.OT.2} := {} & H_{hwas.U2} \cdot H_{hwas.U2.loc} + H_{hwgg.U2} \cdot H_{hwgg.U2.loc} + H_{twgg.U2} \cdot H_{twgg.U2.loc} \cdots = -42003.92 \cdot kN \cdot m \\ & + H_{twgf.U2} \cdot H_{twgf.U2.loc} + H_{twkey.OT.U2} \cdot H_{twkey.OT.U2.loc} + I_{U2} \cdot I_{U2.loc} \cdots \\ & + E_{act.OT.U2} \cdot E_{act.OT.U2.loc} + E_{pas.OT.U2} \cdot E_{pas.OT.U2.loc} + \Sigma M_{Q.E3.2}\end{aligned}$$

Overturning Stability Analysis

$$\Sigma M_{E3.OT.2} := \Sigma M_{V.E3.OT.2} + \Sigma M_{H.E3.OT.2} = 99429.28 \cdot kN \cdot m$$

$X_{R.E3.2} := \dfrac{\Sigma M_{E3.OT.2}}{\Sigma V_{E3.OT.2}} = 6.95\,m$ $\qquad x_{OT.E3.2} := X_{R.E3.2} - \dfrac{L_b}{2} = -2.3\,m$

Overturning Resultant Ratio

$$Ratio_{OT.E3.2} := \frac{X_{R.E3.2}}{L_b} = 0.38$$

$$Ratio_{OT.E3.2.check} := \begin{cases} \text{"OKAY"} & \text{if } Ratio_{OT.E3.2} \ge Ratio_{overturning.allow.Extreme} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

$$x_{OT.check.E3.2} := \begin{cases} \text{"OKAY"} & \text{if } \left|x_{OT.E3.2}\right| \le Kern \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

Seismic Case $Q_{E3.3}$ - 30% Horizontal Seismic Force, 100% Vertical

E3.3 CASE

Include Seismic Load in Analysis? $Eq_{E3.3} := 1$ 0 = No, 1 = Yes

Horizontal Seismic Coefficient: $K_{h.E3.3} := -0.05$

Vertical Seismic Coefficient: $K_{v.E3.3} := -0.10$

HORIZONTAL SEISMIC LOADS	**Loads**	**Moment Arm**
Horiz Seismic Component of Concrete:	$Q_{conc.E3.EQh.3} := D_{conc} \cdot K_{h.E3.3} \cdot Eq_{E3.3} = -1121.9 \cdot kN$	$Y_{conc.loc} = 2.43\,m$
Horiz Seismic Component of Gate:	$Q_{Gate.E3.EQh.3} := D_{Gate} \cdot K_{h.E3.3} \cdot Eq_{E3.3} = -7.0 \cdot kN$	$Y_{gate} = 3.90\,m$
Horiz Seismic Component of Headwater:	$Q_{hwas.E3.EQh.3} := \left(\frac{7}{12}\right) \cdot K_{h.E3.3} \cdot \gamma_w \cdot \left(HW_{U2} - BOK_{elev}\right)^2 \cdot W_{hwas.U2} \cdot Eq_{E3.3} = -385.8 \cdot kN$	$Y_{HWg.E3} = 2.24\,m$
Horizontal Seismic Component of Soil (Woods Method) - Overturning:	$Q_{act.E3.EQh.3.OT} := \left(\gamma_r - \gamma_w\right) \cdot \left(TOC_{as} - BOK_{elev}\right)^2 \cdot K_{h.E3.3} \cdot W_{hwas.U2} \cdot Eq_{E3.3} = -263.3 \cdot kN$	$Y_{E.act.E3.OT} = 1.78\,m$
Horizontal Seismic Component of Soil (Woods Method):	$Q_{act.E3.EQh.3} := \left(\gamma_r - \gamma_w\right) \cdot \left(TOC_{as} - BOF_{elev}\right)^2 \cdot K_{h.E3.3} \cdot W_{hwas.U2} \cdot Eq_{E3.3} = -117.0 \cdot kN$	$Y_{E.act.E3} = 2.52\,m$

VERTICAL SEISMIC LOADS	**Loads**	**Moment Arm**
Vertical Component of Concrete:	$Q_{conc.E3.EQv.3} := D_{conc} \cdot K_{v.E3.3} \cdot Eq_{E3.3} = -2243.9 \cdot kN$	$X_{conc.loc} = 9.35\,m$
Vertical Component of Gate:	$Q_{Gate.E3.EQv.3} := D_{Gate} \cdot K_{v.E3.3} \cdot Eq_{E3.3} = -14.0 \cdot kN$	$X_{gate} = 9.50\,m$
Vertical Seismic Component of Headwater over Apron Slab: (Section 7.9, Design Criteria)	$Q_{H1.E3.EQv.3} := K_{v.E3.3} \cdot H_{1.U2} \cdot Eq_{E3.3} = -473.8 \cdot kN$	$H_{1.U2.loc} = 14.13\,m$
Vertical Seismic Component of Headwater over Fixed Crest Slab: (Section 7.9, Design Criteria)	$Q_{H2.E3.EQv.3} := K_{v.E3.3} \cdot H_{2.U2} \cdot Eq_{E3.3} = -355.7 \cdot kN$	$H_{2.U2.loc} = 5.34\,m$

$$\Sigma H_{Q.E3.EQh.3} := Q_{conc.E3.EQh.3} + Q_{Gate.E3.EQh.3} + Q_{hwas.E3.EQh.3} + Q_{act.E3.EQh.3} = -1631.75 \cdot kN$$

$$\Sigma H_{Q.E3.EQh.3.OT} := Q_{conc.E3.EQh.3} + Q_{Gate.E3.EQh.3} + Q_{hwas.E3.EQh.3} + Q_{act.E3.EQh.3.OT} = -1778.03 \cdot kN$$

$$\Sigma V_{Q.E3.EQv.3} := Q_{conc.E3.EQv.3} + Q_{Gate.E3.EQv.3} + Q_{H1.E3.EQv.3} + Q_{H2.E3.EQv.3} = -3087.4 \cdot kN$$

$$\begin{aligned}\Sigma M_{Q.E3.3} := {} & Q_{conc.E3.EQh.3} \cdot Y_{conc.loc} + Q_{Gate.E3.EQh.3} \cdot Y_{gate} + Q_{hwas.E3.EQh.3} \cdot Y_{HWg.E3} \cdots \\ & + Q_{act.E3.EQh.3.OT} \cdot Y_{E.act.E3.OT} + Q_{conc.E3.EQv.3} \cdot X_{conc.loc} + Q_{Gate.E3.EQv.3} \cdot X_{gate} \cdots \\ & + Q_{H1.E3.EQv.3} \cdot H_{1.U2.loc} + Q_{H2.E3.EQv.3} \cdot H_{2.U2.loc} = -33787.38 \cdot kN \cdot m\end{aligned}$$

STABILITY ASSESSMENT (SLIDNG, BEARING, FLOTATION AND OVERTURNING):

E3.3 CASE

CHECK SLIDING ALONG HORIZONTAL PLANE THRU TOE, IGNORING BEDROCK MOBILIZED BY STRUCTURAL HEEL KEY, OR VOID BEHIND KEY

Sum of Vertical Forces:

$\Sigma V_{E3.3} := \Sigma V_{U2} + \Sigma V_{Q.E3.EQv.3} = 9928.3 \cdot kN$

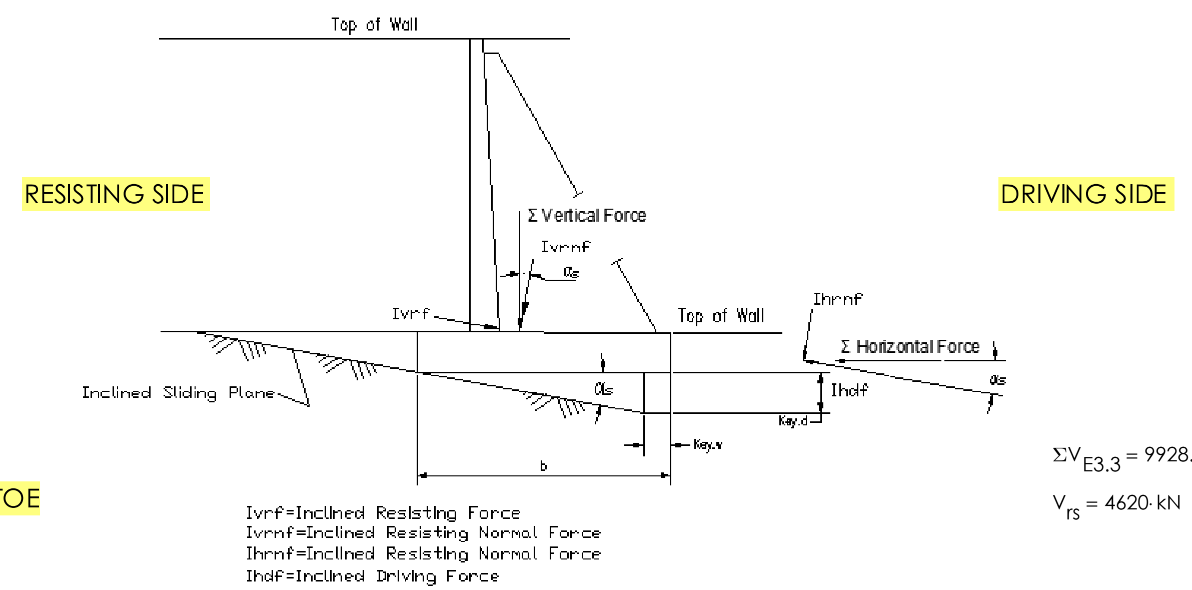
Sum of Horizontal Forces:

$\Sigma H_{E3.3} := \Sigma H_{U2} - I_{U2} + \Sigma H_{Q.E3.EQh.3} = -6166.44 \cdot kN$

Sliding Factor of Safety: $FS_{HorizSliding.E3.3} := \dfrac{\tan_{\phi} \cdot \Sigma V_{E3.3}}{|\Sigma H_{E3.3}|} = 0.79$

$FS_{HorizSliding.E3.3.Check} :=$ | "OKAY" if $FS_{HorizSliding.E3.3} \geq FS_{req.E3.sl}$ = "Check with Key!"
"Check with Key!" otherwise

CHECK SLIDING ALONG INCLINED SLIDING PLANE FROM HEEL KEY TO TOE, WITH BEDROCK MASS MOBILIZED BY REINFOCREDE CONCRETE KEY)



$\Sigma V_{E3.3} = 9928.28 \cdot kN$

$V_{rs} = 4620 \cdot kN$

$\alpha s = 0.11$ as degrees= $\alpha s \cdot \left(\dfrac{180}{\pi}\right) = 6.52$

Resolve $\Sigma Vert_{E3.3}$ & $\Sigma Horiz_{E3.3}$

$\Sigma V_{InclinedE3.3} := \cos(\alpha s) \cdot (\Sigma V_{E3.3} + V_{rs}) + \sin(\alpha s) \cdot |\Sigma H_{E3.3}| = 15154.4 \cdot kN$

$\Sigma H_{InclinedE3.3} := \cos(\alpha s) \cdot |\Sigma H_{E3.3}| - \sin(\alpha s) \cdot (\Sigma V_{E3.3} + V_{rs}) = 4474.6 \cdot kN$

(With properly engineered reinforced concrete Key, horizontal sliding plane thru Toe is protected, critical sliding plane is relocated to the INCLINED SLIDING PLANE FROM HEEL KEY To TOE, Bedrock Mass above this examined plane is mobilized by reinforced concrete key and combined into Structural Wedge.)

Inclined Sliding Plane Length

$L_{incline} = 18.61 \, m$

Safety Factor for Sliding Inclined Failure Plane

$FS_{InclinedlSlidingE3.3} := \dfrac{\Sigma V_{InclinedE3.3} \cdot \tan\left(\phi_{rock} \cdot \dfrac{\pi}{180}\right)}{|\Sigma H_{InclinedE3.3}|} = 1.65$

$FS_{InclinedSliding.check.E3.3} :=$ | "OKAY " if $FS_{InclinedlSlidingE3.3} > FS_{req.E3.sl}$ = "OKAY "
"Revise Structure"" otherwise

$FS_{InclinedSliding.check.E3.3}$ = "OKAY "

OVERTURNING STABILITY CHECK:

CHECK ECCENTRICITY

Sum of the moments:

$$\Sigma M_{E3.3} := \left(\Sigma M_{U2} + \Sigma M_{Q.E3.3}\right) = 117490 \cdot kN \cdot m$$

Eccentricity:

$$e_{E3.3} := \left(\frac{L_{incline}}{2}\right) - \frac{\left(\Sigma M_{E3.3}\right)}{\Sigma V_{InclinedE3.3}} = 1.55\,m$$

Eccentricity Check:

$$e_{check.E3.3} := \begin{vmatrix} \text{"Okay"} & \text{if } e_{E3.3} \le Kern \\ \text{"Revise Structure"} & \text{otherwise} \end{vmatrix}$$

$$e_{check.E3.3} = \text{"Okay"}$$

Foundation Bearing Checks:

Bearing Pressure at Heel:

$$\sigma_{heel.E3.3} := \frac{\Sigma V_{InclinedE3.3}}{A_{b.incline}} - \frac{\left(\Sigma V_{InclinedE3.3} \cdot e_{E3.3}\right)}{S_{b.incline}} = 33.9 \cdot \frac{kN}{m^2}$$

$$\sigma_{heel.E3.3.check} := \left(\begin{vmatrix} \text{"Okay"} & \text{if } \sigma_{heel.E3.3} \le \sigma_{allow.E3} \\ \text{"Revise Structure"} & \text{if } \sigma_{heel.E3.3} < 0\,\frac{kN}{m^2} \end{vmatrix}\right)$$

$$\sigma_{heel.E3.3.check} = \text{"Okay"}$$

Bearing Pressure at Toe:

$$\sigma_{toe.E3.3} := \frac{\Sigma V_{InclinedE3.3}}{A_{b.incline}} + \frac{\left(\Sigma V_{InclinedE3.3} \cdot e_{E3.3}\right)}{S_{b.incline}} = 101.8 \cdot \frac{kN}{m^2}$$

$$\sigma_{toe.E3.3.check.1} := \begin{vmatrix} \text{"Okay"} & \text{if } \sigma_{toe.E3.3} \le \sigma_{allow.E3} \\ \text{"Revise Structure"} & \text{if } \sigma_{toe.E3.3} < 0\,\frac{kN}{m^2} \end{vmatrix}$$

$$\sigma_{toe.E3.3.check.1} = \text{"Okay"}$$

FLOATATION ANALYSIS:

ACCEPTANCE PARAMETERS

Required Factor of Safety: $FS_{req.FE3.3} := 1.1$

VERTICAL LOADS RESISTING:

Dead Load: $\Sigma V_{DL} = 22578.74 \cdot kN$

Water Weight H1+H2: $\Sigma V_{H.FE3.3} := \Sigma V_{H.FU2} + \Sigma V_{Q.E3.EQv.3} = 5207.66 \cdot kN$

Summation Vertical Resisting: $\Sigma V_{FE3.3} := \Sigma V_{DL} + \Sigma V_{H.FE3.3} = 27786.4 \cdot kN$

VERTICAL LOADS UPLIFT:

Uplift: $U_{U2} = -17858.12 \cdot kN$

Factor of Safety Floatation:

$$FS_{act.FE3.3} := \frac{\Sigma V_{FE3.3}}{\left|U_{U2}\right|} = 1.56$$

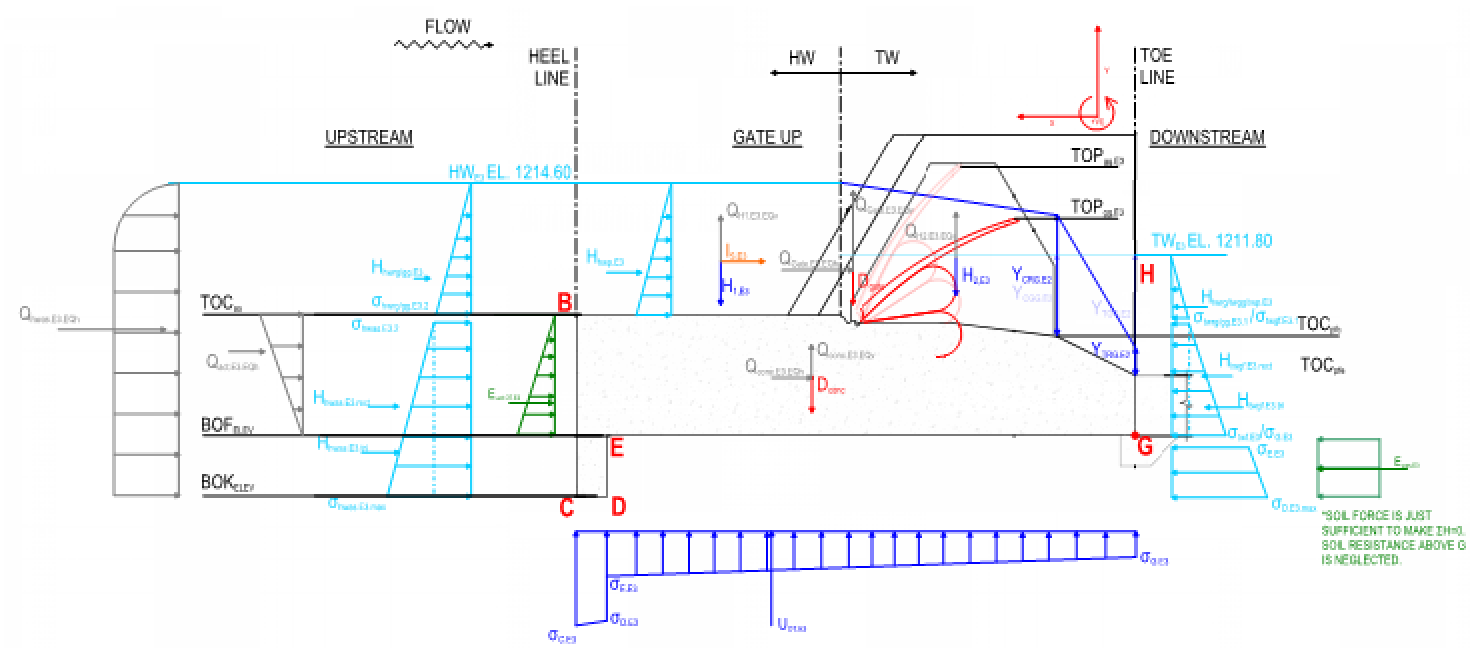
$$FS_{check.FE3.3} := \begin{vmatrix} \text{"OKAY"} & \text{if } FS_{act.FE3.3} \ge FS_{req.FE3.3} \\ \text{"ANCHORS REQUIRED"} & \text{if } FS_{act.FE3.3} < FS_{req.FE3.3} \end{vmatrix} = \text{"OKAY"}$$

MONOLITH OVERTURNING STABILITY ANALYSIS

Seismic Case $Q_{E3.2}$: 100% Horizontal Seismic Force, 30% Vertical

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.
Assumptions are made in order to compute overturning stability of indeterminate forces on monolith with key;
(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.
(b) The horizontal resisting force acting on the key, P.key, is that required for static equilibrium
(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1 $Ratio_{overturning.allow.Extreme} = 0$ Resultant within Base



All Vertical Loads Applicable to Overturning Stability Analysis

Total Concrete Dead Loads:	$D_{conc} = 22438.74 \cdot kN$	at:	$X_{conc.loc} = 9.35\,m$
Dead Load of Gate:	$D_{Gate} = 140.0 \cdot kN$		$X_{gate} = 9.50\,m$
Water Weight (HW) on Apron Slab:	$H_{1.U2} = 4738.2 \cdot kN$		$H_{1.U2.loc} = 14.13\,m$
Water Weight (TW) on Gate Footing:	$H_{2.U2} = 3556.8 \cdot kN$		$H_{2.U2.loc} = 5.34\,m$
Uplift Load for Overturning Analysis:	$U_{OT.U2} = -15650.44 \cdot kN$		$U_{OT.U2.loc} = 9.94 \cdot m$
Vertical Seismic Component of Concrete Structure:	$Q_{conc.E3.EQv.3} = -2243.87 \cdot kN$		$X_{conc.loc} = 9.35\,m$
Vertical Seismic Component of Crest Gate:	$Q_{Gate.E3.EQv.3} = -14 \cdot kN$		$X_{gate} = 9.50\,m$
Vertical Seismic Component of Headwater over Apron Slab:	$Q_{H1.E3.EQv.3} = -473.82 \cdot kN$		$H_{1.U2.loc} = 14.13\,m$
Vertical Seismic Component of Headwater over Fixed Crest Slab:	$Q_{H2.E3.EQv.3} = -355.68 \cdot kN$		$H_{2.U2.loc} = 5.34\,m$

Sum of All Overturning Analysis Vertical Load:

$$\Sigma V_{E3.OT.3} := D_{conc} + D_{Gate} + H_{1.U2} + H_{2.U2} + U_{OT.U2} + \Sigma V_{Q.E3.EQv.2} = 14297.12 \cdot kN$$

Sum of All Overturning Analysis Vertical Load Moments:

$$\Sigma M_{V.E3.OT.3} := D_{conc} \cdot X_{conc.loc} + D_{Gate} \cdot X_{gate} + H_{1.U2} \cdot H_{1.U2.loc} + H_{2.U2} \cdot H_{2.U2.loc} + U_{OT.U2} \cdot U_{OT.U2.loc} = 141433.2 \cdot kN \cdot m$$

Lateral Driving Earth Loads for Overturning Stability Analysis (at rest condition)

E3.3 CASE

Depth of Driving Soil Loads (to top of key): $h_{E.OT.E3.3} := TOC_{as} - BOF_{elev} = 4\,m$

Applicable Soil Load: $E_{act.OT.E3.3} := \dfrac{\left(K_{o.U1} \cdot h_{E.OT.U2}\right)^2}{2} \cdot \left(\gamma_r - \gamma_w\right) \cdot W_{hwas.U2} \cdot -1 = -769.99 \cdot kN$

At Rest- Soil Load Acting from Toe: $E_{act.OT.E3.3.loc} := \dfrac{h_{E.OT.U2}}{3} = 1.33\,m$

All Lateral Loads Applicable to Overturning Stability Analysis

HW Lateral Load on Approach Slab:	$H_{hwas.U2} = -5368.0 \cdot kN$	$H_{hwas.U2.loc} = 0.61\,m$
HW Lateral Load on Guard Gate:	$H_{hwgg.U2} = -518.9 \cdot kN$	$H_{hwgg.U2.loc} = 5.53\,m$
TW Lateral Load on Guard Gate:	$H_{twgg.U2} = 79.5 \cdot kN$	$H_{twgg.U2.loc} = 4.60\,m$
TW Lateral Load on Gate Footing (No Key - Overturning Values Adjusted):	$H_{twgf.U2} = 1789.34 \cdot kN$	$H_{twgf.U2.loc} = 1.65\,m$
TW Lateral Load on Key:	$H_{twkey.OT.U2} = 2195.91 \cdot kN$	$H_{twkey.OT.U2.loc} = -1.04\,m$
Ice / Impact Load:	$I_{U2} = -1050.0 \cdot kN$	$I_{U2.loc} = 8.30\,m$
Lateral Soil Load (driving):	$E_{act.OT.U2} = -770.0 \cdot kN$	$E_{act.OT.U2.loc} = 1.33\,m$
Horizontal Seismic Component of Concrete Structure:	$Q_{conc.E3.EQh.3} = -1121.94 \cdot kN$	$Y_{conc.loc} = 2.43\,m$
Horizontal Seismic Component of Vertical Lift Gate:	$Q_{Gate.E3.EQh.3} = -7 \cdot kN$	$Y_{gate} = 3.90\,m$
Horizontal Seismic Component of Headwater on Slab Footing:	$Q_{hwas.E3.EQh.3} = -385.79 \cdot kN$	$Y_{HWg.E3} = 2.24\,m$
Horizontal Seismic Component of Active Soil: (Section 5-5, USACE EM_1110-2-2100)	$Q_{act.E3.EQh.3} = -117.02 \cdot kN$	$Y_{E.act.E3} = 2.52\,m$

Resisting Lateral Soil Load as required to produce horizontal equilibrium:

$$E_{pas.OT.E3.3} := -\left(H_{hwas.U2} + H_{hwgg.U2} + H_{twgg.U2} + H_{twgf.U2} + H_{twkey.OT.U2} + I_{U2} + E_{act.OT.U2} + \Sigma H_{Q.E3.EQh.3.OT}\right) = 5420.29 \cdot kN$$

Acting at: $E_{pas.OT.E3.3.loc} := -1 \cdot \dfrac{d_{key}}{2} = -1\,m$

Sum of All Overturning Analysis Horizontal Load (ΣH=0):

$$\Sigma H_{E3.OT.3} := H_{hwas.U2} + H_{hwgg.U2} + H_{twgg.U2} + H_{twgf.U2} + H_{twkey.OT.U2} + I_{U2} + E_{act.OT.U2} + E_{pas.OT.E3.3} + \Sigma H_{Q.E3.EQh.3.OT} = 0 \cdot kN$$

Sum of All Overturning Analysis Horizontal Load Moments:

$$\begin{aligned}\Sigma M_{H.E3.OT.3} := {} & H_{hwas.U2} \cdot H_{hwas.U2.loc} + H_{hwgg.U2} \cdot H_{hwgg.U2.loc} + H_{twgg.U2} \cdot H_{twgg.U2.loc} \cdots = -52991.97 \cdot kN \cdot m \\ & + H_{twgf.U2} \cdot H_{twgf.U2.loc} + H_{twkey.OT.U2} \cdot H_{twkey.OT.U2.loc} + I_{U2} \cdot I_{U2.loc} \cdots \\ & + E_{act.OT.U2} \cdot E_{act.OT.U2.loc} + E_{pas.OT.U2} \cdot E_{pas.OT.U2.loc} + \Sigma M_{Q.E3.3}\end{aligned}$$

Overturning Stability Analysis

$\Sigma M_{E3.OT.3} := \Sigma M_{V.E3.OT.3} + \Sigma M_{H.E3.OT.3} = 88441.23 \cdot kN \cdot m$

$X_{R.E3.3} := \dfrac{\Sigma M_{E3.OT.3}}{\Sigma V_{E3.OT.3}} = 6.19\,m$ $\qquad x_{OT.E3.3} := X_{R.E3.3} - \dfrac{L_b}{2} = -3.06\,m$

Overturning Resultant Ratio

$Ratio_{OT.E3.3} := \dfrac{X_{R.E3.2}}{L_b} = 0.38$

$Ratio_{OT.E3.3.check} :=$ | "OKAY" if $Ratio_{OT.E3.3} \geq Ratio_{overturning.allow.Extreme}$ = "OKAY"
| "Revise Structure" otherwise

$x_{OT.check.E3.3} :=$ | "OKAY" if $\left|x_{OT.E3.3}\right| \leq Kern$ = "OKAY"
| "Revise Structure" otherwise

Summary of Results

E3 CASE

E3.1 Case

Sliding Factor of Safety: (Horizontal Plane)	$FS_{HorizSliding.E3.1} = 0.63$	
	$FS_{HorizSliding.E3.1.Check}$ = "Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !"	
Sliding Factor of Safety: (Inclined Plane)	$FS_{InclinedlSlidingE3.1} = 1.14$	$FS_{InclinedSliding.check.E3.1}$ = "OKAY "
Eccentricity: (Inclined Plane)	$e_{E3.1} = 1.94\,m$	$e_{check.E3.1}$ = "Okay"
Bearing Pressure At Heel: (Inclined Plane)	$\sigma_{heel.E3.1} = 31 \cdot kPa$	$\sigma_{heel.E3.1.check}$ = "Okay"
Bearing Pressure At Toe: (Inclined Plane)	$\sigma_{toe.E3.1} = 136 \cdot kPa$	$\sigma_{toe.E3.1.check.1}$ = "Okay"
Flotation Factor of Safety (horizontal plane)	$FS_{act.FE3.1} = 1.73$	$FS_{check.FE3.1}$ = "OKAY"
Overturning Resultant Ratio: (horizontal plane)	$Ratio_{OT.E3.1} = 0.45$	$Ratio_{OT.E3.1.check}$ = "OKAY"
Eccentricity: (horizontal plane)	$x_{OT.E3.1} = -1.00\,m$	$x_{OT.check.E3.1}$ = "OKAY"

E3.2 Case

Sliding Factor of Safety: (Horizontal Plane)	$FS_{HorizSliding.E3.2} = 0.58$	
	$FS_{HorizSliding.E3.2.Check}$ = "Check Inclined Sliding Plane!"	
Sliding Factor of Safety: (Inclined Plane)	$FS_{InclinedlSlidingE3.2} = 1.07$	$FS_{InclinedSliding.check.E3.2}$ = "OKAY "
Eccentricity: (Inclined Plane)	$e_{E3.2} = 2.06\,m$	$e_{check.E3.2}$ = "Okay"
Bearing Pressure At Heel: (Inclined Plane)	$\sigma_{heel.E3.2} = 27 \cdot kPa$	$\sigma_{heel.E3.2.check}$ = "Okay"
Bearing Pressure At Toe: (Inclined Plane)	$\sigma_{toe.E3.2} = 132 \cdot kPa$	$\sigma_{toe.E3.2.check.1}$ = "Okay"
Flotation Factor of Safety (horizontal plane)	$FS_{act.FE3.2} = 1.68$	$FS_{check.FE3.2}$ = "OKAY"
Overturning Resultant Ratio: (horizontal plane)	$Ratio_{OT.E3.2} = 0.38$	$Ratio_{OT.E3.2.check}$ = "OKAY"
Eccentricity: (horizontal plane)	$x_{OT.E3.2} = -2.30\,m$	$x_{OT.check.E3.2}$ = "OKAY"

E3.3 Case

Sliding Factor of Safety: (Horizontal Plane)	$FS_{HorizSliding.E3.3} = 0.79$	
	$FS_{HorizSliding.E3.3.Check} = \text{"Check with Key!"}$	
Sliding Factor of Safety: (Inclined Plane)	$FS_{InclinedlSlidingE3.3} = 1.65$	$FS_{InclinedSliding.check.E3.3} = \text{"OKAY "}$
Eccentricity: (Inclined Plane)	$e_{E3.3} = 1.55\,m$	$e_{check.E3.3} = \text{"Okay"}$
Bearing Pressure At Heel: (Inclined Plane)	$\sigma_{heel.E3.3} = 34 \cdot kPa$	$\sigma_{heel.E3.3.check} = \text{"Okay"}$
Bearing Pressure At Toe: (Inclined Plane)	$\sigma_{toe.E3.3} = 102 \cdot kPa$	$\sigma_{toe.E3.3.check.1} = \text{"Okay"}$
Flotation Factor of Safety (horizontal plane)	$FS_{act.FE3.3} = 1.56$	$FS_{check.FE3.3} = \text{"OKAY"}$
Overturning Resultant Ratio: (horizontal plane)	$Ratio_{OT.E3.3} = 0.38$	$Ratio_{OT.E3.3.check} = \text{"OKAY"}$
Eccentricity: (horizontal plane)	$x_{OT.E3.3} = -3.06\,m$	$x_{OT.check.E3.3} = \text{"OKAY"}$

Calculation Section IV

SS-2A Gate Blocks Stability Calculations

Stantec

Project Number: 110773396

Project Title: SR1 Project

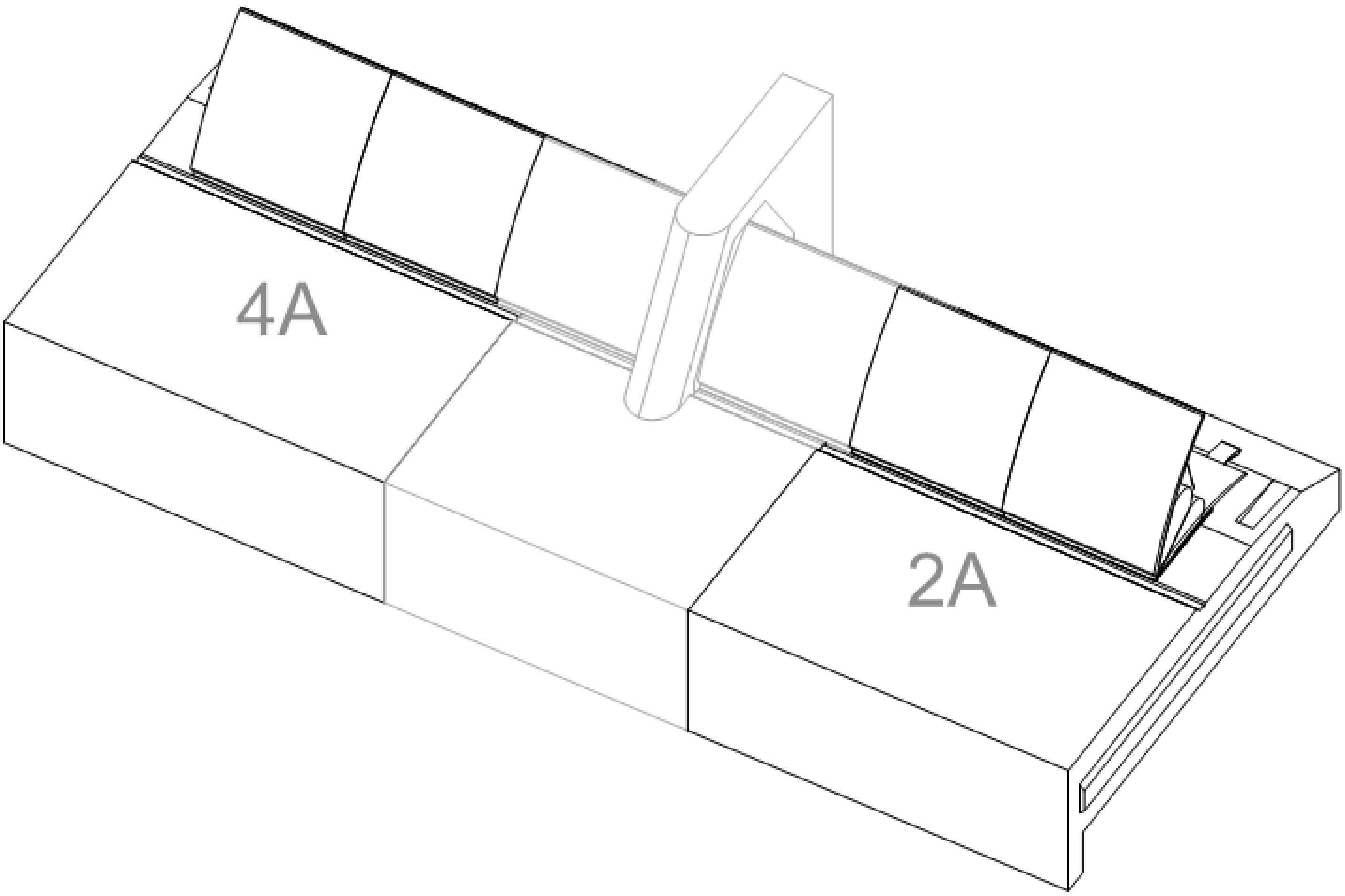
Client: Alberta Transportation

Engineer: Dave Crawford, Derek Cheuk   Date: 12/14/2018

Checker: Sean Xiao   Date: 01/10/2019

Calculation for: Service Spillway Gate 2A - Guard Gate Structure

Structure Isometric:



SERVICE SPILLWAY - Guard Gate 2A Monolith

REGION COLOR CONVENTION   User Input   Calculation Highlights   Results

SERVICE SPILLWAY DEIMENSIONAL INPUT PARAMETERS

BASE SECTION PROPERTIES

Base Length: $L_b := 18.50m$ (Refer to Dwg. S-220 PLAN)

Stilling Basin Length: $L_{sb} := 17.0m$

$Kern := \frac{L_b}{6} = 3.08\,m$

Base Width: $W_b := 15.00m$

Area of Base: $A_b := L_b \cdot W_b = 277.5\,m^2$

$Midhalf := \frac{L_b}{4} = 4.63\,m$

Section Modulus of Base: $S_b := \frac{W_b \cdot L_b^2}{6} = 855.6\,m^3$

FOOTINGS (fixed crest and approach slab, geometry below)

Footing Cross Sectional Area: $A_{gf} := 32.84m^2$ (From Bluebeam Measurement)

Block Footing Width: $w_{gf} := W_b = 15.00\,m$

Total Fixed Crest Footing Volume: $V_{gf} := A_{gf} \cdot w_{gf} = 492.6 \cdot m^3$

Pier Width: $w_p := 0m$

Approach Slab Height: $h_{as} := 4.00m$

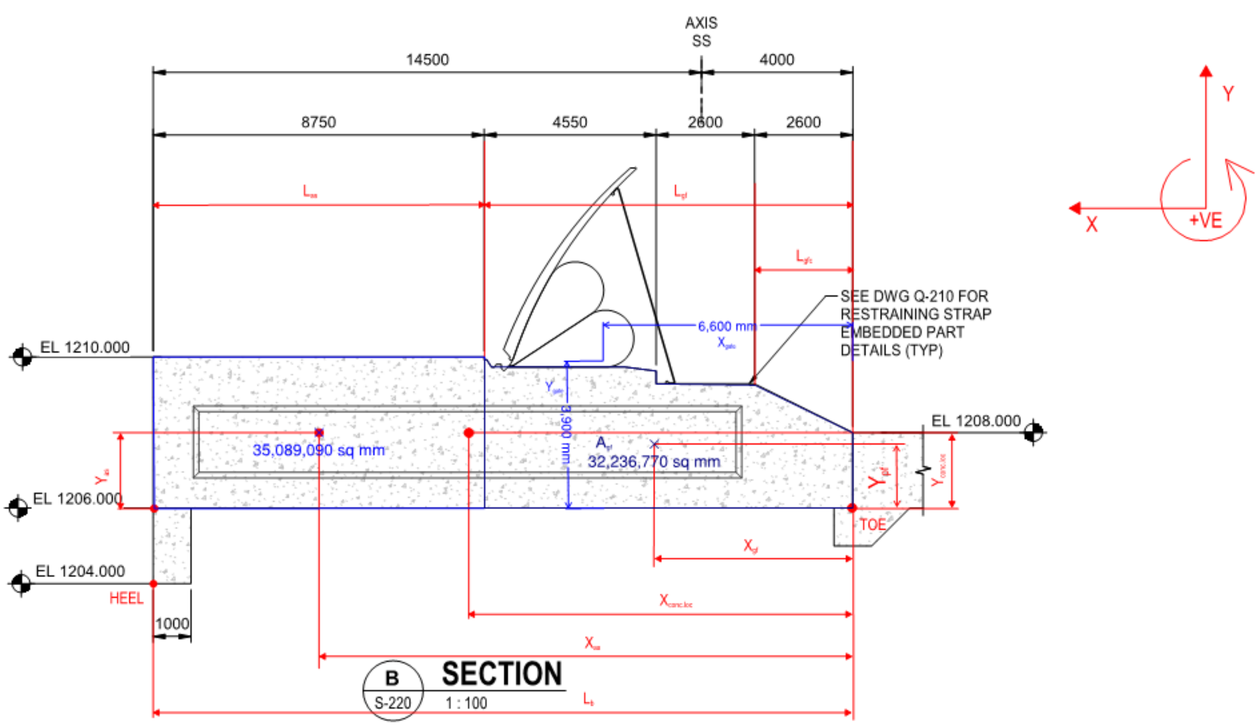
Approach Slab Width: $w_{as} := W_b = 15.00\,m$

Approach Slab Length: $L_{as} := 8.75m$

Gate Footing Length: $L_{gf} := L_b - L_{as} = 9.75\,m$

Gate Footing Crest Length: $L_{gfc} := 2.6m$

Total Approach Slab Volume: $V_{as} := h_{as} \cdot w_{as} \cdot L_{as} = 525.0 \cdot m^3$



SHEAR KEY PARAMETERS

Key depth: $d_{key} := 2.00m$

Key width: $w_{key} := 1.00m$

FOUNDATION PARAMETERS

Granular Fill Internal Angle of Friction: $\phi := 34 \cdot \frac{\pi}{180} = 0.59$ Radians (Section 5.3, Design Criteria)

Friction Angle at Base Concrete / Rock Interface: $\phi_{rock} := 26$ (Section 5.2, Design Criteria)

Base Friction Coefficient: $\tan_{\phi} := \tan\left(\phi_{rock} \frac{\pi}{180}\right) = 0.488$ radians

MATERIAL PROPERTIES

Unit Weight of Concrete: $\gamma_c := 23.5 \frac{kN}{m^3}$ (Section 7.1, Design Criteria)

Unit Weight of Rock Fill: $\gamma_r := 22.0 \frac{kN}{m^3}$ (Section 5.3, Design Criteria)

$\phi_{backfill} := \left(20 \frac{\pi}{180}\right) = 0.35$ radians Assume Rip Rap Backfill

Unit Weight of Water: $\gamma_w := 9.81 \frac{kN}{m^3}$ (Section 7.2, Design Criteria)

CONCRETE DEAD LOADS

Gate Footing (fixed crest): $D_{gf} := V_{gf} \cdot \gamma_c = 11576.1 \cdot kN$

Approach Slab: $D_{as} := V_{as} \cdot \gamma_c + d_{key} \cdot w_{key} \cdot w_{as} \cdot \gamma_c = 13042.5 \cdot kN$

Total Concrete Dead Loads: $D_{conc} := D_{gf} + D_{as} = 24618.6 \cdot kN$

Rock Section Mobilized for Inclined Sliding Failure:

Soil Volume Below Footing (Triangle): $V_{E.tri} := W_b \cdot \frac{1}{2} \cdot d_{key} \cdot \left(L_b - w_{key}\right) = 262.5 \cdot m^3$ $\quad X_{E.tri} := \left(L_b - w_{key}\right) \cdot \frac{2}{3} = 11.67\, m$

Vertical Soil Weight: $E_{v.tri} := V_{E.tri} \cdot \left(\gamma_r\right) = 5775 \cdot kN$ $\quad \Sigma V_{soil} := E_{v.tri} = 5775 \cdot kN$ $\quad \Sigma M_{soil} := E_{v.tri} \cdot X_{E.tri} = 67375 \cdot kN \cdot m$

MOMENT ARM FROM TOE TO COG OF COMPONENT

Dist. from Toe to COG of Gate Footing: $X_{gf} := 5.24m$ (From Bluebeam Measurement)

Dist. from Toe to COG of Approach Slab: $X_{as} := 14.33m$ (From Bluebeam Measurement)

Distance From Toe to COG of Concrete Dead Load : $X_{conc.loc} := \frac{\left(X_{gf} \cdot D_{gf} + X_{as} \cdot D_{as}\right)}{D_{conc}} = 10.06\, m$

MOMENT ARM FROM BASE OF FOOTING TO COG OF COMPONENT

Dist. from Base to COG of Footing: $Y_{gf} := 1.72m$ (From Bluebeam Measurement)

Dist. from Base to COG of Approach Slab: $Y_{as} := 2.0m$ (Center of Approach Slab)

Distance Above Base to COG of Concrete Dead Load:

$$Y_{conc.loc} := \frac{\left(Y_{gf} \cdot D_{gf} + Y_{as} \cdot D_{as}\right)}{D_{conc}} = 1.87\, m$$

CREST GATE (OBERMEYER)

Dead Load of Gates: $D_{Gate} := 140kN \cdot \frac{15}{10} \cdot \frac{m}{m} = 210 \cdot kN$

(Vendor supplied, Dwg. Q-200 Series)

Distance from Toe to COG of Gates: $X_{gate} := 6.60m$ (From Bluebeam Measurement)

Distance from Base to COG of Gates: $Y_{gate} := 3.90m$

(Distance from base to top of Gate Footing, conservative value at Gate Closed)

DEAD LOAD SUMMATION:

$\Sigma V_{DL} := D_{conc} + D_{Gate} = 24828.6 \cdot kN$

$\Sigma M_{DL} := D_{conc} \cdot X_{conc.loc} + D_{Gate} \cdot X_{gate} = 248943.79 \cdot kN \cdot m$

ROCK SECTION MOBILIZED FOR INCLINDED SLIDING FAILURE

Area of Rock Section Mobilized: $A_{rs} := \frac{\left(L_b - w_{key}\right) \cdot d_{key}}{2} = 17.5\,m^2$

Rock Mass Mobilized: $V_{rs} := A_{rs} \cdot \gamma_r \cdot W_b = 5775 \cdot kN$

(Pore pressure taken along assumed inclined sliding plane)

Distance from Toe to COG of Rock Section: $L_{rs} := \frac{2}{3} \cdot \left(L_b - w_{key}\right) = 11.67\,m$

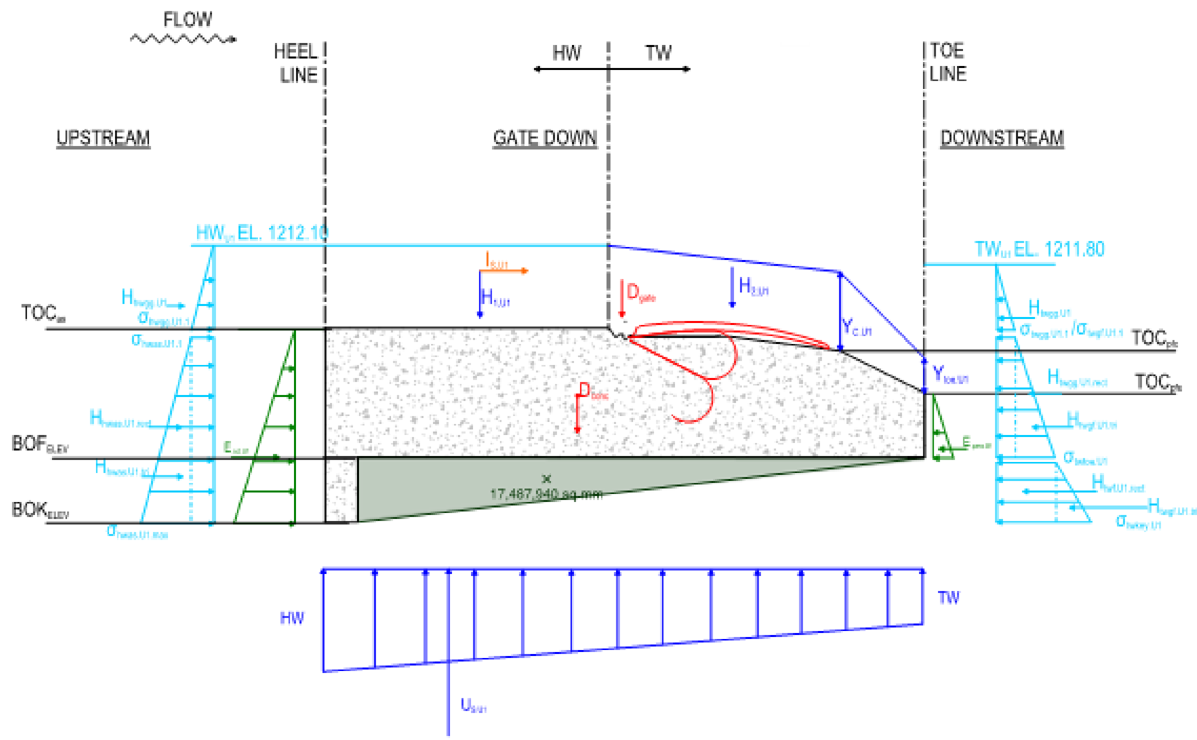
Sum of Moments of Rock Section: $\Sigma M_{rs} := V_{rs} \cdot L_{rs} = 67375 \cdot kN \cdot m$

SERVICE SPILLWAY GATE STRUCTURE 2D HYDRAULIC MODEL RESULTS

Applicable or Relevent Scenarios: Service Spillway (SS) - Gate Structure
Prepared: 24 October 2018

Scenario	Total Inflow (m^3/s)	Service Spillway Discharge (m^3/s)			Headwater (m)	Service Spillway Tailwater (m)	Notes	Water Surface Over SS Gate Bays: Headwater at gate hinge (m)	Critical depth at gate lip (m)	Depth at Basin Toe (m)	SS Tailwater just passed basin end (m)*
		Left Gate	Right Gate	Total							
160 m^3/s, No Diversion, **(U1, E2-Q)**	160	91	69	160	1212.1	1211.8	Diversion Inlet gates closed and Service Spillway gates fully open	LG = RG d = 2.1 EL 1212.1	LG = RG y_c = 1.4; EL 1211.4	LG = RG, toe submerged Uplift = Use tailwater d_{toe} = 0.45; EL 1208.46	d_{tw} = 3.8 EL 1211.8
50-yr Event, Diverting up to 600 m^3/s **(U2, E3-Q)**	530	152	0	152	1214.6	1211.8	Diversion Inlet gates open, Service Spillway left crest gate at EL 1212.1 m and right crest gate at EL 1215.0 m	LG = RG d = 4.6 EL 1214.6	LG = y_c = 1.67; EL 1213.76 RG = Closed	LG = d_{toe} = 0.58; EL 1208.58 RG = Use tailwater Uplift = Use tailwater	d_{tw} = 3.8 EL 1211.8
100-yr Event, Service Spillway Construction/Maintenance, **(UN4)**	765	315	0	315	1215.0	1212.5	Diversion Inlet gates open, Service Spillway left crest gate at EL 1210.9 m and right crest gate at EL 1215.0 m	LG = RG d = 5.0 EL 1215.0	LG = y_c = 2.73; EL 1213.63 RG = Closed	LG = d_{toe} = 1.23 super; EL 1209.23 RG = Use tailwater Uplift = Use tailwater	d_{tw} = 3.9 EL 1211.9
2013 Event, Diverting up to 600 m^3/s **(UN1)**	1240	498	137	634	1215.8	1213.1	Diversion Inlet gates open; Service Spillway left crest gate at EL 1210.0 m and right crest gate at EL 1213.5 m	LG = RG d = 5.8 EL 1215.8	LG = y_c = 3.87; EL 1213.87 RG = y_c = 1.53; EL 1215.03	LG = d_{toe} = 1.95 super; EL 1209.95 RG = d_{toe} = 0.48 super; EL 1208.48 Uplift = Use tailwater	d_{tw} = 5.1 EL 1213.1
2013 Event, Diverting with One Service Spillway Crest Gate Failing to Open **(UN2)**	1240	518	44	562	1216.1	1213.0	Diversion Inlet gates open, Service Spillway left crest gate at EL 1210.0 m and right crest gate at EL 1215.0 m	LG = RG d = 6.1 EL 1216.1	LG = y_c = 4.07; EL 1214.07 RG = y_c = 0.73; EL	LG = d_{toe} = 1.97 super; EL 1209.97 RG = Use tailwater	d_{tw} = 5.0 EL 1213.0
1000-yr Event, No Diversion **(UN3)** Auxiliary Spillway cover eroded	1930	759	708	1467	1217.0	1214.7	Diversion Inlet gates closed and Service Spillway gates fully open. Auxiliary Spillway cover layer eroded	LG = RG d = 7.0 EL 1217.0	LG = RG y_c = 4.67; EL 1214.67	LG = RG d_{toe} = 2.89 super; EL 1210.89 Uplift = Use tailwater	d_{tw} = 6.7 EL 1214.7
Diversion Structure IDF Event, 1/3 Between 1000-yr and PMF, **(E1-F)** No Diversion. AS cover eroded.	2210	812	758	1570	1217.3	1214.9	Diversion Inlet gates closed and Service Spillway gates fully open. Auxiliary Spillway cover layer eroded	LG = RG d = 7.3 EL 1217.3	LG = RG y_c = 4.87; EL 1214.87	LG = RG d_{toe} = 3.06 super; EL 1211.06 Uplift = Use tailwater	d_{tw} = 6.9 EL 1214.9

U1 DESIGN CASE



ACCEPTANCE PARAMETERS

Required Factor of Safety for Sliding: $FS_{req.U1.sl} := 1.5$ (Without Cohesion)

(Section 8.1, Design Criteria)

Resultant Within Middle Third of Base: $e \le \frac{L_b}{6} \wedge e \ge \frac{-L_b}{6}$

Allowable Rock Bearing Pressure: $\sigma_{allow.U1} := 1270 \cdot \frac{kN}{m^2}$ (Section 5.2, Design Criteria)

INPUT PARAMETERS

Headwater Elevation: $HW_{U1} := 1212.10m$ (Section 8.3, Design Criteria)

Tailwater Elevation: $TW_{U1} := 1211.80m$ (2D Hydraulic Results see page above, typ.)

Bottom of Footing Elevation: $BOF_{elev} := 1206.00m$

Approach Slab Top of Concrete Elevation at Upstream Face: $TOC_{as} := 1210.00m$

Footing Top of Concrete Elevation at Stilling Basin: $TOC_{pfe} := 1208.00m$

Footing Top of Concrete Elevation at Center of Footing: $TOC_{pfc} := 1209.30m$

Top of Guard/Regulating Gate Elevation: $TOP_{rg.U1} := 1210.00m$ $TOP_{gg.U1} := 1210.00m$

Gates are open when top of gate elevation is at 1210.00m

Gates are closed/up when top of gate elevation is at 1215.0m

Bottom of Key Elevation: $BOK_{elev} := BOF_{elev} - d_{key} = 1204\,m$

Water Elevation above Crest of Guard Gate: $EL_{C.U1} := 1211.4m$

$$Y_{C.U1} := \begin{cases} (EL_{C.U1} - TOC_{pfc}) & \text{if } TOP_{gg.U1} \le HW_{U1} \\ (TW_{U1} - TOC_{pfc}) & \text{if } TOP_{gg.U1} > HW_{U1} \end{cases} = 2.1 \cdot m$$

Water Elevation above Guard Gate Toe: $EL_{TOE.U1} := 1208.46m$

$$Y_{TOE.U1} := \begin{cases} (EL_{TOE.U1} - TOC_{pfe}) & \text{if } TOP_{gg.U1} \le HW_{U1} \\ (TW_{U1} - TOC_{pfe}) & \text{if } TOP_{gg.U1} > HW_{U1} \end{cases} = 0.46 \cdot m$$

LATERAL WATER LOADS

U1 CASE

HEADWATER (APPROACH SLAB DRIVING):

Headwater Depth on Gate: $D_{hwg.U1} := HW_{U1} - TOC_{as} = 2.10\,m$

Thickness of Approach Slab (Including Key): $T_{as} := \left(TOC_{as} - BOK_{elev}\right) = 6\,m$

Headwater Depth at Heel (U/S face): $D_{hwas.U1} := HW_{U1} - BOK_{elev} = 8.10\,m$

T_{as} taken to bottom of Key for loading, Not for structural thickness parameter.

Headwater Load Unit Width on Approach Slab: $W_{hwas.U1} := W_b = 15.00\,m$

Headwater Unit Load At Top of Approach Slab:

$$H_{hwas.U1.1} := \frac{-\left(\gamma_w \cdot D_{hwg.U1}{}^2\right)}{2} \cdot W_{hwas.U1} = -324.47 \cdot kN$$

Headwater Unit Load At Bottom of Approach Key:

$$H_{hwas.U1.2} := \frac{-\left(\gamma_w \cdot D_{hwas.U1}{}^2\right)}{2} \cdot W_{hwas.U1} = -4827.3 \cdot kN$$

Headwater Line Load At Top of Approach Slab:

$$\sigma_{hwas.U1.1} := -\left(\gamma_w \cdot D_{hwg.U1}\right) = -20.6 \cdot kPa$$

Headwater Line Load At Bottom of Approach Key:

$$\sigma_{hwas.U1.2} := -\left(\gamma_w \cdot D_{hwas.U1}\right) = -79.46 \cdot kPa$$

Triangular Distribution Unit Load on Approach Slab and Key:

$$H_{hwas.U1.2.tri} := \left(\frac{\sigma_{hwas.U1.2} - \sigma_{hwas.U1.1}}{2}\right) \cdot \left(T_{as} \cdot W_{hwas.U1}\right) = -2648.7 \cdot kN$$

Rectangular Distribution Unit Load on Approach Slab and Key:

$$H_{hwas.U1.2.rect} := \sigma_{hwas.U1.1} \cdot \left(T_{as} \cdot W_{hwas.U1}\right) = -1854.09 \cdot kN$$

Total Horizontal Headwater Load on Approach Slab:

$$H_{hwas.U1} := H_{hwas.U1.2.tri} + H_{hwas.U1.2.rect} = -4502.79 \cdot kN$$

Apply Total Footing Headwater Load at:

$$H_{hwas.U1.loc} := \frac{\left(H_{hwas.U1.2.rect} \cdot \frac{T_{as}}{2} + H_{hwas.U1.2.tri} \cdot \frac{T_{as}}{3}\right)}{H_{hwas.U1.2.tri} + H_{hwas.U1.2.rect}} - d_{key} = 0.41\,m$$

Guard Gate (2A) Operating Condition:

Guard Gate Down/Open Condition: $A1_{U1} := TOP_{gg.U1} \le TOC_{as}$

Guard Crest Gate Up/Closed, with Top of Gate Higher than HW Elevation: $B1_{U1} := TOP_{gg.U1} \ge HW_{U1} \wedge TOP_{gg.U1} > TOC_{as}$

Guard Crest Gate Up/Closed, with Top of Gate Lower than HW Elevation: $C1_{U1} := TOP_{gg.U1} > TOC_{as} \wedge HW_{U1} > TOP_{gg.U1}$

Guard Crest Gate Height: $H_{gg.U1} := TOP_{gg.U1} - TOC_{as} = 0\,m$

Headwater Depth at Guard Crest Gate: $D_{hwgg.U1} := HW_{U1} - TOC_{as} = 2.10\,m$

Guard Crest Gate Width: $W_{hwgg.U1} := 15.00m$

Lateral Headwater Pressure at Bottom of Guard Crest Gate:

$$\sigma_{hwgg.U1.1} := \begin{cases} (0.0kPa) & \text{if } A1_{U1} \\ -(\gamma_w \cdot D_{hwgg.U1}) & \text{if } B1_{U1} \\ -(\gamma_w \cdot D_{hwgg.U1}) & \text{if } C1_{U1} \end{cases} = 0.0 \cdot kPa$$

Lateral Headwater Pressure at Top of Guard Crest Gate:
(Load at HW Elevation On Guard Crest Gate if HW is below TOG_{rg})

$$\sigma_{hwgg.U1.2} := \begin{cases} (0.0kPa) & \text{if } A1_{U1} \\ 0.0kPa & \text{if } B1_{U1} \\ -[\gamma_w \cdot (HW_{U1} - TOP_{gg.U1})] & \text{if } C1_{U1} \end{cases} = 0.0 \cdot kPa$$

Average Pressure acting on Guard Crest Gate:

$$\sigma_{hwgg.U1.avg} := \frac{(\sigma_{hwgg.U1.1} + \sigma_{hwgg.U1.2})}{2} = 0 \cdot kPa$$

Total Area water acting on Crest Gate:

$$A_{hwgg.U1} := \begin{cases} D_{hwgg.U1} \cdot W_{hwgg.U1} & \text{if } A1_{U1} \\ D_{hwgg.U1} \cdot W_{hwgg.U1} & \text{if } B1_{U1} \\ H_{gg.U1} \cdot W_{hwgg.U1} & \text{if } C1_{U1} \end{cases} = 31.5 \cdot m^2$$

Total Horizontal Headwater Load on Guard Crest Gate: $H_{hwgg.U1} := \sigma_{hwgg.U1.avg} \cdot A_{hwgg.U1} = 0.0 \cdot kN$

Apply Total Guard Crest Gate Headwater Load at:

$$H_{hwgg.U1.loc} := \begin{cases} (TOC_{as} - BOF_{elev}) & \text{if } A1_{U1} \\ \left[\frac{(HW_{U1} - TOC_{as})}{3} + (TOC_{as} - BOF_{elev})\right] & \text{if } B1_{U1} \\ \left[\frac{\sigma_{hwgg.U1.2} \cdot A_{hwgg.U1} \cdot \frac{(H_{gg.U1})}{2} + \frac{(\sigma_{hwgg.U1.1} - \sigma_{hwgg.U1.2})}{2} A_{hwgg.U1} \cdot \frac{(H_{gg.U1})}{3}}{\sigma_{hwgg.U1.2} \cdot A_{hwgg.U1} + \frac{(\sigma_{hwgg.U1.1} - \sigma_{hwgg.U1.2})}{2} \cdot A_{hwgg.U1}} \ldots \\ + (TOC_{as} - BOF_{elev})\right] & \text{if } C1_{U1} \end{cases} = 4.0 \cdot m$$

LATERAL TAILWATER (RESISTING) Applied to Downstream Side of Guard Crest Gate: U1 CASE

Guard Gate Down/Open Condition: $A2_{U1} := TOP_{gg.U1} \le TOC_{as}$

Guard Crest Gate Up/Closed, with Top of Gate Higher than TW Elevation: $B2_{U1} := TOP_{gg.U1} \ge TW_{U1} \land TOP_{gg.U1} > TOC_{as}$

Guard Crest Gate Up/Closed, with Top of Gate Lower than TW Elevation: $C2_{U1} := TOP_{gg.U1} > TOC_{as} \land TW_{U1} > TOP_{gg.U1}$

Tailwater Depth at Guard Crest Gate: $D_{twgg.U1} := TW_{U1} - TOC_{as} = 1.80\,m$

Guard Crest Gate Width: $W_{twgg.U1} := 15.00m$

Lateral Water Load at Bottom of Guard Crest Gate:

$$\sigma_{twgg.U1.1} := \begin{cases} (0.0kPa) & \text{if } A2_{U1} \\ (\gamma_w \cdot D_{twgg.U1}) & \text{if } B2_{U1} \\ (\gamma_w \cdot D_{twgg.U1}) & \text{if } C2_{U1} \end{cases} = 0.0 \cdot kPa$$

Lateral Water Load at Top of Guard Crest Gate:
(Load at TW Elevation On Guard Crest Gate if TW is below TOG_{gg})

$$\sigma_{twgg.U1.2} := \begin{cases} (0.0kPa) & \text{if } A2_{U1} \\ 0.0kPa & \text{if } B2_{U1} \\ \left[\gamma_w \cdot \left(TW_{U1} - TOP_{gg.U1}\right)\right] & \text{if } C2_{U1} \end{cases} = 0.0 \cdot kPa$$

Average Pressure acting on Guard Crest Gate:

$$\sigma_{twgg.U1.avg} := \frac{\left(\sigma_{twgg.U1.1} + \sigma_{twgg.U1.2}\right)}{2} = 0 \cdot kPa$$

Total Area water acting on Crest Gate:

$$A_{twgg.U1} := \begin{cases} D_{twgg.U1} \cdot W_{twgg.U1} & \text{if } A2_{U1} \\ D_{twgg.U1} \cdot W_{twgg.U1} & \text{if } B2_{U1} \\ H_{gg.U1} \cdot W_{twgg.U1} & \text{if } C2_{U1} \end{cases} = 27 \cdot m^2$$

Total Horizontal Tailwater Load on Guard Crest Gate: $H_{twgg.U1} := \sigma_{twgg.U1.avg} \cdot A_{twgg.U1} = 0.0 \cdot kN$

Apply Total Horiz. TW Load on Guard Gate at:

$$H_{twgg.U1.loc} := \begin{cases} \left(TOC_{as} - BOF_{elev}\right) & \text{if } A2_{U1} \\ \left[\dfrac{\left(TW_{U1} - TOC_{as}\right)}{3} + \left(TOC_{as} - BOF_{elev}\right)\right] & \text{if } B2_{U1} \\ \left[\dfrac{\sigma_{twgg.U1.2} \cdot A_{twgg.U1} \cdot \dfrac{\left(H_{gg.U1}\right)}{2} + \dfrac{\left(\sigma_{twgg.U1.1} - \sigma_{twgg.U1.2}\right)}{2} A_{twgg.U1} \cdot \dfrac{\left(H_{gg.U1}\right)}{3}}{\sigma_{twgg.U1.2} \cdot A_{twgg.U1} + \dfrac{\left(\sigma_{twgg.U1.1} - \sigma_{twgg.U1.2}\right)}{2} \cdot A_{twgg.U1}} \dots \\ + \left(TOC_{as} - BOF_{elev}\right)\right] & \text{if } C2_{U1} \end{cases} = 4.0 \cdot m$$

LATERAL WATER LOADS (continued)

U1 CASE

TAILWATER (RESISTING) Applied to Concrete Structure:

Tailwater Depth At top of Gate Base Footing Elevation: $D_{twgf.U1} := TW_{U1} - TOC_{as} = 1.80\,m$

Water Depth at bottom of Gate Base Footing: $D_{twtoe.U1} := TW_{U1} - BOF_{elev} = 5.80\,m$

Footing Thickness for horizontal at Toe: $h_{toe} := TOC_{as} - BOF_{elev} = 4\,m$

Unit Width of D/S face of crest for application of Tailwater Load: $W_{tw.U1} := W_b = 15.00\,m$

Tailwater Pressure At Top of Gate Footing: $\sigma_{twgf.U1} := \left(\gamma_w \cdot D_{twgf.U1}\right) = 17.66 \cdot kPa$

Tailwater Line Load At Bottom of Gate Footing: $\sigma_{twtoe.U1} := \left(\gamma_w \cdot D_{twtoe.U1}\right) = 56.9 \cdot kPa$

Triangular Distribution Unit Load on Gate Footing Base:

$$H_{twgf.U1.tri} := \left(\frac{\sigma_{twtoe.U1} - \sigma_{twgf.U1}}{2}\right) \cdot \left(h_{toe} \cdot W_{tw.U1}\right) = 1177.2 \cdot kN$$

Rectangular Distribution Unit Load on Gate Footing Base:

$$H_{twgf.U1.rect} := \sigma_{twgf.U1} \cdot \left(h_{toe} \cdot W_{tw.U1}\right) = 1059.48 \cdot kN$$

Tailwater Pressure At Bottom of Sliding Failure Plane:

$$\sigma_{twbk.U1} := \left(HW_{U1} - BOK_{elev}\right) \cdot \gamma_w = 79.46 \cdot kPa$$

Triangular Distribution Unit Load Below Footing:

$$H_{twbk.U1.tri} := \frac{\left(\sigma_{twbk.U1} - \sigma_{twtoe.U1}\right)}{2} \cdot d_{key} \cdot W_{tw.U1} = 338.44 \cdot kN$$

Rectangular Distribution Load Below Footing Base:

$$H_{twbk.U1.rect} := \sigma_{twtoe.U1} \cdot d_{key} \cdot W_{tw.U1} = 1706.94 \cdot kN$$

Total Horizontal Tailwater Load on Gate Footing (including key):

$$H_{twgk.U1} := H_{twgf.U1.tri} + H_{twgf.U1.rect} + H_{twbk.U1.tri} + H_{twbk.U1.rect} = 4282.06 \cdot kN$$

Apply Total Gate Footing Tailwater Load From Toe at:

$$H_{twgk.U1.loc} := \frac{\left[H_{twgf.U1.rect} \cdot \frac{\left(h_{toe}\right)}{2} + H_{twgf.U1.tri} \cdot \frac{\left(h_{toe}\right)}{3} + H_{twbk.U1.tri} \cdot \left(-d_{key} \cdot \frac{2}{3}\right) + H_{twbk.U1.rect} \cdot \left(\frac{-d_{key}}{2}\right)\right]}{H_{twgf.U1.tri} + H_{twgf.U1.rect} + H_{twbk.U1.tri} + H_{twbk.U1.rect}} = 0.36\,m$$

SUMMATION OF LATERAL WATER LOADS:

$$\Sigma H_{Water.U1} := H_{hwas.U1} + H_{hwgg.U1} + H_{twgk.U1} + H_{twgg.U1} = -220.72 \cdot kN$$

$$\Sigma M_{Hwater.U1} := H_{hwas.U1} \cdot H_{hwas.U1.loc} + H_{hwgg.U1} \cdot H_{hwgg.U1.loc} \cdots + H_{twgk.U1} \cdot H_{twgk.U1.loc} + H_{twgg.U1} \cdot H_{twgg.U1.loc} = -323.73 \cdot kN \cdot m$$

VERTICAL WATER LOADS

U1 CASE

HEADWATER:

Water Depth on top of Approach Slab: $d_{hw.U1} := HW_{U1} - TOC_{as} = 2.10\,m$

Length of Approach Slab: $L_{as} = 8.75\,m$

Width of Approach Slab: $w_{as} = 15.00\,m$

Vertical Water Weight (H1) on Approach Slab: $H_{1.U1} := \left(w_{as} \cdot d_{hw.U1} \cdot L_{as}\right) \cdot \gamma_w = 2703.9 \cdot kN$

Moment Arm for Application of Water Weight (H1) from toe: $H_{1.U1.loc} := L_b - \dfrac{L_{as}}{2} = 14.13\,m$

TAILWATER:

Trapezoid Volume Above Gate Footing from Approach Slab to Crest: $V_{asc.U1} := \left(L_{gf} - L_{gfc}\right) W_b \dfrac{d_{hw.U1} + Y_{C.U1}}{2} = 225.23 \cdot m^3$

Trapezoid Volume Above Gate Footing Crest to End of Gate Footing: $V_{gfc.U1} := \left(L_{gfc} \cdot W_b\right) \dfrac{Y_{C.U1} + Y_{TOE.U1}}{2} = 49.92 \cdot m^3$

Load Above Gate Footing from Approach Slab to Crest: $H_{2.U1.asc} := V_{asc.U1} \cdot \gamma_w = 2209.46 \cdot kN$

Load Acting Above Footing Crest from Toe: $H_{2.U1.asc.loc} := \dfrac{\left(L_{gf} - L_{gfc}\right) \cdot \left(2 \cdot d_{hw.U1} + Y_{C.U1}\right)}{3 \cdot \left(d_{hw.U1} + Y_{C.U1}\right)} + L_{gfc} = 6.17\,m$

Load Above Gate Footing from Crest to End: $H_{2.U1.gfc} := V_{gfc.U1} \cdot \gamma_w = 489.72 \cdot kN$

Load Acting Above Gate Footing from Crest to End: $H_{2.U1.gfc.loc} := \dfrac{\left(L_{gfc}\right) \cdot \left(2 \cdot Y_{C.U1} + Y_{TOE.U1}\right)}{3 \cdot \left(Y_{C.U1} + Y_{TOE.U1}\right)} = 1.58\,m$

Vertical Water Weight (H2) on Gate Footing: $H_{2.U1} := H_{2.U1.asc} + H_{2.U1.gfc} = 2699.17 \cdot kN$

Moment Arm for Application of Water Weight (H2) from toe: $H_{2.U1.loc} := \dfrac{H_{2.U1.asc} \cdot H_{2.U1.asc.loc} + H_{2.U1.gfc} \cdot H_{2.U1.gfc.loc}}{H_{2.U1}} = 5.34\,m$

U1 CASE

UPLIFT AT INCLINE SLIDING PLANE

Uplift pressure at U/S Face (heel): $U_{HW.U1} := D_{hwas.U1} \cdot \gamma_w = 79.5 \cdot \frac{kN}{m^2}$

Uplift pressure at D/S Face Stilling Basin: $U_{TW.U1} := \left(D_{twtoe.U1}\right) \cdot \gamma_w = 56.9 \cdot \frac{kN}{m^2}$

Length from U/S of Gate Structure to U/S of Stilling Basin: $L_{overall.Usual} := L_b = 18.50\,m$

Difference between Uplift pressure at HW and TW: $U_{diff.U1} := U_{HW.U1} - U_{TW.U1} = 22.56 \cdot \frac{kN}{m^2}$

Slope of difference between between Uplift pressure at HW and TW: $U_{slope.U1} := \frac{U_{diff.U1}}{L_{overall.Usual}} = 1.22 \cdot \frac{kN}{m^2 \cdot m}$

Tailwater Pressure at toe of Gate Structure: $U_{press.toe.gs.U1} := U_{TW.U1} + \left(L_{overall.Usual} - L_b\right) \cdot U_{slope.U1} = 56.9 \cdot \frac{kN}{m^2}$

Uniform uplift force UA Under Gate Structure due to TW (rectangle): $U_{A.U1} := U_{press.toe.gs.U1} \cdot L_b \cdot W_b \cdot -1 = -15789.19 \cdot kN$

Moment Arm from Toe of Gate Structure for Uplift UA: $L_{A.U1} := \left(\frac{L_b}{2}\right) = 9.25\,m$

Linearly Decreasing Uplift Force U1B Under Gate Structure due to HW-TW Differential (triangle): $U_{B.U1} := \frac{1}{2} \cdot \left(U_{HW.U1} - U_{press.toe.gs.U1}\right) \cdot L_b \cdot W_b \cdot -1 = -3130.62 \cdot kN$

Moment Arm from Toe of Gate Structure for Uplift UB: $L_{B.U1} := \frac{2}{3} \cdot L_b = 12.33\,m$

Total Resultant Uplift force Sliding Check: $U_{S.U1} := U_{A.U1} + U_{B.U1} = -18919.81 \cdot kN$

Resultant Location from Toe: $U_{S.U1.loc} := \frac{U_{A.U1} \cdot L_{A.U1} + U_{B.U1} \cdot L_{B.U1}}{U_{A.U1} + U_{B.U1}} = 9.76\,m$

$\Sigma V_{water.U1} := H_{1.U1} + H_{2.U1} + U_{S.U1} = -13516.76 \cdot kN$

$\Sigma M_{Vwater.U1} := H_{1.U1} \cdot H_{1.U1.loc} + H_{2.U1} \cdot H_{2.U1.loc} + U_{S.U1} \cdot U_{S.U1.loc} = -132052.69 \cdot kN \cdot m$

SOIL LOADS

U1 CASE

Equivalent Fluid Pressure (EFP):

At rest lateral pressure coefficient: $K_{o.U1} := 1 - \sin(\phi_{backfill}) = 0.658$ (Section 5.3, Design Criteria)

Headwater Footing Unit Width: $W_{hwas.U1} = 15.00\,m$

Tailwater Footing Unit Width: $W_{tw.U1} = 15.00\,m$

Footing Thickness at Heel: $t_{hf.U1} := TOC_{as} - BOK_{elev} = 6.00\,m$

Fixed Crest Footing Thickness at Toe: $t_{tf.U1} := TOC_{pfe} - BOF_{elev} = 2.00\,m$

Lateral Driving Force (Headwater Side - at rest condition)

At-Rest Soil Load:

$$E_{act.U1} := \frac{K_{o.U1} \cdot t_{hf.U1}^{\,2}}{2} \cdot (\gamma_r - \gamma_w) \cdot W_{hwas.U1} \cdot -1 = -2165.61 \cdot kN$$

At Rest- Soil Load Acting from Toe:

$$E_{act.U1.loc} := \frac{t_{hf.U1}}{3} - d_{key} = 0.00\,m$$

Lateral Resisting Force (Tailwater Side - at rest condition)

At-rest Soil Load:

$$E_{pass.U1} := \frac{K_{o.U1} \cdot t_{tf.U1}^{\,2}}{2} \cdot (\gamma_r - \gamma_w) \cdot W_{tw.U1} = 240.62 \cdot kN$$

Acting at:

$$E_{pass.U1.loc} := \frac{t_{tf.U1}}{3} = 0.67\,m$$

$$\Sigma H_{soil.U1} := E_{act.U1} + E_{pass.U1} = -1924.99 \cdot kN$$

$$\Sigma M_{soil.U1} := E_{act.U1} \cdot E_{act.U1.loc} + E_{pass.U1} \cdot E_{pass.U1.loc} = 160.42 \cdot kN \cdot m$$

ICE / IMPACT LOADS (ASSUME NO ICE LOADING ON TAILWATER SIDE)

Static Ice load on Gates:

$$I_{G.U1} := \begin{cases} 0\,\frac{kN}{m} & \text{if } TOP_{gg.U1} \le TOC_{as} \\ 75\,\frac{kN}{m} & \text{if } TOP_{gg.U1} > TOC_{as} \end{cases} = 0$$

(Section 7.7, Design Criteria)

Ice Loading Unit Width on Guard Gate: $W_{gg.U1} := 15m$ (Input value for load case)

Total Ice Load on Structure:

$$I_{U1} := -(I_{G.U1} \cdot W_{gg.U1}) = 0 \cdot kN$$

Apply Ice load at:

$$I_{U1.loc} := (TOC_{as} - BOF_{elev}) - 0.3m = 3.70\,m$$

$$\Sigma H_{I.U1} := I_{U1} = 0 \cdot kN$$

$$\Sigma M_{I.U1} := I_{U1} \cdot I_{U1.loc} = 0 \cdot kN \cdot m$$

SEISMIC LOAD (NOT APPLICABLE FOR THIS LOAD CASE)

U1 CASE

SUMMARY OF LOADS

	Loads	Moment Arm
Dead load of Concrete Structure:	$D_{conc} = 24618.6 \cdot kN$	$X_{conc.loc} = 10.06\,m$
Obermyer Gate Weight:	$D_{Gate} = 210.0 \cdot kN$	$X_{gate} = 6.60\,m$
HW Lateral Load on Approach Slab:	$H_{hwas.U1} = -4502.8 \cdot kN$	$H_{hwas.U1.loc} = 0.41\,m$
HW Lateral Load on Guard Gate:	$H_{hwgg.U1} = 0.0 \cdot kN$	$H_{hwgg.U1.loc} = 4.00\,m$
TW Lateral Load on Gate Footing (Including Key - Sliding Check Loads):	$H_{twgk.U1} = 4282.06 \cdot kN$	$H_{twgk.U1.loc} = 0.36\,m$
TW Lateral Load on Guard Gate:	$H_{twgg.U1} = 0.0 \cdot kN$	$H_{twgg.U1.loc} = 4.00\,m$
Vertical HW Load on Approach Slab:	$H_{1.U1} = 2703.9 \cdot kN$	$H_{1.U1.loc} = 14.13\,m$
Vertical TW Load on Pier Footing (crest):	$H_{2.U1} = 2699.2 \cdot kN$	$H_{2.U1.loc} = 5.34\,m$
Uplift:	$U_{S.U1} = -18919.8 \cdot kN$	$U_{S.U1.loc} = 9.76\,m$
Lateral Soil Load (driving):	$E_{act.U1} = -2165.6 \cdot kN$	$E_{act.U1.loc} = 0.00\,m$
Lateral Soil Load (resisting):	$E_{pass.U1} = 240.62 \cdot kN$	$E_{pass.U1.loc} = 0.67\,m$
Ice / Impact Load:	$I_{U1} = 0.0 \cdot kN$	$I_{U1.loc} = 3.70\,m$

STABILITY ASSESSMENT (SLIDNG, BEARING, FLOTATION AND OVERTURNING):

U1 CASE

CHECK SLIDING ALONG HORIZONTAL PLANE THRU TOE, IGNORING BEDROCK MOBILIZED BY STRUCTURAL HEEL KEY, OR VOID BEHIND KEY

Sum of Vertical Forces:

$$\Sigma V_{U1} := \Sigma V_{DL} + \Sigma V_{water.U1} = 11311.8 \cdot kN$$

Sum of Horizontal Forces:

$$\Sigma H_{U1} := \Sigma H_{Water.U1} + \Sigma H_{soil.U1} + \Sigma H_{I.U1} = -2145.71 \cdot kN$$

Sliding Factor of Safety:

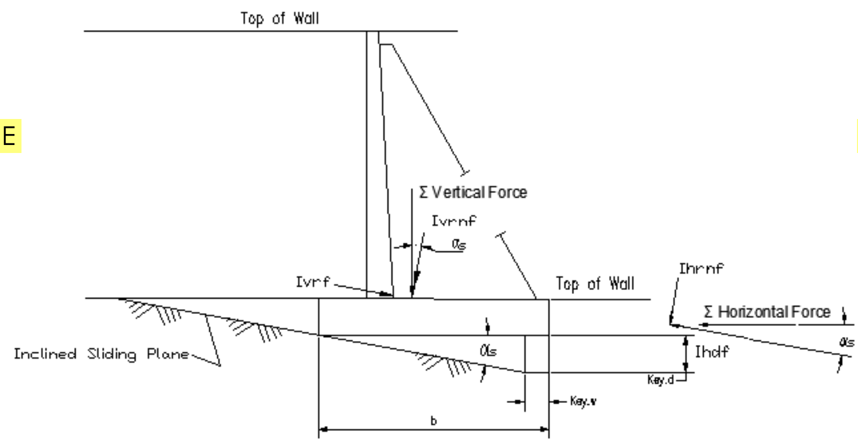
$$FS_{HorizSliding.U1} := \frac{\tan_{\phi} \cdot \Sigma V_{U1}}{\left|\Sigma H_{U1}\right|} = 2.57$$

$$FS_{HorizSliding.U1.Check} := \begin{array}{|l} \text{"OKAY"} \quad \text{if} \quad FS_{HorizSliding.U1} \geq FS_{req.U1.sl} \\ \text{"Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !"} \quad \text{otherwise} \end{array} = \text{"OKAY"}$$

CHECK SLIDING ALONG INCLINED SLIDING PLANE FROM HEEL KEY TO TOE, WITH BEDROCK MASS MOBILIZED BY REINFOCREDE CONCRETE KEY)

RESISTING SIDE

DRIVING SIDE



TOE

HEEL

Ivrf=Inclined Resisting Force
Ivrnf=Inclined Resisting Normal Force
Ihrnf=Inclined Resisting Normal Force
Ihdf=Inclined Driving Force

$$\alpha s := \operatorname{atan}\left(\frac{d_{key}}{L_b - w_{key}}\right) = 0.11$$

as degrees= $\alpha s \cdot \left(\frac{180}{\pi}\right) = 6.52$

$\Sigma V_{U1} = 11311.84 \cdot kN$

$V_{rs} = 5775 \cdot kN$

Resolve $\Sigma Vert_{U1}$ & $\Sigma Horiz_{U1}$

$$\Sigma V_{InclinedU1} := \cos(\alpha s) \cdot \left(\Sigma V_{U1} + V_{rs}\right) + \sin(\alpha s) \cdot \left|\Sigma H_{U1}\right| = 17220.0 \cdot kN$$

$$\Sigma H_{InclinedU1} := \cos(\alpha s) \cdot \left|\Sigma H_{U1}\right| - \sin(\alpha s) \cdot \left(\Sigma V_{U1} + V_{rs}\right) = 191.7 \cdot kN$$

(With properly engineered reinforced concrete Key, horizontal sliding plane thru Toe is protected, critical sliding plane is relocated to the INCLINED SLIDING PLANE FROM HEEL KEY To TOE, Bedrock Mass above this examined plane is mobilized by reinforced concrete key and combined into Structural Wedge.)

Inclined Sliding Plane Length

$$L_{incline} := \left[L_b^{\,2} + \left(BOF_{elev} - BOK_{elev}\right)^2\right]^{0.5} = 18.61\ m$$

Safety Factor for Sliding Inclined Failure Plane

$$FS_{InclinedISlidingU1} := \frac{\Sigma V_{InclinedU1} \cdot \tan\left(\phi_{rock} \cdot \frac{\pi}{180}\right)}{\left|\Sigma H_{InclinedU1}\right|} = 43.82$$

$$FS_{InclinedSliding.check.U1} := \begin{array}{|l} \text{"OKAY "} \quad \text{if} \quad FS_{InclinedISlidingU1} > FS_{req.U1.sl} \\ \text{"Revise Structure""} \quad \text{otherwise} \end{array} = \text{"OKAY "}$$

$$FS_{InclinedSliding.check.U1} = \text{"OKAY "}$$

OVERTURNING STABILITY CHECK:

U1 CASE

CHECK ECCENTRICITY

Sum of the moments:

$$\Sigma M_{U1} := \Sigma M_{DL} + \Sigma M_{Hwater.U1} + \Sigma M_{Vwater.U1} + \Sigma M_{I.U1} + \Sigma M_{soil.U1} + \Sigma M_{soil} = 184103 \cdot kN \cdot m$$

Eccentricity:

$$e_{U1} := \left(\frac{L_{incline}}{2}\right) - \frac{\Sigma M_{U1}}{\Sigma V_{InclinedU1}} = -1.39\,m$$

Eccentricity Check:

$$e_{check.U1} := \begin{cases} \text{"Okay"} & \text{if } |e_{U1}| \le Kern \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$$e_{check.U1} = \text{"Okay"}$$

Foundation Bearing Checks:

Incline Plane Area:

$$A_{b.incline} := L_{incline} \cdot W_b = 279.12\,m^2$$

Incline Plane Section Modulus:

$$S_{b.incline} := \frac{W_b \cdot L_{incline}^2}{6} = 865.63 \cdot m^3$$

Bearing Pressure at Heel:

$$\sigma_{heel.U1} := \frac{\Sigma V_{InclinedU1}}{A_{b.incline}} - \frac{\Sigma V_{InclinedU1} \cdot e_{U1}}{S_{b.incline}} = 89.3 \cdot \frac{kN}{m^2}$$

$$\sigma_{heel.U1.check} := \left(\begin{cases} \text{"Okay"} & \text{if } \sigma_{heel.U1} \le \sigma_{allow.U1} \\ \text{"Revise Structure"} & \text{if } \sigma_{heel.U1} < 0\,\frac{kN}{m^2} \end{cases} \right)$$

$$\sigma_{heel.U1.check} = \text{"Okay"}$$

Bearing Pressure at Toe:

$$\sigma_{toe.U1} := \frac{\Sigma V_{InclinedU1}}{A_{b.incline}} + \frac{\Sigma V_{InclinedU1} \cdot e_{U1}}{S_{b.incline}} = 34.1 \cdot \frac{kN}{m^2}$$

$$\sigma_{toe.U1.1.check} := \begin{cases} \text{"Okay"} & \text{if } \sigma_{toe.U1} \le \sigma_{allow.U1} \\ \text{"Revise Structure"} & \text{if } \sigma_{toe.U1} < 0\,\frac{kN}{m^2} \end{cases}$$

$$\sigma_{toe.U1.1.check} = \text{"Okay"}$$

FLOATATION ANALYSIS:

ACCEPTANCE PARAMETERS

Required Factor of Safety: $FS_{req.FU1} := 1.5$

VERTICAL LOADS RESISTING:

Dead Load: $\Sigma V_{DL} = 24828.6 \cdot kN$

Water Weight H1+H2: $\Sigma V_{H.FU1} := H_{1.U1} + H_{2.U1} = 5403.05 \cdot kN$

Summation Vertical Resisting: $\Sigma V_{FU1} := \Sigma V_{DL} + \Sigma V_{H.FU1} = 30231.7 \cdot kN$

VERTICAL LOADS UPLIFT:

Uplift: $U_{S.U1} = -18919.81 \cdot kN$

Factor of Safety Floatation:

$$FS_{act.FU1} := \frac{\Sigma V_{FU1}}{|U_{S.U1}|} = 1.60$$

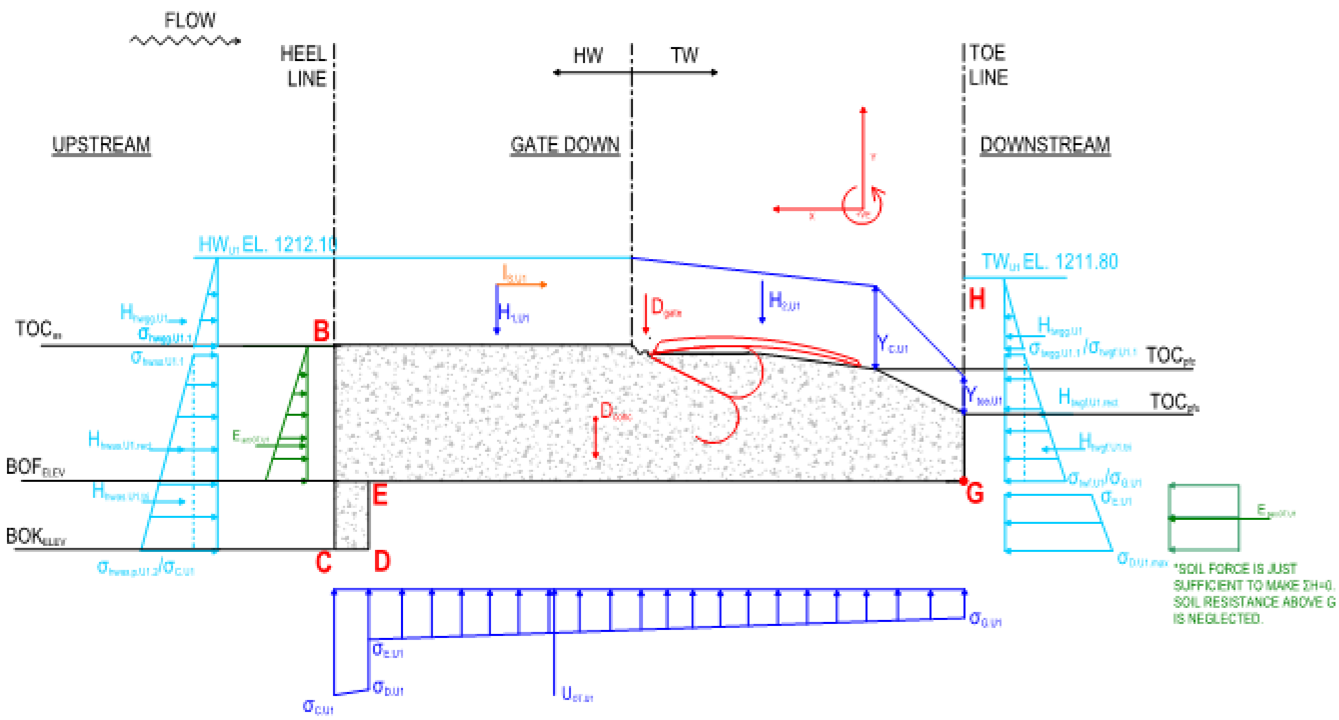
$$FS_{check.FU1} := \begin{cases} \text{"OKAY"} & \text{if } FS_{act.FU1} \ge FS_{req.FU1} \\ \text{"ANCHORS REQUIRED"} & \text{if } FS_{act.FU1} < FS_{req.FU1} \end{cases} = \text{"OKAY"}$$

MONOLITH OVERTURNING STABILITY ANALYSIS

U1 CASE

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.
Assumptions are made in order to compute overturning stability of indeterminate forces on monolith with key;
(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.
(b) The horizontal resisting force acting on the key, P.key, is that required for static equilibrium
(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1 $Ratio_{OT.U1.min} := 0.33$ Resultant at Middle Third



Uplift Loads for Overturning Stability Analysis

Line of Creep:

Change in Water Head: $\Delta_{h.U1} := HW_{U1} - TW_{U1} = 0.3\,m$

Length from Point C to Point G: $L_{CG} := \sqrt{d_{key}^2 + L_b^2} = 18.61\,m$

Length from Various Points to Points: $L_{CD} := w_{key} = 1\,m$ $L_{DE} := d_{key} = 2\,m$ $L_{EG} := L_b - L_{CD} = 17.5\,m$

$L_{GH.U1} := TW_{U1} - BOF_{elev} = 5.8\,m$

Length from Point C, D, E to G: $L_{CDEG} := L_{CD} + L_{DE} + L_{EG} = 20.5\,m$ $L_{CDE} := L_{CD} + L_{DE} = 3\,m$

Water Pressure at Point C: $\sigma_{C.U1} := \sigma_{hwas.U1.2} = -79.46 \cdot kPa$

Water Pressure at Point G: $\sigma_{G.U1} := \sigma_{twtoe.U1} \cdot -1 = -56.9 \cdot kPa$

Water Pressure at Point D: $\sigma_{D.U1} := -\gamma_w \cdot \left[\left(HW_{U1} - BOK_{elev}\right) - \frac{\Delta_{h.U1} \cdot L_{CD}}{L_{CDEG}}\right] = -79.32 \cdot kPa$

Water Pressure at Point E: $\sigma_{E.U1} := -\gamma_w \cdot \left[\left(HW_{U1} - BOF_{elev}\right) - \frac{\Delta_{h.U1} \cdot L_{CDE}}{L_{CDEG}}\right] = -59.41 \cdot kPa$

Uplift for Overturning Analysis on Bottom of Key: $U_{OT.U1.key} := \frac{\sigma_{C.U1} + \sigma_{D.U1}}{2} \cdot L_{CD} \cdot W_b = -1190.84 \cdot kN$

Acting at: $U_{OT.U1.key.loc} := \frac{L_{CD} \cdot \left(2 \cdot \sigma_{C.U1} + \sigma_{D.U1}\right)}{3\left(\sigma_{C.U1} + \sigma_{D.U1}\right)} + L_{EG} = 18\,m$

U1 CASE

Uplift for Overturning Analysis on Bottom of Footing:

$$U_{OT.U1.ftg} := \frac{\sigma_{E.U1} + \sigma_{G.U1}}{2} \cdot L_{EG} \cdot W_b = -15265.47 \cdot kN$$

Acting at:

$$U_{OT.U1.ftg.loc} := \frac{L_{EG} \cdot \left(\sigma_{G.U1} + 2 \cdot \sigma_{E.U1}\right)}{3\left(\sigma_{G.U1} + \sigma_{E.U1}\right)} = 8.81\,m$$

Uplift Load for Overturning Analysis:

$$U_{OT.U1} := U_{OT.U1.key} + U_{OT.U1.ftg} = -16456.3 \cdot kN$$

Uplift Load Acting from Toe:

$$U_{OT.U1.loc} := \frac{U_{OT.U1.key} \cdot U_{OT.U1.key.loc} + U_{OT.U1.ftg} \cdot U_{OT.U1.ftg.loc}}{U_{OT.U1}} = 9.48\,m$$

All Vertical Loads Applicable to Overturning Stability Analysis

Total Concrete Dead Loads:	$D_{conc} = 24618.6 \cdot kN$	at:	$X_{conc.loc} = 10.06\,m$
Dead Load of Gate:	$D_{Gate} = 210.0 \cdot kN$		$X_{gate} = 6.60\,m$
Water Weight (HW) on Apron Slab:	$H_{1.U1} = 2703.9 \cdot kN$		$H_{1.U1.loc} = 14.13\,m$
Water Weight (TW) on Gate Footing:	$H_{2.U1} = 2699.2 \cdot kN$		$H_{2.U1.loc} = 5.34\,m$
Uplift Load for Overturning Analysis:	$U_{OT.U1} = -16456.3 \cdot kN$		$U_{OT.U1.loc} = 9.48 \cdot m$

Sum of All Overturning Analysis Vertical Load:

$$\Sigma V_{U1.OT} := D_{conc} + D_{Gate} + H_{1.U1} + H_{2.U1} + U_{OT.U1} = 13775.35 \cdot kN$$

Sum of All Overturning Analysis Vertical Load Moments:

$$\Sigma M_{V.U1.OT} := D_{conc} \cdot X_{conc.loc} + D_{Gate} \cdot X_{gate} + H_{1.U1} \cdot H_{1.U1.loc} + H_{2.U1} \cdot H_{2.U1.loc} + U_{OT.U1} \cdot U_{OT.U1.loc} = 145582.24 \cdot kN \cdot m$$

Lateral Tailwater Loads for Overturning Stability Analysis

TW Lateral Load on Gate Footing (No Key - Overturning Values Adjusted):

$$H_{twgf.U1} := H_{twgf.U1.tri} + H_{twgf.U1.rect} = 2236.68 \cdot kN$$

Acting at:

$$H_{twgf.U1.loc} := \frac{\frac{h_{toe}}{3} \cdot H_{twgf.U1.tri} + \frac{h_{toe}}{2} \cdot H_{twgf.U1.rect}}{H_{twgf.U1}} = 1.65\,m$$

Horizontal Tailwater Pressure Top of Key (Overturning Analysis):

$$\sigma_{twtk.OT.U1} := \sigma_{E.U1} \cdot -1 = 59.41 \cdot kPa$$

Horizontal Tailwater Pressure Bottom of Key (Overturning Analysis):

$$\sigma_{twbk.OT.U1} := \sigma_{D.U1} \cdot -1 = 79.32 \cdot kPa$$

Triangular Distribution Unit Load Acting at Key:

$$H_{twbk.OT.U1.tri} := \frac{\left(\sigma_{twbk.OT.U1} - \sigma_{twtk.OT.U1}\right)}{2} \cdot d_{key} \cdot W_{tw.U1} = 298.61 \cdot kN$$

Triangular Distribution Unit Load Acting at Key:

$$H_{twbk.OT.U1.rect} := \sigma_{twtk.OT.U1} \cdot d_{key} \cdot W_{tw.U1} = 1782.31 \cdot kN$$

Total Horizontal Tailwater Load on Key (Overturning Values Adjusted):

$$H_{twkey.OT.U1} := H_{twbk.OT.U1.tri} + H_{twbk.OT.U1.rect} = 2080.92 \cdot kN$$

Acting at:

$$H_{twkey.OT.U1.loc} := \frac{H_{twbk.OT.U1.tri} \cdot \frac{-2 \cdot d_{key}}{3} + H_{twbk.OT.U1.rect} \cdot \frac{-d_{key}}{2}}{H_{twkey.OT.U1}} = -1.05\,m$$

Lateral Driving Earth Loads for Overturning Stability Analysis (at rest condition)

U1 CASE

Depth of Driving Soil Loads (to top of key): $h_{E.OT.U1} := TOC_{as} - BOF_{elev} = 4\,m$

At-Rest Soil Load: $E_{act.OT.U1} := \frac{K_{o.U1} \cdot h_{E.OT.U1}^{2}}{2} \cdot (\gamma_r - \gamma_w) \cdot W_{hwas.U1} \cdot -1 = -962.49 \cdot kN$

At Rest- Soil Load Acting from Toe: $E_{act.OT.U1.loc} := \frac{h_{E.OT.U1}}{3} = 1.33\,m$

All Lateral Loads Applicable to Overturning Stability Analysis

HW Lateral Load on Approach Slab:	$H_{hwas.U1} = -4502.8 \cdot kN$	$H_{hwas.U1.loc} = 0.41\,m$
HW Lateral Load on Guard Gate:	$H_{hwgg.U1} = 0.0 \cdot kN$	$H_{hwgg.U1.loc} = 4.00\,m$
TW Lateral Load on Guard Gate:	$H_{twgg.U1} = 0.0 \cdot kN$	$H_{twgg.U1.loc} = 4.00\,m$
TW Lateral Load on Gate Footing (No Key - Overturning Values Adjusted):	$H_{twgf.U1} = 2236.68 \cdot kN$	$H_{twgf.U1.loc} = 1.65\,m$
TW Lateral Load on Key:	$H_{twkey.OT.U1} = 2080.92 \cdot kN$	$H_{twkey.OT.U1.loc} = -1.05\,m$
Ice / Impact Load:	$I_{U1} = 0.0 \cdot kN$	$I_{U1.loc} = 3.70\,m$
Lateral Soil Load (driving):	$E_{act.OT.U1} = -962.5 \cdot kN$	$E_{act.OT.U1.loc} = 1.33\,m$

Resisting Lateral Soil Load as required to produce horizontal equilibrium:

$$E_{pas.OT.U1} := -(H_{hwas.U1} + H_{hwgg.U1} + H_{twgg.U1} + H_{twgf.U1} + H_{twkey.OT.U1} + I_{U1} + E_{act.OT.U1}) = 1147.69 \cdot kN$$

Acting at:

$$E_{pas.OT.U1.loc} := -1 \cdot \frac{d_{key}}{2} = -1\,m$$

Sum of All Overturning Analysis Horizontal Load (ΣH=0):

$$\Sigma H_{U1.OT} := H_{hwas.U1} + H_{hwgg.U1} + H_{twgg.U1} + H_{twgf.U1} + H_{twkey.OT.U1} + I_{U1} + E_{act.OT.U1} + E_{pas.OT.U1} = 0 \cdot kN$$

Sum of All Overturning Analysis Horizontal Load Moments:

$$\Sigma M_{H.U1.OT} := H_{hwas.U1} \cdot H_{hwas.U1.loc} + H_{hwgg.U1} \cdot H_{hwgg.U1.loc} + H_{twgg.U1} \cdot H_{twgg.U1.loc} + H_{twgf.U1} \cdot H_{twgf.U1.loc} \cdots + H_{twkey.OT.U1} \cdot H_{twkey.OT.U1.loc} + I_{U1} \cdot I_{U1.loc} + E_{act.OT.U1} \cdot E_{act.OT.U1.loc} + E_{pas.OT.U1} \cdot E_{pas.OT.U1.loc} = -2776.99 \cdot kN \cdot m$$

Overturning Stability Analysis

$$\Sigma M_{U1.OT} := \Sigma M_{V.U1.OT} + \Sigma M_{H.U1.OT} = 142805.25 \cdot kN \cdot m$$

$$X_{R.U1} := \frac{\Sigma M_{U1.OT}}{\Sigma V_{U1.OT}} = 10.37\,m \qquad x_{OT.U1} := X_{R.U1} - \frac{L_b}{2} = 1.12\,m$$

Overturning Resultant Ratio $Ratio_{OT.U1} := \frac{X_{R.U1}}{L_b} = 0.56$

$$Ratio_{OT.U1.check} := \begin{cases} \text{"OKAY"} & \text{if } Ratio_{OT.U1} \geq Ratio_{OT.U1.min} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

$$x_{OT.check.U1} := \begin{cases} \text{"OKAY"} & \text{if } |x_{OT.U1}| \leq Kern \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

CHECK FOUNDATION BEARING CAPACITY (HORIZONTAL PLANE):

U1 CASE

Bearing Pressure Under Toe:

$$\sigma_{ToeU1.OT} := \frac{\Sigma V_{U1.OT}}{L_b \cdot W_b} + \frac{\left(\Sigma V_{U1.OT} \cdot x_{OT.U1}\right)}{S_b} = 67.6 \cdot kPa$$

$$Bearing_{ChecktoeU1.OT} := \begin{vmatrix} \text{"OKAY "} & \text{if} \quad \sigma_{ToeU1.OT} < \sigma_{allow.U1} \\ \text{"NG""} & \text{otherwise} \end{vmatrix} = \text{"OKAY "}$$

Bearing Pressure Under Heel:

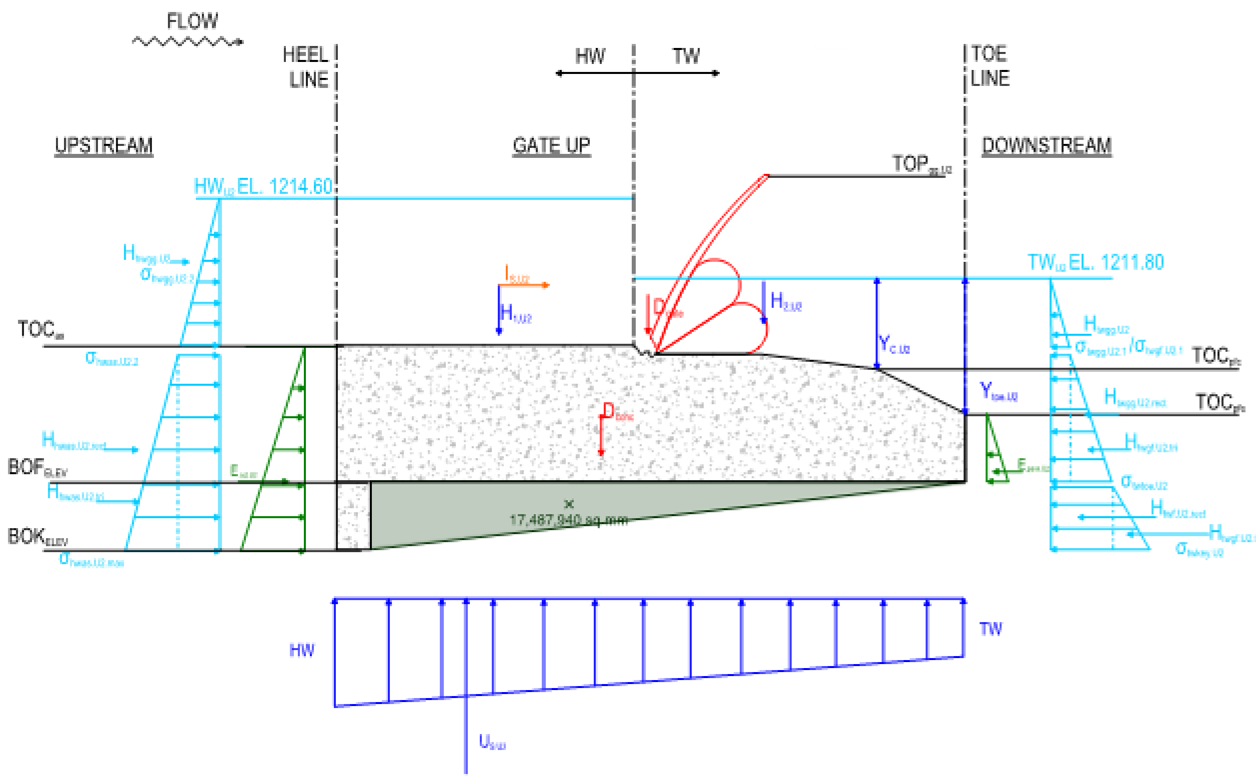
$$\sigma_{HeelU1.OT} := \frac{\Sigma V_{U1.OT}}{L_b \cdot W_b} - \frac{\left(\Sigma V_{U1.OT} \cdot x_{OT.U1}\right)}{S_b} = 31.7 \cdot kPa$$

$$Bearing_{CheckheelU1.OT} := \left(\begin{vmatrix} \text{"OKAY "} & \text{if} \quad \sigma_{HeelU1.OT} < \sigma_{allow.U1} \wedge \sigma_{HeelU1.OT} > 0 \\ \text{"NG""} & \text{otherwise} \end{vmatrix} \right) = \text{"OKAY "}$$

SUMMARY OF STABILITY ASSESSMENT:

Sliding Factor of Safety: (Horizontal Plane)	$FS_{HorizSliding.U1} = 2.57$	$FS_{HorizSliding.U1.Check} = \text{"OKAY"}$
Sliding Factor of Safety: (Inclined Plane)	$FS_{InclinedlSlidingU1} = 43.82$	$FS_{InclinedSliding.check.U1} = \text{"OKAY "}$
Eccentricity: (Inclined Plane)	$e_{U1} = -1.39\,m$	$e_{check.U1} = \text{"Okay"}$
Bearing Pressure At Heel: (Inclined Plane)	$\sigma_{heel.U1} = 89 \cdot kPa$	$\sigma_{heel.U1.check} = \text{"Okay"}$
Bearing Pressure At Toe: (Inclined Plane)	$\sigma_{toe.U1} = 34 \cdot kPa$	$\sigma_{toe.U1.1.check} = \text{"Okay"}$
Flotation Factor of Safety (horizontal plane)	$FS_{act.FU1} = 1.6$	$FS_{check.FU1} = \text{"OKAY"}$
Overturning Resultant Ratio: (horizontal plane)	$Ratio_{OT.U1} = 0.56$	$Ratio_{OT.U1.check} = \text{"OKAY"}$
Eccentricity: (horizontal plane)	$x_{OT.U1} = 1.12\,m$	$x_{OT.check.U1} = \text{"OKAY"}$
Bearing Pressure At Heel: (horizontal plane)	$\sigma_{HeelU1.OT} = 32 \cdot kPa$	$Bearing_{CheckheelU1.OT} = \text{"OKAY "}$
Bearing Pressure At Toe: (horizontal plane)	$\sigma_{ToeU1.OT} = 68 \cdot kPa$	$Bearing_{ChecktoeU1.OT} = \text{"OKAY "}$

U2 DESIGN CASE



ACCEPTANCE PARAMETERS

Required Factor of Safety for Sliding: $FS_{req.U2.sl} := 1.5$ (Without Cohesion) (Section 8.1, Design Criteria)

Resultant Within Middle Third of Base: $e \le \frac{L_b}{6} \wedge e \ge \frac{-L_b}{6}$

Allowable Rock Bearing Pressure: $\sigma_{allow.U2} := 1270 \cdot \frac{kN}{m^2}$ (Section 5.2, Design Criteria)

INPUT PARAMETERS

Headwater Elevation: $HW_{U2} := 1214.60m$ (Section 8.3, Design Criteria)

Tailwater Elevation: $TW_{U2} := 1211.80m$ (Section 8.3, Design Criteria)

Bottom of Footing Elevation: $BOF_{elev} = 1206\,m$

Approach Slab Top of Concrete Elevation at Upstream Face: $TOC_{as} = 1210\,m$

Footing Top of Concrete Elevation at Stilling Basin: $TOC_{pfe} = 1208\,m$

Footing Top of Concrete Elevation at Center of Footing: $TOC_{pfc} = 1209.3\,m$

Top of Guard/Regulating Gate Elevation: $TOP_{rg.U2} := 1212.1m$ $\quad TOP_{gg.U2} := 1215.00m$

Gates are open when top of gate elevation is at 1210.00m

Gates are closed/up when top of gate elevation is at 1215.0m

Bottom of Key Elevation: $BOK_{elev} = 1204\,m$

Crestwater Elevation: Dynamic Flow $EL_{C.U2} := 1211.80m$

$$Y_{C.U2} := \begin{cases} (EL_{C.U2} - TOC_{pfc}) & \text{if } TOP_{gg.U2} \le HW_{U2} \\ (TW_{U2} - TOC_{pfc}) & \text{if } TOP_{gg.U2} > HW_{U2} \end{cases} = 2.5 \cdot m$$

Toewater Elevation: $EL_{TOE.U2} := 1211.80m$

$$Y_{TOE.U2} := \begin{cases} (EL_{TOE.U2} - TOC_{pfe}) & \text{if } TOP_{gg.U2} \le HW_{U2} \\ (TW_{U2} - TOC_{pfe}) & \text{if } TOP_{gg.U2} > HW_{U2} \end{cases} = 3.8 \cdot m$$

LATERAL WATER LOADS

U2 CASE

HEADWATER (APPROACH SLAB DRIVING):

Headwater Depth on Gate: $D_{hwg.U2} := HW_{U2} - TOC_{as} = 4.60\,m$

Thickness of Approach Slab (Including Key): $T_{as} = 6\,m$

Headwater Depth at Heel (U/S face): $D_{hwas.U2} := HW_{U2} - BOK_{elev} = 10.60\,m$

Headwater Load Unit Width on Approach Slab: $W_{hwas.U2} := W_b = 15.00\,m$

Headwater Unit Load At Top of Approach Slab:

$$H_{hwas.U2.1} := \frac{-\left(\gamma_w \cdot D_{hwg.U2}^{\;2}\right)}{2} \cdot W_{hwas.U2} = -1556.85 \cdot kN$$

Headwater Unit Load At Bottom of Approach Key:

$$H_{hwas.U2.2} := \frac{-\left(\gamma_w \cdot D_{hwas.U2}^{\;2}\right)}{2} \cdot W_{hwas.U2} = -8266.9 \cdot kN$$

Headwater Line Load At Top of Approach Slab:

$$\sigma_{hwas.U2.1} := -\left(\gamma_w \cdot D_{hwg.U2}\right) = -45.13 \cdot kPa$$

Headwater Line Load At Bottom of Approach Key:

$$\sigma_{hwas.U2.2} := -\left(\gamma_w \cdot D_{hwas.U2}\right) = -103.99 \cdot kPa$$

Triangular Distribution Unit Load on Approach Slab and Key:

$$H_{hwas.U2.2.tri} := \left(\frac{\sigma_{hwas.U2.2} - \sigma_{hwas.U2.1}}{2}\right) \cdot \left(T_{as} \cdot W_{hwas.U2}\right) = -2648.7 \cdot kN$$

Rectangular Distribution Unit Load on Approach Slab and Key:

$$H_{hwas.U2.2.rect} := \sigma_{hwas.U2.1} \cdot \left(T_{as} \cdot W_{hwas.U2}\right) = -4061.34 \cdot kN$$

Total Horizontal Headwater Load on Approach Slab:

$$H_{hwas.U2} := H_{hwas.U2.2.tri} + H_{hwas.U2.2.rect} = -6710.04 \cdot kN$$

Apply Total Footing Headwater Load at:

$$H_{hwas.U2.loc} := \frac{\left(H_{hwas.U2.2.rect} \cdot \frac{T_{as}}{2} + H_{hwas.U2.2.tri} \cdot \frac{T_{as}}{3}\right)}{H_{hwas.U2.2.tri} + H_{hwas.U2.2.rect}} - d_{key} = 0.61\,m$$

LATERAL WATER LOADS (continued)

U2 CASE

Guard Gate (2A) Operating Condition:

Guard Gate Down/Open Condition: $A1_{U2} := TOP_{gg.U2} \le TOC_{as}$

Guard Crest Gate Up/Closed, with Top of Gate Higher than HW Elevation: $B1_{U2} := TOP_{gg.U2} \ge HW_{U2} \wedge TOP_{gg.U2} > TOC_{as}$

Guard Crest Gate Up/Closed, with Top of Gate Lower than HW Elevation: $C1_{U2} := TOP_{gg.U2} > TOC_{as} \wedge HW_{U2} > TOP_{gg.U2}$

Guard Crest Gate Height: $H_{gg.U2} := TOP_{gg.U2} - TOC_{as} = 5\,m$

Headwater Depth at Guard Crest Gate: $D_{hwgg.U2} := HW_{U2} - TOC_{as} = 4.60\,m$

Guard Crest Gate Width: $W_{hwgg.U2} := 15.00m$

Lateral Headwater Pressure at Bottom of Guard Crest Gate:

$$\sigma_{hwgg.U2.1} := \begin{cases} (0.0kPa) & \text{if } A1_{U2} \\ -(\gamma_w \cdot D_{hwgg.U2}) & \text{if } B1_{U2} \\ -(\gamma_w \cdot D_{hwgg.U2}) & \text{if } C1_{U2} \end{cases} = -45.1 \cdot kPa$$

Lateral Headwater Pressure at Top of Guard Crest Gate: (Load at HW Elevation On Guard Crest Gate if HW is below TOG_{rg})

$$\sigma_{hwgg.U2.2} := \begin{cases} (0.0kPa) & \text{if } A1_{U2} \\ 0.0kPa & \text{if } B1_{U2} \\ -\left[\gamma_w \cdot (HW_{U2} - TOP_{gg.U2})\right] & \text{if } C1_{U2} \end{cases} = 0.0 \cdot kPa$$

Average Pressure acting on Guard Crest Gate:

$$\sigma_{hwgg.U2.avg} := \frac{(\sigma_{hwgg.U2.1} + \sigma_{hwgg.U2.2})}{2} = -22.56 \cdot kPa$$

Total Area of Crest Gate:

$$A_{hwgg.U2} := \begin{cases} D_{hwgg.U2} \cdot W_{hwgg.U2} & \text{if } A1_{U2} \\ D_{hwgg.U2} \cdot W_{hwgg.U2} & \text{if } B1_{U2} \\ H_{gg.U2} \cdot W_{hwgg.U2} & \text{if } C1_{U2} \end{cases} = 69 \cdot m^2$$

Total Horizontal Headwater Load on Guard Crest Gate: $H_{hwgg.U2} := \sigma_{hwgg.U2.avg} \cdot A_{hwgg.U2} = -1556.8 \cdot kN$

Apply Total Guard Crest Gate Headwater Load at:

$$H_{hwgg.U2.loc} := \begin{cases} (TOC_{as} - BOF_{elev}) & \text{if } A1_{U2} \\ \left[\frac{(HW_{U2} - TOC_{as})}{3} + (TOC_{as} - BOF_{elev})\right] & \text{if } B1_{U2} \\ \left[\frac{\sigma_{hwgg.U2.2} \cdot A_{hwgg.U2} \cdot \frac{(H_{gg.U2})}{2} + \frac{(\sigma_{hwgg.U2.1} - \sigma_{hwgg.U2.2})}{2} A_{hwgg.U1} \cdot \frac{(H_{gg.U2})}{3}}{\sigma_{hwgg.U2.2} \cdot A_{hwgg.U2} + \frac{(\sigma_{hwgg.U2.1} - \sigma_{hwgg.U2.2})}{2} \cdot A_{hwgg.U1}} \cdots \\ + (TOC_{as} - BOF_{elev})\right] & \text{if } C1_{U2} \end{cases} = 5.5 \cdot m$$

LATERAL TAILWATER (RESISTING) Applied to Downstream Side of Guard Crest Gate: U2 CASE

Guard Gate Down/Open Condition: $A2_{U2} := TOP_{gg.U2} \le TOC_{as}$

Guard Crest Gate Up/Closed, with Top of Gate Higher than TW Elevation: $B2_{U2} := TOP_{gg.U2} \ge TW_{U2} \wedge TOP_{gg.U2} > TOC_{as}$

Guard Crest Gate Up/Closed, with Top of Gate Lower than TW Elevation: $C2_{U2} := TOP_{gg.U2} > TOC_{as} \wedge TW_{U2} > TOP_{gg.U2}$

Tailwater Depth at Guard Crest Gate: $D_{twgg.U2} := TW_{U2} - TOC_{as} = 1.80\,m$

Guard Crest Gate Width: $W_{twgg.U2} := 15.00m$

Lateral Water Load at Bottom of Guard Crest Gate:

$$\sigma_{twgg.U2.1} := \begin{cases} (0.0kPa) & \text{if } A2_{U2} \\ (\gamma_w \cdot D_{twgg.U2}) & \text{if } B2_{U2} \\ (\gamma_w \cdot D_{twgg.U2}) & \text{if } C2_{U2} \end{cases} = 17.7 \cdot kPa$$

Lateral Water Load at Top of Guard Crest Gate:
(Load at TW Elevation On Guard Crest Gate if TW is below TOG_{gg})

$$\sigma_{twgg.U2.2} := \begin{cases} (0.0kPa) & \text{if } A2_{U2} \\ 0.0kPa & \text{if } B2_{U2} \\ \left[\gamma_w \cdot (TW_{U2} - TOP_{gg.U2})\right] & \text{if } C2_{U2} \end{cases} = 0.0 \cdot kPa$$

Average Pressure acting on Guard Crest Gate:

$$\sigma_{twgg.U2.avg} := \frac{(\sigma_{twgg.U2.1} + \sigma_{twgg.U2.2})}{2} = 8.83 \cdot kPa$$

Total Area water acting on Crest Gate:

$$A_{twgg.U2} := \begin{cases} D_{twgg.U2} \cdot W_{twgg.U2} & \text{if } A2_{U2} \\ D_{twgg.U2} \cdot W_{twgg.U2} & \text{if } B2_{U2} \\ H_{gg.U2} \cdot W_{twgg.U2} & \text{if } C2_{U2} \end{cases} = 27 \cdot m^2$$

Total Horizontal Tailwater Load on Guard Crest Gate: $H_{twgg.U2} := \sigma_{twgg.U2.avg} \cdot A_{twgg.U2} = 238.4 \cdot kN$

Apply Total Horiz. TW Load on Guard Gate at:

$$H_{twgg.U2.loc} := \begin{cases} (TOC_{as} - BOF_{elev}) & \text{if } A2_{U2} \\ \left[\frac{(TW_{U2} - TOC_{as})}{3} + (TOC_{as} - BOF_{elev})\right] & \text{if } B2_{U2} \\ \left[\frac{\sigma_{twgg.U2.2} \cdot A_{twgg.U2} \cdot \frac{(H_{gg.U2})}{2} + \frac{(\sigma_{twgg.U2.1} - \sigma_{twgg.U2.2})}{2} A_{twgg.U2} \cdot \frac{(H_{gg.U2})}{3}}{\sigma_{twgg.U2.2} \cdot A_{twgg.U2} + \frac{(\sigma_{twgg.U2.1} - \sigma_{twgg.U2.2})}{2} \cdot A_{twgg.U2}} \ldots \\ + (TOC_{as} - BOF_{elev})\right] & \text{if } C2_{U2} \end{cases} = 4.6 \cdot m$$

TAILWATER (RESISTING) Applied to Concrete Structure:

Tailwater Depth At top of Gate Base Footing Elevation: $D_{twgf.U2} := TW_{U2} - TOC_{as} = 1.80\,m$

Water Depth at bottom of Gate Base Footing: $D_{twtoe.U2} := TW_{U2} - BOF_{elev} = 5.80\,m$

Footing Thickness at Toe $h_{toe} = 4\,m$

Unit Width of D/S face of crest for application of Tailwater Load: $W_{tw.U2} := W_b = 15.00\,m$

Tailwater Pressure At Top of Gate Footing: $\sigma_{twgf.U2} := \left(\gamma_w \cdot D_{twgf.U2}\right) = 17.66 \cdot kPa$

Tailwater Line Load At Bottom of Gate Footing: $\sigma_{twtoe.U2} := \left(\gamma_w \cdot D_{twtoe.U2}\right) = 56.9 \cdot kPa$

Triangular Distribution Unit Load on Gate Footing Base:

$$H_{twgf.U2.tri} := \left(\frac{\sigma_{twtoe.U2} - \sigma_{twgf.U2}}{2}\right) \cdot \left(h_{toe} \cdot W_{tw.U2}\right) = 1177.2 \cdot kN$$

Rectangular Distribution Unit Load on Gate Footing Base:

$$H_{twgf.U2.rect} := \sigma_{twgf.U2} \cdot \left(h_{toe} \cdot W_{tw.U2}\right) = 1059.48 \cdot kN$$

Tailwater Pressure At Bottom of Sliding Failure Plane:

$$\sigma_{twbk.U2} := \left(HW_{U2} - BOK_{elev}\right) \cdot \gamma_w = 103.99 \cdot kPa$$

Triangular Distribution Unit Load Below Footing:

$$H_{twbk.U2.tri} := \frac{\left(\sigma_{twbk.U2} - \sigma_{twtoe.U2}\right)}{2} \cdot d_{key} \cdot W_{tw.U2} = 706.32 \cdot kN$$

Rectangular Distribution Load Below Footing Base:

$$H_{twbk.U2.rect} := \sigma_{twtoe.U2} \cdot d_{key} \cdot W_{tw.U2} = 1706.94 \cdot kN$$

Total Horizontal Tailwater Load on Gate Footing (including key):

$$H_{twgk.U2} := H_{twgf.U2.tri} + H_{twgf.U2.rect} + H_{twbk.U2.tri} + H_{twbk.U2.rect} = 4649.94 \cdot kN$$

Apply Total Gate Footing Tailwater Load at:

$$H_{twgk.U2.loc} := \frac{\left[H_{twgf.U2.rect} \cdot \frac{\left(h_{toe}\right)}{2} + H_{twgf.U2.tri} \cdot \frac{\left(h_{toe}\right)}{3} + H_{twbk.U2.tri} \cdot \left(-d_{key} \cdot \frac{2}{3}\right) + H_{twbk.U2.rect} \cdot \left(\frac{-d_{key}}{2}\right)\right]}{H_{twgf.U2.tri} + H_{twgf.U2.rect} + H_{twbk.U2.tri} + H_{twbk.U2.rect}} = 0.22\,m$$

SUMMATION OF LATERAL WATER LOADS:

$$\Sigma H_{Water.U2} := H_{hwas.U2} + H_{hwgg.U2} + H_{twgk.U2} + H_{twgg.U2} = -3378.56 \cdot kN$$

$$\Sigma M_{Hwater.U2} := H_{hwas.U2} \cdot H_{hwas.U2.loc} + H_{hwgg.U2} \cdot H_{hwgg.U2.loc} \cdots + H_{twgk.U2} \cdot H_{twgk.U2.loc} + H_{twgg.U2} \cdot H_{twgg.U2.loc} = -10539.47 \cdot kN \cdot m$$

VERTICAL WATER LOADS

U2 CASE

HEADWATER:

Water Depth on top of Approach Slab: $d_{hw.U2} := HW_{U2} - TOC_{as} = 4.60\,m$

Length of Approach Slab: $L_{as} = 8.75\,m$

Width of Approach Slab: $w_{as} = 15.00\,m$

Vertical Water Weight (H1) on Approach Slab: $H_{1.U2} := \left(w_{as} \cdot d_{hw.U2} \cdot L_{as}\right) \cdot \gamma_w = 5922.8 \cdot kN$

Moment Arm for Application of Water Weight (H1) from toe: $H_{1.U2.loc} := L_b - \dfrac{L_{as}}{2} = 14.13\,m$

TAILWATER:

Trapezoid Volume Above Gate Footing from Approach Slab to Crest: $V_{asc.U2} := \left(L_{gf} - L_{gfc}\right) W_b \dfrac{d_{hw.U2} + Y_{C.U2}}{2} = 380.74 \cdot m^3$

Trapezoid Volume Above Gate Footing Crest to End of Gate Footing: $V_{gfc.U2} := \left(L_{gfc} \cdot W_b\right) \dfrac{Y_{C.U2} + Y_{TOE.U2}}{2} = 122.85 \cdot m^3$

Load Above Gate Footing from Approach Slab to Crest: $H_{2.U2.asc} := V_{asc.U2} \cdot \gamma_w = 3735.03 \cdot kN$

Load Acting Above Footing Crest from Toe: $H_{2.U2.asc.loc} := \dfrac{\left(L_{gf} - L_{gfc}\right) \cdot \left(2 \cdot d_{hw.U2} + Y_{C.U2}\right)}{3 \cdot \left(d_{hw.U2} + Y_{C.U2}\right)} + L_{gfc} = 6.53\,m$

Load Above Gate Footing from Crest to End: $H_{2.U2.gfc} := V_{gfc.U2} \cdot \gamma_w = 1205.16 \cdot kN$

Load Acting Above Gate Footing from Crest to End: $H_{2.U2.gfc.loc} := \dfrac{\left(L_{gfc}\right) \cdot \left(2 \cdot Y_{C.U2} + Y_{TOE.U2}\right)}{3 \cdot \left(Y_{C.U2} + Y_{TOE.U2}\right)} = 1.21\,m$

Vertical Water Weight (H2) on Gate Footing: $H_{2.U2} := H_{2.U2.asc} + H_{2.U2.gfc} = 4940.19 \cdot kN$

Moment Arm for Application of Water Weight (H2) from toe: $H_{2.U2.loc} := \dfrac{H_{2.U2.asc} \cdot H_{2.U2.asc.loc} + H_{2.U2.gfc} \cdot H_{2.U2.gfc.loc}}{H_{2.U2}} = 5.23\,m$

UPLIFT AT INCLINE SLIDING PLANE

U2 CASE

Uplift pressure at U/S Face (heel): $U_{HW.U2} := D_{hwas.U2} \cdot \gamma_w = 104.0 \cdot \frac{kN}{m^2}$

Uplift pressure at D/S Face Stilling Basin: $U_{TW.U2} := \left(D_{twtoe.U2}\right) \cdot \gamma_w = 56.9 \cdot \frac{kN}{m^2}$

Length from U/S of Gate Structure to U/S of Stilling Basin: $L_{overall.Usual} = 18.50\,m$

Difference between Uplift pressure at HW and TW: $U_{diff.U2} := U_{HW.U2} - U_{TW.U2} = 47.09 \cdot \frac{kN}{m^2}$

Slope of difference between between Uplift pressure at HW and TW: $U_{slope.U2} := \frac{U_{diff.U2}}{L_{overall.Usual}} = 2.55 \cdot \frac{kN}{m^2 \cdot m}$

Tailwater Pressure at toe of Gate Structure: $U_{press.toe.gs.U2} := U_{TW.U2} + \left(L_{overall.Usual} - L_b\right) \cdot U_{slope.U2} = 56.9 \cdot \frac{kN}{m^2}$

Uniform uplift force UA Under Gate Structure due to TW (rectangle): $U_{A.U2} := U_{press.toe.gs.U2} \cdot L_b \cdot W_b \cdot -1 = -15789.19 \cdot kN$

Moment Arm from Toe of Gate Structure for Uplift UA: $L_{A.U2} := \left(\frac{L_b}{2}\right) = 9.25\,m$

Linearly Decreasing Uplift Force U2B Under Gate Structure due to HW-TW Differential (triangle): $U_{B.U2} := \frac{1}{2} \cdot \left(U_{HW.U2} - U_{press.toe.gs.U2}\right) \cdot L_b \cdot W_b \cdot -1 = -6533.46 \cdot kN$

Moment Arm from Toe of Gate Structure for Uplift UB: $L_{B.U2} := \frac{2}{3} \cdot L_b = 12.33\,m$

Total Resultant Uplift force: $U_{U2} := U_{A.U2} + U_{B.U2} = -22322.65 \cdot kN$

Resultant Location from Toe: $U_{U2.loc} := \frac{\left(U_{A.U2} \cdot L_{A.U2} + U_{B.U2} \cdot L_{B.U2}\right)}{\left(U_{A.U2} + U_{B.U2}\right)} = 10.15\,m$

$\Sigma V_{water.U2} := H_{1.U2} + H_{2.U2} + U_{U2} = -11459.67 \cdot kN$

$\Sigma M_{Vwater.U2} := H_{1.U2} \cdot H_{1.U2.loc} + H_{2.U2} \cdot H_{2.U2.loc} + U_{U2} \cdot U_{U2.loc} = -117130.77 \cdot kN \cdot m$

SOIL LOADS

U2 CASE

Equivalent Fluid Pressure (EFP):

At rest lateral pressure coefficient: $K_{o.U2} := 1 - \sin(\phi_{backfill}) = 0.658$ (Section 5.3, Design Criteria)

Headwater Footing Unit Width: $W_{hwas.U2} = 15.00\,m$

Tailwater Footing Unit Width: $W_{tw.U2} = 15.00\,m$

Footing Thickness at Heel: $t_{hf.U2} := TOC_{as} - BOK_{elev} = 6.00\,m$

Fixed Crest Footing Thickness at Toe: $t_{tf.U2} := TOC_{pfe} - BOF_{elev} = 2.00\,m$

Lateral Driving Force (Headwater Side - at rest condition)

At-Rest Soil Load:

$$E_{act.U2} := \frac{\left(K_{o.U2} \cdot t_{hf.U2}^{\,2}\right)}{2} \cdot (\gamma_r - \gamma_w) \cdot W_{hwas.U2} \cdot -1 = -2165.61 \cdot kN$$

Acting at:

$$E_{act.U2.loc} := \frac{t_{hf.U2}}{3} = 2.00\,m$$

Lateral Resisting Force (Tailwater Side - at rest condition)

At-rest Soil Load:

$$E_{pass.U2} := \frac{\left(K_{o.U2} \cdot t_{tf.U2}^{\,2}\right)}{2} \cdot (\gamma_r - \gamma_w) \cdot W_{tw.U2} = 240.62 \cdot kN$$

Acting at:

$$E_{pass.U2.loc} := \frac{t_{tf.U2}}{3} = 0.67\,m$$

$$\Sigma H_{soil.U2} := E_{act.U2} + E_{pass.U2} = -1924.99 \cdot kN$$

$$\Sigma M_{soil.U2} := E_{act.U2} \cdot E_{act.U2.loc} + E_{pass.U2} \cdot E_{pass.U2.loc} = -4170.8 \cdot kN \cdot m$$

ICE / IMPACT LOADS (ASSUME NO ICE LOADING ON TAILWATER SIDE)

Static Ice load on Gates:

$$I_{G.U2} := \begin{cases} 00 \dfrac{kN}{m} & \text{if } TOP_{gg.U2} \le TOC_{as} \\ 75 \dfrac{kN}{m} & \text{if } TOP_{gg.U2} > TOC_{as} \end{cases} = 75 \cdot \frac{kN}{m}$$

(Section 7.7, Design Criteria)

Ice Loading Unit Width on Guard Gate: $W_{gg.U2} := 15.00m$ (Input value for load case)

Total Ice Load on Structure: $I_{U2} := -\left(I_{G.U2} \cdot W_{gg.U2}\right) = -1125 \cdot kN$

Apply Ice load at: $I_{U2.loc} := \left(TOP_{gg.U2} - BOF_{elev} - 0.30m\right) = 8.70\,m$

$$\Sigma H_{I.U2} := I_{U2} = -1125 \cdot kN$$

$$\Sigma M_{I.U2} := I_{U2} \cdot I_{U2.loc} = -9787.5 \cdot kN \cdot m$$

SEISMIC LOAD (NOT APPLICABLE FOR THIS LOAD CASE)

U2 CASE

SUMMARY OF LOADS

	Loads	Moment Arm
Dead load of Concrete Structure:	$D_{conc} = 24618.6 \cdot kN$	$X_{conc.loc} = 10.06\,m$
Obermyer Gate Weight:	$D_{Gate} = 210.0 \cdot kN$	$X_{gate} = 6.60\,m$
HW Lateral Load on Approach Slab:	$H_{hwas.U2} = -6710.0 \cdot kN$	$H_{hwas.U2.loc} = 0.61\,m$
HW Lateral Load on Guard Gate:	$H_{hwgg.U2} = -1556.8 \cdot kN$	$H_{hwgg.U2.loc} = 5.53\,m$
TW Lateral Load on Gate Footing (Including Key - Sliding Check Loads):	$H_{twgk.U2} = 4649.94 \cdot kN$	$H_{twgk.U2.loc} = 0.22\,m$
TW Lateral Load on Guard Gate:	$H_{twgg.U2} = 238.4 \cdot kN$	$H_{twgg.U2.loc} = 4.60\,m$
Vertical HW Load on Approach Slab:	$H_{1.U2} = 5922.8 \cdot kN$	$H_{1.U2.loc} = 14.13\,m$
Vertical TW Load on Pier Footing (crest):	$H_{2.U2} = 4940.2 \cdot kN$	$H_{2.U2.loc} = 5.23\,m$
Uplift:	$U_{U2} = -22322.7 \cdot kN$	$U_{U2.loc} = 10.15\,m$
Lateral Soil Load (driving):	$E_{act.U2} = -2165.6 \cdot kN$	$E_{act.U2.loc} = 2.00\,m$
Lateral Soil Load (resisting):	$E_{pass.U2} = 240.62 \cdot kN$	$E_{pass.U2.loc} = 0.67\,m$
Ice / Impact Load:	$I_{U2} = -1125.0 \cdot kN$	$I_{U2.loc} = 8.70\,m$

STABILITY ASSESSMENT (SLIDNG, BEARING, FLOTATION AND OVERTURNING):

U2 CASE

CHECK SLIDING ALONG HORIZONTAL PLANE THRU TOE, IGNORING BEDROCK MOBILIZED BY STRUCTURAL HEEL KEY, OR VOID BEHIND KEY

Sum of Vertical Forces:

$\Sigma V_{U2} := \Sigma V_{DL} + \Sigma V_{water.U2} = 13368.9 \cdot kN$

Sum of Horizontal Forces:

$\Sigma H_{U2} := \Sigma H_{Water.U2} + \Sigma H_{soil.U2} + \Sigma H_{I.U2} = -6428.55 \cdot kN$

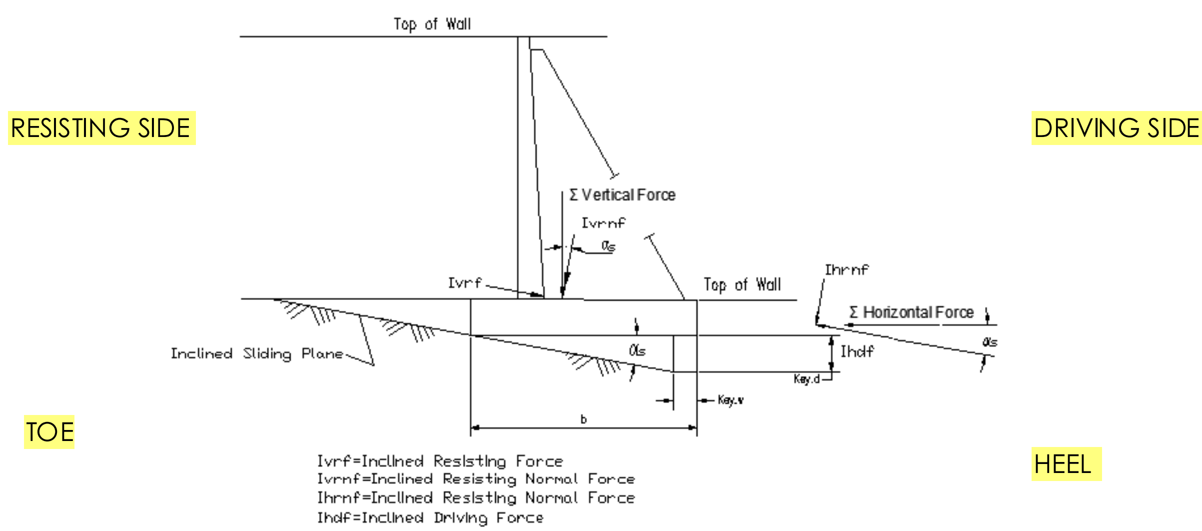
Sliding Factor of Safety:

$$FS_{HorizSliding.U2} := \frac{\tan_{\phi} \cdot \Sigma V_{U2}}{\left|\Sigma H_{U2}\right|} = 1.01$$

$FS_{HorizSliding.U2.Check} :=$ | "OKAY" if $FS_{HorizSliding.U2} \geq FS_{req.U2.sl}$
"Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !" otherwise

= "Horizontal Sliding (No K

CHECK SLIDING ALONG INCLINED SLIDING PLANE FROM HEEL KEY TO TOE, WITH BEDROCK MASS MOBILIZED BY REINFOCREDE CONCRETE KEY)



$\alpha s = 0.11$

as degrees= $\alpha s \cdot \left(\frac{180}{\pi}\right) = 6.52$

$\Sigma V_{U2} = 13368.93 \cdot kN$

$V_{rs} = 5775 \cdot kN$

Resolve $\Sigma Vert_{U2}$ & $\Sigma Horiz_{U2}$

$\Sigma V_{InclinedU2} := \cos(\alpha s) \cdot \left(\Sigma V_{U2} + V_{rs}\right) + \sin(\alpha s) \cdot \left|\Sigma H_{U2}\right| = 19750.1 \cdot kN$

$\Sigma H_{InclinedU2} := \cos(\alpha s) \cdot \left|\Sigma H_{U2}\right| - \sin(\alpha s) \cdot \left(\Sigma V_{U2} + V_{rs}\right) = 4213.2 \cdot kN$

(With properly engineered reinforced concrete Key, horizontal sliding plane thru Toe is protected, critical sliding plane is relocated to the INCLINED SLIDING PLANE FROM HEEL KEY To TOE, Bedrock Mass above this examined plane is mobilized by reinforced concrete key and combined into Structural Wedge.)

Inclined Sliding Plane Length $L_{incline} = 18.61\ m$

Safety Factor for Sliding Inclined Failure Plane

$$FS_{InclinedlSlidingU2} := \frac{\Sigma V_{InclinedU2} \cdot \tan\left(\phi_{rock} \cdot \frac{\pi}{180}\right)}{\left|\Sigma H_{InclinedU2}\right|} = 2.29$$

$FS_{InclinedSliding.check.U2} :=$ | "OKAY " if $FS_{InclinedlSlidingU2} > FS_{req.U2.sl}$
"Revise Structure"" otherwise

= "OKAY "

$FS_{InclinedSliding.check.U2} =$ "OKAY "

OVERTURNING STABILITY CHECK:

U2 CASE

CHECK ECCENTRICITY

Sum of the moments:

$$\Sigma M_{U2} := \Sigma M_{DL} + \Sigma M_{Hwater.U2} + \Sigma M_{Vwater.U2} + \Sigma M_{I.U2} + \Sigma M_{soil.U2} + \Sigma M_{soil} = 174690 \cdot kN \cdot m$$

Eccentricity:

$$e_{U2} := \left(\frac{L_{incline}}{2}\right) - \frac{\Sigma M_{U2}}{\Sigma V_{InclinedU2}} = 0.46\,m$$

Eccentricity Check:

$$e_{check.U2} := \begin{cases} \text{"Okay"} & \text{if } \left|e_{U2}\right| \le Kern \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$$e_{check.U2} = \text{"Okay"}$$

Foundation Bearing Checks:

Incline Plane Area:

$$A_{b.incline} = 279.12\,m^2$$

Incline Plane Section Modulus:

$$S_{b.incline} = 865.63 \cdot m^3$$

Bearing Pressure at Heel:

$$\sigma_{heel.U2} := \frac{\Sigma V_{InclinedU2}}{A_{b.incline}} - \frac{\Sigma V_{InclinedU2} \cdot e_{U2}}{S_{b.incline}} = 60.3 \cdot \frac{kN}{m^2}$$

$$\sigma_{heel.U2.check} := \left(\begin{cases} \text{"Okay"} & \text{if } \sigma_{heel.U2} \le \sigma_{allow.U2} \\ \text{"Revise Structure"} & \text{if } \sigma_{heel.U2} < 0\,\frac{kN}{m^2} \end{cases} \right)$$

$$\sigma_{heel.U2.check} = \text{"Okay"}$$

Bearing Pressure at Toe:

$$\sigma_{toe.U2} := \frac{\Sigma V_{InclinedU2}}{A_{b.incline}} + \frac{\Sigma V_{InclinedU2} \cdot e_{U2}}{S_{b.incline}} = 81.2 \cdot \frac{kN}{m^2}$$

$$\sigma_{toe.U2.1.check} := \begin{cases} \text{"Okay"} & \text{if } \sigma_{toe.U2} \le \sigma_{allow.U2} \\ \text{"Revise Structure"} & \text{if } \sigma_{toe.U2} < 0\,\frac{kN}{m^2} \end{cases}$$

$$\sigma_{toe.U2.1.check} = \text{"Okay"}$$

FLOATATION ANALYSIS:

ACCEPTANCE PARAMETERS

Required Factor of Safety: $FS_{req.FU2} := 1.5$

VERTICAL LOADS RESISTING:

Dead Load: $\Sigma V_{DL} = 24828.6 \cdot kN$

Water Weight H1+H2: $\Sigma V_{H.FU2} := H_{1.U2} + H_{2.U2} = 10862.98 \cdot kN$

Summation Vertical Resisting: $\Sigma V_{FU2} := \Sigma V_{DL} + \Sigma V_{H.FU2} = 35691.6 \cdot kN$

VERTICAL LOADS UPLIFT:

Uplift: $U_{U2} = -22322.65 \cdot kN$

Factor of Safety Floatation:

$$FS_{act.FU2} := \frac{\Sigma V_{FU2}}{\left|U_{U2}\right|} = 1.60$$

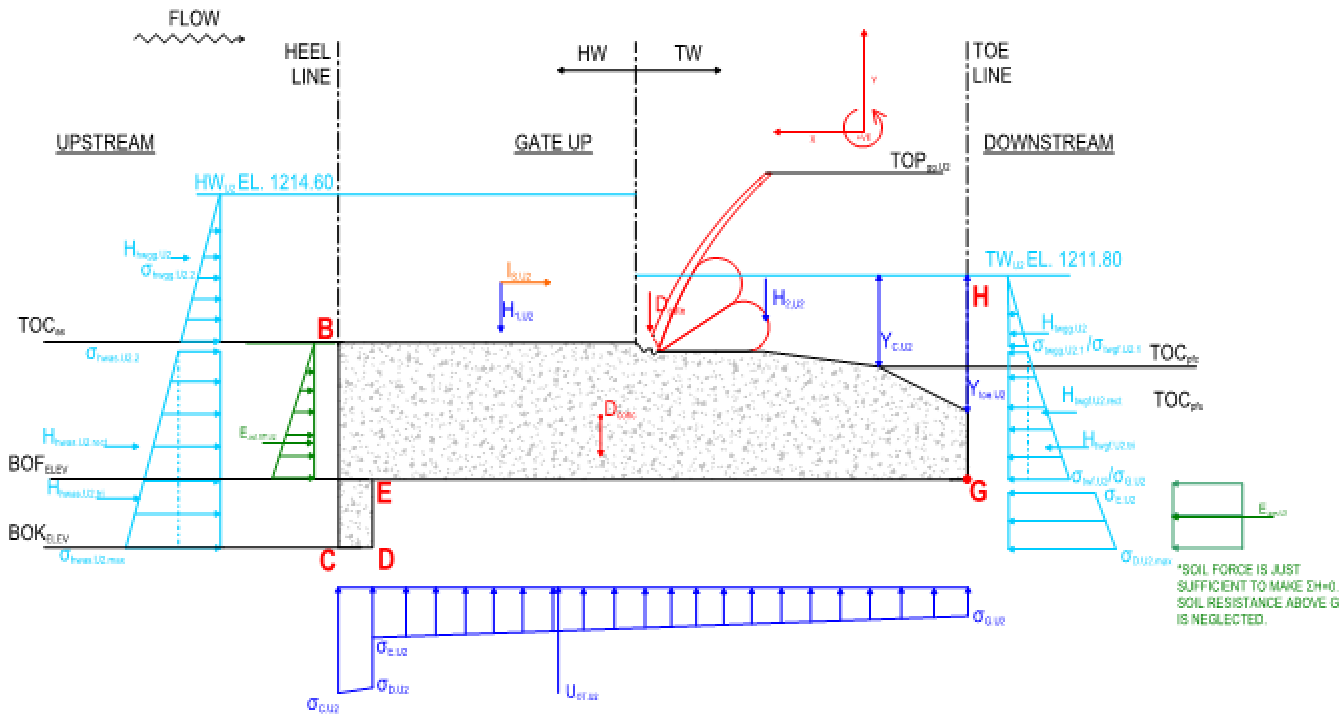
$$FS_{check.FU2} := \begin{cases} \text{"OKAY"} & \text{if } FS_{act.FU2} \ge FS_{req.FU2} \\ \text{"ANCHORS REQUIRED"} & \text{if } FS_{act.FU2} < FS_{req.FU2} \end{cases} = \text{"OKAY"}$$

U2 CASE

MONOLITH OVERTURNING STABILITY ANALYSIS

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.
Assumptions are made in order to compute overturning stability of indeterminate forces on monolith with key;
(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.
(b) The horizontal resisting force acting on the key, P.key, is that required for static equilibrium
(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1 $Ratio_{OT.U2.min} := 0.33$ Resultant at Middle Third



Uplift Loads for Overturning Stability Analysis

Line of Creep:

Change in Water Head: $\Delta_{h.U2} := HW_{U2} - TW_{U2} = 2.8\,m$

Length from Point C to Point G: $L_{CG} = 18.61\,m$

Length from Various Points to Points: $L_{CD} = 1\,m$ $L_{DE} = 2\,m$ $L_{EG} = 17.5\,m$

$L_{GH.U2} := TW_{U2} - BOF_{elev} = 5.8\,m$

Length from Point C, D, E to G: $L_{CDEG} = 20.5\,m$ $L_{CDE} = 3\,m$

Water Pressure at Point C: $\sigma_{C.U2} := \sigma_{hwas.U2.2} = -103.99 \cdot kPa$

Water Pressure at Point G: $\sigma_{G.U2} := \sigma_{twtoe.U2} \cdot -1 = -56.9 \cdot kPa$

Water Pressure at Point D: $$\sigma_{D.U2} := -\gamma_w \cdot \left[\left(HW_{U2} - BOK_{elev}\right) - \frac{\Delta_{h.U2} \cdot L_{CD}}{L_{CDEG}}\right] = -102.65 \cdot kPa$$

Water Pressure at Point E: $$\sigma_{E.U2} := -\gamma_w \cdot \left[\left(HW_{U2} - BOF_{elev}\right) - \frac{\Delta_{h.U2} \cdot L_{CDE}}{L_{CDEG}}\right] = -80.35 \cdot kPa$$

Uplift for Overturning Analysis on Bottom of Key: $$U_{OT.U2.key} := \frac{\sigma_{C.U2} + \sigma_{D.U2}}{2} \cdot L_{CD} \cdot W_b = -1549.74 \cdot kN$$

Acting at: $$U_{OT.U2.key.loc} := \frac{L_{CD} \cdot \left(2 \cdot \sigma_{C.U2} + \sigma_{D.U2}\right)}{3\left(\sigma_{C.U2} + \sigma_{D.U2}\right)} + L_{EG} = 18\,m$$

U2 CASE

Uplift for Overturning Analysis on Bottom of Footing:

$$U_{OT.U2.ftg} := \frac{\sigma_{E.U2} + \sigma_{G.U2}}{2} \cdot L_{EG} \cdot W_b = -18013.31 \cdot kN$$

Acting at:

$$U_{OT.U2.ftg.loc} := \frac{L_{EG} \cdot \left(\sigma_{G.U2} + 2 \cdot \sigma_{E.U2}\right)}{3\left(\sigma_{G.U2} + \sigma_{E.U2}\right)} = 9.25\,m$$

Uplift Load for Overturning Analysis:

$$U_{OT.U2} := U_{OT.U2.key} + U_{OT.U2.ftg} = -19563.05 \cdot kN$$

Uplift Load Acting from Toe:

$$U_{OT.U2.loc} := \frac{U_{OT.U2.key} \cdot U_{OT.U2.key.loc} + U_{OT.U2.ftg} \cdot U_{OT.U2.ftg.loc}}{U_{OT.U2}} = 9.94\,m$$

<u>All Vertical Loads Applicable to Overturning Stability Analysis</u>

Total Concrete Dead Loads:	$D_{conc} = 24618.6 \cdot kN$	at:	$X_{conc.loc} = 10.06\,m$
Dead Load of Gate:	$D_{Gate} = 210.0 \cdot kN$		$X_{gate} = 6.60\,m$
Water Weight (HW) on Apron Slab:	$H_{1.U2} = 5922.8 \cdot kN$		$H_{1.U2.loc} = 14.13\,m$
Water Weight (TW) on Gate Footing:	$H_{2.U2} = 4940.2 \cdot kN$		$H_{2.U2.loc} = 5.23\,m$
Uplift Load for Overturning Analysis:	$U_{OT.U2} = -19563.05 \cdot kN$		$U_{OT.U2.loc} = 9.94 \cdot m$

Sum of All Overtuming Analysis Vertical Load:

$$\Sigma V_{U2.OT} := D_{conc} + D_{Gate} + H_{1.U2} + H_{2.U2} + U_{OT.U2} = 16128.53 \cdot kN$$

Sum of All Overtuming Analysis Vertical Load Moments:

$$\Sigma M_{V.U2.OT} := D_{conc} \cdot X_{conc.loc} + D_{Gate} \cdot X_{gate} + H_{1.U2} \cdot H_{1.U2.loc} + H_{2.U2} \cdot H_{2.U2.loc} + U_{OT.U2} \cdot U_{OT.U2.loc} = 163952.61 \cdot kN \cdot m$$

<u>Lateral Tailwater Loads for Overturning Stability Analysis</u>

TW Lateral Load on Gate Footing (No Key - Overturning Values Adjusted):

$$H_{twgf.U2} := H_{twgf.U2.tri} + H_{twgf.U2.rect} = 2236.68 \cdot kN$$

Acting at:

$$H_{twgf.U2.loc} := \frac{\frac{h_{toe}}{3} \cdot H_{twgf.U2.tri} + \frac{h_{toe}}{2} \cdot H_{twgf.U2.rect}}{H_{twgf.U2}} = 1.65\,m$$

Horizontal Tailwater Pressure Top of Key (Overturning Analysis):

$$\sigma_{twtk.OT.U2} := \sigma_{E.U2} \cdot -1 = 80.35 \cdot kPa$$

Horizontal Tailwater Pressure Bottom of Key (Overturning Analysis):

$$\sigma_{twbk.OT.U2} := \sigma_{D.U2} \cdot -1 = 102.65 \cdot kPa$$

Triangular Distribution Unit Load Acting at Key:

$$H_{twbk.OT.U2.tri} := \frac{\left(\sigma_{twbk.OT.U2} - \sigma_{twtk.OT.U2}\right)}{2} \cdot d_{key} \cdot W_{tw.U2} = 334.5 \cdot kN$$

Triangular Distribution Unit Load Acting at Key:

$$H_{twbk.OT.U2.rect} := \sigma_{twtk.OT.U2} \cdot d_{key} \cdot W_{tw.U2} = 2410.39 \cdot kN$$

Total Horizontal Tailwater Load on Key (Overturning Values Adjusted):

$$H_{twkey.OT.U2} := H_{twbk.OT.U2.tri} + H_{twbk.OT.U2.rect} = 2744.89 \cdot kN$$

Acting at:

$$H_{twkey.OT.U2.loc} := \frac{H_{twbk.OT.U2.tri} \cdot \frac{-2 \cdot d_{key}}{3} + H_{twbk.OT.U2.rect} \cdot \frac{-d_{key}}{2}}{H_{twkey.OT.U2}} = -1.04 \cdot m$$

U2 CASE

Lateral Driving Earth Loads for Overturning Stability Analysis (at rest condition)

Depth of Driving Soil Loads (to top of key): $h_{E.OT.U2} := TOC_{as} - BOF_{elev} = 4\,m$

At-Rest Soil Load: $E_{act.OT.U2} := \frac{\left(K_{o.U2} \cdot h_{E.OT.U2}^{2}\right)}{2} \cdot \left(\gamma_r - \gamma_w\right) \cdot W_{hwas.U2} \cdot -1 = -962.49 \cdot kN$

At Rest- Soil Load Acting from Toe: $E_{act.OT.U2.loc} := \frac{h_{E.OT.U2}}{3} = 1.33\,m$

All Lateral Loads Applicable to Overturning Stability Analysis

HW Lateral Load on Approach Slab:	$H_{hwas.U2} = -6710.0 \cdot kN$	$H_{hwas.U2.loc} = 0.61\,m$
HW Lateral Load on Guard Gate:	$H_{hwgg.U2} = -1556.8 \cdot kN$	$H_{hwgg.U2.loc} = 5.53\,m$
TW Lateral Load on Guard Gate:	$H_{twgg.U2} = 238.4 \cdot kN$	$H_{twgg.U2.loc} = 4.60\,m$
TW Lateral Load on Gate Footing (No Key - Overturning Values Adjusted):	$H_{twgf.U2} = 2236.68 \cdot kN$	$H_{twgf.U2.loc} = 1.65\,m$
TW Lateral Load on Key:	$H_{twkey.OT.U2} = 2744.89 \cdot kN$	$H_{twkey.OT.U2.loc} = -1.04\,m$
Ice / Impact Load:	$I_{U2} = -1125.0 \cdot kN$	$I_{U2.loc} = 8.70\,m$
Lateral Soil Load (driving):	$E_{act.OT.U2} = -962.5 \cdot kN$	$E_{act.OT.U2.loc} = 1.33\,m$

Resisting Lateral Soil Load as required to produce horizontal equilibrium:

$$E_{pas.OT.U2} := -\left(H_{hwas.U2} + H_{hwgg.U2} + H_{twgg.U2} + H_{twgf.U2} + H_{twkey.OT.U2} + I_{U2} + E_{act.OT.U2}\right) = 5134.43 \cdot kN$$

Acting at:

$$E_{pas.OT.U2.loc} := -1 \cdot \frac{d_{key}}{2} = -1\,m$$

Sum of All Overturning Analysis Horizontal Load (ΣH=0):

$$\Sigma H_{U2.OT} := H_{hwas.U2} + H_{hwgg.U2} + H_{twgg.U2} + H_{twgf.U2} + H_{twkey.OT.U2} + I_{U2} + E_{act.OT.U2} + E_{pas.OT.U2} = 0 \cdot kN$$

Sum of All Overturning Analysis Horizontal Load Moments:

$$\Sigma M_{H.U2.OT} := H_{hwas.U2} \cdot H_{hwas.U2.loc} + H_{hwgg.U2} \cdot H_{hwgg.U2.loc} + H_{twgg.U2} \cdot H_{twgg.U2.loc} + H_{twgf.U2} \cdot H_{twgf.U2.loc} \cdots + H_{twkey.OT.U2} \cdot H_{twkey.OT.U2.loc} + I_{U2} \cdot I_{U2.loc} + E_{act.OT.U2} \cdot E_{act.OT.U2.loc} + E_{pas.OT.U2} \cdot E_{pas.OT.U2.loc} = -26952.41 \cdot kN \cdot m$$

Overturning Stability Analysis

$$\Sigma M_{U2.OT} := \Sigma M_{V.U2.OT} + \Sigma M_{H.U2.OT} = 137000.2 \cdot kN \cdot m$$

$$X_{R.U2} := \frac{\Sigma M_{U2.OT}}{\Sigma V_{U2.OT}} = 8.49\,m \qquad x_{OT.U2} := X_{R.U2} - \frac{L_b}{2} = -0.76\,m$$

Overturning Resultant Ratio $Ratio_{OT.U2} := \frac{X_{R.U2}}{L_b} = 0.46$

$$Ratio_{OT.U2.check} := \begin{cases} \text{"OKAY"} & \text{if } Ratio_{OT.U2} \ge Ratio_{OT.U2.min} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

$$x_{OT.check.U2} := \begin{cases} \text{"OKAY"} & \text{if } \left|x_{OT.U2}\right| \le Kern \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

U2 CASE

CHECK FOUNDATION BEARING CAPACITY (HORIZONTAL PLANE):

Bearing Pressure Under Toe:

$$\sigma_{ToeU2.OT} := \frac{\Sigma V_{U2.OT}}{L_b \cdot W_b} + \frac{\left(\Sigma V_{U2.OT} \cdot x_{OT.U2}\right)}{S_b} = 43.9 \cdot kPa$$

$$Bearing_{ChecktoeU2.OT} := \begin{cases} \text{"OKAY "} & \text{if } \sigma_{ToeU2.OT} < \sigma_{allow.U2} \\ \text{"NG""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

Bearing Pressure Under Heel:

$$\sigma_{HeelU2.OT} := \frac{\Sigma V_{U2.OT}}{L_b \cdot W_b} - \frac{\left(\Sigma V_{U2.OT} \cdot x_{OT.U2}\right)}{S_b} = 72.4 \cdot kPa$$

$$Bearing_{CheckheelU2.OT} := \left(\begin{cases} \text{"OKAY "} & \text{if } \sigma_{HeelU2.OT} < \sigma_{allow.U2} \wedge \sigma_{HeelU2.OT} > 0 \\ \text{"NG""} & \text{otherwise} \end{cases} \right) = \text{"OKAY "}$$

SUMMARY OF STABILITY ASSESSMENT:

Sliding Factor of Safety:
(Horizontal Plane)

$FS_{HorizSliding.U2} = 1.01$

$FS_{HorizSliding.U2.Check}$ = "Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !"

Sliding Factor of Safety:
(Inclined Plane)

$FS_{InclinedlSlidingU2} = 2.29$ — $FS_{InclinedSliding.check.U2}$ = "OKAY "

Eccentricity:
(Inclined Plane)

$e_{U2} = 0.46\,m$ — $e_{check.U2}$ = "Okay"

Bearing Pressure At Heel:
(Inclined Plane)

$\sigma_{heel.U2} = 60 \cdot kPa$ — $\sigma_{heel.U2.check}$ = "Okay"

Bearing Pressure At Toe:
(Inclined Plane)

$\sigma_{toe.U2} = 81 \cdot kPa$ — $\sigma_{toe.U2.1.check}$ = "Okay"

Flotation Factor of Safety
(horizontal plane)

$FS_{act.FU2} = 1.6$ — $FS_{check.FU2}$ = "OKAY"

Overturning Resultant Ratio:
(horizontal plane)

$Ratio_{OT.U2} = 0.46$ — $Ratio_{OT.U2.check}$ = "OKAY"

Eccentricity:
(horizontal plane)

$x_{OT.U2} = -0.76\,m$ — $x_{OT.check.U2}$ = "OKAY"

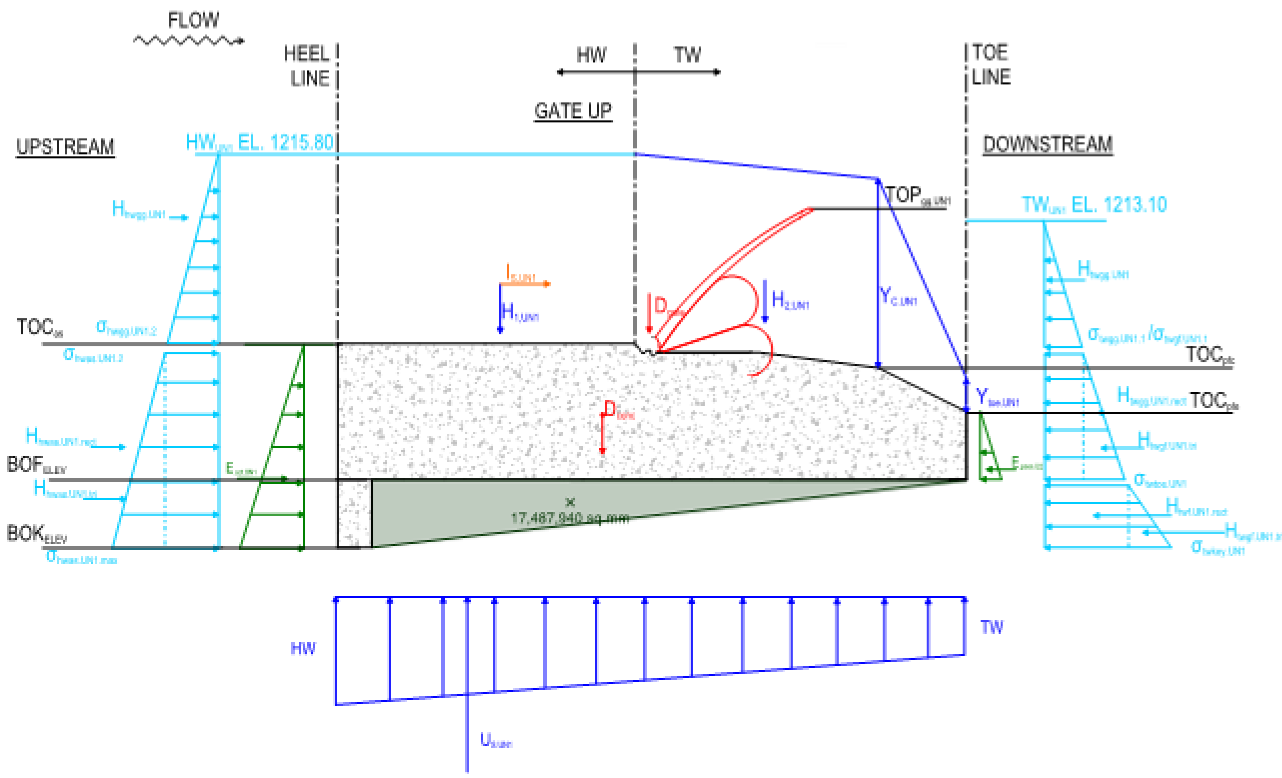
Bearing Pressure At Heel:
(horizontal plane)

$\sigma_{HeelU2.OT} = 72 \cdot kPa$ — $Bearing_{CheckheelU2.OT}$ = "OKAY "

Bearing Pressure At Toe:
(horizontal plane)

$\sigma_{ToeU2.OT} = 44 \cdot kPa$ — $Bearing_{ChecktoeU2.OT}$ = "OKAY "

UN1 DESIGN CASE



ACCEPTANCE PARAMETERS

Required Factor of Safety for Sliding: $FS_{req.UN1.sl} := 1.3$ (Without Cohesion)

(Section 8.1, Design Criteria)

Resultant Within Middle Third of Base: $e \le \frac{L_b}{6} \wedge e \ge \frac{-L_b}{6}$

Allowable Rock Bearing Pressure: $\sigma_{allow.UN1} := 1470 \cdot \frac{kN}{m^2}$ (Section 5.2, Design Criteria)

INPUT PARAMETERS

Headwater Elevation: $HW_{UN1} := 1215.8m$ (Section 8.3, Design Criteria)

Tailwater Elevation: $TW_{UN1} := 1213.1m$ (Section 8.3, Design Criteria)

Bottom of Footing Elevation: $BOF_{elev} = 1206\, m$

Approach Slab Top of Concrete Elevation at Upstream Face: $TOC_{as} = 1210\, m$

Footing Top of Concrete Elevation at Stilling Basin: $TOC_{pfe} = 1208\, m$

Footing Top of Concrete Elevation at Center of Footing: $TOC_{pfc} = 1209.3\, m$

Top of Guard/Regulating Gate Elevation: $TOP_{rg.UN1} := 1210.00m$ $TOP_{gg.UN1} := 1213.50m$

Gates are open when top of gate elevation is at 1210.00m

Gates are closed/up when top of gate elevation is at 1215.0m

Bottom of Key Elevation: $BOK_{elev} = 1204\, m$

Crestwater Elevation: Dynamic Flow $EL_{C.UN1} := 1215.03m$

$$Y_{C.UN1} := \begin{cases} (EL_{C.UN1} - TOC_{pfc}) & \text{if } TOP_{gg.UN1} \le HW_{UN1} \\ (TW_{UN1} - TOC_{pfc}) & \text{if } TOP_{gg.UN1} > HW_{UN1} \end{cases} = 5.73 \cdot m$$

Toewater Elevation: $EL_{TOE.UN1} := 1208.48m$

$$Y_{TOE.UN1} := \begin{cases} (EL_{TOE.UN1} - TOC_{pfe}) & \text{if } TOP_{gg.UN1} \le HW_{UN1} \\ (TW_{UN1} - TOC_{pfe}) & \text{if } TOP_{gg.UN1} > HW_{UN1} \end{cases} = 0.48 \cdot m$$

LATERAL WATER LOADS

UN1 CASE

HEADWATER (DRIVING):

Headwater Depth on Gate: $D_{hwg.UN1} := HW_{UN1} - TOC_{as} = 5.80\,m$

Thickness of Approach Slab (Including Key): $T_{as} = 6\,m$

Headwater Depth at Heel (U/S face): $D_{hwas.UN1} := HW_{UN1} - BOK_{elev} = 11.80\,m$

Headwater Load Unit Width on Approach Slab: $W_{hwas.UN1} := W_b = 15.00\,m$

Headwater Unit Load At Top of Approach Slab: $H_{hwas.UN1.1} := \frac{-\left(\gamma_w \cdot D_{hwg.UN1}^{\;2}\right)}{2} \cdot W_{hwas.UN1} = -2475.06 \cdot kN$

Headwater Unit Load At Bottom of Approach Key: $H_{hwas.UN1.2} := \frac{-\left(\gamma_w \cdot D_{hwas.UN1}^{\;2}\right)}{2} \cdot W_{hwas.UN1} = -10244.6 \cdot kN$

Headwater Line Load At Top of Approach Slab: $\sigma_{hwas.UN1.1} := -\left(\gamma_w \cdot D_{hwg.UN1}\right) = -56.9 \cdot kPa$

Headwater Line Load At Bottom of Approach Key: $\sigma_{hwas.UN1.2} := -\left(\gamma_w \cdot D_{hwas.UN1}\right) = -115.76 \cdot kPa$

Triangular Distribution Unit Load on Approach Slab and Key: $H_{hwas.UN1.2.tri} := \left(\frac{\sigma_{hwas.UN1.2} - \sigma_{hwas.UN1.1}}{2}\right) \cdot \left(T_{as} \cdot W_{hwas.UN1}\right) = -2648.7 \cdot kN$

Rectangular Distribution Unit Load on Approach Slab and Key: $H_{hwas.UN1.2.rect} := \sigma_{hwas.UN1.1} \cdot \left(T_{as} \cdot W_{hwas.UN1}\right) = -5120.82 \cdot kN$

Total Horizontal Headwater Load on Approach Slab: $H_{hwas.UN1} := H_{hwas.UN1.2.tri} + H_{hwas.UN1.2.rect} = -7769.52 \cdot kN$

Apply Total Footing Headwater Load at:

$$H_{hwas.UN1.loc} := \frac{\left[H_{hwas.UN1.2.rect} \cdot \frac{\left(T_{as}\right)}{2} + H_{hwas.UN1.2.tri} \cdot \frac{\left(T_{as}\right)}{3}\right]}{H_{hwas.UN1.2.tri} + H_{hwas.UN1.2.rect}} - d_{key} = 0.66\,m$$

Guard Gate Operating Condition:

Guard Gate Down/Open Condition: $A1_{UN1} := TOP_{gg.UN1} \le TOC_{as}$

Guard Crest Gate Up/Closed, with Top of Gate Higher than HW Elevation: $B1_{UN1} := TOP_{gg.UN1} \ge HW_{UN1} \wedge TOP_{gg.UN1} > TOC_{as}$

Guard Crest Gate Up/Closed, with Top of Gate Lower than HW Elevation: $C1_{UN1} := TOP_{gg.UN1} > TOC_{as} \wedge HW_{UN1} > TOP_{gg.UN1} = 1$

Guard Crest Gate Height: $H_{gg.UN1} := TOP_{gg.UN1} - TOC_{as} = 3.5\,m$

Headwater Depth at Guard Crest Gate: $D_{hwgg.UN1} := HW_{UN1} - TOC_{as} = 5.80\,m$

Guard Crest Gate Width: $W_{hwgg.UN1} := 15.00m$

Lateral Headwater Pressure at Bottom of Guard Crest Gate:

$$\sigma_{hwgg.UN1.1} := \left| \begin{array}{ll} (0.0kPa) & \text{if } A1_{UN1} \\ -(\gamma_w \cdot D_{hwgg.UN1}) & \text{if } B1_{UN1} \\ -(\gamma_w \cdot D_{hwgg.UN1}) & \text{if } C1_{UN1} \end{array} \right. = -56.9 \cdot kPa$$

Lateral Headwater Pressure at Top of Guard Crest Gate:
(Load at HW Elevation On Guard Crest Gate if HW is below TOG_{rg})

$$\sigma_{hwgg.UN1.2} := \left| \begin{array}{ll} (0.0kPa) & \text{if } A1_{UN1} \\ 0.0kPa & \text{if } B1_{UN1} \\ -\left[\gamma_w \cdot (HW_{UN1} - TOP_{gg.UN1})\right] & \text{if } C1_{UN1} \end{array} \right. = -22.6 \cdot kPa$$

Average Pressure acting on Guard Crest Gate:

$$\sigma_{hwgg.UN1.avg} := \frac{(\sigma_{hwgg.UN1.1} + \sigma_{hwgg.UN1.2})}{2} = -39.73 \cdot kPa$$

Total Area of Crest Gate:

$$A_{hwgg.UN1} := \left| \begin{array}{ll} D_{hwgg.UN1} \cdot W_{hwgg.UN1} & \text{if } A1_{UN1} \\ D_{hwgg.UN1} \cdot W_{hwgg.UN1} & \text{if } B1_{UN1} \\ H_{gg.UN1} \cdot W_{hwgg.UN1} & \text{if } C1_{UN1} \end{array} \right. = 52.5 \cdot m^2$$

Total Horizontal Headwater Load on Guard Crest Gate: $H_{hwgg.UN1} := \sigma_{hwgg.UN1.avg} \cdot A_{hwgg.UN1} = -2085.9 \cdot kN$

Apply Total Guard Crest Gate Headwater Load at:

$$H_{hwgg.UN1.loc} := \left| \begin{array}{ll} (TOC_{as} - BOF_{elev}) & \text{if } A1_{UN1} \\ \left[\frac{(HW_{UN1} - TOC_{as})}{3} + (TOC_{as} - BOF_{elev})\right] & \text{if } B1_{UN1} \\ \left[\frac{\sigma_{hwgg.UN1.2} \cdot A_{hwgg.UN1} \cdot \frac{(H_{gg.UN1})}{2} + \frac{(\sigma_{hwgg.UN1.1} - \sigma_{hwgg.UN1.2})}{2} A_{hwgg.UN1} \cdot \frac{(H_{gg.UN1})}{3}}{\sigma_{hwgg.UN1.2} \cdot A_{hwgg.UN1} + \frac{(\sigma_{hwgg.UN1.1} - \sigma_{hwgg.UN1.2})}{2} \cdot A_{hwgg.UN1}} \cdots \\ + (TOC_{as} - BOF_{elev}) \right] & \text{if } C1_{UN1} \end{array} \right. = 5.5 \cdot m$$

LATERAL TAILWATER (RESISTING) Applied to Downstream Side of Guard Crest Gate: UN1 CASE

Guard Gate Down/Open Condition: $A2_{UN1} := TOP_{gg.UN1} \le TOC_{as}$

Guard Crest Gate Up/Closed, with Top of Gate Higher than TW Elevation: $B2_{UN1} := TOP_{gg.UN1} \ge TW_{UN1} \wedge TOP_{gg.UN1} > TOC_{as}$

Guard Crest Gate Up/Closed, with Top of Gate Lower than TW Elevation: $C2_{UN1} := TOP_{gg.UN1} > TOC_{as} \wedge TW_{UN1} > TOP_{gg.UN1}$

Tailwater Depth at Guard Crest Gate: $D_{twgg.UN1} := TW_{UN1} - TOC_{as} = 3.10\,m$

Guard Crest Gate Width: $W_{twgg.UN1} := 15.00m$

Lateral Water Load at Bottom of Guard Crest Gate:

$$\sigma_{twgg.UN1.1} := \begin{cases} (0.0kPa) & \text{if } A2_{UN1} \\ (\gamma_w \cdot D_{twgg.UN1}) & \text{if } B2_{UN1} \\ (\gamma_w \cdot D_{twgg.UN1}) & \text{if } C2_{UN1} \end{cases} = 30.4 \cdot kPa$$

Lateral Water Load at Top of Guard Crest Gate:
(Load at TW Elevation On Guard Crest Gate if TW is below TOG_{gg})

$$\sigma_{twgg.UN1.2} := \begin{cases} (0.0kPa) & \text{if } A2_{UN1} \\ 0.0kPa & \text{if } B2_{UN1} \\ \left[\gamma_w \cdot (TW_{UN1} - TOP_{gg.UN1})\right] & \text{if } C2_{UN1} \end{cases} = 0.0 \cdot kPa$$

Average Pressure acting on Guard Crest Gate:

$$\sigma_{twgg.UN1.avg} := \frac{(\sigma_{twgg.UN1.1} + \sigma_{twgg.UN1.2})}{2} = 15.21 \cdot kPa$$

Total Area water acting on Crest Gate:

$$A_{twgg.UN1} := \begin{cases} D_{twgg.UN1} \cdot W_{twgg.UN1} & \text{if } A2_{UN1} \\ D_{twgg.UN1} \cdot W_{twgg.UN1} & \text{if } B2_{UN1} \\ H_{gg.UN1} \cdot W_{twgg.UN1} & \text{if } C2_{UN1} \end{cases} = 46.5 \cdot m^2$$

Total Horizontal Tailwater Load on Guard Crest Gate: $H_{twgg.UN1} := \sigma_{twgg.UN1.avg} \cdot A_{twgg.UN1} = 707.1 \cdot kN$

Apply Total Horiz. TW Load on Guard Gate at:

$$H_{twgg.UN1.loc} := \begin{cases} (TOC_{as} - BOF_{elev}) & \text{if } A2_{UN1} \\ \left[\frac{(TW_{UN1} - TOC_{as})}{3} + (TOC_{as} - BOF_{elev})\right] & \text{if } B2_{UN1} \\ \left[\frac{\sigma_{twgg.UN1.2} \cdot A_{twgg.UN1} \cdot \frac{(H_{gg.UN1})}{2} + \frac{(\sigma_{twgg.UN1.1} - \sigma_{twgg.UN1.2})}{2} A_{twgg.UN1} \cdot \frac{(H_{gg.UN1})}{3}}{\sigma_{twgg.UN1.2} \cdot A_{twgg.UN1} + \frac{(\sigma_{twgg.UN1.1} - \sigma_{twgg.UN1.2})}{2} \cdot A_{twgg.UN1}} \ldots \\ + (TOC_{as} - BOF_{elev})\right] & \text{if } C2_{UN1} \end{cases} = 5.0 \cdot m$$

TAILWATER (RESISTING) Applied to Concrete Structure:

Tailwater Depth At top of Gate Base Footing Elevation: $D_{twgf.UN1} := TW_{UN1} - TOC_{as} = 3.10\,m$

Water Depth at bottom of Gate Base Footing: $D_{twtoe.UN1} := TW_{UN1} - BOF_{elev} = 7.10\,m$

Footing Thickness at Toe $h_{toe} = 4\,m$

Unit Width of D/S face of crest for application of Tailwater Load: $W_{tw.UN1} := W_b = 15.00\,m$

Tailwater Pressure At Top of Gate Footing: $\sigma_{twgf.UN1} := \left(\gamma_w \cdot D_{twgf.UN1}\right) = 30.41 \cdot kPa$

Tailwater Line Load At Bottom of Gate Footing: $\sigma_{twtoe.UN1} := \left(\gamma_w \cdot D_{twtoe.UN1}\right) = 69.65 \cdot kPa$

Triangular Distribution Unit Load on Gate Footing Base:

$$H_{twgf.UN1.tri} := \left(\frac{\sigma_{twtoe.UN1} - \sigma_{twgf.UN1}}{2}\right) \cdot \left(h_{toe} \cdot W_{tw.UN1}\right) = 1177.2 \cdot kN$$

Rectangular Distribution Unit Load on Gate Footing Base:

$$H_{twgf.UN1.rect} := \sigma_{twgf.UN1} \cdot \left(h_{toe} \cdot W_{tw.UN1}\right) = 1824.66 \cdot kN$$

Tailwater Pressure At Bottom of Sliding Failure Plane:

$$\sigma_{twbk.UN1} := \left(HW_{UN1} - BOK_{elev}\right) \cdot \gamma_w = 115.76 \cdot kPa$$

Triangular Distribution Unit Load Below Footing:

$$H_{twbk.UN1.tri} := \frac{\left(\sigma_{twbk.UN1} - \sigma_{twtoe.UN1}\right)}{2} \cdot d_{key} \cdot W_{tw.UN1} = 691.61 \cdot kN$$

Rectangular Distribution Load Below Footing Base:

$$H_{twbk.UN1.rect} := \sigma_{twtoe.UN1} \cdot d_{key} \cdot W_{tw.UN1} = 2089.53 \cdot kN$$

Total Horizontal Tailwater Load on Gate Footing (including key):

$$H_{twgk.UN1} := H_{twgf.UN1.tri} + H_{twgf.UN1.rect} + H_{twbk.UN1.tri} + H_{twbk.UN1.rect} = 5782.99 \cdot kN$$

Apply Total Gate Footing Tailwater Load at:

$$H_{twgk.UN1.loc} := \frac{\left[H_{twgf.UN1.rect} \cdot \frac{\left(h_{toe}\right)}{2} + H_{twgf.UN1.tri} \cdot \frac{\left(h_{toe}\right)}{3} + H_{twbk.UN1.tri} \cdot \left(-d_{key} \cdot \frac{2}{3}\right) + H_{twbk.UN1.rect} \cdot \left(\frac{-d_{key}}{2}\right)\right]}{H_{twgf.UN1.tri} + H_{twgf.UN1.rect} + H_{twbk.UN1.tri} + H_{twbk.UN1.rect}} = 0.38\,m$$

SUMMATION OF LATERAL WATER LOADS:

$$\Sigma H_{Water.UN1} := H_{hwas.UN1} + H_{hwgg.UN1} + H_{twgk.UN1} + H_{twgg.UN1} = -3365.32 \cdot kN$$

$$\Sigma M_{Hwater.UN1} := H_{hwas.UN1} \cdot H_{hwas.UN1.loc} + H_{hwgg.UN1} \cdot H_{hwgg.UN1.loc} \cdots + H_{twgk.UN1} \cdot H_{twgk.UN1.loc} + H_{twgg.UN1} \cdot H_{twgg.UN1.loc} = -10822.61 \cdot kN \cdot m$$

VERTICAL WATER LOADS

UN1 CASE

HEADWATER:

Water Depth on top of Approach Slab: $d_{hw.UN1} := HW_{UN1} - TOC_{as} = 5.80\,m$

Length of Approach Slab: $L_{as} = 8.75\,m$

Width of Approach Slab: $w_{as} = 15.00\,m$

Vertical Water Weight (H1) on Approach Slab: $H_{1.UN1} := \left(w_{as} \cdot d_{hw.UN1} \cdot L_{as}\right) \cdot \gamma_w = 7467.9 \cdot kN$

Moment Arm for Application of Water Weight (H1) from toe: $H_{1.UN1.loc} := L_b - \dfrac{L_{as}}{2} = 14.13\,m$

TAILWATER:

Trapezoid Volume Above Gate Footing from Approach Slab to Crest: $V_{asc.UN1} := \left(L_{gf} - L_{gfc}\right) W_b \dfrac{d_{hw.UN1} + Y_{C.UN1}}{2} = 618.3 \cdot m^3$

Trapezoid Volume Above Gate Footing Crest to End of Gate Footing: $V_{gfc.UN1} := \left(L_{gfc} \cdot W_b\right) \dfrac{Y_{C.UN1} + Y_{TOE.UN1}}{2} = 121.1 \cdot m^3$

Load Above Gate Footing from Approach Slab to Crest: $H_{2.UN1.asc} := V_{asc.UN1} \cdot \gamma_w = 6065.49 \cdot kN$

Load Acting Above Footing Crest from Toe: $H_{2.UN1.asc.loc} := \dfrac{\left(L_{gf} - L_{gfc}\right) \cdot \left(2 \cdot d_{hw.UN1} + Y_{C.UN1}\right)}{3 \cdot \left(d_{hw.UN1} + Y_{C.UN1}\right)} + L_{gfc} = 6.18\,m$

Load Above Gate Footing from Crest to End: $H_{2.UN1.gfc} := V_{gfc.UN1} \cdot \gamma_w = 1187.94 \cdot kN$

Load Acting Above Gate Footing from Crest to End: $H_{2.UN1.gfc.loc} := \dfrac{\left(L_{gfc}\right) \cdot \left(2 \cdot Y_{C.UN1} + Y_{TOE.UN1}\right)}{3 \cdot \left(Y_{C.UN1} + Y_{TOE.UN1}\right)} = 1.67\,m$

Vertical Water Weight (H2) on Gate Footing: $H_{2.UN1} := H_{2.UN1.asc} + H_{2.UN1.gfc} = 7253.43 \cdot kN$

Moment Arm for Application of Water Weight (H2) from toe: $H_{2.UN1.loc} := \dfrac{H_{2.UN1.asc} \cdot H_{2.UN1.asc.loc} + H_{2.UN1.gfc} \cdot H_{2.UN1.gfc.loc}}{H_{2.UN1}} = 5.44\,m$

UPLIFT AT INCLINE SLIDING PLANE

UN1 CASE

Uplift pressure at U/S Face (heel):	$U_{HW.UN1} := D_{hwas.UN1} \cdot \gamma_w = 115.8 \cdot \frac{kN}{m^2}$
Uplift pressure at D/S Face Stilling Basin:	$U_{TW.UN1} := \left(D_{twtoe.UN1}\right) \cdot \gamma_w = 69.65 \cdot \frac{kN}{m^2}$
Length from U/S of Gate Structure to D/S of Stilling Basin:	$L_{overall} := L_b = 18.50\,m$
Difference between Uplift pressure at HW and TW:	$U_{diff.UN1} := U_{HW.UN1} - U_{TW.UN1} = 46.11 \cdot \frac{kN}{m^2}$
Slope of difference between between Uplift pressure at HW and TW:	$U_{slope.UN1} := \frac{U_{diff.UN1}}{L_{overall}} = 2.49 \cdot \frac{kN}{m^2 \cdot m}$
Tailwater Pressure at toe of Gate Structure:	$U_{press.toe.gs.UN1} := U_{TW.UN1} + \left(L_{overall} - L_b\right) \cdot U_{slope.UN1} = 69.65 \cdot \frac{kN}{m^2}$
Uniform uplift force UA Under Gate Structure due to TW (rectangle):	$U_{A.UN1} := U_{press.toe.gs.UN1} \cdot L_b \cdot W_b \cdot -1 = -19328.15 \cdot kN$
Moment Arm from Toe of Gate Structure for Uplift UA:	$L_{A.UN1} := \left(\frac{L_b}{2}\right) = 9.25\,m$
Linearly Decreasing Uplift Force UN1B Under Gate Structure due to HW-TW Differential (triangle):	$U_{B.UN1} := \frac{1}{2} \cdot \left(U_{HW.UN1} - U_{press.toe.gs.UN1}\right) \cdot L_b \cdot W_b \cdot -1 = -6397.35 \cdot kN$
Moment Arm from Toe of Gate Structure for Uplift UB:	$L_{B.UN1} := \frac{2}{3} \cdot L_b = 12.33\,m$
Total Resultant Uplift force:	$U_{UN1} := U_{A.UN1} + U_{B.UN1} = -25725.5 \cdot kN$
Resultant Location from Toe:	$U_{UN1.loc} := \frac{\left(U_{A.UN1} \cdot L_{A.UN1} + U_{B.UN1} \cdot L_{B.UN1}\right)}{\left(U_{A.UN1} + U_{B.UN1}\right)} = 10.02\,m$

$$\Sigma V_{water.UN1} := H_{1.UN1} + H_{2.UN1} + U_{UN1} = -11004.21 \cdot kN$$

$$\Sigma M_{Vwater.UN1} := H_{1.UN1} \cdot H_{1.UN1.loc} + H_{2.UN1} \cdot H_{2.UN1.loc} + U_{UN1} \cdot U_{UN1.loc} = -112724.68 \cdot kN \cdot m$$

SOIL LOADS

UN1 CASE

Equivalent Fluid Pressure (EFP):

At rest lateral pressure coefficient: $K_{o.UN1} := 1 - \sin(\phi_{backfill}) = 0.658$ (Section 5.3, Design Criteria)

Headwater Pier Footing Unit Width: $W_{hwas.UN1} = 15.00\,m$

Tailwater Pier Footing Unit Width: $W_{tw.UN1} = 15.00\,m$

Pier Footing Thickness at Heel: $t_{hf.UN1} := TOC_{as} - BOK_{elev} = 6.00\,m$

Fixed Crest Footing Thickness at Toe: $t_{tf.UN1} := TOC_{pfe} - BOF_{elev} = 2.00\,m$

Lateral Driving Force (Headwater Side - at rest condition)

At-Rest Soil Load: $E_{act.UN1} := \frac{\left(K_{o.UN1} \cdot t_{hf.UN1}^{\ 2}\right)}{2} \cdot (\gamma_r - \gamma_w) \cdot W_{hwas.UN1} \cdot -1 = -2165.61 \cdot kN$

Acting at: $E_{act.UN1.loc} := \frac{t_{hf.UN1}}{3} = 2.00\,m$

Lateral Resisting Force (Tailwater Side - at rest condition)

At-rest Soil Load: $E_{pass.UN1} := \frac{\left(K_{o.UN1} \cdot t_{tf.UN1}^{\ 2}\right)}{2} \cdot (\gamma_r - \gamma_w) \cdot W_{tw.UN1} = 240.62 \cdot kN$

Acting at: $E_{pass.UN1.loc} := \frac{t_{tf.UN1}}{3} = 0.67\,m$

$\Sigma H_{soil.UN1} := E_{act.UN1} + E_{pass.UN1} = -1924.99 \cdot kN$

$\Sigma M_{soil.UN1} := E_{act.UN1} \cdot E_{act.UN1.loc} + E_{pass.UN1} \cdot E_{pass.UN1.loc} = -4170.8 \cdot kN \cdot m$

ICE / IMPACT LOADS (ASSUME NO ICE LOADING ON TAILWATER SIDE)

Static Ice load on Gates:

$$I_{G.UN1} := \begin{cases} 00 \frac{kN}{m} & \text{if } TOP_{gg.UN1} \le TOC_{as} \\ 0 \frac{kN}{m} & \text{if } TOP_{gg.UN1} > TOC_{as} \end{cases} = 0 \cdot \frac{kN}{m}$$

(Section 7.7, Design Criteria)

Ice Loading Unit Width on Guard Gate: $W_{gg.UN1} := 15.00 m$ (Input value for load case)

Total Ice Load on Structure: $I_{UN1} := -\left(I_{G.UN1} \cdot W_{gg.UN1}\right) = 0 \cdot kN$

Apply Ice load at: $I_{UN1.loc} := \left(TOP_{gg.UN1} - BOF_{elev} - 0.30m\right) = 7.20\,m$

$\Sigma H_{I.UN1} := I_{UN1} = 0 \cdot kN$

$\Sigma M_{I.UN1} := I_{UN1} \cdot I_{UN1.loc} = 0 \cdot kN \cdot m$

SEISMIC LOAD (NOT APPLICABLE FOR THIS LOAD CASE)

UN1 CASE

SUMMARY OF LOADS

	Loads	Moment Arm
Dead load of Concrete Structure:	$D_{conc} = 24618.6 \cdot kN$	$X_{conc.loc} = 10.06\,m$
Obermyer Gate Weight:	$D_{Gate} = 210.0 \cdot kN$	$X_{gate} = 6.60\,m$
HW Lateral Load on Approach Slab:	$H_{hwas.UN1} = -7769.5 \cdot kN$	$H_{hwas.UN1.loc} = 0.66\,m$
HW Lateral Load on Guard Gate:	$H_{hwgg.UN1} = -2085.9 \cdot kN$	$H_{hwgg.UN1.loc} = 5.50\,m$
TW Lateral Load on Gate Footing (Including Key - Sliding Check Loads):	$H_{twgk.UN1} = 5782.99 \cdot kN$	$H_{twgk.UN1.loc} = 0.38\,m$
TW Lateral Load on Guard Gate:	$H_{twgg.UN1} = 707.1 \cdot kN$	$H_{twgg.UN1.loc} = 5.03\,m$
Vertical HW Load on Approach Slab:	$H_{1.UN1} = 7467.9 \cdot kN$	$H_{1.UN1.loc} = 14.13\,m$
Vertical TW Load on Pier Footing (crest):	$H_{2.UN1} = 7253.4 \cdot kN$	$H_{2.UN1.loc} = 5.44\,m$
Uplift:	$U_{UN1} = -25725.5 \cdot kN$	$U_{UN1.loc} = 10.02\,m$
Lateral Soil Load (driving):	$E_{act.UN1} = -2165.6 \cdot kN$	$E_{act.UN1.loc} = 2.00\,m$
Lateral Soil Load (resisting):	$E_{pass.UN1} = 240.62 \cdot kN$	$E_{pass.UN1.loc} = 0.67\,m$
Ice / Impact Load:	$I_{UN1} = 0.0 \cdot kN$	$I_{UN1.loc} = 7.20\,m$

STABILITY ASSESSMENT (SLIDNG, BEARING, FLOTATION AND OVERTURNING):

UN1 CASE

CHECK SLIDING ALONG HORIZONTAL PLANE THRU TOE,
IGNORING BEDROCK MOBILIZED BY STRUCTURAL HEEL KEY, OR VOID BEHIND KEY

Sum of Vertical Forces:

$\Sigma V_{UN1} := \Sigma V_{DL} + \Sigma V_{water.UN1} = 13824.4 \cdot kN$

Sum of Horizontal Forces:

$\Sigma H_{UN1} := \Sigma H_{Water.UN1} + \Sigma H_{soil.UN1} + \Sigma H_{I.UN1} = -5290.31 \cdot kN$

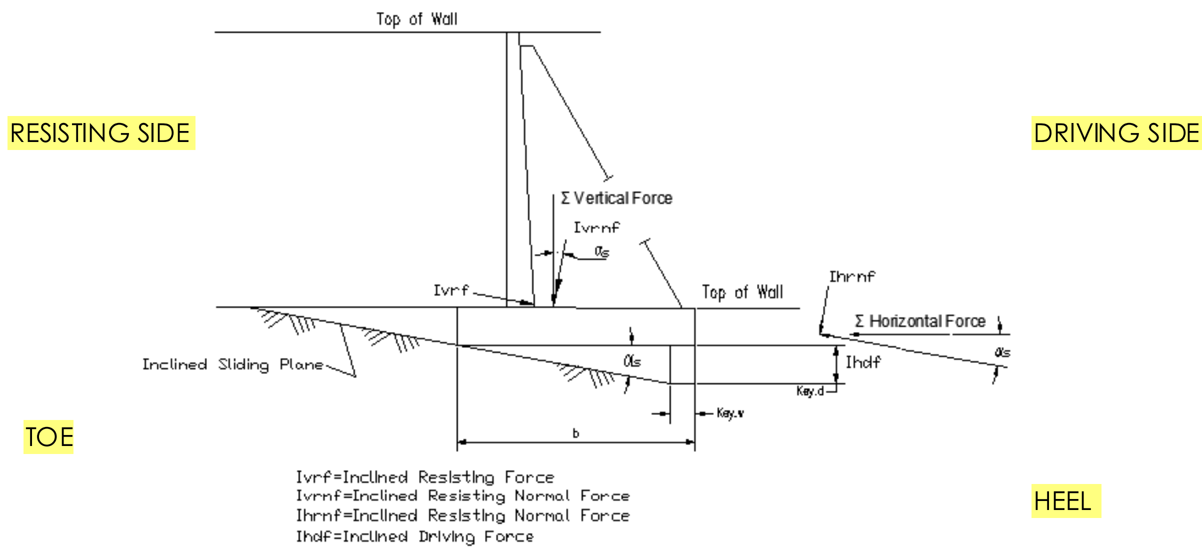
Sliding Factor of Safety:

$$FS_{HorizSliding.UN1} := \frac{\tan_{\phi} \cdot \Sigma V_{UN1}}{\left|\Sigma H_{UN1}\right|} = 1.27$$

ey or Void Behind Ke $FS_{HorizSliding.UN1.Check} :=$ | "OKAY" if $FS_{HorizSliding.UN1} \geq FS_{req.UN1.sl}$
| "Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !" otherwise

= "Horizontal Sliding (N

CHECK SLIDING ALONG INCLINED SLIDING PLANE FROM HEEL KEY TO TOE,
WITH BEDROCK MASS MOBILIZED BY REINFOCREDE CONCRETE KEY)



$\alpha s = 0.11$

as degrees= $\alpha s \cdot \left(\frac{180}{\pi}\right) = 6.52$

$\Sigma V_{UN1} = 13824.39 \cdot kN$

$V_{rs} = 5775 \cdot kN$

Resolve $\Sigma Vert_{UN1}$ & $\Sigma Horiz_{UN1}$

$\Sigma V_{InclinedUN1} := \cos(\alpha s) \cdot \left(\Sigma V_{UN1} + V_{rs}\right) + \sin(\alpha s) \cdot \left|\Sigma H_{UN1}\right| = 20073.3 \cdot kN$

$\Sigma H_{InclinedUN1} := \cos(\alpha s) \cdot \left|\Sigma H_{UN1}\right| - \sin(\alpha s) \cdot \left(\Sigma V_{UN1} + V_{rs}\right) = 3030.6 \cdot kN$

(With properly engineered reinforced concrete Key, horizontal sliding plane thru Toe is protected, critical sliding plane is relocated to the INCLINED SLIDING PLANE FROM HEEL KEY To TOE, Bedrock Mass above this examined plane is mobilized by reinforced concrete key and combined into Structural Wedge.)

Inclined Sliding Plane Length $L_{incline} = 18.61\ m$

Safety Factor for Sliding Inclined Failure Plane

$$FS_{InclinedlSlidingUN1} := \frac{\Sigma V_{InclinedUN1} \cdot \tan\left(\phi_{rock} \cdot \frac{\pi}{180}\right)}{\left|\Sigma H_{InclinedUN1}\right|} = 3.23$$

$FS_{InclinedSliding.check.UN1} :=$ | "OKAY " if $FS_{InclinedlSlidingUN1} > FS_{req.UN1.sl}$
| "Revise Structure"" otherwise

= "OKAY "

$FS_{InclinedSliding.check.UN1}$ = "OKAY "

OVERTURNING STABILITY CHECK:

UN1 CASE

CHECK ECCENTRICITY

Sum of the moments:

$$\Sigma M_{UN1} := \Sigma M_{DL} + \Sigma M_{Hwater.UN1} + \Sigma M_{Vwater.UN1} + \Sigma M_{I.UN1} + \Sigma M_{soil.UN1} + \Sigma M_{soil} = 188601 \cdot kN \cdot m$$

Eccentricity:

$$e_{UN1} := \left(\frac{L_{incline}}{2}\right) - \frac{\Sigma M_{UN1}}{\Sigma V_{InclinedUN1}} = -0.09\,m$$

Eccentricity Check:

$$e_{check.UN1} := \begin{cases} \text{"Okay"} & \text{if } |e_{UN1}| \le Kern \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$$e_{check.UN1} = \text{"Okay"}$$

Foundation Bearing Checks:

Incline Plane Area: $A_{b.incline} = 279.12\,m^2$

Incline Plane Section Modulus: $S_{b.incline} = 865.63 \cdot m^3$

Bearing Pressure at Heel:

$$\sigma_{heel.UN1} := \frac{\Sigma V_{InclinedUN1}}{A_{b.incline}} - \frac{\Sigma V_{InclinedUN1} \cdot e_{UN1}}{S_{b.incline}} = 74.0 \cdot \frac{kN}{m^2}$$

$$\sigma_{heel.UN1.check} := \left(\begin{cases} \text{"Okay"} & \text{if } \sigma_{heel.UN1} \le \sigma_{allow.UN1} \\ \text{"Revise Structure"} & \text{if } \sigma_{heel.UN1} < 0\,\frac{kN}{m^2} \end{cases}\right)$$

$$\sigma_{heel.UN1.check} = \text{"Okay"}$$

Bearing Pressure at Toe:

$$\sigma_{toe.UN1} := \frac{\Sigma V_{InclinedUN1}}{A_{b.incline}} + \frac{\Sigma V_{InclinedUN1} \cdot e_{UN1}}{S_{b.incline}} = 69.8 \cdot \frac{kN}{m^2}$$

$$\sigma_{toe.UN1.1.check} := \begin{cases} \text{"Okay"} & \text{if } \sigma_{toe.UN1} \le \sigma_{allow.UN1} \\ \text{"Revise Structure"} & \text{if } \sigma_{toe.UN1} < 0\,\frac{kN}{m^2} \end{cases}$$

$$\sigma_{toe.UN1.1.check} = \text{"Okay"}$$

FLOATATION ANALYSIS:

ACCEPTANCE PARAMETERS

Required Factor of Safety: $FS_{req.FUN1} := 1.3$

VERTICAL LOADS RESISTING:

Dead Load: $\Sigma V_{DL} = 24828.6 \cdot kN$

Water Weight H1+H2: $\Sigma V_{H.FUN1} := H_{1.UN1} + H_{2.UN1} = 14721.29 \cdot kN$

Summation Vertical Resisting: $\Sigma V_{FUN1} := \Sigma V_{DL} + \Sigma V_{H.FUN1} = 39549.9 \cdot kN$

VERTICAL LOADS UPLIFT:

Uplift: $U_{UN1} = -25725.5 \cdot kN$

Factor of Safety Floatation:

$$FS_{act.FUN1} := \frac{\Sigma V_{FUN1}}{|U_{UN1}|} = 1.54$$

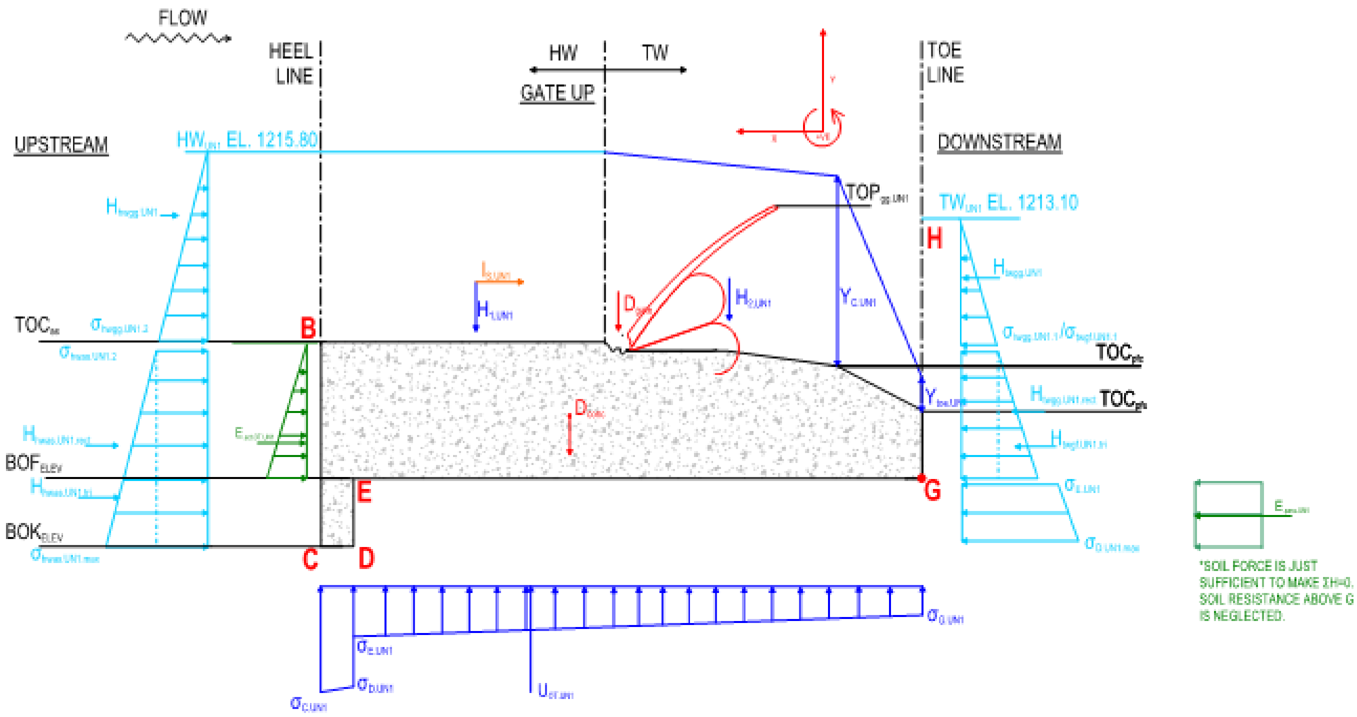
$$FS_{check.FUN1} := \begin{cases} \text{"OKAY"} & \text{if } FS_{act.FUN1} \ge FS_{req.FUN1} \\ \text{"ANCHORS REQUIRED"} & \text{if } FS_{act.FUN1} < FS_{req.FUN1} \end{cases} = \text{"OKAY"}$$

MONOLITH OVERTURNING STABILITY ANALYSIS

UN1 CASE

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.
Assumptions are made in order to compute overturning stability of indetermine forces on monolith with key;
(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.
(b) The horizontal resisting force acting on the key, P.key, is that required for static equilibrium
(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1 $Ratio_{OT.UN1.min} := 0.33$ Resultant at Middle Third



Uplift Loads for Overturning Stability Analysis

Line of Creep:

Change in Water Head: $\Delta_{h.UN1} := HW_{UN1} - TW_{UN1} = 2.7\,m$

Length from Point C to Point G: $L_{CG} = 18.61\,m$

Length from Various Points to Points: $L_{CD} = 1\,m$ $L_{DE} = 2\,m$ $L_{EG} = 17.5\,m$

$L_{GH.UN1} := TW_{UN1} - BOF_{elev} = 7.1\,m$

Length from Point C, D, E to G: $L_{CDEG} = 20.5\,m$ $L_{CDE} = 3\,m$

Water Pressure at Point C: $\sigma_{C.UN1} := \sigma_{hwas.UN1.2} = -115.76 \cdot kPa$

Water Pressure at Point G: $\sigma_{G.UN1} := \sigma_{twtoe.UN1} \cdot -1 = -69.65 \cdot kPa$

Water Pressure at Point D: $\sigma_{D.UN1} := -\gamma_w \cdot \left[\left(HW_{UN1} - BOK_{elev} \right) - \frac{\Delta_{h.UN1} \cdot L_{CD}}{L_{CDEG}} \right] = -114.47 \cdot kPa$

Water Pressure at Point E: $\sigma_{E.UN1} := -\gamma_w \cdot \left[\left(HW_{UN1} - BOF_{elev} \right) - \frac{\Delta_{h.UN1} \cdot L_{CDE}}{L_{CDEG}} \right] = -92.26 \cdot kPa$

Uplift for Overturning Analysis on Bottom of Key: $U_{OT.UN1.key} := \frac{\sigma_{C.UN1} + \sigma_{D.UN1}}{2} \cdot L_{CD} \cdot W_b = -1726.68 \cdot kN$

Acting at: $U_{OT.UN1.key.loc} := \frac{L_{CD} \cdot \left(2 \cdot \sigma_{C.UN1} + \sigma_{D.UN1} \right)}{3 \left(\sigma_{C.UN1} + \sigma_{D.UN1} \right)} + L_{EG} = 18\,m$

UN1 CASE

Uplift for Overturning Analysis on Bottom of Footing:

$$U_{OT.UN1.ftg} := \frac{\sigma_{E.UN1} + \sigma_{G.UN1}}{2} \cdot L_{EG} \cdot W_b = -21251.06 \cdot kN$$

Acting at:

$$U_{OT.UN1.ftg.loc} := \frac{L_{EG} \cdot \left(\sigma_{G.UN1} + 2 \cdot \sigma_{E.UN1}\right)}{3\left(\sigma_{G.UN1} + \sigma_{E.UN1}\right)} = 9.16 m$$

Uplift Load for Overturning Analysis:

$$U_{OT.UN1} := U_{OT.UN1.key} + U_{OT.UN1.ftg} = -22977.74 \cdot kN$$

Uplift Load Acting from Toe:

$$U_{OT.UN1.loc} := \frac{U_{OT.UN1.key} \cdot U_{OT.UN1.key.loc} + U_{OT.UN1.ftg} \cdot U_{OT.UN1.ftg.loc}}{U_{OT.UN1}} = 9.82 m$$

<u>All Vertical Loads Applicable to Overturning Stability Analysis</u>

Total Concrete Dead Loads:	$D_{conc} = 24618.6 \cdot kN$	at:	$X_{conc.loc} = 10.06 m$
Dead Load of Gate:	$D_{Gate} = 210.0 \cdot kN$		$X_{gate} = 6.60 m$
Water Weight (HW) on Apron Slab:	$H_{1.UN1} = 7467.9 \cdot kN$		$H_{1.UN1.loc} = 14.13 m$
Water Weight (TW) on Gate Footing:	$H_{2.UN1} = 7253.4 \cdot kN$		$H_{2.UN1.loc} = 5.44 m$
Uplift Load for Overturning Analysis:	$U_{OT.UN1} = -22977.74 \cdot kN$		$U_{OT.UN1.loc} = 9.82 \cdot m$

Sum of All Overtuming Analysis Vertical Load:

$$\Sigma V_{UN1.OT} := D_{conc} + D_{Gate} + H_{1.UN1} + H_{2.UN1} + U_{OT.UN1} = 16572.15 \cdot kN$$

Sum of All Overtuming Analysis Vertical Load Moments:

$$\Sigma M_{V.UN1.OT} := D_{conc} \cdot X_{conc.loc} + D_{Gate} \cdot X_{gate} + H_{1.UN1} \cdot H_{1.UN1.loc} + H_{2.UN1} \cdot H_{2.UN1.loc} + U_{OT.UN1} \cdot U_{OT.UN1.loc} = 168220.77 \cdot kN \cdot m$$

<u>Lateral Tailwater Loads for Overturning Stability Analysis</u>

TW Lateral Load on Gate Footing (No Key - Overturning Values Adjusted):

$$H_{twgf.UN1} := H_{twgf.UN1.tri} + H_{twgf.UN1.rect} = 3001.86 \cdot kN$$

Acting at:

$$H_{twgf.UN1.loc} := \frac{\frac{h_{toe}}{3} \cdot H_{twgf.UN1.tri} + \frac{h_{toe}}{2} \cdot H_{twgf.UN1.rect}}{H_{twgf.UN1}} = 1.74 m$$

Horizontal Tailwater Pressure Top of Key (Overturning Analysis):

$$\sigma_{twtk.OT.UN1} := \sigma_{E.UN1} \cdot -1 = 92.26 \cdot kPa$$

Horizontal Tailwater Pressure Bottom of Key (Overturning Analysis):

$$\sigma_{twbk.OT.UN1} := \sigma_{D.UN1} \cdot -1 = 114.47 \cdot kPa$$

Triangular Distribution Unit Load Acting at Key:

$$H_{twbk.OT.UN1.tri} := \frac{\left(\sigma_{twbk.OT.UN1} - \sigma_{twtk.OT.UN1}\right)}{2} \cdot d_{key} \cdot W_{tw.UN1} = 333.06 \cdot kN$$

Triangular Distribution Unit Load Acting at Key:

$$H_{twbk.OT.UN1.rect} := \sigma_{twtk.OT.UN1} \cdot d_{key} \cdot W_{tw.UN1} = 2767.86 \cdot kN$$

Total Horizontal Tailwater Load on Key (Overturning Values Adjusted):

$$H_{twkey.OT.UN1} := H_{twbk.OT.UN1.tri} + H_{twbk.OT.UN1.rect} = 3100.92 \cdot kN$$

Acting at:

$$H_{twkey.OT.UN1.loc} := \frac{H_{twbk.OT.UN1.tri} \cdot \frac{-2 \cdot d_{key}}{3} + H_{twbk.OT.UN1.rect} \cdot \frac{-d_{key}}{2}}{H_{twkey.OT.UN1}} = -1.04 \cdot m$$

UN1 CASE

Lateral Driving Earth Loads for Overturning Stability Analysis (at rest condition)

Depth of Driving Soil Loads (to top of key): $h_{E.OT.UN1} := TOC_{as} - BOF_{elev} = 4\ m$

At-Rest Soil Load: $E_{act.OT.UN1} := \dfrac{\left(K_{o.UN1} \cdot h_{E.OT.UN1}{}^{2}\right)}{2} \cdot \left(\gamma_r - \gamma_w\right) \cdot W_{hwas.UN1} \cdot -1 = -962.49 \cdot kN$

At Rest- Soil Load Acting from Toe: $E_{act.OT.UN1.loc} := \dfrac{h_{E.OT.UN1}}{3} = 1.33\ m$

All Lateral Loads Applicable to Overturning Stability Analysis

HW Lateral Load on Approach Slab:	$H_{hwas.UN1} = -7769.5 \cdot kN$	$H_{hwas.UN1.loc} = 0.66\ m$
HW Lateral Load on Guard Gate:	$H_{hwgg.UN1} = -2085.9 \cdot kN$	$H_{hwgg.UN1.loc} = 5.50\ m$
TW Lateral Load on Guard Gate:	$H_{twgg.UN1} = 707.1 \cdot kN$	$H_{twgg.UN1.loc} = 5.03\ m$
TW Lateral Load on Gate Footing (No Key - Overturning Values Adjusted):	$H_{twgf.UN1} = 3001.86 \cdot kN$	$H_{twgf.UN1.loc} = 1.74\ m$
TW Lateral Load on Key:	$H_{twkey.OT.UN1} = 3100.92 \cdot kN$	$H_{twkey.OT.UN1.loc} = -1.04\ m$
Ice / Impact Load:	$I_{UN1} = 0.0 \cdot kN$	$I_{UN1.loc} = 7.20\ m$
Lateral Soil Load (driving):	$E_{act.OT.UN1} = -962.5 \cdot kN$	$E_{act.OT.UN1.loc} = 1.33\ m$

Resisting Lateral Soil Load as required to produce horizontal equilibrium:

$$E_{pas.OT.UN1} := -\left(H_{hwas.UN1} + H_{hwgg.UN1} + H_{twgg.UN1} + H_{twgf.UN1} + H_{twkey.OT.UN1} + I_{UN1} + E_{act.OT.UN1}\right) = 4008.03 \cdot kN$$

Acting at:

$$E_{pas.OT.UN1.loc} := -1 \cdot \frac{d_{key}}{2} = -1\ m$$

Sum of All Overturning Analysis Horizontal Load (ΣH=0):

$$\Sigma H_{UN1.OT} := H_{hwas.UN1} + H_{hwgg.UN1} + H_{twgg.UN1} + H_{twgf.UN1} + H_{twkey.OT.UN1} + I_{UN1} + E_{act.OT.UN1} + E_{pas.OT.UN1} = 0 \cdot kN$$

Sum of All Overturning Analysis Horizontal Load Moments:

$$\begin{aligned}\Sigma M_{H.UN1.OT} := {} & H_{hwas.UN1} \cdot H_{hwas.UN1.loc} + H_{hwgg.UN1} \cdot H_{hwgg.UN1.loc} + H_{twgg.UN1} \cdot H_{twgg.UN1.loc} \cdots = -16314.24 \cdot kN \cdot m \\ & + H_{twgf.UN1} \cdot H_{twgf.UN1.loc} + H_{twkey.OT.UN1} \cdot H_{twkey.OT.UN1.loc} + I_{UN1} \cdot I_{UN1.loc} \cdots \\ & + E_{act.OT.UN1} \cdot E_{act.OT.UN1.loc} + E_{pas.OT.UN1} \cdot E_{pas.OT.UN1.loc}\end{aligned}$$

Overturning Stability Analysis

$\Sigma M_{UN1.OT} := \Sigma M_{V.UN1.OT} + \Sigma M_{H.UN1.OT} = 151906.53 \cdot kN \cdot m$ $\quad X_{R.UN1} := \dfrac{\Sigma M_{UN1.OT}}{\Sigma V_{UN1.OT}} = 9.17\ m$ $\quad x_{OT.UN1} := X_{R.UN1} - \dfrac{L_b}{2} = -0.08\ m$

Overturning Resultant Ratio $\quad Ratio_{OT.UN1} := \dfrac{X_{R.UN1}}{L_b} = 0.5$

$$Ratio_{OT.UN1.check} := \begin{cases} \text{"OKAY"} & \text{if } Ratio_{OT.UN1} \ge Ratio_{OT.UN1.min} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

$$x_{OT.check.UN1} := \begin{cases} \text{"OKAY"} & \text{if } \left|x_{OT.UN1}\right| \le Kern \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

UN1 CASE

CHECK FOUNDATION BEARING CAPACITY (HORIZONTAL PLANE):

Bearing Pressure Under Toe:

$$\sigma_{ToeUN1.OT} := \frac{\Sigma V_{UN1.OT}}{L_b \cdot W_b} + \frac{\left(\Sigma V_{UN1.OT} \cdot x_{OT.UN1}\right)}{S_b} = 58.1 \cdot kPa$$

$$Bearing_{ChecktoeUN1.OT} := \begin{vmatrix} \text{"OKAY "} & \text{if } \sigma_{ToeUN1.OT} < \sigma_{allow.UN1} \\ \text{"NG""} & \text{otherwise} \end{vmatrix} = \text{"OKAY "}$$

Bearing Pressure Under Heel:

$$\sigma_{HeelUN1.OT} := \frac{\Sigma V_{UN1.OT}}{L_b \cdot W_b} - \frac{\left(\Sigma V_{UN1.OT} \cdot x_{OT.UN1}\right)}{S_b} = 61.3 \cdot kPa$$

$$Bearing_{CheckheelUN1.OT} := \left(\begin{vmatrix} \text{"OKAY "} & \text{if } \sigma_{HeelUN1.OT} < \sigma_{allow.UN1} \wedge \sigma_{HeelUN1.OT} > 0 \\ \text{"NG""} & \text{otherwise} \end{vmatrix} \right) = \text{"OKAY "}$$

SUMMARY OF STABILITY ASSESSMENT:

Sliding Factor of Safety:
(Horizontal Plane)

$FS_{HorizSliding.UN1} = 1.27$

$FS_{HorizSliding.UN1.Check}$ = "Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !"

Sliding Factor of Safety:
(Inclined Plane)

$FS_{InclinedlSlidingUN1} = 3.23$ | $FS_{InclinedSliding.check.UN1}$ = "OKAY "

Eccentricity:
(Inclined Plane)

$e_{UN1} = -0.09\,m$ | $e_{check.UN1}$ = "Okay"

Bearing Pressure At Heel:
(Inclined Plane)

$\sigma_{heel.UN1} = 74 \cdot kPa$ | $\sigma_{heel.UN1.check}$ = "Okay"

Bearing Pressure At Toe:
(Inclined Plane)

$\sigma_{toe.UN1} = 70 \cdot kPa$ | $\sigma_{toe.UN1.1.check}$ = "Okay"

Flotation Factor of Safety
(horizontal plane)

$FS_{act.FUN1} = 1.54$ | $FS_{check.FUN1}$ = "OKAY"

Overturning Resultant Ratio:
(horizontal plane)

$Ratio_{OT.UN1} = 0.5$ | $Ratio_{OT.UN1.check}$ = "OKAY"

Eccentricity:
(horizontal plane)

$x_{OT.UN1} = -0.08\,m$ | $x_{OT.check.UN1}$ = "OKAY"

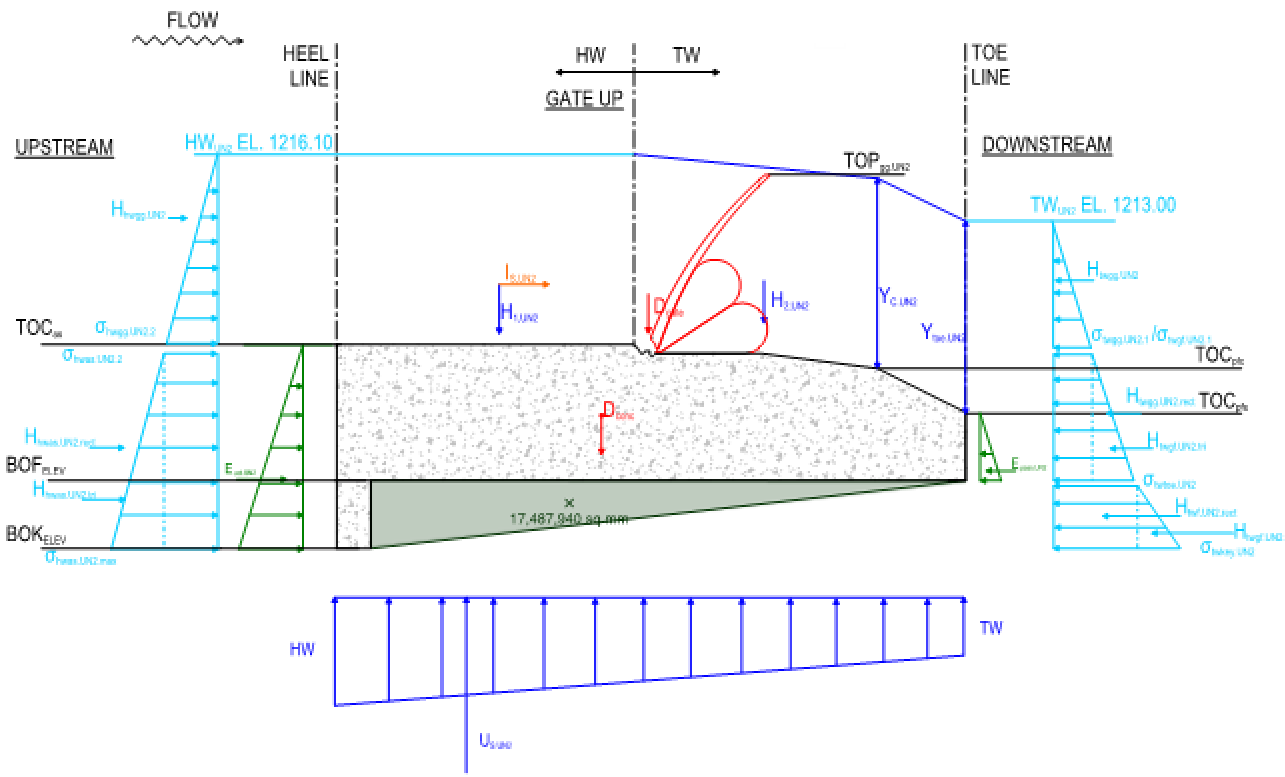
Bearing Pressure At Heel:
(horizontal plane)

$\sigma_{HeelUN1.OT} = 61 \cdot kPa$ | $Bearing_{CheckheelUN1.OT}$ = "OKAY "

Bearing Pressure At Toe:
(horizontal plane)

$\sigma_{ToeUN1.OT} = 58 \cdot kPa$ | $Bearing_{ChecktoeUN1.OT}$ = "OKAY "

UN2 DESIGN CASE



ACCEPTANCE PARAMETERS

Required Factor of Safety for Sliding: $FS_{req.UN2.sl} := 1.3$ (Without Cohesion)

(Section 8.1, Design Criteria)

Resultant Within Middle Third of Base: $e \le \frac{L_b}{6} \wedge e \ge \frac{-L_b}{6}$

Allowable Rock Bearing Pressure: $\sigma_{allow.UN2} := 1470 \cdot \frac{kN}{m^2}$ (Section 5.2, Design Criteria)

INPUT PARAMETERS

Headwater Elevation: $HW_{UN2} := 1216.1m$ (Section 8.3, Design Criteria)

Tailwater Elevation: $TW_{UN2} := 1213.00m$ (Section 8.3, Design Criteria)

Bottom of Footing Elevation: $BOF_{elev} = 1206\,m$

Approach Slab Top of Concrete Elevation at Upstream Face: $TOC_{as} = 1210\,m$

Footing Top of Concrete Elevation at Stilling Basin: $TOC_{pfe} = 1208\,m$

Footing Top of Concrete Elevation at Center of Footing: $TOC_{pfc} = 1209.3\,m$

Gates are open when top of gate elevation is at 1210.00m

Top of Guard/Regulating Gate Elevation: $TOP_{rg.UN2} := 1210.00m$ $TOP_{gg.UN2} := 1215.00m$

Gates are closed/up when top of gate elevation is at 1215.0m

Bottom of Key Elevation: $BOK_{elev} = 1204\,m$

Crestwater Elevation: Dynamic Flow $EL_{C.UN2} := 1215.73m$

$$Y_{C.UN2} := \begin{cases} (EL_{C.UN2} - TOC_{pfc}) & \text{if } TOP_{gg.UN2} \le HW_{UN2} \\ (TW_{UN2} - TOC_{pfc}) & \text{if } TOP_{gg.UN2} > HW_{UN2} \end{cases} = 6.43 \cdot m$$

Toewater Elevation: $EL_{TOE.UN2} := 1213.00m$

$$Y_{TOE.UN2} := \begin{cases} (EL_{TOE.UN2} - TOC_{pfe}) & \text{if } TOP_{gg.UN2} \le HW_{UN2} \\ (TW_{UN2} - TOC_{pfe}) & \text{if } TOP_{gg.UN2} > HW_{UN2} \end{cases} = 5 \cdot m$$

LATERAL WATER LOADS

UN2 CASE

HEADWATER (DRIVING):

Headwater Depth on Gate: $D_{hwg.UN2} := HW_{UN2} - TOC_{as} = 6.10\,m$

Thickness of Approach Slab (Including Key): $T_{as} = 6\,m$

Headwater Depth at Heel (U/S face): $D_{hwas.UN2} := HW_{UN2} - BOK_{elev} = 12.10\,m$

Headwater Load Unit Width on Approach Slab: $W_{hwas.UN2} := W_b = 15.00\,m$

Headwater Unit Load At Top of Approach Slab:

$$H_{hwas.UN2.1} := \frac{-\left(\gamma_w \cdot D_{hwg.UN2}^{\;2}\right)}{2} \cdot W_{hwas.UN2} = -2737.73 \cdot kN$$

Headwater Unit Load At Bottom of Approach Key:

$$H_{hwas.UN2.2} := \frac{-\left(\gamma_w \cdot D_{hwas.UN2}^{\;2}\right)}{2} \cdot W_{hwas.UN2} = -10772.1 \cdot kN$$

Headwater Line Load At Top of Approach Slab:

$$\sigma_{hwas.UN2.1} := -\left(\gamma_w \cdot D_{hwg.UN2}\right) = -59.84 \cdot kPa$$

Headwater Line Load At Bottom of Approach Key:

$$\sigma_{hwas.UN2.2} := -\left(\gamma_w \cdot D_{hwas.UN2}\right) = -118.7 \cdot kPa$$

Triangular Distribution Unit Load on Approach Slab and Key:

$$H_{hwas.UN2.2.tri} := \left(\frac{\sigma_{hwas.UN2.2} - \sigma_{hwas.UN2.1}}{2}\right) \cdot \left(T_{as} \cdot W_{hwas.UN2}\right) = -2648.7 \cdot kN$$

Rectangular Distribution Unit Load on Approach Slab and Key:

$$H_{hwas.UN2.2.rect} := \sigma_{hwas.UN2.1} \cdot \left(T_{as} \cdot W_{hwas.UN2}\right) = -5385.69 \cdot kN$$

Total Horizontal Headwater Load on Approach Slab:

$$H_{hwas.UN2} := H_{hwas.UN2.2.tri} + H_{hwas.UN2.2.rect} = -8034.39 \cdot kN$$

Apply Total Footing Headwater Load at:

$$H_{hwas.UN2.loc} := \frac{\left[H_{hwas.UN2.2.rect} \cdot \frac{\left(T_{as}\right)}{2} + H_{hwas.UN2.2.tri} \cdot \frac{\left(T_{as}\right)}{3}\right]}{H_{hwas.UN2.2.tri} + H_{hwas.UN2.2.rect}} - d_{key} = 0.67\,m$$

Guard Gate Operating Condition:

Guard Gate Down/Open Condition: $A1_{UN2} := TOP_{gg.UN2} \le TOC_{as}$

Guard Crest Gate Up/Closed, with Top of Gate Higher than HW Elevation: $B1_{UN2} := TOP_{gg.UN2} \ge HW_{UN2} \wedge TOP_{gg.UN2} > TOC_{as}$

Guard Crest Gate Up/Closed, with Top of Gate Lower than HW Elevation: $C1_{UN2} := TOP_{gg.UN2} > TOC_{as} \wedge HW_{UN2} > TOP_{gg.UN2}$

Guard Crest Gate Height: $H_{gg.UN2} := TOP_{gg.UN2} - TOC_{as} = 5\,m$

Headwater Depth at Guard Crest Gate: $D_{hwgg.UN2} := HW_{UN2} - TOC_{as} = 6.10\,m$

Guard Crest Gate Width: $W_{hwgg.UN2} := 15.00m$

Lateral Headwater Pressure at Bottom of Guard Crest Gate:

$$\sigma_{hwgg.UN2.1} := \begin{vmatrix} (0.0kPa) & \text{if } A1_{UN2} \\ -(\gamma_w \cdot D_{hwgg.UN2}) & \text{if } B1_{UN2} \\ -(\gamma_w \cdot D_{hwgg.UN2}) & \text{if } C1_{UN2} \end{vmatrix} = -59.8 \cdot kPa$$

Lateral Headwater Pressure at Top of Guard Crest Gate:
(Load at HW Elevation On Guard Crest Gate if HW is below TOG_{rg})

$$\sigma_{hwgg.UN2.2} := \begin{vmatrix} (0.0kPa) & \text{if } A1_{UN2} \\ 0.0kPa & \text{if } B1_{UN2} \\ -[\gamma_w \cdot (HW_{UN2} - TOP_{gg.UN2})] & \text{if } C1_{UN2} \end{vmatrix} = -10.8 \cdot kPa$$

Average Pressure acting on Guard Crest Gate:

$$\sigma_{hwgg.UN2.avg} := \frac{(\sigma_{hwgg.UN2.1} + \sigma_{hwgg.UN2.2})}{2} = -35.32 \cdot kPa$$

Total Area of Crest Gate:

$$A_{hwgg.UN2} := \begin{vmatrix} D_{hwgg.UN2} \cdot W_{hwgg.UN2} & \text{if } A1_{UN2} \\ D_{hwgg.UN2} \cdot W_{hwgg.UN2} & \text{if } B1_{UN2} \\ H_{gg.UN2} \cdot W_{hwgg.UN2} & \text{if } C1_{UN2} \end{vmatrix} = 75 \cdot m^2$$

Total Horizontal Headwater Load on Guard Crest Gate: $H_{hwgg.UN2} := \sigma_{hwgg.UN2.avg} \cdot A_{hwgg.UN2} = -2648.7 \cdot kN$

Apply Total Guard Crest Gate Headwater Load at:

$$H_{hwgg.UN2.loc} := \begin{vmatrix} (TOC_{as} - BOF_{elev}) & \text{if } A1_{UN2} \\ \left[\frac{(HW_{UN2} - TOC_{as})}{3} + (TOC_{as} - BOF_{elev})\right] & \text{if } B1_{UN2} \\ \left[\frac{\sigma_{hwgg.UN2.2} \cdot A_{hwgg.UN2} \cdot \frac{(H_{gg.UN2})}{2} + \frac{(\sigma_{hwgg.UN2.1} - \sigma_{hwgg.UN2.2})}{2} A_{hwgg.UN2} \cdot \frac{(H_{gg.UN2})}{3}}{\sigma_{hwgg.UN2.2} \cdot A_{hwgg.UN2} + \frac{(\sigma_{hwgg.UN2.1} - \sigma_{hwgg.UN2.2})}{2} \cdot A_{hwgg.UN2}} \ldots \\ + (TOC_{as} - BOF_{elev})\right] & \text{if } C1_{UN2} \end{vmatrix} = 5.9 \cdot m$$

LATERAL TAILWATER (RESISTING) Applied to Downstream Side of Guard Crest Gate: UN2 CASE

Guard Gate Down/Open Condition: $A2_{UN2} := TOP_{gg.UN2} \le TOC_{as}$

Guard Crest Gate Up/Closed, with Top of Gate Higher than TW Elevation: $B2_{UN2} := TOP_{gg.UN2} \ge TW_{UN2} \wedge TOP_{gg.UN2} > TOC_{as}$

Guard Crest Gate Up/Closed, with Top of Gate Lower than TW Elevation: $C2_{UN2} := TOP_{gg.UN2} > TOC_{as} \wedge TW_{UN2} > TOP_{gg.UN2}$

Tailwater Depth at Guard Crest Gate: $D_{twgg.UN2} := TW_{UN2} - TOC_{as} = 3.00\,m$

Guard Crest Gate Width: $W_{twgg.UN2} := 15.00m$

Lateral Water Load at Bottom of Guard Crest Gate:

$$\sigma_{twgg.UN2.1} := \begin{cases} (0.0kPa) & \text{if } A2_{UN2} \\ (\gamma_w \cdot D_{twgg.UN2}) & \text{if } B2_{UN2} \\ (\gamma_w \cdot D_{twgg.UN2}) & \text{if } C2_{UN2} \end{cases} = 29.4 \cdot kPa$$

Lateral Water Load at Top of Guard Crest Gate:
(Load at TW Elevation On Guard Crest Gate if TW is below TOG_{gg})

$$\sigma_{twgg.UN2.2} := \begin{cases} (0.0kPa) & \text{if } A2_{UN2} \\ 0.0kPa & \text{if } B2_{UN2} \\ \left[\gamma_w \cdot \left(TW_{UN2} - TOP_{gg.UN2}\right)\right] & \text{if } C2_{UN2} \end{cases} = 0.0 \cdot kPa$$

Average Pressure acting on Guard Crest Gate:

$$\sigma_{twgg.UN2.avg} := \frac{\left(\sigma_{twgg.UN2.1} + \sigma_{twgg.UN2.2}\right)}{2} = 14.71 \cdot kPa$$

Total Area water acting on Crest Gate:

$$A_{twgg.UN2} := \begin{cases} D_{twgg.UN2} \cdot W_{twgg.UN2} & \text{if } A2_{UN2} \\ D_{twgg.UN2} \cdot W_{twgg.UN2} & \text{if } B2_{UN2} \\ H_{gg.UN2} \cdot W_{twgg.UN2} & \text{if } C2_{UN2} \end{cases} = 45 \cdot m^2$$

Total Horizontal Tailwater Load on Guard Crest Gate: $H_{twgg.UN2} := \sigma_{twgg.UN2.avg} \cdot A_{twgg.UN2} = 662.2 \cdot kN$

Apply Total Horiz. TW Load on Guard Gate at:

$$H_{twgg.UN2.loc} := \begin{cases} \left(TOC_{as} - BOF_{elev}\right) & \text{if } A2_{UN2} \\ \left[\frac{\left(TW_{UN2} - TOC_{as}\right)}{3} + \left(TOC_{as} - BOF_{elev}\right)\right] & \text{if } B2_{UN2} \\ \left[\frac{\sigma_{twgg.UN2.2} \cdot A_{twgg.UN2} \cdot \frac{\left(H_{gg.UN2}\right)}{2} + \frac{\left(\sigma_{twgg.UN2.1} - \sigma_{twgg.UN2.2}\right)}{2} A_{twgg.UN2} \cdot \frac{\left(H_{gg.UN2}\right)}{3}}{\sigma_{twgg.UN2.2} \cdot A_{twgg.UN2} + \frac{\left(\sigma_{twgg.UN2.1} - \sigma_{twgg.UN2.2}\right)}{2} \cdot A_{twgg.UN2}} \ldots \\ + \left(TOC_{as} - BOF_{elev}\right)\right] & \text{if } C2_{UN2} \end{cases} = 5.0 \cdot m$$

LATERAL WATER LOADS (continued)

UN2 CASE

TAILWATER (RESISTING) Applied to Concrete Structure:

Tailwater Depth At top of Gate Base Footing Elevation: $D_{twgf.UN2} := TW_{UN2} - TOC_{as} = 3.00\,m$

Water Depth at bottom of Gate Base Footing: $D_{twtoe.UN2} := TW_{UN2} - BOF_{elev} = 7.00\,m$

Footing Thickness at Toe $h_{toe} = 4\,m$

Unit Width of D/S face of crest for application of Tailwater Load: $W_{tw.UN2} := W_b = 15.00\,m$

Tailwater Pressure At Top of Gate Footing: $\sigma_{twgf.UN2} := \left(\gamma_w \cdot D_{twgf.UN2}\right) = 29.43 \cdot kPa$

Tailwater Line Load At Bottom of Gate Footing: $\sigma_{twtoe.UN2} := \left(\gamma_w \cdot D_{twtoe.UN2}\right) = 68.67 \cdot kPa$

Triangular Distribution Unit Load on Gate Footing Base:

$$H_{twgf.UN2.tri} := \left(\frac{\sigma_{twtoe.UN2} - \sigma_{twgf.UN2}}{2}\right) \cdot \left(h_{toe} \cdot W_{tw.UN2}\right) = 1177.2 \cdot kN$$

Rectangular Distribution Unit Load on Gate Footing Base:

$$H_{twgf.UN2.rect} := \sigma_{twgf.UN2} \cdot \left(h_{toe} \cdot W_{tw.UN2}\right) = 1765.8 \cdot kN$$

Tailwater Pressure At Bottom of Sliding Failure Plane: $\sigma_{twbk.UN2} := \left(HW_{UN2} - BOK_{elev}\right) \cdot \gamma_w = 118.7 \cdot kPa$

Triangular Distribution Unit Load Below Footing:

$$H_{twbk.UN2.tri} := \frac{\left(\sigma_{twbk.UN2} - \sigma_{twtoe.UN2}\right)}{2} \cdot d_{key} \cdot W_{tw.UN2} = 750.46 \cdot kN$$

Rectangular Distribution Load Below Footing Base:

$$H_{twbk.UN2.rect} := \sigma_{twtoe.UN2} \cdot d_{key} \cdot W_{tw.UN2} = 2060.1 \cdot kN$$

Total Horizontal Tailwater Load on Gate Footing (including key):

$$H_{twgk.UN2} := H_{twgf.UN2.tri} + H_{twgf.UN2.rect} + H_{twbk.UN2.tri} + H_{twbk.UN2.rect} = 5753.56 \cdot kN$$

Apply Total Gate Footing Tailwater Load at:

$$H_{twgk.UN2.loc} := \frac{\left[H_{twgf.UN2.rect} \cdot \frac{\left(h_{toe}\right)}{2} + H_{twgf.UN2.tri} \cdot \frac{\left(h_{toe}\right)}{3} + H_{twbk.UN2.tri} \cdot \left(-d_{key} \cdot \frac{2}{3}\right) + H_{twbk.UN2.rect} \cdot \left(\frac{-d_{key}}{2}\right)\right]}{H_{twgf.UN2.tri} + H_{twgf.UN2.rect} + H_{twbk.UN2.tri} + H_{twbk.UN2.rect}} = 0.35\,m$$

SUMMATION OF LATERAL WATER LOADS:

$$\Sigma H_{Water.UN2} := H_{hwas.UN2} + H_{hwgg.UN2} + H_{twgk.UN2} + H_{twgg.UN2} = -4267.35 \cdot kN$$

$$\Sigma M_{Hwater.UN2} := H_{hwas.UN2} \cdot H_{hwas.UN2.loc} + H_{hwgg.UN2} \cdot H_{hwgg.UN2.loc} \ldots + H_{twgk.UN2} \cdot H_{twgk.UN2.loc} + H_{twgg.UN2} \cdot H_{twgg.UN2.loc} = -15718.07 \cdot kN \cdot m$$

VERTICAL WATER LOADS

UN2 CASE

HEADWATER:

Water Depth on top of Approach Slab: $d_{hw.UN2} := HW_{UN2} - TOC_{as} = 6.10\,m$

Length of Approach Slab: $L_{as} = 8.75\,m$

Width of Approach Slab: $w_{as} = 15.00\,m$

Vertical Water Weight (H1) on Approach Slab: $H_{1.UN2} := \left(w_{as} \cdot d_{hw.UN2} \cdot L_{as}\right) \cdot \gamma_w = 7854.1 \cdot kN$

Moment Arm for Application of Water Weight (H1) from toe: $H_{1.UN2.loc} := L_b - \dfrac{L_{as}}{2} = 14.13\,m$

TAILWATER:

Trapezoid Volume Above Gate Footing from Approach Slab to Crest: $V_{asc.UN2} := \left(L_{gf} - L_{gfc}\right) W_b \dfrac{d_{hw.UN2} + Y_{C.UN2}}{2} = 671.92 \cdot m^3$

Trapezoid Volume Above Gate Footing Crest to End of Gate Footing: $V_{gfc.UN2} := \left(L_{gfc} \cdot W_b\right) \dfrac{Y_{C.UN2} + Y_{TOE.UN2}}{2} = 222.89 \cdot m^3$

Load Above Gate Footing from Approach Slab to Crest: $H_{2.UN2.asc} := V_{asc.UN2} \cdot \gamma_w = 6591.55 \cdot kN$

Load Acting Above Footing Crest from Toe: $H_{2.UN2.asc.loc} := \dfrac{\left(L_{gf} - L_{gfc}\right) \cdot \left(2 \cdot d_{hw.UN2} + Y_{C.UN2}\right)}{3 \cdot \left(d_{hw.UN2} + Y_{C.UN2}\right)} + L_{gfc} = 6.14\,m$

Load Above Gate Footing from Crest to End: $H_{2.UN2.gfc} := V_{gfc.UN2} \cdot \gamma_w = 2186.5 \cdot kN$

Load Acting Above Gate Footing from Crest to End: $H_{2.UN2.gfc.loc} := \dfrac{\left(L_{gfc}\right) \cdot \left(2 \cdot Y_{C.UN2} + Y_{TOE.UN2}\right)}{3 \cdot \left(Y_{C.UN2} + Y_{TOE.UN2}\right)} = 1.35\,m$

Vertical Water Weight (H2) on Gate Footing: $H_{2.UN2} := H_{2.UN2.asc} + H_{2.UN2.gfc} = 8778.05 \cdot kN$

Moment Arm for Application of Water Weight (H2) from toe: $H_{2.UN2.loc} := \dfrac{H_{2.UN2.asc} \cdot H_{2.UN2.asc.loc} + H_{2.UN2.gfc} \cdot H_{2.UN2.gfc.loc}}{H_{2.UN2}} = 4.95\,m$

UPLIFT AT INCLINE SLIDING PLANE

UN2 CASE

Uplift pressure at U/S Face (heel): $U_{HW.UN2} := D_{hwas.UN2} \cdot \gamma_w = 118.7 \cdot \frac{kN}{m^2}$

Uplift pressure at D/S Face Stilling Basin: $U_{TW.UN2} := \left(D_{twtoe.UN2}\right) \cdot \gamma_w = 68.67 \cdot \frac{kN}{m^2}$

Length from U/S of Gate Structure to D/S of Stilling Basin: $L_{overall} = 18.50\,m$

Difference between Uplift pressure at HW and TW: $U_{diff.UN2} := U_{HW.UN2} - U_{TW.UN2} = 50.03 \cdot \frac{kN}{m^2}$

Slope of difference between between Uplift pressure at HW and TW: $U_{slope.UN2} := \frac{U_{diff.UN2}}{L_{overall}} = 2.70 \cdot \frac{kN}{m^2 \cdot m}$

Tailwater Pressure at toe of Gate Structure: $U_{press.toe.gs.UN2} := U_{TW.UN2} + \left(L_{overall} - L_b\right) \cdot U_{slope.UN2} = 68.67 \cdot \frac{kN}{m^2}$

Uniform uplift force UA Under Gate Structure due to TW (rectangle): $U_{A.UN2} := U_{press.toe.gs.UN2} \cdot L_b \cdot W_b \cdot -1 = -19055.92 \cdot kN$

Moment Arm from Toe of Gate Structure for Uplift UA: $L_{A.UN2} := \left(\frac{L_b}{2}\right) = 9.25\,m$

Linearly Decreasing Uplift Force UN2B Under Gate Structure due to HW-TW Differential (triangle): $U_{B.UN2} := \frac{1}{2} \cdot \left(U_{HW.UN2} - U_{press.toe.gs.UN2}\right) \cdot L_b \cdot W_b \cdot -1 = -6941.8 \cdot kN$

Moment Arm from Toe of Gate Structure for Uplift UB: $L_{B.UN2} := \frac{2}{3} \cdot L_b = 12.33\,m$

Total Resultant Uplift force: $U_{UN2} := U_{A.UN2} + U_{B.UN2} = -25997.73 \cdot kN$

Resultant Location from Toe: $U_{UN2.loc} := \frac{\left(U_{A.UN2} \cdot L_{A.UN2} + U_{B.UN2} \cdot L_{B.UN2}\right)}{\left(U_{A.UN2} + U_{B.UN2}\right)} = 10.07\,m$

$\Sigma V_{water.UN2} := H_{1.UN2} + H_{2.UN2} + U_{UN2} = -9365.55 \cdot kN$

$\Sigma M_{Vwater.UN2} := H_{1.UN2} \cdot H_{1.UN2.loc} + H_{2.UN2} \cdot H_{2.UN2.loc} + U_{UN2} \cdot U_{UN2.loc} = -107486.33 \cdot kN \cdot m$

SOIL LOADS

UN2 CASE

Equivalent Fluid Pressure (EFP):

At rest lateral pressure coefficient: $K_{o.UN2} := 1 - \sin\left(\phi_{backfill}\right) = 0.658$ (Section 5.3, Design Criteria)

Headwater Pier Footing Unit Width: $W_{hwas.UN2} = 15.00\,m$

Tailwater Pier Footing Unit Width: $W_{tw.UN2} = 15.00\,m$

Pier Footing Thickness at Heel: $t_{hf.UN2} := TOC_{as} - BOK_{elev} = 6.00\,m$

Fixed Crest Footing Thickness at Toe: $t_{tf.UN2} := TOC_{pfe} - BOF_{elev} = 2.00\,m$

Lateral Driving Force (Headwater Side - at rest condition)

At-Rest Soil Load: $$E_{act.UN2} := \frac{\left(K_{o.UN2} \cdot t_{hf.UN2}^{\,2}\right)}{2} \cdot \left(\gamma_r - \gamma_w\right) \cdot W_{hwas.UN2} \cdot -1 = -2165.61 \cdot kN$$

Acting at: $$E_{act.UN2.loc} := \frac{t_{hf.UN2}}{3} = 2.00\,m$$

Lateral Resisting Force (Tailwater Side - at rest condition)

At-rest Soil Load: $$E_{pass.UN2} := \frac{\left(K_{o.UN2} \cdot t_{tf.UN2}^{\,2}\right)}{2} \cdot \left(\gamma_r - \gamma_w\right) \cdot W_{tw.UN2} = 240.62 \cdot kN$$

Acting at: $$E_{pass.UN2.loc} := \frac{t_{tf.UN2}}{3} = 0.67\,m$$

$$\Sigma H_{soil.UN2} := E_{act.UN2} + E_{pass.UN2} = -1924.99 \cdot kN$$

$$\Sigma M_{soil.UN2} := E_{act.UN2} \cdot E_{act.UN2.loc} + E_{pass.UN2} \cdot E_{pass.UN2.loc} = -4170.8 \cdot kN \cdot m$$

ICE / IMPACT LOADS (ASSUME NO ICE LOADING ON TAILWATER SIDE)

Static Ice load on Gates: $$I_{G.UN2} := \begin{cases} 00 \dfrac{kN}{m} & \text{if } TOP_{gg.UN2} \le TOC_{as} \\ 0 \dfrac{kN}{m} & \text{if } TOP_{gg.UN2} > TOC_{as} \end{cases} = 0 \cdot \frac{kN}{m}$$ (Section 7.7, Design Criteria)

Ice Loading Unit Width on Guard Gate: $W_{gg.UN2} := 15.00m$ (Input value for load case)

Total Ice Load on Structure: $I_{UN2} := -\left(I_{G.UN2} \cdot W_{gg.UN2}\right) = 0 \cdot kN$

Apply Ice load at: $I_{UN2.loc} := \left(TOP_{gg.UN2} - BOF_{elev} - 0.30m\right) = 8.70\,m$

$$\Sigma H_{I.UN2} := I_{UN2} = 0 \cdot kN$$

$$\Sigma M_{I.UN2} := I_{UN1} \cdot I_{UN1.loc} = 0 \cdot kN \cdot m$$

SEISMIC LOAD (NOT APPLICABLE FOR THIS LOAD CASE)

UN2 CASE

SUMMARY OF LOADS

	Loads	Moment Arm
Dead load of Concrete Structure:	$D_{conc} = 24618.6 \cdot kN$	$X_{conc.loc} = 10.06\, m$
Obermyer Gate Weight:	$D_{Gate} = 210.0 \cdot kN$	$X_{gate} = 6.60\, m$
HW Lateral Load on Approach Slab:	$H_{hwas.UN2} = -8034.4 \cdot kN$	$H_{hwas.UN2.loc} = 0.67\, m$
HW Lateral Load on Guard Gate:	$H_{hwgg.UN2} = -2648.7 \cdot kN$	$H_{hwgg.UN2.loc} = 5.92\, m$
TW Lateral Load on Gate Footing (Including Key - Sliding Check Loads):	$H_{twgk.UN2} = 5753.56 \cdot kN$	$H_{twgk.UN2.loc} = 0.35\, m$
TW Lateral Load on Guard Gate:	$H_{twgg.UN2} = 662.2 \cdot kN$	$H_{twgg.UN2.loc} = 5.00\, m$
Vertical HW Load on Approach Slab:	$H_{1.UN2} = 7854.1 \cdot kN$	$H_{1.UN2.loc} = 14.13\, m$
Vertical TW Load on Pier Footing (crest):	$H_{2.UN2} = 8778.0 \cdot kN$	$H_{2.UN2.loc} = 4.95\, m$
Uplift:	$U_{UN2} = -25997.7 \cdot kN$	$U_{UN2.loc} = 10.07\, m$
Lateral Soil Load (driving):	$E_{act.UN2} = -2165.6 \cdot kN$	$E_{act.UN2.loc} = 2.00\, m$
Lateral Soil Load (resisting):	$E_{pass.UN2} = 240.62 \cdot kN$	$E_{pass.UN2.loc} = 0.67\, m$
Ice / Impact Load:	$I_{UN2} = 0.0 \cdot kN$	$I_{UN2.loc} = 8.70\, m$

STABILITY ASSESSMENT (SLIDNG, BEARING, FLOTATION AND OVERTURNING):

UN2 CASE

CHECK SLIDING ALONG HORIZONTAL PLANE THRU TOE, IGNORING BEDROCK MOBILIZED BY STRUCTURAL HEEL KEY, OR VOID BEHIND KEY

Sum of Vertical Forces:

$\Sigma V_{UN2} := \Sigma V_{DL} + \Sigma V_{water.UN2} = 15463.1 \cdot kN$

Sum of Horizontal Forces:

$\Sigma H_{UN2} := \Sigma H_{Water.UN2} + \Sigma H_{soil.UN2} + \Sigma H_{I.UN2} = -6192.34 \cdot kN$

Sliding Factor of Safety: $FS_{HorizSliding.UN2} := \dfrac{\tan_{\phi} \cdot \Sigma V_{UN2}}{|\Sigma H_{UN2}|} = 1.22$

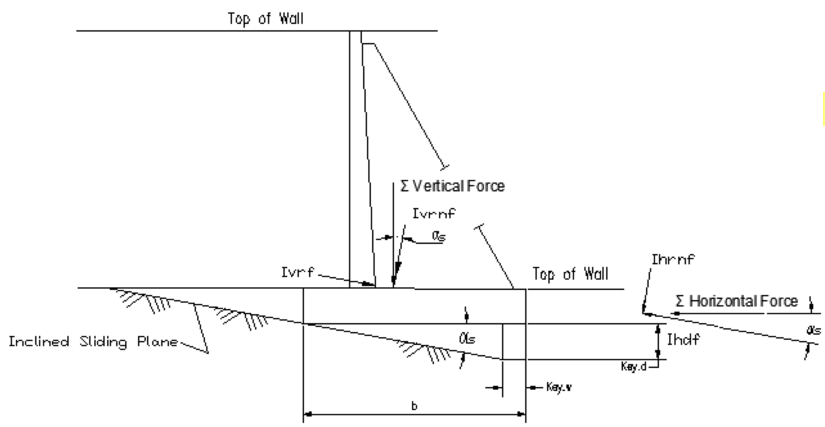
o Key or Void Behinc $FS_{HorizSliding.UN2.Check} :=$ | "OKAY" if $FS_{HorizSliding.UN2} \geq FS_{req.UN2.sl}$ = "Horizontal Sliding (N

"Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !" otherwise

CHECK SLIDING ALONG INCLINED SLIDING PLANE FROM HEEL KEY TO TOE, WITH BEDROCK MASS MOBILIZED BY REINFOCREDE CONCRETE KEY)

RESISTING SIDE

DRIVING SIDE



TOE

Ivrf=Inclined Resisting Force
Ivrnf=Inclined Resisting Normal Force
Ihrnf=Inclined Resisting Normal Force
Ihdf=Inclined Driving Force

HEEL

$\alpha s = 0.11$

as degrees= $\alpha s \cdot \left(\dfrac{180}{\pi}\right) = 6.52$

$\Sigma V_{UN2} = 15463.05 \cdot kN$

$V_{rs} = 5775 \cdot kN$

Resolve $\Sigma Vert_{UN2}$ & $\Sigma Horiz_{UN2}$

$\Sigma V_{InclinedUN2} := \cos(\alpha s) \cdot (\Sigma V_{UN2} + V_{rs}) + \sin(\alpha s) \cdot |\Sigma H_{UN2}| = 21803.8 \cdot kN$

$\Sigma H_{InclinedUN2} := \cos(\alpha s) \cdot |\Sigma H_{UN2}| - \sin(\alpha s) \cdot (\Sigma V_{UN2} + V_{rs}) = 3740.8 \cdot kN$

(With properly engineered reinforced concrete Key, horizontal sliding plane thru Toe is protected, critical sliding plane is relocated to the INCLINED SLIDING PLANE FROM HEEL KEY To TOE, Bedrock Mass above this examined plane is mobilized by reinforced concrete key and combined into Structural Wedge.)

Inclined Sliding Plane Length $L_{incline} = 18.61 \, m$

Safety Factor for Sliding Inclined Failure Plane

$FS_{InclinedISlidingUN2} := \dfrac{\Sigma V_{InclinedUN2} \cdot \tan\left(\phi_{rock} \cdot \dfrac{\pi}{180}\right)}{|\Sigma H_{InclinedUN2}|} = 2.84$

$FS_{InclinedSliding.check.UN2} :=$ | "OKAY " if $FS_{InclinedISlidingUN2} > FS_{req.UN2.sl}$ = "OKAY "

"Revise Structure"" otherwise

$FS_{InclinedSliding.check.UN2}$ = "OKAY "

OVERTURNING STABILITY CHECK:

UN2 CASE

CHECK ECCENTRICITY

Sum of the moments:

$$\Sigma M_{UN2} := \Sigma M_{DL} + \Sigma M_{Hwater.UN2} + \Sigma M_{Vwater.UN2} + \Sigma M_{I.UN2} + \Sigma M_{soil.UN2} + \Sigma M_{soil} = 188944 \cdot kN \cdot m$$

Eccentricity:

$$e_{UN2} := \left(\frac{L_{incline}}{2}\right) - \frac{\Sigma M_{UN2}}{\Sigma V_{InclinedUN2}} = 0.64\,m$$

Eccentricity Check:

$$e_{check.UN2} := \begin{cases} \text{"Okay"} & \text{if } \left|e_{UN2}\right| \le Kern \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$e_{check.UN2} = \text{"Okay"}$

Foundation Bearing Checks:

Incline Plane Area: $A_{b.incline} = 279.12\,m^2$

Incline Plane Section Modulus: $S_{b.incline} = 865.63 \cdot m^3$

Bearing Pressure at Heel:

$$\sigma_{heel.UN2} := \frac{\Sigma V_{InclinedUN2}}{A_{b.incline}} - \frac{\Sigma V_{InclinedUN2} \cdot e_{UN2}}{S_{b.incline}} = 62.0 \cdot \frac{kN}{m^2}$$

$$\sigma_{heel.UN2.check} := \left(\begin{cases} \text{"Okay"} & \text{if } \sigma_{heel.UN2} \le \sigma_{allow.UN2} \\ \text{"Revise Structure"} & \text{if } \sigma_{heel.UN2} < 0\,\frac{kN}{m^2} \end{cases}\right)$$

$\sigma_{heel.UN2.check} = \text{"Okay"}$

Bearing Pressure at Toe:

$$\sigma_{toe.UN2} := \frac{\Sigma V_{InclinedUN2}}{A_{b.incline}} + \frac{\Sigma V_{InclinedUN2} \cdot e_{UN2}}{S_{b.incline}} = 94.2 \cdot \frac{kN}{m^2}$$

$$\sigma_{toe.UN2.1.check} := \begin{cases} \text{"Okay"} & \text{if } \sigma_{toe.UN2} \le \sigma_{allow.UN2} \\ \text{"Revise Structure"} & \text{if } \sigma_{toe.UN2} < 0\,\frac{kN}{m^2} \end{cases}$$

$\sigma_{toe.UN2.1.check} = \text{"Okay"}$

FLOATATION ANALYSIS:

ACCEPTANCE PARAMETERS

Required Factor of Safety: $FS_{req.FUN2} := 1.3$

VERTICAL LOADS RESISTING:

Dead Load: $\Sigma V_{DL} = 24828.6 \cdot kN$

Water Weight H1+H2: $\Sigma V_{H.FUN2} := H_{1.UN2} + H_{2.UN2} = 16632.18 \cdot kN$

Summation Vertical Resisting: $\Sigma V_{FUN2} := \Sigma V_{DL} + \Sigma V_{H.FUN2} = 41460.8 \cdot kN$

VERTICAL LOADS UPLIFT:

Uplift: $U_{UN2} = -25997.73 \cdot kN$

Factor of Safety Floatation:

$$FS_{act.FUN2} := \frac{\Sigma V_{FUN2}}{\left|U_{UN2}\right|} = 1.59$$

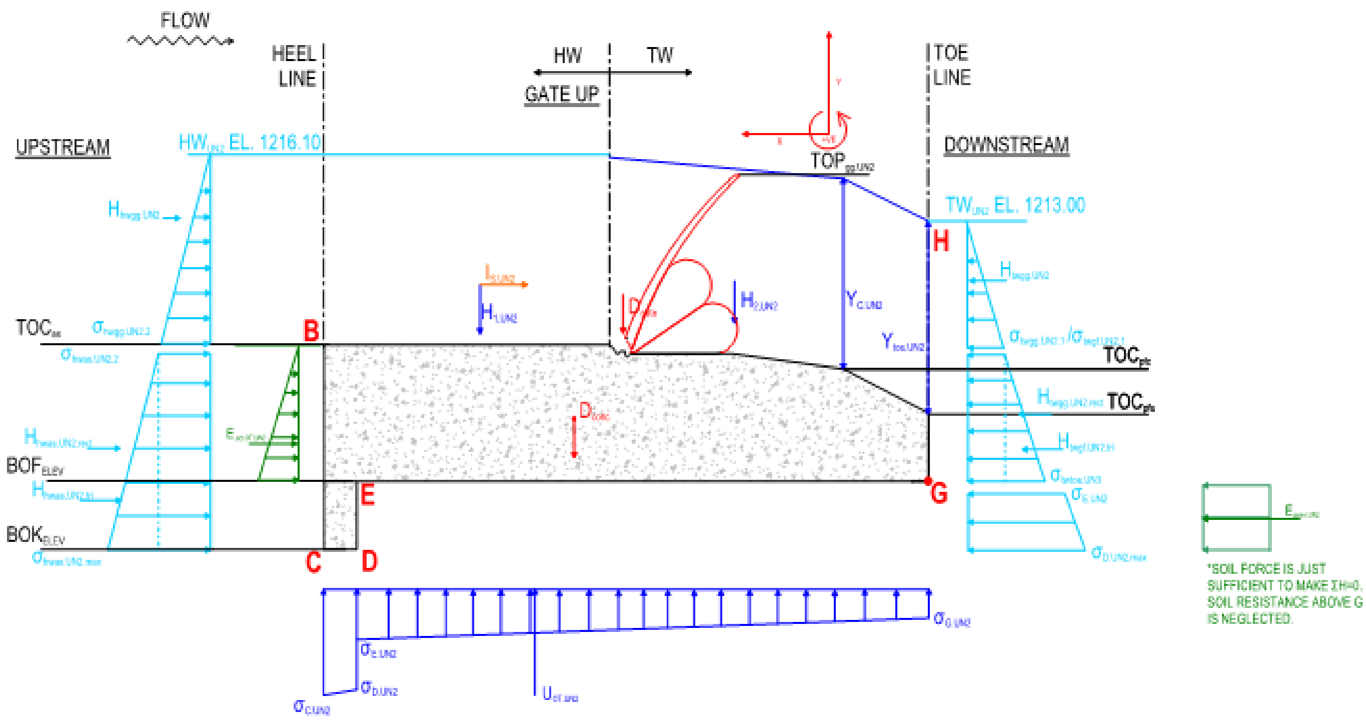
$$FS_{check.FUN2} := \begin{cases} \text{"OKAY"} & \text{if } FS_{act.FUN2} \ge FS_{req.FUN2} \\ \text{"ANCHORS REQUIRED"} & \text{if } FS_{act.FUN2} < FS_{req.FUN2} \end{cases} = \text{"OKAY"}$$

MONOLITH OVERTURNING STABILITY ANALYSIS

UN2 CASE

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.
Assumptions are made in order to compute overturning stability of indetermine forces on monolith with key;
(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.
(b) The horizontal resisting force acting on the key, P.key, is that required for static equilibrium
(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1 $Ratio_{OT.UN2.min} := 0.33$



Uplift Loads for Overturning Stability Analysis

Line of Creep:

Change in Water Head: $\Delta_{h.UN2} := HW_{UN2} - TW_{UN2} = 3.1\ m$

Length from Point C to Point G: $L_{CG} = 18.61\ m$

Length from Various Points to Points: $L_{CD} = 1\ m$ $L_{DE} = 2\ m$ $L_{EG} = 17.5\ m$

$L_{GH.UN2} := TW_{UN2} - BOF_{elev} = 7\ m$

Length from Point C, D, E to G: $L_{CDEG} = 20.5\ m$ $L_{CDE} = 3\ m$

Water Pressure at Point C: $\sigma_{C.UN2} := \sigma_{hwas.UN2.2} = -118.7 \cdot kPa$

Water Pressure at Point G: $\sigma_{G.UN2} := \sigma_{twtoe.UN2} \cdot -1 = -68.67 \cdot kPa$

Water Pressure at Point D: $$\sigma_{D.UN2} := -\gamma_w \cdot \left[\left(HW_{UN2} - BOK_{elev} \right) - \frac{\Delta_{h.UN2} \cdot L_{CD}}{L_{CDEG}} \right] = -117.22 \cdot kPa$$

Water Pressure at Point E: $$\sigma_{E.UN2} := -\gamma_w \cdot \left[\left(HW_{UN2} - BOF_{elev} \right) - \frac{\Delta_{h.UN2} \cdot L_{CDE}}{L_{CDEG}} \right] = -94.63 \cdot kPa$$

Uplift for Overturning Analysis on Bottom of Key: $$U_{OT.UN2.key} := \frac{\sigma_{C.UN2} + \sigma_{D.UN2}}{2} \cdot L_{CD} \cdot W_b = -1769.39 \cdot kN$$

Acting at: $$U_{OT.UN2.key.loc} := \frac{L_{CD} \cdot \left(2 \cdot \sigma_{C.UN2} + \sigma_{D.UN2} \right)}{3 \left(\sigma_{C.UN2} + \sigma_{D.UN2} \right)} + L_{EG} = 18\ m$$

UN2 CASE

Uplift for Overturning Analysis on Bottom of Footing:

$$U_{OT.UN2.ftg} := \frac{\sigma_{E.UN2} + \sigma_{G.UN2}}{2} \cdot L_{EG} \cdot W_b = -21433.21 \cdot kN$$

Acting at:

$$U_{OT.UN2.ftg.loc} := \frac{L_{EG} \cdot \left(\sigma_{G.UN2} + 2 \cdot \sigma_{E.UN2}\right)}{3\left(\sigma_{G.UN2} + \sigma_{E.UN2}\right)} = 9.21\,m$$

Uplift Load for Overturning Analysis:

$$U_{OT.UN2} := U_{OT.UN2.key} + U_{OT.UN2.ftg} = -23202.59 \cdot kN$$

Uplift Load Acting from Toe:

$$U_{OT.UN2.loc} := \frac{U_{OT.UN2.key} \cdot U_{OT.UN2.key.loc} + U_{OT.UN2.ftg} \cdot U_{OT.UN2.ftg.loc}}{U_{OT.UN2}} = 9.88\,m$$

<u>All Vertical Loads Applicable to Overturning Stability Analysis</u>

Total Concrete Dead Loads:	$D_{conc} = 24618.6 \cdot kN$	at:	$X_{conc.loc} = 10.06\,m$
Dead Load of Gate:	$D_{Gate} = 210.0 \cdot kN$		$X_{gate} = 6.60\,m$
Water Weight (HW) on Apron Slab:	$H_{1.UN2} = 7854.1 \cdot kN$		$H_{1.UN2.loc} = 14.13\,m$
Water Weight (TW) on Gate Footing:	$H_{2.UN2} = 8778.0 \cdot kN$		$H_{2.UN2.loc} = 4.95\,m$
Uplift Load for Overturning Analysis:	$U_{OT.UN2} = -23202.59 \cdot kN$		$U_{OT.UN2.loc} = 9.88 \cdot m$

Sum of All Overtuming Analysis Vertical Load:

$$\Sigma V_{UN2.OT} := D_{conc} + D_{Gate} + H_{1.UN2} + H_{2.UN2} + U_{OT.UN2} = 18258.19 \cdot kN$$

Sum of All Overtuming Analysis Vertical Load Moments:

$$\Sigma M_{V.UN2.OT} := D_{conc} \cdot X_{conc.loc} + D_{Gate} \cdot X_{gate} + H_{1.UN2} \cdot H_{1.UN2.loc} + H_{2.UN2} \cdot H_{2.UN2.loc} + U_{OT.UN2} \cdot U_{OT.UN2.loc} = 174010.87 \cdot kN \cdot m$$

<u>Lateral Tailwater Loads for Overturning Stability Analysis</u>

TW Lateral Load on Gate Footing (No Key - Overturning Values Adjusted):

$$H_{twgf.UN2} := H_{twgf.UN2.tri} + H_{twgf.UN2.rect} = 2943 \cdot kN$$

Acting at:

$$H_{twgf.UN2.loc} := \frac{\frac{h_{toe}}{3} \cdot H_{twgf.UN2.tri} + \frac{h_{toe}}{2} \cdot H_{twgf.UN2.rect}}{H_{twgf.UN2}} = 1.73\,m$$

Horizontal Tailwater Pressure Top of Key (Overturning Analysis):

$$\sigma_{twtk.OT.UN2} := \sigma_{E.UN2} \cdot -1 = 94.63 \cdot kPa$$

Horizontal Tailwater Pressure Bottom of Key (Overturning Analysis):

$$\sigma_{twbk.OT.UN2} := \sigma_{D.UN2} \cdot -1 = 117.22 \cdot kPa$$

Triangular Distribution Unit Load Acting at Key:

$$H_{twbk.OT.UN2.tri} := \frac{\left(\sigma_{twbk.OT.UN2} - \sigma_{twtk.OT.UN2}\right)}{2} \cdot d_{key} \cdot W_{tw.UN2} = 338.8 \cdot kN$$

Triangular Distribution Unit Load Acting at Key:

$$H_{twbk.OT.UN2.rect} := \sigma_{twtk.OT.UN2} \cdot d_{key} \cdot W_{tw.UN2} = 2838.92 \cdot kN$$

Total Horizontal Tailwater Load on Key (Overturning Values Adjusted):

$$H_{twkey.OT.UN2} := H_{twbk.OT.UN2.tri} + H_{twbk.OT.UN2.rect} = 3177.72 \cdot kN$$

Acting at:

$$H_{twkey.OT.UN2.loc} := \frac{H_{twbk.OT.UN2.tri} \cdot \frac{-2 \cdot d_{key}}{3} + H_{twbk.OT.UN2.rect} \cdot \frac{-d_{key}}{2}}{H_{twkey.OT.UN2}} = -1.04 \cdot m$$

UN2 CASE

Lateral Driving Earth Loads for Overturning Stability Analysis (at rest condition)

Depth of Driving Soil Loads (to top of key): $h_{E.OT.UN2} := TOC_{as} - BOF_{elev} = 4\,m$

At-Rest Soil Load: $E_{act.OT.UN2} := \frac{\left(K_{o.UN2} \cdot h_{E.OT.UN2}^{2}\right)}{2} \cdot \left(\gamma_r - \gamma_w\right) \cdot W_{hwas.UN2} \cdot -1 = -962.49 \cdot kN$

At Rest- Soil Load Acting from Toe: $E_{act.OT.UN2.loc} := \frac{h_{E.OT.UN2}}{3} = 1.33\,m$

All Lateral Loads Applicable to Overturning Stability Analysis

HW Lateral Load on Approach Slab:	$H_{hwas.UN2} = -8034.4 \cdot kN$	$H_{hwas.UN2.loc} = 0.67\,m$
HW Lateral Load on Guard Gate:	$H_{hwgg.UN2} = -2648.7 \cdot kN$	$H_{hwgg.UN2.loc} = 5.92\,m$
TW Lateral Load on Guard Gate:	$H_{twgg.UN2} = 662.2 \cdot kN$	$H_{twgg.UN2.loc} = 5.00\,m$
TW Lateral Load on Gate Footing (No Key - Overturning Values Adjusted):	$H_{twgf.UN2} = 2943 \cdot kN$	$H_{twgf.UN2.loc} = 1.73\,m$
TW Lateral Load on Key:	$H_{twkey.OT.UN2} = 3177.72 \cdot kN$	$H_{twkey.OT.UN2.loc} = -1.04\,m$
Ice / Impact Load:	$I_{UN2} = 0.0 \cdot kN$	$I_{UN2.loc} = 8.70\,m$
Lateral Soil Load (driving):	$E_{act.OT.UN2} = -962.5 \cdot kN$	$E_{act.OT.UN2.loc} = 1.33\,m$

Resisting Lateral Soil Load as required to produce horizontal equilibrium:

$$E_{pas.OT.UN2} := -\left(H_{hwas.UN2} + H_{hwgg.UN2} + H_{twgg.UN2} + H_{twgf.UN2} + H_{twkey.OT.UN2} + I_{UN2} + E_{act.OT.UN2}\right) = 4862.69 \cdot kN$$

Acting at:

$$E_{pas.OT.UN2.loc} := -1 \cdot \frac{d_{key}}{2} = -1\,m$$

Sum of All Overturning Analysis Horizontal Load (ΣH=0):

$$\Sigma H_{UN2.OT} := H_{hwas.UN2} + H_{hwgg.UN2} + H_{twgg.UN2} + H_{twgf.UN2} + H_{twkey.OT.UN2} + I_{UN2} + E_{act.OT.UN2} + E_{pas.OT.UN2} = 0 \cdot kN$$

Sum of All Overturning Analysis Horizontal Load Moments:

$$\Sigma M_{H.UN2.OT} := H_{hwas.UN2} \cdot H_{hwas.UN2.loc} + H_{hwgg.UN2} \cdot H_{hwgg.UN2.loc} + H_{twgg.UN2} \cdot H_{twgg.UN2.loc} \cdots + H_{twgf.UN2} \cdot H_{twgf.UN2.loc} + H_{twkey.OT.UN2} \cdot H_{twkey.OT.UN2.loc} + I_{UN2} \cdot I_{UN2.loc} \cdots + E_{act.OT.UN2} \cdot E_{act.OT.UN2.loc} + E_{pas.OT.UN2} \cdot E_{pas.OT.UN2.loc} = -22094.02 \cdot kN \cdot m$$

Overturning Stability Analysis

$\Sigma M_{UN2.OT} := \Sigma M_{V.UN2.OT} + \Sigma M_{H.UN2.OT} = 151916.85 \cdot kN \cdot m$ $\quad X_{R.UN2} := \frac{\Sigma M_{UN2.OT}}{\Sigma V_{UN2.OT}} = 8.32\,m$ $\quad x_{OT.UN2} := X_{R.UN2} - \frac{L_b}{2} = -0.93\,m$

Overturning Resultant Ratio $\quad Ratio_{OT.UN2} := \frac{X_{R.UN2}}{L_b} = 0.45$

$$Ratio_{OT.UN2.check} := \begin{cases} \text{"OKAY"} & \text{if } Ratio_{OT.UN2} \geq Ratio_{OT.UN2.min} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

$$x_{OT.check.UN2} := \begin{cases} \text{"OKAY"} & \text{if } \left|x_{OT.UN2}\right| \leq Kern \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

UN2 CASE

CHECK FOUNDATION BEARING CAPACITY (HORIZONTAL PLANE):

Bearing Pressure Under Toe:

$$\sigma_{ToeUN2.OT} := \frac{\Sigma V_{UN2.OT}}{L_b \cdot W_b} + \frac{\left(\Sigma V_{UN2.OT} \cdot x_{OT.UN2}\right)}{S_b} = 46.0 \cdot kPa$$

$$Bearing_{ChecktoeUN2.OT} := \begin{vmatrix} \text{"OKAY "} & \text{if } \sigma_{ToeUN2.OT} < \sigma_{allow.UN2} \\ \text{"NG""} & \text{otherwise} \end{vmatrix} = \text{"OKAY "}$$

Bearing Pressure Under Heel:

$$\sigma_{HeelUN2.OT} := \frac{\Sigma V_{UN2.OT}}{L_b \cdot W_b} - \frac{\left(\Sigma V_{UN2.OT} \cdot x_{OT.UN2}\right)}{S_b} = 85.6 \cdot kPa$$

$$Bearing_{CheckheelUN2.OT} := \left(\begin{vmatrix} \text{"OKAY "} & \text{if } \sigma_{HeelUN2.OT} < \sigma_{allow.UN2} \wedge \sigma_{HeelUN2.OT} > 0 \\ \text{"NG""} & \text{otherwise} \end{vmatrix} \right) = \text{"OKAY "}$$

SUMMARY OF STABILITY ASSESSMENT:

Sliding Factor of Safety:
(Horizontal Plane)

$FS_{HorizSliding.UN2} = 1.22$

$FS_{HorizSliding.UN2.Check}$ = "Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !"

Sliding Factor of Safety:
(Inclined Plane)

$FS_{InclinedlSlidingUN2} = 2.84$ $\quad$ $FS_{InclinedSliding.check.UN2}$ = "OKAY "

Eccentricity:
(Inclined Plane)

$e_{UN2} = 0.64\,m$ $\quad$ $e_{check.UN2}$ = "Okay"

Bearing Pressure At Heel:
(Inclined Plane)

$\sigma_{heel.UN2} = 62 \cdot kPa$ $\quad$ $\sigma_{heel.UN2.check}$ = "Okay"

Bearing Pressure At Toe:
(Inclined Plane)

$\sigma_{toe.UN2} = 94 \cdot kPa$ $\quad$ $\sigma_{toe.UN2.1.check}$ = "Okay"

Flotation Factor of Safety
(horizontal plane)

$FS_{act.FUN2} = 1.59$ $\quad$ $FS_{check.FUN2}$ = "OKAY"

Overturning Resultant Ratio:
(horizontal plane)

$Ratio_{OT.UN2} = 0.45$ $\quad$ $Ratio_{OT.UN2.check}$ = "OKAY"

Eccentricity:
(horizontal plane)

$x_{OT.UN2} = -0.93\,m$ $\quad$ $x_{OT.check.UN2}$ = "OKAY"

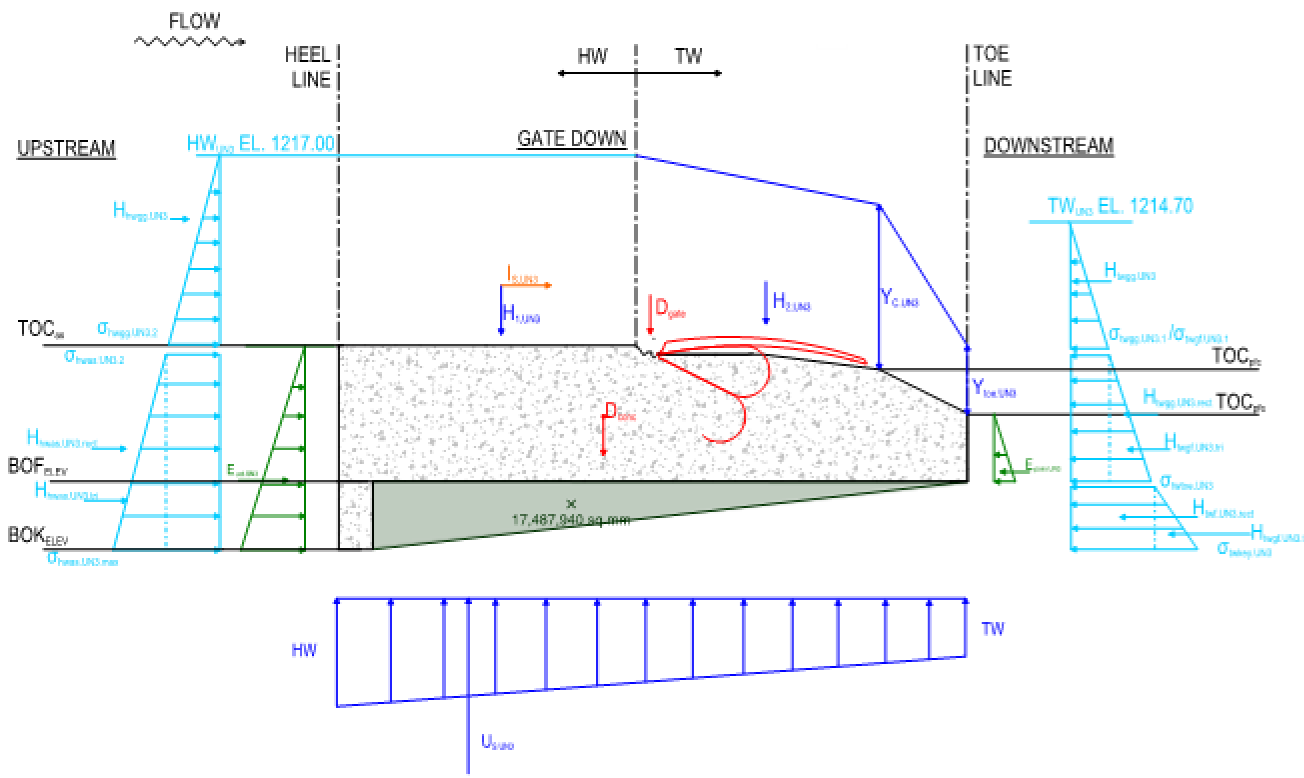
Bearing Pressure At Heel:
(horizontal plane)

$\sigma_{HeelUN2.OT} = 86 \cdot kPa$ $\quad$ $Bearing_{CheckheelUN2.OT}$ = "OKAY "

Bearing Pressure At Toe:
(horizontal plane)

$\sigma_{ToeUN2.OT} = 46 \cdot kPa$ $\quad$ $Bearing_{ChecktoeUN2.OT}$ = "OKAY "

UN3 DESIGN CASE



ACCEPTANCE PARAMETERS

Required Factor of Safety for Sliding: $FS_{req.UN3.sl} := 1.3$ (Without Cohesion) (Section 8.1, Design Criteria)

Resultant Within Middle Third of Base: $e \le \frac{L_b}{6} \wedge e \ge \frac{-L_b}{6}$

Allowable Rock Bearing Pressure: $\sigma_{allow.UN3} := 1470 \cdot \frac{kN}{m^2}$ (Section 5.2, Design Criteria)

INPUT PARAMETERS

Headwater Elevation: $HW_{UN3} := 1217.0m$ (Section 8.3, Design Criteria)

Tailwater Elevation: $TW_{UN3} := 1214.70m$ (Section 8.3, Design Criteria)

Bottom of Footing Elevation: $BOF_{elev} = 1206\,m$

Approach Slab Top of Concrete Elevation at Upstream Face: $TOC_{as} = 1210\,m$

Footing Top of Concrete Elevation at Stilling Basin: $TOC_{pfe} = 1208\,m$

Footing Top of Concrete Elevation at Center of Footing: $TOC_{pfc} = 1209.3\,m$

Gates are open when top of gate elevation is at 1210.00m

Top of Guard/Regulating Gate Elevation: $TOP_{rg.UN3} := 1210.00m$ $TOP_{gg.UN3} := 1210.00m$

Gates are closed/up when top of gate elevation is at 1215.0m

Bottom of Key Elevation: $BOK_{elev} = 1204\,m$

Crestwater Elevation: Dynamic Flow $EL_{C.UN3} := 1214.67m$

$$Y_{C.UN3} := \begin{cases} (EL_{C.UN3} - TOC_{pfc}) & \text{if } TOP_{gg.UN3} \le HW_{UN3} \\ (TW_{UN3} - TOC_{pfc}) & \text{if } TOP_{gg.UN3} > HW_{UN3} \end{cases} = 5.37 \cdot m$$

Toewater Elevation: $EL_{TOE.UN3} := 1210.89m$

$$Y_{TOE.UN3} := \begin{cases} (EL_{TOE.UN3} - TOC_{pfe}) & \text{if } TOP_{gg.UN3} \le HW_{UN3} \\ (TW_{UN3} - TOC_{pfe}) & \text{if } TOP_{gg.UN3} > HW_{UN3} \end{cases} = 2.89 \cdot m$$

LATERAL WATER LOADS

UN3 CASE

HEADWATER (DRIVING):

Headwater Depth on Gate: $D_{hwg.UN3} := HW_{UN3} - TOC_{as} = 7.00\,m$

Thickness of Approach Slab (Including Key): $T_{as} = 6\,m$

Headwater Depth at Heel (U/S face): $D_{hwas.UN3} := HW_{UN3} - BOK_{elev} = 13.00\,m$

Headwater Load Unit Width on Approach Slab: $W_{hwas.UN3} := W_b = 15.00\,m$

Headwater Unit Load At Top of Approach Slab:

$$H_{hwas.UN3.1} := \frac{-\left(\gamma_w \cdot D_{hwg.UN3}^{\;2}\right)}{2} \cdot W_{hwas.UN3} = -3605.18 \cdot kN$$

Headwater Unit Load At Bottom of Approach Key:

$$H_{hwas.UN3.2} := \frac{-\left(\gamma_w \cdot D_{hwas.UN3}^{\;2}\right)}{2} \cdot W_{hwas.UN3} = -12434.2 \cdot kN$$

Headwater Line Load At Top of Approach Slab:

$$\sigma_{hwas.UN3.1} := -\left(\gamma_w \cdot D_{hwg.UN3}\right) = -68.67 \cdot kPa$$

Headwater Line Load At Bottom of Approach Key:

$$\sigma_{hwas.UN3.2} := -\left(\gamma_w \cdot D_{hwas.UN3}\right) = -127.53 \cdot kPa$$

Triangular Distribution Unit Load on Approach Slab and Key:

$$H_{hwas.UN3.2.tri} := \left(\frac{\sigma_{hwas.UN3.2} - \sigma_{hwas.UN3.1}}{2}\right) \cdot \left(T_{as} \cdot W_{hwas.UN3}\right) = -2648.7 \cdot kN$$

Rectangular Distribution Unit Load on Approach Slab and Key:

$$H_{hwas.UN3.2.rect} := \sigma_{hwas.UN3.1} \cdot \left(T_{as} \cdot W_{hwas.UN3}\right) = -6180.3 \cdot kN$$

Total Horizontal Headwater Load on Approach Slab:

$$H_{hwas.UN3} := H_{hwas.UN3.2.tri} + H_{hwas.UN3.2.rect} = -8829 \cdot kN$$

Apply Total Footing Headwater Load at:

$$H_{hwas.UN3.loc} := \frac{\left[H_{hwas.UN3.2.rect} \cdot \frac{\left(T_{as}\right)}{2} + H_{hwas.UN3.2.tri} \cdot \frac{\left(T_{as}\right)}{3}\right]}{H_{hwas.UN3.2.tri} + H_{hwas.UN3.2.rect}} - d_{key} = 0.70\,m$$

Guard Gate Operating Condition:

Guard Gate Down/Open Condition: $A1_{UN3} := TOP_{gg.UN3} \le TOC_{as}$

Guard Crest Gate Up/Closed, with Top of Gate Higher than HW Elevation: $B1_{UN3} := TOP_{gg.UN3} \ge HW_{UN3} \wedge TOP_{gg.UN3} > TOC_{as}$

Guard Crest Gate Up/Closed, with Top of Gate Lower than HW Elevation: $C1_{UN3} := TOP_{gg.UN3} > TOC_{as} \wedge HW_{UN3} > TOP_{gg.UN3}$

Guard Crest Gate Height: $H_{gg.UN3} := TOP_{gg.UN3} - TOC_{as} = 0\,m$

Headwater Depth at Guard Crest Gate: $D_{hwgg.UN3} := HW_{UN3} - TOC_{as} = 7.00\,m$

Guard Crest Gate Width: $W_{hwgg.UN3} := 15.00m$

Lateral Headwater Pressure at Bottom of Guard Crest Gate:

$$\sigma_{hwgg.UN3.1} := \begin{cases} (0.0kPa) & \text{if } A1_{UN3} \\ -(\gamma_w \cdot D_{hwgg.UN3}) & \text{if } B1_{UN3} \\ -(\gamma_w \cdot D_{hwgg.UN3}) & \text{if } C1_{UN3} \end{cases} = 0.0\cdot kPa$$

Lateral Headwater Pressure at Top of Guard Crest Gate:
(Load at HW Elevation On Guard Crest Gate if HW is below TOG_{rg})

$$\sigma_{hwgg.UN3.2} := \begin{cases} (0.0kPa) & \text{if } A1_{UN3} \\ 0.0kPa & \text{if } B1_{UN3} \\ -\left[\gamma_w \cdot (HW_{UN3} - TOP_{gg.UN3})\right] & \text{if } C1_{UN3} \end{cases} = 0.0\cdot kPa$$

Average Pressure acting on Guard Crest Gate:

$$\sigma_{hwgg.UN3.avg} := \frac{(\sigma_{hwgg.UN3.1} + \sigma_{hwgg.UN3.2})}{2} = 0\cdot kPa$$

Total Area of Crest Gate:

$$A_{hwgg.UN3} := \begin{cases} D_{hwgg.UN3} \cdot W_{hwgg.UN3} & \text{if } A1_{UN3} \\ D_{hwgg.UN3} \cdot W_{hwgg.UN3} & \text{if } B1_{UN3} \\ H_{gg.UN3} \cdot W_{hwgg.UN3} & \text{if } C1_{UN3} \end{cases} = 105\cdot m^2$$

Total Horizontal Headwater Load on Guard Crest Gate: $H_{hwgg.UN3} := \sigma_{hwgg.UN3.avg} \cdot A_{hwgg.UN3} = 0.0\cdot kN$

Apply Total Guard Crest Gate Headwater Load at:

$$H_{hwgg.UN3.loc} := \begin{cases} (TOC_{as} - BOF_{elev}) & \text{if } A1_{UN3} \\ \left[\frac{(HW_{UN3} - TOC_{as})}{3} + (TOC_{as} - BOF_{elev})\right] & \text{if } B1_{UN3} \\ \left[\frac{\sigma_{hwgg.UN3.2} \cdot A_{hwgg.UN3} \cdot \frac{(H_{gg.UN3})}{2} + \frac{(\sigma_{hwgg.UN3.1} - \sigma_{hwgg.UN3.2})}{2} A_{hwgg.UN3} \cdot \frac{(H_{gg.UN3})}{3}}{\sigma_{hwgg.UN3.2} \cdot A_{hwgg.UN3} + \frac{(\sigma_{hwgg.UN3.1} - \sigma_{hwgg.UN3.2})}{2} \cdot A_{hwgg.UN3}} \ldots \right. \\ \left. + (TOC_{as} - BOF_{elev}) \right] & \text{if } C1_{UN3} \end{cases} = 4.0\cdot m$$

LATERAL TAILWATER (RESISTING) Applied to Downstream Side of Guard Crest Gate: UN3 CASE

Guard Gate Down/Open Condition:

$$A2_{UN3} := TOP_{gg.UN3} \le TOC_{as}$$

Guard Crest Gate Up/Closed, with Top of Gate Higher than TW Elevation:

$$B2_{UN3} := TOP_{gg.UN3} \ge TW_{UN3} \wedge TOP_{gg.UN3} > TOC_{as}$$

Guard Crest Gate Up/Closed, with Top of Gate Lower than TW Elevation:

$$C2_{UN3} := TOP_{gg.UN3} > TOC_{as} \wedge TW_{UN3} > TOP_{gg.UN3}$$

Tailwater Depth at Guard Crest Gate:

$$D_{twgg.UN3} := TW_{UN3} - TOC_{as} = 4.70\,m$$

Guard Crest Gate Width:

$$W_{twgg.UN3} := 15.00m$$

Lateral Water Load at Bottom of Guard Crest Gate:

$$\sigma_{twgg.UN3.1} := \begin{cases} (0.0kPa) & \text{if } A2_{UN3} \\ (\gamma_w \cdot D_{twgg.UN3}) & \text{if } B2_{UN3} \\ (\gamma_w \cdot D_{twgg.UN3}) & \text{if } C2_{UN3} \end{cases} = 0.0 \cdot kPa$$

Lateral Water Load at Top of Guard Crest Gate:
(Load at TW Elevation On Guard Crest Gate if TW is below TOG_{gg})

$$\sigma_{twgg.UN3.2} := \begin{cases} (0.0kPa) & \text{if } A2_{UN3} \\ 0.0kPa & \text{if } B2_{UN3} \\ \left[\gamma_w \cdot (TW_{UN3} - TOP_{gg.UN3})\right] & \text{if } C2_{UN3} \end{cases} = 0.0 \cdot kPa$$

Average Pressure acting on Guard Crest Gate:

$$\sigma_{twgg.UN3.avg} := \frac{(\sigma_{twgg.UN3.1} + \sigma_{twgg.UN3.2})}{2} = 0 \cdot kPa$$

Total Area water acting on Crest Gate:

$$A_{twgg.UN3} := \begin{cases} D_{twgg.UN3} \cdot W_{twgg.UN3} & \text{if } A2_{UN3} \\ D_{twgg.UN3} \cdot W_{twgg.UN3} & \text{if } B2_{UN3} \\ H_{gg.UN3} \cdot W_{twgg.UN3} & \text{if } C2_{UN3} \end{cases} = 70.5 \cdot m^2$$

Total Horizontal Tailwater Load on Guard Crest Gate:

$$H_{twgg.UN3} := \sigma_{twgg.UN3.avg} \cdot A_{twgg.UN3} = 0.0 \cdot kN$$

Apply Total Horiz. TW Load on Guard Gate at:

$$H_{twgg.UN3.loc} := \begin{cases} (TOC_{as} - BOF_{elev}) & \text{if } A2_{UN3} \\ \left[\frac{(TW_{UN3} - TOC_{as})}{3} + (TOC_{as} - BOF_{elev})\right] & \text{if } B2_{UN3} \\ \left[\frac{\sigma_{twgg.UN3.2} \cdot A_{twgg.UN3} \cdot \frac{(H_{gg.UN3})}{2} + \frac{(\sigma_{twgg.UN3.1} - \sigma_{twgg.UN3.2})}{2} \cdot A_{twgg.UN3} \cdot \frac{(H_{gg.UN3})}{3}}{\sigma_{twgg.UN3.2} \cdot A_{twgg.UN3} + \frac{(\sigma_{twgg.UN3.1} - \sigma_{twgg.UN3.2})}{2} \cdot A_{twgg.UN3}} \ldots \\ + (TOC_{as} - BOF_{elev}) \right] & \text{if } C2_{UN3} \end{cases} = 4.0 \cdot m$$

LATERAL WATER LOADS (continued)

UN3 CASE

TAILWATER (RESISTING) Applied to Concrete Structure:

Tailwater Depth At top of Gate Base Footing Elevation: $D_{twgf.UN3} := TW_{UN3} - TOC_{as} = 4.70\,m$

Water Depth at bottom of Gate Base Footing: $D_{twtoe.UN3} := TW_{UN3} - BOF_{elev} = 8.70\,m$

Footing Thickness at Toe $h_{toe} = 4\,m$

Unit Width of D/S face of crest for application of Tailwater Load: $W_{tw.UN3} := W_b = 15.00\,m$

Tailwater Pressure At Top of Gate Footing: $\sigma_{twgf.UN3} := \left(\gamma_w \cdot D_{twgf.UN3}\right) = 46.11 \cdot kPa$

Tailwater Line Load At Bottom of Gate Footing: $\sigma_{twtoe.UN3} := \left(\gamma_w \cdot D_{twtoe.UN3}\right) = 85.35 \cdot kPa$

Triangular Distribution Unit Load on Gate Footing Base:

$$H_{twgf.UN3.tri} := \left(\frac{\sigma_{twtoe.UN3} - \sigma_{twgf.UN3}}{2}\right) \cdot \left(h_{toe} \cdot W_{tw.UN3}\right) = 1177.2 \cdot kN$$

Rectangular Distribution Unit Load on Gate Footing Base:

$$H_{twgf.UN3.rect} := \sigma_{twgf.UN3} \cdot \left(h_{toe} \cdot W_{tw.UN3}\right) = 2766.42 \cdot kN$$

Tailwater Pressure At Bottom of Sliding Failure Plane:

$$\sigma_{twbk.UN3} := \left(HW_{UN3} - BOK_{elev}\right) \cdot \gamma_w = 127.53 \cdot kPa$$

Triangular Distribution Unit Load Below Footing:

$$H_{twbk.UN3.tri} := \frac{\left(\sigma_{twbk.UN3} - \sigma_{twtoe.UN3}\right)}{2} \cdot d_{key} \cdot W_{tw.UN3} = 632.74 \cdot kN$$

Rectangular Distribution Load Below Footing Base:

$$H_{twbk.UN3.rect} := \sigma_{twtoe.UN3} \cdot d_{key} \cdot W_{tw.UN3} = 2560.41 \cdot kN$$

Total Horizontal Tailwater Load on Gate Footing (including key):

$$H_{twgk.UN3} := H_{twgf.UN3.tri} + H_{twgf.UN3.rect} + H_{twbk.UN3.tri} + H_{twbk.UN3.rect} = 7136.78 \cdot kN$$

Apply Total Gate Footing Tailwater Load at:

$$H_{twgk.UN3.loc} := \frac{\left[H_{twgf.UN3.rect} \cdot \frac{\left(h_{toe}\right)}{2} + H_{twgf.UN3.tri} \cdot \frac{\left(h_{toe}\right)}{3} + H_{twbk.UN3.tri} \cdot \left(-d_{key} \cdot \frac{2}{3}\right) + H_{twbk.UN3.rect} \cdot \left(\frac{-d_{key}}{2}\right)\right]}{H_{twgf.UN3.tri} + H_{twgf.UN3.rect} + H_{twbk.UN3.tri} + H_{twbk.UN3.rect}} = 0.52\,m$$

SUMMATION OF LATERAL WATER LOADS:

$$\Sigma H_{Water.UN3} := H_{hwas.UN3} + H_{hwgg.UN3} + H_{twgk.UN3} + H_{twgg.UN3} = -1692.22 \cdot kN$$

$$\Sigma M_{Hwater.UN3} := H_{hwas.UN3} \cdot H_{hwas.UN3.loc} + H_{hwgg.UN3} \cdot H_{hwgg.UN3.loc} \cdots + H_{twgk.UN3} \cdot H_{twgk.UN3.loc} + H_{twgg.UN3} \cdot H_{twgg.UN3.loc} = -2481.93 \cdot kN \cdot m$$

VERTICAL WATER LOADS

UN3 CASE

HEADWATER:

Water Depth on top of Approach Slab: $d_{hw.UN3} := HW_{UN3} - TOC_{as} = 7.00\,m$

Length of Approach Slab: $L_{as} = 8.75\,m$

Width of Approach Slab: $w_{as} = 15.00\,m$

Vertical Water Weight (H1) on Approach Slab: $H_{1.UN3} := \left(w_{as} \cdot d_{hw.UN3} \cdot L_{as}\right) \cdot \gamma_w = 9012.9 \cdot kN$

Moment Arm for Application of Water Weight (H1) from toe: $H_{1.UN3.loc} := L_b - \dfrac{L_{as}}{2} = 14.13\,m$

TAILWATER:

Trapezoid Volume Above Gate Footing from Approach Slab to Crest: $V_{asc.UN3} := \left(L_{gf} - L_{gfc}\right) W_b \dfrac{d_{hw.UN3} + Y_{C.UN3}}{2} = 663.34 \cdot m^3$

Trapezoid Volume Above Gate Footing Crest to End of Gate Footing: $V_{gfc.UN3} := \left(L_{gfc} \cdot W_b\right) \dfrac{Y_{C.UN3} + Y_{TOE.UN3}}{2} = 161.07 \cdot m^3$

Load Above Gate Footing from Approach Slab to Crest: $H_{2.UN3.asc} := V_{asc.UN3} \cdot \gamma_w = 6507.38 \cdot kN$

Load Acting Above Footing Crest from Toe: $H_{2.UN3.asc.loc} := \dfrac{\left(L_{gf} - L_{gfc}\right) \cdot \left(2 \cdot d_{hw.UN3} + Y_{C.UN3}\right)}{3 \cdot \left(d_{hw.UN3} + Y_{C.UN3}\right)} + L_{gfc} = 6.33\,m$

Load Above Gate Footing from Crest to End: $H_{2.UN3.gfc} := V_{gfc.UN3} \cdot \gamma_w = 1580.1 \cdot kN$

Load Acting Above Gate Footing from Crest to End: $H_{2.UN3.gfc.loc} := \dfrac{\left(L_{gfc}\right) \cdot \left(2 \cdot Y_{C.UN3} + Y_{TOE.UN3}\right)}{3 \cdot \left(Y_{C.UN3} + Y_{TOE.UN3}\right)} = 1.43\,m$

Vertical Water Weight (H2) on Gate Footing: $H_{2.UN3} := H_{2.UN3.asc} + H_{2.UN3.gfc} = 8087.47 \cdot kN$

Moment Arm for Application of Water Weight (H2) from toe: $H_{2.UN3.loc} := \dfrac{H_{2.UN3.asc} \cdot H_{2.UN3.asc.loc} + H_{2.UN3.gfc} \cdot H_{2.UN3.gfc.loc}}{H_{2.UN3}} = 5.37\,m$

UPLIFT AT INCLINE SLIDING PLANE

UN3 CASE

Uplift pressure at U/S Face (heel): $U_{HW.UN3} := D_{hwas.UN3} \cdot \gamma_w = 127.5 \cdot \frac{kN}{m^2}$

Uplift pressure at D/S Face Stilling Basin: $U_{TW.UN3} := \left(D_{twtoe.UN3}\right) \cdot \gamma_w = 85.35 \cdot \frac{kN}{m^2}$

Length from U/S of Gate Structure to D/S of Stilling Basin: $L_{overall} = 18.50\,m$

Difference between Uplift pressure at HW and TW: $U_{diff.UN3} := U_{HW.UN3} - U_{TW.UN3} = 42.18 \cdot \frac{kN}{m^2}$

Slope of difference between between Uplift pressure at HW and TW: $U_{slope.UN3} := \frac{U_{diff.UN3}}{L_{overall}} = 2.28 \cdot \frac{kN}{m^2 \cdot m}$

Tailwater Pressure at toe of Gate Structure: $U_{press.toe.gs.UN3} := U_{TW.UN3} + \left(L_{overall} - L_b\right) \cdot U_{slope.UN3} = 85.35 \cdot \frac{kN}{m^2}$

Uniform uplift force UA Under Gate Structure due to TW (rectangle): $U_{A.UN3} := U_{press.toe.gs.UN3} \cdot L_b \cdot W_b \cdot -1 = -23683.79 \cdot kN$

Moment Arm from Toe of Gate Structure for Uplift UA: $L_{A.UN3} := \left(\frac{L_b}{2}\right) = 9.25\,m$

Linearly Decreasing Uplift Force UN3B Under Gate Structure due to HW-TW Differential (triangle): $U_{B.UN3} := \frac{1}{2} \cdot \left(U_{HW.UN3} - U_{press.toe.gs.UN3}\right) \cdot L_b \cdot W_b \cdot -1 = -5852.89 \cdot kN$

Moment Arm from Toe of Gate Structure for Uplift UB: $L_{B.UN3} := \frac{2}{3} \cdot L_b = 12.33\,m$

Total Resultant Uplift force: $U_{UN3} := U_{A.UN3} + U_{B.UN3} = -29536.68 \cdot kN$

Resultant Location from Toe: $U_{UN3.loc} := \frac{\left(U_{A.UN3} \cdot L_{A.UN3} + U_{B.UN3} \cdot L_{B.UN3}\right)}{\left(U_{A.UN3} + U_{B.UN3}\right)} = 9.86\,m$

$\Sigma V_{water.UN3} := H_{1.UN3} + H_{2.UN3} + U_{UN3} = -12436.27 \cdot kN$

$\Sigma M_{Vwater.UN3} := H_{1.UN3} \cdot H_{1.UN3.loc} + H_{2.UN3} \cdot H_{2.UN3.loc} + U_{UN3} \cdot U_{UN3.loc} = -120488.41 \cdot kN \cdot m$

SOIL LOADS

UN3 CASE

Equivalent Fluid Pressure (EFP):

At rest lateral pressure coefficient: $K_{o.UN3} := 1 - \sin(\phi_{backfill}) = 0.658$ (Section 5.3, Design Criteria)

Headwater Pier Footing Unit Width: $W_{hwas.UN3} = 15.00\,m$

Tailwater Pier Footing Unit Width: $W_{tw.UN3} = 15.00\,m$

Pier Footing Thickness at Heel: $t_{hf.UN3} := TOC_{as} - BOK_{elev} = 6.00\,m$

Fixed Crest Footing Thickness at Toe: $t_{tf.UN3} := TOC_{pfe} - BOF_{elev} = 2.00\,m$

Lateral Driving Force (Headwater Side - at rest condition)

At-Rest Soil Load:

$$E_{act.UN3} := \frac{\left(K_{o.UN3} \cdot t_{hf.UN3}^{\ 2}\right)}{2} \cdot (\gamma_r - \gamma_w) \cdot W_{hwas.UN3} \cdot -1 = -2165.61 \cdot kN$$

Acting at:

$$E_{act.UN3.loc} := \frac{t_{hf.UN3}}{3} = 2.00\,m$$

Lateral Resisting Force (Tailwater Side - at rest condition)

At-rest Soil Load:

$$E_{pass.UN3} := \frac{\left(K_{o.UN3} \cdot t_{tf.UN3}^{\ 2}\right)}{2} \cdot (\gamma_r - \gamma_w) \cdot W_{tw.UN3} = 240.62 \cdot kN$$

Acting at:

$$E_{pass.UN3.loc} := \frac{t_{tf.UN3}}{3} = 0.67\,m$$

$$\Sigma H_{soil.UN3} := E_{act.UN3} + E_{pass.UN3} = -1924.99 \cdot kN$$

$$\Sigma M_{soil.UN3} := E_{act.UN3} \cdot E_{act.UN3.loc} + E_{pass.UN3} \cdot E_{pass.UN3.loc} = -4170.8 \cdot kN \cdot m$$

ICE / IMPACT LOADS (ASSUME NO ICE LOADING ON TAILWATER SIDE)

ICE & IMPACT LOADS DO NOT APPLY FOR THIS LOAD CASE

Static Ice load on Gates:

$$I_{G.UN3} := \begin{cases} 00 \dfrac{kN}{m} & \text{if } TOP_{gg.UN3} \le TOC_{as} \\ 0 \dfrac{kN}{m} & \text{if } TOP_{gg.UN3} > TOC_{as} \end{cases} = 0 \cdot \frac{kN}{m}$$

(Section 7.7, Design Criteria)

Ice Loading Unit Width on Guard Gate: $W_{gg.UN3} := 15.00m$ (Input value for load case)

Total Ice Load on Structure: $I_{UN3} := -\left(I_{G.UN3} \cdot W_{gg.UN3}\right) = 0 \cdot kN$

Apply Ice load at: $I_{UN3.loc} := \left(TOP_{gg.UN3} - BOF_{elev} - 0.30m\right) = 3.70\,m$

$$\Sigma H_{I.UN3} := I_{UN3} = 0 \cdot kN$$

$$\Sigma M_{I.UN3} := I_{UN3} \cdot I_{UN3.loc} = 0 \cdot kN \cdot m$$

SEISMIC LOAD (NOT APPLICABLE FOR THIS LOAD CASE)

UN3 CASE

SUMMARY OF LOADS

	Loads	Moment Arm
Dead load of Concrete Structure:	$D_{conc} = 24618.6 \cdot kN$	$X_{conc.loc} = 10.06\,m$
Obermyer Gate Weight:	$D_{Gate} = 210.0 \cdot kN$	$X_{gate} = 6.60\,m$
HW Lateral Load on Approach Slab:	$H_{hwas.UN3} = -8829.0 \cdot kN$	$H_{hwas.UN3.loc} = 0.70\,m$
HW Lateral Load on Guard Gate:	$H_{hwgg.UN3} = 0.0 \cdot kN$	$H_{hwgg.UN3.loc} = 4.00\,m$
TW Lateral Load on Gate Footing (Including Key - Sliding Check Loads):	$H_{twgk.UN3} = 7136.78 \cdot kN$	$H_{twgk.UN3.loc} = 0.52\,m$
TW Lateral Load on Guard Gate:	$H_{twgg.UN3} = 0.0 \cdot kN$	$H_{twgg.UN3.loc} = 4.00\,m$
Vertical HW Load on Approach Slab:	$H_{1.UN3} = 9012.9 \cdot kN$	$H_{1.UN3.loc} = 14.13\,m$
Vertical TW Load on Pier Footing (crest):	$H_{2.UN3} = 8087.5 \cdot kN$	$H_{2.UN3.loc} = 5.37\,m$
Uplift:	$U_{UN3} = -29536.7 \cdot kN$	$U_{UN3.loc} = 9.86\,m$
Lateral Soil Load (driving):	$E_{act.UN3} = -2165.6 \cdot kN$	$E_{act.UN3.loc} = 2.00\,m$
Lateral Soil Load (resisting):	$E_{pass.UN3} = 240.62 \cdot kN$	$E_{pass.UN3.loc} = 0.67\,m$
Ice / Impact Load:	$I_{UN3} = 0.0 \cdot kN$	$I_{UN3.loc} = 3.70\,m$

STABILITY ASSESSMENT (SLIDNG, BEARING, FLOTATION AND OVERTURNING):

UN3 CASE

CHECK SLIDING ALONG HORIZONTAL PLANE THRU TOE,
IGNORING BEDROCK MOBILIZED BY STRUCTURAL HEEL KEY, OR VOID BEHIND KEY

Sum of Vertical Forces:

$\Sigma V_{UN3} := \Sigma V_{DL} + \Sigma V_{water.UN3} = 12392.3 \cdot kN$

Sum of Horizontal Forces:

$\Sigma H_{UN3} := \Sigma H_{Water.UN3} + \Sigma H_{soil.UN3} + \Sigma H_{I.UN3} = -3617.21 \cdot kN$

Sliding Factor of Safety:

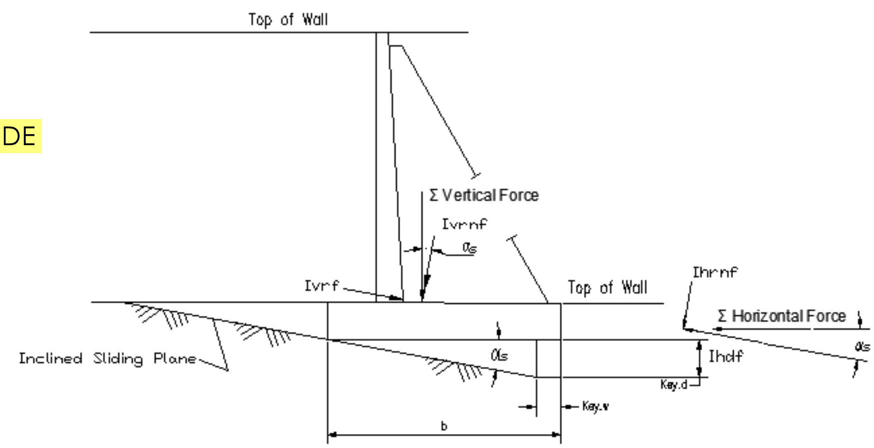
$$FS_{HorizSliding.UN3} := \frac{\tan_{\phi} \cdot \Sigma V_{UN3}}{\left|\Sigma H_{UN3}\right|} = 1.67$$

o Key or Void Behinc $FS_{HorizSliding.UN3.Check} :=$ | "OKAY" if $FS_{HorizSliding.UN3} \geq FS_{req.UN3.sl}$ | = "OKAY"
"Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !" otherwise

CHECK SLIDING ALONG INCLINED SLIDING PLANE FROM HEEL KEY TO TOE,
WITH BEDROCK MASS MOBILIZED BY REINFOCREDE CONCRETE KEY)

RESISTING SIDE

DRIVING SIDE



TOE

HEEL

Ivrf=Inclined Resisting Force
Ivrnf=Inclined Resisting Normal Force
Ihrnf=Inclined Resisting Normal Force
Ihdf=Inclined Driving Force

$\alpha s = 0.11$

as degrees= $\alpha s \cdot \left(\frac{180}{\pi}\right) = 6.52$

$\Sigma V_{UN3} = 12392.33 \cdot kN$

$V_{rs} = 5775 \cdot kN$

Resolve $\Sigma Vert_{UN3}$ & $\Sigma Horiz_{UN3}$

$\Sigma V_{InclinedUN3} := \cos(\alpha s) \cdot \left(\Sigma V_{UN3} + V_{rs}\right) + \sin(\alpha s) \cdot \left|\Sigma H_{UN3}\right| = 18460.6 \cdot kN$

$\Sigma H_{InclinedUN3} := \cos(\alpha s) \cdot \left|\Sigma H_{UN3}\right| - \sin(\alpha s) \cdot \left(\Sigma V_{UN3} + V_{rs}\right) = 1531.0 \cdot kN$

(With properly engineered reinforced concrete Key, horizontal sliding plane thru Toe is protected, critical sliding plane is relocated to the INCLINED SLIDING PLANE FROM HEEL KEY To TOE, Bedrock Mass above this examined plane is mobilized by reinforced concrete key and combined into Structural Wedge.)

Inclined Sliding Plane Length

$L_{incline} = 18.61\ m$

Safety Factor for Sliding Inclined Failure Plane

$$FS_{InclinedISlidingUN3} := \frac{\Sigma V_{InclinedUN3} \cdot \tan\left(\phi_{rock} \cdot \frac{\pi}{180}\right)}{\left|\Sigma H_{InclinedUN3}\right|} = 5.88$$

$FS_{InclinedSliding.check.UN3} :=$ | "OKAY " if $FS_{InclinedISlidingUN3} > FS_{req.UN3.sl}$ | = "OKAY "
"Revise Structure"" otherwise

$FS_{InclinedSliding.check.UN3} =$ "OKAY "

OVERTURNING STABILITY CHECK:

UN3 CASE

CHECK ECCENTRICITY

Sum of the moments:

$$\Sigma M_{UN3} := \Sigma M_{DL} + \Sigma M_{Hwater.UN3} + \Sigma M_{Vwater.UN3} + \Sigma M_{I.UN3} + \Sigma M_{soil.UN3} + \Sigma M_{soil} = 189178 \cdot kN \cdot m$$

Eccentricity:

$$e_{UN3} := \left(\frac{L_{incline}}{2}\right) - \frac{\Sigma M_{UN3}}{\Sigma V_{InclinedUN3}} = -0.94\,m$$

Eccentricity Check:

$$e_{check.UN3} := \begin{cases} \text{"Okay"} & \text{if } \left|e_{UN3}\right| \le Kern \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$$e_{check.UN3} = \text{"Okay"}$$

Foundation Bearing Checks:

Incline Plane Area:

$$A_{b.incline} = 279.12\,m^2$$

Incline Plane Section Modulus:

$$S_{b.incline} = 865.63 \cdot m^3$$

Bearing Pressure at Heel:

$$\sigma_{heel.UN3} := \frac{\Sigma V_{InclinedUN3}}{A_{b.incline}} - \frac{\Sigma V_{InclinedUN3} \cdot e_{UN3}}{S_{b.incline}} = 86.3 \cdot \frac{kN}{m^2}$$

$$\sigma_{heel.UN3.check} := \left(\begin{cases} \text{"Okay"} & \text{if } \sigma_{heel.UN3} \le \sigma_{allow.UN3} \\ \text{"Revise Structure"} & \text{if } \sigma_{heel.UN3} < 0\,\frac{kN}{m^2} \end{cases}\right)$$

$$\sigma_{heel.UN3.check} = \text{"Okay"}$$

Bearing Pressure at Toe:

$$\sigma_{toe.UN3} := \frac{\Sigma V_{InclinedUN3}}{A_{b.incline}} + \frac{\Sigma V_{InclinedUN3} \cdot e_{UN3}}{S_{b.incline}} = 46.0 \cdot \frac{kN}{m^2}$$

$$\sigma_{toe.UN3.1.check} := \begin{cases} \text{"Okay"} & \text{if } \sigma_{toe.UN3} \le \sigma_{allow.UN3} \\ \text{"Revise Structure"} & \text{if } \sigma_{toe.UN3} < 0\,\frac{kN}{m^2} \end{cases}$$

$$\sigma_{toe.UN3.1.check} = \text{"Okay"}$$

FLOATATION ANALYSIS:

ACCEPTANCE PARAMETERS

Required Factor of Safety: $FS_{req.FUN3} := 1.3$

VERTICAL LOADS RESISTING:

Dead Load: $\Sigma V_{DL} = 24828.6 \cdot kN$

Water Weight H1+H2: $\Sigma V_{H.FUN3} := H_{1.UN3} + H_{2.UN3} = 17100.41 \cdot kN$

Summation Vertical Resisting: $\Sigma V_{FUN3} := \Sigma V_{DL} + \Sigma V_{H.FUN3} = 41929.0 \cdot kN$

VERTICAL LOADS UPLIFT:

Uplift: $U_{UN3} = -29536.68 \cdot kN$

Factor of Safety Floatation:

$$FS_{act.FUN3} := \frac{\Sigma V_{FUN3}}{\left|U_{UN3}\right|} = 1.42$$

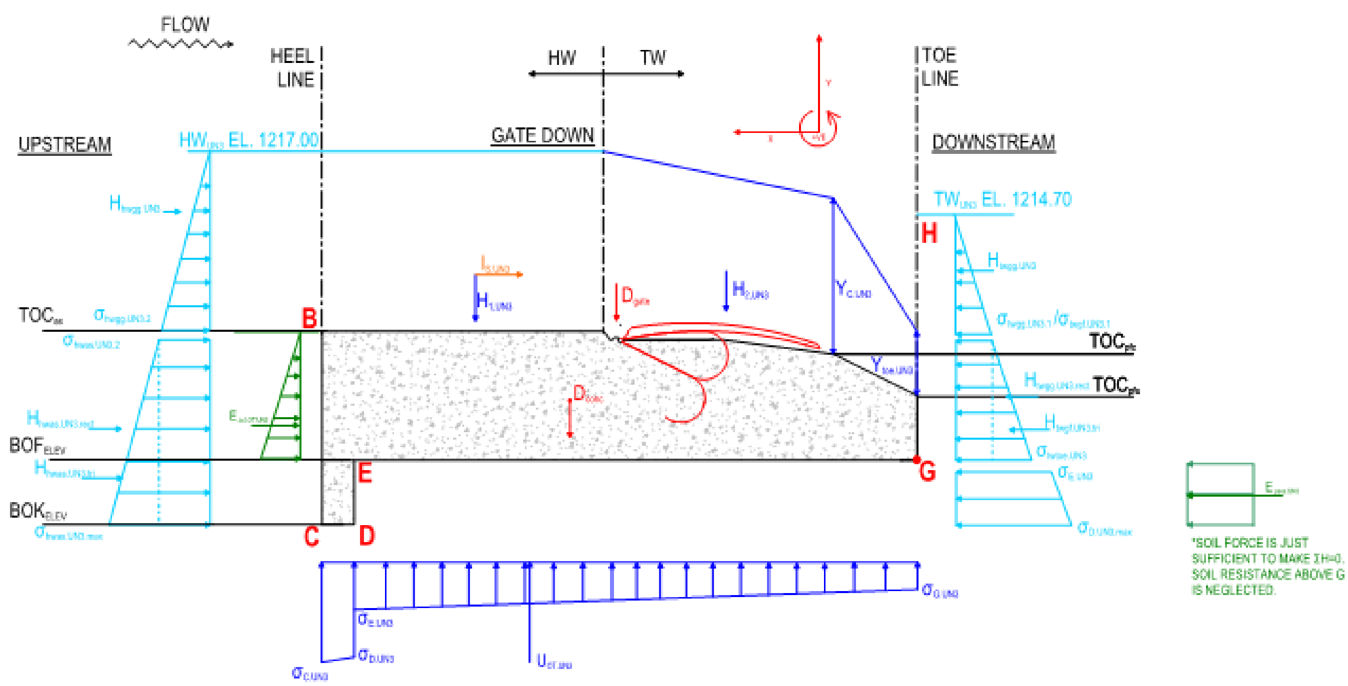
$$FS_{check.FUN3} := \begin{cases} \text{"OKAY"} & \text{if } FS_{act.FUN3} \ge FS_{req.FUN3} \\ \text{"ANCHORS REQUIRED"} & \text{if } FS_{act.FUN3} < FS_{req.FUN3} \end{cases} = \text{"OKAY"}$$

MONOLITH OVERTURNING STABILITY ANALYSIS

UN3 CASE

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.
Assumptions are made in order to compute overturning stability of indetermine forces on monolith with key;
(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.
(b) The horizontal resisting force acting on the key, P.key, is that required for static equilibrium
(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1 $Ratio_{OT.UN3.min} := 0.33$



Uplift Loads for Overturning Stability Analysis

Line of Creep:

Change in Water Head: $\Delta_{h.UN3} := HW_{UN3} - TW_{UN3} = 2.3\,m$

Length from Point C to Point G: $L_{CG} = 18.61\,m$

Length from Various Points to Points: $L_{CD} = 1\,m$ $L_{DE} = 2\,m$ $L_{EG} = 17.5\,m$

$L_{GH.UN3} := TW_{UN3} - BOF_{elev} = 8.7\,m$

Length from Point C, D, E to G: $L_{CDEG} = 20.5\,m$ $L_{CDE} = 3\,m$

Water Pressure at Point C: $\sigma_{C.UN3} := \sigma_{hwas.UN3.2} = -127.53 \cdot kPa$

Water Pressure at Point G: $\sigma_{G.UN3} := \sigma_{twtoe.UN3} \cdot -1 = -85.35 \cdot kPa$

Water Pressure at Point D:
$$\sigma_{D.UN3} := -\gamma_w \cdot \left[\left(HW_{UN3} - BOK_{elev} \right) - \frac{\Delta_{h.UN3} \cdot L_{CD}}{L_{CDEG}} \right] = -126.43 \cdot kPa$$

Water Pressure at Point E:
$$\sigma_{E.UN3} := -\gamma_w \cdot \left[\left(HW_{UN3} - BOF_{elev} \right) - \frac{\Delta_{h.UN3} \cdot L_{CDE}}{L_{CDEG}} \right] = -104.61 \cdot kPa$$

Uplift for Overturning Analysis on Bottom of Key:
$$U_{OT.UN3.key} := \frac{\sigma_{C.UN3} + \sigma_{D.UN3}}{2} \cdot L_{CD} \cdot W_b = -1904.7 \cdot kN$$

Acting at:
$$U_{OT.UN3.key.loc} := \frac{L_{CD} \cdot \left(2 \cdot \sigma_{C.UN3} + \sigma_{D.UN3} \right)}{3 \left(\sigma_{C.UN3} + \sigma_{D.UN3} \right)} + L_{EG} = 18\,m$$

UN3 CASE

Uplift for Overturning Analysis on Bottom of Footing: $U_{OT.UN3.ftg} := \frac{\sigma_{E.UN3} + \sigma_{G.UN3}}{2} \cdot L_{EG} \cdot W_b = -24931.61 \cdot kN$

Acting at: $U_{OT.UN3.ftg.loc} := \frac{L_{EG} \cdot \left(\sigma_{G.UN3} + 2 \cdot \sigma_{E.UN3}\right)}{3\left(\sigma_{G.UN3} + \sigma_{E.UN3}\right)} = 9.05\,m$

Uplift Load for Overturning Analysis: $U_{OT.UN3} := U_{OT.UN3.key} + U_{OT.UN3.ftg} = -26836.3 \cdot kN$

Uplift Load Acting from Toe: $U_{OT.UN3.loc} := \frac{U_{OT.UN3.key} \cdot U_{OT.UN3.key.loc} + U_{OT.UN3.ftg} \cdot U_{OT.UN3.ftg.loc}}{U_{OT.UN3}} = 9.68\,m$

<u>All Vertical Loads Applicable to Overturning Stability Analysis</u>

Total Concrete Dead Loads:	$D_{conc} = 24618.6 \cdot kN$	at:	$X_{conc.loc} = 10.06\,m$
Dead Load of Gate:	$D_{Gate} = 210.0 \cdot kN$		$X_{gate} = 6.60\,m$
Water Weight (HW) on Apron Slab:	$H_{1.UN3} = 9012.9 \cdot kN$		$H_{1.UN3.loc} = 14.13\,m$
Water Weight (TW) on Gate Footing:	$H_{2.UN3} = 8087.5 \cdot kN$		$H_{2.UN3.loc} = 5.37\,m$
Uplift Load for Overturning Analysis:	$U_{OT.UN3} = -26836.3 \cdot kN$		$U_{OT.UN3.loc} = 9.68 \cdot m$

Sum of All Overturning Analysis Vertical Load:

$$\Sigma V_{UN3.OT} := D_{conc} + D_{Gate} + H_{1.UN3} + H_{2.UN3} + U_{OT.UN3} = 15092.71 \cdot kN$$

Sum of All Overturning Analysis Vertical Load Moments:

$$\Sigma M_{V.UN3.OT} := D_{conc} \cdot X_{conc.loc} + D_{Gate} \cdot X_{gate} + H_{1.UN3} \cdot H_{1.UN3.loc} + H_{2.UN3} \cdot H_{2.UN3.loc} + U_{OT.UN3} \cdot U_{OT.UN3.loc} = 159905.29 \cdot kN \cdot m$$

<u>Lateral Tailwater Loads for Overturning Stability Analysis</u>

TW Lateral Load on Gate Footing (No Key - Overturning Values Adjusted): $H_{twgf.UN3} := H_{twgf.UN3.tri} + H_{twgf.UN3.rect} = 3943.62 \cdot kN$

Acting at: $H_{twgf.UN3.loc} := \frac{\frac{h_{toe}}{3} \cdot H_{twgf.UN3.tri} + \frac{h_{toe}}{2} \cdot H_{twgf.UN3.rect}}{H_{twgf.UN3}} = 1.8\,m$

Horizontal Tailwater Pressure Top of Key (Overturning Analysis): $\sigma_{twtk.OT.UN3} := \sigma_{E.UN3} \cdot -1 = 104.61 \cdot kPa$

Horizontal Tailwater Pressure Bottom of Key (Overturning Analysis): $\sigma_{twbk.OT.UN3} := \sigma_{D.UN3} \cdot -1 = 126.43 \cdot kPa$

Triangular Distribution Unit Load Acting at Key: $H_{twbk.OT.UN3.tri} := \frac{\left(\sigma_{twbk.OT.UN3} - \sigma_{twtk.OT.UN3}\right)}{2} \cdot d_{key} \cdot W_{tw.UN3} = 327.32 \cdot kN$

Triangular Distribution Unit Load Acting at Key: $H_{twbk.OT.UN3.rect} := \sigma_{twtk.OT.UN3} \cdot d_{key} \cdot W_{tw.UN3} = 3138.24 \cdot kN$

Total Horizontal Tailwater Load on Key (Overturning Values Adjusted): $H_{twkey.OT.UN3} := H_{twbk.OT.UN3.tri} + H_{twbk.OT.UN3.rect} = 3465.56 \cdot kN$

Acting at: $H_{twkey.OT.UN3.loc} := \frac{H_{twbk.OT.UN3.tri} \cdot \frac{-2 \cdot d_{key}}{3} + H_{twbk.OT.UN3.rect} \cdot \frac{-d_{key}}{2}}{H_{twkey.OT.UN3}} = -1.03 \cdot m$

UN3 CASE

Lateral Driving Earth Loads for Overturning Stability Analysis (at rest condition)

Depth of Driving Soil Loads (to top of key): $h_{E.OT.UN3} := TOC_{as} - BOF_{elev} = 4\,m$

At-Rest Soil Load: $E_{act.OT.UN3} := \frac{\left(K_{o.UN3} \cdot h_{E.OT.UN3}{}^{2}\right)}{2} \cdot \left(\gamma_r - \gamma_w\right) \cdot W_{hwas.UN3} \cdot -1 = -962.49 \cdot kN$

At Rest- Soil Load Acting from Toe: $E_{act.OT.UN3.loc} := \frac{h_{E.OT.UN3}}{3} = 1.33\,m$

All Lateral Loads Applicable to Overturning Stability Analysis

HW Lateral Load on Approach Slab:	$H_{hwas.UN3} = -8829.0 \cdot kN$	$H_{hwas.UN3.loc} = 0.70\,m$
HW Lateral Load on Guard Gate:	$H_{hwgg.UN3} = 0.0 \cdot kN$	$H_{hwgg.UN3.loc} = 4.00\,m$
TW Lateral Load on Guard Gate:	$H_{twgg.UN3} = 0.0 \cdot kN$	$H_{twgg.UN3.loc} = 4.00\,m$
TW Lateral Load on Gate Footing (No Key - Overturning Values Adjusted):	$H_{twgf.UN3} = 3943.62 \cdot kN$	$H_{twgf.UN3.loc} = 1.8\,m$
TW Lateral Load on Key:	$H_{twkey.OT.UN3} = 3465.56 \cdot kN$	$H_{twkey.OT.UN3.loc} = -1.03\,m$
Ice / Impact Load:	$I_{UN3} = 0.0 \cdot kN$	$I_{UN3.loc} = 3.70\,m$
Lateral Soil Load (driving):	$E_{act.OT.UN3} = -962.5 \cdot kN$	$E_{act.OT.UN3.loc} = 1.33\,m$

Resisting Lateral Soil Load as required to produce horizontal equilibrium:

$$E_{pas.OT.UN3} := -\left(H_{hwas.UN3} + H_{hwgg.UN3} + H_{twgg.UN3} + H_{twgf.UN3} + H_{twkey.OT.UN3} + I_{UN3} + E_{act.OT.UN3}\right) = 2382.31 \cdot kN$$

Acting at:

$$E_{pas.OT.UN3.loc} := -1 \cdot \frac{d_{key}}{2} = -1\,m$$

Sum of All Overturning Analysis Horizontal Load (ΣH=0):

$$\Sigma H_{UN3.OT} := H_{hwas.UN3} + H_{hwgg.UN3} + H_{twgg.UN3} + H_{twgf.UN3} + H_{twkey.OT.UN3} + I_{UN3} + E_{act.OT.UN3} + E_{pas.OT.UN3} = 0 \cdot kN$$

Sum of All Overturning Analysis Horizontal Load Moments:

$$\Sigma M_{H.UN3.OT} := H_{hwas.UN3} \cdot H_{hwas.UN3.loc} + H_{hwgg.UN3} \cdot H_{hwgg.UN3.loc} + H_{twgg.UN3} \cdot H_{twgg.UN3.loc} \cdots + H_{twgf.UN3} \cdot H_{twgf.UN3.loc} + H_{twkey.OT.UN3} \cdot H_{twkey.OT.UN3.loc} + I_{UN3} \cdot I_{UN3.loc} \cdots + E_{act.OT.UN3} \cdot E_{act.OT.UN3.loc} + E_{pas.OT.UN3} \cdot E_{pas.OT.UN3.loc} = -6318.16 \cdot kN \cdot m$$

Overturning Stability Analysis

$\Sigma M_{UN3.OT} := \Sigma M_{V.UN3.OT} + \Sigma M_{H.UN3.OT} = 153587.12 \cdot kN \cdot m$

$X_{R.UN3} := \frac{\Sigma M_{UN3.OT}}{\Sigma V_{UN3.OT}} = 10.18\,m$

$x_{OT.UN3} := X_{R.UN3} - \frac{L_b}{2} = 0.93\,m$

Overturning Resultant Ratio

$$Ratio_{OT.UN3} := \frac{X_{R.UN3}}{L_b} = 0.55$$

$$Ratio_{OT.UN3.check} := \begin{cases} \text{"OKAY"} & \text{if } Ratio_{OT.UN3} \geq Ratio_{OT.UN3.min} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

$$x_{OT.check.UN3} := \begin{cases} \text{"OKAY"} & \text{if } \left|x_{OT.UN3}\right| \leq Kern \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

UN3 CASE

CHECK FOUNDATION BEARING CAPACITY (HORIZONTAL PLANE):

Bearing Pressure Under Toe:

$$\sigma_{ToeUN3.OT} := \frac{\Sigma V_{UN3.OT}}{L_b \cdot W_b} + \frac{\left(\Sigma V_{UN3.OT} \cdot x_{OT.UN3}\right)}{S_b} = 70.7 \cdot kPa$$

$$Bearing_{ChecktoeUN3.OT} := \begin{vmatrix} \text{"OKAY "} & \text{if } \sigma_{ToeUN3.OT} < \sigma_{allow.UN3} \\ \text{"NG""} & \text{otherwise} \end{vmatrix} = \text{"OKAY "}$$

Bearing Pressure Under Heel:

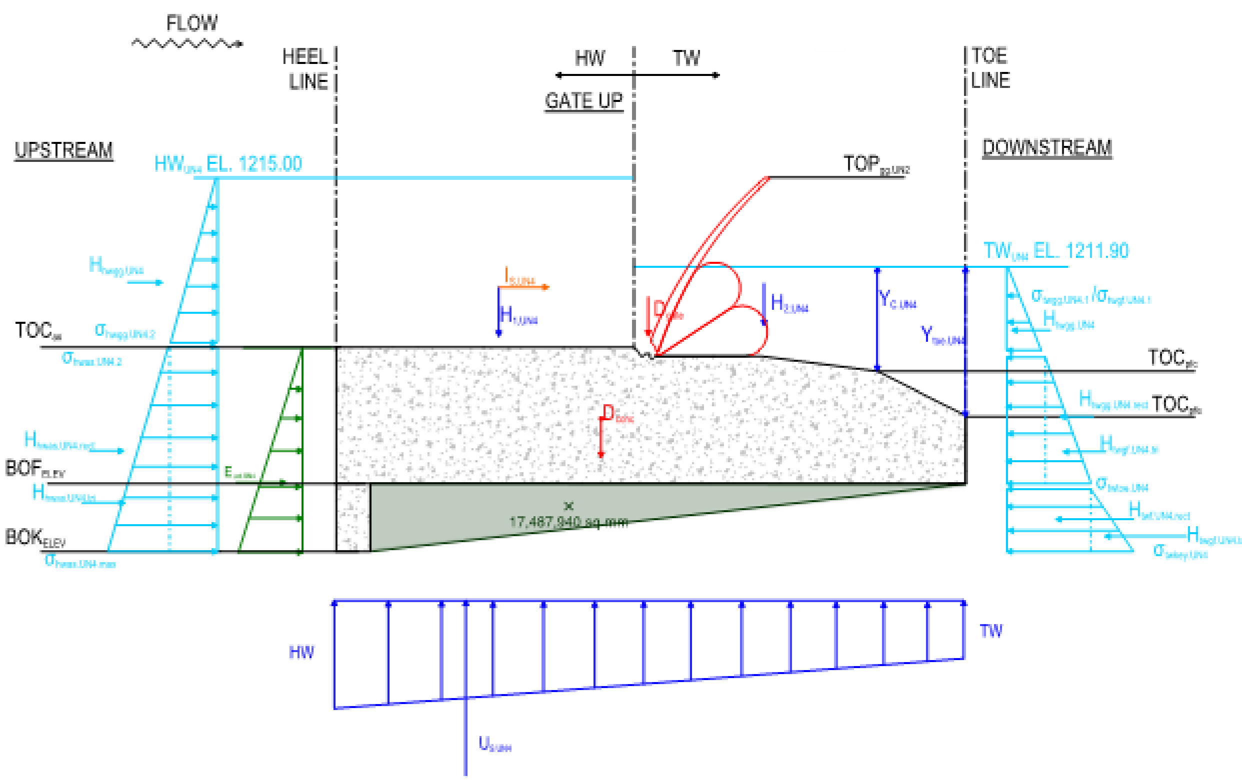
$$\sigma_{HeelUN3.OT} := \frac{\Sigma V_{UN3.OT}}{L_b \cdot W_b} - \frac{\left(\Sigma V_{UN3.OT} \cdot x_{OT.UN3}\right)}{S_b} = 38.0 \cdot kPa$$

$$Bearing_{CheckheelUN3.OT} := \left(\begin{vmatrix} \text{"OKAY "} & \text{if } \sigma_{HeelUN3.OT} < \sigma_{allow.UN3} \wedge \sigma_{HeelUN3.OT} > 0 \\ \text{"NG""} & \text{otherwise} \end{vmatrix} \right) = \text{"OKAY "}$$

SUMMARY OF STABILITY ASSESSMENT:

Sliding Factor of Safety: (Horizontal Plane)	$FS_{HorizSliding.UN3} = 1.67$	$FS_{HorizSliding.UN3.Check} = \text{"OKAY"}$
Sliding Factor of Safety: (Inclined Plane)	$FS_{InclinedlSlidingUN3} = 5.88$	$FS_{InclinedSliding.check.UN3} = \text{"OKAY "}$
Eccentricity: (Inclined Plane)	$e_{UN3} = -0.94\,m$	$e_{check.UN3} = \text{"Okay"}$
Bearing Pressure At Heel: (Inclined Plane)	$\sigma_{heel.UN3} = 86 \cdot kPa$	$\sigma_{heel.UN3.check} = \text{"Okay"}$
Bearing Pressure At Toe: (Inclined Plane)	$\sigma_{toe.UN3} = 46 \cdot kPa$	$\sigma_{toe.UN3.1.check} = \text{"Okay"}$
Flotation Factor of Safety (horizontal plane)	$FS_{act.FUN3} = 1.42$	$FS_{check.FUN3} = \text{"OKAY"}$
Overturning Resultant Ratio: (horizontal plane)	$Ratio_{OT.UN3} = 0.55$	$Ratio_{OT.UN3.check} = \text{"OKAY"}$
Eccentricity: (horizontal plane)	$x_{OT.UN3} = 0.93\,m$	$x_{OT.check.UN3} = \text{"OKAY"}$
Bearing Pressure At Heel: (horizontal plane)	$\sigma_{HeelUN3.OT} = 38 \cdot kPa$	$Bearing_{CheckheelUN3.OT} = \text{"OKAY "}$
Bearing Pressure At Toe: (horizontal plane)	$\sigma_{ToeUN3.OT} = 71 \cdot kPa$	$Bearing_{ChecktoeUN3.OT} = \text{"OKAY "}$

UN4 DESIGN CASE



ACCEPTANCE PARAMETERS

Required Factor of Safety for Sliding: $FS_{req.UN4.sl} := 1.3$ (Without Cohesion)

(Section 8.1, Design Criteria)

Resultant Within Middle Third of Base: $e \le \frac{L_b}{6} \wedge e \ge \frac{-L_b}{6}$

Allowable Rock Bearing Pressure: $\sigma_{allow.UN4} := 1470 \cdot \frac{kN}{m^2}$ (Section 5.2, Design Criteria)

INPUT PARAMETERS

Headwater Elevation: $HW_{UN4} := 1215.00m$ (Section 8.3, Design Criteria)

Tailwater Elevation: $TW_{UN4} := 1211.90m$ (Section 8.3, Design Criteria)

Bottom of Footing Elevation: $BOF_{elev} = 1206\,m$

Approach Slab Top of Concrete Elevation at Upstream Face: $TOC_{as} = 1210\,m$

Footing Top of Concrete Elevation at Stilling Basin: $TOC_{pfe} = 1208\,m$

Footing Top of Concrete Elevation at Center of Footing: $TOC_{pfc} = 1209.3\,m$

Gates are open when top of gate elevation is at 1210.00m

Top of Guard/Regulating Gate Elevation: $TOP_{rg.UN4} := 1210.90m$ $TOP_{gg.UN4} := 1215.00m$

Gates are closed/up when top of gate elevation is at 1215.0m

Bottom of Key Elevation: $BOK_{elev} = 1204\,m$

Crestwater Elevation: Dynamic Flow $EL_{C.UN4} := 1211.9m$

$$Y_{C.UN4} := \begin{cases} (EL_{C.UN4} - TOC_{pfc}) & \text{if } TOP_{gg.UN4} < HW_{UN4} \\ (TW_{UN4} - TOC_{pfc}) & \text{if } TOP_{gg.UN4} \ge HW_{UN4} \end{cases} = 2.6 \cdot m$$

Toewater Elevation: $EL_{TOE.UN4} := 1211.9m$

$$Y_{TOE.UN4} := \begin{cases} (EL_{TOE.UN4} - TOC_{pfe}) & \text{if } TOP_{gg.UN4} \le HW_{UN4} \\ (TW_{UN4} - TOC_{pfe}) & \text{if } TOP_{gg.UN4} > HW_{UN4} \end{cases} = 3.9 \cdot m$$

UN4 CASE

This load case is the Construction / Maintenance / Single Gate Bay Dewatered Load Case. One bay is open, while the other has been blocked off for gate maintenance. Calculation highlighted in Orange where calculation is affected.

CREST GATE (OBERMEYER)

Dead Load of Gates: $D_{Gate.UN4} := \frac{D_{Gate}}{2} = 105 \cdot kN$ (Vendor supplied, Dwg. Q-200 Series)

DEAD LOAD SUMMATION:

$\Sigma V_{DL.UN4} := D_{conc} + D_{Gate} = 24828.6 \cdot kN$

$\Sigma M_{DL.UN4} := D_{conc} \cdot X_{conc.loc} + D_{Gate.UN4} \cdot X_{gate} = 248250.79 \cdot kN \cdot m$

LATERAL WATER LOADS

HEADWATER (DRIVING):

Headwater Depth on Pier: $D_{hwg.UN4} := HW_{UN4} - TOC_{as} = 5.00\,m$

Thickness of Approach Slab (Including Key): $T_{as} = 6\,m$

Headwater Depth at Heel (U/S face): $D_{hwas.UN4} := HW_{UN4} - BOK_{elev} = 11.00\,m$

Headwater Load Unit Width on Approach Slab: $W_{hwas.UN4} := W_b = 15.00\,m$

Headwater Unit Load At Top of Approach Slab: $H_{hwas.UN4.1} := \frac{-\left(\gamma_w \cdot D_{hwg.UN4}^{\;2}\right)}{2} \cdot W_{hwas.UN4} = -1839.38 \cdot kN$

Headwater Unit Load At Bottom of Approach Key: $H_{hwas.UN4.2} := \frac{-\left(\gamma_w \cdot D_{hwas.UN4}^{\;2}\right)}{2} \cdot W_{hwas.UN4} = -8902.6 \cdot kN$

Headwater Line Load At Top of Approach Slab: $\sigma_{hwas.UN4.1} := -\left(\gamma_w \cdot D_{hwg.UN4}\right) = -49.05 \cdot kPa$

Headwater Line Load At Bottom of Approach Key: $\sigma_{hwas.UN4.2} := -\left(\gamma_w \cdot D_{hwas.UN4}\right) = -107.91 \cdot kPa$

Triangular Distribution Unit Load on Approach Slab and Key: $H_{hwas.UN4.2.tri} := \left(\frac{\sigma_{hwas.UN4.2} - \sigma_{hwas.UN4.1}}{2}\right) \cdot \left(T_{as} \cdot W_{hwas.UN4}\right) = -2648.7 \cdot kN$

Rectangular Distribution Unit Load on Approach Slab and Key: $H_{hwas.UN4.2.rect} := \sigma_{hwas.UN4.1} \cdot \left(T_{as} \cdot W_{hwas.UN4}\right) = -4414.5 \cdot kN$

Total Horizontal Headwater Load on Approach Slab: $H_{hwas.UN4} := H_{hwas.UN4.2.tri} + H_{hwas.UN4.2.rect} = -7063.2 \cdot kN$

Apply Total Footing Headwater Load at:

$$H_{hwas.UN4.loc} := \frac{\left[H_{hwas.UN4.2.rect} \cdot \frac{\left(T_{as}\right)}{2} + H_{hwas.UN4.2.tri} \cdot \frac{\left(T_{as}\right)}{3}\right]}{H_{hwas.UN4.2.tri} + H_{hwas.UN4.2.rect}} - d_{key} = 0.63\,m$$

Guard Gate Operating Condition:

Guard Gate Down/Open Condition: $A1_{UN4} := TOP_{gg.UN4} \le TOC_{as}$

Guard Crest Gate Up/Closed, with Top of Gate Higher than HW Elevation: $B1_{UN4} := TOP_{gg.UN4} \ge HW_{UN4} \wedge TOP_{gg.UN4} > TOC_{as}$

Guard Crest Gate Up/Closed, with Top of Gate Lower than HW Elevation: $C1_{UN4} := TOP_{gg.UN4} > TOC_{as} \wedge HW_{UN4} > TOP_{gg.UN4} = 0$

Guard Crest Gate Height: $H_{gg.UN4} := TOP_{gg.UN4} - TOC_{as} = 5\ m$

Headwater Depth at Guard Crest Gate: $D_{hwgg.UN4} := HW_{UN4} - TOC_{as} = 5.00\ m$

Guard Crest Gate Width: $W_{hwgg.UN4} := 15.00m$

Lateral Headwater Pressure at Bottom of Guard Crest Gate:

$$\sigma_{hwgg.UN4.1} := \begin{vmatrix} (0.0kPa) & \text{if } A1_{UN4} \\ -(\gamma_w \cdot D_{hwgg.UN4}) & \text{if } B1_{UN4} \\ -(\gamma_w \cdot D_{hwgg.UN4}) & \text{if } C1_{UN4} \end{vmatrix} = -49.0 \cdot kPa$$

Lateral Headwater Pressure at Top of Guard Crest Gate: (Load at HW Elevation On Guard Crest Gate if HW is below TOG_{rg})

$$\sigma_{hwgg.UN4.2} := \begin{vmatrix} (0.0kPa) & \text{if } A1_{UN4} \\ 0.0kPa & \text{if } B1_{UN4} \\ -\left[\gamma_w \cdot (HW_{UN4} - TOP_{gg.UN4})\right] & \text{if } C1_{UN4} \end{vmatrix} = 0.0 \cdot kPa$$

Average Pressure acting on Guard Crest Gate:

$$\sigma_{hwgg.UN4.avg} := \frac{(\sigma_{hwgg.UN4.1} + \sigma_{hwgg.UN4.2})}{2} = -24.52 \cdot kPa$$

Total Area of Crest Gate:

$$A_{hwgg.UN4} := \begin{vmatrix} D_{hwgg.UN4} \cdot W_{hwgg.UN4} & \text{if } A1_{UN4} \\ D_{hwgg.UN4} \cdot W_{hwgg.UN4} & \text{if } B1_{UN4} \\ H_{gg.UN4} \cdot W_{hwgg.UN4} & \text{if } C1_{UN4} \end{vmatrix} = 75 \cdot m^2$$

Total Horizontal Headwater Load on Guard Crest Gate: $H_{hwgg.UN4} := \sigma_{hwgg.UN4.avg} \cdot A_{hwgg.UN4} = -1839.4 \cdot kN$

Apply Total Guard Crest Gate Headwater Load at:

$$H_{hwgg.UN4.loc} := \begin{vmatrix} (TOC_{as} - BOF_{elev}) & \text{if } A1_{UN4} \\ \left[\frac{(HW_{UN4} - TOC_{as})}{3} + (TOC_{as} - BOF_{elev})\right] & \text{if } B1_{UN4} \\ \left[\frac{\sigma_{hwgg.UN4.2} \cdot A_{hwgg.UN4} \cdot \frac{(H_{gg.UN4})}{2} + \frac{(\sigma_{hwgg.UN4.1} - \sigma_{hwgg.UN4.2})}{2} A_{hwgg.UN4} \cdot \frac{(H_{gg.UN4})}{3}}{\sigma_{hwgg.UN4.2} \cdot A_{hwgg.UN4} + \frac{(\sigma_{hwgg.UN4.1} - \sigma_{hwgg.UN4.2})}{2} \cdot A_{hwgg.UN4}} \ldots \\ + (TOC_{as} - BOF_{elev})\right] & \text{if } C1_{UN4} \end{vmatrix} = 5.7 \cdot m$$

LATERAL TAILWATER (RESISTING) Applied to Downstream Side of Guard Crest Gate: UN4 CASE

Guard Gate Down/Open Condition:

$A2_{UN4} := TOP_{gg.UN4} \le TOC_{as}$

Guard Crest Gate Up/Closed, with Top of Gate Higher than TW Elevation:

$B2_{UN4} := TOP_{gg.UN4} \ge TW_{UN4} \wedge TOP_{gg.UN4} > TOC_{as} = 1$

Guard Crest Gate Up/Closed, with Top of Gate Lower than TW Elevation:

$C2_{UN4} := TOP_{gg.UN4} > TOC_{as} \wedge TW_{UN4} > TOP_{gg.UN4} = 0$

Tailwater Depth at Guard Crest Gate:

$D_{twgg.UN4} := TW_{UN4} - TOC_{as} = 1.90\,m$

Guard Crest Gate Width:

$W_{twgg.UN4} := 15.00m$

Lateral Water Load at Bottom of Guard Crest Gate:

$$\sigma_{twgg.UN4.1} := \begin{cases} (0.0kPa) & \text{if } A2_{UN4} \\ (\gamma_w \cdot D_{twgg.UN4}) & \text{if } B2_{UN4} \\ (\gamma_w \cdot D_{twgg.UN4}) & \text{if } C2_{UN4} \end{cases} = 18.6 \cdot kPa$$

Lateral Water Load at Top of Guard Crest Gate:
(Load at TW Elevation On Guard Crest Gate if TW is below TOG_{gg})

$$\sigma_{twgg.UN4.2} := \begin{cases} (0.0kPa) & \text{if } A2_{UN4} \\ 0.0kPa & \text{if } B2_{UN4} \\ \left[\gamma_w \cdot \left(TW_{UN4} - TOP_{gg.UN4}\right)\right] & \text{if } C2_{UN4} \end{cases} = 0.0 \cdot kPa$$

Average Pressure acting on Guard Crest Gate:

$$\sigma_{twgg.UN4.avg} := \frac{\left(\sigma_{twgg.UN4.1} + \sigma_{twgg.UN4.2}\right)}{2} = 9.32 \cdot kPa$$

Total Area water acting on Crest Gate:

$$A_{twgg.UN4} := \begin{cases} D_{twgg.UN4} \cdot W_{twgg.UN4} & \text{if } A2_{UN4} \\ D_{twgg.UN4} \cdot W_{twgg.UN4} & \text{if } B2_{UN4} \\ H_{gg.UN4} \cdot W_{twgg.UN4} & \text{if } C2_{UN4} \end{cases} = 28.5 \cdot m^2$$

Total Horizontal Tailwater Load on Guard Crest Gate:

$H_{twgg.UN4} := \sigma_{twgg.UN4.avg} \cdot A_{twgg.UN4} = 265.6 \cdot kN$

Apply Total Horiz. TW Load on Guard Gate at:

$$H_{twgg.UN4.loc} := \begin{cases} \left(TOC_{as} - BOF_{elev}\right) & \text{if } A2_{UN4} \\ \left[\frac{\left(TW_{UN4} - TOC_{as}\right)}{3} + \left(TOC_{as} - BOF_{elev}\right)\right] & \text{if } B2_{UN4} \\ \left[\frac{\sigma_{twgg.UN4.2} \cdot A_{twgg.UN4} \cdot \frac{\left(H_{gg.UN4}\right)}{2} + \frac{\left(\sigma_{twgg.UN4.1} - \sigma_{twgg.UN4.2}\right)}{2} \cdot A_{twgg.UN4} \cdot \frac{\left(H_{gg.UN4}\right)}{3}}{\sigma_{twgg.UN4.2} \cdot A_{twgg.UN4} + \frac{\left(\sigma_{twgg.UN4.1} - \sigma_{twgg.UN4.2}\right)}{2} \cdot A_{twgg.UN4}} \ldots \\ + \left(TOC_{as} - BOF_{elev}\right)\right] & \text{if } C2_{UN4} \end{cases} = 4.6 \cdot m$$

TAILWATER (RESISTING) Applied to Concrete Structure:

Tailwater Depth At top of Gate Base Footing Elevation: $D_{twgf.UN4} := TW_{UN4} - TOC_{as} = 1.90\,m$

Water Depth at bottom of Gate Base Footing: $D_{twtoe.UN4} := TW_{UN4} - BOF_{elev} = 5.90\,m$

Footing Thickness at Toe $h_{toe} = 4\,m$

Unit Width of D/S face of crest for application of Tailwater Load: $W_{tw.UN4} := W_b = 15.00\,m$

Tailwater Pressure At Top of Gate Footing: $\sigma_{twgf.UN4} := \left(\gamma_w \cdot D_{twgf.UN4}\right) = 18.64 \cdot kPa$

Tailwater Line Load At Bottom of Gate Footing: $\sigma_{twtoe.UN4} := \left(\gamma_w \cdot D_{twtoe.UN4}\right) = 57.88 \cdot kPa$

Triangular Distribution Unit Load on Gate Footing Base: $H_{twgf.UN4.tri} := \left(\dfrac{\sigma_{twtoe.UN4} - \sigma_{twgf.UN4}}{2}\right) \cdot \left(h_{toe} \cdot W_{tw.UN4}\right) = 1177.2 \cdot kN$

Rectangular Distribution Unit Load on Gate Footing Base: $H_{twgf.UN4.rect} := \sigma_{twgf.UN4} \cdot \left(h_{toe} \cdot W_{tw.UN4}\right) = 1118.34 \cdot kN$

Tailwater Pressure At Bottom of Sliding Failure Plane: $\sigma_{twbk.UN4} := \left(HW_{UN4} - BOK_{elev}\right) \cdot \gamma_w = 107.91 \cdot kPa$

Triangular Distribution Unit Load Below Footing: $H_{twbk.UN4.tri} := \dfrac{\left(\sigma_{twbk.UN4} - \sigma_{twtoe.UN4}\right)}{2} \cdot d_{key} \cdot W_{tw.UN4} = 750.46 \cdot kN$

Rectangular Distribution Load Below Footing Base: $H_{twbk.UN4.rect} := \sigma_{twtoe.UN4} \cdot d_{key} \cdot W_{tw.UN4} = 1736.37 \cdot kN$

Total Horizontal Tailwater Load on Gate Footing (including key):

$$H_{twgk.UN4} := H_{twgf.UN4.tri} + H_{twgf.UN4.rect} + H_{twbk.UN4.tri} + H_{twbk.UN4.rect} = 4782.38 \cdot kN$$

Apply Total Gate Footing Tailwater Load at:

$$H_{twgk.UN4.loc} := \frac{\left[H_{twgf.UN4.rect} \cdot \dfrac{\left(h_{toe}\right)}{2} + H_{twgf.UN4.tri} \cdot \dfrac{\left(h_{toe}\right)}{3} + H_{twbk.UN4.tri} \cdot \left(-d_{key} \cdot \dfrac{2}{3}\right) + H_{twbk.UN4.rect} \cdot \left(\dfrac{-d_{key}}{2}\right)\right]}{H_{twgf.UN4.tri} + H_{twgf.UN4.rect} + H_{twbk.UN4.tri} + H_{twbk.UN4.rect}} = 0.22\,m$$

SUMMATION OF LATERAL WATER LOADS:

$$\Sigma H_{Water.UN4} := H_{hwas.UN4} + H_{hwgg.UN4} + H_{twgk.UN4} + H_{twgg.UN4} = -3854.59 \cdot kN$$

$$\Sigma M_{Hwater.UN4} := H_{hwas.UN4} \cdot H_{hwas.UN4.loc} + H_{hwgg.UN4} \cdot H_{hwgg.UN4.loc} \cdots + H_{twgk.UN4} \cdot H_{twgk.UN4.loc} + H_{twgg.UN4} \cdot H_{twgg.UN4.loc} = -12537.7 \cdot kN \cdot m$$

VERTICAL WATER LOADS

UN4 CASE

HEADWATER:

Water Depth on top of Approach Slab: $d_{hw.UN4} := HW_{UN4} - TOC_{as} = 5.00\,m$

Length of Approach Slab: $L_{as} = 8.75\,m$

Width of Approach Slab: $w_{as} = 15.00\,m$

(Weight on Apron is required for stability. Coffer U/S of pier nose must include fill to offset reduced water load.)

Vertical Water Weight (H1) on Approach Slab: $H_{1.UN4} := \left(w_{as} \cdot d_{hw.UN4} \cdot L_{as}\right) \cdot \gamma_w \cdot \frac{3}{4} = 4828.4 \cdot kN$

Moment Arm for Application of Water Weight (H1) from toe: $H_{1.UN4.loc} := L_b - \frac{L_{as}}{2} = 14.13\,m$

TAILWATER:

Trapezoid Volume Above Gate Footing from Approach Slab to Crest: $V_{asc.UN4} := \left(L_{gf} - L_{gfc}\right) W_b \frac{d_{hw.UN4} + Y_{C.UN4}}{2} = 407.55 \cdot m^3$

Trapezoid Volume Above Gate Footing Crest to End of Gate Footing: $V_{gfc.UN4} := \left(L_{gfc} \cdot W_b\right) \frac{Y_{C.UN4} + Y_{TOE.UN4}}{2} = 126.75 \cdot m^3$

Load Above Gate Footing from Approach Slab to Crest: $H_{2.UN4.asc} := V_{asc.UN4} \cdot \gamma_w = 3998.07 \cdot kN$

Load Acting Above Footing Crest from Toe: $H_{2.UN4.asc.loc} := \frac{\left(L_{gf} - L_{gfc}\right) \cdot \left(2 \cdot d_{hw.UN4} + Y_{C.UN4}\right)}{3 \cdot \left(d_{hw.UN4} + Y_{C.UN4}\right)} + L_{gfc} = 6.55\,m$

Load Above Gate Footing from Crest to End: $H_{2.UN4.gfc} := V_{gfc.UN4} \cdot \gamma_w = 1243.42 \cdot kN$

Load Acting Above Gate Footing from Crest to End: $H_{2.UN4.gfc.loc} := \frac{\left(L_{gfc}\right) \cdot \left(2 \cdot Y_{C.UN4} + Y_{TOE.UN4}\right)}{3 \cdot \left(Y_{C.UN4} + Y_{TOE.UN4}\right)} = 1.21\,m$

Vertical Water Weight (H2) on Gate Footing: $H_{2.UN4} := H_{2.UN4.asc} + H_{2.UN4.gfc} = 5241.48 \cdot kN$

Moment Arm for Application of Water Weight (H2) from toe: $H_{2.UN4.loc} := \frac{H_{2.UN4.asc} \cdot H_{2.UN4.asc.loc} + H_{2.UN4.gfc} \cdot H_{2.UN4.gfc.loc}}{H_{2.UN4}} = 5.29\,m$

UPLIFT AT INCLINE SLIDING PLANE

UN4 CASE

Uplift pressure at U/S Face (heel): $U_{HW.UN4} := D_{hwas.UN4} \cdot \gamma_w = 107.9 \cdot \frac{kN}{m^2}$

Uplift pressure at D/S Face Stilling Basin: $U_{TW.UN4} := \left(D_{twtoe.UN4}\right) \cdot \gamma_w = 57.88 \cdot \frac{kN}{m^2}$

Length from U/S of Gate Structure to D/S of Stilling Basin: $L_{overall} = 18.50\,m$

Difference between Uplift pressure at HW and TW: $U_{diff.UN4} := U_{HW.UN4} - U_{TW.UN4} = 50.03 \cdot \frac{kN}{m^2}$

Slope of difference between between Uplift pressure at HW and TW: $U_{slope.UN4} := \frac{U_{diff.UN4}}{L_{overall}} = 2.70 \cdot \frac{kN}{m^2 \cdot m}$

Tailwater Pressure at toe of Gate Structure: $U_{press.toe.gs.UN4} := U_{TW.UN4} + \left(L_{overall} - L_b\right) \cdot U_{slope.UN4} = 57.88 \cdot \frac{kN}{m^2}$

Uniform uplift force UA Under Gate Structure due to TW (rectangle): $U_{A.UN4} := U_{press.toe.gs.UN4} \cdot L_b \cdot W_b \cdot -1 = -16061.42 \cdot kN$

Moment Arm from Toe of Gate Structure for Uplift UA: $L_{A.UN4} := \left(\frac{L_b}{2}\right) = 9.25\,m$

Linearly Decreasing Uplift Force UN4B Under Gate Structure due to HW-TW Differential (triangle): $U_{B.UN4} := \frac{1}{2} \cdot \left(U_{HW.UN4} - U_{press.toe.gs.UN4}\right) \cdot L_b \cdot W_b \cdot -1 = -6941.8 \cdot kN$

Moment Arm from Toe of Gate Structure for Uplift UB: $L_{B.UN4} := \frac{2}{3} \cdot L_b = 12.33\,m$

Total Resultant Uplift force: $U_{UN4} := U_{A.UN4} + U_{B.UN4} = -23003.22 \cdot kN$

Resultant Location from Toe: $U_{UN4.loc} := \frac{\left(U_{A.UN4} \cdot L_{A.UN4} + U_{B.UN4} \cdot L_{B.UN4}\right)}{\left(U_{A.UN4} + U_{B.UN4}\right)} = 10.18\,m$

$\Sigma V_{water.UN4} := H_{1.UN4} + H_{2.UN4} + U_{UN4} = -12933.38 \cdot kN$

$\Sigma M_{Vwater.UN4} := H_{1.UN4} \cdot H_{1.UN4.loc} + H_{2.UN4} \cdot H_{2.UN4.loc} + U_{UN4} \cdot U_{UN4.loc} = -138281.86 \cdot kN \cdot m$

SOIL LOADS

UN4 CASE

Equivalent Fluid Pressure (EFP):

At rest lateral pressure coefficient: $K_{o.UN4} := 1 - \sin(\phi_{backfill}) = 0.658$ (Section 5.3, Design Criteria)

Headwater Pier Footing Unit Width: $W_{hwas.UN4} = 15.00\,m$

Tailwater Pier Footing Unit Width: $W_{tw.UN4} = 15.00\,m$

Pier Footing Thickness at Heel: $t_{hf.UN4} := TOC_{as} - BOK_{elev} = 6.00\,m$

Fixed Crest Footing Thickness at Toe: $t_{tf.UN4} := TOC_{pfe} - BOF_{elev} = 2.00\,m$

Lateral Driving Force (Headwater Side - at rest condition)

At-Rest Soil Load: $E_{act.UN4} := \dfrac{\left(K_{o.UN4} \cdot t_{hf.UN4}^{\ 2}\right)}{2} \cdot \left(\gamma_r - \gamma_w\right) \cdot W_{hwas.UN4} \cdot -1 = -2165.61 \cdot kN$

Acting at: $E_{act.UN4.loc} := \dfrac{t_{hf.UN4}}{3} = 2.00\,m$

Lateral Resisting Force (Tailwater Side - at rest condition)

At-rest Soil Load: $E_{pass.UN4} := \dfrac{\left(K_{o.UN4} \cdot t_{tf.UN4}^{\ 2}\right)}{2} \cdot \left(\gamma_r - \gamma_w\right) \cdot W_{tw.UN4} = 240.62 \cdot kN$

Acting at: $E_{pass.UN4.loc} := \dfrac{t_{tf.UN4}}{3} = 0.67\,m$

$\Sigma H_{soil.UN4} := E_{act.UN4} + E_{pass.UN4} = -1924.99 \cdot kN$

$\Sigma M_{soil.UN4} := E_{act.UN4} \cdot E_{act.UN4.loc} + E_{pass.UN4} \cdot E_{pass.UN4.loc} = -4170.8 \cdot kN \cdot m$

ICE / IMPACT LOADS (ASSUME NO ICE LOADING ON TAILWATER SIDE)

ICE & IMPACT LOADS DO NOT APPLY FOR THIS LOAD CASE

Static Ice load on Gates:

$$I_{G.UN4} := \begin{cases} 00\,\dfrac{kN}{m} & \text{if } TOP_{gg.UN4} \le TOC_{as} \\ 0\,\dfrac{kN}{m} & \text{if } TOP_{gg.UN4} > TOC_{as} \end{cases} = 0 \cdot \frac{kN}{m}$$

(Section 7.7, Design Criteria)

Ice Loading Unit Width on Guard Gate: $W_{gg.UN4} := 15.00m$ (Input value for load case)

Total Ice Load on Structure: $I_{UN4} := -\left(I_{G.UN4} \cdot W_{gg.UN4}\right) = 0 \cdot kN$

Apply Ice load at: $I_{UN4.loc} := \left(TOP_{gg.UN4} - BOF_{elev} - 0.30m\right) = 8.70\,m$

$\Sigma H_{I.UN4} := I_{UN4} = 0 \cdot kN$

$\Sigma M_{I.UN4} := I_{UN4} \cdot I_{UN4.loc} = 0 \cdot kN \cdot m$

SEISMIC LOAD (NOT APPLICABLE FOR THIS LOAD CASE)

UN4 CASE

SUMMARY OF LOADS

	Loads	Moment Arm
Dead load of Concrete Structure:	$D_{conc} = 24618.6 \cdot kN$	$X_{conc.loc} = 10.06\,m$
Obermyer Gate Weight:	$D_{Gate.UN4} = 105.0 \cdot kN$	$X_{gate} = 6.60\,m$
HW Lateral Load on Approach Slab:	$H_{hwas.UN4} = -7063.2 \cdot kN$	$H_{hwas.UN4.loc} = 0.63\,m$
HW Lateral Load on Guard Gate:	$H_{hwgg.UN4} = -1839.4 \cdot kN$	$H_{hwgg.UN4.loc} = 5.67\,m$
TW Lateral Load on Gate Footing (Including Key - Sliding Check Loads):	$H_{twgk.UN4} = 4782.38 \cdot kN$	$H_{twgk.UN4.loc} = 0.22\,m$
TW Lateral Load on Guard Gate:	$H_{twgg.UN4} = 265.6 \cdot kN$	$H_{twgg.UN4.loc} = 4.63\,m$
Vertical HW Load on Approach Slab:	$H_{1.UN4} = 4828.4 \cdot kN$	$H_{1.UN4.loc} = 14.13\,m$
Vertical TW Load on Pier Footing (crest):	$H_{2.UN4} = 5241.5 \cdot kN$	$H_{2.UN4.loc} = 5.29\,m$
Uplift:	$U_{UN4} = -23003.2 \cdot kN$	$U_{UN4.loc} = 10.18\,m$
Lateral Soil Load (driving):	$E_{act.UN4} = -2165.6 \cdot kN$	$E_{act.UN4.loc} = 2.00\,m$
Lateral Soil Load (resisting):	$E_{pass.UN4} = 240.62 \cdot kN$	$E_{pass.UN4.loc} = 0.67\,m$
Ice / Impact Load:	$I_{UN4} = 0.0 \cdot kN$	$I_{UN4.loc} = 8.70\,m$

STABILITY ASSESSMENT (SLIDNG, BEARING, FLOTATION AND OVERTURNING):

UN4 CASE

CHECK SLIDING ALONG HORIZONTAL PLANE THRU TOE,
IGNORING BEDROCK MOBILIZED BY STRUCTURAL HEEL KEY, OR VOID BEHIND KEY

Sum of Vertical Forces:

$\Sigma V_{UN4} := \Sigma V_{DL} + \Sigma V_{water.UN4} = 11895.2 \cdot kN$

Sum of Horizontal Forces:

$\Sigma H_{UN4} := \Sigma H_{Water.UN4} + \Sigma H_{soil.UN4} + \Sigma H_{I.UN4} = -5779.58 \cdot kN$

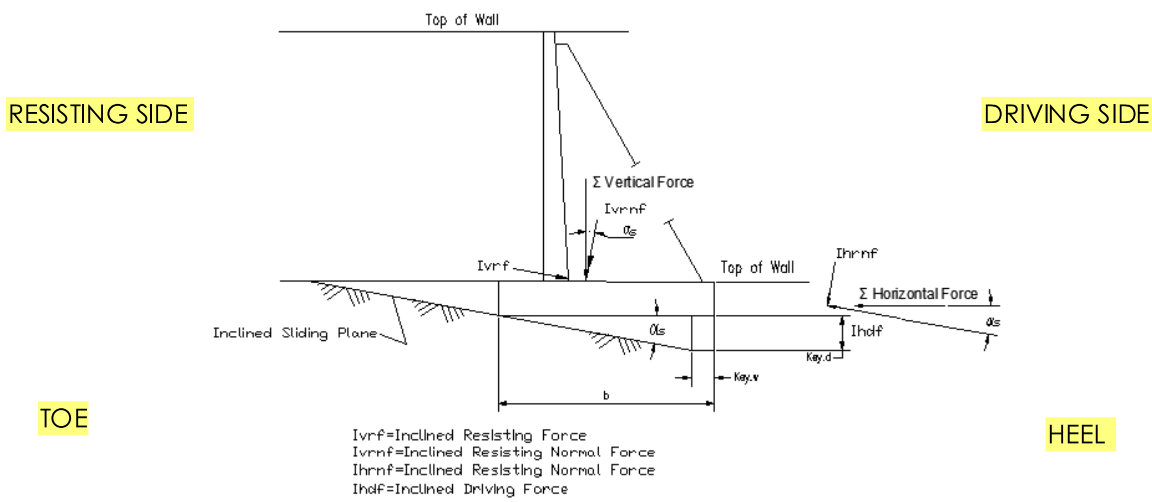
Sliding Factor of Safety:

$$FS_{HorizSliding.UN4} := \frac{\tan_{\phi} \cdot \Sigma V_{UN4}}{\left|\Sigma H_{UN4}\right|} = 1.00$$

$FS_{HorizSliding.UN4.Check} :=$ | "OKAY" if $FS_{HorizSliding.UN4} \geq FS_{req.UN4.sl}$
"Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !" otherwise

= "Horizontal Sliding (No

CHECK SLIDING ALONG INCLINED SLIDING PLANE FROM HEEL KEY TO TOE,
WITH BEDROCK MASS MOBILIZED BY REINFOCREDE CONCRETE KEY)



$\alpha s = 0.11$ as degrees= $\alpha s \cdot \left(\frac{180}{\pi}\right) = 6.52$

$\Sigma V_{UN3} = 12392.33 \cdot kN$

$V_{rs} = 5775 \cdot kN$

Resolve $\Sigma Vert_{UN4}$ & $\Sigma Horiz_{UN4}$

$\Sigma V_{InclinedUN4} := \cos(\alpha s) \cdot \left(\Sigma V_{UN4} + V_{rs}\right) + \sin(\alpha s) \cdot \left|\Sigma H_{UN4}\right| = 18212.2 \cdot kN$

$\Sigma H_{InclinedUN4} := \cos(\alpha s) \cdot \left|\Sigma H_{UN4}\right| - \sin(\alpha s) \cdot \left(\Sigma V_{UN4} + V_{rs}\right) = 3735.8 \cdot kN$

(With properly engineered reinforced concrete Key, horizontal sliding plane thru Toe is protected, critical sliding plane is relocated to the INCLINED SLIDING PLANE FROM HEEL KEY To TOE, Bedrock Mass above this examined plane is mobilized by reinforced concrete key and combined into Structural Wedge.)

Inclined Sliding Plane Length

$L_{incline} = 18.61 \, m$

Safety Factor for Sliding
Inclined Failure Plane

$$FS_{InclinedlSlidingUN4} := \frac{\Sigma V_{InclinedUN4} \cdot \tan\left(\phi_{rock} \cdot \frac{\pi}{180}\right)}{\left|\Sigma H_{InclinedUN4}\right|} = 2.38$$

$FS_{InclinedSliding.check.UN4} :=$ | "OKAY " if $FS_{InclinedlSlidingUN4} > FS_{req.UN4.sl}$
"Revise Structure"" otherwise

= "OKAY "

$FS_{InclinedSliding.check.UN4} =$ "OKAY "

OVERTURNING STABILITY CHECK:

UN4 CASE

CHECK ECCENTRICITY

Sum of the moments:

$$\Sigma M_{UN4} := \Sigma M_{DL.UN4} + \Sigma M_{Hwater.UN4} + \Sigma M_{Vwater.UN4} + \Sigma M_{I.UN4} + \Sigma M_{soil.UN4} + \Sigma M_{soil} = 160635 \cdot kN \cdot m$$

Eccentricity:

$$e_{UN4} := \left(\frac{L_{incline}}{2}\right) - \frac{\Sigma M_{UN4}}{\Sigma V_{InclinedUN4}} = 0.48\,m$$

Eccentricity Check:

$$e_{check.UN4} := \begin{cases} \text{"Okay"} & \text{if } \left|e_{UN4}\right| \le Kern \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$$e_{check.UN4} = \text{"Okay"}$$

Foundation Bearing Checks:

Incline Plane Area: $A_{b.incline} = 279.12\,m^2$

Incline Plane Section Modulus: $S_{b.incline} = 865.63 \cdot m^3$

Bearing Pressure at Heel:

$$\sigma_{heel.UN4} := \frac{\Sigma V_{InclinedUN4}}{A_{b.incline}} - \frac{\Sigma V_{InclinedUN4} \cdot e_{UN4}}{S_{b.incline}} = 55.1 \cdot \frac{kN}{m^2}$$

$$\sigma_{heel.UN4.check} := \left(\begin{cases} \text{"Okay"} & \text{if } \sigma_{heel.UN4} \le \sigma_{allow.UN4} \\ \text{"Revise Structure"} & \text{if } \sigma_{heel.UN4} < 0\,\frac{kN}{m^2} \end{cases}\right)$$

$$\sigma_{heel.UN4.check} = \text{"Okay"}$$

Bearing Pressure at Toe:

$$\sigma_{toe.UN4} := \frac{\Sigma V_{InclinedUN4}}{A_{b.incline}} + \frac{\Sigma V_{InclinedUN4} \cdot e_{UN4}}{S_{b.incline}} = 75.4 \cdot \frac{kN}{m^2}$$

$$\sigma_{toe.UN4.1.check} := \begin{cases} \text{"Okay"} & \text{if } \sigma_{toe.UN4} \le \sigma_{allow.UN4} \\ \text{"Revise Structure"} & \text{if } \sigma_{toe.UN4} < 0\,\frac{kN}{m^2} \end{cases}$$

$$\sigma_{toe.UN4.1.check} = \text{"Okay"}$$

FLOATATION ANALYSIS:

ACCEPTANCE PARAMETERS

Required Factor of Safety: $FS_{req.FUN4} := 1.3$

VERTICAL LOADS RESISTING:

Dead Load: $\Sigma V_{DL} = 24828.6 \cdot kN$

Water Weight H1+H2: $\Sigma V_{H.FUN4} := H_{1.UN4} + H_{2.UN4} = 10069.84 \cdot kN$

Summation Vertical Resisting: $\Sigma V_{FUN4} := \Sigma V_{DL} + \Sigma V_{H.FUN4} = 34898.4 \cdot kN$

VERTICAL LOADS UPLIFT:

Uplift: $U_{UN4} = -23003.22 \cdot kN$

Factor of Safety Floatation:

$$FS_{act.FUN4} := \frac{\Sigma V_{FUN4}}{\left|U_{UN4}\right|} = 1.52$$

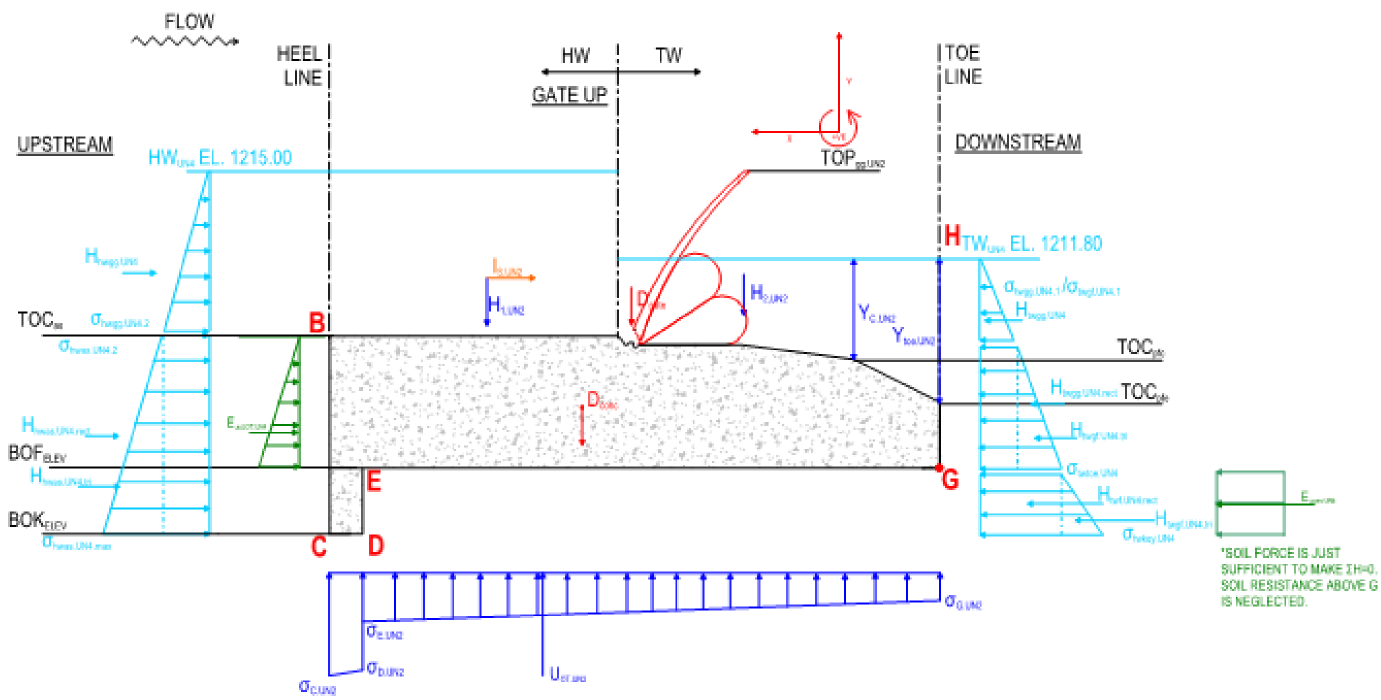
$$FS_{check.FUN4} := \begin{cases} \text{"OKAY"} & \text{if } FS_{act.FUN4} \ge FS_{req.FUN4} \\ \text{"ANCHORS REQUIRED"} & \text{if } FS_{act.FUN4} < FS_{req.FUN4} \end{cases} = \text{"OKAY"}$$

UN4 CASE

MONOLITH OVERTURNING STABILITY ANALYSIS

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.
Assumptions are made in order to compute overturning stability of indetermine forces on monolith with key;
(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.
(b) The horizontal resisting force acting on the key, P.key, is that required for static equilibrium
(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1 $Ratio_{OT.UN4.min} := 0.33$ Resultant at Middle Third



Uplift Loads for Overturning Stability Analysis

Line of Creep:

Change in Water Head: $\Delta_{h.UN4} := HW_{UN4} - TW_{UN4} = 3.1\ m$

Length from Point C to Point G: $L_{CG} = 18.61\ m$

Length from Various Points to Points: $L_{CD} = 1\ m$ $L_{DE} = 2\ m$ $L_{EG} = 17.5\ m$

$L_{GH.UN4} := TW_{UN4} - BOF_{elev} = 5.9\ m$

Length from Point C, D, E to G: $L_{CDEG} = 20.5\ m$ $L_{CDE} = 3\ m$

Water Pressure at Point C: $\sigma_{C.UN4} := \sigma_{hwas.UN4.2} = -107.91 \cdot kPa$

Water Pressure at Point G: $\sigma_{G.UN4} := \sigma_{twtoe.UN4} \cdot -1 = -57.88 \cdot kPa$

Water Pressure at Point D: $$\sigma_{D.UN4} := -\gamma_w \cdot \left[\left(HW_{UN4} - BOK_{elev}\right) - \frac{\Delta_{h.UN4} \cdot L_{CD}}{L_{CDEG}}\right] = -106.43 \cdot kPa$$

Water Pressure at Point E: $$\sigma_{E.UN4} := -\gamma_w \cdot \left[\left(HW_{UN4} - BOF_{elev}\right) - \frac{\Delta_{h.UN4} \cdot L_{CDE}}{L_{CDEG}}\right] = -83.84 \cdot kPa$$

Uplift for Overturning Analysis on Bottom of Key: $$U_{OT.UN4.key} := \frac{\sigma_{C.UN4} + \sigma_{D.UN4}}{2} \cdot L_{CD} \cdot W_b = -1607.52 \cdot kN$$

Acting at: $$U_{OT.UN4.key.loc} := \frac{L_{CD} \cdot \left(2 \cdot \sigma_{C.UN4} + \sigma_{D.UN4}\right)}{3\left(\sigma_{C.UN4} + \sigma_{D.UN4}\right)} + L_{EG} = 18\ m$$

Uplift for Overturning Analysis on Bottom of Footing: $U_{OT.UN4.ftg} := \frac{\sigma_{E.UN4} + \sigma_{G.UN4}}{2} \cdot L_{EG} \cdot W_b = -18600.57 \cdot kN$

UN4 CASE

Acting at: $U_{OT.UN4.ftg.loc} := \frac{L_{EG} \cdot \left(\sigma_{G.UN4} + 2 \cdot \sigma_{E.UN4}\right)}{3\left(\sigma_{G.UN4} + \sigma_{E.UN4}\right)} = 9.28\,m$

Uplift Load for Overturning Analysis: $U_{OT.UN4} := U_{OT.UN4.key} + U_{OT.UN4.ftg} = -20208.09 \cdot kN$

Uplift Load Acting from Toe: $U_{OT.UN4.loc} := \frac{U_{OT.UN4.key} \cdot U_{OT.UN4.key.loc} + U_{OT.UN4.ftg} \cdot U_{OT.UN4.ftg.loc}}{U_{OT.UN4}} = 9.98\,m$

All Vertical Loads Applicable to Overturning Stability Analysis

		at:
Total Concrete Dead Loads:	$D_{conc} = 24618.6 \cdot kN$	$X_{conc.loc} = 10.06\,m$
Dead Load of Gate:	$D_{Gate} = 210.0 \cdot kN$	$X_{gate} = 6.60\,m$
Water Weight (HW) on Apron Slab:	$H_{1.UN4} = 4828.4 \cdot kN$	$H_{1.UN4.loc} = 14.13\,m$
Water Weight (TW) on Gate Footing:	$H_{2.UN4} = 5241.5 \cdot kN$	$H_{2.UN4.loc} = 5.29\,m$
Uplift Load for Overturning Analysis:	$U_{OT.UN4} = -20208.09 \cdot kN$	$U_{OT.UN4.loc} = 9.98 \cdot m$

Sum of All Overturning Analysis Vertical Load:

$$\Sigma V_{UN4.OT} := D_{conc} + D_{Gate} + H_{1.UN4} + H_{2.UN4} + U_{OT.UN4} = 14690.35 \cdot kN$$

Sum of All Overturning Analysis Vertical Load Moments:

$$\Sigma M_{V.UN4.OT} := D_{conc} \cdot X_{conc.loc} + D_{Gate} \cdot X_{gate} + H_{1.UN4} \cdot H_{1.UN4.loc} + H_{2.UN4} \cdot H_{2.UN4.loc} + U_{OT.UN4} \cdot U_{OT.UN4.loc} = 143215.34 \cdot kN \cdot m$$

Lateral Tailwater Loads for Overturning Stability Analysis

TW Lateral Load on Gate Footing (No Key - Overturning Values Adjusted): $H_{twgf.UN4} := H_{twgf.UN4.tri} + H_{twgf.UN4.rect} = 2295.54 \cdot kN$

Acting at: $H_{twgf.UN4.loc} := \frac{\frac{h_{toe}}{3} \cdot H_{twgf.UN4.tri} + \frac{h_{toe}}{2} \cdot H_{twgf.UN4.rect}}{H_{twgf.UN4}} = 1.66\,m$

Horizontal Tailwater Pressure Top of Key (Overturning Analysis): $\sigma_{twtk.OT.UN4} := \sigma_{E.UN4} \cdot -1 = 83.84 \cdot kPa$

Horizontal Tailwater Pressure Bottom of Key (Overturning Analysis): $\sigma_{twbk.OT.UN4} := \sigma_{D.UN4} \cdot -1 = 106.43 \cdot kPa$

Triangular Distribution Unit Load Acting at Key: $H_{twbk.OT.UN4.tri} := \frac{\left(\sigma_{twbk.OT.UN4} - \sigma_{twtk.OT.UN4}\right)}{2} \cdot d_{key} \cdot W_{tw.UN4} = 338.8 \cdot kN$

Triangular Distribution Unit Load Acting at Key: $H_{twbk.OT.UN4.rect} := \sigma_{twtk.OT.UN4} \cdot d_{key} \cdot W_{tw.UN4} = 2515.19 \cdot kN$

Total Horizontal Tailwater Load on Key (Overturning Values Adjusted): $H_{twkey.OT.UN4} := H_{twbk.OT.UN4.tri} + H_{twbk.OT.UN4.rect} = 2853.99 \cdot kN$

Acting at: $H_{twkey.OT.UN4.loc} := \frac{H_{twbk.OT.UN4.tri} \cdot \frac{-2 \cdot d_{key}}{3} + H_{twbk.OT.UN4.rect} \cdot \frac{-d_{key}}{2}}{H_{twkey.OT.UN4}} = -1.04 \cdot m$

UN4 CASE

Lateral Driving Earth Loads for Overturning Stability Analysis (at rest condition)

Depth of Driving Soil Loads (to top of key): $h_{E.OT.UN4} := TOC_{as} - BOF_{elev} = 4\,m$

At-Rest Soil Load:

$$E_{act.OT.UN4} := \frac{\left(K_{o.UN4} \cdot h_{E.OT.UN4}^{\;2}\right)}{2} \cdot \left(\gamma_r - \gamma_w\right) \cdot W_{hwas.UN4} \cdot -1 = -962.49 \cdot kN$$

At Rest- Soil Load Acting from Toe:

$$E_{act.OT.UN4.loc} := \frac{h_{E.OT.UN4}}{3} = 1.33\,m$$

All Lateral Loads Applicable to Overturning Stability Analysis

HW Lateral Load on Approach Slab:	$H_{hwas.UN4} = -7063.2 \cdot kN$	$H_{hwas.UN4.loc} = 0.63\,m$
HW Lateral Load on Guard Gate:	$H_{hwgg.UN4} = -1839.4 \cdot kN$	$H_{hwgg.UN4.loc} = 5.67\,m$
TW Lateral Load on Guard Gate:	$H_{twgg.UN4} = 265.6 \cdot kN$	$H_{twgg.UN4.loc} = 4.63\,m$
TW Lateral Load on Gate Footing (No Key - Overturning Values Adjusted):	$H_{twgf.UN4} = 2295.54 \cdot kN$	$H_{twgf.UN4.loc} = 1.66\,m$
TW Lateral Load on Key:	$H_{twkey.OT.UN4} = 2853.99 \cdot kN$	$H_{twkey.OT.UN4.loc} = -1.04\,m$
Ice / Impact Load:	$I_{UN4} = 0.0 \cdot kN$	$I_{UN4.loc} = 8.70\,m$
Lateral Soil Load (driving):	$E_{act.OT.UN4} = -962.5 \cdot kN$	$E_{act.OT.UN4.loc} = 1.33\,m$

Resisting Lateral Soil Load as required to produce horizontal equilibrium:

$$E_{pas.OT.UN4} := -\left(H_{hwas.UN4} + H_{hwgg.UN4} + H_{twgg.UN4} + H_{twgf.UN4} + H_{twkey.OT.UN4} + I_{UN4} + E_{act.OT.UN4}\right) = 4449.93 \cdot kN$$

Acting at:

$$E_{pas.OT.UN4.loc} := -1 \cdot \frac{d_{key}}{2} = -1\,m$$

Sum of All Overtuming Analysis Horizontal Load (ΣH=0):

$$\Sigma H_{UN4.OT} := H_{hwas.UN4} + H_{hwgg.UN4} + H_{twgg.UN4} + H_{twgf.UN4} + H_{twkey.OT.UN4} + I_{UN4} + E_{act.OT.UN4} + E_{pas.OT.UN4} = 0 \cdot kN$$

Sum of All Overtuming Analysis Horizontal Load Moments:

$$\begin{aligned}\Sigma M_{H.UN4.OT} := {} & H_{hwas.UN4} \cdot H_{hwas.UN4.loc} + H_{hwgg.UN4} \cdot H_{hwgg.UN4.loc} + H_{twgg.UN4} \cdot H_{twgg.UN4.loc} \cdots \\ & + H_{twgf.UN4} \cdot H_{twgf.UN4.loc} + H_{twkey.OT.UN4} \cdot H_{twkey.OT.UN4.loc} + I_{UN4} \cdot I_{UN4.loc} \cdots \\ & + E_{act.OT.UN4} \cdot E_{act.OT.UN4.loc} + E_{pas.OT.UN4} \cdot E_{pas.OT.UN4.loc}\end{aligned} = -18500.89 \cdot kN \cdot m$$

Overturning Stability Analysis

$\Sigma M_{UN4.OT} := \Sigma M_{V.UN4.OT} + \Sigma M_{H.UN4.OT} = 124714.45 \cdot kN \cdot m$ $\quad X_{R.UN4} := \frac{\Sigma M_{UN4.OT}}{\Sigma V_{UN4.OT}} = 8.49\,m$ $\quad x_{OT.UN4} := X_{R.UN4} - \frac{L_b}{2} = -0.76\,m$

Overturning Resultant Ratio

$$Ratio_{OT.UN4} := \frac{X_{R.UN4}}{L_b} = 0.46$$

$$Ratio_{OT.UN4.check} := \begin{cases} \text{"OKAY"} & \text{if } Ratio_{OT.UN4} \geq Ratio_{OT.UN4.min} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

$$x_{OT.check.UN4} := \begin{cases} \text{"OKAY"} & \text{if } \left|x_{OT.UN4}\right| \leq Kern \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

CHECK FOUNDATION BEARING CAPACITY (HORIZONTAL PLANE): UN4 CASE

Bearing Pressure Under Toe:

$$\sigma_{ToeUN4.OT} := \frac{\Sigma V_{UN4.OT}}{L_b \cdot W_b} + \frac{\left(\Sigma V_{UN4.OT} \cdot x_{OT.UN4}\right)}{S_b} = 39.9 \cdot kPa$$

$$Bearing_{ChecktoeUN4.OT} := \begin{vmatrix} \text{"OKAY "} & \text{if } \sigma_{ToeUN4.OT} < \sigma_{allow.UN4} \\ \text{"NG""} & \text{otherwise} \end{vmatrix} = \text{"OKAY "}$$

Bearing Pressure Under Heel:

$$\sigma_{HeelUN4.OT} := \frac{\Sigma V_{UN4.OT}}{L_b \cdot W_b} - \frac{\left(\Sigma V_{UN4.OT} \cdot x_{OT.UN4}\right)}{S_b} = 66.0 \cdot kPa$$

$$Bearing_{CheckheelUN4.OT} := \left(\begin{vmatrix} \text{"OKAY "} & \text{if } \sigma_{HeelUN4.OT} < \sigma_{allow.UN4} \wedge \sigma_{HeelUN4.OT} > 0 \\ \text{"NG""} & \text{otherwise} \end{vmatrix} \right) = \text{"OKAY "}$$

SUMMARY OF STABILITY ASSESSMENT:

Sliding Factor of Safety: (Horizontal Plane)

$FS_{HorizSliding.UN4} = 1.00$

$FS_{HorizSliding.UN4.Check} =$ "Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !"

Sliding Factor of Safety: (Inclined Plane)

$FS_{InclinedlSlidingUN4} = 2.38$ $FS_{InclinedSliding.check.UN4} =$ "OKAY "

Eccentricity: (Inclined Plane)

$e_{UN4} = 0.48 m$ $e_{check.UN4} =$ "Okay"

Bearing Pressure At Heel: (Inclined Plane)

$\sigma_{heel.UN4} = 55 \cdot kPa$ $\sigma_{heel.UN4.check} =$ "Okay"

Bearing Pressure At Toe: (Inclined Plane)

$\sigma_{toe.UN4} = 75 \cdot kPa$ $\sigma_{toe.UN4.1.check} =$ "Okay"

Flotation Factor of Safety (horizontal plane)

$FS_{act.FUN4} = 1.52$ $FS_{check.FUN4} =$ "OKAY"

Overturning Resultant Ratio: (horizontal plane)

$Ratio_{OT.UN4} = 0.46$ $Ratio_{OT.UN4.check} =$ "OKAY"

Eccentricity: (horizontal plane)

$x_{OT.UN4} = -0.76 m$ $x_{OT.check.UN4} =$ "OKAY"

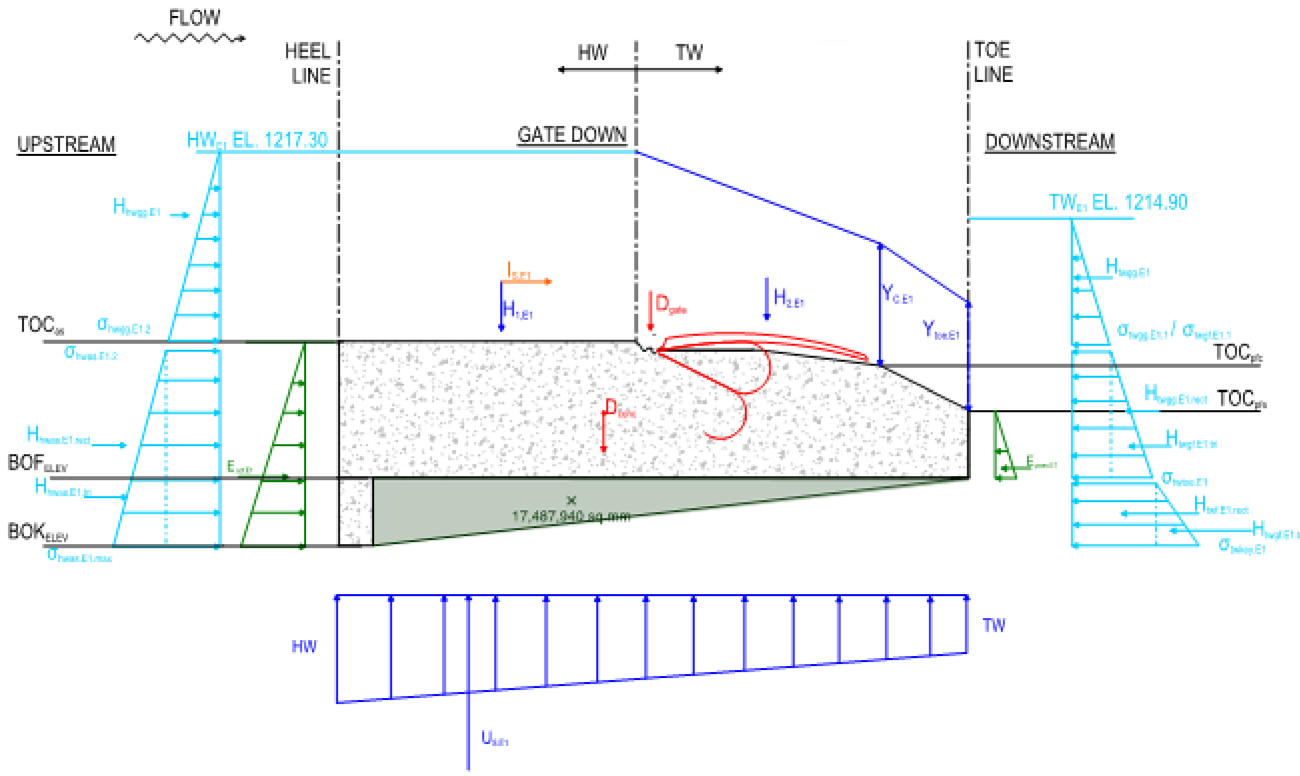
Bearing Pressure At Heel: (horizontal plane)

$\sigma_{HeelUN4.OT} = 66 \cdot kPa$ $Bearing_{CheckheelUN4.OT} =$ "OKAY "

Bearing Pressure At Toe: (horizontal plane)

$\sigma_{ToeUN4.OT} = 40 \cdot kPa$ $Bearing_{ChecktoeUN4.OT} =$ "OKAY "

E1 DESIGN CASE



ACCEPTANCE PARAMETERS

Required Factor of Safety for Sliding: $FS_{req.E1.sl} := 1.1$ (Without Cohesion) (Section 8.1, Design Criteria)

Resultant Within Middle Half of Base: $e \le \frac{L_b}{4} \wedge e \ge \frac{-L_b}{4}$

Allowable Rock Bearing Pressure: $\sigma_{allow.E1} := 1740 \cdot \frac{kN}{m^2}$ (Section 5.2, Design Criteria)

INPUT PARAMETERS

Headwater Elevation: $HW_{E1} := 1217.30m$ (Section 8.3, Design Criteria)

Tailwater Elevation: $TW_{E1} := 1214.90m$ (Section 8.3, Design Criteria)

Bottom of Footing Elevation: $BOF_{elev} = 1206\,m$

Approach Slab Top of Concrete Elevation at Upstream Face: $TOC_{as} = 1210\,m$

Footing Top of Concrete Elevation at Stilling Basin: $TOC_{pfe} = 1208\,m$

Footing Top of Concrete Elevation at Center of Footing: $TOC_{pfc} = 1209.3\,m$

Top of Guard/Regulating Gate Elevation: $TOP_{rg.E1} := 1210.00m$ $TOP_{gg.E1} := 1210.00m$

Bottom of Key Elevation: $BOK_{elev} = 1204\,m$

Gates are open when top of gate elevation is at 1210.00m

Gates are closed/up when top of gate elevation is at 1215.0m

Crestwater Elevation: Dynamic Flow $EL_{C.E1} := 1214.87m$

$$Y_{C.E1} := \begin{cases} (EL_{C.E1} - TOC_{pfc}) & \text{if } TOP_{gg.E1} \le HW_{E1} \\ (TW_{E1} - TOC_{pfc}) & \text{if } TOP_{gg.E1} > HW_{E1} \end{cases} = 5.57 \cdot m$$

Toewater Elevation: $EL_{TOE.E1} := 1211.06m$

$$Y_{TOE.E1} := \begin{cases} (EL_{TOE.E1} - TOC_{pfe}) & \text{if } TOP_{gg.E1} \le HW_{E1} \\ (TW_{E1} - TOC_{pfe}) & \text{if } TOP_{gg.E1} > HW_{E1} \end{cases} = 3.06 \cdot m$$

LATERAL WATER LOADS

E1 CASE

HEADWATER (DRIVING):

Headwater Depth on Gate: $D_{hwg.E1} := HW_{E1} - TOC_{as} = 7.30\,m$

Thickness of Approach Slab (Including Key): $T_{as} = 6\,m$

Headwater Depth at Heel (U/S face): $D_{hwas.E1} := HW_{E1} - BOK_{elev} = 13.30\,m$

Headwater Load Unit Width on Approach Slab: $W_{hwas.E1} := W_b = 15.00\,m$

Headwater Unit Load At Top of Approach Slab:

$$H_{hwas.E1.1} := \frac{-\left(\gamma_w \cdot D_{hwg.E1}{}^2\right)}{2} \cdot W_{hwas.E1} = -3920.81 \cdot kN$$

Headwater Unit Load At Bottom of Approach Key:

$$H_{hwas.E1.2} := \frac{-\left(\gamma_w \cdot D_{hwas.E1}{}^2\right)}{2} \cdot W_{hwas.E1} = -13014.7 \cdot kN$$

Headwater Line Load At Top of Approach Slab: $\sigma_{hwas.E1.1} := -\left(\gamma_w \cdot D_{hwg.E1}\right) = -71.61 \cdot kPa$

Headwater Line Load At Bottom of Approach Key: $\sigma_{hwas.E1.2} := -\left(\gamma_w \cdot D_{hwas.E1}\right) = -130.47 \cdot kPa$

Triangular Distribution Unit Load on Approach Slab and Key:

$$H_{hwas.E1.2.tri} := \left(\frac{\sigma_{hwas.E1.2} - \sigma_{hwas.E1.1}}{2}\right) \cdot \left(T_{as} \cdot W_{hwas.E1}\right) = -2648.7 \cdot kN$$

Rectangular Distribution Unit Load on Approach Slab and Key:

$$H_{hwas.E1.2.rect} := \sigma_{hwas.E1.1} \cdot \left(T_{as} \cdot W_{hwas.E1}\right) = -6445.17 \cdot kN$$

Total Horizontal Headwater Load on Approach Slab:

$$H_{hwas.E1} := H_{hwas.E1.2.tri} + H_{hwas.E1.2.rect} = -9093.87 \cdot kN$$

Apply Total Footing Headwater Load at:

$$H_{hwas.E1.loc} := \frac{\left(H_{hwas.E1.2.rect} \cdot \frac{T_{as}}{2} + H_{hwas.E1.2.tri} \cdot \frac{T_{as}}{3}\right)}{H_{hwas.E1.2.tri} + H_{hwas.E1.2.rect}} - d_{key} = 0.71\,m$$

Guard Gate Operating Condition:

Guard Gate Down/Open Condition: $A1_{E1} := TOP_{gg.E1} \le TOC_{as}$

Guard Crest Gate Up/Closed, with Top of Gate Higher than HW Elevation: $B1_{E1} := TOP_{gg.E1} \ge HW_{E1} \wedge TOP_{gg.E1} > TOC_{as}$

Guard Crest Gate Up/Closed, with Top of Gate Lower than HW Elevation: $C1_{E1} := TOP_{gg.E1} > TOC_{as} \wedge HW_{E1} > TOP_{gg.E1} = 0$

Guard Crest Gate Height: $H_{gg.E1} := TOP_{gg.E1} - TOC_{as} = 0\,m$

Headwater Depth at Guard Crest Gate: $D_{hwgg.E1} := HW_{E1} - TOC_{as} = 7.30\,m$

Guard Crest Gate Width: $W_{hwgg.E1} := 15.00m$

Lateral Headwater Pressure at Bottom of Guard Crest Gate:

$$\sigma_{hwgg.E1.1} := \begin{cases} (0.0kPa) & \text{if } A1_{E1} \\ -(\gamma_w \cdot D_{hwgg.E1}) & \text{if } B1_{E1} \\ -(\gamma_w \cdot D_{hwgg.E1}) & \text{if } C1_{E1} \end{cases} = 0.0 \cdot kPa$$

Lateral Headwater Pressure at Top of Guard Crest Gate:
(Load at HW Elevation On Guard Crest Gate if HW is below TOG_{rg})

$$\sigma_{hwgg.E1.2} := \begin{cases} (0.0kPa) & \text{if } A1_{E1} \\ 0.0kPa & \text{if } B1_{E1} \\ -\left[\gamma_w \cdot \left(HW_{E1} - TOP_{gg.E1}\right)\right] & \text{if } C1_{E1} \end{cases} = 0.0 \cdot kPa$$

Average Pressure acting on Guard Crest Gate:

$$\sigma_{hwgg.E1.avg} := \frac{\left(\sigma_{hwgg.E1.1} + \sigma_{hwgg.E1.2}\right)}{2} = 0 \cdot kPa$$

Total Area of Crest Gate:

$$A_{hwgg.E1} := \begin{cases} D_{hwgg.E1} \cdot W_{hwgg.E1} & \text{if } A1_{E1} \\ D_{hwgg.E1} \cdot W_{hwgg.E1} & \text{if } B1_{E1} \\ H_{gg.E1} \cdot W_{hwgg.E1} & \text{if } C1_{E1} \end{cases} = 109.5 \cdot m^2$$

Total Horizontal Headwater Load on Guard Crest Gate: $H_{hwgg.E1} := \sigma_{hwgg.E1.avg} \cdot A_{hwgg.E1} = 0.0 \cdot kN$

Apply Total Guard Crest Gate Headwater Load at:

$$H_{hwgg.E1.loc} := \begin{cases} \left(TOC_{as} - BOF_{elev}\right) & \text{if } A1_{E1} \\ \left[\dfrac{\left(HW_{E1} - TOC_{as}\right)}{3} + \left(TOC_{as} - BOF_{elev}\right)\right] & \text{if } B1_{E1} \\ \left[\dfrac{\sigma_{hwgg.E1.2} \cdot A_{hwgg.E1} \cdot \dfrac{\left(H_{gg.E1}\right)}{2} + \dfrac{\left(\sigma_{hwgg.E1.1} - \sigma_{hwgg.E1.2}\right)}{2} A_{hwgg.E1} \cdot \dfrac{\left(H_{gg.E1}\right)}{3}}{\sigma_{hwgg.E1.2} \cdot A_{hwgg.E1} + \dfrac{\left(\sigma_{hwgg.E1.1} - \sigma_{hwgg.E1.2}\right)}{2} \cdot A_{hwgg.E1}} \dots \\ + \left(TOC_{as} - BOF_{elev}\right)\right] & \text{if } C1_{E1} \end{cases} = 4.0 \cdot m$$

LATERAL TAILWATER (RESISTING) Applied to Downstream Side of Guard Crest Gate: E1 CASE

Guard Gate Down/Open Condition: $A2_{E1} := TOP_{gg.E1} \le TOC_{as}$

Guard Crest Gate Up/Closed, with Top of Gate Higher than TW Elevation: $B2_{E1} := TOP_{gg.E1} \ge TW_{E1} \wedge TOP_{gg.E1} > TOC_{as} = 0$

Guard Crest Gate Up/Closed, with Top of Gate Lower than TW Elevation: $C2_{E1} := TOP_{gg.E1} > TOC_{as} \wedge TW_{E1} > TOP_{gg.E1} = 0$

Tailwater Depth at Guard Crest Gate: $D_{twgg.E1} := TW_{E1} - TOC_{as} = 4.90\,m$

Guard Crest Gate Width: $W_{twgg.E1} := 15.00m$

Lateral Water Load at Bottom of Guard Crest Gate:

$$\sigma_{twgg.E1.1} := \begin{cases} (0.0kPa) & \text{if } A2_{E1} \\ (\gamma_w \cdot D_{twgg.E1}) & \text{if } B2_{E1} \\ (\gamma_w \cdot D_{twgg.E1}) & \text{if } C2_{E1} \end{cases} = 0.0 \cdot kPa$$

Lateral Water Load at Top of Guard Crest Gate:
(Load at TW Elevation On Guard Crest Gate if TW is below TOG_{gg})

$$\sigma_{twgg.E1.2} := \begin{cases} (0.0kPa) & \text{if } A2_{E1} \\ 0.0kPa & \text{if } B2_{E1} \\ \left[\gamma_w \cdot (TW_{E1} - TOP_{gg.E1})\right] & \text{if } C2_{E1} \end{cases} = 0.0 \cdot kPa$$

Average Pressure acting on Guard Crest Gate:

$$\sigma_{twgg.E1.avg} := \frac{(\sigma_{twgg.E1.1} + \sigma_{twgg.E1.2})}{2} = 0 \cdot kPa$$

Total Area water acting on Crest Gate:

$$A_{twgg.E1} := \begin{cases} D_{twgg.E1} \cdot W_{twgg.E1} & \text{if } A2_{E1} \\ D_{twgg.E1} \cdot W_{twgg.E1} & \text{if } B2_{E1} \\ H_{gg.E1} \cdot W_{twgg.E1} & \text{if } C2_{E1} \end{cases} = 73.5 \cdot m^2$$

Total Horizontal Tailwater Load on Guard Crest Gate: $H_{twgg.E1} := \sigma_{twgg.E1.avg} \cdot A_{twgg.E1} = 0.0 \cdot kN$

Apply Total Horiz. TW Load on Guard Gate at:

$$H_{twgg.E1.loc} := \begin{cases} (TOC_{as} - BOF_{elev}) & \text{if } A2_{E1} \\ \left[\frac{(TW_{E1} - TOC_{as})}{3} + (TOC_{as} - BOF_{elev})\right] & \text{if } B2_{E1} \\ \left[\dfrac{\sigma_{twgg.E1.2} \cdot A_{twgg.E1} \cdot \frac{(H_{gg.E1})}{2} + \frac{(\sigma_{twgg.E1.1} - \sigma_{twgg.E1.2})}{2} A_{twgg.E1} \cdot \frac{(H_{gg.E1})}{3}}{\sigma_{twgg.E1.2} \cdot A_{twgg.E1} + \frac{(\sigma_{twgg.E1.1} - \sigma_{twgg.E1.2})}{2} \cdot A_{twgg.E1}} \ldots \\ + (TOC_{as} - BOF_{elev})\right] & \text{if } C2_{E1} \end{cases} = 4.0 \cdot m$$

LATERAL WATER LOADS (continued)

E1 CASE

TAILWATER (RESISTING) Applied to Concrete Structure:

Tailwater Depth At top of Gate Base Footing Elevation: $D_{twgf.E1} := TW_{E1} - TOC_{as} = 4.90\,m$

Water Depth at bottom of Gate Base Footing: $D_{twtoe.E1} := TW_{E1} - BOF_{elev} = 8.90\,m$

Footing Thickness at Toe $h_{toe} = 4\,m$

Unit Width of D/S face of crest for application of Tailwater Load: $W_{tw.E1} := W_b = 15.00\,m$

Tailwater Pressure At Top of Gate Footing: $\sigma_{twgf.E1} := \left(\gamma_w \cdot D_{twgf.E1}\right) = 48.07 \cdot kPa$

Tailwater Line Load At Bottom of Gate Footing: $\sigma_{twtoe.E1} := \left(\gamma_w \cdot D_{twtoe.E1}\right) = 87.31 \cdot kPa$

Triangular Distribution Unit Load on Gate Footing Base:

$$H_{twgf.E1.tri} := \left(\frac{\sigma_{twtoe.E1} - \sigma_{twgf.E1}}{2}\right) \cdot \left(h_{toe} \cdot W_{tw.E1}\right) = 1177.2 \cdot kN$$

Rectangular Distribution Unit Load on Gate Footing Base:

$$H_{twgf.E1.rect} := \sigma_{twgf.E1} \cdot \left(h_{toe} \cdot W_{tw.E1}\right) = 2884.14 \cdot kN$$

Tailwater Pressure At Bottom of Sliding Failure Plane: $\sigma_{twbk.E1} := \left(HW_{E1} - BOK_{elev}\right) \cdot \gamma_w = 130.47 \cdot kPa$

Triangular Distribution Unit Load Below Footing:

$$H_{twbk.E1.tri} := \frac{\left(\sigma_{twbk.E1} - \sigma_{twtoe.E1}\right)}{2} \cdot d_{key} \cdot W_{tw.E1} = 647.46 \cdot kN$$

Rectangular Distribution Load Below Footing Base: $H_{twbk.E1.rect} := \sigma_{twtoe.E1} \cdot d_{key} \cdot W_{tw.E1} = 2619.27 \cdot kN$

Total Horizontal Tailwater Load on Gate Footing (including key):

$$H_{twgk.E1} := H_{twgf.E1.tri} + H_{twgf.E1.rect} + H_{twbk.E1.tri} + H_{twbk.E1.rect} = 7328.07 \cdot kN$$

Apply Total Gate Footing Tailwater Load at:

$$H_{twgk.E1.loc} := \frac{\left[H_{twgf.E1.rect} \cdot \frac{\left(h_{toe}\right)}{2} + H_{twgf.E1.tri} \cdot \frac{\left(h_{toe}\right)}{3} + H_{twbk.E1.tri} \cdot \left(-d_{key} \cdot \frac{2}{3}\right) + H_{twbk.E1.rect} \cdot \left(\frac{-d_{key}}{2}\right)\right]}{H_{twgf.E1.tri} + H_{twgf.E1.rect} + H_{twbk.E1.tri} + H_{twbk.E1.rect}} = 0.53\,m$$

SUMMATION OF LATERAL WATER LOADS:

$$\Sigma H_{Water.E1} := H_{hwas.E1} + H_{hwgg.E1} + H_{twgk.E1} + H_{twgg.E1} = -1765.8 \cdot kN$$

$$\Sigma M_{Hwater.E1} := H_{hwas.E1} \cdot H_{hwas.E1.loc} + H_{hwgg.E1} \cdot H_{hwgg.E1.loc} \cdots + H_{twgk.E1} \cdot H_{twgk.E1.loc} + H_{twgg.E1} \cdot H_{twgg.E1.loc} = -2589.84 \cdot kN \cdot m$$

VERTICAL WATER LOADS

E1 CASE

HEADWATER:

Water Depth on top of Approach Slab: $d_{hw.E1} := HW_{E1} - TOC_{as} = 7.30\,m$

Length of Approach Slab: $L_{as} = 8.75\,m$

Width of Approach Slab: $w_{as} = 15.00\,m$

Vertical Water Weight (H1) on Approach Slab: $H_{1.E1} := \left(w_{as} \cdot d_{hw.E1} \cdot L_{as}\right) \cdot \gamma_w = 9399.2 \cdot kN$

Moment Arm for Application of Water Weight (H1) from toe: $H_{1.E1.loc} := L_b - \frac{L_{as}}{2} = 14.13\,m$

TAILWATER:

Trapezoid Volume Above Gate Footing from Approach Slab to Crest: $V_{asc.E1} := \left(L_{gf} - L_{gfc}\right) W_b \frac{d_{hw.E1} + Y_{C.E1}}{2} = 690.15 \cdot m^3$

Trapezoid Volume Above Gate Footing Crest to End of Gate Footing: $V_{gfc.E1} := \left(L_{gfc} \cdot W_b\right) \frac{Y_{C.E1} + Y_{TOE.E1}}{2} = 168.28 \cdot m^3$

Load Above Gate Footing from Approach Slab to Crest: $H_{2.E1.asc} := V_{asc.E1} \cdot \gamma_w = 6770.41 \cdot kN$

Load Acting Above Footing Crest from Toe: $H_{2.E1.asc.loc} := \frac{\left(L_{gf} - L_{gfc}\right) \cdot \left(2 \cdot d_{hw.E1} + Y_{C.E1}\right)}{3 \cdot \left(d_{hw.E1} + Y_{C.E1}\right)} + L_{gfc} = 6.34\,m$

Load Above Gate Footing from Crest to End: $H_{2.E1.gfc} := V_{gfc.E1} \cdot \gamma_w = 1650.88 \cdot kN$

Load Acting Above Gate Footing from Crest to End: $H_{2.E1.gfc.loc} := \frac{\left(L_{gfc}\right) \cdot \left(2 \cdot Y_{C.E1} + Y_{TOE.E1}\right)}{3 \cdot \left(Y_{C.E1} + Y_{TOE.E1}\right)} = 1.43\,m$

Vertical Water Weight (H2) on Gate Footing: $H_{2.E1} := H_{2.E1.asc} + H_{2.E1.gfc} = 8421.28 \cdot kN$

Moment Arm for Application of Water Weight (H2) from toe: $H_{2.E1.loc} := \frac{H_{2.E1.asc} \cdot H_{2.E1.asc.loc} + H_{2.E1.gfc} \cdot H_{2.E1.gfc.loc}}{H_{2.E1}} = 5.37\,m$

UPLIFT AT INCLINE SLIDING PLANE

E1 CASE

Uplift pressure at U/S Face (heel): $U_{HW.E1} := D_{hwas.E1} \cdot \gamma_w = 130.5 \cdot \frac{kN}{m^2}$

Uplift pressure at D/S Face Stilling Basin: $U_{TW.E1} := \left(D_{twtoe.E1}\right) \cdot \gamma_w = 87.31 \cdot \frac{kN}{m^2}$

Length from U/S of Gate Structure to D/S of Stilling Basin: $L_{overall} = 18.50\,m$

Difference between Uplift pressure at HW and TW: $U_{diff.E1} := U_{HW.E1} - U_{TW.E1} = 43.16 \cdot \frac{kN}{m^2}$

Slope of difference between between Uplift pressure at HW and TW: $U_{slope.E1} := \frac{U_{diff.E1}}{L_{overall}} = 2.33 \cdot \frac{kN}{m^2 \cdot m}$

Tailwater Pressure at toe of Gate Structure: $U_{press.toe.gs.E1} := U_{TW.E1} + \left(L_{overall} - L_b\right) \cdot U_{slope.E1} = 87.31 \cdot \frac{kN}{m^2}$

Uniform uplift force UA Under Gate Structure due to TW (rectangle): $U_{A.E1} := U_{press.toe.gs.E1} \cdot L_b \cdot W_b \cdot -1 = -24228.25 \cdot kN$

Moment Arm from Toe of Gate Structure for Uplift UA: $L_{A.E1} := \left(\frac{L_b}{2}\right) = 9.25\,m$

Linearly Decreasing Uplift Force E1B Under Gate Structure due to HW-TW Differential (triangle): $U_{B.E1} := \frac{1}{2} \cdot \left(U_{HW.E1} - U_{press.toe.gs.E1}\right) \cdot L_b \cdot W_b \cdot -1 = -5989 \cdot kN$

Moment Arm from Toe of Gate Structure for Uplift UB: $L_{B.E1} := \frac{2}{3} \cdot L_b = 12.33\,m$

Total Resultant Uplift force: $U_{E1} := U_{A.E1} + U_{B.E1} = -30217.25 \cdot kN$

Resultant Location from Toe: $U_{E1.loc} := \frac{\left(U_{A.E1} \cdot L_{A.E1} + U_{B.E1} \cdot L_{B.E1}\right)}{\left(U_{A.E1} + U_{B.E1}\right)} = 9.86\,m$

$\Sigma V_{water.E1} := H_{1.E1} + H_{2.E1} + U_{E1} = -12396.76 \cdot kN$

$\Sigma M_{Vwater.E1} := H_{1.E1} \cdot H_{1.E1.loc} + H_{2.E1} \cdot H_{2.E1.loc} + U_{E1} \cdot U_{E1.loc} = -119965.9 \cdot kN \cdot m$

SOIL LOADS

E1 CASE

Equivalent Fluid Pressure (EFP):

At rest lateral pressure coefficient: $K_{o.E1} := 1 - \sin(\phi_{backfill}) = 0.658$ (Section 5.3, Design Criteria)

Headwater Pier Footing Unit Width: $W_{hwas.E1} = 15.00\,m$

Tailwater Pier Footing Unit Width: $W_{tw.E1} = 15.00\,m$

Pier Footing Thickness at Heel: $t_{hf.E1} := TOC_{as} - BOK_{elev} = 6.00\,m$

Fixed Crest Footing Thickness at Toe: $t_{tf.E1} := TOC_{pfe} - BOF_{elev} = 2.00\,m$

Lateral Driving Force (Headwater Side - at rest condition)

At-Rest Soil Load:

$$E_{act.E1} := \frac{\left(K_{o.E1} \cdot t_{hf.E1}^{\,2}\right)}{2} \cdot (\gamma_r - \gamma_w) \cdot W_{hwas.E1} \cdot -1 = -2165.61 \cdot kN$$

Acting at:

$$E_{act.E1.loc} := \frac{t_{hf.E1}}{3} = 2.00\,m$$

Lateral Resisting Force (Tailwater Side - at rest condition)

At-rest Soil Load:

$$E_{pass.E1} := \frac{\left(K_{o.E1} \cdot t_{tf.E1}^{\,2}\right)}{2} \cdot (\gamma_r - \gamma_w) \cdot W_{tw.E1} = 240.62 \cdot kN$$

Acting at:

$$E_{pass.E1.loc} := \frac{t_{tf.E1}}{3} = 0.67\,m$$

$$\Sigma H_{soil.E1} := E_{act.E1} + E_{pass.E1} = -1924.99 \cdot kN$$

$$\Sigma M_{soil.E1} := E_{act.E1} \cdot E_{act.E1.loc} + E_{pass.E1} \cdot E_{pass.E1.loc} = -4170.8 \cdot kN \cdot m$$

ICE / IMPACT LOADS (ASSUME NO ICE LOADING ON TAILWATER SIDE)

Static Ice load on Gates:

$$I_{G.E1} := \begin{cases} 00 \dfrac{kN}{m} & \text{if } TOP_{gg.E1} \le TOC_{as} \\ 0.0 \dfrac{kN}{m} & \text{if } TOP_{gg.E1} > TOC_{as} \end{cases} = 0 \cdot \frac{kN}{m}$$

(Section 7.7, Design Criteria)

Ice Loading Unit Width on Guard Gate: $W_{gg.E1} := 15.00m$ (Input value for load case)

Total Ice Load on Structure: $I_{E1} := -\left(I_{G.E1} \cdot W_{gg.E1}\right) = 0 \cdot kN$

Apply Ice load at: $I_{E1.loc} := \left(TOP_{gg.E1} - BOF_{elev} - 0.30m\right) = 3.70\,m$

$$\Sigma H_{I.E1} := I_{E1} = 0 \cdot kN$$

$$\Sigma M_{I.E1} := I_{E1} \cdot I_{E1.loc} = 0 \cdot kN \cdot m$$

SEISMIC LOAD (NOT APPLICABLE FOR THIS LOAD CASE)

E1 CASE

SUMMARY OF LOADS

	Loads	Moment Arm
Dead load of Concrete Structure:	$D_{conc} = 24618.6 \cdot kN$	$X_{conc.loc} = 10.06\,m$
Obermyer Gate Weight:	$D_{Gate} = 210.0 \cdot kN$	$X_{gate} = 6.60\,m$
HW Lateral Load on Approach Slab:	$H_{hwas.E1} = -9093.9 \cdot kN$	$H_{hwas.E1.loc} = 0.71\,m$
HW Lateral Load on Guard Gate:	$H_{hwgg.E1} = 0.0 \cdot kN$	$H_{hwgg.E1.loc} = 4.00\,m$
TW Lateral Load on Gate Footing (Including Key - Sliding Check Loads):	$H_{twgk.E1} = 7328.07 \cdot kN$	$H_{twgk.E1.loc} = 0.53\,m$
TW Lateral Load on Guard Gate:	$H_{twgg.E1} = 0.0 \cdot kN$	$H_{twgg.E1.loc} = 4.00\,m$
Vertical HW Load on Approach Slab:	$H_{1.E1} = 9399.2 \cdot kN$	$H_{1.E1.loc} = 14.13\,m$
Vertical TW Load on Pier Footing (crest):	$H_{2.E1} = 8421.3 \cdot kN$	$H_{2.E1.loc} = 5.37\,m$
Uplift:	$U_{E1} = -30217.3 \cdot kN$	$U_{E1.loc} = 9.86\,m$
Lateral Soil Load (driving):	$E_{act.E1} = -2165.6 \cdot kN$	$E_{act.E1.loc} = 2.00\,m$
Lateral Soil Load (resisting):	$E_{pass.E1} = 240.62 \cdot kN$	$E_{pass.E1.loc} = 0.67\,m$
Ice / Impact Load:	$I_{E1} = 0.0 \cdot kN$	$I_{E1.loc} = 3.70\,m$

STABILITY ASSESSMENT (SLIDNG, BEARING, FLOTATION AND OVERTURNING):

E1 CASE

CHECK SLIDING ALONG HORIZONTAL PLANE THRU TOE, IGNORING BEDROCK MOBILIZED BY STRUCTURAL HEEL KEY, OR VOID BEHIND KEY

Sum of Vertical Forces:

$\Sigma V_{E1} := \Sigma V_{DL} + \Sigma V_{water.E1} = 12431.8 \cdot kN$

Sum of Horizontal Forces:

$\Sigma H_{E1} := \Sigma H_{Water.E1} + \Sigma H_{soil.E1} + \Sigma H_{I.E1} = -3690.79 \cdot kN$

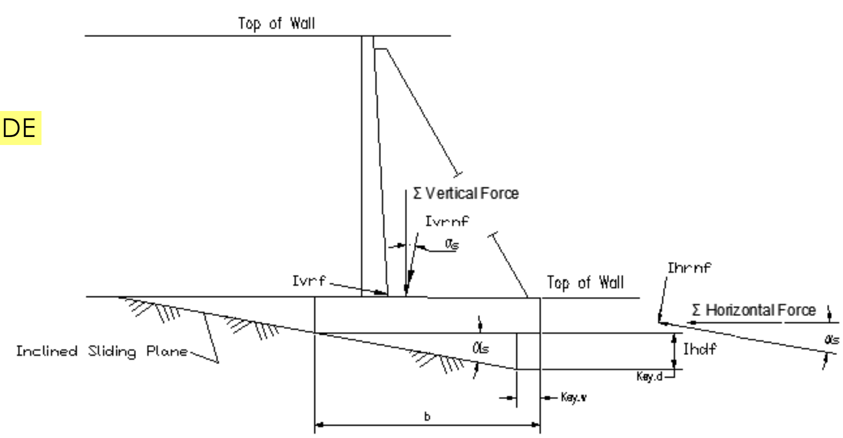
Sliding Factor of Safety: $FS_{HorizSliding.E1} := \dfrac{\tan_{\phi} \cdot \Sigma V_{E1}}{|\Sigma H_{E1}|} = 1.64$

ɔ Key or Void Behinc $FS_{HorizSliding.E1.Check} :=$ | "OKAY" if $FS_{HorizSliding.E1} \geq FS_{req.E1.sl}$ = "OKAY"
| "Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !" otherwise

CHECK SLIDING ALONG INCLINED SLIDING PLANE FROM HEEL KEY TO TOE, WITH BEDROCK MASS MOBILIZED BY REINFOCREDE CONCRETE KEY)

RESISTING SIDE

DRIVING SIDE



TOE

HEEL

Ivrf=Inclined Resisting Force
Ivrnf=Inclined Resisting Normal Force
Ihrnf=Inclined Resisting Normal Force
Ihdf=Inclined Driving Force

$\alpha s = 0.11$

as degrees= $\alpha s \cdot \left(\dfrac{180}{\pi}\right) = 6.52$

$\Sigma V_{UN3} = 12392.33 \cdot kN$

$V_{rs} = 5775 \cdot kN$

Resolve $\Sigma Vert_{E1}$ & $\Sigma Horiz_{E1}$

$\Sigma V_{InclinedE1} := \cos(\alpha s) \cdot \left(\Sigma V_{E1} + V_{rs}\right) + \sin(\alpha s) \cdot |\Sigma H_{E1}| = 18508.2 \cdot kN$

$\Sigma H_{InclinedE1} := \cos(\alpha s) \cdot |\Sigma H_{E1}| - \sin(\alpha s) \cdot \left(\Sigma V_{E1} + V_{rs}\right) = 1599.6 \cdot kN$

(With properly engineered reinforced concrete Key, horizontal sliding plane thru Toe is protected, critical sliding plane is relocated to the INCLINED SLIDING PLANE FROM HEEL KEY To TOE, Bedrock Mass above this examined plane is mobilized by reinforced concrete key and combined into Structural Wedge.)

Inclined Sliding Plane Length

$L_{incline} = 18.61 \, m$

Safety Factor for Sliding Inclined Failure Plane

$FS_{InclinedlSlidingE1} := \dfrac{\Sigma V_{InclinedE1} \cdot \tan\left(\phi_{rock} \cdot \dfrac{\pi}{180}\right)}{|\Sigma H_{InclinedE1}|} = 5.64$

$FS_{InclinedSliding.check.E1} :=$ | "OKAY " if $FS_{InclinedlSlidingE1} > FS_{req.E1.sl}$ = "OKAY "
| "Revise Structure"" otherwise

$FS_{InclinedSliding.check.E1}$ = "OKAY "

OVERTURNING STABILITY CHECK:

E1 CASE

CHECK ECCENTRICITY

Sum of the moments:

$$\Sigma M_{E1} := \Sigma M_{DL} + \Sigma M_{Hwater.E1} + \Sigma M_{Vwater.E1} + \Sigma M_{I.E1} + \Sigma M_{soil.E1} + \Sigma M_{soil} = 189592 \cdot kN \cdot m$$

Eccentricity:

$$e_{E1} := \left(\frac{L_{incline}}{2}\right) - \frac{\Sigma M_{E1}}{\Sigma V_{InclinedE1}} = -0.94\,m$$

Eccentricity Check:

$$e_{check.E1} := \begin{vmatrix} \text{"Okay"} & \text{if } \left|e_{E1}\right| \le Midhalf \\ \text{"Revise Structure"} & \text{otherwise} \end{vmatrix}$$

$e_{check.E1} = \text{"Okay"}$

Foundation Bearing Checks:

Incline Plane Area: $A_{b.incline} = 279.12\,m^2$

Incline Plane Section Modulus: $S_{b.incline} = 865.63 \cdot m^3$

Bearing Pressure at Heel:

$$\sigma_{heel.E1} := \frac{\Sigma V_{InclinedE1}}{A_{b.incline}} - \frac{\Sigma V_{InclinedE1} \cdot e_{E1}}{S_{b.incline}} = 86.4 \cdot \frac{kN}{m^2}$$

$$\sigma_{heel.E1.check} := \left(\begin{vmatrix} \text{"Okay"} & \text{if } \sigma_{heel.E1} \le \sigma_{allow.E1} \\ \text{"Revise Structure"} & \text{if } \sigma_{heel.E1} < 0\,\frac{kN}{m^2} \end{vmatrix}\right)$$

$\sigma_{heel.E1.check} = \text{"Okay"}$

Bearing Pressure at Toe:

$$\sigma_{toe.E1} := \frac{\Sigma V_{InclinedE1}}{A_{b.incline}} + \frac{\Sigma V_{InclinedE1} \cdot e_{E1}}{S_{b.incline}} = 46.2 \cdot \frac{kN}{m^2}$$

$$\sigma_{toe.E1.1.check} := \begin{vmatrix} \text{"Okay"} & \text{if } \sigma_{toe.E1} \le \sigma_{allow.E1} \\ \text{"Revise Structure"} & \text{if } \sigma_{toe.E1} < 0\,\frac{kN}{m^2} \end{vmatrix}$$

$\sigma_{toe.E1.1.check} = \text{"Okay"}$

FLOATATION ANALYSIS:

ACCEPTANCE PARAMETERS

Required Factor of Safety: $FS_{req.FE1} := 1.1$

VERTICAL LOADS RESISTING:

Dead Load: $\Sigma V_{DL} = 24828.6 \cdot kN$

Water Weight H1+H2: $\Sigma V_{H.FE1} := H_{1.E1} + H_{2.E1} = 17820.49 \cdot kN$

Summation Vertical Resisting: $\Sigma V_{FE1} := \Sigma V_{DL} + \Sigma V_{H.FE1} = 42649.1 \cdot kN$

VERTICAL LOADS UPLIFT:

Uplift: $U_{E1} = -30217.25 \cdot kN$

Factor of Safety Floatation:

$$FS_{act.FE1} := \frac{\Sigma V_{FE1}}{\left|U_{E1}\right|} = 1.41$$

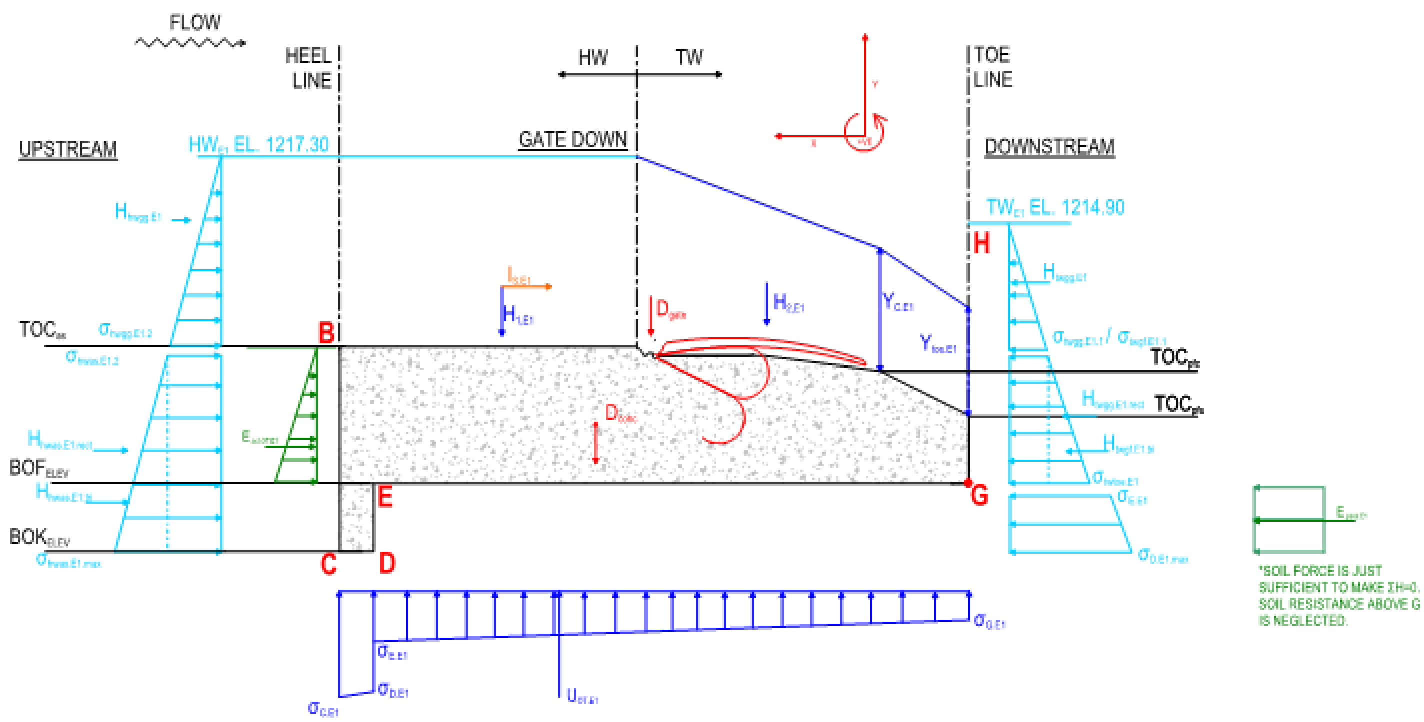
$$FS_{check.FE1} := \begin{vmatrix} \text{"OKAY"} & \text{if } FS_{act.FE1} \ge FS_{req.FE1} \\ \text{"ANCHORS REQUIRED"} & \text{if } FS_{act.FE1} < FS_{req.FE1} \end{vmatrix} = \text{"OKAY"}$$

MONOLITH OVERTURNING STABILITY ANALYSIS

E1 CASE

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.
Assumptions are made in order to compute overturning stability of indetermine forces on monolith with key;
(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.
(b) The horizontal resisting force acting on the key, P.key, is that required for static equilibrium
(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1 $\text{Ratio}_{OT.E1.min} := 0.25$ Resultant at Middle Half



Uplift Loads for Overturning Stability Analysis

Line of Creep:

Change in Water Head: $\Delta_{h.E1} := HW_{E1} - TW_{E1} = 2.4\,m$

Length from Point C to Point G: $L_{CG} = 18.61\,m$

Length from Various Points to Points: $L_{CD} = 1\,m$ $L_{DE} = 2\,m$ $L_{EG} = 17.5\,m$

$L_{GH.E1} := TW_{E1} - BOF_{elev} = 8.9\,m$

Length from Point C, D, E to G: $L_{CDEG} = 20.5\,m$ $L_{CDE} = 3\,m$

Water Pressure at Point C: $\sigma_{C.E1} := \sigma_{hwas.E1.2} = -130.47\cdot kPa$

Water Pressure at Point G: $\sigma_{G.E1} := \sigma_{twtoe.E1}\cdot -1 = -87.31\cdot kPa$

Water Pressure at Point D: $$\sigma_{D.E1} := -\gamma_w\cdot\left[\left(HW_{E1} - BOK_{elev}\right) - \frac{\Delta_{h.E1}\cdot L_{CD}}{L_{CDEG}}\right] = -129.32\cdot kPa$$

Water Pressure at Point E: $$\sigma_{E.E1} := -\gamma_w\cdot\left[\left(HW_{E1} - BOF_{elev}\right) - \frac{\Delta_{h.E1}\cdot L_{CDE}}{L_{CDEG}}\right] = -107.41\cdot kPa$$

Uplift for Overturning Analysis on Bottom of Key: $$U_{OT.E1.key} := \frac{\sigma_{C.E1} + \sigma_{D.E1}}{2}\cdot L_{CD}\cdot W_b = -1948.48\cdot kN$$

Acting at: $$U_{OT.E1.key.loc} := \frac{L_{CD}\cdot\left(2\cdot\sigma_{C.E1} + \sigma_{D.E1}\right)}{3\left(\sigma_{C.E1} + \sigma_{D.E1}\right)} + L_{EG} = 18\,m$$

E1 CASE

Uplift for Overturning Analysis on Bottom of Footing:

$$U_{OT.E1.ftg} := \frac{\sigma_{E.E1} + \sigma_{G.E1}}{2} \cdot L_{EG} \cdot W_b = -25556.55 \cdot kN$$

Acting at:

$$U_{OT.E1.ftg.loc} := \frac{L_{EG} \cdot \left(\sigma_{G.E1} + 2 \cdot \sigma_{E.E1}\right)}{3\left(\sigma_{G.E1} + \sigma_{E.E1}\right)} = 9.05\,m$$

Uplift Load for Overturning Analysis:

$$U_{OT.E1} := U_{OT.E1.key} + U_{OT.E1.ftg} = -27505.03 \cdot kN$$

Uplift Load Acting from Toe:

$$U_{OT.E1.loc} := \frac{U_{OT.E1.key} \cdot U_{OT.E1.key.loc} + U_{OT.E1.ftg} \cdot U_{OT.E1.ftg.loc}}{U_{OT.E1}} = 9.69\,m$$

All Vertical Loads Applicable to Overturning Stability Analysis

Total Concrete Dead Loads:	$D_{conc} = 24618.6 \cdot kN$	at:	$X_{conc.loc} = 10.06\,m$
Dead Load of Gate:	$D_{Gate} = 210.0 \cdot kN$		$X_{gate} = 6.60\,m$
Water Weight (HW) on Apron Slab:	$H_{1.E1} = 9399.2 \cdot kN$		$H_{1.E1.loc} = 14.13\,m$
Water Weight (TW) on Gate Footing:	$H_{2.E1} = 8421.3 \cdot kN$		$H_{2.E1.loc} = 5.37\,m$
Uplift Load for Overturning Analysis:	$U_{OT.E1} = -27505.03 \cdot kN$		$U_{OT.E1.loc} = 9.69 \cdot m$

Sum of All Overturning Analysis Vertical Load:

$$\Sigma V_{E1.OT} := D_{conc} + D_{Gate} + H_{1.E1} + H_{2.E1} + U_{OT.E1} = 15144.06 \cdot kN$$

Sum of All Overturning Analysis Vertical Load Moments:

$$\Sigma M_{V.E1.OT} := D_{conc} \cdot X_{conc.loc} + D_{Gate} \cdot X_{gate} + H_{1.E1} \cdot H_{1.E1.loc} + H_{2.E1} \cdot H_{2.E1.loc} + U_{OT.E1} \cdot U_{OT.E1.loc} = 160565.73 \cdot kN \cdot m$$

Lateral Tailwater Loads for Overturning Stability Analysis

TW Lateral Load on Gate Footing (No Key - Overturning Values Adjusted):

$$H_{twgf.E1} := H_{twgf.E1.tri} + H_{twgf.E1.rect} = 4061.34 \cdot kN$$

Acting at:

$$H_{twgf.E1.loc} := \frac{\frac{h_{toe}}{3} \cdot H_{twgf.E1.tri} + \frac{h_{toe}}{2} \cdot H_{twgf.E1.rect}}{H_{twgf.E1}} = 1.81\,m$$

Horizontal Tailwater Pressure Top of Key (Overturning Analysis):

$$\sigma_{twtk.OT.E1} := \sigma_{E.E1} \cdot -1 = 107.41 \cdot kPa$$

Horizontal Tailwater Pressure Bottom of Key (Overturning Analysis):

$$\sigma_{twbk.OT.E1} := \sigma_{D.E1} \cdot -1 = 129.32 \cdot kPa$$

Triangular Distribution Unit Load Acting at Key:

$$H_{twbk.OT.E1.tri} := \frac{\left(\sigma_{twbk.OT.E1} - \sigma_{twtk.OT.E1}\right)}{2} \cdot d_{key} \cdot W_{tw.E1} = 328.75 \cdot kN$$

Triangular Distribution Unit Load Acting at Key:

$$H_{twbk.OT.E1.rect} := \sigma_{twtk.OT.E1} \cdot d_{key} \cdot W_{tw.E1} = 3222.23 \cdot kN$$

Total Horizontal Tailwater Load on Key (Overturning Values Adjusted):

$$H_{twkey.OT.E1} := H_{twbk.OT.E1.tri} + H_{twbk.OT.E1.rect} = 3550.98 \cdot kN$$

Acting at:

$$H_{twkey.OT.E1.loc} := \frac{H_{twbk.OT.E1.tri} \cdot \frac{-2 \cdot d_{key}}{3} + H_{twbk.OT.E1.rect} \cdot \frac{-d_{key}}{2}}{H_{twkey.OT.E1}} = -1.03 \cdot m$$

E1 CASE

Lateral Driving Earth Loads for Overturning Stability Analysis (at rest condition)

Depth of Driving Soil Loads (to top of key): $h_{E.OT.E1} := TOC_{as} - BOF_{elev} = 4\ m$

At-Rest Soil Load: $E_{act.OT.E1} := \dfrac{\left(K_{o.E1} \cdot h_{E.OT.E1}^{\ 2}\right)}{2} \cdot \left(\gamma_r - \gamma_w\right) \cdot W_{hwas.E1} \cdot -1 = -962.49 \cdot kN$

At Rest- Soil Load Acting from Toe: $E_{act.OT.E1.loc} := \dfrac{h_{E.OT.E1}}{3} = 1.33\ m$

All Lateral Loads Applicable to Overturning Stability Analysis

HW Lateral Load on Approach Slab:	$H_{hwas.E1} = -9093.9 \cdot kN$	$H_{hwas.E1.loc} = 0.71\ m$
HW Lateral Load on Guard Gate:	$H_{hwgg.E1} = 0.0 \cdot kN$	$H_{hwgg.E1.loc} = 4.00\ m$
TW Lateral Load on Guard Gate:	$H_{twgg.E1} = 0.0 \cdot kN$	$H_{twgg.E1.loc} = 4.00\ m$
TW Lateral Load on Gate Footing (No Key - Overturning Values Adjusted):	$H_{twgf.E1} = 4061.34 \cdot kN$	$H_{twgf.E1.loc} = 1.81\ m$
TW Lateral Load on Key:	$H_{twkey.OT.E1} = 3550.98 \cdot kN$	$H_{twkey.OT.E1.loc} = -1.03\ m$
Ice / Impact Load:	$I_{E1} = 0.0 \cdot kN$	$I_{E1.loc} = 3.70\ m$
Lateral Soil Load (driving):	$E_{act.OT.E1} = -962.5 \cdot kN$	$E_{act.OT.E1.loc} = 1.33\ m$

Resisting Lateral Soil Load as required to produce horizontal equilibrium:

$$E_{pas.OT.E1} := -\left(H_{hwas.E1} + H_{hwgg.E1} + H_{twgg.E1} + H_{twgf.E1} + H_{twkey.OT.E1} + I_{E1} + E_{act.OT.E1}\right) = 2444.04 \cdot kN$$

Acting at:

$$E_{pas.OT.E1.loc} := -1 \cdot \frac{d_{key}}{2} = -1\ m$$

Sum of All Overturning Analysis Horizontal Load (ΣH=0):

$$\Sigma H_{E1.OT} := H_{hwas.E1} + H_{hwgg.E1} + H_{twgg.E1} + H_{twgf.E1} + H_{twkey.OT.E1} + I_{E1} + E_{act.OT.E1} + E_{pas.OT.E1} = 0 \cdot kN$$

Sum of All Overturning Analysis Horizontal Load Moments:

$$\Sigma M_{H.E1.OT} := H_{hwas.E1} \cdot H_{hwas.E1.loc} + H_{hwgg.E1} \cdot H_{hwgg.E1.loc} + H_{twgg.E1} \cdot H_{twgg.E1.loc} \cdots + H_{twgf.E1} \cdot H_{twgf.E1.loc} + H_{twkey.OT.E1} \cdot H_{twkey.OT.E1.loc} + I_{E1} \cdot I_{E1.loc} \cdots + E_{act.OT.E1} \cdot E_{act.OT.E1.loc} + E_{pas.OT.E1} \cdot E_{pas.OT.E1.loc} = -6495.22 \cdot kN \cdot m$$

Overturning Stability Analysis

$\Sigma M_{E1.OT} := \Sigma M_{V.E1.OT} + \Sigma M_{H.E1.OT} = 154070.51 \cdot kN \cdot m$

$X_{R.E1} := \dfrac{\Sigma M_{E1.OT}}{\Sigma V_{E1.OT}} = 10.17\ m$

$x_{OT.E1} := X_{R.E1} - \dfrac{L_b}{2} = 0.92\ m$

Overturning Resultant Ratio $Ratio_{OT.E1} := \dfrac{X_{R.E1}}{L_b} = 0.55$

$$Ratio_{OT.E1.check} := \begin{cases} \text{"OKAY"} & \text{if } Ratio_{OT.E1} \geq Ratio_{OT.E1.min} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

$$x_{OT.check.E1} := \begin{cases} \text{"OKAY"} & \text{if } \left|x_{OT.E1}\right| \leq Kern \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

CHECK FOUNDATION BEARING CAPACITY (HORIZONTAL PLANE):

E1 CASE

Bearing Pressure Under Toe:

$$\sigma_{ToeE1.OT} := \frac{\Sigma V_{E1.OT}}{L_b \cdot W_b} + \frac{\left(\Sigma V_{E1.OT} \cdot x_{OT.E1}\right)}{S_b} = 70.9 \cdot kPa$$

$$Bearing_{ChecktoeE1.OT} := \begin{vmatrix} \text{"OKAY "} & \text{if } \sigma_{ToeE1.OT} < \sigma_{allow.E1} \\ \text{"NG""} & \text{otherwise} \end{vmatrix} = \text{"OKAY "}$$

Bearing Pressure Under Heel:

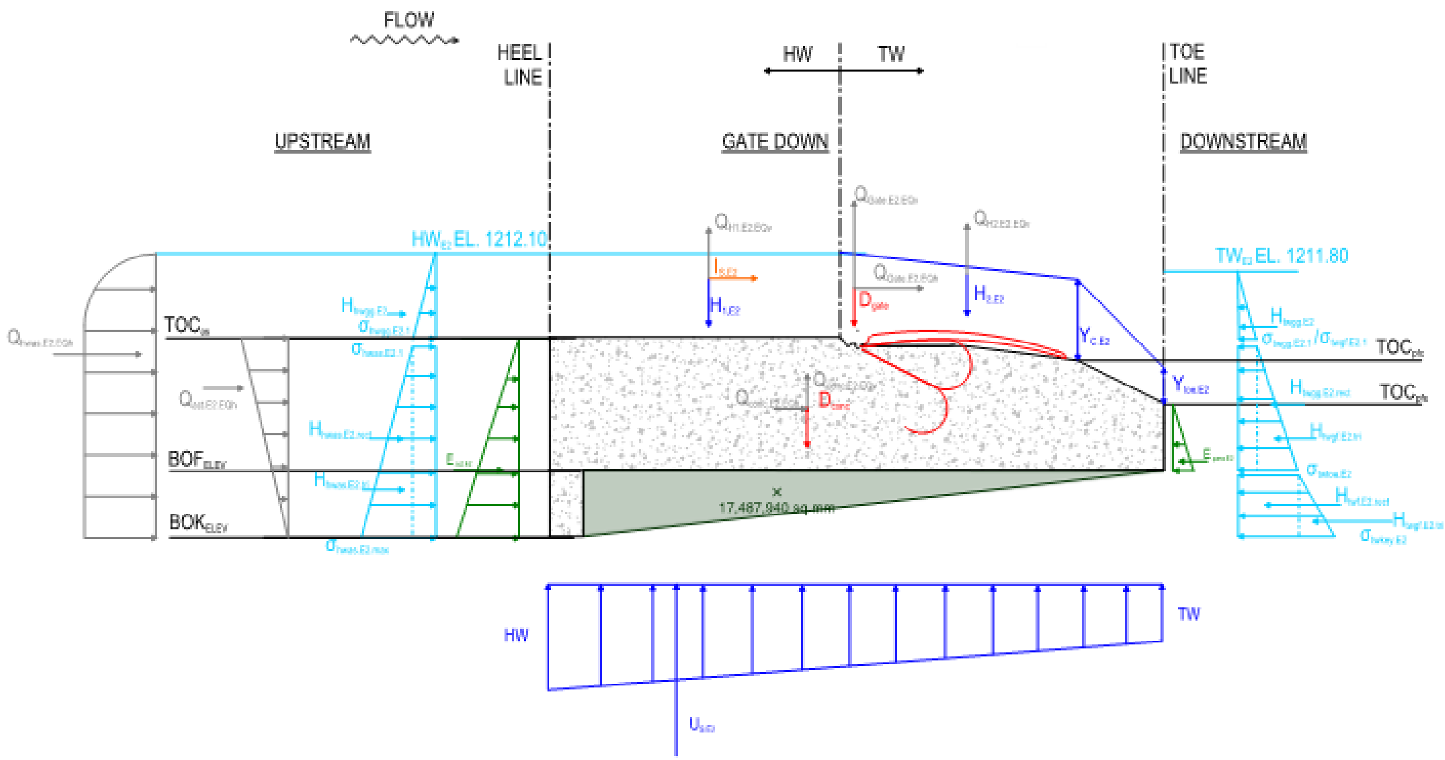
$$\sigma_{HeelE1.OT} := \frac{\Sigma V_{E1.OT}}{L_b \cdot W_b} - \frac{\left(\Sigma V_{E1.OT} \cdot x_{OT.E1}\right)}{S_b} = 38.2 \cdot kPa$$

$$Bearing_{CheckheelE1.OT} := \left(\begin{vmatrix} \text{"OKAY "} & \text{if } \sigma_{HeelE1.OT} < \sigma_{allow.E1} \wedge \sigma_{HeelE1.OT} > 0 \\ \text{"NG""} & \text{otherwise} \end{vmatrix}\right) = \text{"OKAY "}$$

SUMMARY OF STABILITY ASSESSMENT:

Sliding Factor of Safety: (Horizontal Plane)	$FS_{HorizSliding.E1} = 1.64$	$FS_{HorizSliding.E1.Check} = \text{"OKAY"}$
Sliding Factor of Safety: (Inclined Plane)	$FS_{InclinedlSlidingE1} = 5.64$	$FS_{InclinedSliding.check.E1} = \text{"OKAY "}$
Eccentricity: (Inclined Plane)	$e_{E1} = -0.94\,m$	$e_{check.E1} = \text{"Okay"}$
Bearing Pressure At Heel: (Inclined Plane)	$\sigma_{heel.E1} = 86 \cdot kPa$	$\sigma_{heel.E1.check} = \text{"Okay"}$
Bearing Pressure At Toe: (Inclined Plane)	$\sigma_{toe.E1} = 46 \cdot kPa$	$\sigma_{toe.E1.1.check} = \text{"Okay"}$
Flotation Factor of Safety (horizontal plane)	$FS_{act.FE1} = 1.41$	$FS_{check.FE1} = \text{"OKAY"}$
Overturning Resultant Ratio: (horizontal plane)	$Ratio_{OT.E1} = 0.55$	$Ratio_{OT.E1.check} = \text{"OKAY"}$
Eccentricity: (horizontal plane)	$x_{OT.E1} = 0.92\,m$	$x_{OT.check.E1} = \text{"OKAY"}$
Bearing Pressure At Heel: (horizontal plane)	$\sigma_{HeelE1.OT} = 38 \cdot kPa$	$Bearing_{CheckheelE1.OT} = \text{"OKAY "}$
Bearing Pressure At Toe: (horizontal plane)	$\sigma_{ToeE1.OT} = 71 \cdot kPa$	$Bearing_{ChecktoeE1.OT} = \text{"OKAY "}$

E2 DESIGN CASE



U1 CASE PLUS SEISMIC

ACCEPTANCE PARAMETERS

Required Factor of Safety for Sliding: $FS_{req.E2.sl} := 1.0$ (Without Cohesion)

(Section 8.1, Design Criteria)

Resultant Within Middle Half of Base: $e \le \frac{L_b}{4} \wedge e \ge \frac{-L_b}{4}$

Allowable Rock Bearing Pressure: $\sigma_{allow.E2} := 1740 \cdot \frac{kN}{m^2}$ (Section 5.2, Design Criteria)

INPUT PARAMETERS

Headwater Elevation: $HW_{E2} := 1212.10m$ (Section 8.3, Design Criteria)

Tailwater Elevation: $TW_{E2} := 1211.80m$ (Section 8.3, Design Criteria)

Bottom of Footing Elevation: $BOF_{elev} = 1206\,m$

Approach Slab Top of Concrete Elevation at Upstream Face: $TOC_{as} = 1210\,m$

Footing Top of Concrete Elevation at Stilling Basin: $TOC_{pfe} = 1208\,m$

Footing Top of Concrete Elevation at Center of Footing: $TOC_{pfc} = 1209.3\,m$

Top of Guard/Regulating Gate Elevation: $TOP_{rg.U1} = 1210\,m$ $TOP_{gg.U1} = 1210.00\,m$

Gates are open when top of gate elevation is at 1210.00m

Gates are closed/up when top of gate elevation is at 1215.0m

Bottom of Key Elevation: $BOK_{elev} = 1204\,m$

Crestwater Elevation: Dynamic Flow $EL_{C.E2} := 1211.40m$

$$Y_{C.E2} := \begin{cases} (EL_{C.E2} - TOC_{pfc}) & \text{if } TOP_{gg.U1} \le HW_{E2} \\ (TW_{E2} - TOC_{pfc}) & \text{if } TOP_{gg.U1} > HW_{E2} \end{cases} = 2.1 \cdot m$$

Toewater Elevation: $EL_{TOE.E2} := 1208.46m$

$$Y_{TOE.E2} := \begin{cases} (EL_{TOE.E2} - TOC_{pfe}) & \text{if } TOP_{gg.U1} \le HW_{E2} \\ (TW_{E2} - TOC_{pfe}) & \text{if } TOP_{gg.U1} > HW_{E2} \end{cases} = 0.46 \cdot m$$

SEISMIC LOAD (Three combinations of E_h and E_v considered) E2.1 CASE

Seismic Case $Q_{E2.1}$ - 100% Horizontal Seismic Force, No Vertical

Include Seismic Load in Analysis? $Eq_{E2.1} := 1$

Horizontal Seismic Coefficient: $K_{h.E2.1} := -0.17$

Vertical Seismic Coefficient: $K_{v.E2.1} := -0.00$

HORIZONTAL SEISMIC LOADS — **Loads** — **Moment Arm**

Horiz Seismic Component of Concrete: $Q_{conc.E2.EQh.1} := D_{conc} \cdot K_{h.E2.1} \cdot Eq_{E2.1} = -4185.2 \cdot kN$ — $Y_{conc.loc} = 1.87\,m$

Horiz Seismic Component of Gates: $Q_{Gate.E2.EQh.1} := D_{Gate} \cdot K_{h.E2.1} \cdot Eq_{E2.1} = -35.7 \cdot kN$ — $Y_{gate} = 3.90\,m$

Horizontal Seismic Component of Headwater - Sliding:

$$Q_{hwas.E2.EQh.1} := \left(\frac{7}{12}\right) \cdot K_{h.E2.1} \cdot \gamma_w \cdot \left(HW_{U1} - BOK_{elev}\right)^2 \cdot W_{hwas.U1} \cdot Eq_{E2.1} = -957.4 \cdot kN$$

$$Y_{HWg.E2} := 0.4 \cdot \left(HW_{U1} - BOK_{elev}\right) = 3.24\,m$$

Horizontal Seismic Component of Soil (Woods Method)-Overturning:

$$Q_{act.E2.EQh.1.OT} := \left(\gamma_r - \gamma_w\right) \cdot \left(TOC_{as} - BOK_{elev}\right)^2 \cdot K_{h.E2.1} \cdot W_{hwas.U1} \cdot Eq_{E2.1} = -1119.0 \cdot kN$$

$$Y_{E.act.E2.OT} := 0.63 \cdot \left(TOC_{as} - BOK_{elev}\right) = 3.78\,m$$

Horizontal Seismic Component of Soil (Woods Method)

$$Q_{act.E2.EQh.1} := \left(\gamma_r - \gamma_w\right) \cdot \left(TOC_{as} - BOF_{elev}\right)^2 \cdot K_{h.E2.1} \cdot W_{hwas.U1} \cdot Eq_{E2.1} = -497.4 \cdot kN$$

$$Y_{E.act.E2} := 0.63 \cdot \left(TOC_{as} - BOF_{elev}\right) = 2.52\,m$$

VERTICAL SEISMIC LOADS — **Loads** — **Moment Arm**

Vertical Component of Concrete: $Q_{conc.E2.EQv.1} := D_{conc} \cdot K_{v.E2.1} \cdot Eq_{E2.1} = 0.0 \cdot kN$ — $X_{conc.loc} = 10.06\,m$

Vertical Component of Gate: $Q_{Gate.E2.EQv.1} := D_{Gate} \cdot K_{v.E2.1} \cdot Eq_{E2.1} = 0.0 \cdot kN$ — $X_{gate} = 6.60\,m$

Vertical Seismic Component of Headwater over Apron Slab: $Q_{H1.E2.EQv.1} := K_{v.E2.1} \cdot H_{1.U1} \cdot Eq_{E2.1} = 0.0 \cdot kN$ — $H_{1.U1.loc} = 14.13\,m$

Vertical Seismic Component of Tailwater over Pier Footing: $Q_{H2.E2.EQv.1} := K_{v.E2.1} \cdot H_{2.U1} \cdot Eq_{E2.1} = 0.0 \cdot kN$ — $H_{2.U1.loc} = 5.34\,m$

$$\Sigma H_{Q.E2.EQh.1} := Q_{conc.E2.EQh.1} + Q_{Gate.E2.EQh.1} + Q_{hwas.E2.EQh.1} + Q_{act.E2.EQh.1} = -5675.62 \cdot kN$$

$$\Sigma H_{Q.E2.EQh.1.OT} := Q_{conc.E2.EQh.1} + Q_{Gate.E2.EQh.1} + Q_{hwas.E2.EQh.1} + Q_{act.E2.EQh.1.OT} = -6297.31 \cdot kN$$

$$\Sigma V_{Q.E2.EQv.1} := Q_{conc.E2.EQv.1} + Q_{Gate.E2.EQv.1} + Q_{H1.E2.EQv.1} + Q_{H2.E2.EQv.1} = 0.0 \cdot kN$$

$$\Sigma M_{Q.E2.1} := Q_{conc.E2.EQh.1} \cdot Y_{conc.loc} + Q_{Gate.E2.EQh.1} \cdot Y_{gate} + Q_{hwas.E2.EQh.1} \cdot Y_{HWg.E2} \cdots + Q_{act.E2.EQh.1.OT} \cdot Y_{E.act.E2.OT} + Q_{conc.E2.EQv.1} \cdot X_{conc.loc} + Q_{Gate.E2.EQv.1} \cdot X_{gate} \cdots + Q_{H1.E2.EQv.1} \cdot H_{1.U1.loc} + Q_{H2.E2.EQv.1} \cdot H_{2.U1.loc} = -15290.5 \cdot kN \cdot m$$

STABILITY ASSESSMENT (SLIDNG, BEARING, FLOTATION AND OVERTURNING):

E2.1 CASE

CHECK SLIDING ALONG HORIZONTAL PLANE THRU TOE,
IGNORING BEDROCK MOBILIZED BY STRUCTURAL HEEL KEY, OR VOID BEHIND KEY

Sum of Vertical Forces:

$\Sigma V_{E2.1} := \Sigma V_{U1} + \Sigma V_{Q.E2.EQv.1} = 11311.8 \cdot kN$

Sum of Horizontal Forces:

$\Sigma H_{E2.1} := \Sigma H_{U1} - I_{U1} + \Sigma H_{Q.E2.EQh.1} = -7821.33 \cdot kN$

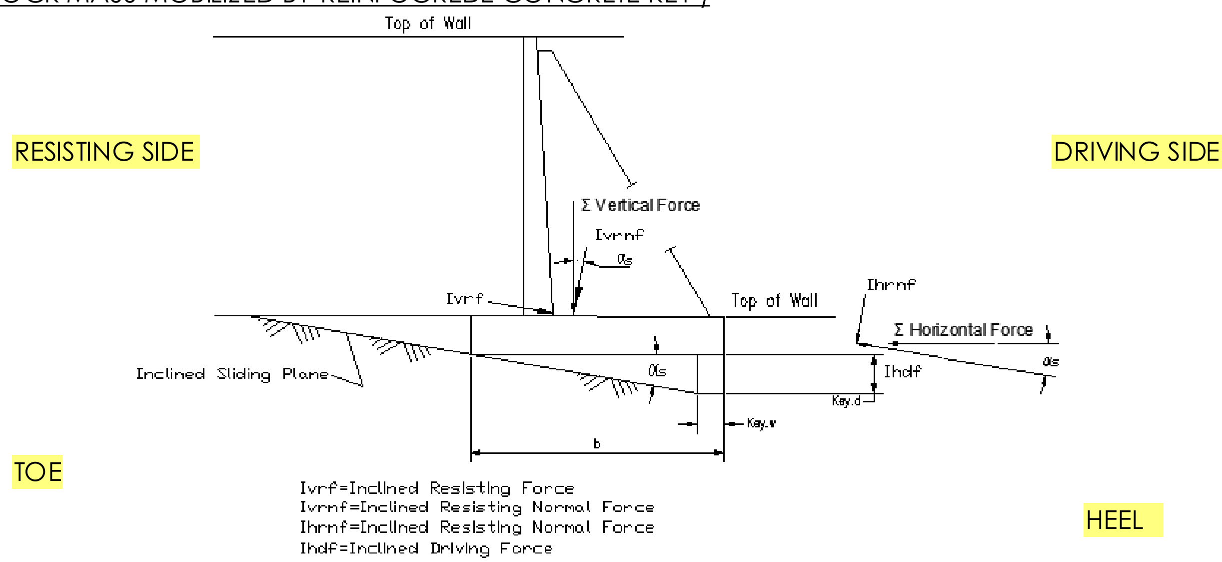
Sliding Factor of Safety:

$$FS_{HorizSliding.E2.1} := \frac{\tan_{\phi} \cdot \Sigma V_{E2.1}}{|\Sigma H_{E2.1}|} = 0.71$$

$FS_{HorizSliding.E2.1.Check} :=$ | "OKAY" if $FS_{HorizSliding.E2.1} \ge FS_{req.E2.sl}$
"Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !" otherwise

$FS_{HorizSliding.E2.1.Check} =$ "Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !"

CHECK SLIDING ALONG INCLINED SLIDING PLANE FROM HEEL KEY TO TOE,
WITH BEDROCK MASS MOBILIZED BY REINFOCREDE CONCRETE KEY)



$\alpha s = 0.11$

as degrees= $\alpha s \cdot \left(\frac{180}{\pi}\right) = 6.52$

$V_{rs} = 5775 \cdot kN$

Resolve $\Sigma Vert_{E2.1}$ & $\Sigma Horiz_{E2.1}$

$\Sigma V_{InclinedE2.1} := \cos(\alpha s) \cdot (\Sigma V_{E2.1} + V_{rs}) + \sin(\alpha s) \cdot |\Sigma H_{E2.1}| = 17864.4 \cdot kN$

$\Sigma H_{InclinedE2.1} := \cos(\alpha s) \cdot |\Sigma H_{E2.1}| - \sin(\alpha s) \cdot (\Sigma V_{E2.1} + V_{rs}) = 5830.6 \cdot kN$

Inclined Sliding Plane Length

$L_{incline} = 18.61 \ m$

Safety Factor for Sliding
Inclined Failure Plane

$$FS_{InclinedlSlidingE2.1} := \frac{\Sigma V_{InclinedE2.1} \cdot \tan\left(\phi_{rock} \cdot \frac{\pi}{180}\right)}{|\Sigma H_{InclinedE2.1}|} = 1.49$$

$FS_{InclinedSliding.check.E2.1} :=$ | "OKAY " if $FS_{InclinedlSlidingE2.1} > FS_{req.E2.sl}$ = "OKAY "
"Revise Structure"" otherwise

$FS_{InclinedSliding.check.E2.1} =$ "OKAY "

E2.1 CASE

OVERTURNING STABILITY CHECK:

CHECK ECCENTRICITY

Sum of the moments:

$$\Sigma M_{E2.1} := \left(\Sigma M_{U1} + \Sigma M_{Q.E2.1}\right) = 168812 \cdot kN \cdot m$$

Eccentricity:
$$e_{E2.1} := \left(\frac{L_{incline}}{2}\right) - \frac{\left(\Sigma M_{E2.1}\right)}{\Sigma V_{InclinedE2.1}} = -0.15\,m$$

Eccentricity Check:
$$e_{check.E2.1} := \begin{cases} \text{"Okay"} & \text{if } e_{E2.1} \le Midhalf \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$$e_{check.E2.1} = \text{"Okay"}$$

Foundation Bearing Checks:

Bearing Pressure at Heel:
$$\sigma_{heel.E2.1} := \frac{\Sigma V_{InclinedE2.1}}{A_{b.incline}} - \frac{\left(\Sigma V_{InclinedE2.1} \cdot e_{E2.1}\right)}{S_{b.incline}} = 67.0 \cdot \frac{kN}{m^2}$$

$$\sigma_{heel.E2.1.check} := \left(\begin{cases} \text{"Okay"} & \text{if } \sigma_{heel.E2.1} \le \sigma_{allow.E2} \\ \text{"Revise Structure"} & \text{if } \sigma_{heel.E2.1} < 0\,\frac{kN}{m^2} \end{cases}\right)$$

$$\sigma_{heel.E2.1.check} = \text{"Okay"}$$

Bearing Pressure at Toe:
$$\sigma_{toe.E2.1} := \frac{\Sigma V_{InclinedE2.1}}{A_{b.incline}} + \frac{\left(\Sigma V_{InclinedE2.1} \cdot e_{E2.1}\right)}{S_{b.incline}} = 61.0 \cdot \frac{kN}{m^2}$$

$$\sigma_{toe.E2.1.check.1} := \begin{cases} \text{"Okay"} & \text{if } \sigma_{toe.E2.1} \le \sigma_{allow.E2} \\ \text{"Revise Structure"} & \text{if } \sigma_{toe.E2.1} < 0\,\frac{kN}{m^2} \end{cases}$$

$$\sigma_{toe.E2.1.check.1} = \text{"Okay"}$$

FLOATATION ANALYSIS:

ACCEPTANCE PARAMETERS

Required Factor of Safety: $FS_{req.FE2.1} := 1.1$

VERTICAL LOADS RESISTING:

Dead Load: $\Sigma V_{DL} = 24828.6 \cdot kN$

Water Weight H1+H2: $\Sigma V_{H.FE2.1} := \Sigma V_{H.FU1} + \Sigma V_{Q.E2.EQv.1} = 5403.05 \cdot kN$

Summation Vertical Resisting: $\Sigma V_{FE2.1} := \Sigma V_{DL} + \Sigma V_{H.FE2.1} = 30231.7 \cdot kN$

VERTICAL LOADS UPLIFT:

Uplift: $U_{S.U1} = -18919.81 \cdot kN$

Factor of Safety Floatation:

$$FS_{act.FE2.1} := \frac{\Sigma V_{FE2.1}}{\left|U_{S.U1}\right|} = 1.60$$

$$FS_{check.FE2.1} := \begin{cases} \text{"OKAY"} & \text{if } FS_{act.FE2.1} \ge FS_{req.FE2.1} \\ \text{"ANCHORS REQUIRED"} & \text{if } FS_{act.FE2.1} < FS_{req.FE2.1} \end{cases} = \text{"OKAY"}$$

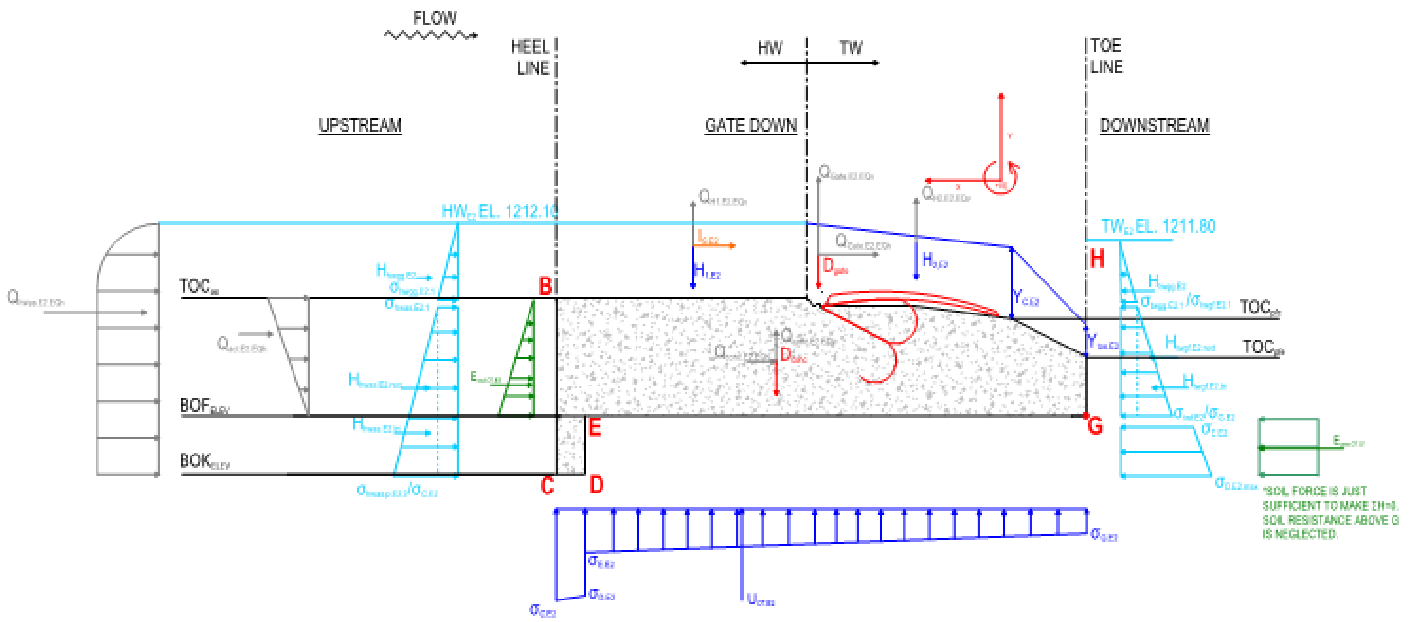
E2.1 CASE

MONOLITH OVERTURNING STABILITY ANALYSIS

Seismic Case $Q_{E2.1}$: 100% Horizontal Seismic Force, No Vertical

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.
Assumptions are made in order to compute overturning stability of indetermine forces on monolith with key;
(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.
(b) The horizontal resisting force acting on the key, P.key, is that required for static equilibrium
(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1 $Ratio_{overturning.allow.Extreme} := 0.25$ Resultant within Middle Half



All Vertical Loads Applicable to Overturning Stability Analysis

Total Concrete Dead Loads:	$D_{conc} = 24618.6 \cdot kN$	at:	$X_{conc.loc} = 10.06\,m$
Dead Load of Gate:	$D_{Gate} = 210.0 \cdot kN$		$X_{gate} = 6.60\,m$
Water Weight (HW) on Apron Slab:	$H_{1.U1} = 2703.9 \cdot kN$		$H_{1.U1.loc} = 14.13\,m$
Water Weight (TW) on Gate Footing:	$H_{2.U1} = 2699.2 \cdot kN$		$H_{2.U1.loc} = 5.34\,m$
Uplift Load for Overturning Analysis:	$U_{OT.U1} = -16456.3 \cdot kN$		$U_{OT.U1.loc} = 9.48 \cdot m$
Vertical Seismic Component of Concrete Structure:	$Q_{conc.E2.EQv.1} = 0$		$X_{conc.loc} = 10.06\,m$
Vertical Seismic Component of Crest Gate:	$Q_{Gate.E2.EQv.1} = 0$		$X_{gate} = 6.60\,m$
Vertical Seismic Component of Headwater over Apron Slab:	$Q_{H1.E2.EQv.1} = 0$		$H_{1.U2.loc} = 14.13\,m$
Vertical Seismic Component of Headwater over Fixed Crest Slab:	$Q_{H2.E2.EQv.1} = 0$		$H_{2.U2.loc} = 5.23\,m$

Sum of All Overtuming Analysis Vertical Load:

$$\Sigma V_{E2.OT.1} := D_{conc} + D_{Gate} + H_{1.U1} + H_{2.U1} + U_{OT.U1} + \Sigma V_{Q.E2.EQv.1} = 13775.35 \cdot kN$$

Sum of All Overtuming Analysis Vertical Load Moments:

$$\Sigma M_{V.E2.OT.1} := D_{conc} \cdot X_{conc.loc} + D_{Gate} \cdot X_{gate} + H_{1.U1} \cdot H_{1.U1.loc} + H_{2.U1} \cdot H_{2.U1.loc} + U_{OT.U1} \cdot U_{OT.U1.loc} = 145582.24 \cdot kN \cdot m$$

Lateral Driving Earth Loads for Overturning Stability Analysis (at rest condition)

E2.1 CASE

Depth of Driving Soil Loads (to top of key): $h_{E.OT.E2.1} := TOC_{as} - BOF_{elev} = 4\,m$

At-Rest Soil Load: $E_{act.OT.E2.1} := \frac{K_{o.U1} \cdot h_{E.OT.U1}^{\,2}}{2} \cdot (\gamma_r - \gamma_w) \cdot W_{hwas.U1} \cdot -1 = -962.49 \cdot kN$

At Rest- Soil Load Acting from Toe: $E_{act.OT.E2.1.loc} := \frac{h_{E.OT.U1}}{3} = 1.33\,m$

All Lateral Loads Applicable to Overturning Stability Analysis

HW Lateral Load on Approach Slab:	$H_{hwas.U1} = -4502.8 \cdot kN$	$H_{hwas.U1.loc} = 0.41\,m$
HW Lateral Load on Guard Gate:	$H_{hwgg.U1} = 0.0 \cdot kN$	$H_{hwgg.U1.loc} = 4.00\,m$
TW Lateral Load on Guard Gate:	$H_{twgg.U1} = 0.0 \cdot kN$	$H_{twgg.U1.loc} = 4.00\,m$
TW Lateral Load on Gate Footing (No Key - Overturning Values Adjusted):	$H_{twgf.U1} = 2236.68 \cdot kN$	$H_{twgf.U1.loc} = 1.65\,m$
TW Lateral Load on Key:	$H_{twkey.OT.U1} = 2080.92 \cdot kN$	$H_{twkey.OT.U1.loc} = -1.05\,m$
Ice / Impact Load:	$I_{U1} = 0.0 \cdot kN$	$I_{U1.loc} = 3.70\,m$
Lateral Soil Load (driving):	$E_{act.OT.U1} = -962.5 \cdot kN$	$E_{act.OT.U1.loc} = 1.33\,m$
Horizontal Seismic Component of Concrete Structure:	$Q_{conc.E2.EQh.1} = -4185.16 \cdot kN$	$Y_{conc.loc} = 1.87\,m$
Horizontal Seismic Component of Vertical Lift Gate:	$Q_{Gate.E2.EQh.1} = -35.7 \cdot kN$	$Y_{gate} = 3.90\,m$
Horizontal Seismic Component of Headwater on Gate:	$Q_{hwas.E2.EQh.1} = -957.41 \cdot kN$	$Y_{HWg.E2} = 3.24\,m$
Horizontal Seismic Component of Active Soil: (Section 5-5, USACE EM_1110-2-2100)	$Q_{act.E2.EQh.1.OT} = -1119042\,N$	$Y_{E.act.E2.OT} = 3.78\,m$

Resisting Lateral Soil Load as required to produce horizontal equilibrium:

$$E_{pas.OT.E2.1} := -\left(H_{hwas.U1} + H_{hwgg.U1} + H_{twgg.U1} + H_{twgf.U1} + H_{twkey.OT.U1} + I_{U1} + E_{act.OT.U1} + \Sigma H_{Q.E2.EQh.1.OT}\right) = 7445 \cdot kN$$

Acting at: $E_{pas.OT.E2.1.loc} := -1 \cdot \frac{d_{key}}{2} = -1\,m$

Sum of All Overturning Analysis Horizontal Load (ΣH=0):

$$\Sigma H_{E2.OT.1} := H_{hwas.U1} + H_{hwgg.U1} + H_{twgg.U1} + H_{twgf.U1} + H_{twkey.OT.U1} + I_{U1} + E_{act.OT.U1} + E_{pas.OT.E2.1} + \Sigma H_{Q.E2.EQh.1.OT} = 0 \cdot kN$$

Sum of All Overturning Analysis Horizontal Load Moments:

$$\Sigma M_{H.E2.OT.1} := H_{hwas.U1} \cdot H_{hwas.U1.loc} + H_{hwgg.U1} \cdot H_{hwgg.U1.loc} + H_{twgg.U1} \cdot H_{twgg.U1.loc} \cdots + H_{twgf.U1} \cdot H_{twgf.U1.loc} + H_{twkey.OT.U1} \cdot H_{twkey.OT.U1.loc} + I_{U1} \cdot I_{U1.loc} \cdots + E_{act.OT.U1} \cdot E_{act.OT.U1.loc} + E_{pas.OT.U1} \cdot E_{pas.OT.U1.loc} + \Sigma M_{Q.E2.1} = -18067.5 \cdot kN \cdot m$$

Overturning Stability Analysis

$$\Sigma M_{E2.OT.1} := \Sigma M_{V.E2.OT.1} + \Sigma M_{H.E2.OT.1} = 127514.74 \cdot kN \cdot m$$

$X_{R.E2.1} := \frac{\Sigma M_{E2.OT.1}}{\Sigma V_{E2.OT.1}} = 9.26\,m$ $\quad x_{OT.E2.1} := X_{R.E2.1} - \frac{L_b}{2} = 0.01\,m$

Overturning Resultant Ratio $\quad Ratio_{OT.E2.1} := \frac{X_{R.E2.1}}{L_b} = 0.5$

$$Ratio_{OT.E2.1.check} := \begin{cases} \text{"OKAY"} & \text{if } Ratio_{OT.E2.1} \geq Ratio_{overturning.allow.Extreme} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

$$x_{OT.check.E2.1} := \begin{cases} \text{"OKAY"} & \text{if } \left|x_{OT.E2.1}\right| \leq Midhalf \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

Seismic Case $Q_{E2.2}$ - 100% Horizontal Seismic Force, 30% Vertical **E2.2 CASE**

Include Seismic Load in Analysis? $Eq_{E2.2} := 1$

Horizontal Seismic Coefficient: $K_{h.E2.2} := -0.17$

Vertical Seismic Coefficient: $K_{v.E2.2} := -0.03$

HORIZONTAL SEISMIC LOADS	Loads	Moment Arm
Horiz Seismic Component of Concrete:	$Q_{conc.E2.EQh.2} := D_{conc} \cdot K_{h.E2.2} \cdot Eq_{E2.2} = -4185.2 \cdot kN$	$Y_{conc.loc} = 1.87\,m$
Horiz Seismic Component of Gates:	$Q_{Gate.E2.EQh.2} := D_{Gate} \cdot K_{h.E2.2} \cdot Eq_{E2.2} = -35.7 \cdot kN$	$Y_{gate} = 3.90\,m$
Horizontal Seismic Component of Headwater - Sliding:	$Q_{hwas.E2.EQh.2} := \left(\frac{7}{12}\right) \cdot K_{h.E2.2} \cdot \gamma_w \cdot \left(HW_{U1} - BOK_{elev}\right)^2 \cdot W_{hwas.U1} \cdot Eq_{E2.2} = -957.4 \cdot kN$	$Y_{HWg.E2} = 3.24\,m$
Horizontal Seismic Component of Soil (Woods Method)-Overturning:	$Q_{act.E2.EQh.2.OT} := \left(\gamma_r - \gamma_w\right) \cdot \left(TOC_{as} - BOK_{elev}\right)^2 \cdot K_{h.E2.2} \cdot W_{hwas.U1} \cdot Eq_{E2.2} = -1119.0 \cdot kN$	$Y_{E.act.E2.OT} = 3.78\,m$
Horizontal Seismic Component of Soil (Woods Method)	$Q_{act.E2.EQh.2} := \left(\gamma_r - \gamma_w\right) \cdot \left(TOC_{as} - BOF_{elev}\right)^2 \cdot K_{h.E2.2} \cdot W_{hwas.U1} \cdot Eq_{E2.2} = -497.4 \cdot kN$	$Y_{E.act.E2} = 2.52\,m$

VERTICAL SEISMIC LOADS	Loads	Moment Arm
Vertical Component of Concrete:	$Q_{conc.E2.EQv.2} := D_{conc} \cdot K_{v.E2.2} \cdot Eq_{E2.2} = -738.6 \cdot kN$	$X_{conc.loc} = 10.06\,m$
Vertical Component of Gate:	$Q_{Gate.E2.EQv.2} := D_{Gate} \cdot K_{v.E2.2} \cdot Eq_{E2.2} = -6.3 \cdot kN$	$X_{gate} = 6.60\,m$
Vertical Seismic Component of Headwater over Apron Slab: (Section 7.9, Design Criteria)	$Q_{H1.E2.EQv.2} := K_{v.E2.2} \cdot H_{1.U1} \cdot Eq_{E2.2} = -81.1 \cdot kN$	$H_{1.U1.loc} = 14.13\,m$
Vertical Seismic Component of Headwater over Fixed Crest Slab: (Section 7.9, Design Criteria)	$Q_{H2.E2.EQv.2} := K_{v.E2.2} \cdot H_{2.U1} \cdot Eq_{E2.2} = -81.0 \cdot kN$	$H_{2.U1.loc} = 5.34\,m$

$$\Sigma H_{Q.E2.EQh.2} := Q_{conc.E2.EQh.2} + Q_{Gate.E2.EQh.2} + Q_{hwas.E2.EQh.2} + Q_{act.E2.EQh.2} = -5675.62 \cdot kN$$

$$\Sigma H_{Q.E2.EQh.2.OT} := Q_{conc.E2.EQh.2} + Q_{Gate.E2.EQh.2} + Q_{hwas.E2.EQh.2} + Q_{act.E2.EQh.2.OT} = -6297.31 \cdot kN$$

$$\Sigma V_{Q.E2.EQv.2} := Q_{conc.E2.EQv.2} + Q_{Gate.E2.EQv.2} + Q_{H1.E2.EQv.2} + Q_{H2.E2.EQv.2} = -906.9 \cdot kN$$

$$\begin{aligned}\Sigma M_{Q.E2.2} := {} & Q_{conc.E2.EQh.2} \cdot Y_{conc.loc} + Q_{Gate.E2.EQh.2} \cdot Y_{gate} + Q_{hwas.E2.EQh.2} \cdot Y_{HWg.E2} \cdots \\ & + Q_{act.E2.EQh.2.OT} \cdot Y_{E.act.E2.OT} + Q_{conc.E2.EQv.2} \cdot X_{conc.loc} + Q_{Gate.E2.EQv.2} \cdot X_{gate} \cdots \\ & + Q_{H1.E2.EQv.2} \cdot H_{1.U1.loc} + Q_{H2.E2.EQv.2} \cdot H_{2.U1.loc}\end{aligned} = -24337.07 \cdot kN \cdot m$$

STABILITY ASSESSMENT (SLIDNG, BEARING, FLOTATION AND OVERTURNING):

E2.2 CASE

CHECK SLIDING ALONG HORIZONTAL PLANE THRU TOE,
IGNORING BEDROCK MOBILIZED BY STRUCTURAL HEEL KEY, OR VOID BEHIND KEY

Sum of Vertical Forces:

$\Sigma V_{E2.2} := \Sigma V_{U1} + \Sigma V_{Q.E2.EQv.2} = 10404.9 \cdot kN$

Sum of Horizontal Forces:

$\Sigma H_{E2.2} := \Sigma H_{U1} - I_{U1} + \Sigma H_{Q.E2.EQh.2} = -7821.33 \cdot kN$

Sliding Factor of Safety:

$$FS_{HorizSliding.E2.2} := \frac{\tan_{\phi} \cdot \Sigma V_{E2.2}}{\left|\Sigma H_{E2.2}\right|} = 0.65$$

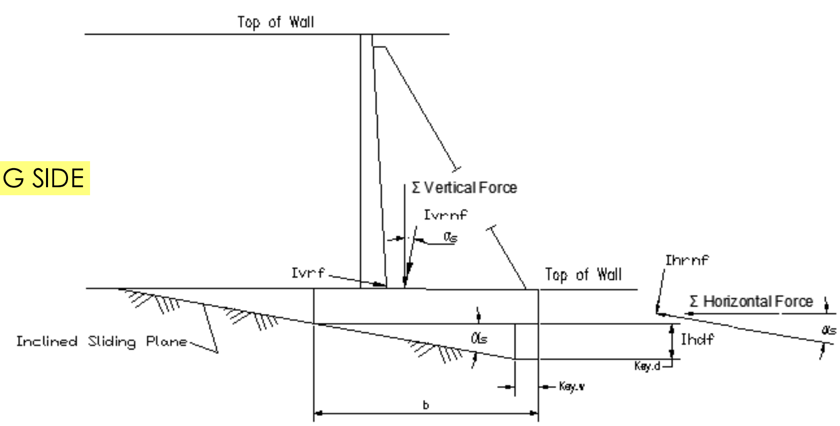
$FS_{HorizSliding.E2.2.Check} :=$ | "OKAY" if $FS_{HorizSliding.E2.2} \geq FS_{req.E2.sl}$
"Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !" otherwise

$FS_{HorizSliding.E2.2.Check} =$ "Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !"

CHECK SLIDING ALONG INCLINED SLIDING PLANE FROM HEEL KEY TO TOE,
WITH BEDROCK MASS MOBILIZED BY REINFOCREDE CONCRETE KEY)

RESISTING SIDE

DRIVING SIDE



TOE

HEEL

$\Sigma V_{E2.2} = 10404.89 \cdot kN$

$V_{rs} = 5775 \cdot kN$

$\alpha s = 0.11$

as degrees= $\alpha s \cdot \left(\frac{180}{\pi}\right) = 6.52$

Resolve $\Sigma Vert_{E2.2}$ & $\Sigma Horiz_{E2.2}$

$\Sigma V_{InclinedE2.2} := \cos(\alpha s) \cdot \left(\Sigma V_{E2.2} + V_{rs}\right) + \sin(\alpha s) \cdot \left|\Sigma H_{E2.2}\right| = 16963.3 \cdot kN$

$\Sigma H_{InclinedE2.2} := \cos(\alpha s) \cdot \left|\Sigma H_{E2.2}\right| - \sin(\alpha s) \cdot \left(\Sigma V_{E2.2} + V_{rs}\right) = 5933.6 \cdot kN$

(With properly engineered reinforced concrete Key, horizontal sliding plane thru Toe is protected, critical sliding plane is relocated to the INCLINED SLIDING PLANE FROM HEEL KEY To TOE, Bedrock Mass above this examing plane is mobilized by reinforced concrete key and combined into Structural Wedge.)

Inclined Sliding Plane Length

$L_{incline} = 18.61\ m$

Safety Factor for Sliding
Inclined Failure Plane

$$FS_{InclinedlSlidingE2.2} := \frac{\Sigma V_{InclinedE2.2} \cdot \tan\left(\phi_{rock} \cdot \frac{\pi}{180}\right)}{\left|\Sigma H_{InclinedE2.2}\right|} = 1.39$$

$FS_{InclinedSliding.check.E2.2} :=$ | "OKAY " if $FS_{InclinedlSlidingE2.2} > FS_{req.E2.sl}$ = "OKAY "
"Revise Structure"" otherwise

$FS_{InclinedSliding.check.E2.2} =$ "OKAY "

OVERTURNING STABILITY CHECK:

E2.2 CASE

CHECK ECCENTRICITY - OBSOLETE

Sum of the moments:

$$\Sigma M_{E2.2} := \left(\Sigma M_{U1} + \Sigma M_{Q.E2.2}\right) = 159766 \cdot kN \cdot m$$

Eccentricity:

$$e_{E2.2} := \left(\frac{L_{incline}}{2}\right) - \frac{\left(\Sigma M_{E2.2}\right)}{\Sigma V_{InclinedE2.2}} = -0.11\,m$$

Eccentricity Check:

$$e_{check.E2.2} := \begin{cases} \text{"Okay"} & \text{if } e_{E2.2} \le Midhalf \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$e_{check.E2.2} = \text{"Okay"}$

Foundation Bearing Checks:

Bearing Pressure at Heel:

$$\sigma_{heel.E2.2} := \frac{\Sigma V_{InclinedE2.2}}{A_{b.incline}} - \frac{\left(\Sigma V_{InclinedE2.2} \cdot e_{E2.2}\right)}{S_{b.incline}} = 63.0 \cdot \frac{kN}{m^2}$$

$$\sigma_{heel.E2.2.check} := \left(\begin{cases} \text{"Okay"} & \text{if } \sigma_{heel.E2.2} \le \sigma_{allow.E2} \\ \text{"Revise Structure"} & \text{if } \sigma_{heel.E2.2} < 0 \dfrac{kN}{m^2} \end{cases} \right)$$

$\sigma_{heel.E2.2.check} = \text{"Okay"}$

Bearing Pressure at Toe:

$$\sigma_{toe.E2.2} := \frac{\Sigma V_{InclinedE2.2}}{A_{b.incline}} + \frac{\left(\Sigma V_{InclinedE2.2} \cdot e_{E2.2}\right)}{S_{b.incline}} = 58.5 \cdot \frac{kN}{m^2}$$

$$\sigma_{toe.E2.2.check.1} := \begin{cases} \text{"Okay"} & \text{if } \sigma_{toe.E2.2} \le \sigma_{allow.E2} \\ \text{"Revise Structure"} & \text{if } \sigma_{toe.E2.2} < 0 \dfrac{kN}{m^2} \end{cases}$$

$\sigma_{toe.E2.2.check.1} = \text{"Okay"}$

FLOATATION ANALYSIS:

ACCEPTANCE PARAMETERS

Required Factor of Safety: $FS_{req.FE2.2} := 1.1$

VERTICAL LOADS RESISTING:

Dead Load: $\Sigma V_{DL} = 24828.6 \cdot kN$

Water Weight H1+H2: $\Sigma V_{H.FE2.2} := \Sigma V_{H.FU1} + \Sigma V_{Q.E2.EQv.2} = 4496.1 \cdot kN$

Summation Vertical Resisting: $\Sigma V_{FE2.2} := \Sigma V_{DL} + \Sigma V_{H.FE2.2} = 29324.7 \cdot kN$

VERTICAL LOADS UPLIFT:

Uplift: $U_{S.U1} = -18919.81 \cdot kN$

Factor of Safety Floatation:

$$FS_{act.FE2.2} := \frac{\Sigma V_{FE2.2}}{\left|U_{S.U1}\right|} = 1.55$$

$$FS_{check.FE2.2} := \begin{cases} \text{"OKAY"} & \text{if } FS_{act.FE2.2} \ge FS_{req.FE2.2} \\ \text{"ANCHORS REQUIRED"} & \text{if } FS_{act.FE2.2} < FS_{req.FE2.2} \end{cases} = \text{"OKAY"}$$

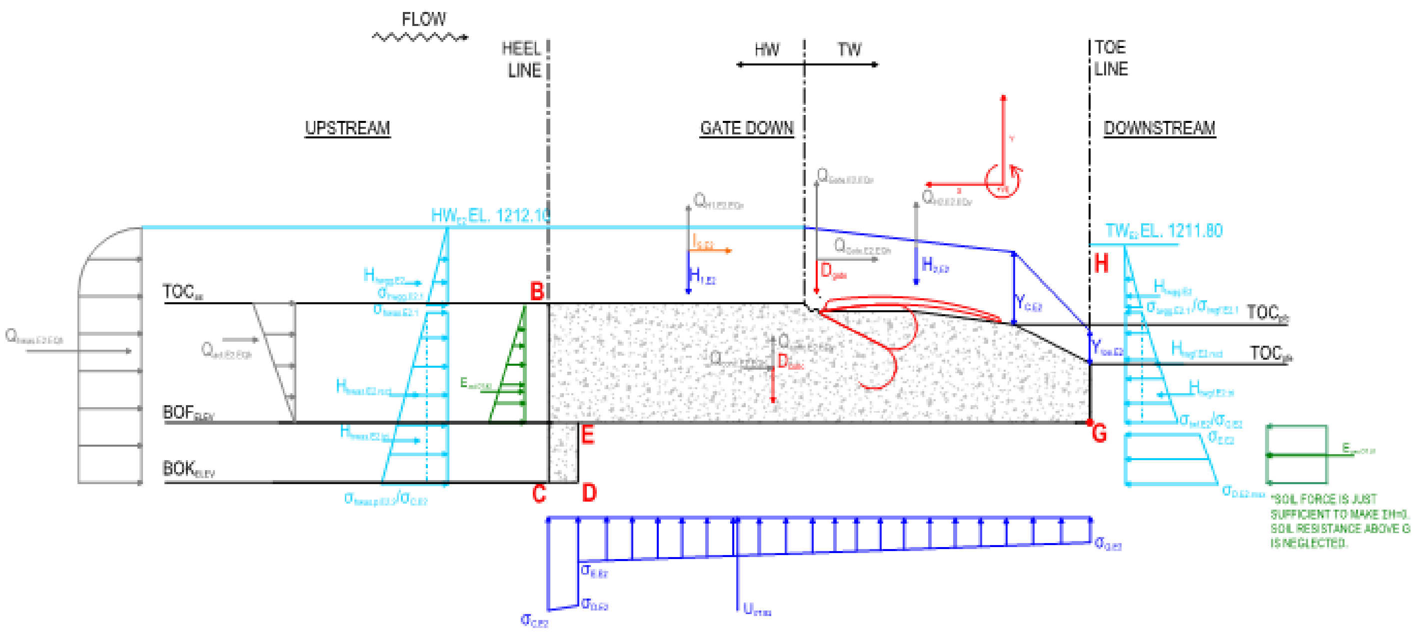
MONOLITH OVERTURNING STABILITY ANALYSIS

E2.2 CASE

Seismic Case $Q_{E2.2}$: 100% Horizontal Seismic Force, 30% Vertical

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.
Assumptions are made in order to compute overturning stability of indetermine forces on monolith with key;
(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.
(b) The horizontal resisting force acting on the key, P.key, is that required for static equilibrium
(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1 $Ratio_{overturning.allow.Extreme} = 0.25$ Resultant within Middle Half



All Vertical Loads Applicable to Overturning Stability Analysis

Total Concrete Dead Loads:	$D_{conc} = 24618.6 \cdot kN$	at:	$X_{conc.loc} = 10.06\,m$
Dead Load of Gate:	$D_{Gate} = 210.0 \cdot kN$		$X_{gate} = 6.60\,m$
Water Weight (HW) on Apron Slab:	$H_{1.U1} = 2703.9 \cdot kN$		$H_{1.U1.loc} = 14.13\,m$
Water Weight (TW) on Gate Footing:	$H_{2.U1} = 2699.2 \cdot kN$		$H_{2.U1.loc} = 5.34\,m$
Uplift Load for Overturning Analysis:	$U_{OT.U1} = -16456.3 \cdot kN$		$U_{OT.U1.loc} = 9.48 \cdot m$
Vertical Seismic Component of Concrete Structure:	$Q_{conc.E2.EQv.2} = -738.56 \cdot kN$		$X_{conc.loc} = 10.06\,m$
Vertical Seismic Component of Crest Gate:	$Q_{Gate.E2.EQv.2} = -6.3 \cdot kN$		$X_{gate} = 6.60\,m$
Vertical Seismic Component of Headwater over Apron Slab:	$Q_{H1.E2.EQv.2} = -81.12 \cdot kN$		$H_{1.U1.loc} = 14.13\,m$
Vertical Seismic Component of Headwater over Fixed Crest Slab:	$Q_{H2.E2.EQv.2} = -80.98 \cdot kN$		$H_{2.U1.loc} = 5.34\,m$

Sum of All Overturning Analysis Vertical Load:

$$\Sigma V_{E2.OT.2} := D_{conc} + D_{Gate} + H_{1.U1} + H_{2.U1} + U_{OT.U1} + \Sigma V_{Q.E2.EQv.2} = 12868.4 \cdot kN$$

Sum of All Overturning Analysis Vertical Load Moments:

$$\Sigma M_{V.E2.OT.2} := D_{conc} \cdot X_{conc.loc} + D_{Gate} \cdot X_{gate} + H_{1.U1} \cdot H_{1.U1.loc} + H_{2.U1} \cdot H_{2.U1.loc} + U_{OT.U1} \cdot U_{OT.U1.loc} = 145582.24 \cdot kN \cdot m$$

Lateral Driving Earth Loads for Overturning Stability Analysis (at rest condition)

E2.2 CASE

Depth of Driving Soil Loads (to top of key): $h_{E.OT.E2.2} := TOC_{as} - BOF_{elev} = 4\,m$

At-Rest Soil Load: $E_{act.OT.E2.2} := \dfrac{\left(K_{o.U1} \cdot h_{E.OT.U1}\right)^2}{2} \cdot \left(\gamma_r - \gamma_w\right) \cdot W_{hwas.U1} \cdot -1 = -962.49 \cdot kN$

At Rest- Soil Load Acting from Toe: $E_{act.OT.E2.2.loc} := \dfrac{h_{E.OT.U1}}{3} = 1.33\,m$

All Lateral Loads Applicable to Overturning Stability Analysis

HW Lateral Load on Approach Slab:	$H_{hwas.U1} = -4502.8 \cdot kN$	$H_{hwas.U1.loc} = 0.41\,m$
HW Lateral Load on Guard Gate:	$H_{hwgg.U1} = 0.0 \cdot kN$	$H_{hwgg.U1.loc} = 4.00\,m$
TW Lateral Load on Guard Gate:	$H_{twgg.U1} = 0.0 \cdot kN$	$H_{twgg.U1.loc} = 4.00\,m$
TW Lateral Load on Gate Footing (No Key - Overturning Values Adjusted):	$H_{twgf.U1} = 2236.68 \cdot kN$	$H_{twgf.U1.loc} = 1.65\,m$
TW Lateral Load on Key:	$H_{twkey.OT.U1} = 2080.92 \cdot kN$	$H_{twkey.OT.U1.loc} = -1.05\,m$
Ice / Impact Load:	$I_{U1} = 0.0 \cdot kN$	$I_{U1.loc} = 3.70\,m$
Lateral Soil Load (driving):	$E_{act.OT.U1} = -962.5 \cdot kN$	$E_{act.OT.U1.loc} = 1.33\,m$
Horizontal Seismic Component of Concrete Structure:	$Q_{conc.E2.EQh.2} = -4185.16 \cdot kN$	$Y_{conc.loc} = 1.87\,m$
Horizontal Seismic Component of Vertical Lift Gate:	$Q_{Gate.E2.EQh.2} = -35.7 \cdot kN$	$Y_{gate} = 3.90\,m$
Horizontal Seismic Component of Headwater on Gate:	$Q_{hwas.E2.EQh.2} = -957.41 \cdot kN$	$Y_{HWg.E2} = 3.24\,m$
Horizontal Seismic Component of Active Soil: (Section 5-5, USACE EM_1110-2-2100)	$Q_{act.E2.EQh.2} = -497.35 \cdot kN$	$Y_{E.act.E2} = 2.52\,m$

Resisting Lateral Soil Load as required to produce horizontal equilibrium:

$$E_{pas.OT.E2.2} := -\left(H_{hwas.U1} + H_{hwgg.U1} + H_{twgg.U1} + H_{twgf.U1} + H_{twkey.OT.U1} + I_{U1} + E_{act.OT.U1} + \Sigma H_{Q.E2.EQh.2.OT}\right) = 7445 \cdot kN$$

Acting at: $E_{pas.OT.E2.2.loc} := -1 \cdot \dfrac{d_{key}}{2} = -1\,m$

Sum of All Overturning Analysis Horizontal Load (ΣH=0):

$$\Sigma H_{E2.OT.2} := H_{hwas.U1} + H_{hwgg.U1} + H_{twgg.U1} + H_{twgf.U1} + H_{twkey.OT.U1} + I_{U1} + E_{act.OT.U1} + E_{pas.OT.E2.2} + \Sigma H_{Q.E2.EQh.2.OT} = 0 \cdot kN$$

Sum of All Overturning Analysis Horizontal Load Moments:

$$\begin{aligned}\Sigma M_{H.E2.OT.2} := {} & H_{hwas.U1} \cdot H_{hwas.U1.loc} + H_{hwgg.U1} \cdot H_{hwgg.U1.loc} + H_{twgg.U1} \cdot H_{twgg.U1.loc} \cdots = -27114.06 \cdot kN \cdot m \\ & + H_{twgf.U1} \cdot H_{twgf.U1.loc} + H_{twkey.OT.U1} \cdot H_{twkey.OT.U1.loc} + I_{U1} \cdot I_{U1.loc} \cdots \\ & + E_{act.OT.U1} \cdot E_{act.OT.U1.loc} + E_{pas.OT.U1} \cdot E_{pas.OT.U1.loc} + \Sigma M_{Q.E2.2}\end{aligned}$$

Overturning Stability Analysis

$$\Sigma M_{E2.OT.2} := \Sigma M_{V.E2.OT.2} + \Sigma M_{H.E2.OT.2} = 118468.18 \cdot kN \cdot m$$

$$X_{R.E2.2} := \frac{\Sigma M_{E2.OT.2}}{\Sigma V_{E2.OT.2}} = 9.21\,m \qquad x_{OT.E2.2} := X_{R.E2.2} - \frac{L_b}{2} = -0.04\,m$$

Overturning Resultant Ratio

$$Ratio_{OT.E2.2} := \frac{X_{R.E2.2}}{L_b} = 0.5$$

$$Ratio_{OT.E2.2.check} := \begin{cases} \text{"OKAY"} & \text{if } Ratio_{OT.E2.2} \geq Ratio_{overturning.allow.Extreme} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

$$x_{OT.check.E2.2} := \begin{cases} \text{"OKAY"} & \text{if } \left|x_{OT.E2.2}\right| \leq Midhalf \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

Seismic Case $Q_{E2.3}$ - 30% Horizontal Seismic Force, 100% Vertical

E2.3 CASE

Include Seismic Load in Analysis?	$Eq_{E2.3} := 1$	0 = No, 1 = Yes
Horizontal Seismic Coefficient:	$K_{h.E2.3} := -0.05$	
Vertical Seismic Coefficient:	$K_{v.E2.3} := -0.10$	

HORIZONTAL SEISMIC LOADS	Loads	Moment Arm
Horiz Seismic Component of Concrete:	$Q_{conc.E2.EQh.3} := D_{conc} \cdot K_{h.E2.3} \cdot Eq_{E2.3} = -1230.9 \cdot kN$	$Y_{conc.loc} = 1.87\,m$
Horiz Seismic Component of Gates:	$Q_{Gate.E2.EQh.3} := D_{Gate} \cdot K_{h.E2.3} \cdot Eq_{E2.3} = -10.5 \cdot kN$	$Y_{gate} = 3.90\,m$
Horizontal Seismic Component of Headwater - Sliding:	$Q_{hwas.E2.EQh.3} := \left(\frac{7}{12}\right) \cdot K_{h.E2.3} \cdot \gamma_w \cdot \left(HW_{U1} - BOK_{elev}\right)^2 \cdot W_{hwas.U1} \cdot Eq_{E2.3} = -281.6 \cdot kN$	$Y_{HWg.E2} = 3.24\,m$
Horizontal Seismic Component of Soil (Woods Method)-Overturning:	$Q_{act.E2.EQh.3.OT} := \left(\gamma_r - \gamma_w\right) \cdot \left(TOC_{as} - BOK_{elev}\right)^2 \cdot K_{h.E2.3} \cdot W_{hwas.U1} \cdot Eq_{E2.3} = -329.1 \cdot kN$	$Y_{E.act.E2.OT} = 3.78\,m$
Horizontal Seismic Component of Soil (Woods Method)	$Q_{act.E2.EQh.3} := \left(\gamma_r - \gamma_w\right) \cdot \left(TOC_{as} - BOF_{elev}\right)^2 \cdot K_{h.E2.3} \cdot W_{hwas.U1} \cdot Eq_{E2.3} = -146.3 \cdot kN$	$Y_{E.act.E2} = 2.52\,m$

VERTICAL SEISMIC LOADS	Loads	Moment Arm
Vertical Component of Concrete:	$Q_{conc.E2.EQv.3} := D_{conc} \cdot K_{v.E2.2} \cdot Eq_{E2.3} = -738.6 \cdot kN$	$X_{conc.loc} = 10.06\,m$
Vertical Component of Gate:	$Q_{Gate.E2.EQv.3} := D_{Gate} \cdot K_{v.E2.2} \cdot Eq_{E2.3} = -6.3 \cdot kN$	$X_{gate} = 6.60\,m$
Vertical Seismic Component of Headwater over Apron Slab: (Section 7.9, Design Criteria)	$Q_{H1.E2.EQv.3} := K_{v.E2.3} \cdot H_{1.U1} \cdot Eq_{E2.3} = -270.4 \cdot kN$	$H_{1.U1.loc} = 14.13\,m$
Vertical Seismic Component of Headwater over Fixed Crest Slab: (Section 7.9, Design Criteria)	$Q_{H2.E2.EQv.3} := K_{v.E2.3} \cdot H_{2.U1} \cdot Eq_{E2.3} = -269.9 \cdot kN$	$H_{2.U1.loc} = 5.34\,m$

$$\Sigma H_{Q.E2.EQh.3} := Q_{conc.E2.EQh.3} + Q_{Gate.E2.EQh.3} + Q_{hwas.E2.EQh.3} + Q_{act.E2.EQh.3} = -1669.3 \cdot kN$$

$$\Sigma H_{Q.E2.EQh.3.OT} := Q_{conc.E2.EQh.3} + Q_{Gate.E2.EQh.3} + Q_{hwas.E2.EQh.3} + Q_{act.E2.EQh.3.OT} = -1852.15 \cdot kN$$

$$\Sigma V_{Q.E2.EQv.3} := Q_{conc.E2.EQv.3} + Q_{Gate.E2.EQv.3} + Q_{H1.E2.EQv.3} + Q_{H2.E2.EQv.3} = -1285.2 \cdot kN$$

$$\begin{aligned}\Sigma M_{Q.E2.3} := {} & Q_{conc.E2.EQh.3} \cdot Y_{conc.loc} + Q_{Gate.E2.EQh.3} \cdot Y_{gate} + Q_{hwas.E2.EQh.3} \cdot Y_{HWg.E2} \cdots \\ & + Q_{act.E2.EQh.3.OT} \cdot Y_{E.act.E2.OT} + Q_{conc.E2.EQv.3} \cdot X_{conc.loc} + Q_{Gate.E2.EQv.3} \cdot X_{gate} \cdots \\ & + Q_{H1.E2.EQv.3} \cdot H_{1.U1.loc} + Q_{H2.E2.EQv.3} \cdot H_{2.U1.loc}\end{aligned} = -17226.35 \cdot kN \cdot m$$

STABILITY ASSESSMENT (SLIDNG, BEARING, FLOTATION AND OVERTURNING):

E2.3 CASE

CHECK SLIDING ALONG HORIZONTAL PLANE THRU TOE,
IGNORING BEDROCK MOBILIZED BY STRUCTURAL HEEL KEY, OR VOID BEHIND KEY

Sum of Vertical Forces:

$\Sigma V_{E2.3} := \Sigma V_{U1} + \Sigma V_{Q.E2.EQv.3} = 10026.7 \cdot kN$

Sum of Horizontal Forces:

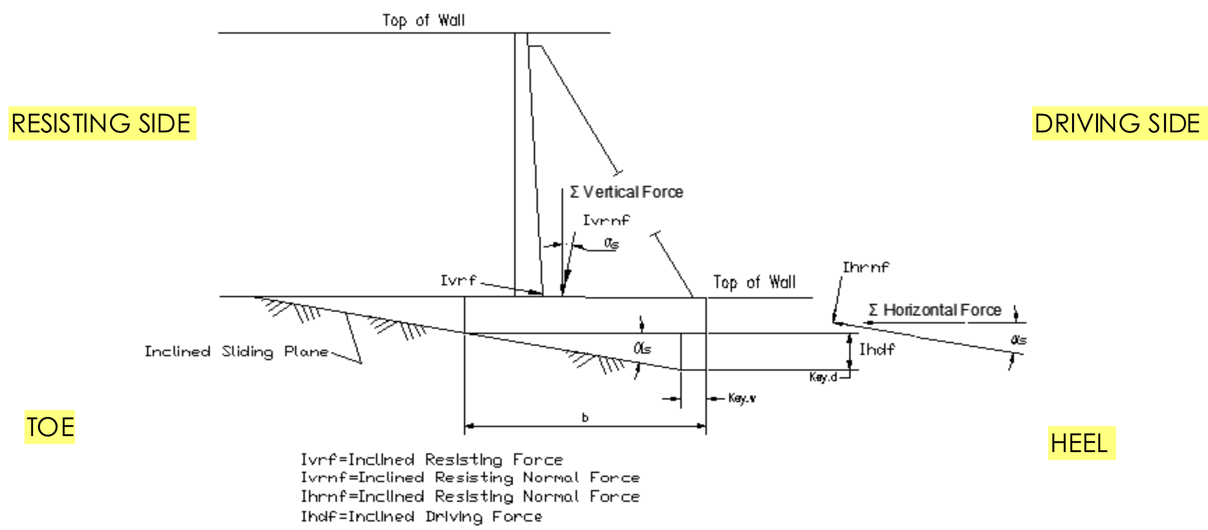
$\Sigma H_{E2.3} := \Sigma H_{U1} - I_{U1} + \Sigma H_{Q.E2.EQh.3} = -3815.01 \cdot kN$

Sliding Factor of Safety:

$$FS_{HorizSliding.E2.3} := \frac{\tan_{\phi} \cdot \Sigma V_{E2.3}}{\left|\Sigma H_{E2.3}\right|} = 1.28$$

$FS_{HorizSliding.E2.3.Check} :=$ | "OKAY" if $FS_{HorizSliding.E2.3} \geq FS_{req.E2.sl}$; "Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !" otherwise $=$ "OKAY"

CHECK SLIDING ALONG INCLINED SLIDING PLANE FROM HEEL KEY TO TOE,
WITH BEDROCK MASS MOBILIZED BY REINFOCREDE CONCRETE KEY)



$\alpha s = 0.11$ as degrees= $\alpha s \cdot \left(\frac{180}{\pi}\right) = 6.52$ $\Sigma V_{E2.3} = 10026.68 \cdot kN$ $V_{rs} = 5775 \cdot kN$

Resolve $\Sigma Vert_{E2.3}$ & $\Sigma Horiz_{E2.3}$

$$\Sigma V_{InclinedE2.3} := \cos(\alpha s) \cdot \left(\Sigma V_{E2.3} + V_{rs}\right) + \sin(\alpha s) \cdot \left|\Sigma H_{E2.3}\right| = 16132.7 \cdot kN$$

$$\Sigma H_{InclinedE2.3} := \cos(\alpha s) \cdot \left|\Sigma H_{E2.3}\right| - \sin(\alpha s) \cdot \left(\Sigma V_{E2.3} + V_{rs}\right) = 1996.1 \cdot kN$$

(With properly engineered reinforced concrete Key, horizontal sliding plane thru Toe is protected, critical sliding plane is relocated to the INCLINED SLIDING PLANE FROM HEEL KEY To TOE, Bedrock Mass above this examing plane is mobilized by reinforced concrete key and combined into Structural Wedge.)

Inclined Sliding Plane Length $L_{incline} = 18.61 \, m$

Safety Factor for Sliding Inclined Failure Plane

$$FS_{InclinedlSlidingE2.3} := \frac{\Sigma V_{InclinedE2.3} \cdot \tan\left(\phi_{rock} \cdot \frac{\pi}{180}\right)}{\left|\Sigma H_{InclinedE2.3}\right|} = 3.94$$

$FS_{InclinedSliding.check.E2.3} :=$ | "OKAY " if $FS_{InclinedlSlidingE2.3} > FS_{req.E2.sl}$; "Revise Structure"" otherwise $=$ "OKAY "

$FS_{InclinedSliding.check.E2.3} =$ "OKAY "

OVERTURNING STABILITY CHECK:

E2.3 CASE

CHECK ECCENTRICITY

Sum of the moments:

$$\Sigma M_{E2.3} := \left(\Sigma M_{U1} + \Sigma M_{Q.E2.3}\right) = 166876 \cdot kN \cdot m$$

Eccentricity:

$$e_{E2.3} := \left(\frac{L_{incline}}{2}\right) - \frac{\left(\Sigma M_{E2.3}\right)}{\Sigma V_{InclinedE2.3}} = -1.04\,m$$

Eccentricity Check:

$$e_{check.E2.3} := \begin{cases} \text{"Okay"} & \text{if } e_{E2.3} \le Midhalf \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$e_{check.E2.3} = \text{"Okay"}$

Foundation Bearing Checks:

Bearing Pressure at Heel:

$$\sigma_{heel.E2.3} := \frac{\Sigma V_{InclinedE2.3}}{A_{b.incline}} - \frac{\left(\Sigma V_{InclinedE2.3} \cdot e_{E2.3}\right)}{S_{b.incline}} = 77.2 \cdot \frac{kN}{m^2}$$

$$\sigma_{heel.E2.3.check} := \left(\begin{cases} \text{"Okay"} & \text{if } \sigma_{heel.E2.3} \le \sigma_{allow.E2} \\ \text{"Revise Structure"} & \text{if } \sigma_{heel.E2.3} < 0\,\frac{kN}{m^2} \end{cases}\right)$$

$\sigma_{heel.E2.3.check} = \text{"Okay"}$

Bearing Pressure at Toe:

$$\sigma_{toe.E2.3} := \frac{\Sigma V_{InclinedE2.3}}{A_{b.incline}} + \frac{\left(\Sigma V_{InclinedE2.3} \cdot e_{E2.3}\right)}{S_{b.incline}} = 38.4 \cdot \frac{kN}{m^2}$$

$$\sigma_{toe.E2.3.check.1} := \begin{cases} \text{"Okay"} & \text{if } \sigma_{toe.E2.3} \le \sigma_{allow.E2} \\ \text{"Revise Structure"} & \text{if } \sigma_{toe.E2.3} < 0\,\frac{kN}{m^2} \end{cases}$$

$\sigma_{toe.E2.3.check.1} = \text{"Okay"}$

FLOATATION ANALYSIS:

ACCEPTANCE PARAMETERS

Required Factor of Safety: $FS_{req.FE2.3} := 1.1$

VERTICAL LOADS RESISTING:

Dead Load: $\Sigma V_{DL} = 24828.6 \cdot kN$

Water Weight H1+H2: $\Sigma V_{H.FE2.3} := \Sigma V_{H.FU1} + \Sigma V_{Q.E2.EQv.3} = 4117.89 \cdot kN$

Summation Vertical Resisting: $\Sigma V_{FE2.3} := \Sigma V_{DL} + \Sigma V_{H.FE2.3} = 28946.5 \cdot kN$

VERTICAL LOADS UPLIFT:

Uplift: $U_{S.U1} = -18919.81 \cdot kN$

Factor of Safety Floatation:

$$FS_{act.FE2.3} := \frac{\Sigma V_{FE2.3}}{\left|U_{S.U1}\right|} = 1.53$$

$$FS_{check.FE2.3} := \begin{cases} \text{"OKAY"} & \text{if } FS_{act.FE2.3} \ge FS_{req.FE2.3} \\ \text{"ANCHORS REQUIRED"} & \text{if } FS_{act.FE2.3} < FS_{req.FE2.3} \end{cases} = \text{"OKAY"}$$

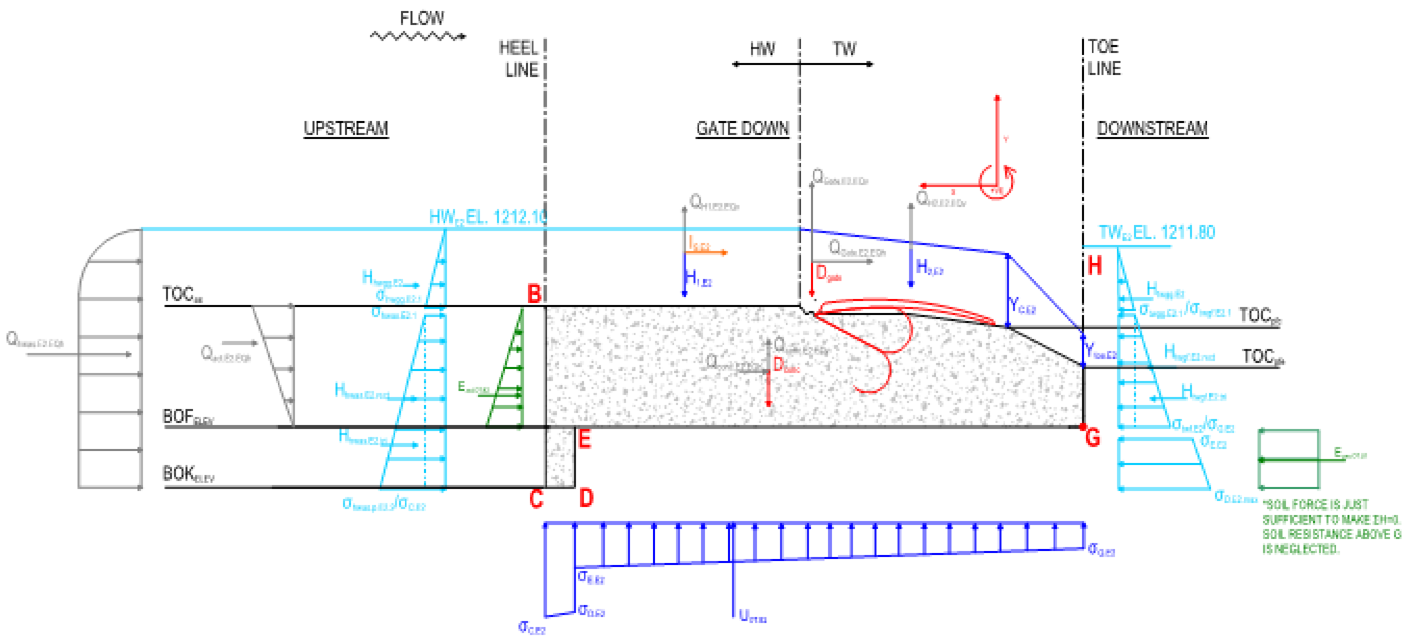
E2.3 CASE

MONOLITH OVERTURNING STABILITY ANALYSIS

Seismic Case $Q_{E2.3}$: 30% Horizontal Seismic Force, 100% Vertical

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.
Assumptions are made in order to compute overturning stability of indeterminate forces on monolith with key;
(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.
(b) The horizontal resisting force acting on the key, P.key, is that required for static equilibrium
(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1 $Ratio_{overturning.allow.Extreme} = 0.25$ Resultant within Middle Half



All Vertical Loads Applicable to Overturning Stability Analysis

Total Concrete Dead Loads:	$D_{conc} = 24618.6 \cdot kN$	at:	$X_{conc.loc} = 10.06\,m$
Dead Load of Gate:	$D_{Gate} = 210.0 \cdot kN$		$X_{gate} = 6.60\,m$
Water Weight (HW) on Apron Slab:	$H_{1.U1} = 2703.9 \cdot kN$		$H_{1.U1.loc} = 14.13\,m$
Water Weight (TW) on Gate Footing:	$H_{2.U1} = 2699.2 \cdot kN$		$H_{2.U1.loc} = 5.34\,m$
Uplift Load for Overturning Analysis:	$U_{OT.U1} = -16456.3 \cdot kN$		$U_{OT.U1.loc} = 9.48 \cdot m$
Vertical Seismic Component of Concrete Structure:	$Q_{conc.E2.EQv.3} = -738.56 \cdot kN$		$X_{conc.loc} = 10.06\,m$
Vertical Seismic Component of Crest Gate:	$Q_{Gate.E2.EQv.3} = -6.3 \cdot kN$		$X_{gate} = 6.60\,m$
Vertical Seismic Component of Headwater over Apron Slab:	$Q_{H1.E2.EQv.3} = -270.39 \cdot kN$		$H_{1.U1.loc} = 14.13\,m$
Vertical Seismic Component of Headwater over Fixed Crest Slab:	$Q_{H2.E2.EQv.3} = -269.92 \cdot kN$		$H_{2.U1.loc} = 5.34\,m$

Sum of All Overturning Analysis Vertical Load:

$$\Sigma V_{E2.OT.3} := D_{conc} + D_{Gate} + H_{1.U1} + H_{2.U1} + U_{OT.U1} + \Sigma V_{Q.E2.EQv.3} = 12490.19 \cdot kN$$

Sum of All Overturning Analysis Vertical Load Moments:

$$\Sigma M_{V.E2.OT.3} := D_{conc} \cdot X_{conc.loc} + D_{Gate} \cdot X_{gate} + H_{1.U1} \cdot H_{1.U1.loc} + H_{2.U1} \cdot H_{2.U1.loc} + U_{OT.U1} \cdot U_{OT.U1.loc} = 145582.24 \cdot kN \cdot m$$

Lateral Driving Earth Loads for Overturning Stability Analysis (at rest condition) **E2.3 CASE**

Depth of Driving Soil Loads (to top of key): $h_{E.OT.E2.3} := TOC_{as} - BOF_{elev} = 4\,m$

At-Rest Soil Load: $E_{act.OT.E2.3} := \frac{\left(K_{o.U1} \cdot h_{E.OT.U1}\right)^2}{2} \cdot \left(\gamma_r - \gamma_w\right) \cdot W_{hwas.U1} \cdot -1 = -962.49 \cdot kN$

At Rest- Soil Load Acting from Toe: $E_{act.OT.E2.3.loc} := \frac{h_{E.OT.U1}}{3} = 1.33\,m$

All Lateral Loads Applicable to Overturning Stability Analysis

HW Lateral Load on Approach Slab:	$H_{hwas.U1} = -4502.8 \cdot kN$	$H_{hwas.U1.loc} = 0.41\,m$
HW Lateral Load on Guard Gate:	$H_{hwgg.U1} = 0.0 \cdot kN$	$H_{hwgg.U1.loc} = 4.00\,m$
TW Lateral Load on Guard Gate:	$H_{twgg.U1} = 0.0 \cdot kN$	$H_{twgg.U1.loc} = 4.00\,m$
TW Lateral Load on Gate Footing (No Key - Overturning Values Adjusted):	$H_{twgf.U1} = 2236.68 \cdot kN$	$H_{twgf.U1.loc} = 1.65\,m$
TW Lateral Load on Key:	$H_{twkey.OT.U1} = 2080.92 \cdot kN$	$H_{twkey.OT.U1.loc} = -1.05\,m$
Ice / Impact Load:	$I_{U1} = 0.0 \cdot kN$	$I_{U1.loc} = 3.70\,m$
Lateral Soil Load (driving):	$E_{act.OT.U1} = -962.5 \cdot kN$	$E_{act.OT.U1.loc} = 1.33\,m$
Horizontal Seismic Component of Concrete Structure:	$Q_{conc.E2.EQh.3} = -1230.93 \cdot kN$	$Y_{conc.loc} = 1.87\,m$
Horizontal Seismic Component of Vertical Lift Gate:	$Q_{Gate.E2.EQh.3} = -10.5 \cdot kN$	$Y_{gate} = 3.90\,m$
Horizontal Seismic Component of Headwater on Gate:	$Q_{hwas.E2.EQh.3} = -281.59 \cdot kN$	$Y_{HWg.E2} = 3.24\,m$
Horizontal Seismic Component of Active Soil: (Section 5-5, USACE EM_1110-2-2100)	$Q_{act.E2.EQh.3} = -146.28 \cdot kN$	$Y_{E.act.E2} = 2.52\,m$

Resisting Lateral Soil Load as required to produce horizontal equilibrium:

$$E_{pas.OT.E2.3} := -\left(H_{hwas.U1} + H_{hwgg.U1} + H_{twgg.U1} + H_{twgf.U1} + H_{twkey.OT.U1} + I_{U1} + E_{act.OT.U1} + \Sigma H_{Q.E2.EQh.3.OT}\right) = 2999.84 \cdot kN$$

Acting at: $E_{pas.OT.E2.3.loc} := -1 \cdot \frac{d_{key}}{2} = -1\,m$

Sum of All Overturning Analysis Horizontal Load (ΣH=0):

$$\Sigma H_{E2.OT.3} := H_{hwas.U1} + H_{hwgg.U1} + H_{twgg.U1} + H_{twgf.U1} + H_{twkey.OT.U1} + I_{U1} + E_{act.OT.U1} + E_{pas.OT.E2.3} + \Sigma H_{Q.E2.EQh.3.OT} = 0 \cdot kN$$

Sum of All Overturning Analysis Horizontal Load Moments:

$$\Sigma M_{H.E2.OT.3} := H_{hwas.U1} \cdot H_{hwas.U1.loc} + H_{hwgg.U1} \cdot H_{hwgg.U1.loc} + H_{twgg.U1} \cdot H_{twgg.U1.loc} \cdots + H_{twgf.U1} \cdot H_{twgf.U1.loc} + H_{twkey.OT.U1} \cdot H_{twkey.OT.U1.loc} + I_{U1} \cdot I_{U1.loc} \cdots + E_{act.OT.U1} \cdot E_{act.OT.U1.loc} + E_{pas.OT.U1} \cdot E_{pas.OT.U1.loc} + \Sigma M_{Q.E2.3} = -20003.34 \cdot kN \cdot m$$

Overturning Stability Analysis

$$\Sigma M_{E2.OT.3} := \Sigma M_{V.E2.OT.3} + \Sigma M_{H.E2.OT.3} = 125578.9 \cdot kN \cdot m$$

$$X_{R.E2.3} := \frac{\Sigma M_{E2.OT.3}}{\Sigma V_{E2.OT.3}} = 10.05\,m \qquad x_{OT.E2.3} := X_{R.E2.3} - \frac{L_b}{2} = 0.8\,m$$

Overturning Resultant Ratio

$$Ratio_{OT.E2.3} := \frac{X_{R.E2.3}}{L_b} = 0.54$$

$$Ratio_{OT.E2.3.check} := \begin{cases} \text{"OKAY"} & \text{if } Ratio_{OT.E2.3} \geq Ratio_{overturning.allow.Extreme} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

$$x_{OT.check.E2.3} := \begin{cases} \text{"OKAY"} & \text{if } \left|x_{OT.E2.3}\right| \leq Midhalf \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

Summary of Results

E2 CASE

E2.1 Case

Sliding Factor of Safety: (Horizontal Plane)	$FS_{HorizSliding.E2.1} = 0.71$	
	$FS_{HorizSliding.E2.1.Check}$ = "Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !"	
Sliding Factor of Safety: (Inclined Plane)	$FS_{InclinedlSlidingE2.1} = 1.49$	$FS_{InclinedSliding.check.E2.1}$ = "OKAY "
Eccentricity: (Inclined Plane)	$e_{E2.1} = -0.15\,m$	$e_{check.E2.1}$ = "Okay"
Bearing Pressure At Heel: (Inclined Plane)	$\sigma_{heel.E2.1} = 67 \cdot kPa$	$\sigma_{heel.E2.1.check}$ = "Okay"
Bearing Pressure At Toe: (Inclined Plane)	$\sigma_{toe.E2.1} = 61 \cdot kPa$	$\sigma_{toe.E2.1.check.1}$ = "Okay"
Flotation Factor of Safety (horizontal plane)	$FS_{act.FE2.1} = 1.6$	$FS_{check.FE2.1}$ = "OKAY"
Overturning Resultant Ratio: (horizontal plane)	$Ratio_{OT.E2.1} = 0.5$	$Ratio_{OT.E2.1.check}$ = "OKAY"
Eccentricity: (horizontal plane)	$x_{OT.E2.1} = 0.01\,m$	$x_{OT.check.E2.1}$ = "OKAY"

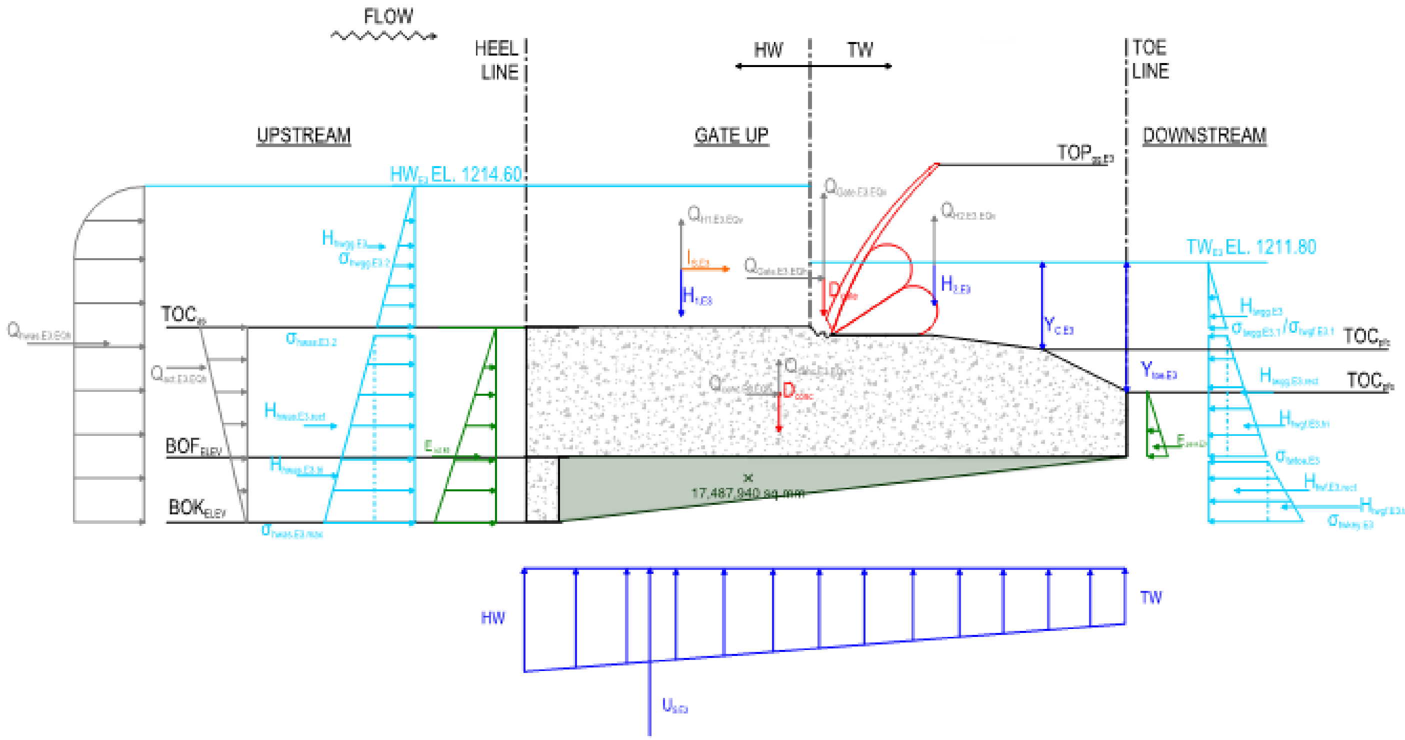
E2.2 Case

Sliding Factor of Safety: (Horizontal Plane)	$FS_{HorizSliding.E2.2} = 0.65$	
	$FS_{HorizSliding.E2.2.Check}$ = "Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !"	
Sliding Factor of Safety: (Inclined Plane)	$FS_{InclinedlSlidingE2.2} = 1.39$	$FS_{InclinedSliding.check.E2.2}$ = "OKAY "
Eccentricity: (Inclined Plane)	$e_{E2.2} = -0.11\,m$	$e_{check.E2.2}$ = "Okay"
Bearing Pressure At Heel: (Inclined Plane)	$\sigma_{heel.E2.2} = 63 \cdot kPa$	$\sigma_{heel.E2.2.check}$ = "Okay"
Bearing Pressure At Toe: (Inclined Plane)	$\sigma_{toe.E2.2} = 59 \cdot kPa$	$\sigma_{toe.E2.2.check.1}$ = "Okay"
Flotation Factor of Safety (horizontal plane)	$FS_{act.FE2.2} = 1.55$	$FS_{check.FE2.2}$ = "OKAY"
Overturning Resultant Ratio: (horizontal plane)	$Ratio_{OT.E2.2} = 0.5$	$Ratio_{OT.E2.2.check}$ = "OKAY"
Eccentricity: (horizontal plane)	$x_{OT.E2.2} = -0.04\,m$	$x_{OT.check.E2.2}$ = "OKAY"

E2.3 Case

Sliding Factor of Safety: (Horizontal Plane)	$FS_{HorizSliding.E2.3} = 1.28$ $FS_{HorizSliding.E2.3.Check} = \text{"OKAY"}$	
Sliding Factor of Safety: (Inclined Plane)	$FS_{InclinedlSlidingE2.3} = 3.94$	$FS_{InclinedSliding.check.E2.3} = \text{"OKAY "}$
Eccentricity: (Inclined Plane)	$e_{E2.3} = -1.04\,m$	$e_{check.E2.3} = \text{"Okay"}$
Bearing Pressure At Heel: (Inclined Plane)	$\sigma_{heel.E2.3} = 77 \cdot kPa$	$\sigma_{heel.E2.3.check} = \text{"Okay"}$
Bearing Pressure At Toe: (Inclined Plane)	$\sigma_{toe.E2.3} = 38 \cdot kPa$	$\sigma_{toe.E2.3.check.1} = \text{"Okay"}$
Flotation Factor of Safety (horizontal plane)	$FS_{act.FE2.3} = 1.53$	$FS_{check.FE2.3} = \text{"OKAY"}$
Overturning Resultant Ratio: (horizontal plane)	$Ratio_{OT.E2.3} = 0.54$	$Ratio_{OT.E2.3.check} = \text{"OKAY"}$
Eccentricity: (horizontal plane)	$x_{OT.E2.3} = 0.80\,m$	$x_{OT.check.E2.3} = \text{"OKAY"}$

E3 DESIGN CASE



U2 CASE PLUS SEISMIC

ACCEPTANCE PARAMETERS

Required Factor of Safety for Sliding: $FS_{req.E3.sl} := 1.0$ (Without Cohesion) (Section 8.1, Design Criteria)

Resultant Within Middle Half of Base: $e \le \frac{L_b}{4} \wedge e \ge \frac{-L_b}{4}$

Allowable Rock Bearing Pressure: $\sigma_{allow.E3} := 1740 \cdot \frac{kN}{m^2}$ (Section 5.2, Design Criteria)

INPUT PARAMETERS

Headwater Elevation: $HW_{E3} := 1214.60m$ (Section 8.3, Design Criteria)

Tailwater Elevation: $TW_{E3} := 1211.80m$ (Section 8.3, Design Criteria)

Bottom of Footing Elevation: $BOF_{elev} = 1206\,m$

Approach Slab Top of Concrete Elevation at Upstream Face: $TOC_{as} = 1210\,m$

Footing Top of Concrete Elevation at Stilling Basin: $TOC_{pfe} = 1208\,m$

Footing Top of Concrete Elevation at Center of Footing: $TOC_{pfc} = 1209.3\,m$

Top of Guard/Regulating Gate Elevation: $TOP_{rg.U2} = 1212.1\,m$ $TOP_{gg.U2} = 1215.00\,m$

Gates are open when top of gate elevation is at 1210.00m

Gates are closed/up when top of gate elevation is at 1215.0m

Bottom of Key Elevation: $BOK_{elev} = 1204\,m$

Crestwater Elevation: Dynamic Flow $EL_{C.E3} := 1211.8m$

$$Y_{C.E3} := \begin{cases} (EL_{C.E3} - TOC_{pfc}) & \text{if } TOP_{gg.U2} \le HW_{E3} \\ (TW_{E3} - TOC_{pfc}) & \text{if } TOP_{gg.U2} > HW_{E3} \end{cases} = 2.5 \cdot m$$

Toewater Elevation: $EL_{TOE.E3} := 1208.58m$

$$Y_{TOE.E3} := \begin{cases} (EL_{TOE.E3} - TOC_{pfe}) & \text{if } TOP_{gg.U2} \le HW_{E3} \\ (TW_{E3} - TOC_{pfe}) & \text{if } TOP_{gg.U2} > HW_{E3} \end{cases} = 3.8 \cdot m$$

SEISMIC LOAD (Three combinations of E_h and E_v considered)

E3.1 CASE

Seismic Case $Q_{E2.1}$ - 100% Horizontal Seismic Force, No Vertical

Include Seismic Load in Analysis? $Eq_{E3.1} := 1$

Horizontal Seismic Coefficient: $K_{h.E3.1} := -0.17$

Vertical Seismic Coefficient: $K_{v.E3.1} := -0.00$

HORIZONTAL SEISMIC LOADS	Loads	Moment Arm
Horiz Seismic Component of Concrete:	$Q_{conc.E3.EQh.1} := D_{conc} \cdot K_{h.E3.1} \cdot Eq_{E3.1} = -4185.2 \cdot kN$	$Y_{conc.loc} = 1.87\,m$
Horiz Seismic Component of Gates:	$Q_{Gate.E3.EQh.1} := D_{Gate} \cdot K_{h.E3.1} \cdot Eq_{E3.1} = -35.7 \cdot kN$	$Y_{gate} = 3.90\,m$
Horizontal Seismic Component of Headwater - Sliding:	$Q_{hwas.E3.EQh.1} := \left(\frac{7}{12}\right) \cdot K_{h.E3.1} \cdot \gamma_w \cdot \left(HW_{U2} - BOK_{elev}\right)^2 \cdot W_{hwas.U2} \cdot Eq_{E3.1} = -1639.6 \cdot kN$ $Y_{HWg.E3} := 0.4 \cdot \left(HW_{U2} - BOK_{elev}\right) = 4.24\,m$	
Horizontal Seismic Component of Soil (Woods Method)-Overturning:	$Q_{act.E3.EQh.1.OT} := \left(\gamma_r - \gamma_w\right) \cdot \left(TOC_{as} - BOK_{elev}\right)^2 \cdot K_{h.E3.1} \cdot W_{hwas.U2} \cdot Eq_{E3.1} = -1119.0 \cdot kN$ $Y_{E.act.E3.OT} := 0.63 \cdot \left(TOC_{as} - BOK_{elev}\right) = 3.78\,m$	
Horizontal Seismic Component of Soil (Woods Method)	$Q_{act.E3.EQh.1} := \left(\gamma_r - \gamma_w\right) \cdot \left(TOC_{as} - BOF_{elev}\right)^2 \cdot K_{h.E3.1} \cdot W_{hwas.U2} \cdot Eq_{E3.1} = -497.4 \cdot kN$ $Y_{E.act.E3} := 0.63 \cdot \left(TOC_{as} - BOF_{elev}\right) = 2.52\,m$	

VERTICAL SEISMIC LOADS	Loads	Moment Arm
Vertical Component of Concrete:	$Q_{conc.E3.EQv.1} := D_{conc} \cdot K_{v.E3.1} \cdot Eq_{E3.1} = 0.0 \cdot kN$	$X_{conc.loc} = 10.06\,m$
Vertical Component of Gate:	$Q_{Gate.E3.EQv.1} := D_{Gate} \cdot K_{v.E3.1} \cdot Eq_{E3.1} = 0.0 \cdot kN$	$X_{gate} = 6.60\,m$
Vertical Seismic Component of Headwater over Apron Slab:	$Q_{H1.E3.EQv.1} := K_{v.E3.1} \cdot H_{1.U2} \cdot Eq_{E3.1} = 0.0 \cdot kN$	$H_{1.U2.loc} = 14.13\,m$
Vertical Seismic Component of Headwater over Pier Footing:	$Q_{H2.E3.EQv.1} := K_{v.E3.1} \cdot H_{2.U2} \cdot Eq_{E3.1} = 0.0 \cdot kN$	$H_{2.U2.loc} = 5.23\,m$

$$\Sigma H_{Q.E3.EQh.1} := Q_{conc.E3.EQh.1} + Q_{Gate.E3.EQh.1} + Q_{hwas.E3.EQh.1} + Q_{act.E3.EQh.1} = -6357.81 \cdot kN$$

$$\Sigma H_{Q.E3.EQh.1.OT} := Q_{conc.E3.EQh.1} + Q_{Gate.E3.EQh.1} + Q_{hwas.E3.EQh.1} + Q_{act.E3.EQh.1.OT} = -6979.5 \cdot kN$$

$$\Sigma V_{Q.E3.EQv.1} := Q_{conc.E3.EQv.1} + Q_{Gate.E3.EQv.1} + Q_{H1.E3.EQv.1} + Q_{H2.E3.EQv.1} = 0.0 \cdot kN$$

$$\Sigma M_{Q.E3.1} := Q_{conc.E3.EQh.1} \cdot Y_{conc.loc} + Q_{Gate.E3.EQh.1} \cdot Y_{gate} + Q_{hwas.E3.EQh.1} \cdot Y_{HWg.E3} \cdots + Q_{act.E3.EQh.1.OT} \cdot Y_{E.act.E3.OT} + Q_{conc.E3.EQv.1} \cdot X_{conc.loc} + Q_{Gate.E3.EQv.1} \cdot X_{gate} \cdots + Q_{H1.E3.EQv.1} \cdot H_{1.U2.loc} + Q_{H2.E3.EQv.1} \cdot H_{2.U2.loc} = -19140.41 \cdot kN \cdot m$$

STABILITY ASSESSMENT (SLIDNG, BEARING, FLOTATION AND OVERTURNING):

E3.1 CASE

CHECK SLIDING ALONG HORIZONTAL PLANE THRU TOE,
IGNORING BEDROCK MOBILIZED BY STRUCTURAL HEEL KEY, OR VOID BEHIND KEY

Sum of Vertical Forces: $\Sigma V_{E3.1} := \Sigma V_{U2} + \Sigma V_{Q.E3.EQv.1} = 13368.9 \cdot kN$

Sum of Horizontal Forces: $\Sigma H_{E3.1} := \Sigma H_{U2} - I_{U2} + \Sigma H_{Q.E3.EQh.1} = -11661.36 \cdot kN$

Sliding Factor of Safety: $FS_{HorizSliding.E3.1} := \dfrac{\tan_{\phi} \cdot \Sigma V_{E3.1}}{\left|\Sigma H_{E3.1}\right|} = 0.56$

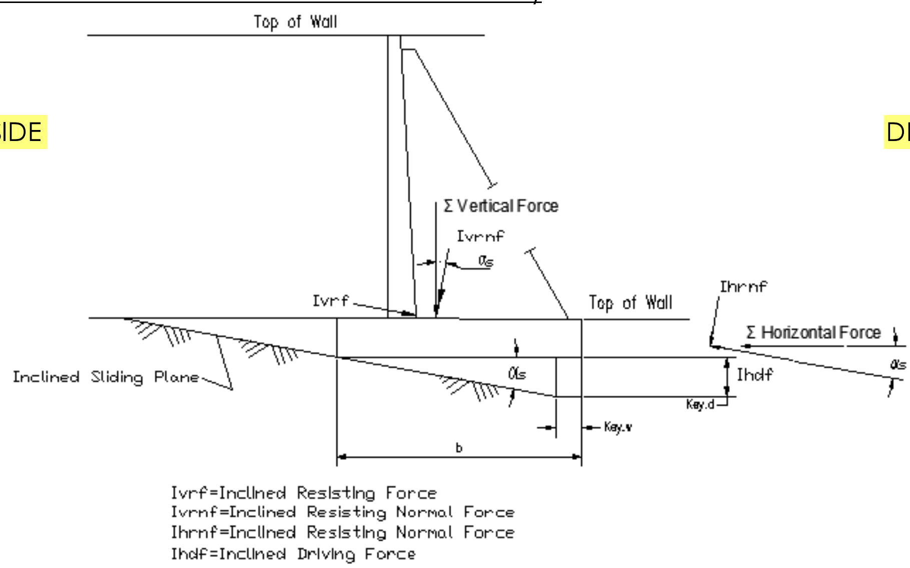
$FS_{HorizSliding.E3.1.Check} :=$ "OKAY" if $FS_{HorizSliding.E3.1} \geq FS_{req.E3.sl}$
"Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !" otherwise

$FS_{HorizSliding.E3.1.Check} =$ "Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !"

CHECK SLIDING ALONG INCLINED SLIDING PLANE FROM HEEL KEY TO TOE,
WITH BEDROCK MASS MOBILIZED BY REINFOCREDE CONCRETE KEY)

RESISTING SIDE

DRIVING SIDE



TOE

HEEL

$\alpha s = 0.11$ as degrees= $\alpha s \cdot \left(\dfrac{180}{\pi}\right) = 6.52$ $V_{rs} = 5775 \cdot kN$

Resolve $\Sigma Vert_{E3.1}$ & $\Sigma Horiz_{E3.1}$

$$\Sigma V_{InclinedE3.1} := \cos(\alpha s) \cdot \left(\Sigma V_{E3.1} + V_{rs}\right) + \sin(\alpha s) \cdot \left|\Sigma H_{E3.1}\right| = 20344.2 \cdot kN$$

$$\Sigma H_{InclinedE3.1} := \cos(\alpha s) \cdot \left|\Sigma H_{E3.1}\right| - \sin(\alpha s) \cdot \left(\Sigma V_{E3.1} + V_{rs}\right) = 9412.2 \cdot kN$$

Inclined Sliding Plane Length $L_{incline} = 18.61\ m$

Safety Factor for Sliding Inclined Failure Plane

$$FS_{InclinedISlidingE3.1} := \frac{\Sigma V_{InclinedE3.1} \cdot \tan\left(\phi_{rock} \cdot \frac{\pi}{180}\right)}{\left|\Sigma H_{InclinedE3.1}\right|} = 1.05$$

$FS_{InclinedSliding.check.E3.1} :=$ "OKAY " if $FS_{InclinedISlidingE3.1} > FS_{req.E3.sl}$ = "OKAY "
"Revise Structure"" otherwise

$FS_{InclinedSliding.check.E3.1} =$ "OKAY "

E3.1 CASE

OVERTURNING STABILITY CHECK:

CHECK ECCENTRICITY

Sum of the moments:

$$\Sigma M_{E3.1} := \left(\Sigma M_{U2} + \Sigma M_{Q.E3.1}\right) = 155550 \cdot kN \cdot m$$

Eccentricity:

$$e_{E3.1} := \left(\frac{L_{incline}}{2}\right) - \frac{\left(\Sigma M_{E3.1}\right)}{\Sigma V_{InclinedE3.1}} = 1.66\,m$$

Eccentricity Check:

$$e_{check.E3.1} := \begin{cases} \text{"Okay"} & \text{if } e_{E3.1} \le Midhalf \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$e_{check.E3.1} = \text{"Okay"}$

Foundation Bearing Checks:

Bearing Pressure at Heel:

$$\sigma_{heel.E3.1} := \frac{\Sigma V_{InclinedE3.1}}{A_{b.incline}} - \frac{\left(\Sigma V_{InclinedE3.1} \cdot e_{E3.1}\right)}{S_{b.incline}} = 33.9 \cdot \frac{kN}{m^2}$$

$$\sigma_{heel.E3.1.check} := \left(\begin{cases} \text{"Okay"} & \text{if } \sigma_{heel.E3.1} \le \sigma_{allow.E2} \\ \text{"Revise Structure"} & \text{if } \sigma_{heel.E3.1} < 0\,\frac{kN}{m^2} \end{cases}\right)$$

$\sigma_{heel.E3.1.check} = \text{"Okay"}$

Bearing Pressure at Toe:

$$\sigma_{toe.E3.1} := \frac{\Sigma V_{InclinedE3.1}}{A_{b.incline}} + \frac{\left(\Sigma V_{InclinedE3.1} \cdot e_{E3.1}\right)}{S_{b.incline}} = 111.9 \cdot \frac{kN}{m^2}$$

$$\sigma_{toe.E3.1.check.1} := \begin{cases} \text{"Okay"} & \text{if } \sigma_{toe.E3.1} \le \sigma_{allow.E2} \\ \text{"Revise Structure"} & \text{if } \sigma_{toe.E3.1} < 0\,\frac{kN}{m^2} \end{cases}$$

$\sigma_{toe.E3.1.check.1} = \text{"Okay"}$

FLOATATION ANALYSIS:

ACCEPTANCE PARAMETERS

Required Factor of Safety: $FS_{req.FE3.1} := 1.1$

VERTICAL LOADS RESISTING:

Dead Load: $\Sigma V_{DL} = 24828.6 \cdot kN$

Water Weight H1+H2: $\Sigma V_{H.FE3.1} := \Sigma V_{H.FU2} + \Sigma V_{Q.E3.EQv.1} = 10862.98 \cdot kN$

Summation Vertical Resisting: $\Sigma V_{FE3.1} := \Sigma V_{DL} + \Sigma V_{H.FE3.1} = 35691.6 \cdot kN$

VERTICAL LOADS UPLIFT:

Uplift: $U_{U2} = -22322.65 \cdot kN$

Factor of Safety Floatation:

$$FS_{act.FE3.1} := \frac{\Sigma V_{FE3.1}}{\left|U_{U2}\right|} = 1.60$$

$$FS_{check.FE3.1} := \begin{cases} \text{"OKAY"} & \text{if } FS_{act.FE3.1} \ge FS_{req.FE3.1} \\ \text{"ANCHORS REQUIRED"} & \text{if } FS_{act.FE3.1} < FS_{req.FE3.1} \end{cases} = \text{"OKAY"}$$

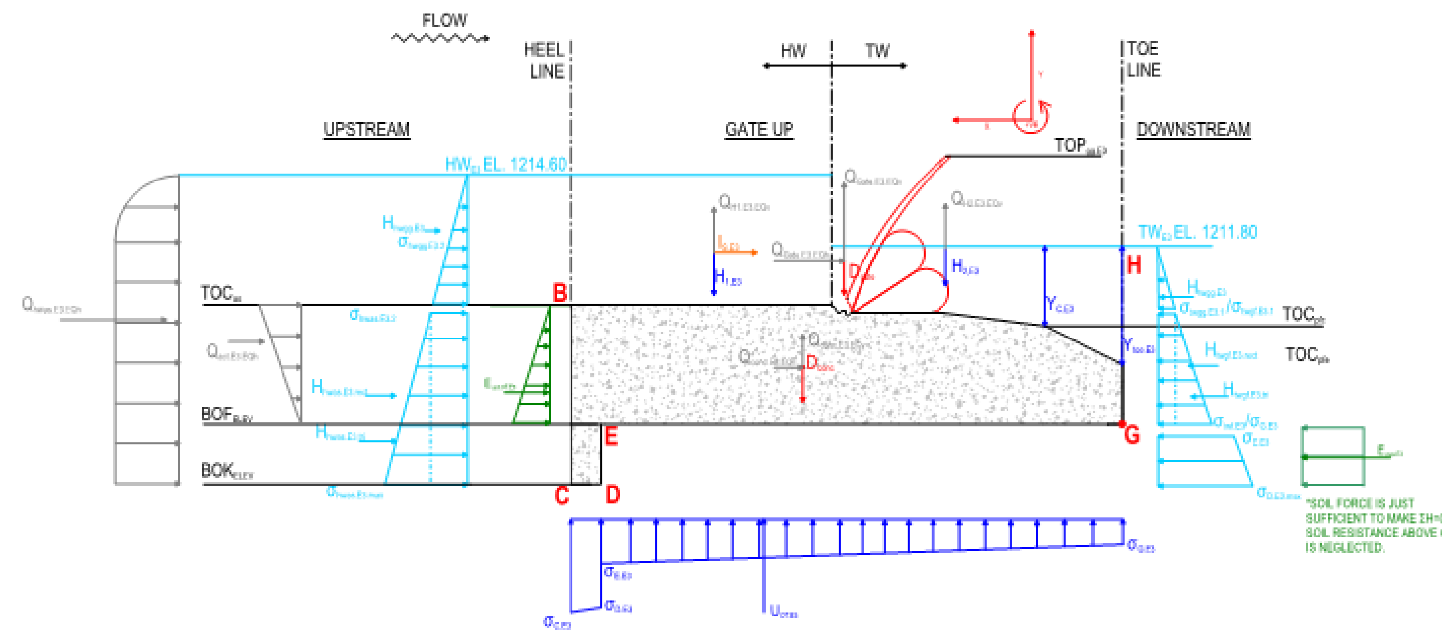
E3.1 CASE

MONOLITH OVERTURNING STABILITY ANALYSIS

Seismic Case $Q_{E3.1}$: 100% Horizontal Seismic Force, No Vertical

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.
Assumptions are made in order to compute overturning stability of indetermine forces on monolith with key;
(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.
(b) The horizontal resisting force acting on the key, P.key, is that required for static equilibrium
(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1 $Ratio_{overturning.allow.Extreme} = 0.25$ Resultant within Middle Half



All Vertical Loads Applicable to Overturning Stability Analysis

Total Concrete Dead Loads:	$D_{conc} = 24618.6 \cdot kN$	at:	$X_{conc.loc} = 10.06\,m$
Dead Load of Gate:	$D_{Gate} = 210.0 \cdot kN$		$X_{gate} = 6.60\,m$
Water Weight (HW) on Apron Slab:	$H_{1.U2} = 5922.8 \cdot kN$		$H_{1.U2.loc} = 14.13\,m$
Water Weight (TW) on Gate Footing:	$H_{2.U2} = 4940.2 \cdot kN$		$H_{2.U2.loc} = 5.23\,m$
Uplift Load for Overturning Analysis:	$U_{OT.U2} = -19563.05 \cdot kN$		$U_{OT.U2.loc} = 9.94 \cdot m$
Vertical Seismic Component of Concrete Structure:	$Q_{conc.E3.EQv.1} = 0$		$X_{conc.loc} = 10.06\,m$
Vertical Seismic Component of Crest Gate:	$Q_{Gate.E3.EQv.1} = 0$		$X_{gate} = 6.60\,m$
Vertical Seismic Component of Headwater over Apron Slab:	$Q_{H1.E3.EQv.1} = 0$		$H_{1.U2.loc} = 14.13\,m$
Vertical Seismic Component of Headwater over Fixed Crest Slab:	$Q_{H2.E3.EQv.1} = 0$		$H_{2.U2.loc} = 5.23\,m$

Sum of All Overturning Analysis Vertical Load:

$$\Sigma V_{E3.OT.1} := D_{conc} + D_{Gate} + H_{1.U2} + H_{2.U2} + U_{OT.U2} + \Sigma V_{Q.E3.EQv.1} = 16128.53 \cdot kN$$

Sum of All Overturning Analysis Vertical Load Moments:

$$\Sigma M_{V.E3.OT.1} := D_{conc} \cdot X_{conc.loc} + D_{Gate} \cdot X_{gate} + H_{1.U2} \cdot H_{1.U2.loc} + H_{2.U2} \cdot H_{2.U2.loc} + U_{OT.U2} \cdot U_{OT.U2.loc} = 163952.61 \cdot kN \cdot m$$

Lateral Driving Earth Loads for Overturning Stability Analysis (at rest condition)

E3.1 CASE

Depth of Driving Soil Loads (to top of key): $h_{E.OT.E3.1} := TOC_{as} - BOF_{elev} = 4\,m$

At-Rest Soil Load: $E_{act.OT.E3.1} := \frac{K_{o.U2} \cdot h_{E.OT.U2}^{\;2}}{2} \cdot (\gamma_r - \gamma_w) \cdot W_{hwas.U2} \cdot -1 = -962.49 \cdot kN$

At Rest- Soil Load Acting from Toe: $E_{act.OT.E3.1.loc} := \frac{h_{E.OT.U2}}{3} = 1.33\,m$

All Lateral Loads Applicable to Overturning Stability Analysis

HW Lateral Load on Approach Slab:	$H_{hwas.U1} = -4502.8 \cdot kN$	$H_{hwas.U1.loc} = 0.41\,m$
HW Lateral Load on Guard Gate:	$H_{hwgg.U1} = 0.0 \cdot kN$	$H_{hwgg.U1.loc} = 4.00\,m$
TW Lateral Load on Guard Gate:	$H_{twgg.E1} = 0.0 \cdot kN$	$H_{twgg.E1.loc} = 4.00\,m$
TW Lateral Load on Gate Footing (No Key - Overturning Values Adjusted):	$H_{twgf.E1} = 4061.34 \cdot kN$	$H_{twgf.E1.loc} = 1.81\,m$
TW Lateral Load on Key:	$H_{twkey.OT.E1} = 3550.98 \cdot kN$	$H_{twkey.OT.E1.loc} = -1.03\,m$
Ice / Impact Load:	$I_{E1} = 0.0 \cdot kN$	$I_{E1.loc} = 3.70\,m$
Lateral Soil Load (driving):	$E_{act.OT.E1} = -962.5 \cdot kN$	$E_{act.OT.E1.loc} = 1.33\,m$
Horizontal Seismic Component of Concrete Structure:	$Q_{conc.E3.EQh.1} = -4185.16 \cdot kN$	$Y_{conc.loc} = 1.87\,m$
Horizontal Seismic Component of Vertical Lift Gate:	$Q_{Gate.E3.EQh.1} = -35.7 \cdot kN$	$Y_{gate} = 3.90\,m$
Horizontal Seismic Component of Headwater on Footing:	$Q_{hwas.E3.EQh.1} = -1639.6 \cdot kN$	$Y_{HWg.E3} = 4.24\,m$
Horizontal Seismic Component of Active Soil: (Section 5-5, USACE EM_1110-2-2100)	$Q_{act.E3.EQh.1} = -497352\,N$	$Y_{E.act.E3} = 2.52\,m$

Resisting Lateral Soil Load as required to produce horizontal equilibrium:

$$E_{pas.OT.E3.1} := -\left(H_{hwas.U2} + H_{hwgg.U2} + H_{twgg.U2} + H_{twgf.U2} + H_{twkey.OT.U2} + I_{U2} + E_{act.OT.U2} + \Sigma H_{Q.E3.EQh.1}\right) = 11492.24 \cdot kN$$

Acting at: $E_{pas.OT.E3.1.loc} := -1 \cdot \frac{d_{key}}{2} = -1\,m$

Sum of All Overturning Analysis Horizontal Load (ΣH=0):

$$\Sigma H_{E3.OT.1} := H_{hwas.U2} + H_{hwgg.U2} + H_{twgg.U2} + H_{twgf.U2} + H_{twkey.OT.U2} + I_{U2} + E_{act.OT.U2} + E_{pas.OT.E3.1} + \Sigma H_{Q.E3.EQh.1} = 0 \cdot kN$$

Sum of All Overturning Analysis Horizontal Load Moments:

$$\begin{aligned}\Sigma M_{H.E3.OT.1} := {} & H_{hwas.U2} \cdot H_{hwas.E1.loc} + H_{hwgg.E1} \cdot H_{hwgg.E1.loc} + H_{twgg.E1} \cdot H_{twgg.E1.loc} \cdots = -23946.12 \cdot kN \cdot m \\ & + H_{twgf.E1} \cdot H_{twgf.E1.loc} + H_{twkey.OT.E1} \cdot H_{twkey.OT.E1.loc} + I_{E1} \cdot I_{E1.loc} \cdots \\ & + E_{act.OT.E1} \cdot E_{act.OT.E1.loc} + E_{pas.OT.E1} \cdot E_{pas.OT.E1.loc} + \Sigma M_{Q.E3.1}\end{aligned}$$

Overturning Stability Analysis

$$\Sigma M_{E3.OT.1} := \Sigma M_{V.E1.OT} + \Sigma M_{H.E1.OT} = 154070.51 \cdot kN \cdot m$$

$X_{R.E3.1} := \frac{\Sigma M_{E3.OT.1}}{\Sigma V_{E3.OT.1}} = 9.55\,m$ $\quad x_{OT.E3.1} := X_{R.E3.1} - \frac{L_b}{2} = 0.3\,m$

Overturning Resultant Ratio

$$Ratio_{OT.E3.1} := \frac{X_{R.E3.1}}{L_b} = 0.52$$

$$Ratio_{OT.E3.1.check} := \begin{cases} \text{"OKAY"} & \text{if } Ratio_{OT.E3.1} \geq Ratio_{overturning.allow.Extreme} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

$$x_{OT.check.E3.1} := \begin{cases} \text{"OKAY"} & \text{if } \left|x_{OT.E3.1}\right| \leq Midhalf \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

Seismic Case $Q_{E2.2}$ - 100% Horizontal Seismic Force, 30% Vertical **E3.2 CASE**

Include Seismic Load in Analysis? $Eq_{E3.2} := 1$

Horizontal Seismic Coefficient: $K_{h.E3.2} := -0.17$

Vertical Seismic Coefficient: $K_{v.E3.2} := -0.03$

HORIZONTAL SEISMIC LOADS	Loads	Moment Arm
Horiz Seismic Component of Concrete:	$Q_{conc.E3.EQh.2} := D_{conc} \cdot K_{h.E3.2} \cdot Eq_{E3.2} = -4185.2 \cdot kN$	$Y_{conc.loc} = 1.87\,m$
Horiz Seismic Component of Gates:	$Q_{Gate.E3.EQh.2} := D_{Gate} \cdot K_{h.E3.2} \cdot Eq_{E3.2} = -35.7 \cdot kN$	$Y_{gate} = 3.90\,m$
Horizontal Seismic Component of Headwater - Sliding:	$Q_{hwas.E3.EQh.2} := \left(\frac{7}{12}\right) \cdot K_{h.E3.2} \cdot \gamma_w \cdot \left(HW_{U2} - BOK_{elev}\right)^2 \cdot W_{hwas.U2} \cdot Eq_{E3.2} = -1639.6 \cdot kN$	$Y_{HWg.E3} = 4.24\,m$
Horizontal Seismic Component of Soil (Woods Method)- Overturning:	$Q_{act.E3.EQh.2.OT} := \left(\gamma_r - \gamma_w\right) \cdot \left(TOC_{as} - BOK_{elev}\right)^2 \cdot K_{h.E3.2} \cdot W_{hwas.U2} \cdot Eq_{E3.2} = -1119.0 \cdot kN$	$Y_{E.act.E3.OT} = 3.78\,m$
Horizontal Seismic Component of Soil (Woods Method)	$Q_{act.E3.EQh.2} := \left(\gamma_r - \gamma_w\right) \cdot \left(TOC_{as} - BOF_{elev}\right)^2 \cdot K_{h.E3.2} \cdot W_{hwas.U2} \cdot Eq_{E3.2} = -497.4 \cdot kN$	$Y_{E.act.E3} = 2.52\,m$

VERTICAL SEISMIC LOADS	Loads	Moment Arm
Vertical Component of Concrete:	$Q_{conc.E3.EQv.2} := D_{conc} \cdot K_{v.E3.2} \cdot Eq_{E3.2} = -738.6 \cdot kN$	$X_{conc.loc} = 10.06\,m$
Vertical Component of Gate:	$Q_{Gate.E3.EQv.2} := D_{Gate} \cdot K_{v.E3.2} \cdot Eq_{E3.2} = -6.3 \cdot kN$	$X_{gate} = 6.60\,m$
Vertical Seismic Component of Headwater over Apron Slab: (Section 7.9, Design Criteria)	$Q_{H1.E3.EQv.2} := K_{v.E3.2} \cdot H_{1.U1} \cdot Eq_{E3.2} = -81.1 \cdot kN$	$H_{1.U2.loc} = 14.13\,m$
Vertical Seismic Component of Headwater over Fixed Crest Slab: (Section 7.9, Design Criteria)	$Q_{H2.E3.EQv.2} := K_{v.E3.2} \cdot H_{2.U1} \cdot Eq_{E3.2} = -81.0 \cdot kN$	$H_{2.U2.loc} = 5.23\,m$

$$\Sigma H_{Q.E3.EQh.2} := Q_{conc.E3.EQh.2} + Q_{Gate.E3.EQh.2} + Q_{hwas.E3.EQh.2} + Q_{act.E2.EQh.2} = -6357.81 \cdot kN$$

$$\Sigma H_{Q.E3.EQh.2.OT} := Q_{conc.E3.EQh.2} + Q_{Gate.E3.EQh.2} + Q_{hwas.E3.EQh.2} + Q_{act.E3.EQh.2.OT} = -6979.5 \cdot kN$$

$$\Sigma V_{Q.E3.EQv.2} := Q_{conc.E3.EQv.2} + Q_{Gate.E3.EQv.2} + Q_{H1.E3.EQv.2} + Q_{H2.E3.EQv.2} = -906.9 \cdot kN$$

$$\begin{aligned}\Sigma M_{Q.E3.2} := {} & Q_{conc.E3.EQh.2} \cdot Y_{conc.loc} + Q_{Gate.E3.EQh.2} \cdot Y_{gate} + Q_{hwas.E3.EQh.2} \cdot Y_{HWg.E3} \cdots \\ & + Q_{act.E3.EQh.2.OT} \cdot Y_{E.act.E3.OT} + Q_{conc.E3.EQv.2} \cdot X_{conc.loc} + Q_{Gate.E3.EQv.2} \cdot X_{gate} \cdots \\ & + Q_{H1.E3.EQv.2} \cdot H_{1.U2.loc} + Q_{H2.E3.EQv.2} \cdot H_{2.U2.loc}\end{aligned} = -28178.03 \cdot kN \cdot m$$

STABILITY ASSESSMENT (SLIDNG, BEARING, FLOTATION AND OVERTURNING):

E3.2 CASE

CHECK SLIDING ALONG HORIZONTAL PLANE THRU TOE,
IGNORING BEDROCK MOBILIZED BY STRUCTURAL HEEL KEY, OR VOID BEHIND KEY

Sum of Vertical Forces: Sum of Horizontal Forces:

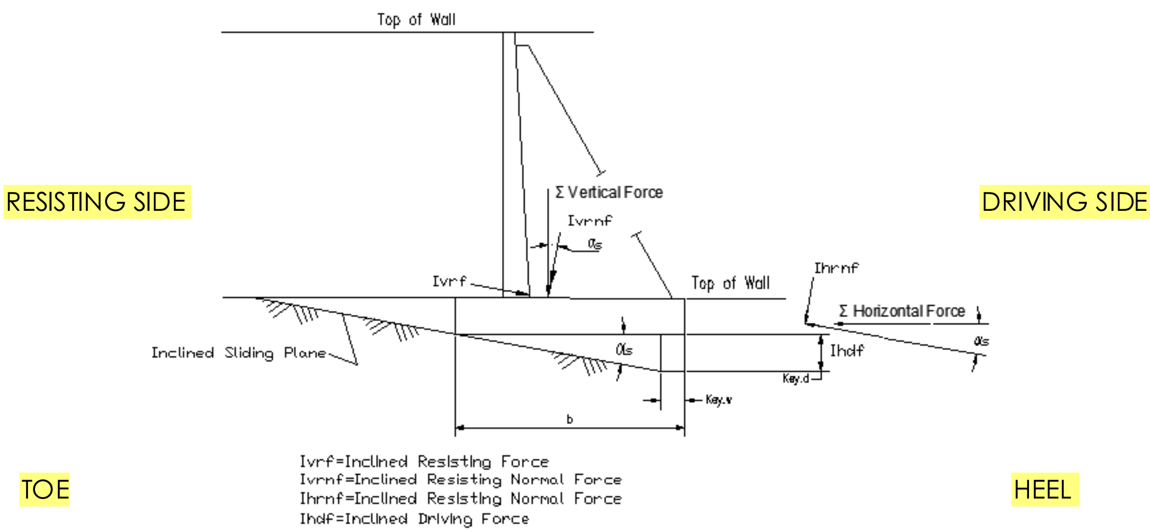
$\Sigma V_{E3.2} := \Sigma V_{U2} + \Sigma V_{Q.E3.EQv.2} = 12462.0 \cdot kN$ $\Sigma H_{E3.2} := \Sigma H_{U2} - I_{U2} + \Sigma H_{Q.E3.EQh.2} = -11661.36 \cdot kN$

Sliding Factor of Safety: $FS_{HorizSliding.E3.2} := \dfrac{\tan_{\phi} \cdot \Sigma V_{E3.2}}{\left|\Sigma H_{E3.2}\right|} = 0.52$

$FS_{HorizSliding.E3.2.Check} :=$ | "OKAY" if $FS_{HorizSliding.E3.2} \geq FS_{req.E3.sl}$
"Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !" otherwise

$FS_{HorizSliding.E3.2.Check}$ = "Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !"

CHECK SLIDING ALONG INCLINED SLIDING PLANE FROM HEEL KEY TO TOE,
WITH BEDROCK MASS MOBILIZED BY REINFOCREDE CONCRETE KEY)



$\Sigma V_{E3.2} = 12461.98 \cdot kN$

$\alpha s = 0.11$ as degrees= $\alpha s \cdot \left(\dfrac{180}{\pi}\right) = 6.52$ $V_{rs} = 5775 \cdot kN$

Resolve $\Sigma Vert_{E3.2}$ & $\Sigma Horiz_{E3.2}$ $\Sigma V_{InclinedE3.2} := \cos(\alpha s) \cdot \left(\Sigma V_{E3.2} + V_{rs}\right) + \sin(\alpha s) \cdot \left|\Sigma H_{E3.2}\right| = 19443.1 \cdot kN$

$\Sigma H_{InclinedE3.2} := \cos(\alpha s) \cdot \left|\Sigma H_{E3.2}\right| - \sin(\alpha s) \cdot \left(\Sigma V_{E3.2} + V_{rs}\right) = 9515.2 \cdot kN$

(With properly engineered reinforced concrete Key, horizontal sliding plane thru Toe is protected, critical sliding plane is relocated to the INCLINED SLIDING PLANE FROM HEEL KEY To TOE, Bedrock Mass above this examing plane is mobilized by reinforced concrete key and combined into Structural Wedge.)

Inclined Sliding Plane Length $L_{incline} = 18.61\ m$

Safety Factor for Sliding Inclined Failure Plane $FS_{InclinedISlidingE3.2} := \mathrm{round}\left(\dfrac{\Sigma V_{InclinedE3.2} \cdot \tan\left(\phi_{rock} \cdot \dfrac{\pi}{180}\right)}{\left|\Sigma H_{InclinedE3.2}\right|}, 1\right) = 1$

$FS_{InclinedSliding.check.E3.2} :=$ | "OKAY " if $FS_{InclinedISlidingE3.2} \geq FS_{req.E3.sl}$ = "OKAY "
"Revise Structure"" otherwise

$FS_{InclinedSliding.check.E3.2}$ = "OKAY "

OVERTURNING STABILITY CHECK:

E3.2 CASE

CHECK ECCENTRICITY - OBSOLETE

Sum of the moments:

$$\Sigma M_{E3.2} := \left(\Sigma M_{U2} + \Sigma M_{Q.E3.2}\right) = 146512 \cdot kN \cdot m$$

Eccentricity:

$$e_{E3.2} := \left(\frac{L_{incline}}{2}\right) - \frac{\left(\Sigma M_{E3.2}\right)}{\Sigma V_{InclinedE3.2}} = 1.77\,m$$

Eccentricity Check:

$$e_{check.E3.2} := \begin{cases} \text{"Okay"} & \text{if } e_{E3.2} \le Midhalf \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$e_{check.E3.2} = \text{"Okay"}$

Foundation Bearing Checks:

Bearing Pressure at Heel:

$$\sigma_{heel.E3.2} := \frac{\Sigma V_{InclinedE3.2}}{A_{b.incline}} - \frac{\left(\Sigma V_{InclinedE3.2} \cdot e_{E3.2}\right)}{S_{b.incline}} = 29.9 \cdot \frac{kN}{m^2}$$

$$\sigma_{heel.E3.2.check} := \left(\begin{cases} \text{"Okay"} & \text{if } \sigma_{heel.E3.2} \le \sigma_{allow.E2} \\ \text{"Revise Structure"} & \text{if } \sigma_{heel.E3.2} < 0 \frac{kN}{m^2} \end{cases} \right)$$

$\sigma_{heel.E3.2.check} = \text{"Okay"}$

Bearing Pressure at Toe:

$$\sigma_{toe.E3.2} := \frac{\Sigma V_{InclinedE3.2}}{A_{b.incline}} + \frac{\left(\Sigma V_{InclinedE3.2} \cdot e_{E3.2}\right)}{S_{b.incline}} = 109.4 \cdot \frac{kN}{m^2}$$

$$\sigma_{toe.E3.2.check.1} := \begin{cases} \text{"Okay"} & \text{if } \sigma_{toe.E3.2} \le \sigma_{allow.E2} \\ \text{"Revise Structure"} & \text{if } \sigma_{toe.E3.2} < 0 \frac{kN}{m^2} \end{cases}$$

$\sigma_{toe.E3.2.check.1} = \text{"Okay"}$

FLOATATION ANALYSIS:

ACCEPTANCE PARAMETERS

Required Factor of Safety: $FS_{req.FE3.2} := 1.1$

VERTICAL LOADS RESISTING:

Dead Load: $\Sigma V_{DL} = 24828.6 \cdot kN$

Water Weight H1+H2: $\Sigma V_{H.FE3.2} := \Sigma V_{H.FU2} + \Sigma V_{Q.E3.EQv.2} = 9956.03 \cdot kN$

Summation Vertical Resisting: $\Sigma V_{FE3.2} := \Sigma V_{DL} + \Sigma V_{H.FE3.2} = 34784.6 \cdot kN$

VERTICAL LOADS UPLIFT:

Uplift: $U_{U2} = -22322.65 \cdot kN$

Factor of Safety Floatation:

$$FS_{act.FE3.2} := \frac{\Sigma V_{FE3.2}}{\left|U_{U2}\right|} = 1.56$$

$$FS_{check.FE3.2} := \begin{cases} \text{"OKAY"} & \text{if } FS_{act.FE3.2} \ge FS_{req.FE3.2} \\ \text{"ANCHORS REQUIRED"} & \text{if } FS_{act.FE3.2} < FS_{req.FE3.2} \end{cases} = \text{"OKAY"}$$

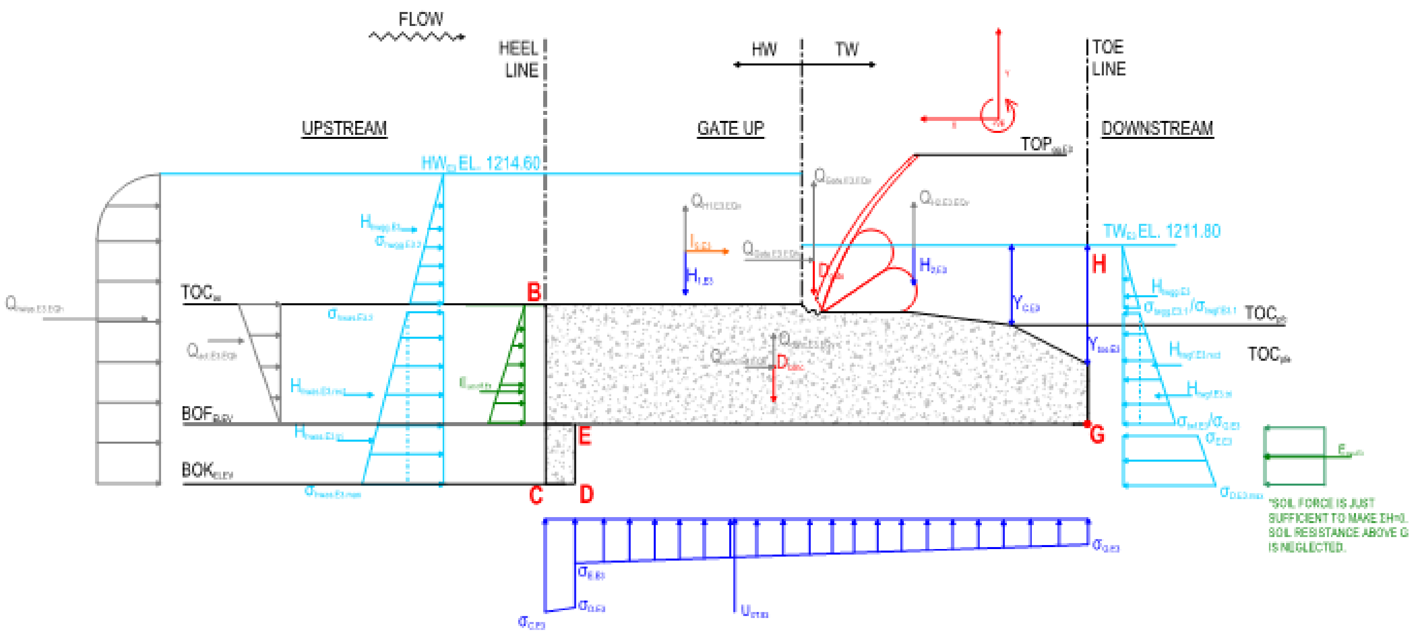
MONOLITH OVERTURNING STABILITY ANALYSIS

E3.2 CASE

Seismic Case $Q_{E3.2}$: 100% Horizontal Seismic Force, 30% Vertical

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.
Assumptions are made in order to compute overturning stability of indetermine forces on monolith with key;
(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.
(b) The horizontal resisting force acting on the key, P.key, is that required for static equilibrium
(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1 $Ratio_{overturning.allow.Extreme} = 0.25$ Resultant within Middle Half



All Vertical Loads Applicable to Overturning Stability Analysis

Total Concrete Dead Loads:	$D_{conc} = 24618.6 \cdot kN$	at:	$X_{conc.loc} = 10.06\,m$
Dead Load of Gate:	$D_{Gate} = 210.0 \cdot kN$		$X_{gate} = 6.60\,m$
Water Weight (HW) on Apron Slab:	$H_{1.U2} = 5922.8 \cdot kN$		$H_{1.U2.loc} = 14.13\,m$
Water Weight (TW) on Gate Footing:	$H_{2.U2} = 4940.2 \cdot kN$		$H_{2.U2.loc} = 5.23\,m$
Uplift Load for Overturning Analysis:	$U_{OT.U2} = -19563.05 \cdot kN$		$U_{OT.U2.loc} = 9.94 \cdot m$
Vertical Seismic Component of Concrete Structure:	$Q_{conc.E3.EQv.2} = -738.56 \cdot kN$		$X_{conc.loc} = 10.06\,m$
Vertical Seismic Component of Crest Gate:	$Q_{Gate.E3.EQv.2} = -6.3 \cdot kN$		$X_{gate} = 6.60\,m$
Vertical Seismic Component of Headwater over Apron Slab:	$Q_{H1.E3.EQv.2} = -81.12 \cdot kN$		$H_{1.U2.loc} = 14.13\,m$
Vertical Seismic Component of Headwater over Fixed Crest Slab:	$Q_{H2.E3.EQv.2} = -80.98 \cdot kN$		$H_{2.U2.loc} = 5.23\,m$

Sum of All Overturning Analysis Vertical Load:

$$\Sigma V_{E3.OT.2} := D_{conc} + D_{Gate} + H_{1.U2} + H_{2.U2} + U_{OT.U2} + \Sigma V_{Q.E3.EQv.2} = 15221.58 \cdot kN$$

Sum of All Overturning Analysis Vertical Load Moments:

$$\Sigma M_{V.E3.OT.2} := D_{conc} \cdot X_{conc.loc} + D_{Gate} \cdot X_{gate} + H_{1.U2} \cdot H_{1.U2.loc} + H_{2.U2} \cdot H_{2.U2.loc} + U_{OT.U2} \cdot U_{OT.U2.loc} = 163952.61 \cdot kN \cdot m$$

Lateral Driving Earth Loads for Overturning Stability Analysis (at rest condition) **E3.2 CASE**

Depth of Driving Soil Loads (to top of key): $h_{E.OT.E3.2} := TOC_{as} - BOF_{elev} = 4\,m$

At-Rest Soil Load: $E_{act.OT.E3.2} := \dfrac{\left(K_{o.U1} \cdot h_{E.OT.U2}^{\;2}\right)}{2} \cdot \left(\gamma_r - \gamma_w\right) \cdot W_{hwas.U2} \cdot -1 = -962.49 \cdot kN$

At Rest- Soil Load Acting from Toe: $E_{act.OT.E3..loc} := \dfrac{h_{E.OT.U2}}{3} = 1.33\,m$

All Lateral Loads Applicable to Overturning Stability Analysis

HW Lateral Load on Approach Slab:	$H_{hwas.U2} = -6710.0 \cdot kN$	$H_{hwas.U2.loc} = 0.61\,m$
HW Lateral Load on Guard Gate:	$H_{hwgg.U2} = -1556.8 \cdot kN$	$H_{hwgg.U2.loc} = 5.53\,m$
TW Lateral Load on Guard Gate:	$H_{twgg.U2} = 238.4 \cdot kN$	$H_{twgg.U2.loc} = 4.60\,m$
TW Lateral Load on Gate Footing (No Key - Overturning Values Adjusted):	$H_{twgf.U2} = 2236.68 \cdot kN$	$H_{twgf.U2.loc} = 1.65\,m$
TW Lateral Load on Key:	$H_{twkey.OT.U2} = 2744.89 \cdot kN$	$H_{twkey.OT.U2.loc} = -1.04\,m$
Ice / Impact Load:	$I_{U2} = -1125.0 \cdot kN$	$I_{U2.loc} = 8.70\,m$
Lateral Soil Load (driving):	$E_{act.OT.U2} = -962.5 \cdot kN$	$E_{act.OT.U1.loc} = 1.33\,m$
Horizontal Seismic Component of Concrete Structure:	$Q_{conc.E3.EQh.2} = -4185.16 \cdot kN$	$Y_{conc.loc} = 1.87\,m$
Horizontal Seismic Component of Vertical Lift Gate:	$Q_{Gate.E3.EQh.2} = -35.7 \cdot kN$	$Y_{gate} = 3.90\,m$
Horizontal Seismic Component of Headwater on Gate:	$Q_{hwas.E3.EQh.2} = -1639.6 \cdot kN$	$Y_{HWg.E3} = 4.24\,m$
Horizontal Seismic Component of Active Soil: (Section 5-5, USACE EM_1110-2-2100)	$Q_{act.E3.EQh.2} = -497.35 \cdot kN$	$Y_{E.act.E3} = 2.52\,m$

Resisting Lateral Soil Load as required to produce horizontal equilibrium:

$$E_{pas.OT.E3.2} := -\left(H_{hwas.U2} + H_{hwgg.U2} + H_{twgg.U2} + H_{twgf.U2} + H_{twkey.OT.U2} + I_{U2} + E_{act.OT.U2} + \Sigma H_{Q.E3.EQh.2.OT}\right) = 12113.93 \cdot kN$$

Acting at: $E_{pas.OT.E3.2.loc} := -1 \cdot \dfrac{d_{key}}{2} = -1\,m$

Sum of All Overturning Analysis Horizontal Load (ΣH=0):

$$\Sigma H_{E3.OT.2} := H_{hwas.U2} + H_{hwgg.U2} + H_{twgg.U2} + H_{twgf.U2} + H_{twkey.OT.U2} + I_{U2} + E_{act.OT.U2} + E_{pas.OT.E3.2} + \Sigma H_{Q.E3.EQh.2.OT} = 0 \cdot kN$$

Sum of All Overturning Analysis Horizontal Load Moments:

$$\begin{aligned}\Sigma M_{H.E3.OT.2} := & H_{hwas.U2} \cdot H_{hwas.U2.loc} + H_{hwgg.U2} \cdot H_{hwgg.U2.loc} + H_{twgg.U2} \cdot H_{twgg.U2.loc} \cdots \\ & + H_{twgf.U2} \cdot H_{twgf.U2.loc} + H_{twkey.OT.U2} \cdot H_{twkey.OT.U2.loc} + I_{U2} \cdot I_{U2.loc} \cdots \\ & + E_{act.OT.U2} \cdot E_{act.OT.U2.loc} + E_{pas.OT.U2} \cdot E_{pas.OT.U2.loc} + \Sigma M_{Q.E3.2}\end{aligned} = -55130.44 \cdot kN \cdot m$$

Overturning Stability Analysis

$$\Sigma M_{E3.OT.2} := \Sigma M_{V.E3.OT.2} + \Sigma M_{H.E3.OT.2} = 108822.17 \cdot kN \cdot m$$

$X_{R.E3.2} := \dfrac{\Sigma M_{E3.OT.2}}{\Sigma V_{E3.OT.2}} = 7.15\,m$ $\qquad x_{OT.E3.2} := X_{R.E3.2} - \dfrac{L_b}{2} = -2.1\,m$

Overturning Resultant Ratio $\quad Ratio_{OT.E3.2} := \dfrac{X_{R.E3.2}}{L_b} = 0.39$

$$Ratio_{OT.E3.2.check} := \begin{cases} \text{"OKAY"} & \text{if } Ratio_{OT.E3.2} \geq Ratio_{overturning.allow.Extreme} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

$$x_{OT.check.E3.2} := \begin{cases} \text{"OKAY"} & \text{if } \left|x_{OT.E3.2}\right| \leq Midhalf \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

Seismic Case $Q_{E3.3}$ - 30% Horizontal Seismic Force, 100% Vertical **E3.3 CASE**

Include Seismic Load in Analysis? $Eq_{E3.3} := 1$ 0 = No, 1 = Yes

Horizontal Seismic Coefficient: $K_{h.E3.3} := -0.05$

Vertical Seismic Coefficient: $K_{v.E3.3} := -0.10$

HORIZONTAL SEISMIC LOADS	Loads	Moment Arm
Horiz Seismic Component of Concrete:	$Q_{conc.E3.EQh.3} := D_{conc} \cdot K_{h.E3.3} \cdot Eq_{E3.3} = -1230.9 \cdot kN$	$Y_{conc.loc} = 1.87\,m$
Horiz Seismic Component of Gate:	$Q_{Gate.E3.EQh.3} := D_{Gate} \cdot K_{h.E3.3} \cdot Eq_{E3.3} = -10.5 \cdot kN$	$Y_{gate} = 3.90\,m$
Horiz Seismic Component of Headwater:	$Q_{hwas.E3.EQh.3} := \left(\frac{7}{12}\right) \cdot K_{h.E3.3} \cdot \gamma_w \cdot \left(HW_{U2} - BOK_{elev}\right)^2 \cdot W_{hwas.U2} \cdot Eq_{E3.3} = -482.2 \cdot kN$	$Y_{HWg.E3} = 4.24\,m$
Horizontal Seismic Component of Soil (Woods Method)-Overturning:	$Q_{act.E3.EQh.3.OT} := \left(\gamma_r - \gamma_w\right) \cdot \left(TOC_{as} - BOK_{elev}\right)^2 \cdot K_{h.E3.3} \cdot W_{hwas.U2} \cdot Eq_{E3.3} = -329.1 \cdot kN$	$Y_{E.act.E3.OT} = 3.78\,m$
Horizontal Seismic Component of Soil (Woods Method):	$Q_{act.E3.EQh.3} := \left(\gamma_r - \gamma_w\right) \cdot \left(TOC_{as} - BOF_{elev}\right)^2 \cdot K_{h.E3.3} \cdot W_{hwas.U2} \cdot Eq_{E3.3} = -146.3 \cdot kN$	$Y_{E.act.E3} = 2.52\,m$

VERTICAL SEISMIC LOADS	Loads	Moment Arm
Vertical Component of Concrete:	$Q_{conc.E3.EQv.3} := D_{conc} \cdot K_{v.E3.3} \cdot Eq_{E3.3} = -2461.9 \cdot kN$	$X_{conc.loc} = 10.06\,m$
Vertical Component of Gate:	$Q_{Gate.E3.EQv.3} := D_{Gate} \cdot K_{v.E3.3} \cdot Eq_{E3.3} = -21.0 \cdot kN$	$X_{gate} = 6.60\,m$
Vertical Seismic Component of Headwater over Apron Slab: (Section 7.9, Design Criteria)	$Q_{H1.E3.EQv.3} := K_{v.E3.3} \cdot H_{1.U2} \cdot Eq_{E3.3} = -592.3 \cdot kN$	$H_{1.U2.loc} = 14.13\,m$
Vertical Seismic Component of Headwater over Fixed Crest Slab: (Section 7.9, Design Criteria)	$Q_{H2.E3.EQv.3} := K_{v.E3.3} \cdot H_{2.U2} \cdot Eq_{E3.3} = -494.0 \cdot kN$	$H_{2.U2.loc} = 5.23\,m$

$$\Sigma H_{Q.E3.EQh.3} := Q_{conc.E3.EQh.3} + Q_{Gate.E3.EQh.3} + Q_{hwas.E3.EQh.3} + Q_{act.E3.EQh.3} = -1869.95 \cdot kN$$

$$\Sigma H_{Q.E3.EQh.3.OT} := Q_{conc.E3.EQh.3} + Q_{Gate.E3.EQh.3} + Q_{hwas.E3.EQh.3} + Q_{act.E3.EQh.3.OT} = -2052.8 \cdot kN$$

$$\Sigma V_{Q.E3.EQv.3} := Q_{conc.E3.EQv.3} + Q_{Gate.E3.EQv.3} + Q_{H1.E3.EQv.3} + Q_{H2.E3.EQv.3} = -3569.2 \cdot kN$$

$$\begin{aligned} \Sigma M_{Q.E3.3} := {} & Q_{conc.E3.EQh.3} \cdot Y_{conc.loc} + Q_{Gate.E3.EQh.3} \cdot Y_{gate} + Q_{hwas.E3.EQh.3} \cdot Y_{HWg.E3} \cdots \\ & + Q_{act.E3.EQh.3.OT} \cdot Y_{E.act.E3.OT} + Q_{conc.E3.EQv.3} \cdot X_{conc.loc} + Q_{Gate.E3.EQv.3} \cdot X_{gate} \cdots \\ & + Q_{H1.E3.EQv.3} \cdot H_{1.U2.loc} + Q_{H2.E3.EQv.3} \cdot H_{2.U2.loc} \end{aligned} = -41473.77 \cdot kN \cdot m$$

STABILITY ASSESSMENT (SLIDNG, BEARING, FLOTATION AND OVERTURNING):

E3.3 CASE

CHECK SLIDING ALONG HORIZONTAL PLANE THRU TOE,
IGNORING BEDROCK MOBILIZED BY STRUCTURAL HEEL KEY, OR VOID BEHIND KEY

Sum of Vertical Forces:

$\Sigma V_{E3.3} := \Sigma V_{U2} + \Sigma V_{Q.E3.EQv.3} = 9799.8 \cdot kN$

Sum of Horizontal Forces:

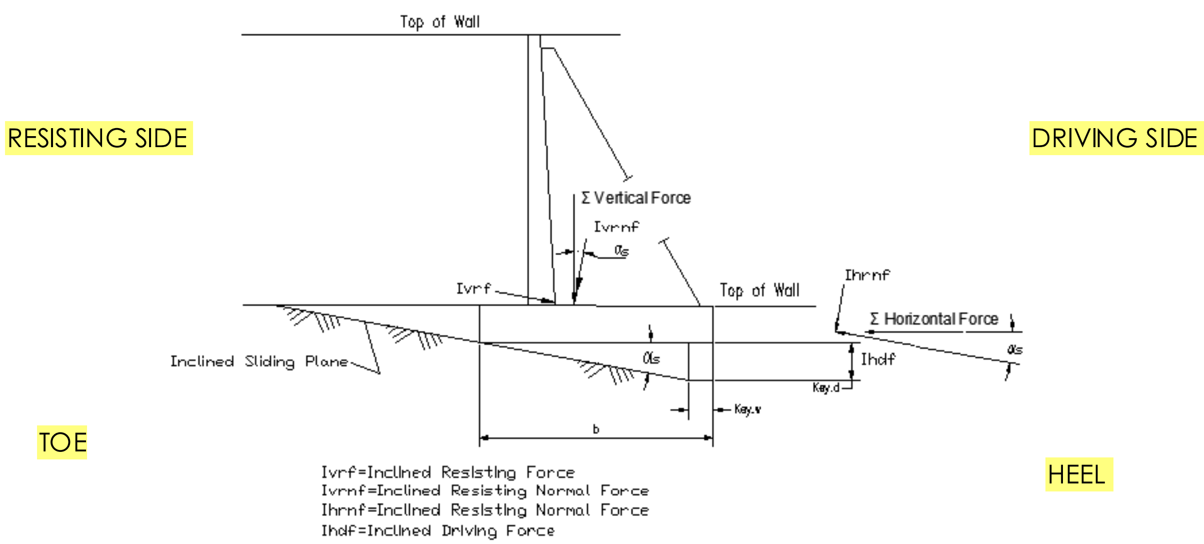
$\Sigma H_{E3.3} := \Sigma H_{U2} - I_{U2} + \Sigma H_{Q.E3.EQh.3} = -7173.49 \cdot kN$

Sliding Factor of Safety: $FS_{HorizSliding.E3.3} := \dfrac{\tan_{\phi} \cdot \Sigma V_{E3.3}}{|\Sigma H_{E3.3}|} = 0.67$

$FS_{HorizSliding.E3.3.Check} :=$ | "OKAY" if $FS_{HorizSliding.E3.3} \geq FS_{req.E3.sl}$
"Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !" otherwise

$FS_{HorizSliding.E3.3.Check}$ = "Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !"

CHECK SLIDING ALONG INCLINED SLIDING PLANE FROM HEEL KEY TO TOE,
WITH BEDROCK MASS MOBILIZED BY REINFOCREDE CONCRETE KEY)



$\alpha s = 0.11$ as degrees= $\alpha s \cdot \left(\dfrac{180}{\pi}\right) = 6.52$

$\Sigma V_{E3.3} = 9799.77 \cdot kN$

$V_{rs} = 5775 \cdot kN$

Resolve $\Sigma Vert_{E3.3}$ & $\Sigma Horiz_{E3.3}$

$\Sigma V_{InclinedE3.3} := \cos(\alpha s) \cdot (\Sigma V_{E3.3} + V_{rs}) + \sin(\alpha s) \cdot |\Sigma H_{E3.3}| = 16288.6 \cdot kN$

$\Sigma H_{InclinedE3.3} := \cos(\alpha s) \cdot |\Sigma H_{E3.3}| - \sin(\alpha s) \cdot (\Sigma V_{E3.3} + V_{rs}) = 5358.6 \cdot kN$

(With properly engineered reinforced concrete Key, horizontal sliding plane thru Toe is protected, critical sliding plane is relocated to the INCLINED SLIDING PLANE FROM HEEL KEY To TOE, Bedrock Mass above this examing plane is mobilized by reinforced concrete key and combined into Structural Wedge.)

Inclined Sliding Plane Length $L_{incline} = 18.61\ m$

Safety Factor for Sliding Inclined Failure Plane

$FS_{InclinedlSlidingE3.3} := \dfrac{\Sigma V_{InclinedE3.3} \cdot \tan\left(\phi_{rock} \cdot \dfrac{\pi}{180}\right)}{|\Sigma H_{InclinedE3.3}|} = 1.48$

$FS_{InclinedSliding.check.E3.3} :=$ | "OKAY " if $FS_{InclinedlSlidingE3.3} > FS_{req.E3.sl}$ = "OKAY "
"Revise Structure"" otherwise

$FS_{InclinedSliding.check.E3.3}$ = "OKAY "

OVERTURNING STABILITY CHECK:

E3.3 CASE

CHECK ECCENTRICITY

Sum of the moments:

$$\Sigma M_{E3.3} := \left(\Sigma M_{U2} + \Sigma M_{Q.E3.3}\right) = 133216 \cdot kN \cdot m$$

Eccentricity: $$e_{E3.3} := \left(\frac{L_{incline}}{2}\right) - \frac{\left(\Sigma M_{E3.3}\right)}{\Sigma V_{InclinedE3.3}} = 1.13\,m$$

Eccentricity Check: $$e_{check.E3.3} := \begin{cases} \text{"Okay"} & \text{if } e_{E3.1} \le Midhalf \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$$e_{check.E3.1} = \text{"Okay"}$$

Foundation Bearing Checks:

Bearing Pressure at Heel: $$\sigma_{heel.E3.3} := \frac{\Sigma V_{InclinedE3.3}}{A_{b.incline}} - \frac{\left(\Sigma V_{InclinedE3.3} \cdot e_{E3.3}\right)}{S_{b.incline}} = 37.2 \cdot \frac{kN}{m^2}$$

$$\sigma_{heel.E3.3.check} := \left(\begin{cases} \text{"Okay"} & \text{if } \sigma_{heel.E3.3} \le \sigma_{allow.E2} \\ \text{"Revise Structure"} & \text{if } \sigma_{heel.E3.3} < 0 \frac{kN}{m^2} \end{cases} \right)$$

$$\sigma_{heel.E3.3.check} = \text{"Okay"}$$

Bearing Pressure at Toe: $$\sigma_{toe.E3.3} := \frac{\Sigma V_{InclinedE3.3}}{A_{b.incline}} + \frac{\left(\Sigma V_{InclinedE3.3} \cdot e_{E3.3}\right)}{S_{b.incline}} = 79.5 \cdot \frac{kN}{m^2}$$

$$\sigma_{toe.E3.3.check.1} := \begin{cases} \text{"Okay"} & \text{if } \sigma_{toe.E3.3} \le \sigma_{allow.E2} \\ \text{"Revise Structure"} & \text{if } \sigma_{toe.E3.3} < 0 \frac{kN}{m^2} \end{cases}$$

$$\sigma_{toe.E3.3.check.1} = \text{"Okay"}$$

FLOATATION ANALYSIS:

ACCEPTANCE PARAMETERS

Required Factor of Safety: $FS_{req.FE3.3} := 1.1$

VERTICAL LOADS RESISTING:

Dead Load: $\Sigma V_{DL} = 24828.6 \cdot kN$

Water Weight H1+H2: $\Sigma V_{H.FE3.3} := \Sigma V_{H.FU2} + \Sigma V_{Q.E3.EQv.3} = 7293.82 \cdot kN$

Summation Vertical Resisting: $\Sigma V_{FE3.3} := \Sigma V_{DL} + \Sigma V_{H.FE3.3} = 32122.4 \cdot kN$

VERTICAL LOADS UPLIFT:

Uplift: $U_{U2} = -22322.65 \cdot kN$

Factor of Safety Floatation:

$$FS_{act.FE3.3} := \frac{\Sigma V_{FE3.3}}{\left|U_{U2}\right|} = 1.44$$

$$FS_{check.FE3.3} := \begin{cases} \text{"OKAY"} & \text{if } FS_{act.FE3.3} \ge FS_{req.FE3.3} \\ \text{"ANCHORS REQUIRED"} & \text{if } FS_{act.FE3.3} < FS_{req.FE3.3} \end{cases} = \text{"OKAY"}$$

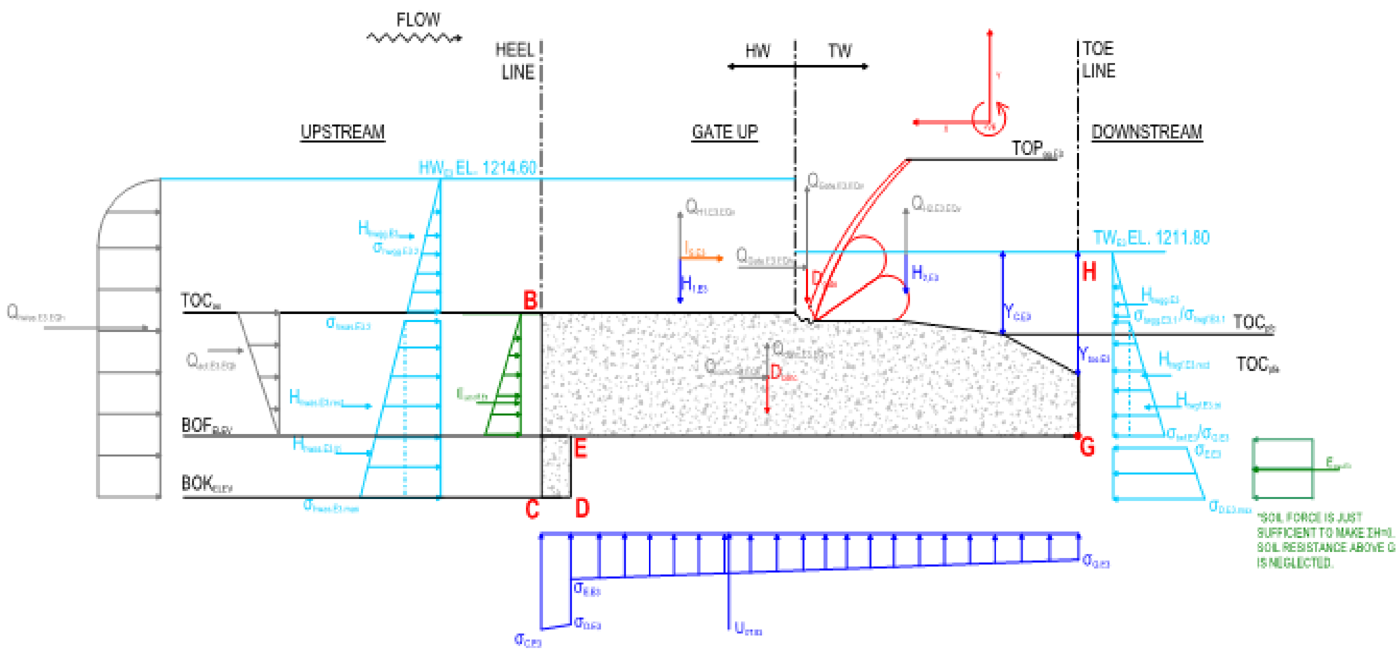
E3.3 CASE

MONOLITH OVERTURNING STABILITY ANALYSIS

Seismic Case $Q_{E3.2}$: 100% Horizontal Seismic Force, 30% Vertical

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.
Assumptions are made in order to compute overturning stability of indetermine forces on monolith with key;
(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.
(b) The horizontal resisting force acting on the key, P.key, is that required for static equilibrium
(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1 $Ratio_{overturning.allow.Extreme} = 0.25$ Resultant within Middle Half



All Vertical Loads Applicable to Overturning Stability Analysis

Total Concrete Dead Loads:	$D_{conc} = 24618.6 \cdot kN$	at:	$X_{conc.loc} = 10.06\,m$
Dead Load of Gate:	$D_{Gate} = 210.0 \cdot kN$		$X_{gate} = 6.60\,m$
Water Weight (HW) on Apron Slab:	$H_{1.U2} = 5922.8 \cdot kN$		$H_{1.U2.loc} = 14.13\,m$
Water Weight (TW) on Gate Footing:	$H_{2.U2} = 4940.2 \cdot kN$		$H_{2.U2.loc} = 5.23\,m$
Uplift Load for Overturning Analysis:	$U_{OT.U2} = -19563.05 \cdot kN$		$U_{OT.U2.loc} = 9.94 \cdot m$
Vertical Seismic Component of Concrete Structure:	$Q_{conc.E3.EQv.3} = -2461.86 \cdot kN$		$X_{conc.loc} = 10.06\,m$
Vertical Seismic Component of Crest Gate:	$Q_{Gate.E3.EQv.3} = -21 \cdot kN$		$X_{gate} = 6.60\,m$
Vertical Seismic Component of Headwater over Apron Slab:	$Q_{H1.E3.EQv.3} = -592.28 \cdot kN$		$H_{1.U2.loc} = 14.13\,m$
Vertical Seismic Component of Headwater over Fixed Crest Slab:	$Q_{H2.E3.EQv.3} = -494.02 \cdot kN$		$H_{2.U2.loc} = 5.23\,m$

Sum of All Overturning Analysis Vertical Load:

$$\Sigma V_{E3.OT.3} := D_{conc} + D_{Gate} + H_{1.U2} + H_{2.U2} + U_{OT.U2} + \Sigma V_{Q.E3.EQv.2} = 15221.58 \cdot kN$$

Sum of All Overturning Analysis Vertical Load Moments:

$$\Sigma M_{V.E3.OT.3} := D_{conc} \cdot X_{conc.loc} + D_{Gate} \cdot X_{gate} + H_{1.U2} \cdot H_{1.U2.loc} + H_{2.U2} \cdot H_{2.U2.loc} + U_{OT.U2} \cdot U_{OT.U2.loc} = 163952.61 \cdot kN \cdot m$$

Lateral Driving Earth Loads for Overturning Stability Analysis (at rest condition)

E3.3 CASE

Depth of Driving Soil Loads (to top of key): $h_{E.OT.E3.3} := TOC_{as} - BOF_{elev} = 4\,m$

At-Rest Soil Load: $E_{act.OT.E3.3} := \frac{\left(K_{o.U1} \cdot h_{E.OT.U2}^{2}\right)}{2} \cdot \left(\gamma_r - \gamma_w\right) \cdot W_{hwas.U2} \cdot -1 = -962.49 \cdot kN$

At Rest- Soil Load Acting from Toe: $E_{act.OT.E3.3.loc} := \frac{h_{E.OT.U2}}{3} = 1.33\,m$

All Lateral Loads Applicable to Overturning Stability Analysis

HW Lateral Load on Approach Slab:	$H_{hwas.U2} = -6710.0 \cdot kN$	$H_{hwas.U2.loc} = 0.61\,m$
HW Lateral Load on Guard Gate:	$H_{hwgg.U2} = -1556.8 \cdot kN$	$H_{hwgg.U2.loc} = 5.53\,m$
TW Lateral Load on Guard Gate:	$H_{twgg.U2} = 238.4 \cdot kN$	$H_{twgg.U2.loc} = 4.60\,m$
TW Lateral Load on Gate Footing (No Key - Overturning Values Adjusted):	$H_{twgf.U2} = 2236.68 \cdot kN$	$H_{twgf.U2.loc} = 1.65\,m$
TW Lateral Load on Key:	$H_{twkey.OT.U2} = 2744.89 \cdot kN$	$H_{twkey.OT.U2.loc} = -1.04\,m$
Ice / Impact Load:	$I_{U2} = -1125.0 \cdot kN$	$I_{U2.loc} = 8.70\,m$
Lateral Soil Load (driving):	$E_{act.OT.U2} = -962.5 \cdot kN$	$E_{act.OT.U2.loc} = 1.33\,m$
Horizontal Seismic Component of Concrete Structure:	$Q_{conc.E3.EQh.3} = -1230.93 \cdot kN$	$Y_{conc.loc} = 1.87\,m$
Horizontal Seismic Component of Vertical Lift Gate:	$Q_{Gate.E3.EQh.3} = -10.5 \cdot kN$	$Y_{gate} = 3.90\,m$
Horizontal Seismic Component of Headwater on Gate:	$Q_{hwas.E3.EQh.3} = -482.24 \cdot kN$	$Y_{HWg.E3} = 4.24\,m$
Horizontal Seismic Component of Active Soil: (Section 5-5, USACE EM_1110-2-2100)	$Q_{act.E3.EQh.3} = -146.28 \cdot kN$	$Y_{E.act.E3} = 2.52\,m$

Resisting Lateral Soil Load as required to produce horizontal equilibrium:

$$E_{pas.OT.E3.3} := -\left(H_{hwas.U2} + H_{hwgg.U2} + H_{twgg.U2} + H_{twgf.U2} + H_{twkey.OT.U2} + I_{U2} + E_{act.OT.U2} + \Sigma H_{Q.E3.EQh.3.OT}\right) = 7187.23 \cdot kN$$

Acting at: $E_{pas.OT.E3.3.loc} := -1 \cdot \frac{d_{key}}{2} = -1\,m$

Sum of All Overturning Analysis Horizontal Load (ΣH=0):

$$\Sigma H_{E3.OT.3} := H_{hwas.U2} + H_{hwgg.U2} + H_{twgg.U2} + H_{twgf.U2} + H_{twkey.OT.U2} + I_{U2} + E_{act.OT.U2} + E_{pas.OT.E3.3} + \Sigma H_{Q.E3.EQh.3.OT} = 0 \cdot kN$$

Sum of All Overturning Analysis Horizontal Load Moments:

$$\Sigma M_{H.E3.OT.3} := H_{hwas.U2} \cdot H_{hwas.U2.loc} + H_{hwgg.U2} \cdot H_{hwgg.U2.loc} + H_{twgg.U2} \cdot H_{twgg.U2.loc} \cdots + H_{twgf.U2} \cdot H_{twgf.U2.loc} + H_{twkey.OT.U2} \cdot H_{twkey.OT.U2.loc} + I_{U2} \cdot I_{U2.loc} \cdots + E_{act.OT.U2} \cdot E_{act.OT.U2.loc} + E_{pas.OT.U2} \cdot E_{pas.OT.U2.loc} + \Sigma M_{Q.E3.3} = -68426.19 \cdot kN \cdot m$$

Overturning Stability Analysis

$$\Sigma M_{E3.OT.3} := \Sigma M_{V.E3.OT.3} + \Sigma M_{H.E3.OT.3} = 95526.43 \cdot kN \cdot m$$

$$X_{R.E3.3} := \frac{\Sigma M_{E3.OT.3}}{\Sigma V_{E3.OT.3}} = 6.28\,m \qquad x_{OT.E3.3} := X_{R.E3.3} - \frac{L_b}{2} = -2.97\,m$$

Overturning Resultant Ratio $Ratio_{OT.E3.3} := \frac{X_{R.E3.2}}{L_b} = 0.39$

$Ratio_{OT.E3.3.check} :=$ "OKAY" if $Ratio_{OT.E3.3} \geq Ratio_{overturning.allow.Extreme}$; "Revise Structure" otherwise $=$ "OKAY"

$x_{OT.check.E3.3} :=$ "OKAY" if $\left|x_{OT.E3.3}\right| \leq Midhalf$; "Revise Structure" otherwise $=$ "OKAY"

Summary of Results

E3 CASE

E3.1 Case

Sliding Factor of Safety: (Horizontal Plane)	$FS_{HorizSliding.E3.1} = 0.56$	
	$FS_{HorizSliding.E3.1.Check}$ = "Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !"	
Sliding Factor of Safety: (Inclined Plane)	$FS_{InclinedlSlidingE3.1} = 1.05$	$FS_{InclinedSliding.check.E3.1}$ = "OKAY "
Eccentricity: (Inclined Plane)	$e_{E3.1} = 1.66\,m$	$e_{check.E3.1}$ = "Okay"
Bearing Pressure At Heel: (Inclined Plane)	$\sigma_{heel.E3.1} = 34\cdot kPa$	$\sigma_{heel.E3.1.check}$ = "Okay"
Bearing Pressure At Toe: (Inclined Plane)	$\sigma_{toe.E3.1} = 112\cdot kPa$	$\sigma_{toe.E3.1.check.1}$ = "Okay"
Flotation Factor of Safety (horizontal plane)	$FS_{act.FE3.1} = 1.6$	$FS_{check.FE3.1}$ = "OKAY"
Overturning Resultant Ratio: (horizontal plane)	$Ratio_{OT.E3.1} = 0.52$	$Ratio_{OT.E3.1.check}$ = "OKAY"
Eccentricity: (horizontal plane)	$x_{OT.E3.1} = 0.30\,m$	$x_{OT.check.E3.1}$ = "OKAY"

E3.2 Case

Sliding Factor of Safety: (Horizontal Plane)	$FS_{HorizSliding.E3.2} = 0.52$	
	$FS_{HorizSliding.E3.2.Check}$ = "Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !"	
Sliding Factor of Safety: (Inclined Plane)	$FS_{InclinedlSlidingE3.2} = 1$	$FS_{InclinedSliding.check.E3.2}$ = "OKAY "
Eccentricity: (Inclined Plane)	$e_{E3.2} = 1.77\,m$	$e_{check.E3.2}$ = "Okay"
Bearing Pressure At Heel: (Inclined Plane)	$\sigma_{heel.E3.2} = 30\cdot kPa$	$\sigma_{heel.E3.2.check}$ = "Okay"
Bearing Pressure At Toe: (Inclined Plane)	$\sigma_{toe.E3.2} = 109\cdot kPa$	$\sigma_{toe.E3.2.check.1}$ = "Okay"
Flotation Factor of Safety (horizontal plane)	$FS_{act.FE3.2} = 1.56$	$FS_{check.FE3.2}$ = "OKAY"
Overturning Resultant Ratio: (horizontal plane)	$Ratio_{OT.E3.2} = 0.39$	$Ratio_{OT.E3.2.check}$ = "OKAY"
Eccentricity: (horizontal plane)	$x_{OT.E3.2} = -2.10\,m$	$x_{OT.check.E3.2}$ = "OKAY"

E3 CASE

E3.3 Case

Sliding Factor of Safety: (Horizontal Plane)	$FS_{HorizSliding.E3.3} = 0.67$	
	$FS_{HorizSliding.E3.3.Check}$ = "Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !"	
Sliding Factor of Safety: (Inclined Plane)	$FS_{InclinedlSlidingE3.3} = 1.48$	$FS_{InclinedSliding.check.E3.3}$ = "OKAY "
Eccentricity: (Inclined Plane)	$e_{E3.3} = 1.13\,m$	$e_{check.E3.3}$ = "Okay"
Bearing Pressure At Heel: (Inclined Plane)	$\sigma_{heel.E3.3} = 37 \cdot kPa$	$\sigma_{heel.E3.3.check}$ = "Okay"
Bearing Pressure At Toe: (Inclined Plane)	$\sigma_{toe.E3.3} = 80 \cdot kPa$	$\sigma_{toe.E3.3.check.1}$ = "Okay"
Flotation Factor of Safety (horizontal plane)	$FS_{act.FE3.3} = 1.44$	$FS_{check.FE3.3}$ = "OKAY"
Overturning Resultant Ratio: (horizontal plane)	$Ratio_{OT.E3.3} = 0.39$	$Ratio_{OT.E3.3.check}$ = "OKAY"
Eccentricity: (horizontal plane)	$x_{OT.E3.3} = -2.97\,m$	$x_{OT.check.E3.3}$ = "OKAY"

Calculation Section V

SS-4A Gate Blocks Stability Calculations

Project Number: 110773396

Project Title: SR1 Project

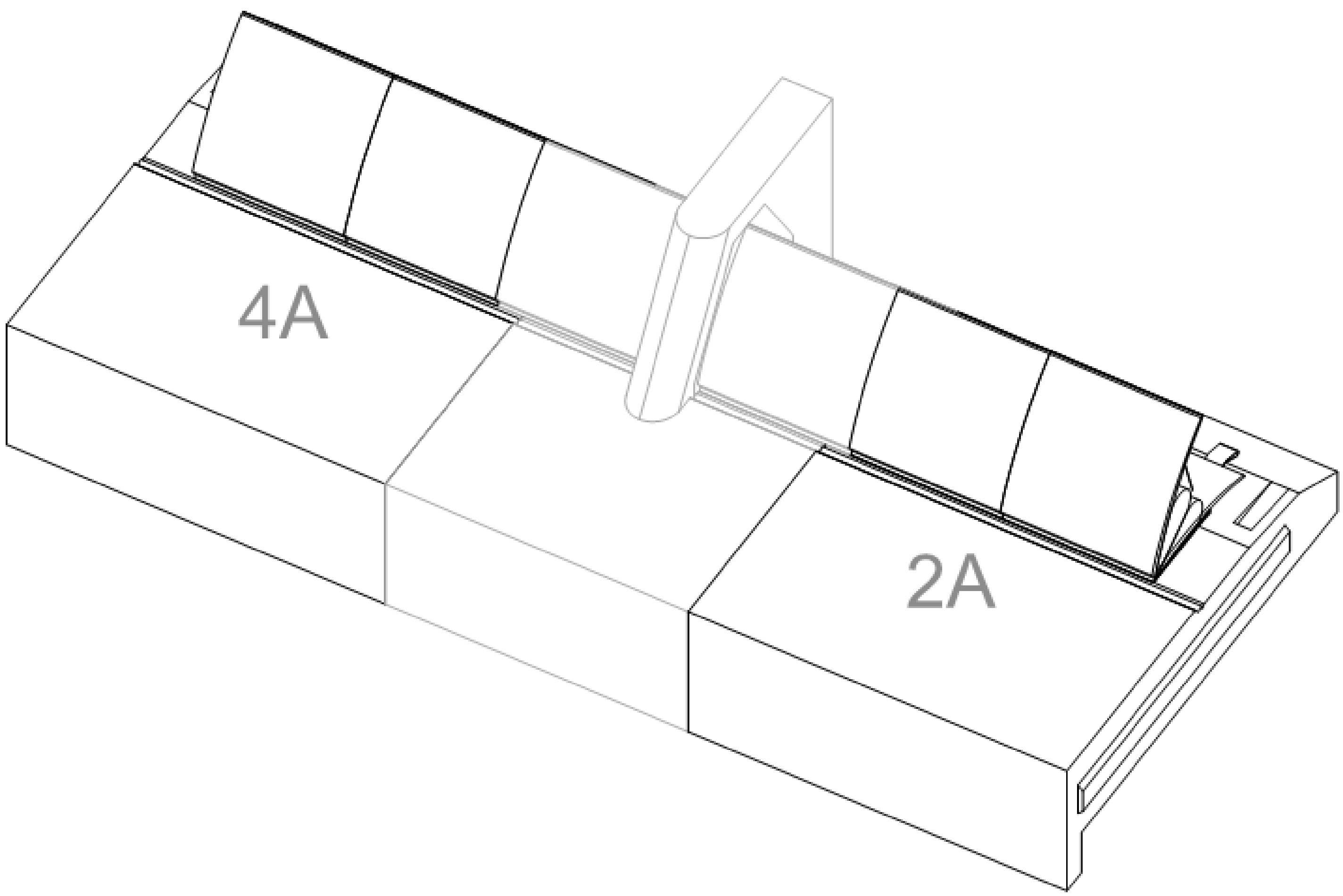
Client: Alberta Transportation

Engineer: Dave Crawford, Derek Cheuk — Date: 12/14/2018

Checker: Sean Xiao — Date: 01/10/2019

Calculation for: Service Spillway 4A - Gate Regulating Gate Structure

Structure Isometric:



SERVICE SPILLWAY - Regulating Gate - 4A

REGION COLOR CONVENTION | User Input | Calculation Highlights | Results

SERVICE SPILLWAY DEIMENSIONAL INPUT PARAMETERS

BASE SECTION PROPERTIES

Base Length: $L_b := 18.50m$

Stilling Basin Length: $L_{sb} := 17.0m$

(Refer to Dwg. S-220 PLAN)

Base Width: $W_b := 15.00m$

$Kern := \frac{L_b}{6} = 3.08\,m$

$Midhalf := \frac{L_b}{4} = 4.63\,m$

Area of Base: $A_b := L_b \cdot W_b = 277.5\,m^2$

Section Modulus of Base: $S_b := \frac{\left(W_b \cdot L_b{}^2\right)}{6} = 855.6\,m^3$

FOOTINGS (fixed crest and approach slab)

Footing Cross Sectional Area: $A_{gf} := 32.84m^2$ (From Bluebeam Measurement)

Block Footing Width: $w_{gf} := W_b = 15.00\,m$

Total Fixed Crest Footing Volume: $V_{gf} := A_{gf} \cdot w_{gf} = 492.6 \cdot m^3$

Approach Slab Height: $h_{as} := 4.00m$

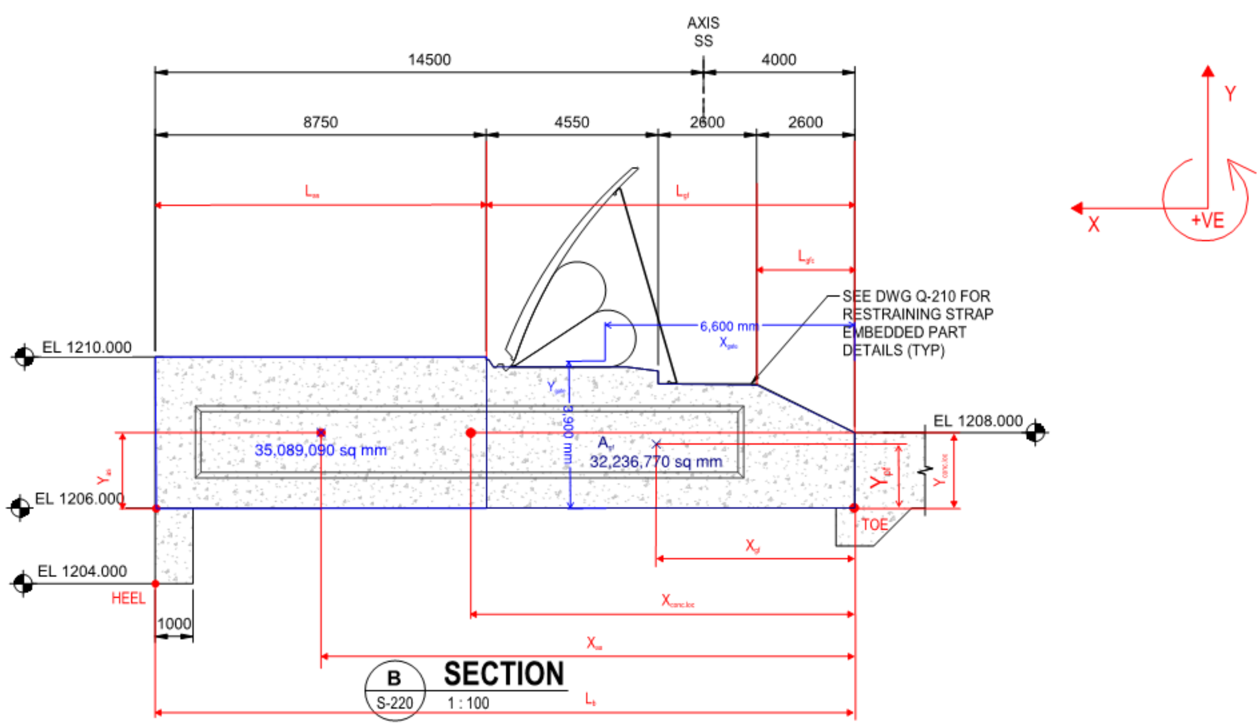
Approach Slab Width: $w_{as} := W_b = 15.00\,m$

Approach Slab Length: $L_{as} := 8.75m$

Gate Footing Length: $L_{gf} := L_b - L_{as} = 9.75\,m$

Gate Footing Crest Length: $L_{gfc} := 2.6m$

Total Approach Slab Volume: $V_{as} := h_{as} \cdot w_{as} \cdot L_{as} = 525.0 \cdot m^3$



SHEAR KEY PARAMETERS

Key depth: $d_{key} := 2.00m$

Key width: $w_{key} := 1.00m$

FOUNDATION PARAMETERS

Granular Fill Internal Angle of Friction: $\phi := 34 \cdot \frac{\pi}{180} = 0.59$ Radians (Section 5.3, Design Criteria)

Friction Angle at Base Concrete / Rock Interface: $\phi_{rock} := 26$ (Section 5.2, Design Criteria)

Base Friction Coefficient: $\tan_{\phi} := \tan\left(\phi_{rock} \frac{\pi}{180}\right) = 0.488$ radians

MATERIAL PROPERTIES

Unit Weight of Concrete: $\gamma_c := 23.5 \frac{kN}{m^3}$ (Section 7.1, Design Criteria)

Unit Weight of Rock Fill: $\gamma_r := 22.0 \frac{kN}{m^3}$ (Section 5.3, Design Criteria)

$\phi_{backfill} := \left(20 \frac{\pi}{180}\right) = 0.35$ radians Assume Rip Rap Backfill

Unit Weight of Water: $\gamma_w := 9.81 \frac{kN}{m^3}$ (Section 7.2, Design Criteria)

CONCRETE DEAD LOADS

Pier Footing (fixed crest): $D_{gf} := V_{gf} \cdot \gamma_c = 11576.1 \cdot kN$

Approach Slab: $D_{as} := V_{as} \cdot \gamma_c + d_{key} \cdot w_{key} \cdot w_{as} \cdot \gamma_c = 13042.5 \cdot kN$

Total Concrete Dead Loads: $D_{conc} := D_{gf} + D_{as} = 24618.6 \cdot kN$

Rock Section Mobilized for Inclined Sliding Failure:

Soil Volume Below Footing (Triangle): $V_{E.tri} := W_b \cdot \frac{1}{2} \cdot d_{key} \cdot \left(L_b - w_{key}\right) = 262.5 \cdot m^3$ $X_{E.tri} := \left(L_b - w_{key}\right) \cdot \frac{2}{3} = 11.67\, m$

Vertical Soil Weight: $E_{v.tri} := V_{E.tri} \cdot \left(\gamma_r\right) = 5775 \cdot kN$ $\Sigma V_{soil} := E_{v.tri} = 5775 \cdot kN$ $\Sigma M_{soil} := E_{v.tri} \cdot X_{E.tri} = 67375 \cdot kN \cdot m$

MOMENT ARM FROM TOE TO COG OF COMPONENT

Dist. from Toe to COG of Gate Footing: $X_{gf} := 5.24m$ (From Bluebeam Measurement)

Dist. from Toe to COG of Approach Slab: $X_{as} := 14.33m$

Distance From Toe to COG of Concrete Dead Load : $X_{conc.loc} := \frac{\left(X_{gf} \cdot D_{gf} + X_{as} \cdot D_{as}\right)}{D_{conc}} = 10.06\, m$

MOMENT ARM FROM BASE OF FOOTING TO COG OF COMPONENT

Dist. from Base to COG of Footing: $Y_{gf} := 1.72m$ (From Bluebeam Measurement)

Dist. from Base to COG of Approach Slab: $Y_{as} := 2.0m$

Distance Above Base to COG of Concrete Dead Load: $Y_{conc.loc} := \frac{\left(Y_{gf} \cdot D_{gf} + Y_{as} \cdot D_{as}\right)}{D_{conc}} = 1.87\, m$

CREST GATE (OBERMEYER)

Dead Load of Gates: $D_{Gate} := 140kN \cdot \frac{15}{10} \frac{m}{m} = 210 \cdot kN$ (Vendor supplied, Dwg. Q-200 Series)

Distance from Toe to COG of Gates: $X_{gate} := 6.60m$

Distance from Base to COG of Gates: $Y_{gate} := 3.90m$ Distance from base to top of Pier Footing

DEAD LOAD SUMMATION:

$$\Sigma V_{DL} := D_{conc} + D_{Gate} = 24828.6 \cdot kN$$

$$\Sigma M_{DL} := D_{conc} \cdot X_{conc.loc} + D_{Gate} \cdot X_{gate} = 248943.79 \cdot kN \cdot m$$

ROCK SECTION MOBILIZED FOR INCLINDED SLIDING FAILURE

Area of Rock Section Mobilized: $A_{rs} := \frac{(L_b - w_{key}) \cdot d_{key}}{2} = 17.5 m^2$

Rock Mass Mobilized: $V_{rs} := A_{rs} \cdot \gamma_r \cdot W_b = 5775 \cdot kN$

(Pore pressure taken along assumed inclined sliding plane)

Distance from Toe to COG of Rock Section: $L_{rs} := \frac{2}{3} \cdot (L_b - w_{key}) = 11.67 m$

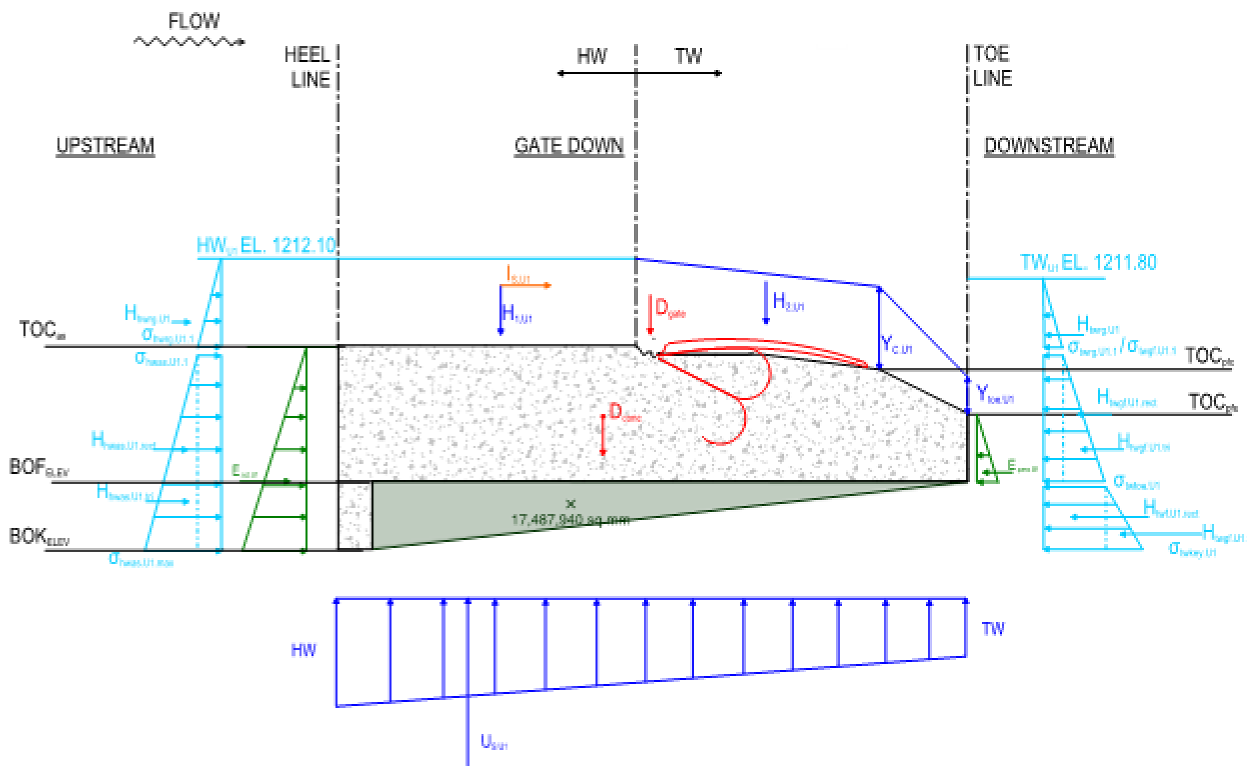
(From Bluebeam Measurement)

SERVICE SPILLWAY GATE STRUCTURE 2D HYDRAULIC MODEL RESULTS

Applicable or Relevent Scenarios: Service Spillway (SS) - Gate Structure
Prepared: 24 October 2018

								Water Surface Over SS Gate Bays			
Scenario	**Total Inflow (m^3/s)**	**Service Spillway Discharge (m^3/s)**			**Headwater (m)**	**Service Spillway Tailwater (m)**	**Notes**	**Headwater at gate hinge (m)**	**Critical depth at gate lip (m)**	**Depth at Basin Toe (m)**	**SS Tailwater just passed basin end (m)***
		Left Gate	**Right Gate**	**Total**							
160 m^3/s, No Diversion, **(U1, E2-Q)**	160	91	69	160	1212.1	1211.8	Diversion Inlet gates closed and Service Spillway gates fully open	LG = RG d = 2.1 EL 1212.1	LG = RG y_c = 1.4; EL 1211.4	LG = RG, toe submerged Uplift = Use tailwater d_{toe} = 0.45; EL 1208.46	d_{tw} = 3.8 EL 1211.8
50-yr Event, Diverting up to 600 m^3/s **(U2, E3-Q)**	530	152	0	152	1214.6	1211.8	Diversion Inlet gates open, Service Spillway left crest gate at EL 1212.1 m and right crest gate at EL 1215.0 m	LG = RG d = 4.6 EL 1214.6	LG = y_c = 1.67; EL 1213.76 RG = Closed	LG = d_{toe} = 0.58; EL 1208.58 RG = Use tailwater Uplift = Use tailwater	d_{tw} = 3.8 EL 1211.8
100-yr Event, Service Spillway Construction/Maintenance, **(UN4)**	765	315	0	315	1215.0	1212.5	Diversion Inlet gates open, Service Spillway left crest gate at EL 1210.9 m and right crest gate at EL 1215.0 m	LG = RG d = 5.0 EL 1215.0	LG = y_c = 2.73; EL 1213.63 RG = Closed	LG = d_{toe} = 1.23 super; EL 1209.23 RG = Use tailwater Uplift = Use tailwater	d_{tw} = 3.9 EL 1211.9
2013 Event, Diverting up to 600 m^3/s **(UN1)**	1240	498	137	634	1215.8	1213.1	Diversion Inlet gates open; Service Spillway left crest gate at EL 1210.0 m and right crest gate at EL 1213.5 m	LG = RG d = 5.8 EL 1215.8	LG = y_c = 3.87; EL 1213.87 RG = y_c = 1.53; EL 1215.03	LG = d_{toe} = 1.95 super; EL 1209.95 RG = d_{toe} = 0.48 super; EL 1208.48 Uplift = Use tailwater	d_{tw} = 5.1 EL 1213.1
2013 Event, Diverting with One Service Spillway Crest Gate Failing to Open **(UN2)**	1240	518	44	562	1216.1	1213.0	Diversion Inlet gates open, Service Spillway left crest gate at EL 1210.0 m and right crest gate at EL 1215.0 m	LG = RG d = 6.1 EL 1216.1	LG = y_c = 4.07; EL 1214.07 RG = y_c = 0.73; EL	LG = d_{toe} = 1.97 super; EL 1209.97 RG = Use tailwater	d_{tw} = 5.0 EL 1213.0
1000-yr Event, No Diversion **(UN3)** Auxiliary Spillway cover eroded	1930	759	708	1467	1217.0	1214.7	Diversion Inlet gates closed and Service Spillway gates fully open. Auxiliary Spillway cover layer eroded	LG = RG d = 7.0 EL 1217.0	LG = RG y_c = 4.67; EL 1214.67	LG = RG d_{toe} = 2.89 super; EL 1210.89 Uplift = Use tailwater	d_{tw} = 6.7 EL 1214.7
Diversion Structure IDF Event, 1/3 Between 1000-yr and PMF, **(E1-F)** No Diversion. AS cover eroded.	2210	812	758	1570	1217.3	1214.9	Diversion Inlet gates closed and Service Spillway gates fully open. Auxiliary Spillway cover layer eroded	LG = RG d = 7.3 EL 1217.3	LG = RG y_c = 4.87; EL 1214.87	LG = RG d_{toe} = 3.06 super; EL 1211.06 Uplift = Use tailwater	d_{tw} = 6.9 EL 1214.9

U1 DESIGN CASE



ACCEPTANCE PARAMETERS

Required Factor of Safety for Sliding: $FS_{req.U1.sl} := 1.5$ (Without Cohesion)

(Section 8.1, Design Criteria)

Resultant Within Middle Third of Base: $e \le \frac{L_b}{6} \wedge e \ge \frac{-L_b}{6}$

Allowable Rock Bearing Pressure: $\sigma_{allow.U1} := 1270 \cdot \frac{kN}{m^2}$ (Section 5.2, Design Criteria)

INPUT PARAMETERS

Headwater Elevation: $HW_{U1} := 1212.10m$ (Section 8.3, Design Criteria)

Tailwater Elevation: $TW_{U1} := 1211.80m$ (Section 8.3, Design Criteria)

Bottom of Footing Elevation: $BOF_{elev} := 1206.00m$

Approach Slab Top of Concrete Elevation at Upstream Face: $TOC_{as} := 1210.00m$

Footing Top of Concrete Elevation at Stilling Basin: $TOC_{pfe} := 1208.00m$

Footing Top of Concrete Elevation at Center of Footing: $TOC_{pfc} := 1209.30m$

Top of Guard/Regulating Gate Elevation: $TOP_{rg.U1} := 1210.00m$ $TOP_{gg.U1} := 1210.00m$

Gates are open when top of gate elevation is at 1210.00m

Bottom of Key Elevation: $BOK_{elev} := BOF_{elev} - d_{key} = 1204\,m$

Gates are closed/up when top of gate elevation is at 1215.0m

Water Elevation above Crest of Reg. Gate: $EL_{C.U1} := 1211.4m$

$$Y_{C.U1} := \begin{cases} (EL_{C.U1} - TOC_{pfc}) & \text{if } TOP_{rg.U1} \le HW_{U1} \\ (TW_{U1} - TOC_{pfc}) & \text{if } TOP_{rg.U1} > HW_{U1} \end{cases} = 2.1 \cdot m$$

Water Elevation above Reg. Gate Toe: $EL_{TOE.U1} := 1208.46m$

$$Y_{TOE.U1} := \begin{cases} (EL_{TOE.U1} - TOC_{pfe}) & \text{if } TOP_{rg.U1} \le HW_{U1} \\ (TW_{U1} - TOC_{pfe}) & \text{if } TOP_{rg.U1} > HW_{U1} \end{cases} = 0.46 \cdot m$$

LATERAL WATER LOADS

U1 CASE

HEADWATER (APPROACH SLAB DRIVING):

Headwater Depth on Gate: $D_{hwg.U1} := HW_{U1} - TOC_{as} = 2.10\,m$

Thickness of Approach Slab (Including Key): $T_{as} := \left(TOC_{as} - BOK_{elev}\right) = 6\,m$

Headwater Depth at Heel (U/S face): $D_{hwas.U1} := HW_{U1} - BOK_{elev} = 8.10\,m$

Headwater Load Unit Width on Approach Slab: $W_{hwas.U1} := W_b = 15.00\,m$

Headwater Unit Load At Top of Approach Slab: $H_{hwas.U1.1} := \frac{-\left(\gamma_w \cdot D_{hwg.U1}{}^2\right)}{2} \cdot W_{hwas.U1} = -324.47 \cdot kN$

Headwater Unit Load At Bottom of Approach Key: $H_{hwas.U1.2} := \frac{-\left(\gamma_w \cdot D_{hwas.U1}{}^2\right)}{2} \cdot W_{hwas.U1} = -4827.3 \cdot kN$

Headwater Line Load At Top of Approach Slab: $\sigma_{hwas.U1.1} := -\left(\gamma_w \cdot D_{hwg.U1}\right) = -20.6 \cdot kPa$

Headwater Line Load At Bottom of Approach Key: $\sigma_{hwas.U1.2} := -\left(\gamma_w \cdot D_{hwas.U1}\right) = -79.46 \cdot kPa$

Triangular Distribution Unit Load on Approach Slab and Key: $H_{hwas.U1.2.tri} := \left(\frac{\sigma_{hwas.U1.2} - \sigma_{hwas.U1.1}}{2}\right) \cdot \left(T_{as} \cdot W_{hwas.U1}\right) = -2648.7 \cdot kN$

Rectangular Distribution Unit Load on Approach Slab and Key: $H_{hwas.U1.2.rect} := \sigma_{hwas.U1.1} \cdot \left(T_{as} \cdot W_{hwas.U1}\right) = -1854.09 \cdot kN$

Total Horizontal Headwater Load on Approach Slab: $H_{hwas.U1} := H_{hwas.U1.2.tri} + H_{hwas.U1.2.rect} = -4502.79 \cdot kN$

Apply Total Footing Headwater Load at:

$$H_{hwas.U1.loc} := \frac{\left[H_{hwas.U1.2.rect} \cdot \frac{\left(T_{as}\right)}{2} + H_{hwas.U1.2.tri} \cdot \frac{\left(T_{as}\right)}{3}\right]}{H_{hwas.U1.2.tri} + H_{hwas.U1.2.rect}} - d_{key} = 0.41\,m$$

LATERAL WATER LOADS (continued)

U1 CASE

Regulating Gate (4A) Operating Condition:

Reg. Gate Down/Open Condition: $A1_{U1} := TOP_{rg.U1} \leq TOC_{as}$

Reg. Crest Gate Up/Closed, with Top of Gate Higher than HW Elevation: $B1_{U1} := TOP_{rg.U1} \geq HW_{U1} \wedge TOP_{rg.U1} > TOC_{as}$

Reg. Crest Gate Up/Closed, with Top of Gate Lower than HW Elevation: $C1_{U1} := TOP_{rg.U1} > TOC_{as} \wedge HW_{U1} > TOP_{rg.U1}$

Reg. Crest Gate Height: $H_{rg.U1} := TOP_{rg.U1} - TOC_{as} = 0\,m$

Headwater Depth at Reg. Crest Gate: $D_{hwrg.U1} := HW_{U1} - TOC_{as} = 2.10\,m$

Reg. Crest Gate Width: $W_{hwrg.U1} := 15.00m$

Lateral Headwater Pressure at Bottom of Reg. Crest Gate:

$$\sigma_{hwrg.U1.1} := \begin{cases} (0.0kPa) & \text{if } A1_{U1} \\ -(\gamma_w \cdot D_{hwrg.U1}) & \text{if } B1_{U1} \\ -(\gamma_w \cdot D_{hwrg.U1}) & \text{if } C1_{U1} \end{cases} = 0.0 \cdot kPa$$

Lateral Headwater Pressure at Top of Reg. Crest Gate:
(Load at HW Elevation On Reg. Crest Gate if HW is below TOG_{rg})

$$\sigma_{hwrg.U1.2} := \begin{cases} (0.0kPa) & \text{if } A1_{U1} \\ 0.0kPa & \text{if } B1_{U1} \\ -\left[\gamma_w \cdot (HW_{U1} - TOP_{rg.U1})\right] & \text{if } C1_{U1} \end{cases} = 0.0 \cdot kPa$$

Average Pressure acting on Reg. Crest Gate:

$$\sigma_{hwrg.U1.avg} := \frac{(\sigma_{hwrg.U1.1} + \sigma_{hwrg.U1.2})}{2} = 0 \cdot kPa$$

Total Area water acting on Crest Gate:

$$A_{hwrg.U1} := \begin{cases} D_{hwrg.U1} \cdot W_{hwrg.U1} & \text{if } A1_{U1} \\ D_{hwrg.U1} \cdot W_{hwrg.U1} & \text{if } B1_{U1} \\ H_{rg.U1} \cdot W_{hwrg.U1} & \text{if } C1_{U1} \end{cases} = 31.5 \cdot m^2$$

Total Horizontal Headwater Load on Reg. Crest Gate: $H_{hwrg.U1} := \sigma_{hwrg.U1.avg} \cdot A_{hwrg.U1} = 0.0 \cdot kN$

Apply Total Reg. Crest Gate Headwater Load at:

$$H_{hwrg.U1.loc} := \begin{cases} (TOC_{as} - BOF_{elev}) & \text{if } A1_{U1} \\ \left[\frac{(HW_{U1} - TOC_{as})}{3} + (TOC_{as} - BOF_{elev})\right] & \text{if } B1_{U1} \\ \left[\frac{\sigma_{hwrg.U1.2} \cdot A_{hwrg.U1} \cdot \frac{(H_{rg.U1})}{2} + \frac{(\sigma_{hwrg.U1.1} - \sigma_{hwrg.U1.2})}{2} A_{hwrg.U1} \cdot \frac{(H_{rg.U1})}{3}}{\sigma_{hwrg.U1.2} \cdot A_{hwrg.U1} + \frac{(\sigma_{hwrg.U1.1} - \sigma_{hwrg.U1.2})}{2} \cdot A_{hwrg.U1}} \ldots \\ + (TOC_{as} - BOF_{elev})\right] & \text{if } C1_{U1} \end{cases} = 4.0 \cdot m$$

LATERAL TAILWATER (RESISTING) Applied to Downstream Side of Reg. Crest Gate: **U1 CASE**

Reg. Gate Down/Open Condition: $A2_{U1} := TOP_{rg.U1} \le TOC_{as}$

Reg. Crest Gate Up/Closed, with Top of Gate Higher than TW Elevation: $B2_{U1} := TOP_{rg.U1} \ge TW_{U1} \wedge TOP_{rg.U1} > TOC_{as}$

Reg. Crest Gate Up/Closed, with Top of Gate Lower than TW Elevation: $C2_{U1} := TOP_{rg.U1} > TOC_{as} \wedge TW_{U1} > TOP_{rg.U1}$

Tailwater Depth at Reg. Crest Gate: $D_{twrg.U1} := TW_{U1} - TOC_{as} = 1.80\,m$

Reg. Crest Gate Width: $W_{twrg.U1} := 15.00m$

Lateral Water Load at Bottom of Reg. Crest Gate:

$$\sigma_{twrg.U1.1} := \begin{vmatrix} (0.0kPa) & \text{if } A2_{U1} \\ (\gamma_w \cdot D_{twrg.U1}) & \text{if } B2_{U1} \\ (\gamma_w \cdot D_{twrg.U1}) & \text{if } C2_{U1} \end{vmatrix} = 0.0 \cdot kPa$$

Lateral Water Load at Top of Reg. Crest Gate:
(Load at TW Elevation On Reg. Crest Gate if TW is below TOG_{rg})

$$\sigma_{twrg.U1.2} := \begin{vmatrix} (0.0kPa) & \text{if } A2_{U1} \\ 0.0kPa & \text{if } B2_{U1} \\ \left[\gamma_w \cdot (TW_{U1} - TOP_{rg.U1})\right] & \text{if } C2_{U1} \end{vmatrix} = 0.0 \cdot kPa$$

Average Pressure acting on Reg. Crest Gate:

$$\sigma_{twrg.U1.avg} := \frac{(\sigma_{twrg.U1.1} + \sigma_{twrg.U1.2})}{2} = 0 \cdot kPa$$

Total Area water acting on Crest Gate:

$$A_{twrg.U1} := \begin{vmatrix} D_{twrg.U1} \cdot W_{twrg.U1} & \text{if } A2_{U1} \\ D_{twrg.U1} \cdot W_{twrg.U1} & \text{if } B2_{U1} \\ H_{rg.U1} \cdot W_{twrg.U1} & \text{if } C2_{U1} \end{vmatrix} = 27 \cdot m^2$$

Total Horizontal Tailwater Load on Reg. Crest Gate: $H_{twrg.U1} := \sigma_{twrg.U1.avg} \cdot A_{twrg.U1} = 0.0 \cdot kN$

Apply Total Horiz. TW Load on Reg. Gate at:

$$H_{twrg.U1.loc} := \begin{vmatrix} (TOC_{as} - BOF_{elev}) & \text{if } A2_{U1} \\ \left[\frac{(TW_{U1} - TOC_{as})}{3} + (TOC_{as} - BOF_{elev})\right] & \text{if } B2_{U1} \\ \left[\frac{\sigma_{twrg.U1.2} \cdot A_{twrg.U1} \cdot \frac{(H_{rg.U1})}{2} + \frac{(\sigma_{twrg.U1.1} - \sigma_{twrg.U1.2})}{2} A_{twrg.U1} \cdot \frac{(H_{rg.U1})}{3}}{\sigma_{twrg.U1.2} \cdot A_{twrg.U1} + \frac{(\sigma_{twrg.U1.1} - \sigma_{twrg.U1.2})}{2} \cdot A_{twrg.U1}} \cdots + (TOC_{as} - BOF_{elev})\right] & \text{if } C2_{U1} \end{vmatrix} = 4.0 \cdot m$$

LATERAL WATER LOADS (continued)

U1 CASE

TAILWATER (RESISTING) Applied to Concrete Structure:

Tailwater Depth At top of Gate Base Footing Elevation: $D_{twgf.U1} := TW_{U1} - TOC_{as} = 1.80\,m$

Water Depth at bottom of Gate Base Footing: $D_{twtoe.U1} := TW_{U1} - BOF_{elev} = 5.80\,m$

Footing Thickness for horizontal at Toe: $h_{toe} := TOC_{as} - BOF_{elev} = 4\,m$

Unit Width of D/S face of crest for application of Tailwater Load: $W_{tw.U1} := W_b = 15.00\,m$

Tailwater Pressure At Top of Gate Footing: $\sigma_{twgf.U1} := \left(\gamma_w \cdot D_{twgf.U1}\right) = 17.66 \cdot kPa$

Tailwater Line Load At Bottom of Gate Footing: $\sigma_{twtoe.U1} := \left(\gamma_w \cdot D_{twtoe.U1}\right) = 56.9 \cdot kPa$

Triangular Distribution Unit Load on Gate Footing Base: $H_{twgf.U1.tri} := \left(\frac{\sigma_{twtoe.U1} - \sigma_{twgf.U1}}{2}\right) \cdot \left(h_{toe} \cdot W_{tw.U1}\right) = 1177.2 \cdot kN$

Rectangular Distribution Unit Load on Gate Footing Base: $H_{twgf.U1.rect} := \sigma_{twgf.U1} \cdot \left(h_{toe} \cdot W_{tw.U1}\right) = 1059.48 \cdot kN$

Tailwater Pressure At Bottom of Sliding Failure Plane: $\sigma_{twbk.U1} := \left(HW_{U1} - BOK_{elev}\right) \cdot \gamma_w = 79.46 \cdot kPa$

Triangular Distribution Unit Load Below Footing: $H_{twbk.U1.tri} := \frac{\left(\sigma_{twbk.U1} - \sigma_{twtoe.U1}\right)}{2} \cdot d_{key} \cdot W_{tw.U1} = 338.44 \cdot kN$

Rectangular Distribution Load Below Footing Base: $H_{twbk.U1.rect} := \sigma_{twtoe.U1} \cdot d_{key} \cdot W_{tw.U1} = 1706.94 \cdot kN$

Total Horizontal Tailwater Load on Gate Footing (including key):

$$H_{twgk.U1} := H_{twgf.U1.tri} + H_{twgf.U1.rect} + H_{twbk.U1.tri} + H_{twbk.U1.rect} = 4282.06 \cdot kN$$

Apply Total Gate Footing Tailwater Load From Toe at:

$$H_{twgk.U1.loc} := \frac{\left[H_{twgf.U1.rect} \cdot \frac{\left(h_{toe}\right)}{2} + H_{twgf.U1.tri} \cdot \frac{\left(h_{toe}\right)}{3} + H_{twbk.U1.tri} \cdot \left(-d_{key} \cdot \frac{2}{3}\right) + H_{twbk.U1.rect} \cdot \left(\frac{-d_{key}}{2}\right)\right]}{H_{twgf.U1.tri} + H_{twgf.U1.rect} + H_{twbk.U1.tri} + H_{twbk.U1.rect}} = 0.36\,m$$

SUMMATION OF LATERAL WATER LOADS:

$$\Sigma H_{Water.U1} := H_{hwas.U1} + H_{hwrg.U1} + H_{twgk.U1} + H_{twrg.U1} = -220.72 \cdot kN$$

$$\Sigma M_{Hwater.U1} := H_{hwas.U1} \cdot H_{hwas.U1.loc} + H_{hwrg.U1} \cdot H_{hwrg.U1.loc} + H_{twgk.U1} \cdot H_{twgk.U1.loc} + H_{twrg.U1} \cdot H_{twrg.U1.loc} = -323.73 \cdot kN \cdot m$$

VERTICAL WATER LOADS

U1 CASE

HEADWATER:

Water Depth on top of Approach Slab: $d_{hw.U1} := HW_{U1} - TOC_{as} = 2.10\,m$

Length of Approach Slab: $L_{as} = 8.75\,m$

Width of Approach Slab: $w_{as} = 15.00\,m$

Vertical Water Weight (H1) on Approach Slab: $H_{1.U1} := \left(w_{as} \cdot d_{hw.U1} \cdot L_{as}\right) \cdot \gamma_w = 2703.9 \cdot kN$

Moment Arm for Application of Water Weight (H1) from toe: $H_{1.U1.loc} := L_b - \frac{L_{as}}{2} = 14.13\,m$

TAILWATER:

Trapezoid Volume Above Gate Footing from Approach Slab to Crest: $V_{asc.U1} := \left(L_{gf} - L_{gfc}\right) W_b \frac{d_{hw.U1} + Y_{C.U1}}{2} = 225.23 \cdot m^3$

Trapezoid Volume Above Gate Footing Crest to End of Gate Footing: $V_{gfc.U1} := \left(L_{gfc} \cdot W_b\right) \frac{Y_{C.U1} + Y_{TOE.U1}}{2} = 49.92 \cdot m^3$

Load Above Gate Footing from Approach Slab to Crest: $H_{2.U1.asc} := V_{asc.U1} \cdot \gamma_w = 2209.46 \cdot kN$

Load Acting Above Footing Crest from Toe: $H_{2.U1.asc.loc} := \frac{\left(L_{gf} - L_{gfc}\right) \cdot \left(2 \cdot d_{hw.U1} + Y_{C.U1}\right)}{3 \cdot \left(d_{hw.U1} + Y_{C.U1}\right)} + L_{gfc} = 6.17\,m$

Load Above Gate Footing from Crest to End: $H_{2.U1.gfc} := V_{gfc.U1} \cdot \gamma_w = 489.72 \cdot kN$

Load Acting Above Gate Footing from Crest to End: $H_{2.U1.gfc.loc} := \frac{\left(L_{gfc}\right) \cdot \left(2 \cdot Y_{C.U1} + Y_{TOE.U1}\right)}{3 \cdot \left(Y_{C.U1} + Y_{TOE.U1}\right)} = 1.58\,m$

Vertical Water Weight (H2) on Gate Footing: $H_{2.U1} := H_{2.U1.asc} + H_{2.U1.gfc} = 2699.17 \cdot kN$

Moment Arm for Application of Water Weight (H2) from toe: $H_{2.U1.loc} := \frac{H_{2.U1.asc} \cdot H_{2.U1.asc.loc} + H_{2.U1.gfc} \cdot H_{2.U1.gfc.loc}}{H_{2.U1}} = 5.34\,m$

UPLIFT AT INCLINE SLIDING PLANE

U1 CASE

Uplift pressure at U/S Face (heel): $U_{HW.U1} := D_{hwas.U1} \cdot \gamma_w = 79.5 \cdot \frac{kN}{m^2}$

Uplift pressure at D/S Face Stilling Basin: $U_{TW.U1} := \left(D_{twtoe.U1}\right) \cdot \gamma_w = 56.9 \cdot \frac{kN}{m^2}$

Length from U/S of Gate Structure to U/S of Stilling Basin: $L_{overall.Usual} := L_b = 18.50\,m$

Difference between Uplift pressure at HW and TW: $U_{diff.U1} := U_{HW.U1} - U_{TW.U1} = 22.56 \cdot \frac{kN}{m^2}$

Slope of difference between between Uplift pressure at HW and TW: $U_{slope.U1} := \frac{U_{diff.U1}}{L_{overall.Usual}} = 1.22 \cdot \frac{kN}{m^2 \cdot m}$

Tailwater Pressure at toe of Gate Structure: $U_{press.toe.gs.U1} := U_{TW.U1} + \left(L_{overall.Usual} - L_b\right) \cdot U_{slope.U1} = 56.9 \cdot \frac{kN}{m^2}$

Uniform uplift force UA Under Gate Structure due to TW (rectangle): $U_{A.U1} := U_{press.toe.gs.U1} \cdot L_b \cdot W_b \cdot -1 = -15789.19 \cdot kN$

Moment Arm from Toe of Gate Structure for Uplift UA: $L_{A.U1} := \left(\frac{L_b}{2}\right) = 9.25\,m$

Linearly Decreasing Uplift Force U1B Under Gate Structure due to HW-TW Differential (triangle): $U_{B.U1} := \frac{1}{2} \cdot \left(U_{HW.U1} - U_{press.toe.gs.U1}\right) \cdot L_b \cdot W_b \cdot -1 = -3130.62 \cdot kN$

Moment Arm from Toe of Gate Structure for Uplift UB: $L_{B.U1} := \frac{2}{3} \cdot L_b = 12.33\,m$

Total Resultant Uplift force Sliding Check: $U_{S.U1} := U_{A.U1} + U_{B.U1} = -18919.81 \cdot kN$

Resultant Location from Toe: $U_{S.U1.loc} := \frac{\left(U_{A.U1} \cdot L_{A.U1} + U_{B.U1} \cdot L_{B.U1}\right)}{\left(U_{A.U1} + U_{B.U1}\right)} = 9.76\,m$

$\Sigma V_{water.U1} := H_{1.U1} + H_{2.U1} + U_{S.U1} = -13516.76 \cdot kN$

$\Sigma M_{Vwater.U1} := H_{1.U1} \cdot H_{1.U1.loc} + H_{2.U1} \cdot H_{2.U1.loc} + U_{S.U1} \cdot U_{S.U1.loc} = -132052.69 \cdot kN \cdot m$

SOIL LOADS

U1 CASE

Equivalent Fluid Pressure (EFP):

At rest lateral pressure coefficient: $K_{o.U1} := 1 - \sin(\phi_{backfill}) = 0.658$ (Section 5.3, Design Criteria)

Headwater Footing Unit Width: $W_{hwas.U1} = 15.00\,m$

Tailwater Footing Unit Width: $W_{tw.U1} = 15.00\,m$

Footing Thickness at Heel: $t_{hf.U1} := TOC_{as} - BOK_{elev} = 6.00\,m$

Fixed Crest Footing Thickness at Toe: $t_{tf.U1} := TOC_{pfe} - BOF_{elev} = 2.00\,m$

Lateral Driving Force (Headwater Side - at rest condition)

At-Rest Soil Load: $E_{act.U1} := \frac{\left(K_{o.U1} \cdot t_{hf.U1}^{\,2}\right)}{2} \cdot (\gamma_r - \gamma_w) \cdot W_{hwas.U1} \cdot -1 = -2165.61 \cdot kN$

At Rest- Soil Load Acting from Toe: $E_{act.U1.loc} := \frac{t_{hf.U1}}{3} - d_{key} = 0.00\,m$

Lateral Resisting Force (Tailwater Side - at rest condition)

At-rest Soil Load: $E_{pass.U1} := \frac{\left(K_{o.U1} \cdot t_{tf.U1}^{\,2}\right)}{2} \cdot (\gamma_r - \gamma_w) \cdot W_{tw.U1} = 240.62 \cdot kN$

Acting at: $E_{pass.U1.loc} := \frac{t_{tf.U1}}{3} = 0.67\,m$

$\Sigma H_{soil.U1} := E_{act.U1} + E_{pass.U1} = -1924.99 \cdot kN$

$\Sigma M_{soil.U1} := E_{act.U1} \cdot E_{act.U1.loc} + E_{pass.U1} \cdot E_{pass.U1.loc} = 160.42 \cdot kN \cdot m$

ICE / IMPACT LOADS (ASSUME NO ICE LOADING ON TAILWATER SIDE)

Static Ice load on Gates:

$$I_{G.U1} := \begin{cases} 0\,\frac{kN}{m} & \text{if } TOP_{rg.U1} \le TOC_{as} \\ 75\,\frac{kN}{m} & \text{if } TOP_{rg.U1} > TOC_{as} \end{cases} = 0$$

(Section 7.7, Design Criteria)

Ice Loading Unit Width on Reg. Gate: $W_{rg.U1} := 15m$ (Input value for load case)

Total Ice Load on Structure: $I_{U1} := -\left(I_{G.U1} \cdot W_{rg.U1}\right) = 0 \cdot kN$

Apply Ice load at: $I_{U1.loc} := \left(TOC_{as} - BOF_{elev}\right) - 0.3m = 3.70\,m$

$\Sigma H_{I.U1} := I_{U1} = 0 \cdot kN$

$\Sigma M_{I.U1} := I_{U1} \cdot I_{U1.loc} = 0 \cdot kN \cdot m$

(SEISMIC LOAD (NOT APPLICABLE FOR THIS LOAD CASE)

U1 CASE

SUMMARY OF LOADS

	Loads	Moment Arm
Dead load of Concrete Structure:	$D_{conc} = 24618.6 \cdot kN$	$X_{conc.loc} = 10.06\,m$
Obermyer Gate Weight:	$D_{Gate} = 210.0 \cdot kN$	$X_{gate} = 6.60\,m$
HW Lateral Load on Approach Slab:	$H_{hwas.U1} = -4502.8 \cdot kN$	$H_{hwas.U1.loc} = 0.41\,m$
HW Lateral Load on Reg. Gate:	$H_{hwrg.U1} = 0.0 \cdot kN$	$H_{hwrg.U1.loc} = 4.00\,m$
TW Lateral Load on Gate Footing (Including Key - Sliding Check Loads):	$H_{twgk.U1} = 4282.06 \cdot kN$	$H_{twgk.U1.loc} = 0.36\,m$
TW Lateral Load on Reg. Gate:	$H_{twrg.U1} = 0.0 \cdot kN$	$H_{twrg.U1.loc} = 4.00\,m$
Vertical HW Load on Approach Slab:	$H_{1.U1} = 2703.9 \cdot kN$	$H_{1.U1.loc} = 14.13\,m$
Vertical TW Load on Pier Footing (crest):	$H_{2.U1} = 2699.2 \cdot kN$	$H_{2.U1.loc} = 5.34\,m$
Uplift:	$U_{S.U1} = -18919.8 \cdot kN$	$U_{S.U1.loc} = 9.76\,m$
Lateral Soil Load (driving):	$E_{act.U1} = -2165.6 \cdot kN$	$E_{act.U1.loc} = 0.00\,m$
Ice / Impact Load:	$I_{U1} = 0.0 \cdot kN$	$I_{U1.loc} = 3.70\,m$

STABILITY ASSESSMENT (SLIDNG, BEARING, FLOTATION AND OVERTURNING):

U1 CASE

CHECK SLIDING ALONG HORIZONTAL PLANE THRU TOE,
IGNORING BEDROCK MOBILIZED BY STRUCTURAL HEEL KEY, OR VOID BEHIND KEY

Sum of Vertical Forces:

$$\Sigma V_{U1} := \Sigma V_{DL} + \Sigma V_{water.U1} = 11311.8 \cdot kN$$

Sum of Horizontal Forces:

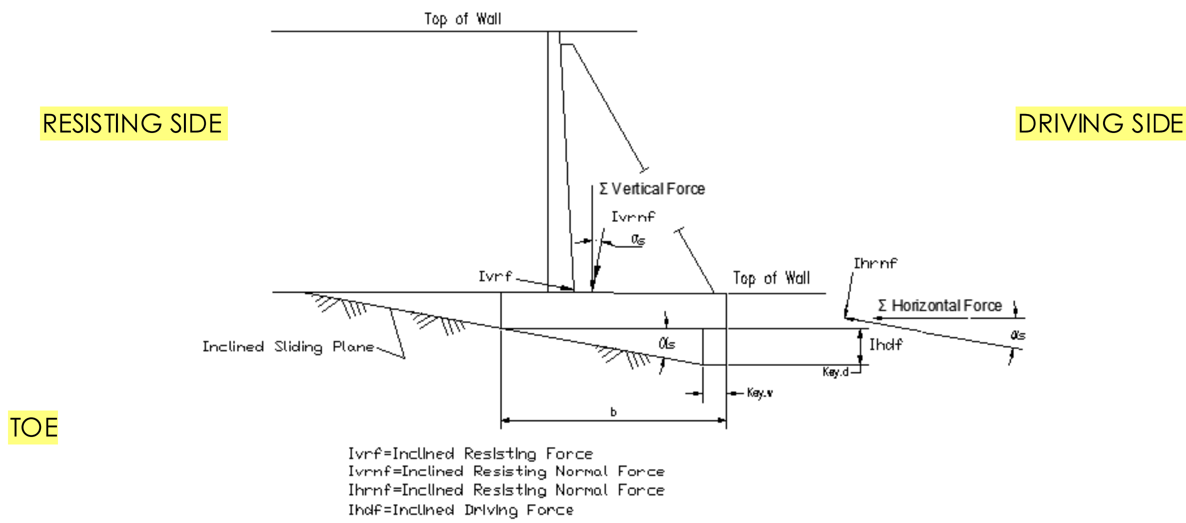
$$\Sigma H_{U1} := \Sigma H_{Water.U1} + \Sigma H_{soil.U1} + \Sigma H_{I.U1} = -2145.71 \cdot kN$$

Sliding Factor of Safety:

$$FS_{HorizSliding.U1} := \frac{\tan_{\phi} \cdot \Sigma V_{U1}}{\left|\Sigma H_{U1}\right|} = 2.57$$

$$FS_{HorizSliding.U1.Check} := \begin{array}{|l} \text{"OKAY"} \quad \text{if} \quad FS_{HorizSliding.U1} \ge FS_{req.U1.sl} \\ \text{"Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !"} \quad \text{otherwise} \end{array} = \text{"OKAY"}$$

CHECK SLIDING ALONG INCLINED SLIDING PLANE FROM HEEL KEY TO TOE,
WITH BEDROCK MASS MOBILIZED BY REINFOCREDE CONCRETE KEY)



$$\alpha s := \operatorname{atan}\left(\frac{d_{key}}{L_b - w_{key}}\right) = 0.11$$

as degrees= $\alpha s \cdot \left(\frac{180}{\pi}\right) = 6.52$

$\Sigma V_{U1} = 11311.84 \cdot kN$

$V_{rs} = 5775 \cdot kN$

Resolve $\Sigma Vert_{U1}$ & $\Sigma Horiz_{U1}$

$$\Sigma V_{InclinedU1} := \cos(\alpha s) \cdot \left(\Sigma V_{U1} + V_{rs}\right) + \sin(\alpha s) \cdot \left|\Sigma H_{U1}\right| = 17220.0 \cdot kN$$

$$\Sigma H_{InclinedU1} := \cos(\alpha s) \cdot \left|\Sigma H_{U1}\right| - \sin(\alpha s) \cdot \left(\Sigma V_{U1} + V_{rs}\right) = 191.7 \cdot kN$$

(With properly engineered reinforced concrete Key, horizontal sliding plane thru Toe is protected, critical sliding plane is relocated to the INCLINED SLIDING PLANE FROM HEEL KEY To TOE, Bedrock Mass above this examined plane is mobilized by reinforced concrete key and combined into Structural Wedge.)

Inclined Sliding Plane Length

$$L_{incline} := \left[L_b^{\,2} + \left(BOF_{elev} - BOK_{elev}\right)^2\right]^{0.5} = 18.61\,m$$

Safety Factor for Sliding
Inclined Failure Plane

$$FS_{InclinedlSlidingU1} := \frac{\Sigma V_{InclinedU1} \cdot \tan\left(\phi_{rock} \cdot \frac{\pi}{180}\right)}{\left|\Sigma H_{InclinedU1}\right|} = 43.82$$

$$FS_{InclinedSliding.check.U1} := \begin{array}{|l} \text{"OKAY "} \quad \text{if} \quad FS_{InclinedlSlidingU1} > FS_{req.U1.sl} \\ \text{"Revise Structure""} \quad \text{otherwise} \end{array} = \text{"OKAY "}$$

$FS_{InclinedSliding.check.U1} = \text{"OKAY "}$

OVERTURNING STABILITY CHECK:

U1 CASE

CHECK ECCENTRICITY

Sum of the moments:

$$\Sigma M_{U1} := \Sigma M_{DL} + \Sigma M_{Hwater.U1} + \Sigma M_{Vwater.U1} + \Sigma M_{I.U1} + \Sigma M_{soil.U1} + \Sigma M_{soil} = 184103 \cdot kN \cdot m$$

Eccentricity:

$$e_{U1} := \left(\frac{L_{incline}}{2}\right) - \frac{\left(\Sigma M_{U1}\right)}{\Sigma V_{InclinedU1}} = -1.39\,m$$

Eccentricity Check:

$$e_{check.U1} := \begin{cases} \text{"Okay"} & \text{if } \left|e_{U1}\right| \le Kern \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$$e_{check.U1} = \text{"Okay"}$$

Foundation Bearing Checks:

Incline Plane Area:

$$A_{b.incline} := L_{incline} \cdot W_b = 279.12\,m^2$$

Incline Plane Section Modulus:

$$S_{b.incline} := \frac{W_b \cdot L_{incline}^{\,2}}{6} = 865.63 \cdot m^3$$

Bearing Pressure at Heel:

$$\sigma_{heel.U1} := \frac{\Sigma V_{InclinedU1}}{A_{b.incline}} - \frac{\left(\Sigma V_{InclinedU1} \cdot e_{U1}\right)}{S_{b.incline}} = 89.3 \cdot \frac{kN}{m^2}$$

$$\sigma_{heel.U1.check} := \left(\begin{cases} \text{"Okay"} & \text{if } \sigma_{heel.U1} \le \sigma_{allow.U1} \\ \text{"Revise Structure"} & \text{if } \sigma_{heel.U1} < 0\,\frac{kN}{m^2} \end{cases}\right)$$

$$\sigma_{heel.U1.check} = \text{"Okay"}$$

Bearing Pressure at Toe:

$$\sigma_{toe.U1} := \frac{\Sigma V_{InclinedU1}}{A_{b.incline}} + \frac{\left(\Sigma V_{InclinedU1} \cdot e_{U1}\right)}{S_{b.incline}} = 34.1 \cdot \frac{kN}{m^2}$$

$$\sigma_{toe.U1.1.check} := \begin{cases} \text{"Okay"} & \text{if } \sigma_{toe.U1} \le \sigma_{allow.U1} \\ \text{"Revise Structure"} & \text{if } \sigma_{toe.U1} < 0\,\frac{kN}{m^2} \end{cases}$$

$$\sigma_{toe.U1.1.check} = \text{"Okay"}$$

FLOATATION ANALYSIS:

ACCEPTANCE PARAMETERS

Required Factor of Safety: $FS_{req.FU1} := 1.5$

VERTICAL LOADS RESISTING:

Dead Load: $\Sigma V_{DL} = 24828.6 \cdot kN$

Water Weight H1+H2: $\Sigma V_{H.FU1} := H_{1.U1} + H_{2.U1} = 5403.05 \cdot kN$

Summation Vertical Resisting: $\Sigma V_{FU1} := \Sigma V_{DL} + \Sigma V_{H.FU1} = 30231.7 \cdot kN$

VERTICAL LOADS UPLIFT:

Uplift: $U_{S.U1} = -18919.81 \cdot kN$

Factor of Safety Floatation:

$$FS_{act.FU1} := \frac{\Sigma V_{FU1}}{\left|U_{S.U1}\right|} = 1.60$$

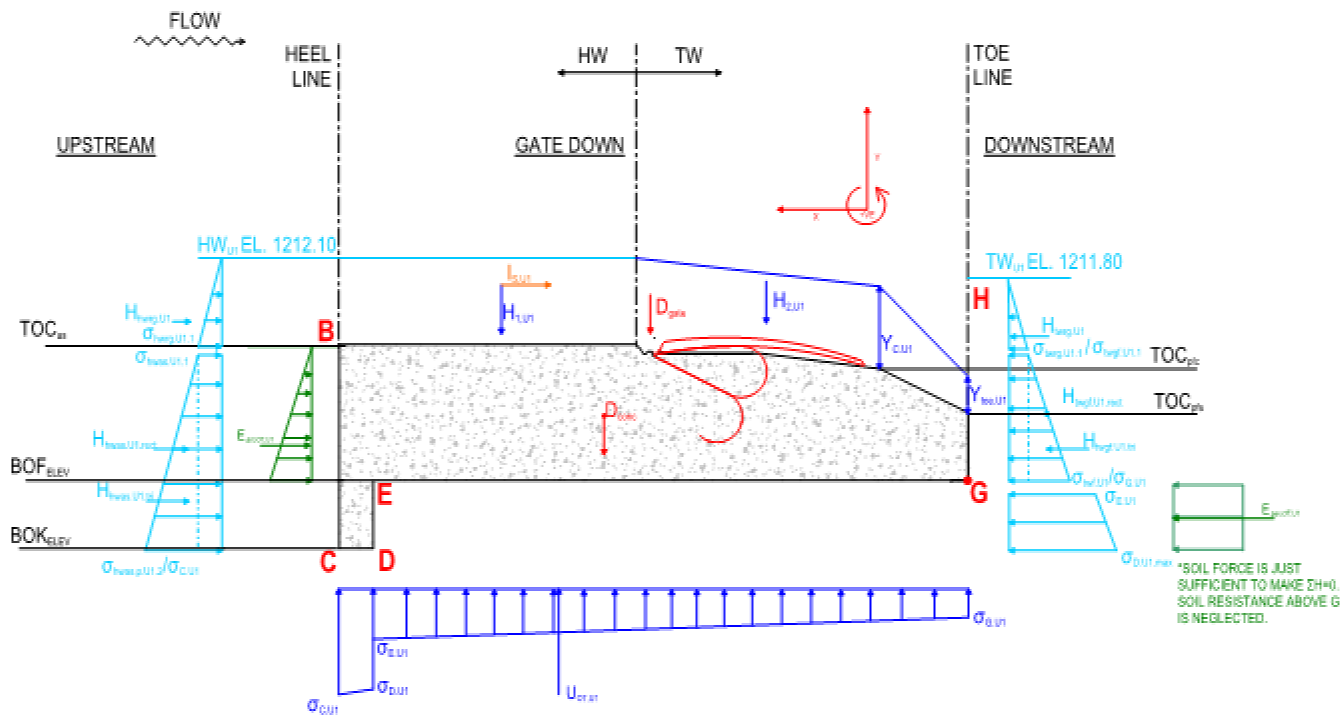
$$FS_{check.FU1} := \begin{cases} \text{"OKAY"} & \text{if } FS_{act.FU1} \ge FS_{req.FU1} \\ \text{"ANCHORS REQUIRED"} & \text{if } FS_{act.FU1} < FS_{req.FU1} \end{cases} = \text{"OKAY"}$$

MONOLITH OVERTURNING STABILITY ANALYSIS

U1 CASE

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.
Assumptions are made in order to compute overturning stability of indetermine forces on monolith with key;
(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.
(b) The horizontal resisting force acting on the key, P.key, is that required for static equilibrium
(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1 $Ratio_{OT.U1.min} := 0.33$



Uplift Loads for Overturning Stability Analysis

Line of Creep:

Change in Water Head: $\Delta_{h.U1} := HW_{U1} - TW_{U1} = 0.3\,m$

Length from Point C to Point G: $L_{CG} := \sqrt{d_{key}^{\,2} + L_b^{\,2}} = 18.61\,m$

Length from Various Points to Points: $L_{CD} := w_{key} = 1\,m$ $\quad L_{DE} := d_{key} = 2\,m$ $\quad L_{EG} := L_b - L_{CD} = 17.5\,m$

$L_{GH.U1} := TW_{U1} - BOF_{elev} = 5.8\,m$

Length from Point C, D, E to G: $L_{CDEG} := L_{CD} + L_{DE} + L_{EG} = 20.5\,m$ $\quad L_{CDE} := L_{CD} + L_{DE} = 3\,m$

Water Pressure at Point C: $\sigma_{C.U1} := \sigma_{hwas.U1.2} = -79.46 \cdot kPa$

Water Pressure at Point G: $\sigma_{G.U1} := \sigma_{twtoe.U1} \cdot -1 = -56.9 \cdot kPa$

Water Pressure at Point D: $$\sigma_{D.U1} := -\gamma_w \cdot \left[\left(HW_{U1} - BOK_{elev}\right) - \frac{\Delta_{h.U1} \cdot L_{CD}}{L_{CDEG}}\right] = -79.32 \cdot kPa$$

Water Pressure at Point E: $$\sigma_{E.U1} := -\gamma_w \cdot \left[\left(HW_{U1} - BOF_{elev}\right) - \frac{\Delta_{h.U1} \cdot L_{CDE}}{L_{CDEG}}\right] = -59.41 \cdot kPa$$

Uplift for Overturning Analysis on Bottom of Key: $$U_{OT.U1.key} := \frac{\sigma_{C.U1} + \sigma_{D.U1}}{2} \cdot L_{CD} \cdot W_b = -1190.84 \cdot kN$$

Acting at: $$U_{OT.U1.key.loc} := \frac{L_{CD} \cdot \left(2 \cdot \sigma_{C.U1} + \sigma_{D.U1}\right)}{3\left(\sigma_{C.U1} + \sigma_{D.U1}\right)} + L_{EG} = 18\,m$$

U1 CASE

Uplift for Overturning Analysis on Bottom of Footing: $U_{OT.U1.ftg} := \frac{\sigma_{E.U1} + \sigma_{G.U1}}{2} \cdot L_{EG} \cdot W_b = -15265.47 \cdot kN$

Acting at: $U_{OT.U1.ftg.loc} := \frac{L_{EG} \cdot \left(\sigma_{G.U1} + 2 \cdot \sigma_{E.U1}\right)}{3\left(\sigma_{G.U1} + \sigma_{E.U1}\right)} = 8.81\,m$

Uplift Load for Overturning Analysis: $U_{OT.U1} := U_{OT.U1.key} + U_{OT.U1.ftg} = -16456.3 \cdot kN$

Uplift Load Acting from Toe: $U_{OT.U1.loc} := \frac{U_{OT.U1.key} \cdot U_{OT.U1.key.loc} + U_{OT.U1.ftg} \cdot U_{OT.U1.ftg.loc}}{U_{OT.U1}} = 9.48\,m$

All Vertical Loads Applicable to Overturning Stability Analysis

Total Concrete Dead Loads:	$D_{conc} = 24618.6 \cdot kN$	at:	$X_{conc.loc} = 10.06\,m$
Dead Load of Gate:	$D_{Gate} = 210.0 \cdot kN$		$X_{gate} = 6.60\,m$
Water Weight (HW) on Apron Slab:	$H_{1.U1} = 2703.9 \cdot kN$		$H_{1.U1.loc} = 14.13\,m$
Water Weight (TW) on Gate Footing:	$H_{2.U1} = 2699.2 \cdot kN$		$H_{2.U1.loc} = 5.34\,m$
Uplift Load for Overturning Analysis:	$U_{OT.U1} = -16456.3 \cdot kN$		$U_{OT.U1.loc} = 9.48 \cdot m$

Sum of All Overtuming Analysis Vertical Load:

$$\Sigma V_{U1.OT} := D_{conc} + D_{Gate} + H_{1.U1} + H_{2.U1} + U_{OT.U1} = 13775.35 \cdot kN$$

Sum of All Overtuming Analysis Vertical Load Moments:

$$\Sigma M_{V.U1.OT} := D_{conc} \cdot X_{conc.loc} + D_{Gate} \cdot X_{gate} + H_{1.U1} \cdot H_{1.U1.loc} + H_{2.U1} \cdot H_{2.U1.loc} + U_{OT.U1} \cdot U_{OT.U1.loc} = 145582.24 \cdot kN \cdot m$$

Lateral Tailwater Loads for Overturning Stability Analysis

TW Lateral Load on Gate Footing (No Key - Overturning Values Adjusted): $H_{twgf.U1} := H_{twgf.U1.tri} + H_{twgf.U1.rect} = 2236.68 \cdot kN$

Acting at: $H_{twgf.U1.loc} := \frac{\frac{h_{toe}}{3} \cdot H_{twgf.U1.tri} + \frac{h_{toe}}{2} \cdot H_{twgf.U1.rect}}{H_{twgf.U1}} = 1.65\,m$

Horizontal Tailwater Pressure Top of Key (Overturning Analysis): $\sigma_{twtk.OT.U1} := \sigma_{E.U1} \cdot -1 = 59.41 \cdot kPa$

Horizontal Tailwater Pressure Bottom of Key (Overturning Analysis): $\sigma_{twbk.OT.U1} := \sigma_{D.U1} \cdot -1 = 79.32 \cdot kPa$

Triangular Distribution Unit Load Acting at Key: $H_{twbk.OT.U1.tri} := \frac{\left(\sigma_{twbk.OT.U1} - \sigma_{twtk.OT.U1}\right)}{2} \cdot d_{key} \cdot W_{tw.U1} = 298.61 \cdot kN$

Triangular Distribution Unit Load Acting at Key: $H_{twbk.OT.U1.rect} := \sigma_{twtk.OT.U1} \cdot d_{key} \cdot W_{tw.U1} = 1782.31 \cdot kN$

Total Horizontal Tailwater Load on Key (Overturning Values Adjusted): $H_{twkey.OT.U1} := H_{twbk.OT.U1.tri} + H_{twbk.OT.U1.rect} = 2080.92 \cdot kN$

Acting at: $H_{twkey.OT.U1.loc} := \frac{H_{twbk.OT.U1.tri} \cdot \frac{-2 \cdot d_{key}}{3} + H_{twbk.OT.U1.rect} \cdot \frac{-d_{key}}{2}}{H_{twkey.OT.U1}} = -1.05 \cdot m$

Lateral Driving Earth Loads for Overturning Stability Analysis (at rest condition)

Depth of Driving Soil Loads (to top of key): $h_{E.OT.U1} := TOC_{as} - BOF_{elev} = 4\,m$

At-Rest Soil Load: $E_{act.OT.U1} := \dfrac{\left(K_{o.U1} \cdot h_{E.OT.U1}^{\,2}\right)}{2} \cdot \left(\gamma_r - \gamma_w\right) \cdot W_{hwas.U1} \cdot -1 = -962.49 \cdot kN$

At Rest- Soil Load Acting from Toe: $E_{act.OT.U1.loc} := \dfrac{h_{E.OT.U1}}{3} = 1.33\,m$

All Lateral Loads Appliable to Overturning Stability Analysis

HW Lateral Load on Approach Slab:	$H_{hwas.U1} = -4502.8 \cdot kN$	$H_{hwas.U1.loc} = 0.41\,m$
HW Lateral Load on Reg. Gate:	$H_{hwrg.U1} = 0.0 \cdot kN$	$H_{hwrg.U1.loc} = 4.00\,m$
TW Lateral Load on Reg. Gate:	$H_{twrg.U1} = 0.0 \cdot kN$	$H_{twrg.U1.loc} = 4.00\,m$
TW Lateral Load on Gate Footing (No Key - Overturning Values Adjusted):	$H_{twgf.U1} = 2236.68 \cdot kN$	$H_{twgf.U1.loc} = 1.65\,m$
TW Lateral Load on Key:	$H_{twkey.OT.U1} = 2080.92 \cdot kN$	$H_{twkey.OT.U1.loc} = -1.05\,m$
Ice / Impact Load:	$I_{U1} = 0.0 \cdot kN$	$I_{U1.loc} = 3.70\,m$
Lateral Soil Load (driving):	$E_{act.OT.U1} = -962.5 \cdot kN$	$E_{act.OT.U1.loc} = 1.33\,m$

Resisting Lateral Soil Load as required to produce horizontal equilibrium:

$$E_{pas.OT.U1} := -\left(H_{hwas.U1} + H_{hwrg.U1} + H_{twrg.U1} + H_{twgf.U1} + H_{twkey.OT.U1} + I_{U1} + E_{act.OT.U1}\right) = 1147.69 \cdot kN$$

Acting at:

$$E_{pas.OT.U1.loc} := -1 \cdot \frac{d_{key}}{2} = -1\,m$$

Sum of All Overturning Analysis Horizontal Load (ΣH=0):

$$\Sigma H_{U1.OT} := H_{hwas.U1} + H_{hwrg.U1} + H_{twrg.U1} + H_{twgf.U1} + H_{twkey.OT.U1} + I_{U1} + E_{act.OT.U1} + E_{pas.OT.U1} = 0 \cdot kN$$

Sum of All Overturning Analysis Horizontal Load Moments:

$$\Sigma M_{H.U1.OT} := H_{hwas.U1} \cdot H_{hwas.U1.loc} + H_{hwrg.U1} \cdot H_{hwrg.U1.loc} + H_{twrg.U1} \cdot H_{twrg.U1.loc} + H_{twgf.U1} \cdot H_{twgf.U1.loc} \cdots + H_{twkey.OT.U1} \cdot H_{twkey.OT.U1.loc} + I_{U1} \cdot I_{U1.loc} + E_{act.OT.U1} \cdot E_{act.OT.U1.loc} + E_{pas.OT.U1} \cdot E_{pas.OT.U1.loc} = -2776.99 \cdot kN \cdot m$$

Overturning Stability Analysis

$\Sigma M_{U1.OT} := \Sigma M_{V.U1.OT} + \Sigma M_{H.U1.OT} = 142805.25 \cdot kN \cdot m$ $\quad X_{R.U1} := \dfrac{\Sigma M_{U1.OT}}{\Sigma V_{U1.OT}} = 10.37\,m$ $\quad x_{OT.U1} := X_{R.U1} - \dfrac{L_b}{2} = 1.12\,m$

Overturning Resultant Ratio $\quad Ratio_{OT.U1} := \dfrac{X_{R.U1}}{L_b} = 0.56$

$$Ratio_{OT.U1.check} := \begin{cases} \text{"OKAY"} & \text{if } Ratio_{OT.U1} \geq Ratio_{OT.U1.min} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

$$x_{OT.check.U1} := \begin{cases} \text{"OKAY"} & \text{if } \left|x_{OT.U1}\right| \leq Kern \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

CHECK FOUNDATION BEARING CAPACITY (HORIZONTAL PLANE):

U1 CASE

Bearing Pressure Under Toe:

$$\sigma_{ToeU1.OT} := \frac{\Sigma V_{U1.OT}}{L_b \cdot W_b} + \frac{\left(\Sigma V_{U1.OT} \cdot x_{OT.U1}\right)}{S_b} = 67.6 \cdot kPa$$

$$Bearing_{ChecktoeU1.OT} := \begin{vmatrix} \text{"OKAY "} & \text{if} & \sigma_{ToeU1.OT} < \sigma_{allow.U1} \\ \text{"NG""} & \text{otherwise} & \end{vmatrix} = \text{"OKAY "}$$

Bearing Pressure Under Heel:

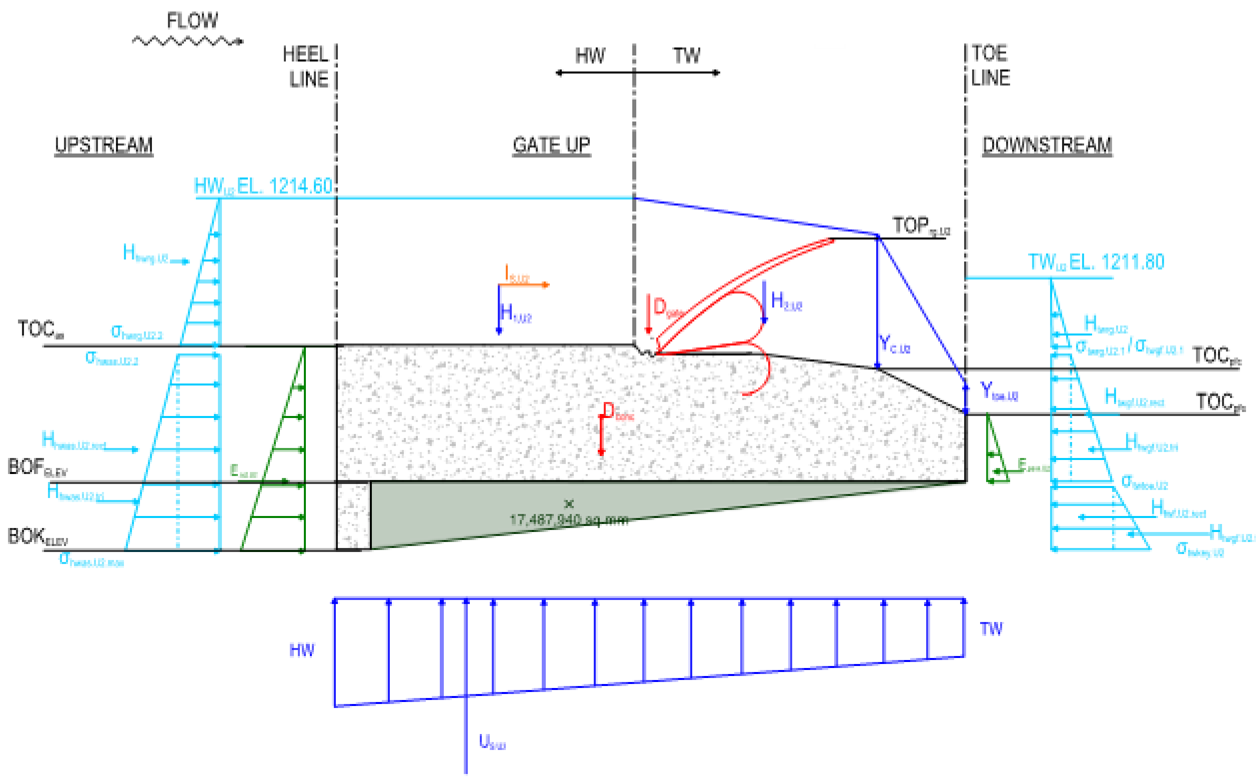
$$\sigma_{HeelU1.OT} := \frac{\Sigma V_{U1.OT}}{L_b \cdot W_b} - \frac{\left(\Sigma V_{U1.OT} \cdot x_{OT.U1}\right)}{S_b} = 31.7 \cdot kPa$$

$$Bearing_{CheckheelU1.OT} := \left(\begin{vmatrix} \text{"OKAY "} & \text{if} & \sigma_{HeelU1.OT} < \sigma_{allow.U1} \wedge \sigma_{HeelU1.OT} > 0 \\ \text{"NG""} & \text{otherwise} & \end{vmatrix} \right) = \text{"OKAY "}$$

SUMMARY OF STABILITY ASSESSMENT:

Sliding Factor of Safety: (Horizontal Plane)	$FS_{HorizSliding.U1} = 2.57$	$FS_{HorizSliding.U1.Check}$ = "OKAY"
Sliding Factor of Safety: (Inclined Plane)	$FS_{InclinedlSlidingU1} = 43.82$	$FS_{InclinedSliding.check.U1}$ = "OKAY "
Eccentricity: (Inclined Plane)	$e_{U1} = -1.39\,m$	$e_{check.U1}$ = "Okay"
Bearing Pressure At Heel: (Inclined Plane)	$\sigma_{heel.U1} = 89 \cdot kPa$	$\sigma_{heel.U1.check}$ = "Okay"
Bearing Pressure At Toe: (Inclined Plane)	$\sigma_{toe.U1} = 34 \cdot kPa$	$\sigma_{toe.U1.1.check}$ = "Okay"
Flotation Factor of Safety (horizontal plane)	$FS_{act.FU1} = 1.6$	$FS_{check.FU1}$ = "OKAY"
Overturning Resultant Ratio: (horizontal plane)	$Ratio_{OT.U1} = 0.56$	$Ratio_{OT.U1.check}$ = "OKAY"
Eccentricity: (horizontal plane)	$x_{OT.U1} = 1.12\,m$	$x_{OT.check.U1}$ = "OKAY"
Bearing Pressure At Heel: (horizontal plane)	$\sigma_{HeelU1.OT} = 32 \cdot kPa$	$Bearing_{CheckheelU1.OT}$ = "OKAY "
Bearing Pressure At Toe: (horizontal plane)	$\sigma_{ToeU1.OT} = 68 \cdot kPa$	$Bearing_{ChecktoeU1.OT}$ = "OKAY "

U2 DESIGN CASE



ACCEPTANCE PARAMETERS

Required Factor of Safety for Sliding: $FS_{req.U2.sl} := 1.5$ (Without Cohesion)

(Section 8.1, Design Criteria)

Resultant Within Middle Third of Base: $e \le \frac{L_b}{6} \wedge e \ge \frac{-L_b}{6}$

Allowable Rock Bearing Pressure: $\sigma_{allow.U2} := 1270 \cdot \frac{kN}{m^2}$ (Section 5.2, Design Criteria)

INPUT PARAMETERS

Headwater Elevation: $HW_{U2} := 1214.60m$ (Section 8.3, Design Criteria)

Tailwater Elevation: $TW_{U2} := 1211.80m$ (Section 8.3, Design Criteria)

Bottom of Footing Elevation: $BOF_{elev} = 1206\,m$

Approach Slab Top of Concrete Elevation at Upstream Face: $TOC_{as} = 1210\,m$

Footing Top of Concrete Elevation at Stilling Basin: $TOC_{pfe} = 1208\,m$

Footing Top of Concrete Elevation at Center of Footing: $TOC_{pfc} = 1209.3\,m$

Top of Guard/Regulating Gate Elevation: $TOP_{rg.U2} := 1212.1m$ $TOP_{gg.U2} := 1215.00m$

Gates are open when top of gate elevation is at 1210.00m

Gates are closed/up when top of gate elevation is at 1215.0m

Bottom of Key Elevation: $BOK_{elev} = 1204\,m$

Crestwater Elevation: Dynamic Flow $EL_{C.U2} := 1213.76m$

$$Y_{C.U2} := \begin{vmatrix} (EL_{C.U2} - TOC_{pfc}) & \text{if } TOP_{rg.U2} \le HW_{U2} \\ (TW_{U2} - TOC_{pfc}) & \text{if } TOP_{rg.U2} > HW_{U2} \end{vmatrix} = 4.46 \cdot m$$

Toewater Elevation: $EL_{TOE.U2} := 1208.58m$

$$Y_{TOE.U2} := \begin{vmatrix} (EL_{TOE.U2} - TOC_{pfe}) & \text{if } TOP_{rg.U2} \le HW_{U2} \\ (TW_{U2} - TOC_{pfe}) & \text{if } TOP_{rg.U2} > HW_{U2} \end{vmatrix} = 0.58 \cdot m$$

LATERAL WATER LOADS

U2 CASE

HEADWATER (APPROACH SLAB DRIVING):

Headwater Depth on Gate: $D_{hwg.U2} := HW_{U2} - TOC_{as} = 4.60\,m$

Thickness of Approach Slab (Including Key): $T_{as} = 6\,m$

Headwater Depth at Heel (U/S face): $D_{hwas.U2} := HW_{U2} - BOK_{elev} = 10.60\,m$

Headwater Load Unit Width on Approach Slab: $W_{hwas.U2} := W_b = 15.00\,m$

Headwater Unit Load At Top of Approach Slab:

$$H_{hwas.U2.1} := \frac{-\left(\gamma_w \cdot D_{hwg.U2}^{\,2}\right)}{2} \cdot W_{hwas.U2} = -1556.85 \cdot kN$$

Headwater Unit Load At Bottom of Approach Key:

$$H_{hwas.U2.2} := \frac{-\left(\gamma_w \cdot D_{hwas.U2}^{\,2}\right)}{2} \cdot W_{hwas.U2} = -8266.9 \cdot kN$$

Headwater Line Load At Top of Approach Slab:

$$\sigma_{hwas.U2.1} := -\left(\gamma_w \cdot D_{hwg.U2}\right) = -45.13 \cdot kPa$$

Headwater Line Load At Bottom of Approach Key:

$$\sigma_{hwas.U2.2} := -\left(\gamma_w \cdot D_{hwas.U2}\right) = -103.99 \cdot kPa$$

Triangular Distribution Unit Load on Approach Slab and Key:

$$H_{hwas.U2.2.tri} := \left(\frac{\sigma_{hwas.U2.2} - \sigma_{hwas.U2.1}}{2}\right) \cdot \left(T_{as} \cdot W_{hwas.U2}\right) = -2648.7 \cdot kN$$

Rectangular Distribution Unit Load on Approach Slab and Key:

$$H_{hwas.U2.2.rect} := \sigma_{hwas.U2.1} \cdot \left(T_{as} \cdot W_{hwas.U2}\right) = -4061.34 \cdot kN$$

Total Horizontal Headwater Load on Approach Slab:

$$H_{hwas.U2} := H_{hwas.U2.2.tri} + H_{hwas.U2.2.rect} = -6710.04 \cdot kN$$

Apply Total Footing Headwater Load at:

$$H_{hwas.U2.loc} := \frac{\left[H_{hwas.U2.2.rect} \cdot \frac{\left(T_{as}\right)}{2} + H_{hwas.U2.2.tri} \frac{\left(T_{as}\right)}{3}\right]}{H_{hwas.U2.2.tri} + H_{hwas.U2.2.rect}} - d_{key} = 0.61\,m$$

Regulating Gate (4A) Operating Condition:

Reg. Gate Down/Open Condition: $A1_{U2} := TOP_{rg.U2} \le TOC_{as}$

Reg. Crest Gate Up/Closed, with Top of Gate Higher than HW Elevation: $B1_{U2} := TOP_{rg.U2} \ge HW_{U2} \wedge TOP_{rg.U2} > TOC_{as}$

Reg. Crest Gate Up/Closed, with Top of Gate Lower than HW Elevation: $C1_{U2} := TOP_{rg.U2} > TOC_{as} \wedge HW_{U2} > TOP_{rg.U2}$

Reg. Crest Gate Height: $H_{rg.U2} := TOP_{rg.U2} - TOC_{as} = 2.1\,m$

Headwater Depth at Reg. Crest Gate: $D_{hwrg.U2} := HW_{U2} - TOC_{as} = 4.60\,m$

Reg. Crest Gate Width: $W_{hwrg.U2} := 15.00m$

Lateral Headwater Pressure at Bottom of Reg. Crest Gate:

$$\sigma_{hwrg.U2.1} := \begin{cases} (0.0kPa) & \text{if } A1_{U2} \\ -(\gamma_w \cdot D_{hwrg.U2}) & \text{if } B1_{U2} \\ -(\gamma_w \cdot D_{hwrg.U2}) & \text{if } C1_{U2} \end{cases} = -45.1 \cdot kPa$$

Lateral Headwater Pressure at Top of Reg. Crest Gate:
(Load at HW Elevation On Reg. Crest Gate if HW is below TOG_{rg})

$$\sigma_{hwrg.U2.2} := \begin{cases} (0.0kPa) & \text{if } A1_{U2} \\ 0.0kPa & \text{if } B1_{U2} \\ -\left[\gamma_w \cdot (HW_{U2} - TOP_{rg.U2})\right] & \text{if } C1_{U2} \end{cases} = -24.5 \cdot kPa$$

Average Pressure acting on Reg. Crest Gate:

$$\sigma_{hwrg.U2.avg} := \frac{(\sigma_{hwrg.U2.1} + \sigma_{hwrg.U2.2})}{2} = -34.83 \cdot kPa$$

Total Area of Crest Gate:

$$A_{hwrg.U2} := \begin{cases} D_{hwrg.U2} \cdot W_{hwrg.U2} & \text{if } A1_{U2} \\ D_{hwrg.U2} \cdot W_{hwrg.U2} & \text{if } B1_{U2} \\ H_{rg.U2} \cdot W_{hwrg.U2} & \text{if } C1_{U2} \end{cases} = 31.5 \cdot m^2$$

Total Horizontal Headwater Load on Reg. Crest Gate: $H_{hwrg.U2} := \sigma_{hwrg.U2.avg} \cdot A_{hwrg.U2} = -1097.0 \cdot kN$

Apply Total Reg. Crest Gate Headwater Load at:

$$H_{hwrg.U2.loc} := \begin{cases} (TOC_{as} - BOF_{elev}) & \text{if } A1_{U2} \\ \left[\frac{(HW_{U2} - TOC_{as})}{3} + (TOC_{as} - BOF_{elev})\right] & \text{if } B1_{U2} \\ \left[\frac{\sigma_{hwrg.U2.2} \cdot A_{hwrg.U2} \cdot \frac{(H_{rg.U2})}{2} + \frac{(\sigma_{hwrg.U2.1} - \sigma_{hwrg.U2.2})}{2} A_{hwrg.U1} \cdot \frac{(H_{rg.U2})}{3}}{\sigma_{hwrg.U2.2} \cdot A_{hwrg.U2} + \frac{(\sigma_{hwrg.U2.1} - \sigma_{hwrg.U2.2})}{2} \cdot A_{hwrg.U1}} \ldots \\ + (TOC_{as} - BOF_{elev})\right] & \text{if } C1_{U2} \end{cases} = 4.9 \cdot m$$

LATERAL TAILWATER (RESISTING) Applied to Downstream Side of Reg. Crest Gate: U2 CASE

Reg. Gate Down/Open Condition: $A2_{U2} := TOP_{rg.U2} \le TOC_{as}$

Reg. Crest Gate Up/Closed, with Top of Gate Higher than TW Elevation: $B2_{U2} := TOP_{rg.U2} \ge TW_{U2} \wedge TOP_{rg.U2} > TOC_{as}$

Reg. Crest Gate Up/Closed, with Top of Gate Lower than TW Elevation: $C2_{U2} := TOP_{rg.U2} > TOC_{as} \wedge TW_{U2} > TOP_{rg.U2}$

Tailwater Depth at Reg. Crest Gate: $D_{twrg.U2} := TW_{U2} - TOC_{as} = 1.80\,m$

Reg. Crest Gate Width: $W_{twrg.U2} := 15.00m$

Lateral Water Load at Bottom of Reg. Crest Gate:

$$\sigma_{twrg.U2.1} := \begin{vmatrix} (0.0kPa) & \text{if } A2_{U2} \\ (\gamma_w \cdot D_{twrg.U2}) & \text{if } B2_{U2} \\ (\gamma_w \cdot D_{twrg.U2}) & \text{if } C2_{U2} \end{vmatrix} = 17.7 \cdot kPa$$

Lateral Water Load at Top of Reg. Crest Gate:
(Load at TW Elevation On Reg. Crest Gate if TW is below TOG_{rg})

$$\sigma_{twrg.U2.2} := \begin{vmatrix} (0.0kPa) & \text{if } A2_{U2} \\ 0.0kPa & \text{if } B2_{U2} \\ \left[\gamma_w \cdot (TW_{U2} - TOP_{rg.U2})\right] & \text{if } C2_{U2} \end{vmatrix} = 0.0 \cdot kPa$$

Average Pressure acting on Reg. Crest Gate:

$$\sigma_{twrg.U2.avg} := \frac{(\sigma_{twrg.U2.1} + \sigma_{twrg.U2.2})}{2} = 8.83 \cdot kPa$$

Total Area water acting on Crest Gate:

$$A_{twrg.U2} := \begin{vmatrix} D_{twrg.U2} \cdot W_{twrg.U2} & \text{if } A2_{U2} \\ D_{twrg.U2} \cdot W_{twrg.U2} & \text{if } B2_{U2} \\ H_{rg.U2} \cdot W_{twrg.U2} & \text{if } C2_{U2} \end{vmatrix} = 27 \cdot m^2$$

Total Horizontal Tailwater Load on Reg. Crest Gate: $H_{twrg.U2} := \sigma_{twrg.U2.avg} \cdot A_{twrg.U2} = 238.4 \cdot kN$

Apply Total Horiz. TW Load on Reg. Gate at:

$$H_{twrg.U2.loc} := \begin{vmatrix} (TOC_{as} - BOF_{elev}) & \text{if } A2_{U2} \\ \left[\frac{(TW_{U2} - TOC_{as})}{3} + (TOC_{as} - BOF_{elev})\right] & \text{if } B2_{U2} \\ \left[\frac{\sigma_{twrg.U2.2} \cdot A_{twrg.U2} \cdot \frac{(H_{rg.U2})}{2} + \frac{(\sigma_{twrg.U2.1} - \sigma_{twrg.U2.2})}{2} A_{twrg.U2} \cdot \frac{(H_{rg.U2})}{3}}{\sigma_{twrg.U2.2} \cdot A_{twrg.U2} + \frac{(\sigma_{twrg.U2.1} - \sigma_{twrg.U2.2})}{2} \cdot A_{twrg.U2}} \ldots \\ + (TOC_{as} - BOF_{elev})\right] & \text{if } C2_{U2} \end{vmatrix} = 4.6 \cdot m$$

LATERAL WATER LOADS (continued)

U2 CASE

TAILWATER (RESISTING) Applied to Concrete Structure:

Tailwater Depth At top of Gate Base Footing Elevation: $D_{twgf.U2} := TW_{U2} - TOC_{as} = 1.80\,m$

Water Depth at bottom of Gate Base Footing: $D_{twtoe.U2} := TW_{U2} - BOF_{elev} = 5.80\,m$

Footing Thickness at Toe $h_{toe} = 4\,m$

Unit Width of D/S face of crest for application of Tailwater Load: $W_{tw.U2} := W_b = 15.00\,m$

Tailwater Pressure At Top of Gate Footing: $\sigma_{twgf.U2} := \left(\gamma_w \cdot D_{twgf.U2}\right) = 17.66 \cdot kPa$

Tailwater Line Load At Bottom of Gate Footing: $\sigma_{twtoe.U2} := \left(\gamma_w \cdot D_{twtoe.U2}\right) = 56.9 \cdot kPa$

Triangular Distribution Unit Load on Gate Footing Base $H_{twgf.U2.tri} := \left(\frac{\sigma_{twtoe.U2} - \sigma_{twgf.U2}}{2}\right) \cdot \left(h_{toe} \cdot W_{tw.U2}\right) = 1177.2 \cdot kN$

Rectangular Distribution Unit Load on Gate Footing Base: $H_{twgf.U2.rect} := \sigma_{twgf.U2} \cdot \left(h_{toe} \cdot W_{tw.U2}\right) = 1059.48 \cdot kN$

Tailwater Pressure At Bottom of Sliding Failure Plane: $\sigma_{twbk.U2} := \left(HW_{U2} - BOK_{elev}\right) \cdot \gamma_w = 103.99 \cdot kPa$

Triangular Distribution Unit Load Below Footing: $H_{twbk.U2.tri} := \frac{\left(\sigma_{twbk.U2} - \sigma_{twtoe.U2}\right)}{2} \cdot d_{key} \cdot W_{tw.U2} = 706.32 \cdot kN$

Rectangular Distribution Load Below Footing Base: $H_{twbk.U2.rect} := \sigma_{twtoe.U2} \cdot d_{key} \cdot W_{tw.U2} = 1706.94 \cdot kN$

Total Horizontal Tailwater Load on Gate Footing (including key):

$$H_{twgk.U2} := H_{twgf.U2.tri} + H_{twgf.U2.rect} + H_{twbk.U2.tri} + H_{twbk.U2.rect} = 4649.94 \cdot kN$$

Apply Total Gate Footing Tailwater Load at:

$$H_{twgk.U2.loc} := \frac{\left[H_{twgf.U2.rect} \cdot \frac{\left(h_{toe}\right)}{2} + H_{twgf.U2.tri} \cdot \frac{\left(h_{toe}\right)}{3} + H_{twbk.U2.tri} \cdot \left(-d_{key} \cdot \frac{2}{3}\right) + H_{twbk.U2.rect} \cdot \left(\frac{-d_{key}}{2}\right)\right]}{H_{twgf.U2.tri} + H_{twgf.U2.rect} + H_{twbk.U2.tri} + H_{twbk.U2.rect}} = 0.22\,m$$

SUMMATION OF LATERAL WATER LOADS:

$$\Sigma H_{Water.U2} := H_{hwas.U2} + H_{hwrg.U2} + H_{twgk.U2} + H_{twrg.U2} = -2918.72 \cdot kN$$

$$\Sigma M_{Hwater.U2} := H_{hwas.U2} \cdot H_{hwas.U2.loc} + H_{hwrg.U2} \cdot H_{hwrg.U2.loc} + H_{twgk.U2} \cdot H_{twgk.U2.loc} + H_{twrg.U2} \cdot H_{twrg.U2.loc} = -7351.22 \cdot kN \cdot m$$

VERTICAL WATER LOADS

U2 CASE

HEADWATER:

Water Depth on top of Approach Slab: $d_{hw.U2} := HW_{U2} - TOC_{as} = 4.60\,m$

Length of Approach Slab: $L_{as} = 8.75\,m$

Width of Approach Slab: $w_{as} = 15.00\,m$

Vertical Water Weight (H1) on Approach Slab: $H_{1.U2} := \left(w_{as} \cdot d_{hw.U2} \cdot L_{as}\right) \cdot \gamma_w = 5922.8 \cdot kN$

Moment Arm for Application of Water Weight (H1) from toe: $H_{1.U2.loc} := L_b - \dfrac{L_{as}}{2} = 14.13\,m$

TAILWATER:

Trapezoid Volume Above Gate Footing from Approach Slab to Crest: $V_{asc.U2} := \left(L_{gf} - L_{gfc}\right) W_b \dfrac{d_{hw.U2} + Y_{C.U2}}{2} = 485.84 \cdot m^3$

Trapezoid Volume Above Gate Footing Crest to End of Gate Footing: $V_{gfc.U2} := \left(L_{gfc} \cdot W_b\right) \dfrac{Y_{C.U2} + Y_{TOE.U2}}{2} = 98.28 \cdot m^3$

Load Above Gate Footing from Approach Slab to Crest: $H_{2.U2.asc} := V_{asc.U2} \cdot \gamma_w = 4766.11 \cdot kN$

Load Acting Above Footing Crest from Toe: $H_{2.U2.asc.loc} := \dfrac{\left(L_{gf} - L_{gfc}\right) \cdot \left(2 \cdot d_{hw.U2} + Y_{C.U2}\right)}{3 \cdot \left(d_{hw.U2} + Y_{C.U2}\right)} + L_{gfc} = 6.19\,m$

Load Above Gate Footing from Crest to End: $H_{2.U2.gfc} := V_{gfc.U2} \cdot \gamma_w = 964.13 \cdot kN$

Load Acting Above Gate Footing from Crest to End: $H_{2.U2.gfc.loc} := \dfrac{\left(L_{gfc}\right) \cdot \left(2 \cdot Y_{C.U2} + Y_{TOE.U2}\right)}{3 \cdot \left(Y_{C.U2} + Y_{TOE.U2}\right)} = 1.63\,m$

Vertical Water Weight (H2) on Gate Footing: $H_{2.U2} := H_{2.U2.asc} + H_{2.U2.gfc} = 5730.24 \cdot kN$

Moment Arm for Application of Water Weight (H2) from toe: $H_{2.U2.loc} := \dfrac{H_{2.U2.asc} \cdot H_{2.U2.asc.loc} + H_{2.U2.gfc} \cdot H_{2.U2.gfc.loc}}{H_{2.U2}} = 5.43\,m$

UPLIFT AT INCLINE SLIDING PLANE

U2 CASE

Uplift pressure at U/S Face (heel): $U_{HW.U2} := D_{hwas.U2} \cdot \gamma_w = 104.0 \cdot \frac{kN}{m^2}$

Uplift pressure at D/S Face Stilling Basin: $U_{TW.U2} := \left(D_{twtoe.U2}\right) \cdot \gamma_w = 56.9 \cdot \frac{kN}{m^2}$

Length from U/S of Gate Structure to U/S of Stilling Basin: $L_{overall.Usual} = 18.50\,m$

Difference between Uplift pressure at HW and TW: $U_{diff.U2} := U_{HW.U2} - U_{TW.U2} = 47.09 \cdot \frac{kN}{m^2}$

Slope of difference between between Uplift pressure at HW and TW: $U_{slope.U2} := \frac{U_{diff.U2}}{L_{overall.Usual}} = 2.55 \cdot \frac{kN}{m^2 \cdot m}$

Tailwater Pressure at toe of Gate Structure: $U_{press.toe.gs.U2} := U_{TW.U2} + \left(L_{overall.Usual} - L_b\right) \cdot U_{slope.U2} = 56.9 \cdot \frac{kN}{m^2}$

Uniform uplift force UA Under Gate Structure due to TW (rectangle): $U_{A.U2} := U_{press.toe.gs.U2} \cdot L_b \cdot W_b \cdot -1 = -15789.19 \cdot kN$

Moment Arm from Toe of Gate Structure for Uplift UA: $L_{A.U2} := \left(\frac{L_b}{2}\right) = 9.25\,m$

Linearly Decreasing Uplift Force U2B Under Gate Structure due to HW-TW Differential (triangle): $U_{B.U2} := \frac{1}{2} \cdot \left(U_{HW.U2} - U_{press.toe.gs.U2}\right) \cdot L_b \cdot W_b \cdot -1 = -6533.46 \cdot kN$

Moment Arm from Toe of Gate Structure for Uplift UB: $L_{B.U2} := \frac{2}{3} \cdot L_b = 12.33\,m$

Total Resultant Uplift force: $U_{U2} := U_{A.U2} + U_{B.U2} = -22322.65 \cdot kN$

Resultant Location from Toe: $U_{U2.loc} := \frac{\left(U_{A.U2} \cdot L_{A.U2} + U_{B.U2} \cdot L_{B.U2}\right)}{\left(U_{A.U2} + U_{B.U2}\right)} = 10.15\,m$

$\Sigma V_{water.U2} := H_{1.U2} + H_{2.U2} + U_{U2} = -10669.63 \cdot kN$

$\Sigma M_{Vwater.U2} := H_{1.U2} \cdot H_{1.U2.loc} + H_{2.U2} \cdot H_{2.U2.loc} + U_{U2} \cdot U_{U2.loc} = -111876.5 \cdot kN \cdot m$

SOIL LOADS

U2 CASE

Equivalent Fluid Pressure (EFP):

At rest lateral pressure coefficient: $K_{o.U2} := 1 - \sin(\phi_{backfill}) = 0.658$ (Section 5.3, Design Criteria)

Headwater Footing Unit Width: $W_{hwas.U2} = 15.00\,m$

Tailwater Footing Unit Width: $W_{tw.U2} = 15.00\,m$

Footing Thickness at Heel: $t_{hf.U2} := TOC_{as} - BOK_{elev} = 6.00\,m$

Fixed Crest Footing Thickness at Toe: $t_{tf.U2} := TOC_{pfe} - BOF_{elev} = 2.00\,m$

Lateral Driving Force (Headwater Side - at rest condition)

At-Rest Soil Load: $E_{act.U2} := \frac{\left(K_{o.U2} \cdot t_{hf.U2}^{2}\right)}{2} \cdot (\gamma_r - \gamma_w) \cdot W_{hwas.U2} \cdot -1 = -2165.61 \cdot kN$

Acting at: $E_{act.U2.loc} := \frac{t_{hf.U2}}{3} = 2.00\,m$

Lateral Resisting Force (Tailwater Side - at rest condition)

At-rest Soil Load: $E_{pass.U2} := \frac{\left(K_{o.U2} \cdot t_{tf.U2}^{2}\right)}{2} \cdot (\gamma_r - \gamma_w) \cdot W_{tw.U2} = 240.62 \cdot kN$

Acting at: $E_{pass.U2.loc} := \frac{t_{tf.U2}}{3} = 0.67\,m$

$\Sigma H_{soil.U2} := E_{act.U2} + E_{pass.U2} = -1924.99 \cdot kN$

$\Sigma M_{soil.U2} := E_{act.U2} \cdot E_{act.U2.loc} + E_{pass.U2} \cdot E_{pass.U2.loc} = -4170.8 \cdot kN \cdot m$

ICE / IMPACT LOADS (ASSUME NO ICE LOADING ON TAILWATER SIDE)

Static Ice load on Gates:

$$I_{G.U2} := \begin{cases} 00 \frac{kN}{m} & \text{if } TOP_{rg.U2} \le TOC_{as} \\ 75 \frac{kN}{m} & \text{if } TOP_{rg.U2} > TOC_{as} \end{cases} = 75 \cdot \frac{kN}{m}$$

(Section 7.7, Design Criteria)

Ice Loading Unit Width on Reg. Gate: $W_{rg.U2} := 15.00m$ (Input value for load case)

Total Ice Load on Structure: $I_{U2} := -\left(I_{G.U2} \cdot W_{rg.U2}\right) = -1125 \cdot kN$

Apply Ice load at: $I_{U2.loc} := \left(TOP_{rg.U2} - BOF_{elev} - 0.30m\right) = 5.80\,m$

$\Sigma H_{I.U2} := I_{U2} = -1125 \cdot kN$

$\Sigma M_{I.U2} := I_{U2} \cdot I_{U2.loc} = -6525 \cdot kN \cdot m$

(SEISMIC LOAD (NOT APPLICABLE FOR THIS LOAD CASE)

U2 CASE

SUMMARY OF LOADS

	Loads	Moment Arm
Dead load of Concrete Structure:	$D_{conc} = 24618.6 \cdot kN$	$X_{conc.loc} = 10.06\,m$
Obermyer Gate Weight:	$D_{Gate} = 210.0 \cdot kN$	$X_{gate} = 6.60\,m$
HW Lateral Load on Approach Slab:	$H_{hwas.U2} = -6710.0 \cdot kN$	$H_{hwas.U2.loc} = 0.61\,m$
HW Lateral Load on Reg. Gate:	$H_{hwrg.U2} = -1097.0 \cdot kN$	$H_{hwrg.U2.loc} = 4.95\,m$
TW Lateral Load on Gate Footing (Including Key - Sliding Check Loads):	$H_{twgk.U2} = 4649.94 \cdot kN$	$H_{twgk.U2.loc} = 0.22\,m$
TW Lateral Load on Reg. Gate:	$H_{twrg.U2} = 238.4 \cdot kN$	$H_{twrg.U2.loc} = 4.60\,m$
Vertical HW Load on Approach Slab:	$H_{1.U2} = 5922.8 \cdot kN$	$H_{1.U2.loc} = 14.13\,m$
Vertical TW Load on Pier Footing (crest):	$H_{2.U2} = 5730.2 \cdot kN$	$H_{2.U2.loc} = 5.43\,m$
Uplift:	$U_{U2} = -22322.7 \cdot kN$	$U_{U2.loc} = 10.15\,m$
Lateral Soil Load (driving):	$E_{act.U2} = -2165.6 \cdot kN$	$E_{act.U2.loc} = 2.00\,m$
Lateral Soil Load (resisting):	$E_{pass.U2} = 240.62 \cdot kN$	$E_{pass.U2.loc} = 0.67\,m$
Ice / Impact Load:	$I_{U2} = -1125.0 \cdot kN$	$I_{U2.loc} = 5.80\,m$

STABILITY ASSESSMENT (SLIDNG, BEARING, FLOTATION AND OVERTURNING):

CHECK SLIDING ALONG HORIZONTAL PLANE THRU TOE, IGNORING BEDROCK MOBILIZED BY STRUCTURAL HEEL KEY, OR VOID BEHIND KEY

U2 CASE

Sum of Vertical Forces:

$\Sigma V_{U2} := \Sigma V_{DL} + \Sigma V_{water.U2} = 14159.0 \cdot kN$

Sum of Horizontal Forces:

$\Sigma H_{U2} := \Sigma H_{Water.U2} + \Sigma H_{soil.U2} + \Sigma H_{I.U2} = -5968.71 \cdot kN$

Sliding Factor of Safety:

$$FS_{HorizSliding.U2} := \frac{\tan_{\phi} \cdot \Sigma V_{U2}}{\left|\Sigma H_{U2}\right|} = 1.16$$

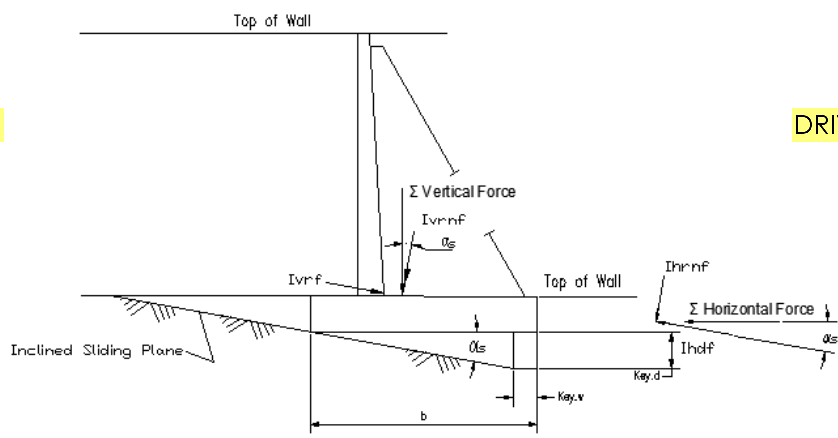
$FS_{HorizSliding.U2.Check} :=$ | "OKAY" if $FS_{HorizSliding.U2} \ge FS_{req.U2.sl}$
"Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !" otherwise

= "Horizontal Sliding (No K

CHECK SLIDING ALONG INCLINED SLIDING PLANE FROM HEEL KEY TO TOE, WITH BEDROCK MASS MOBILIZED BY REINFOCREDE CONCRETE KEY)

RESISTING SIDE

DRIVING SIDE



TOE

Ivrf=Inclined Resisting Force
Ivrnf=Inclined Resisting Normal Force
Ihrnf=Inclined Resisting Normal Force
Ihdf=Inclined Driving Force

$\alpha s = 0.11$

as degrees= $\alpha s \cdot \left(\frac{180}{\pi}\right) = 6.52$

$\Sigma V_{U2} = 14158.97 \cdot kN$

$V_{rs} = 5775 \cdot kN$

Resolve $\Sigma Vert_{U2}$ & $\Sigma Horiz_{U2}$

$\Sigma V_{InclinedU2} := \cos(\alpha s) \cdot \left(\Sigma V_{U2} + V_{rs}\right) + \sin(\alpha s) \cdot \left|\Sigma H_{U2}\right| = 20482.8 \cdot kN$

$\Sigma H_{InclinedU2} := \cos(\alpha s) \cdot \left|\Sigma H_{U2}\right| - \sin(\alpha s) \cdot \left(\Sigma V_{U2} + V_{rs}\right) = 3666.7 \cdot kN$

(With properly engineered reinforced concrete Key, horizontal sliding plane thru Toe is protected, critical sliding plane is relocated to the INCLINED SLIDING PLANE FROM HEEL KEY To TOE, Bedrock Mass above this examined plane is mobilized by reinforced concrete key and combined into Structural Wedge.)

Inclined Sliding Plane Length

$L_{incline} = 18.61 \, m$

Safety Factor for Sliding Inclined Failure Plane

$$FS_{InclinedlSlidingU2} := \frac{\Sigma V_{InclinedU2} \cdot \tan\left(\phi_{rock} \cdot \frac{\pi}{180}\right)}{\left|\Sigma H_{InclinedU2}\right|} = 2.72$$

$FS_{InclinedSliding.check.U2} :=$ | "OKAY " if $FS_{InclinedlSlidingU2} > FS_{req.U2.sl}$
"Revise Structure"" otherwise

= "OKAY "

$FS_{InclinedSliding.check.U2}$ = "OKAY "

OVERTURNING STABILITY CHECK:

U2 CASE

CHECK ECCENTRICITY

Sum of the moments:

$$\Sigma M_{U2} := \Sigma M_{DL} + \Sigma M_{Hwater.U2} + \Sigma M_{Vwater.U2} + \Sigma M_{I.U2} + \Sigma M_{soil.U2} + \Sigma M_{soil} = 186395 \cdot kN \cdot m$$

Eccentricity:

$$e_{U2} := \left(\frac{L_{incline}}{2}\right) - \frac{\left(\Sigma M_{U2}\right)}{\Sigma V_{InclinedU2}} = 0.20\,m$$

Eccentricity Check:

$$e_{check.U2} := \begin{cases} \text{"Okay"} & \text{if } \left|e_{U2}\right| \le Kern \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$$e_{check.U2} = \text{"Okay"}$$

Foundation Bearing Checks:

Incline Plane Area:

$$A_{b.incline} = 279.12\,m^2$$

Incline Plane Section Modulus:

$$S_{b.incline} = 865.63 \cdot m^3$$

Bearing Pressure at Heel:

$$\sigma_{heel.U2} := \frac{\Sigma V_{InclinedU2}}{A_{b.incline}} - \frac{\left(\Sigma V_{InclinedU2} \cdot e_{U2}\right)}{S_{b.incline}} = 68.6 \cdot \frac{kN}{m^2}$$

$$\sigma_{heel.U2.check} := \left(\begin{cases} \text{"Okay"} & \text{if } \sigma_{heel.U2} \le \sigma_{allow.U2} \\ \text{"Revise Structure"} & \text{if } \sigma_{heel.U2} < 0 \frac{kN}{m^2} \end{cases}\right)$$

$$\sigma_{heel.U2.check} = \text{"Okay"}$$

Bearing Pressure at Toe:

$$\sigma_{toe.U2} := \frac{\Sigma V_{InclinedU2}}{A_{b.incline}} + \frac{\left(\Sigma V_{InclinedU2} \cdot e_{U2}\right)}{S_{b.incline}} = 78.2 \cdot \frac{kN}{m^2}$$

$$\sigma_{toe.U2.1.check} := \begin{cases} \text{"Okay"} & \text{if } \sigma_{toe.U2} \le \sigma_{allow.U2} \\ \text{"Revise Structure"} & \text{if } \sigma_{toe.U2} < 0 \frac{kN}{m^2} \end{cases}$$

$$\sigma_{toe.U2.1.check} = \text{"Okay"}$$

FLOATATION ANALYSIS:

ACCEPTANCE PARAMETERS

Required Factor of Safety: $FS_{req.FU2} := 1.5$

VERTICAL LOADS RESISTING:

Dead Load: $\Sigma V_{DL} = 24828.6 \cdot kN$

Water Weight H1+H2: $\Sigma V_{H.FU2} := H_{1.U2} + H_{2.U2} = 11653.03 \cdot kN$

Summation Vertical Resisting: $\Sigma V_{FU2} := \Sigma V_{DL} + \Sigma V_{H.FU2} = 36481.6 \cdot kN$

VERTICAL LOADS UPLIFT:

Uplift: $U_{U2} = -22322.65 \cdot kN$

Factor of Safety Floatation:

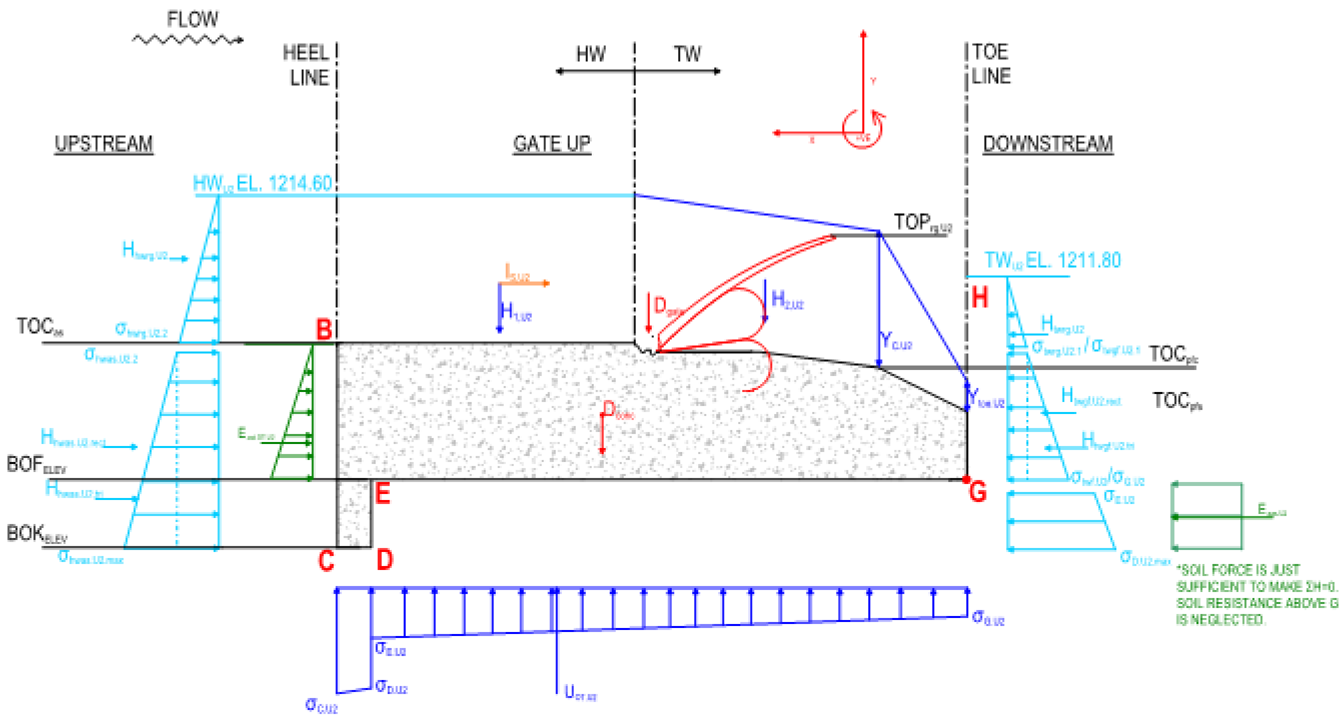
$$FS_{act.FU2} := \frac{\Sigma V_{FU2}}{\left|U_{U2}\right|} = 1.63$$

$$FS_{check.FU2} := \begin{cases} \text{"OKAY"} & \text{if } FS_{act.FU2} \ge FS_{req.FU2} \\ \text{"ANCHORS REQUIRED"} & \text{if } FS_{act.FU2} < FS_{req.FU2} \end{cases} = \text{"OKAY"}$$

MONOLITH OVERTURNING STABILITY ANALYSIS

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.
Assumptions are made in order to compute overturning stability of indetermine forces on monolith with key;
(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.
(b) The horizontal resisting force acting on the key, P.key, is that required for static equilibrium
(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1 $Ratio_{OT.U2.min} := 0.33$



Uplift Loads for Overturning Stability Analysis

Line of Creep:

Change in Water Head: $\Delta_{h.U2} := HW_{U2} - TW_{U2} = 2.8\,m$

Length from Point C to Point G: $L_{CG} = 18.61\,m$

Length from Various Points to Points: $L_{CD} = 1\,m$ $L_{DE} = 2\,m$ $L_{EG} = 17.5\,m$

$L_{GH.U2} := TW_{U2} - BOF_{elev} = 5.8\,m$

Length from Point C, D, E to G: $L_{CDEG} = 20.5\,m$ $L_{CDE} = 3\,m$

Water Pressure at Point C: $\sigma_{C.U2} := \sigma_{hwas.U2.2} = -103.99\cdot kPa$

Water Pressure at Point G: $\sigma_{G.U2} := \sigma_{twtoe.U2}\cdot -1 = -56.9\cdot kPa$

Water Pressure at Point D:

$$\sigma_{D.U2} := -\gamma_w \cdot \left[\left(HW_{U2} - BOK_{elev}\right) - \frac{\Delta_{h.U2}\cdot L_{CD}}{L_{CDEG}}\right] = -102.65\cdot kPa$$

Water Pressure at Point E:

$$\sigma_{E.U2} := -\gamma_w \cdot \left[\left(HW_{U2} - BOF_{elev}\right) - \frac{\Delta_{h.U2}\cdot L_{CDE}}{L_{CDEG}}\right] = -80.35\cdot kPa$$

Uplift for Overturning Analysis on Bottom of Key:

$$U_{OT.U2.key} := \frac{\sigma_{C.U2} + \sigma_{D.U2}}{2}\cdot L_{CD}\cdot W_b = -1549.74\cdot kN$$

Acting at:

$$U_{OT.U2.key.loc} := \frac{L_{CD}\cdot\left(2\cdot\sigma_{C.U2} + \sigma_{D.U2}\right)}{3\left(\sigma_{C.U2} + \sigma_{D.U2}\right)} + L_{EG} = 18\,m$$

U2 CASE

Uplift for Overturning Analysis on Bottom of Footing: $U_{OT.U2.ftg} := \frac{\sigma_{E.U2} + \sigma_{G.U2}}{2} \cdot L_{EG} \cdot W_b = -18013.31 \cdot kN$

Acting at: $U_{OT.U2.ftg.loc} := \frac{L_{EG} \cdot \left(\sigma_{G.U2} + 2 \cdot \sigma_{E.U2}\right)}{3\left(\sigma_{G.U2} + \sigma_{E.U2}\right)} = 9.25\,m$

Uplift Load for Overturning Analysis: $U_{OT.U2} := U_{OT.U2.key} + U_{OT.U2.ftg} = -19563.05 \cdot kN$

Uplift Load Acting from Toe: $U_{OT.U2.loc} := \frac{U_{OT.U2.key} \cdot U_{OT.U2.key.loc} + U_{OT.U2.ftg} \cdot U_{OT.U2.ftg.loc}}{U_{OT.U2}} = 9.94\,m$

<u>All Vertical Loads Applicable to Overturning Stability Analysis</u>

Total Concrete Dead Loads:	$D_{conc} = 24618.6 \cdot kN$	at:	$X_{conc.loc} = 10.06\,m$
Dead Load of Gate:	$D_{Gate} = 210.0 \cdot kN$		$X_{gate} = 6.60\,m$
Water Weight (HW) on Apron Slab:	$H_{1.U2} = 5922.8 \cdot kN$		$H_{1.U2.loc} = 14.13\,m$
Water Weight (TW) on Gate Footing:	$H_{2.U2} = 5730.2 \cdot kN$		$H_{2.U2.loc} = 5.43\,m$
Uplift Load for Overturning Analysis:	$U_{OT.U2} = -19563.05 \cdot kN$		$U_{OT.U2.loc} = 9.94 \cdot m$

Sum of All Overtuming Analysis Vertical Load:

$$\Sigma V_{U2.OT} := D_{conc} + D_{Gate} + H_{1.U2} + H_{2.U2} + U_{OT.U2} = 16918.58 \cdot kN$$

Sum of All Overtuming Analysis Vertical Load Moments:

$$\Sigma M_{V.U2.OT} := D_{conc} \cdot X_{conc.loc} + D_{Gate} \cdot X_{gate} + H_{1.U2} \cdot H_{1.U2.loc} + H_{2.U2} \cdot H_{2.U2.loc} + U_{OT.U2} \cdot U_{OT.U2.loc} = 169206.88 \cdot kN \cdot m$$

<u>Lateral Tailwater Loads for Overturning Stability Analysis</u>

TW Lateral Load on Gate Footing (No Key - Overturning Values Adjusted): $H_{twgf.U2} := H_{twgf.U2.tri} + H_{twgf.U2.rect} = 2236.68 \cdot kN$

Acting at: $H_{twgf.U2.loc} := \frac{\frac{h_{toe}}{3} \cdot H_{twgf.U2.tri} + \frac{h_{toe}}{2} \cdot H_{twgf.U2.rect}}{H_{twgf.U2}} = 1.65\,m$

Horizontal Tailwater Pressure Top of Key (Overturning Analysis): $\sigma_{twtk.OT.U2} := \sigma_{E.U2} \cdot -1 = 80.35 \cdot kPa$

Horizontal Tailwater Pressure Bottom of Key (Overturning Analysis): $\sigma_{twbk.OT.U2} := \sigma_{D.U2} \cdot -1 = 102.65 \cdot kPa$

Triangular Distribution Unit Load Acting at Key: $H_{twbk.OT.U2.tri} := \frac{\left(\sigma_{twbk.OT.U2} - \sigma_{twtk.OT.U2}\right)}{2} \cdot d_{key} \cdot W_{tw.U2} = 334.5 \cdot kN$

Triangular Distribution Unit Load Acting at Key: $H_{twbk.OT.U2.rect} := \sigma_{twtk.OT.U2} \cdot d_{key} \cdot W_{tw.U2} = 2410.39 \cdot kN$

Total Horizontal Tailwater Load on Key (Overturning Values Adjusted): $H_{twkey.OT.U2} := H_{twbk.OT.U2.tri} + H_{twbk.OT.U2.rect} = 2744.89 \cdot kN$

Acting at: $H_{twkey.OT.U2.loc} := \frac{H_{twbk.OT.U2.tri} \cdot \frac{-2 \cdot d_{key}}{3} + H_{twbk.OT.U2.rect} \cdot \frac{-d_{key}}{2}}{H_{twkey.OT.U2}} = -1.04 \cdot m$

U2 CASE

__Lateral Driving Earth Loads for Overturning Stability Analysis (at rest condition)__

Depth of Driving Soil Loads (to top of key): $h_{E.OT.U2} := TOC_{as} - BOF_{elev} = 4\ m$

At-Rest Soil Load: $E_{act.OT.U2} := \frac{\left(K_{o.U2} \cdot h_{E.OT.U2}^{\ 2}\right)}{2} \cdot \left(\gamma_r - \gamma_w\right) \cdot W_{hwas.U2} \cdot -1 = -962.49 \cdot kN$

At Rest- Soil Load Acting from Toe: $E_{act.OT.U2.loc} := \frac{h_{E.OT.U2}}{3} = 1.33\ m$

__All Lateral Loads Appliable to Overturning Stability Analysis__

HW Lateral Load on Approach Slab:	$H_{hwas.U2} = -6710.0 \cdot kN$	$H_{hwas.U2.loc} = 0.61\ m$
HW Lateral Load on Reg. Gate:	$H_{hwrg.U2} = -1097.0 \cdot kN$	$H_{hwrg.U2.loc} = 4.95\ m$
TW Lateral Load on Reg. Gate:	$H_{twrg.U2} = 238.4 \cdot kN$	$H_{twrg.U2.loc} = 4.60\ m$
TW Lateral Load on Gate Footing (No Key - Overturning Values Adjusted):	$H_{twgf.U2} = 2236.68 \cdot kN$	$H_{twgf.U2.loc} = 1.65\ m$
TW Lateral Load on Key:	$H_{twkey.OT.U2} = 2744.89 \cdot kN$	$H_{twkey.OT.U2.loc} = -1.04\ m$
Ice / Impact Load:	$I_{U2} = -1125.0 \cdot kN$	$I_{U2.loc} = 5.80\ m$
Lateral Soil Load (driving):	$E_{act.OT.U2} = -962.5 \cdot kN$	$E_{act.OT.U2.loc} = 1.33\ m$

Resisting Lateral Soil Load as required to produce horizontal equilibrium:

$$E_{pas.OT.U2} := -\left(H_{hwas.U2} + H_{hwrg.U2} + H_{twrg.U2} + H_{twgf.U2} + H_{twkey.OT.U2} + I_{U2} + E_{act.OT.U2}\right) = 4674.59 \cdot kN$$

Acting at:

$$E_{pas.OT.U2.loc} := -1 \cdot \frac{d_{key}}{2} = -1\ m$$

Sum of All Overturning Analysis Horizontal Load (ΣH=0):

$$\Sigma H_{U2.OT} := H_{hwas.U2} + H_{hwrg.U2} + H_{twrg.U2} + H_{twgf.U2} + H_{twkey.OT.U2} + I_{U2} + E_{act.OT.U2} + E_{pas.OT.U2} = 0 \cdot kN$$

Sum of All Overturning Analysis Horizontal Load Moments:

$$\Sigma M_{H.U2.OT} := H_{hwas.U2} \cdot H_{hwas.U2.loc} + H_{hwrg.U2} \cdot H_{hwrg.U2.loc} + H_{twrg.U2} \cdot H_{twrg.U2.loc} + H_{twgf.U2} \cdot H_{twgf.U2.loc} \cdots + H_{twkey.OT.U2} \cdot H_{twkey.OT.U2.loc} + I_{U2} \cdot I_{U2.loc} + E_{act.OT.U2} \cdot E_{act.OT.U2.loc} + E_{pas.OT.U2} \cdot E_{pas.OT.U2.loc} = -20041.82 \cdot kN \cdot m$$

__Overturning Stability Analysis__

$\Sigma M_{U2.OT} := \Sigma M_{V.U2.OT} + \Sigma M_{H.U2.OT} = 149165.06 \cdot kN \cdot m$

$X_{R.U2} := \frac{\Sigma M_{U2.OT}}{\Sigma V_{U2.OT}} = 8.82\ m$

$x_{OT.U2} := X_{R.U2} - \frac{L_b}{2} = -0.43\ m$

Overturning Resultant Ratio $Ratio_{OT.U2} := \frac{X_{R.U2}}{L_b} = 0.48$

$$Ratio_{OT.U2.check} := \begin{cases} \text{"OKAY"} & \text{if } Ratio_{OT.U2} \geq Ratio_{OT.U2.min} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

$$x_{OT.check.U2} := \begin{cases} \text{"OKAY"} & \text{if } \left|x_{OT.U2}\right| \leq Kern \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

CHECK FOUNDATION BEARING CAPACITY (HORIZONTAL PLANE):

U2 CASE

Bearing Pressure Under Toe:

$$\sigma_{ToeU2.OT} := \frac{\Sigma V_{U2.OT}}{L_b \cdot W_b} + \frac{\left(\Sigma V_{U2.OT} \cdot x_{OT.U2}\right)}{S_b} = 52.4 \cdot kPa$$

$$Bearing_{ChecktoeU2.OT} := \begin{vmatrix} \text{"OKAY "} & \text{if } \sigma_{ToeU2.OT} < \sigma_{allow.U2} \\ \text{"NG""} & \text{otherwise} \end{vmatrix} = \text{"OKAY "}$$

Bearing Pressure Under Heel:

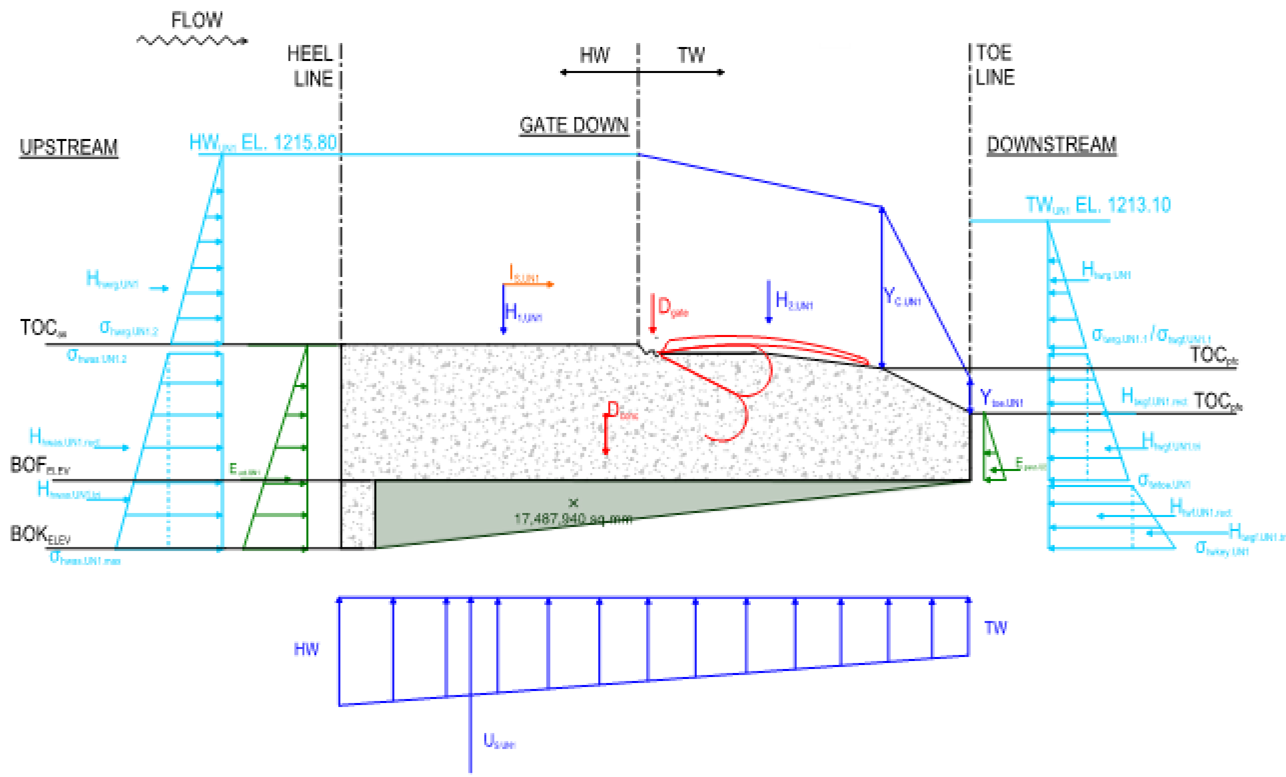
$$\sigma_{HeelU2.OT} := \frac{\Sigma V_{U2.OT}}{L_b \cdot W_b} - \frac{\left(\Sigma V_{U2.OT} \cdot x_{OT.U2}\right)}{S_b} = 69.5 \cdot kPa$$

$$Bearing_{CheckheelU2.OT} := \left(\begin{vmatrix} \text{"OKAY "} & \text{if } \sigma_{HeelU2.OT} < \sigma_{allow.U2} \wedge \sigma_{HeelU2.OT} > 0 \\ \text{"NG""} & \text{otherwise} \end{vmatrix}\right) = \text{"OKAY "}$$

SUMMARY OF STABILITY ASSESSMENT:

Sliding Factor of Safety: (Horizontal Plane)	$FS_{HorizSliding.U2} = 1.16$	$FS_{HorizSliding.U2.Check} =$ "Horizontal Sliding (No Key c
Sliding Factor of Safety: (Inclined Plane)	$FS_{InclinedlSlidingU2} = 2.72$	$FS_{InclinedSliding.check.U2} =$ "OKAY "
Eccentricity: (Inclined Plane)	$e_{U2} = 0.20\,m$	$e_{check.U2} =$ "Okay"
Bearing Pressure At Heel: (Inclined Plane)	$\sigma_{heel.U2} = 69 \cdot kPa$	$\sigma_{heel.U2.check} =$ "Okay"
Bearing Pressure At Toe: (Inclined Plane)	$\sigma_{toe.U2} = 78 \cdot kPa$	$\sigma_{toe.U2.1.check} =$ "Okay"
Flotation Factor of Safety (horizontal plane)	$FS_{act.FU2} = 1.63$	$FS_{check.FU2} =$ "OKAY"
Overturning Resultant Ratio: (horizontal plane)	$Ratio_{OT.U2} = 0.48$	$Ratio_{OT.U2.check} =$ "OKAY"
Eccentricity: (horizontal plane)	$x_{OT.U2} = -0.43\,m$	$x_{OT.check.U2} =$ "OKAY"
Bearing Pressure At Heel: (horizontal plane)	$\sigma_{HeelU2.OT} = 70 \cdot kPa$	$Bearing_{CheckheelU2.OT} =$ "OKAY "
Bearing Pressure At Toe: (horizontal plane)	$\sigma_{ToeU2.OT} = 52 \cdot kPa$	$Bearing_{ChecktoeU2.OT} =$ "OKAY "

UN1 DESIGN CASE



ACCEPTANCE PARAMETERS

Required Factor of Safety for Sliding: $FS_{req.UN1.sl} := 1.3$ (Without Cohesion) (Section 8.1, Design Criteria)

Resultant Within Middle Third of Base: $e \le \frac{L_b}{6} \wedge e \ge \frac{-L_b}{6}$

Allowable Rock Bearing Pressure: $\sigma_{allow.UN1} := 1470 \cdot \frac{kN}{m^2}$ (Section 5.2, Design Criteria)

INPUT PARAMETERS

Headwater Elevation: $HW_{UN1} := 1215.8m$ (Section 8.3, Design Criteria)

Tailwater Elevation: $TW_{UN1} := 1213.1m$ (Section 8.3, Design Criteria)

Bottom of Footing Elevation: $BOF_{elev} = 1206\,m$

Approach Slab Top of Concrete Elevation at Upstream Face: $TOC_{as} = 1210\,m$

Footing Top of Concrete Elevation at Stilling Basin: $TOC_{pfe} = 1208\,m$

Footing Top of Concrete Elevation at Center of Footing: $TOC_{pfc} = 1209.3\,m$

Gates are open when top of gate elevation is at 1210.00m

Top of Guard/Regulating Gate Elevation: $TOP_{rg.UN1} := 1210.00m$ $TOP_{gg.UN1} := 1213.50m$

Gates are closed/up when top of gate elevation is at 1215.0m

Bottom of Key Elevation: $BOK_{elev} = 1204\,m$

Crestwater Elevation: Dynamic Flow $EL_{C.UN1} := 1213.87m$

$$Y_{C.UN1} := \begin{cases} (EL_{C.UN1} - TOC_{pfc}) & \text{if } TOP_{rg.UN1} \le HW_{UN1} \\ (TW_{UN1} - TOC_{pfc}) & \text{if } TOP_{rg.UN1} > HW_{UN1} \end{cases} = 4.57 \cdot m$$

Toewater Elevation: $EL_{TOE.UN1} := 1209.95m$

$$Y_{TOE.UN1} := \begin{cases} (EL_{TOE.UN1} - TOC_{pfe}) & \text{if } TOP_{rg.UN1} \le HW_{UN1} \\ (TW_{UN1} - TOC_{pfe}) & \text{if } TOP_{rg.UN1} > HW_{UN1} \end{cases} = 1.95 \cdot m$$

LATERAL WATER LOADS

UN1 CASE

HEADWATER (DRIVING):

Headwater Depth on Gate: $D_{hwg.UN1} := HW_{UN1} - TOC_{as} = 5.80\,m$

Thickness of Approach Slab (Including Key): $T_{as} = 6\,m$

Headwater Depth at Heel (U/S face): $D_{hwas.UN1} := HW_{UN1} - BOK_{elev} = 11.80\,m$

Headwater Load Unit Width on Approach Slab: $W_{hwas.UN1} := W_b = 15.00\,m$

Headwater Unit Load At Top of Approach Slab:

$$H_{hwas.UN1.1} := \frac{-\left(\gamma_w \cdot D_{hwg.UN1}{}^2\right)}{2} \cdot W_{hwas.UN1} = -2475.06 \cdot kN$$

Headwater Unit Load At Bottom of Approach Key:

$$H_{hwas.UN1.2} := \frac{-\left(\gamma_w \cdot D_{hwas.UN1}{}^2\right)}{2} \cdot W_{hwas.UN1} = -10244.6 \cdot kN$$

Headwater Line Load At Top of Approach Slab: $\sigma_{hwas.UN1.1} := -\left(\gamma_w \cdot D_{hwg.UN1}\right) = -56.9 \cdot kPa$

Headwater Line Load At Bottom of Approach Key: $\sigma_{hwas.UN1.2} := -\left(\gamma_w \cdot D_{hwas.UN1}\right) = -115.76 \cdot kPa$

Triangular Distribution Unit Load on Approach Slab and Key:

$$H_{hwas.UN1.2.tri} := \left(\frac{\sigma_{hwas.UN1.2} - \sigma_{hwas.UN1.1}}{2}\right) \cdot \left(T_{as} \cdot W_{hwas.UN1}\right) = -2648.7 \cdot kN$$

Rectangular Distribution Unit Load on Approach Slab and Key:

$$H_{hwas.UN1.2.rect} := \sigma_{hwas.UN1.1} \cdot \left(T_{as} \cdot W_{hwas.UN1}\right) = -5120.82 \cdot kN$$

Total Horizontal Headwater Load on Approach Slab:

$$H_{hwas.UN1} := H_{hwas.UN1.2.tri} + H_{hwas.UN1.2.rect} = -7769.52 \cdot kN$$

Apply Total Footing Headwater Load at:

$$H_{hwas.UN1.loc} := \frac{\left[H_{hwas.UN1.2.rect} \cdot \frac{\left(T_{as}\right)}{2} + H_{hwas.UN1.2.tri} \cdot \frac{\left(T_{as}\right)}{3}\right]}{H_{hwas.UN1.2.tri} + H_{hwas.UN1.2.rect}} - d_{key} = 0.66\,m$$

Regulating Gate (4A) Operating Condition:

Reg. Gate Down/Open Condition: $A1_{UN1} := TOP_{rg.UN1} \le TOC_{as}$

Reg. Crest Gate Up/Closed, with Top of Gate Higher than HW Elevation: $B1_{UN1} := TOP_{rg.UN1} \ge HW_{UN1} \wedge TOP_{rg.UN1} > TOC_{as}$

Reg. Crest Gate Up/Closed, with Top of Gate Lower than HW Elevation: $C1_{UN1} := TOP_{rg.UN1} > TOC_{as} \wedge HW_{UN1} > TOP_{rg.UN1} = 0$

Reg. Crest Gate Height: $H_{rg.UN1} := TOP_{rg.UN1} - TOC_{as} = 0\,m$

Headwater Depth at Reg. Crest Gate: $D_{hwrg.UN1} := HW_{UN1} - TOC_{as} = 5.80\,m$

Reg. Crest Gate Width: $W_{hwrg.UN1} := 15.00m$

Lateral Headwater Pressure at Bottom of Reg. Crest Gate:

$$\sigma_{hwrg.UN1.1} := \begin{cases} (0.0kPa) & \text{if } A1_{UN1} \\ -(\gamma_w \cdot D_{hwrg.UN1}) & \text{if } B1_{UN1} \\ -(\gamma_w \cdot D_{hwrg.UN1}) & \text{if } C1_{UN1} \end{cases} = 0.0 \cdot kPa$$

Lateral Headwater Pressure at Top of Reg. Crest Gate:
(Load at HW Elevation On Reg. Crest Gate if HW is below TOG_{rg})

$$\sigma_{hwrg.UN1.2} := \begin{cases} (0.0kPa) & \text{if } A1_{UN1} \\ 0.0kPa & \text{if } B1_{UN1} \\ -\left[\gamma_w \cdot (HW_{UN1} - TOP_{rg.UN1})\right] & \text{if } C1_{UN1} \end{cases} = 0.0 \cdot kPa$$

Average Pressure acting on Reg. Crest Gate:

$$\sigma_{hwrg.UN1.avg} := \frac{(\sigma_{hwrg.UN1.1} + \sigma_{hwrg.UN1.2})}{2} = 0 \cdot kPa$$

Total Area of Crest Gate:

$$A_{hwrg.UN1} := \begin{cases} D_{hwrg.UN1} \cdot W_{hwrg.UN1} & \text{if } A1_{UN1} \\ D_{hwrg.UN1} \cdot W_{hwrg.UN1} & \text{if } B1_{UN1} \\ H_{rg.UN1} \cdot W_{hwrg.UN1} & \text{if } C1_{UN1} \end{cases} = 87 \cdot m^2$$

Total Horizontal Headwater Load on Reg. Crest Gate: $H_{hwrg.UN1} := \sigma_{hwrg.UN1.avg} \cdot A_{hwrg.UN1} = 0.0 \cdot kN$

Apply Total Reg. Crest Gate Headwater Load at:

$$H_{hwrg.UN1.loc} := \begin{cases} (TOC_{as} - BOF_{elev}) & \text{if } A1_{UN1} \\ \left[\frac{(HW_{UN1} - TOC_{as})}{3} + (TOC_{as} - BOF_{elev})\right] & \text{if } B1_{UN1} \\ \left[\frac{\sigma_{hwrg.UN1.2} \cdot A_{hwrg.UN1} \cdot \frac{(H_{rg.UN1})}{2} + \frac{(\sigma_{hwrg.UN1.1} - \sigma_{hwrg.UN1.2})}{2} \cdot A_{hwrg.UN1} \cdot \frac{(H_{rg.UN1})}{3}}{\sigma_{hwrg.UN1.2} \cdot A_{hwrg.UN1} + \frac{(\sigma_{hwrg.UN1.1} - \sigma_{hwrg.UN1.2})}{2} \cdot A_{hwrg.UN1}} \ldots \right. \\ \left. + (TOC_{as} - BOF_{elev}) \right] & \text{if } C1_{UN1} \end{cases} = 4.0 \cdot m$$

LATERAL TAILWATER (RESISTING) Applied to Downstream Side of Reg. Crest Gate: UN1 CASE

Reg. Gate Down/Open Condition: $A2_{UN1} := TOP_{rg.UN1} \le TOC_{as}$

Reg. Crest Gate Up/Closed, with Top of Gate Higher than TW Elevation: $B2_{UN1} := TOP_{rg.UN1} \ge TW_{UN1} \wedge TOP_{rg.UN1} > TOC_{as}$

Reg. Crest Gate Up/Closed, with Top of Gate Lower than TW Elevation: $C2_{UN1} := TOP_{rg.UN1} > TOC_{as} \wedge TW_{UN1} > TOP_{rg.UN1}$

Tailwater Depth at Reg. Crest Gate: $D_{twrg.UN1} := TW_{UN1} - TOC_{as} = 3.10\,m$

Reg. Crest Gate Width: $W_{twrg.UN1} := 15.00m$

Lateral Water Load at Bottom of Reg. Crest Gate:

$$\sigma_{twrg.UN1.1} := \left| \begin{array}{ll} (0.0kPa) & \text{if } A2_{UN1} \\ (\gamma_w \cdot D_{twrg.UN1}) & \text{if } B2_{UN1} \\ (\gamma_w \cdot D_{twrg.UN1}) & \text{if } C2_{UN1} \end{array} \right. = 0.0 \cdot kPa$$

Lateral Water Load at Top of Reg. Crest Gate:
(Load at TW Elevation On Reg. Crest Gate if TW is below TOG_{rg})

$$\sigma_{twrg.UN1.2} := \left| \begin{array}{ll} (0.0kPa) & \text{if } A2_{UN1} \\ 0.0kPa & \text{if } B2_{UN1} \\ \left[\gamma_w \cdot (TW_{UN1} - TOP_{rg.UN1})\right] & \text{if } C2_{UN1} \end{array} \right. = 0.0 \cdot kPa$$

Average Pressure acting on Reg. Crest Gate:

$$\sigma_{twrg.UN1.avg} := \frac{(\sigma_{twrg.UN1.1} + \sigma_{twrg.UN1.2})}{2} = 0 \cdot kPa$$

Total Area water acting on Crest Gate:

$$A_{twrg.UN1} := \left| \begin{array}{ll} D_{twrg.UN1} \cdot W_{twrg.UN1} & \text{if } A2_{UN1} \\ D_{twrg.UN1} \cdot W_{twrg.UN1} & \text{if } B2_{UN1} \\ H_{rg.UN1} \cdot W_{twrg.UN1} & \text{if } C2_{UN1} \end{array} \right. = 46.5 \cdot m^2$$

Total Horizontal Tailwater Load on Reg. Crest Gate: $H_{twrg.UN1} := \sigma_{twrg.UN1.avg} \cdot A_{twrg.UN1} = 0.0 \cdot kN$

Apply Total Horiz. TW Load on Reg. Gate at:

$$H_{twrg.UN1.loc} := \left| \begin{array}{ll} (TOC_{as} - BOF_{elev}) & \text{if } A2_{UN1} \\ \left[\frac{(TW_{UN1} - TOC_{as})}{3} + (TOC_{as} - BOF_{elev})\right] & \text{if } B2_{UN1} \\ \left[\frac{\sigma_{twrg.UN1.2} \cdot A_{twrg.UN1} \cdot \frac{(H_{rg.UN1})}{2} + \frac{(\sigma_{twrg.UN1.1} - \sigma_{twrg.UN1.2})}{2} A_{twrg.UN1} \cdot \frac{(H_{rg.UN1})}{3}}{\sigma_{twrg.UN1.2} \cdot A_{twrg.UN1} + \frac{(\sigma_{twrg.UN1.1} - \sigma_{twrg.UN1.2})}{2} \cdot A_{twrg.UN1}} \ldots \\ + (TOC_{as} - BOF_{elev})\right] & \text{if } C2_{UN1} \end{array} \right. = 4.0 \cdot m$$

LATERAL WATER LOADS (continued)

UN1 CASE

TAILWATER (RESISTING) Applied to Concrete Structure:

Tailwater Depth At top of Gate Base Footing Elevation: $D_{twgf.UN1} := TW_{UN1} - TOC_{as} = 3.10\,m$

Water Depth at bottom of Gate Base Footing: $D_{twtoe.UN1} := TW_{UN1} - BOF_{elev} = 7.10\,m$

Footing Thickness at Toe $h_{toe} = 4\,m$

Unit Width of D/S face of crest for application of Tailwater Load: $W_{tw.UN1} := W_b = 15.00\,m$

Tailwater Pressure At Top of Gate Footing: $\sigma_{twgf.UN1} := \left(\gamma_w \cdot D_{twgf.UN1}\right) = 30.41 \cdot kPa$

Tailwater Line Load At Bottom of Gate Footing: $\sigma_{twtoe.UN1} := \left(\gamma_w \cdot D_{twtoe.UN1}\right) = 69.65 \cdot kPa$

Triangular Distribution Unit Load on Gate Footing Base $H_{twgf.UN1.tri} := \left(\frac{\sigma_{twtoe.UN1} - \sigma_{twgf.UN1}}{2}\right) \cdot \left(h_{toe} \cdot W_{tw.UN1}\right) = 1177.2 \cdot kN$

Rectangular Distribution Unit Load on Gate Footing Base: $H_{twgf.UN1.rect} := \sigma_{twgf.UN1} \cdot \left(h_{toe} \cdot W_{tw.UN1}\right) = 1824.66 \cdot kN$

Tailwater Pressure At Bottom of Sliding Failure Plane: $\sigma_{twbk.UN1} := \left(HW_{UN1} - BOK_{elev}\right) \cdot \gamma_w = 115.76 \cdot kPa$

Triangular Distribution Unit Load Below Footing: $H_{twbk.UN1.tri} := \frac{\left(\sigma_{twbk.UN1} - \sigma_{twtoe.UN1}\right)}{2} \cdot d_{key} \cdot W_{tw.UN1} = 691.61 \cdot kN$

Rectangular Distribution Load Below Footing Base: $H_{twbk.UN1.rect} := \sigma_{twtoe.UN1} \cdot d_{key} \cdot W_{tw.UN1} = 2089.53 \cdot kN$

Total Horizontal Tailwater Load on Gate Footing (including key):

$$H_{twgk.UN1} := H_{twgf.UN1.tri} + H_{twgf.UN1.rect} + H_{twbk.UN1.tri} + H_{twbk.UN1.rect} = 5782.99 \cdot kN$$

Apply Total Gate Footing Tailwater Load at:

$$H_{twgk.UN1.loc} := \frac{\left[H_{twgf.UN1.rect} \cdot \frac{\left(h_{toe}\right)}{2} + H_{twgf.UN1.tri} \cdot \frac{\left(h_{toe}\right)}{3} + H_{twbk.UN1.tri} \cdot \left(-d_{key} \cdot \frac{2}{3}\right) + H_{twbk.UN1.rect} \cdot \left(\frac{-d_{key}}{2}\right)\right]}{H_{twgf.UN1.tri} + H_{twgf.UN1.rect} + H_{twbk.UN1.tri} + H_{twbk.UN1.rect}} = 0.38\,m$$

SUMMATION OF LATERAL WATER LOADS:

$$\Sigma H_{Water.UN1} := H_{hwas.UN1} + H_{hwrg.UN1} + H_{twgk.UN1} + H_{twrg.UN1} = -1986.53 \cdot kN$$

$$\Sigma M_{Hwater.UN1} := H_{hwas.UN1} \cdot H_{hwas.UN1.loc} + H_{hwrg.UN1} \cdot H_{hwrg.UN1.loc} \cdots + H_{twgk.UN1} \cdot H_{twgk.UN1.loc} + H_{twrg.UN1} \cdot H_{twrg.UN1.loc} = -2913.57 \cdot kN \cdot m$$

VERTICAL WATER LOADS

UN1 CASE

HEADWATER:

Water Depth on top of Approach Slab: $d_{hw.UN1} := HW_{UN1} - TOC_{as} = 5.80\,m$

Length of Approach Slab: $L_{as} = 8.75\,m$

Width of Approach Slab: $w_{as} = 15.00\,m$

Vertical Water Weight (H1) on Approach Slab: $H_{1.UN1} := \left(w_{as} \cdot d_{hw.UN1} \cdot L_{as}\right) \cdot \gamma_w = 7467.9 \cdot kN$

Moment Arm for Application of Water Weight (H1) from toe: $H_{1.UN1.loc} := L_b - \dfrac{L_{as}}{2} = 14.13\,m$

TAILWATER:

Trapezoid Volume Above Gate Footing from Approach Slab to Crest: $V_{asc.UN1} := \left(L_{gf} - L_{gfc}\right) W_b \dfrac{d_{hw.UN1} + Y_{C.UN1}}{2} = 556.09 \cdot m^3$

Trapezoid Volume Above Gate Footing Crest to End of Gate Footing: $V_{gfc.UN1} := \left(L_{gfc} \cdot W_b\right) \dfrac{Y_{C.UN1} + Y_{TOE.UN1}}{2} = 127.14 \cdot m^3$

Load Above Gate Footing from Approach Slab to Crest: $H_{2.UN1.asc} := V_{asc.UN1} \cdot \gamma_w = 5455.26 \cdot kN$

Load Acting Above Footing Crest from Toe: $H_{2.UN1.asc.loc} := \dfrac{\left(L_{gf} - L_{gfc}\right) \cdot \left(2 \cdot d_{hw.UN1} + Y_{C.UN1}\right)}{3 \cdot \left(d_{hw.UN1} + Y_{C.UN1}\right)} + L_{gfc} = 6.32\,m$

Load Above Gate Footing from Crest to End: $H_{2.UN1.gfc} := V_{gfc.UN1} \cdot \gamma_w = 1247.24 \cdot kN$

Load Acting Above Gate Footing from Crest to End: $H_{2.UN1.gfc.loc} := \dfrac{\left(L_{gfc}\right) \cdot \left(2 \cdot Y_{C.UN1} + Y_{TOE.UN1}\right)}{3 \cdot \left(Y_{C.UN1} + Y_{TOE.UN1}\right)} = 1.47\,m$

Vertical Water Weight (H2) on Gate Footing: $H_{2.UN1} := H_{2.UN1.asc} + H_{2.UN1.gfc} = 6702.5 \cdot kN$

Moment Arm for Application of Water Weight (H2) from toe: $H_{2.UN1.loc} := \dfrac{H_{2.UN1.asc} \cdot H_{2.UN1.asc.loc} + H_{2.UN1.gfc} \cdot H_{2.UN1.gfc.loc}}{H_{2.UN1}} = 5.42\,m$

UPLIFT AT INCLINE SLIDING PLANE

UN1 CASE

Uplift pressure at U/S Face (heel): $U_{HW.UN1} := D_{hwas.UN1} \cdot \gamma_w = 115.8 \cdot \frac{kN}{m^2}$

Uplift pressure at D/S Face Stilling Basin: $U_{TW.UN1} := \left(D_{twtoe.UN1}\right) \cdot \gamma_w = 69.65 \cdot \frac{kN}{m^2}$

Length from U/S of Gate Structure to D/S of Stilling Basin: $L_{overall} := L_b = 18.50\,m$

Difference between Uplift pressure at HW and TW: $U_{diff.UN1} := U_{HW.UN1} - U_{TW.UN1} = 46.11 \cdot \frac{kN}{m^2}$

Slope of difference between between Uplift pressure at HW and TW: $U_{slope.UN1} := \frac{U_{diff.UN1}}{L_{overall}} = 2.49 \cdot \frac{kN}{m^2 \cdot m}$

Tailwater Pressure at toe of Gate Structure: $U_{press.toe.gs.UN1} := U_{TW.UN1} + \left(L_{overall} - L_b\right) \cdot U_{slope.UN1} = 69.65 \cdot \frac{kN}{m^2}$

Uniform uplift force UA Under Gate Structure due to TW (rectangle): $U_{A.UN1} := U_{press.toe.gs.UN1} \cdot L_b \cdot W_b \cdot -1 = -19328.15 \cdot kN$

Moment Arm from Toe of Gate Structure for Uplift UA: $L_{A.UN1} := \left(\frac{L_b}{2}\right) = 9.25\,m$

Linearly Decreasing Uplift Force UN1B Under Gate Structure due to HW-TW Differential (triangle): $U_{B.UN1} := \frac{1}{2} \cdot \left(U_{HW.UN1} - U_{press.toe.gs.UN1}\right) \cdot L_b \cdot W_b \cdot -1 = -6397.35 \cdot kN$

Moment Arm from Toe of Gate Structure for Uplift UB: $L_{B.UN1} := \frac{2}{3} \cdot L_b = 12.33\,m$

Total Resultant Uplift force: $U_{UN1} := U_{A.UN1} + U_{B.UN1} = -25725.5 \cdot kN$

Resultant Location from Toe: $U_{UN1.loc} := \frac{\left(U_{A.UN1} \cdot L_{A.UN1} + U_{B.UN1} \cdot L_{B.UN1}\right)}{\left(U_{A.UN1} + U_{B.UN1}\right)} = 10.02\,m$

$$\Sigma V_{water.UN1} := H_{1.UN1} + H_{2.UN1} + U_{UN1} = -11555.14 \cdot kN$$

$$\Sigma M_{Vwater.UN1} := H_{1.UN1} \cdot H_{1.UN1.loc} + H_{2.UN1} \cdot H_{2.UN1.loc} + U_{UN1} \cdot U_{UN1.loc} = -115906.58 \cdot kN \cdot m$$

SOIL LOADS

UN1 CASE

Equivalent Fluid Pressure (EFP):

At rest lateral pressure coefficient: $K_{o.UN1} := 1 - \sin(\phi_{backfill}) = 0.658$ (Section 5.3, Design Criteria)

Headwater Pier Footing Unit Width: $W_{hwas.UN1} = 15.00\,m$

Tailwater Pier Footing Unit Width: $W_{tw.UN1} = 15.00\,m$

Pier Footing Thickness at Heel: $t_{hf.UN1} := TOC_{as} - BOK_{elev} = 6.00\,m$

Fixed Crest Footing Thickness at Toe: $t_{tf.UN1} := TOC_{pfe} - BOF_{elev} = 2.00\,m$

Lateral Driving Force (Headwater Side - at rest condition)

At-Rest Soil Load:

$$E_{act.UN1} := \frac{\left(K_{o.UN1} \cdot t_{hf.UN1}^{\;2}\right)}{2} \cdot \left(\gamma_r - \gamma_w\right) \cdot W_{hwas.UN1} \cdot -1 = -2165.61 \cdot kN$$

Acting at:

$$E_{act.UN1.loc} := \frac{t_{hf.UN1}}{3} = 2.00\,m$$

Lateral Resisting Force (Tailwater Side - at rest condition)

At-rest Soil Load:

$$E_{pass.UN1} := \frac{\left(K_{o.UN1} \cdot t_{tf.UN1}^{\;2}\right)}{2} \cdot \left(\gamma_r - \gamma_w\right) \cdot W_{tw.UN1} = 240.62 \cdot kN$$

Acting at:

$$E_{pass.UN1.loc} := \frac{t_{tf.UN1}}{3} = 0.67\,m$$

$$\Sigma H_{soil.UN1} := E_{act.UN1} + E_{pass.UN1} = -1924.99 \cdot kN$$

$$\Sigma M_{soil.UN1} := E_{act.UN1} \cdot E_{act.UN1.loc} + E_{pass.UN1} \cdot E_{pass.UN1.loc} = -4170.8 \cdot kN \cdot m$$

ICE / IMPACT LOADS (ASSUME NO ICE LOADING ON TAILWATER SIDE)

Static Ice load on Gates:

$$I_{G.UN1} := \begin{cases} 00\,\dfrac{kN}{m} & \text{if } TOP_{rg.UN1} \le TOC_{as} \\ 0\,\dfrac{kN}{m} & \text{if } TOP_{rg.UN1} > TOC_{as} \end{cases} = 0 \cdot \frac{kN}{m}$$

(Section 7.7, Design Criteria)

Ice Loading Unit Width on Reg. Gate: $W_{rg.UN1} := 15.00m$ (Input value for load case)

Total Ice Load on Structure: $I_{UN1} := -\left(I_{G.UN1} \cdot W_{rg.UN1}\right) = 0 \cdot kN$

Apply Ice load at: $I_{UN1.loc} := \left(TOP_{rg.UN1} - BOF_{elev} - 0.30m\right) = 3.70\,m$

$$\Sigma H_{I.UN1} := I_{UN1} = 0 \cdot kN$$

$$\Sigma M_{I.UN1} := I_{UN1} \cdot I_{UN1.loc} = 0 \cdot kN \cdot m$$

(SEISMIC LOAD (NOT APPLICABLE FOR THIS LOAD CASE)

UN1 CASE

SUMMARY OF LOADS

	Loads	Moment Arm
Dead load of Concrete Structure:	$D_{conc} = 24618.6 \cdot kN$	$X_{conc.loc} = 10.06\,m$
Obermyer Gate Weight:	$D_{Gate} = 210.0 \cdot kN$	$X_{gate} = 6.60\,m$
HW Lateral Load on Approach Slab:	$H_{hwas.UN1} = -7769.5 \cdot kN$	$H_{hwas.UN1.loc} = 0.66\,m$
HW Lateral Load on Reg. Gate:	$H_{hwrg.UN1} = 0.0 \cdot kN$	$H_{hwrg.UN1.loc} = 4.00\,m$
TW Lateral Load on Gate Footing (Including Key - Sliding Check Loads):	$H_{twgk.UN1} = 5782.99 \cdot kN$	$H_{twgk.UN1.loc} = 0.38\,m$
TW Lateral Load on Reg. Gate:	$H_{twrg.UN1} = 0.0 \cdot kN$	$H_{twrg.UN1.loc} = 4.00\,m$
Vertical HW Load on Approach Slab:	$H_{1.UN1} = 7467.9 \cdot kN$	$H_{1.UN1.loc} = 14.13\,m$
Vertical TW Load on Pier Footing (crest):	$H_{2.UN1} = 6702.5 \cdot kN$	$H_{2.UN1.loc} = 5.42\,m$
Uplift:	$U_{UN1} = -25725.5 \cdot kN$	$U_{UN1.loc} = 10.02\,m$
Lateral Soil Load (driving):	$E_{act.UN1} = -2165.6 \cdot kN$	$E_{act.UN1.loc} = 2.00\,m$
Lateral Soil Load (resisting):	$E_{pass.UN1} = 240.62 \cdot kN$	$E_{pass.UN1.loc} = 0.67\,m$
Ice / Impact Load:	$I_{UN1} = 0.0 \cdot kN$	$I_{UN1.loc} = 3.70\,m$

STABILITY ASSESSMENT (SLIDNG, BEARING, FLOTATION AND OVERTURNING):UN1 CASE

CHECK SLIDING ALONG HORIZONTAL PLANE THRU TOE,
IGNORING BEDROCK MOBILIZED BY STRUCTURAL HEEL KEY, OR VOID BEHIND KEY

Sum of Vertical Forces:

$\Sigma V_{UN1} := \Sigma V_{DL} + \Sigma V_{water.UN1} = 13273.5 \cdot kN$

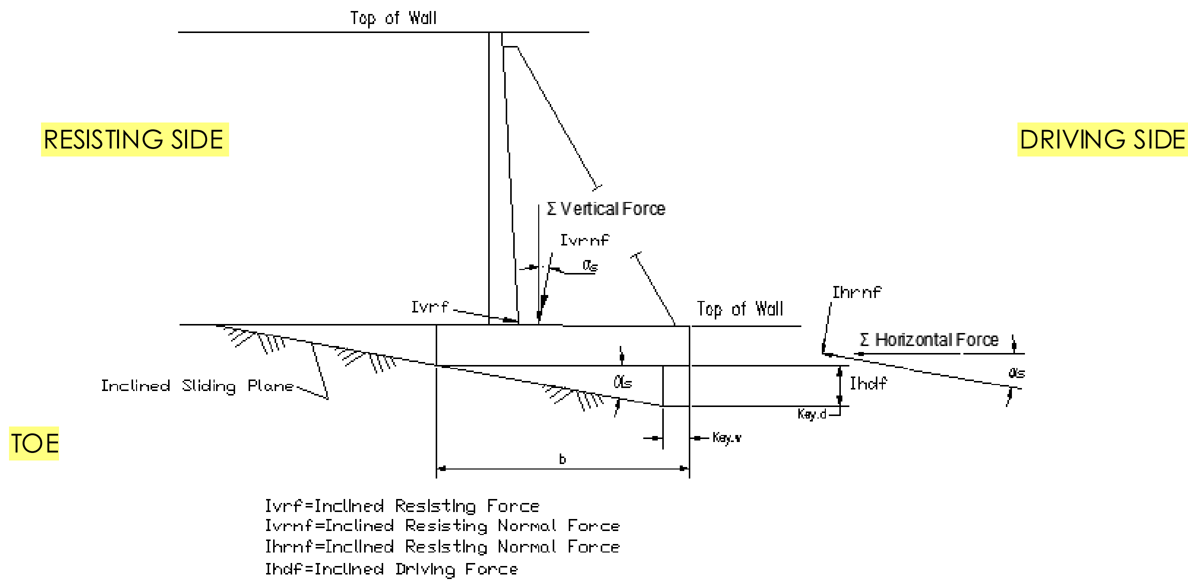
Sum of Horizontal Forces:

$\Sigma H_{UN1} := \Sigma H_{Water.UN1} + \Sigma H_{soil.UN1} + \Sigma H_{I.UN1} = -3911.51 \cdot kN$

Sliding Factor of Safety: $FS_{HorizSliding.UN1} := \dfrac{\tan_{\phi} \cdot \Sigma V_{UN1}}{|\Sigma H_{UN1}|} = 1.66$

ey or Void Behind Ke $FS_{HorizSliding.UN1.Check} :=$ | "OKAY" if $FS_{HorizSliding.UN1} \geq FS_{req.UN1.sl}$ = "OKAY"
| "Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !" otherwise

CHECK SLIDING ALONG INCLINED SLIDING PLANE FROM HEEL KEY TO TOE,
WITH BEDROCK MASS MOBILIZED BY REINFOCREDE CONCRETE KEY)



$\alpha s = 0.11$ as degrees= $\alpha s \cdot \left(\dfrac{180}{\pi}\right) = 6.52$ $\Sigma V_{UN1} = 13273.46 \cdot kN$ $V_{rs} = 5775 \cdot kN$

Resolve $\Sigma Vert_{UN1}$ & $\Sigma Horiz_{UN1}$ $\Sigma V_{InclinedUN1} := \cos(\alpha s) \cdot (\Sigma V_{UN1} + V_{rs}) + \sin(\alpha s) \cdot |\Sigma H_{UN1}| = 19369.4 \cdot kN$

$\Sigma H_{InclinedUN1} := \cos(\alpha s) \cdot |\Sigma H_{UN1}| - \sin(\alpha s) \cdot (\Sigma V_{UN1} + V_{rs}) = 1723.3 \cdot kN$

(With properly engineered reinforced concrete Key, horizontal sliding plane thru Toe is protected, critical sliding plane is relocated to the INCLINED SLIDING PLANE FROM HEEL KEY To TOE, Bedrock Mass above this examined plane is mobilized by reinforced concrete key and combined into Structural Wedge.)

Inclined Sliding Plane Length

$L_{incline} = 18.61 \, m$

Safety Factor for Sliding Inclined Failure Plane

$FS_{InclinedlSlidingUN1} := \dfrac{\Sigma V_{InclinedUN1} \cdot \tan\left(\phi_{rock} \cdot \dfrac{\pi}{180}\right)}{|\Sigma H_{InclinedUN1}|} = 5.48$

$FS_{InclinedSliding.check.UN1} :=$ | "OKAY " if $FS_{InclinedlSlidingUN1} > FS_{req.UN1.sl}$ = "OKAY "
| "Revise Structure"" otherwise

$FS_{InclinedSliding.check.UN1}$ = "OKAY "

OVERTURNING STABILITY CHECK:

UN1 CASE

CHECK ECCENTRICITY

Sum of the moments:

$$\Sigma M_{UN1} := \Sigma M_{DL} + \Sigma M_{Hwater.UN1} + \Sigma M_{Vwater.UN1} + \Sigma M_{I.UN1} + \Sigma M_{soil.UN1} + \Sigma M_{soil} = 193328 \cdot kN \cdot m$$

Eccentricity:

$$e_{UN1} := \left(\frac{L_{incline}}{2}\right) - \frac{\left(\Sigma M_{UN1}\right)}{\Sigma V_{InclinedUN1}} = -0.68\,m$$

Eccentricity Check:

$$e_{check.UN1} := \begin{vmatrix} \text{"Okay"} & \text{if } \left|e_{UN1}\right| \le Kern \\ \text{"Revise Structure"} & \text{otherwise} \end{vmatrix}$$

$$e_{check.UN1} = \text{"Okay"}$$

Foundation Bearing Checks:

Incline Plane Area: $A_{b.incline} = 279.12\,m^2$

Incline Plane Section Modulus: $S_{b.incline} = 865.63 \cdot m^3$

Bearing Pressure at Heel:

$$\sigma_{heel.UN1} := \frac{\Sigma V_{InclinedUN1}}{A_{b.incline}} - \frac{\left(\Sigma V_{InclinedUN1} \cdot e_{UN1}\right)}{S_{b.incline}} = 84.5 \cdot \frac{kN}{m^2}$$

$$\sigma_{heel.UN1.check} := \left(\begin{vmatrix} \text{"Okay"} & \text{if } \sigma_{heel.UN1} \le \sigma_{allow.UN1} \\ \text{"Revise Structure"} & \text{if } \sigma_{heel.UN1} < 0\,\frac{kN}{m^2} \end{vmatrix}\right)$$

$$\sigma_{heel.UN1.check} = \text{"Okay"}$$

Bearing Pressure at Toe:

$$\sigma_{toe.UN1} := \frac{\Sigma V_{InclinedUN1}}{A_{b.incline}} + \frac{\left(\Sigma V_{InclinedUN1} \cdot e_{UN1}\right)}{S_{b.incline}} = 54.2 \cdot \frac{kN}{m^2}$$

$$\sigma_{toe.UN1.1.check} := \begin{vmatrix} \text{"Okay"} & \text{if } \sigma_{toe.UN1} \le \sigma_{allow.UN1} \\ \text{"Revise Structure"} & \text{if } \sigma_{toe.UN1} < 0\,\frac{kN}{m^2} \end{vmatrix}$$

$$\sigma_{toe.UN1.1.check} = \text{"Okay"}$$

FLOATATION ANALYSIS:

ACCEPTANCE PARAMETERS

Required Factor of Safety: $FS_{req.FUN1} := 1.3$

VERTICAL LOADS RESISTING:

Dead Load: $\Sigma V_{DL} = 24828.6 \cdot kN$

Water Weight H1+H2: $\Sigma V_{H.FUN1} := H_{1.UN1} + H_{2.UN1} = 14170.36 \cdot kN$

Summation Vertical Resisting: $\Sigma V_{FUN1} := \Sigma V_{DL} + \Sigma V_{H.FUN1} = 38999.0 \cdot kN$

VERTICAL LOADS UPLIFT:

Uplift: $U_{UN1} = -25725.5 \cdot kN$

Factor of Safety Floatation:

$$FS_{act.FUN1} := \frac{\Sigma V_{FUN1}}{\left|U_{UN1}\right|} = 1.52$$

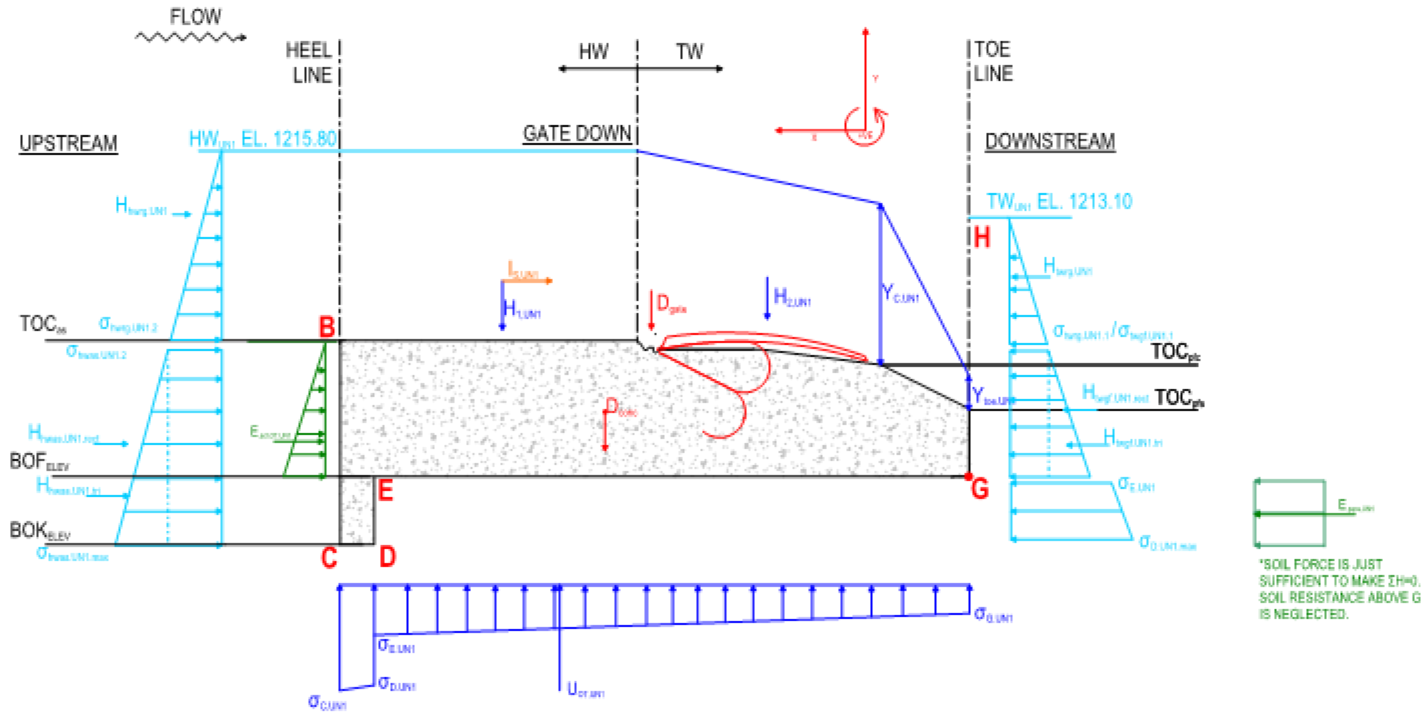
$$FS_{check.FUN1} := \begin{vmatrix} \text{"OKAY"} & \text{if } FS_{act.FUN1} \ge FS_{req.FUN1} \\ \text{"ANCHORS REQUIRED"} & \text{if } FS_{act.FUN1} < FS_{req.FUN1} \end{vmatrix} = \text{"OKAY"}$$

UN1 CASE

MONOLITH OVERTURNING STABILITY ANALYSIS

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.
Assumptions are made in order to compute overturning stability of indetermine forces on monolith with key;
(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.
(b) The horizontal resisting force acting on the key, P.key, is that required for static equilibrium
(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1 $Ratio_{OT.UN1.min} := 0.33$



Uplift Loads for Overturning Stability Analysis

Line of Creep:

Change in Water Head: $\Delta_{h.UN1} := HW_{UN1} - TW_{UN1} = 2.7\ m$

Length from Point C to Point G: $L_{CG} = 18.61\ m$

Length from Various Points to Points: $L_{CD} = 1\ m$ $L_{DE} = 2\ m$ $L_{EG} = 17.5\ m$

$L_{GH.UN1} := TW_{UN1} - BOF_{elev} = 7.1\ m$

Length from Point C, D, E to G: $L_{CDEG} = 20.5\ m$ $L_{CDE} = 3\ m$

Water Pressure at Point C: $\sigma_{C.UN1} := \sigma_{hwas.UN1.2} = -115.76 \cdot kPa$

Water Pressure at Point G: $\sigma_{G.UN1} := \sigma_{twtoe.UN1} \cdot -1 = -69.65 \cdot kPa$

Water Pressure at Point D: $\sigma_{D.UN1} := -\gamma_w \cdot \left[\left(HW_{UN1} - BOK_{elev} \right) - \frac{\Delta_{h.UN1} \cdot L_{CD}}{L_{CDEG}} \right] = -114.47 \cdot kPa$

Water Pressure at Point E: $\sigma_{E.UN1} := -\gamma_w \cdot \left[\left(HW_{UN1} - BOF_{elev} \right) - \frac{\Delta_{h.UN1} \cdot L_{CDE}}{L_{CDEG}} \right] = -92.26 \cdot kPa$

Uplift for Overturning Analysis on Bottom of Key: $U_{OT.UN1.key} := \frac{\sigma_{C.UN1} + \sigma_{D.UN1}}{2} \cdot L_{CD} \cdot W_b = -1726.68 \cdot kN$

Acting at: $U_{OT.UN1.key.loc} := \frac{L_{CD} \cdot \left(2 \cdot \sigma_{C.UN1} + \sigma_{D.UN1} \right)}{3 \left(\sigma_{C.UN1} + \sigma_{D.UN1} \right)} + L_{EG} = 18\ m$

UN1 CASE

Uplift for Overturning Analysis on Bottom of Footing:

$$U_{OT.UN1.ftg} := \frac{\sigma_{E.UN1} + \sigma_{G.UN1}}{2} \cdot L_{EG} \cdot W_b = -21251.06 \cdot kN$$

Acting at:

$$U_{OT.UN1.ftg.loc} := \frac{L_{EG} \cdot \left(\sigma_{G.UN1} + 2 \cdot \sigma_{E.UN1}\right)}{3\left(\sigma_{G.UN1} + \sigma_{E.UN1}\right)} = 9.16\,m$$

Uplift Load for Overturning Analysis:

$$U_{OT.UN1} := U_{OT.UN1.key} + U_{OT.UN1.ftg} = -22977.74 \cdot kN$$

Uplift Load Acting from Toe:

$$U_{OT.UN1.loc} := \frac{U_{OT.UN1.key} \cdot U_{OT.UN1.key.loc} + U_{OT.UN1.ftg} \cdot U_{OT.UN1.ftg.loc}}{U_{OT.UN1}} = 9.82\,m$$

<u>All Vertical Loads Applicable to Overturning Stability Analysis</u>

Total Concrete Dead Loads:	$D_{conc} = 24618.6 \cdot kN$	at:	$X_{conc.loc} = 10.06\,m$
Dead Load of Gate:	$D_{Gate} = 210.0 \cdot kN$		$X_{gate} = 6.60\,m$
Water Weight (HW) on Apron Slab:	$H_{1.UN1} = 7467.9 \cdot kN$		$H_{1.UN1.loc} = 14.13\,m$
Water Weight (TW) on Gate Footing:	$H_{2.UN1} = 6702.5 \cdot kN$		$H_{2.UN1.loc} = 5.42\,m$
Uplift Load for Overturning Analysis:	$U_{OT.UN1} = -22977.74 \cdot kN$		$U_{OT.UN1.loc} = 9.82 \cdot m$

Sum of All Overturning Analysis Vertical Load:

$$\Sigma V_{UN1.OT} := D_{conc} + D_{Gate} + H_{1.UN1} + H_{2.UN1} + U_{OT.UN1} = 16021.22 \cdot kN$$

Sum of All Overturning Analysis Vertical Load Moments:

$$\Sigma M_{V.UN1.OT} := D_{conc} \cdot X_{conc.loc} + D_{Gate} \cdot X_{gate} + H_{1.UN1} \cdot H_{1.UN1.loc} + H_{2.UN1} \cdot H_{2.UN1.loc} + U_{OT.UN1} \cdot U_{OT.UN1.loc} = 165038.86 \cdot kN \cdot m$$

<u>Lateral Tailwater Loads for Overturning Stability Analysis</u>

TW Lateral Load on Gate Footing (No Key - Overturning Values Adjusted):

$$H_{twgf.UN1} := H_{twgf.UN1.tri} + H_{twgf.UN1.rect} = 3001.86 \cdot kN$$

Acting at:

$$H_{twgf.UN1.loc} := \frac{\frac{h_{toe}}{3} \cdot H_{twgf.UN1.tri} + \frac{h_{toe}}{2} \cdot H_{twgf.UN1.rect}}{H_{twgf.UN1}} = 1.74\,m$$

Horizontal Tailwater Pressure Top of Key (Overturning Analysis):

$$\sigma_{twtk.OT.UN1} := \sigma_{E.UN1} \cdot -1 = 92.26 \cdot kPa$$

Horizontal Tailwater Pressure Bottom of Key (Overturning Analysis):

$$\sigma_{twbk.OT.UN1} := \sigma_{D.UN1} \cdot -1 = 114.47 \cdot kPa$$

Triangular Distribution Unit Load Acting at Key:

$$H_{twbk.OT.UN1.tri} := \frac{\left(\sigma_{twbk.OT.UN1} - \sigma_{twtk.OT.UN1}\right)}{2} \cdot d_{key} \cdot W_{tw.UN1} = 333.06 \cdot kN$$

Triangular Distribution Unit Load Acting at Key:

$$H_{twbk.OT.UN1.rect} := \sigma_{twtk.OT.UN1} \cdot d_{key} \cdot W_{tw.UN1} = 2767.86 \cdot kN$$

Total Horizontal Tailwater Load on Key (Overturning Values Adjusted):

$$H_{twkey.OT.UN1} := H_{twbk.OT.UN1.tri} + H_{twbk.OT.UN1.rect} = 3100.92 \cdot kN$$

Acting at:

$$H_{twkey.OT.UN1.loc} := \frac{H_{twbk.OT.UN1.tri} \cdot \frac{-2 \cdot d_{key}}{3} + H_{twbk.OT.UN1.rect} \cdot \frac{-d_{key}}{2}}{H_{twkey.OT.UN1}} = -1.04 \cdot m$$

UN1 CASE

Lateral Driving Earth Loads for Overturning Stability Analysis (at rest condition)

Depth of Driving Soil Loads (to top of key): $h_{E.OT.UN1} := TOC_{as} - BOF_{elev} = 4\,m$

At-Rest Soil Load: $E_{act.OT.UN1} := \frac{\left(K_{o.UN1} \cdot h_{E.OT.UN1}^{2}\right)}{2} \cdot \left(\gamma_r - \gamma_w\right) \cdot W_{hwas.UN1} \cdot -1 = -962.49 \cdot kN$

At Rest- Soil Load Acting from Toe: $E_{act.OT.UN1.loc} := \frac{h_{E.OT.UN1}}{3} = 1.33\,m$

All Lateral Loads Appliable to Overturning Stability Analysis

HW Lateral Load on Approach Slab:	$H_{hwas.UN1} = -7769.5 \cdot kN$	$H_{hwas.UN1.loc} = 0.66\,m$
HW Lateral Load on Reg. Gate:	$H_{hwrg.UN1} = 0.0 \cdot kN$	$H_{hwrg.UN1.loc} = 4.00\,m$
TW Lateral Load on Reg. Gate:	$H_{twrg.UN1} = 0.0 \cdot kN$	$H_{twrg.UN1.loc} = 4.00\,m$
TW Lateral Load on Gate Footing (No Key - Overturning Values Adjusted):	$H_{twgf.UN1} = 3001.86 \cdot kN$	$H_{twgf.UN1.loc} = 1.74\,m$
TW Lateral Load on Key:	$H_{twkey.OT.UN1} = 3100.92 \cdot kN$	$H_{twkey.OT.UN1.loc} = -1.04\,m$
Ice / Impact Load:	$I_{UN1} = 0.0 \cdot kN$	$I_{UN1.loc} = 3.70\,m$
Lateral Soil Load (driving):	$E_{act.OT.UN1} = -962.5 \cdot kN$	$E_{act.OT.UN1.loc} = 1.33\,m$

Resisting Lateral Soil Load as required to produce horizontal equilibrium:

$$E_{pas.OT.UN1} := -\left(H_{hwas.UN1} + H_{hwrg.UN1} + H_{twrg.UN1} + H_{twgf.UN1} + H_{twkey.OT.UN1} + I_{UN1} + E_{act.OT.UN1}\right) = 2629.24 \cdot kN$$

Acting at:

$$E_{pas.OT.UN1.loc} := -1 \cdot \frac{d_{key}}{2} = -1\,m$$

Sum of All Overturning Analysis Horizontal Load (ΣH=0):

$$\Sigma H_{UN1.OT} := H_{hwas.UN1} + H_{hwrg.UN1} + H_{twrg.UN1} + H_{twgf.UN1} + H_{twkey.OT.UN1} + I_{UN1} + E_{act.OT.UN1} + E_{pas.OT.UN1} = 0 \cdot kN$$

Sum of All Overturning Analysis Horizontal Load Moments:

$$\begin{aligned}\Sigma M_{H.UN1.OT} := {} & H_{hwas.UN1} \cdot H_{hwas.UN1.loc} + H_{hwrg.UN1} \cdot H_{hwrg.UN1.loc} + H_{twrg.UN1} \cdot H_{twrg.UN1.loc} \cdots = -7026.4 \cdot kN \cdot m \\ & + H_{twgf.UN1} \cdot H_{twgf.UN1.loc} + H_{twkey.OT.UN1} \cdot H_{twkey.OT.UN1.loc} + I_{UN1} \cdot I_{UN1.loc} \cdots \\ & + E_{act.OT.UN1} \cdot E_{act.OT.UN1.loc} + E_{pas.OT.UN1} \cdot E_{pas.OT.UN1.loc}\end{aligned}$$

Overturning Stability Analysis

$\Sigma M_{UN1.OT} := \Sigma M_{V.UN1.OT} + \Sigma M_{H.UN1.OT} = 158012.47 \cdot kN \cdot m$ $\quad X_{R.UN1} := \frac{\Sigma M_{UN1.OT}}{\Sigma V_{UN1.OT}} = 9.86\,m$ $\quad x_{OT.UN1} := X_{R.UN1} - \frac{L_b}{2} = 0.61\,m$

Overturning Resultant Ratio $\quad Ratio_{OT.UN1} := \frac{X_{R.UN1}}{L_b} = 0.53$

$$Ratio_{OT.UN1.check} := \begin{cases} \text{"OKAY"} & \text{if } Ratio_{OT.UN1} \geq Ratio_{OT.UN1.min} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

$$x_{OT.check.UN1} := \begin{cases} \text{"OKAY"} & \text{if } \left|x_{OT.UN1}\right| \leq Kern \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

CHECK FOUNDATION BEARING CAPACITY (HORIZONTAL PLANE):

UN1 CASE

Bearing Pressure Under Toe:

$$\sigma_{ToeUN1.OT} := \frac{\Sigma V_{UN1.OT}}{L_b \cdot W_b} + \frac{\left(\Sigma V_{UN1.OT} \cdot x_{OT.UN1}\right)}{S_b} = 69.2 \cdot kPa$$

$$Bearing_{ChecktoeUN1.OT} := \begin{vmatrix} \text{"OKAY "} & \text{if} \quad \sigma_{ToeUN1.OT} < \sigma_{allow.UN1} \\ \text{"NG""} & \text{otherwise} \end{vmatrix} = \text{"OKAY "}$$

Bearing Pressure Under Heel:

$$\sigma_{HeelUN1.OT} := \frac{\Sigma V_{UN1.OT}}{L_b \cdot W_b} - \frac{\left(\Sigma V_{UN1.OT} \cdot x_{OT.UN1}\right)}{S_b} = 46.3 \cdot kPa$$

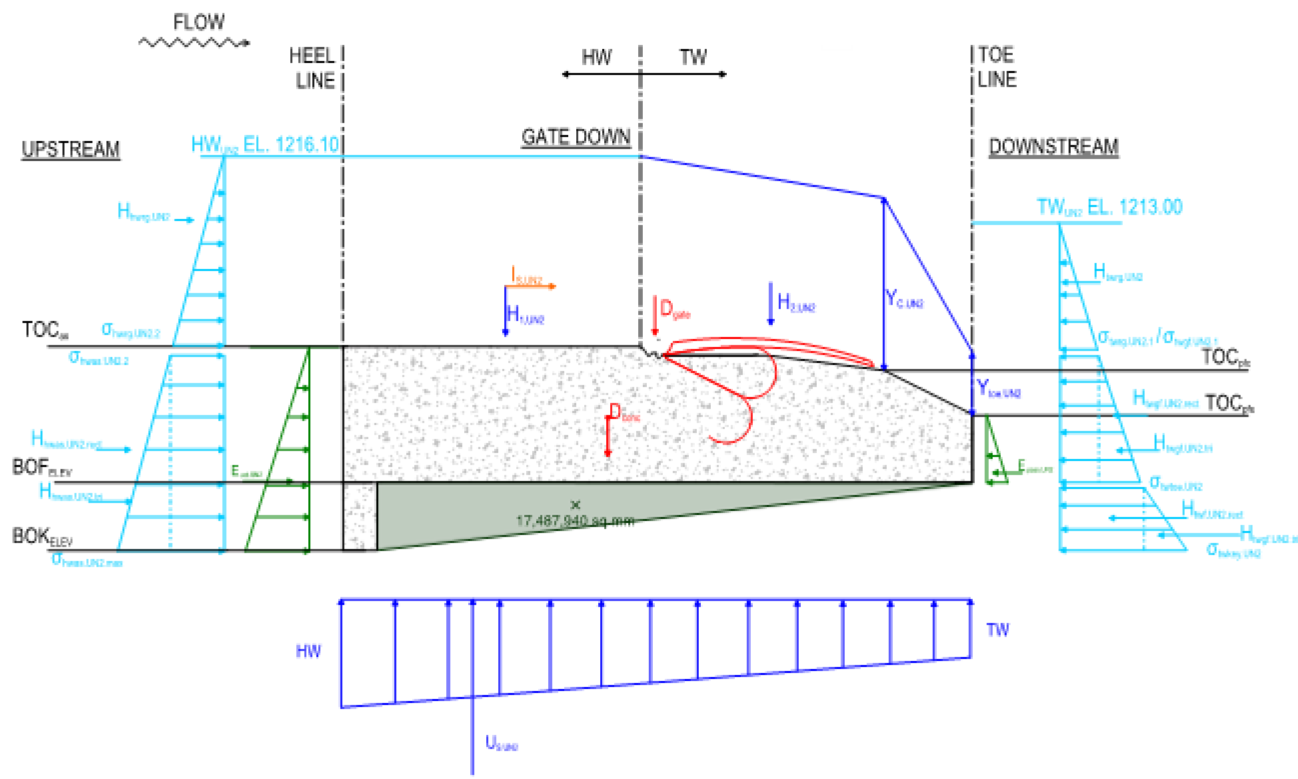
$$Bearing_{CheckheelUN1.OT} := \left(\begin{vmatrix} \text{"OKAY "} & \text{if} \quad \sigma_{HeelUN1.OT} < \sigma_{allow.UN1} \wedge \sigma_{HeelUN1.OT} > 0 \\ \text{"NG""} & \text{otherwise} \end{vmatrix} \right) = \text{"OKAY "}$$

SUMMARY OF STABILITY ASSESSMENT:

r Void Behin

Sliding Factor of Safety: (Horizontal Plane)	$FS_{HorizSliding.UN1} = 1.66$	$FS_{HorizSliding.UN1.Check}$ = "OKAY"
Sliding Factor of Safety: (Inclined Plane)	$FS_{InclinedlSlidingUN1} = 5.48$	$FS_{InclinedSliding.check.UN1}$ = "OKAY "
Eccentricity: (Inclined Plane)	$e_{UN1} = -0.68\,m$	$e_{check.UN1}$ = "Okay"
Bearing Pressure At Heel: (Inclined Plane)	$\sigma_{heel.UN1} = 85 \cdot kPa$	$\sigma_{heel.UN1.check}$ = "Okay"
Bearing Pressure At Toe: (Inclined Plane)	$\sigma_{toe.UN1} = 54 \cdot kPa$	$\sigma_{toe.UN1.1.check}$ = "Okay"
Flotation Factor of Safety (horizontal plane)	$FS_{act.FUN1} = 1.52$	$FS_{check.FUN1}$ = "OKAY"
Overturning Resultant Ratio: (horizontal plane)	$Ratio_{OT.UN1} = 0.53$	$Ratio_{OT.UN1.check}$ = "OKAY"
Eccentricity: (horizontal plane)	$x_{OT.UN1} = 0.61\,m$	$x_{OT.check.UN1}$ = "OKAY"
Bearing Pressure At Heel: (horizontal plane)	$\sigma_{HeelUN1.OT} = 46 \cdot kPa$	$Bearing_{CheckheelUN1.OT}$ = "OKAY "
Bearing Pressure At Toe: (horizontal plane)	$\sigma_{ToeUN1.OT} = 69 \cdot kPa$	$Bearing_{ChecktoeUN1.OT}$ = "OKAY "

UN2 DESIGN CASE



ACCEPTANCE PARAMETERS

Required Factor of Safety for Sliding: $FS_{req.UN2.sl} := 1.3$ (Without Cohesion) (Section 8.1, Design Criteria)

Resultant Within Middle Third of Base: $e \le \frac{L_b}{6} \wedge e \ge \frac{-L_b}{6}$

Allowable Rock Bearing Pressure: $\sigma_{allow.UN2} := 1470 \cdot \frac{kN}{m^2}$ (Section 5.2, Design Criteria)

INPUT PARAMETERS

Headwater Elevation: $HW_{UN2} := 1216.1m$ (Section 8.3, Design Criteria)

Tailwater Elevation: $TW_{UN2} := 1213.00m$ (Section 8.3, Design Criteria)

Bottom of Footing Elevation: $BOF_{elev} = 1206\,m$

Approach Slab Top of Concrete Elevation at Upstream Face: $TOC_{as} = 1210\,m$

Footing Top of Concrete Elevation at Stilling Basin: $TOC_{pfe} = 1208\,m$

Footing Top of Concrete Elevation at Center of Footing: $TOC_{pfc} = 1209.3\,m$

Top of Guard/Regulating Gate Elevation: $TOP_{rg.UN2} := 1210.00m$ $TOP_{gg.UN2} := 1215.00m$

Gates are open when top of gate elevation is at 1210.00m

Gates are closed/up when top of gate elevation is at 1215.0m

Bottom of Key Elevation: $BOK_{elev} = 1204\,m$

Crestwater Elevation: Dynamic Flow $EL_{C.UN2} := 1214.07m$

$$Y_{C.UN2} := \begin{array}{|l} (EL_{C.UN2} - TOC_{pfc}) \text{ if } TOP_{rg.UN2} \le HW_{UN2} \\ (TW_{UN2} - TOC_{pfc}) \text{ if } TOP_{rg.UN2} > HW_{UN2} \end{array} = 4.77 \cdot m$$

Toewater Elevation: $EL_{TOE.UN2} := 1209.97m$

$$Y_{TOE.UN2} := \begin{array}{|l} (EL_{TOE.UN2} - TOC_{pfe}) \text{ if } TOP_{rg.UN2} \le HW_{UN2} \\ (TW_{UN2} - TOC_{pfe}) \text{ if } TOP_{rg.UN2} > HW_{UN2} \end{array} = 1.97 \cdot m$$

LATERAL WATER LOADS

UN2 CASE

HEADWATER (DRIVING):

Headwater Depth on Gate: $D_{hwg.UN2} := HW_{UN2} - TOC_{as} = 6.10\,m$

Thickness of Approach Slab (Including Key): $T_{as} = 6\,m$

Headwater Depth at Heel (U/S face): $D_{hwas.UN2} := HW_{UN2} - BOK_{elev} = 12.10\,m$

Headwater Load Unit Width on Approach Slab: $W_{hwas.UN2} := W_b = 15.00\,m$

Headwater Unit Load At Top of Approach Slab: $H_{hwas.UN2.1} := \dfrac{-\left(\gamma_w \cdot D_{hwg.UN2}^{\ 2}\right)}{2} \cdot W_{hwas.UN2} = -2737.73 \cdot kN$

Headwater Unit Load At Bottom of Approach Key: $H_{hwas.UN2.2} := \dfrac{-\left(\gamma_w \cdot D_{hwas.UN2}^{\ 2}\right)}{2} \cdot W_{hwas.UN2} = -10772.1 \cdot kN$

Headwater Line Load At Top of Approach Slab: $\sigma_{hwas.UN2.1} := -\left(\gamma_w \cdot D_{hwg.UN2}\right) = -59.84 \cdot kPa$

Headwater Line Load At Bottom of Approach Key: $\sigma_{hwas.UN2.2} := -\left(\gamma_w \cdot D_{hwas.UN2}\right) = -118.7 \cdot kPa$

Triangular Distribution Unit Load on Approach Slab and Key: $H_{hwas.UN2.2.tri} := \left(\dfrac{\sigma_{hwas.UN2.2} - \sigma_{hwas.UN2.1}}{2}\right) \cdot \left(T_{as} \cdot W_{hwas.UN2}\right) = -2648.7 \cdot kN$

Rectangular Distribution Unit Load on Approach Slab and Key: $H_{hwas.UN2.2.rect} := \sigma_{hwas.UN2.1} \cdot \left(T_{as} \cdot W_{hwas.UN2}\right) = -5385.69 \cdot kN$

Total Horizontal Headwater Load on Approach Slab: $H_{hwas.UN2} := H_{hwas.UN2.2.tri} + H_{hwas.UN2.2.rect} = -8034.39 \cdot kN$

Apply Total Footing Headwater Load at:

$$H_{hwas.UN2.loc} := \frac{\left[H_{hwas.UN2.2.rect} \cdot \frac{\left(T_{as}\right)}{2} + H_{hwas.UN2.2.tri} \cdot \frac{\left(T_{as}\right)}{3}\right]}{H_{hwas.UN2.2.tri} + H_{hwas.UN2.2.rect}} - d_{key} = 0.67\,m$$

LATERAL WATER LOADS (continued)

UN2 CASE

Regulating Gate (4A) Operating Condition:

Reg. Gate Down/Open Condition: $A1_{UN2} := TOP_{rg.UN2} \le TOC_{as}$

Reg. Crest Gate Up/Closed, with Top of Gate Higher than HW Elevation: $B1_{UN2} := TOP_{rg.UN2} \ge HW_{UN2} \wedge TOP_{rg.UN2} > TOC_{as}$

Reg. Crest Gate Up/Closed, with Top of Gate Lower than HW Elevation: $C1_{UN2} := TOP_{rg.UN2} > TOC_{as} \wedge HW_{UN2} > TOP_{rg.UN2}$

Reg. Crest Gate Height: $H_{rg.UN2} := TOP_{rg.UN2} - TOC_{as} = 0\ m$

Headwater Depth at Reg. Crest Gate: $D_{hwrg.UN2} := HW_{UN2} - TOC_{as} = 6.10\ m$

Reg. Crest Gate Width: $W_{hwrg.UN2} := 15.00m$

Lateral Headwater Pressure at Bottom of Reg. Crest Gate:

$$\sigma_{hwrg.UN2.1} := \begin{cases} (0.0kPa) & \text{if } A1_{UN2} \\ -(\gamma_w \cdot D_{hwrg.UN2}) & \text{if } B1_{UN2} \\ -(\gamma_w \cdot D_{hwrg.UN2}) & \text{if } C1_{UN2} \end{cases} = 0.0 \cdot kPa$$

Lateral Headwater Pressure at Top of Reg. Crest Gate: (Load at HW Elevation On Reg. Crest Gate if HW is below TOG_{rg})

$$\sigma_{hwrg.UN2.2} := \begin{cases} (0.0kPa) & \text{if } A1_{UN2} \\ 0.0kPa & \text{if } B1_{UN2} \\ -\left[\gamma_w \cdot (HW_{UN2} - TOP_{rg.UN2})\right] & \text{if } C1_{UN2} \end{cases} = 0.0 \cdot kPa$$

Average Pressure acting on Reg. Crest Gate:

$$\sigma_{hwrg.UN2.avg} := \frac{(\sigma_{hwrg.UN2.1} + \sigma_{hwrg.UN2.2})}{2} = 0 \cdot kPa$$

Total Area of Crest Gate:

$$A_{hwrg.UN2} := \begin{cases} D_{hwrg.UN2} \cdot W_{hwrg.UN2} & \text{if } A1_{UN2} \\ D_{hwrg.UN2} \cdot W_{hwrg.UN2} & \text{if } B1_{UN2} \\ H_{rg.UN2} \cdot W_{hwrg.UN2} & \text{if } C1_{UN2} \end{cases} = 91.5 \cdot m^2$$

Total Horizontal Headwater Load on Reg. Crest Gate: $H_{hwrg.UN2} := \sigma_{hwrg.UN2.avg} \cdot A_{hwrg.UN2} = 0.0 \cdot kN$

Apply Total Reg. Crest Gate Headwater Load at:

$$H_{hwrg.UN2.loc} := \begin{cases} (TOC_{as} - BOF_{elev}) & \text{if } A1_{UN2} \\ \left[\frac{(HW_{UN2} - TOC_{as})}{3} + (TOC_{as} - BOF_{elev})\right] & \text{if } B1_{UN2} \\ \left[\frac{\sigma_{hwrg.UN2.2} \cdot A_{hwrg.UN2} \cdot \frac{(H_{rg.UN2})}{2} + \frac{(\sigma_{hwrg.UN2.1} - \sigma_{hwrg.UN2.2})}{2} \cdot A_{hwrg.UN2} \cdot \frac{(H_{rg.UN2})}{3}}{\sigma_{hwrg.UN2.2} \cdot A_{hwrg.UN2} + \frac{(\sigma_{hwrg.UN2.1} - \sigma_{hwrg.UN2.2})}{2} \cdot A_{hwrg.UN2}} \ldots \\ + (TOC_{as} - BOF_{elev})\right] & \text{if } C1_{UN2} \end{cases} = 4.0 \cdot m$$

LATERAL TAILWATER (RESISTING) Applied to Downstream Side of Reg. Crest Gate: UN2 CASE

Reg. Gate Down/Open Condition: $A2_{UN2} := TOP_{rg.UN2} \le TOC_{as}$

Reg. Crest Gate Up/Closed, with Top of Gate Higher than TW Elevation: $B2_{UN2} := TOP_{rg.UN2} \ge TW_{UN2} \wedge TOP_{rg.UN2} > TOC_{as}$

Reg. Crest Gate Up/Closed, with Top of Gate Lower than TW Elevation: $C2_{UN2} := TOP_{rg.UN2} > TOC_{as} \wedge TW_{UN2} > TOP_{rg.UN2}$

Tailwater Depth at Reg. Crest Gate: $D_{twrg.UN2} := TW_{UN2} - TOC_{as} = 3.00\,m$

Reg. Crest Gate Width: $W_{twrg.UN2} := 15.00m$

Lateral Water Load at Bottom of Reg. Crest Gate:

$$\sigma_{twrg.UN2.1} := \left| \begin{array}{ll} (0.0kPa) & \text{if } A2_{UN2} \\ (\gamma_w \cdot D_{twrg.UN2}) & \text{if } B2_{UN2} \\ (\gamma_w \cdot D_{twrg.UN2}) & \text{if } C2_{UN2} \end{array} \right. = 0.0 \cdot kPa$$

Lateral Water Load at Top of Reg. Crest Gate:
(Load at TW Elevation On Reg. Crest Gate if TW is below TOG_{rg})

$$\sigma_{twrg.UN2.2} := \left| \begin{array}{ll} (0.0kPa) & \text{if } A2_{UN2} \\ 0.0kPa & \text{if } B2_{UN2} \\ \left[\gamma_w \cdot (TW_{UN2} - TOP_{rg.UN2})\right] & \text{if } C2_{UN2} \end{array} \right. = 0.0 \cdot kPa$$

Average Pressure acting on Reg. Crest Gate:

$$\sigma_{twrg.UN2.avg} := \frac{(\sigma_{twrg.UN2.1} + \sigma_{twrg.UN2.2})}{2} = 0 \cdot kPa$$

Total Area water acting on Crest Gate:

$$A_{twrg.UN2} := \left| \begin{array}{ll} D_{twrg.UN2} \cdot W_{twrg.UN2} & \text{if } A2_{UN2} \\ D_{twrg.UN2} \cdot W_{twrg.UN2} & \text{if } B2_{UN2} \\ H_{rg.UN2} \cdot W_{twrg.UN2} & \text{if } C2_{UN2} \end{array} \right. = 45 \cdot m^2$$

Total Horizontal Tailwater Load on Reg. Crest Gate: $H_{twrg.UN2} := \sigma_{twrg.UN2.avg} \cdot A_{twrg.UN2} = 0.0 \cdot kN$

Apply Total Horiz. TW Load on Reg. Gate at:

$$H_{twrg.UN2.loc} := \left| \begin{array}{ll} (TOC_{as} - BOF_{elev}) & \text{if } A2_{UN2} \\ \left[\frac{(TW_{UN2} - TOC_{as})}{3} + (TOC_{as} - BOF_{elev})\right] & \text{if } B2_{UN2} \\ \left[\frac{\sigma_{twrg.UN2.2} \cdot A_{twrg.UN2} \cdot \frac{(H_{rg.UN2})}{2} + \frac{(\sigma_{twrg.UN2.1} - \sigma_{twrg.UN2.2})}{2} \cdot A_{twrg.UN2} \cdot \frac{(H_{rg.UN2})}{3}}{\sigma_{twrg.UN2.2} \cdot A_{twrg.UN2} + \frac{(\sigma_{twrg.UN2.1} - \sigma_{twrg.UN2.2})}{2} \cdot A_{twrg.UN2}} \ldots \\ + (TOC_{as} - BOF_{elev})\right] & \text{if } C2_{UN2} \end{array} \right. = 4.0 \cdot m$$

TAILWATER (RESISTING) Applied to Concrete Structure:

Tailwater Depth At top of Gate Base Footing Elevation: $D_{twgf.UN2} := TW_{UN2} - TOC_{as} = 3.00\,m$

Water Depth at bottom of Gate Base Footing: $D_{twtoe.UN2} := TW_{UN2} - BOF_{elev} = 7.00\,m$

Footing Thickness at Toe $h_{toe} = 4\,m$

Unit Width of D/S face of crest for application of Tailwater Load: $W_{tw.UN2} := W_b = 15.00\,m$

Tailwater Pressure At Top of Gate Footing: $\sigma_{twgf.UN2} := \left(\gamma_w \cdot D_{twgf.UN2}\right) = 29.43 \cdot kPa$

Tailwater Line Load At Bottom of Gate Footing: $\sigma_{twtoe.UN2} := \left(\gamma_w \cdot D_{twtoe.UN2}\right) = 68.67 \cdot kPa$

Triangular Distribution Unit Load on Gate Footing Base $H_{twgf.UN2.tri} := \left(\frac{\sigma_{twtoe.UN2} - \sigma_{twgf.UN2}}{2}\right) \cdot \left(h_{toe} \cdot W_{tw.UN2}\right) = 1177.2 \cdot kN$

Rectangular Distribution Unit Load on Gate Footing Base: $H_{twgf.UN2.rect} := \sigma_{twgf.UN2} \cdot \left(h_{toe} \cdot W_{tw.UN2}\right) = 1765.8 \cdot kN$

Tailwater Pressure At Bottom of Sliding Failure Plane: $\sigma_{twbk.UN2} := \left(HW_{UN2} - BOK_{elev}\right) \cdot \gamma_w = 118.7 \cdot kPa$

Triangular Distribution Unit Load Below Footing: $H_{twbk.UN2.tri} := \frac{\left(\sigma_{twbk.UN2} - \sigma_{twtoe.UN2}\right)}{2} \cdot d_{key} \cdot W_{tw.UN2} = 750.46 \cdot kN$

Rectangular Distribution Load Below Footing Base: $H_{twbk.UN2.rect} := \sigma_{twtoe.UN2} \cdot d_{key} \cdot W_{tw.UN2} = 2060.1 \cdot kN$

Total Horizontal Tailwater Load on Gate Footing (including key):

$$H_{twgk.UN2} := H_{twgf.UN2.tri} + H_{twgf.UN2.rect} + H_{twbk.UN2.tri} + H_{twbk.UN2.rect} = 5753.56 \cdot kN$$

Apply Total Gate Footing Tailwater Load at:

$$H_{twgk.UN2.loc} := \frac{\left[H_{twgf.UN2.rect} \cdot \frac{\left(h_{toe}\right)}{2} + H_{twgf.UN2.tri} \cdot \frac{\left(h_{toe}\right)}{3} + H_{twbk.UN2.tri} \cdot \left(-d_{key} \cdot \frac{2}{3}\right) + H_{twbk.UN2.rect} \cdot \left(\frac{-d_{key}}{2}\right)\right]}{H_{twgf.UN2.tri} + H_{twgf.UN2.rect} + H_{twbk.UN2.tri} + H_{twbk.UN2.rect}} = 0.35\,m$$

SUMMATION OF LATERAL WATER LOADS:

$$\Sigma H_{Water.UN2} := H_{hwas.UN2} + H_{hwrg.UN2} + H_{twgk.UN2} + H_{twrg.UN2} = -2280.82 \cdot kN$$

$$\Sigma M_{Hwater.UN2} := H_{hwas.UN2} \cdot H_{hwas.UN2.loc} + H_{hwrg.UN2} \cdot H_{hwrg.UN2.loc} \cdots + H_{twgk.UN2} \cdot H_{twgk.UN2.loc} + H_{twrg.UN2} \cdot H_{twrg.UN2.loc} = -3345.21 \cdot kN \cdot m$$

VERTICAL WATER LOADS

UN2 CASE

HEADWATER:

Water Depth on top of Approach Slab: $d_{hw.UN2} := HW_{UN2} - TOC_{as} = 6.10\,m$

Length of Approach Slab: $L_{as} = 8.75\,m$

Width of Approach Slab: $w_{as} = 15.00\,m$

Vertical Water Weight (H1) on Approach Slab: $H_{1.UN2} := \left(w_{as} \cdot d_{hw.UN2} \cdot L_{as}\right) \cdot \gamma_w = 7854.1 \cdot kN$

Moment Arm for Application of Water Weight (H1) from toe: $H_{1.UN2.loc} := L_b - \frac{L_{as}}{2} = 14.13\,m$

TAILWATER:

Trapezoid Volume Above Gate Footing from Approach Slab to Crest: $V_{asc.UN2} := \left(L_{gf} - L_{gfc}\right) W_b \frac{d_{hw.UN2} + Y_{C.UN2}}{2} = 582.9 \cdot m^3$

Trapezoid Volume Above Gate Footing Crest to End of Gate Footing: $V_{gfc.UN2} := \left(L_{gfc} \cdot W_b\right) \frac{Y_{C.UN2} + Y_{TOE.UN2}}{2} = 131.43 \cdot m^3$

Load Above Gate Footing from Approach Slab to Crest: $H_{2.UN2.asc} := V_{asc.UN2} \cdot \gamma_w = 5718.29 \cdot kN$

Load Acting Above Footing Crest from Toe: $H_{2.UN2.asc.loc} := \frac{\left(L_{gf} - L_{gfc}\right) \cdot \left(2 \cdot d_{hw.UN2} + Y_{C.UN2}\right)}{3 \cdot \left(d_{hw.UN2} + Y_{C.UN2}\right)} + L_{gfc} = 6.32\,m$

Load Above Gate Footing from Crest to End: $H_{2.UN2.gfc} := V_{gfc.UN2} \cdot \gamma_w = 1289.33 \cdot kN$

Load Acting Above Gate Footing from Crest to End: $H_{2.UN2.gfc.loc} := \frac{\left(L_{gfc}\right) \cdot \left(2 \cdot Y_{C.UN2} + Y_{TOE.UN2}\right)}{3 \cdot \left(Y_{C.UN2} + Y_{TOE.UN2}\right)} = 1.48\,m$

Vertical Water Weight (H2) on Gate Footing: $H_{2.UN2} := H_{2.UN2.asc} + H_{2.UN2.gfc} = 7007.61 \cdot kN$

Moment Arm for Application of Water Weight (H2) from toe: $H_{2.UN2.loc} := \frac{H_{2.UN2.asc} \cdot H_{2.UN2.asc.loc} + H_{2.UN2.gfc} \cdot H_{2.UN2.gfc.loc}}{H_{2.UN2}} = 5.43\,m$

UPLIFT AT INCLINE SLIDING PLANE

UN2 CASE

Uplift pressure at U/S Face (heel): $U_{HW.UN2} := D_{hwas.UN2} \cdot \gamma_w = 118.7 \cdot \frac{kN}{m^2}$

Uplift pressure at D/S Face Stilling Basin: $U_{TW.UN2} := \left(D_{twtoe.UN2}\right) \cdot \gamma_w = 68.67 \cdot \frac{kN}{m^2}$

Length from U/S of Gate Structure to D/S of Stilling Basin: $L_{overall} = 18.50\,m$

Difference between Uplift pressure at HW and TW: $U_{diff.UN2} := U_{HW.UN2} - U_{TW.UN2} = 50.03 \cdot \frac{kN}{m^2}$

Slope of difference between between Uplift pressure at HW and TW: $U_{slope.UN2} := \frac{U_{diff.UN2}}{L_{overall}} = 2.70 \cdot \frac{kN}{m^2 \cdot m}$

Tailwater Pressure at toe of Gate Structure: $U_{press.toe.gs.UN2} := U_{TW.UN2} + \left(L_{overall} - L_b\right) \cdot U_{slope.UN2} = 68.67 \cdot \frac{kN}{m^2}$

Uniform uplift force UA Under Gate Structure due to TW (rectangle): $U_{A.UN2} := U_{press.toe.gs.UN2} \cdot L_b \cdot W_b \cdot -1 = -19055.92 \cdot kN$

Moment Arm from Toe of Gate Structure for Uplift UA: $L_{A.UN2} := \left(\frac{L_b}{2}\right) = 9.25\,m$

Linearly Decreasing Uplift Force UN2B Under Gate Structure due to HW-TW Differential (triangle): $U_{B.UN2} := \frac{1}{2} \cdot \left(U_{HW.UN2} - U_{press.toe.gs.UN2}\right) \cdot L_b \cdot W_b \cdot -1 = -6941.8 \cdot kN$

Moment Arm from Toe of Gate Structure for Uplift UB: $L_{B.UN2} := \frac{2}{3} \cdot L_b = 12.33\,m$

Total Resultant Uplift force: $U_{UN2} := U_{A.UN2} + U_{B.UN2} = -25997.73 \cdot kN$

Resultant Location from Toe: $U_{UN2.loc} := \frac{\left(U_{A.UN2} \cdot L_{A.UN2} + U_{B.UN2} \cdot L_{B.UN2}\right)}{\left(U_{A.UN2} + U_{B.UN2}\right)} = 10.07\,m$

$\Sigma V_{water.UN2} := H_{1.UN2} + H_{2.UN2} + U_{UN2} = -11135.98 \cdot kN$

$\Sigma M_{Vwater.UN2} := H_{1.UN2} \cdot H_{1.UN2.loc} + H_{2.UN2} \cdot H_{2.UN2.loc} + U_{UN2} \cdot U_{UN2.loc} = -112890.84 \cdot kN \cdot m$

SOIL LOADS

UN2 CASE

Equivalent Fluid Pressure (EFP):

At rest lateral pressure coefficient: $K_{o.UN2} := 1 - \sin(\phi_{backfill}) = 0.658$ (Section 5.3, Design Criteria)

Headwater Pier Footing Unit Width: $W_{hwas.UN2} = 15.00\,m$

Tailwater Pier Footing Unit Width: $W_{tw.UN2} = 15.00\,m$

Pier Footing Thickness at Heel: $t_{hf.UN2} := TOC_{as} - BOK_{elev} = 6.00\,m$

Fixed Crest Footing Thickness at Toe: $t_{tf.UN2} := TOC_{pfe} - BOF_{elev} = 2.00\,m$

Lateral Driving Force (Headwater Side - at rest condition)

At-Rest Soil Load:

$$E_{act.UN2} := \frac{\left(K_{o.UN2} \cdot t_{hf.UN2}^{\;2}\right)}{2} \cdot (\gamma_r - \gamma_w) \cdot W_{hwas.UN2} \cdot -1 = -2165.61 \cdot kN$$

Acting at:

$$E_{act.UN2.loc} := \frac{t_{hf.UN2}}{3} = 2.00\,m$$

Lateral Resisting Force (Tailwater Side - at rest condition)

At-rest Soil Load:

$$E_{pass.UN2} := \frac{\left(K_{o.UN2} \cdot t_{tf.UN2}^{\;2}\right)}{2} \cdot (\gamma_r - \gamma_w) \cdot W_{tw.UN2} = 240.62 \cdot kN$$

Acting at:

$$E_{pass.UN2.loc} := \frac{t_{tf.UN2}}{3} = 0.67\,m$$

$$\Sigma H_{soil.UN2} := E_{act.UN2} + E_{pass.UN2} = -1924.99 \cdot kN$$

$$\Sigma M_{soil.UN2} := E_{act.UN2} \cdot E_{act.UN2.loc} + E_{pass.UN2} \cdot E_{pass.UN2.loc} = -4170.8 \cdot kN \cdot m$$

ICE / IMPACT LOADS (ASSUME NO ICE LOADING ON TAILWATER SIDE)

Static Ice load on Gates:

$$I_{G.UN2} := \begin{cases} 00\,\frac{kN}{m} & \text{if } TOP_{rg.UN2} \le TOC_{as} \\ 0\,\frac{kN}{m} & \text{if } TOP_{rg.UN2} > TOC_{as} \end{cases} = 0 \cdot \frac{kN}{m}$$

(Section 7.7, Design Criteria)

Ice Loading Unit Width on Reg. Gate: $W_{rg.UN2} := 15.00\,m$ (Input value for load case)

Total Ice Load on Structure: $I_{UN2} := -\left(I_{G.UN2} \cdot W_{rg.UN2}\right) = 0 \cdot kN$

Apply Ice load at: $I_{UN2.loc} := \left(TOP_{rg.UN2} - BOF_{elev} - 0.30m\right) = 3.70\,m$

$$\Sigma H_{I.UN2} := I_{UN2} = 0 \cdot kN$$

$$\Sigma M_{I.UN2} := I_{UN1} \cdot I_{UN1.loc} = 0 \cdot kN \cdot m$$

(SEISMIC LOAD (NOT APPLICABLE FOR THIS LOAD CASE)

UN2 CASE

SUMMARY OF LOADS

	Loads	Moment Arm
Dead load of Concrete Structure:	$D_{conc} = 24618.6 \cdot kN$	$X_{conc.loc} = 10.06\,m$
Obermyer Gate Weight:	$D_{Gate} = 210.0 \cdot kN$	$X_{gate} = 6.60\,m$
HW Lateral Load on Approach Slab:	$H_{hwas.UN2} = -8034.4 \cdot kN$	$H_{hwas.UN2.loc} = 0.67\,m$
HW Lateral Load on Reg. Gate:	$H_{hwrg.UN2} = 0.0 \cdot kN$	$H_{hwrg.UN2.loc} = 4.00\,m$
TW Lateral Load on Gate Footing (Including Key - Sliding Check Loads):	$H_{twgk.UN2} = 5753.56 \cdot kN$	$H_{twgk.UN2.loc} = 0.35\,m$
TW Lateral Load on Reg. Gate:	$H_{twrg.UN2} = 0.0 \cdot kN$	$H_{twrg.UN2.loc} = 4.00\,m$
Vertical HW Load on Approach Slab:	$H_{1.UN2} = 7854.1 \cdot kN$	$H_{1.UN2.loc} = 14.13\,m$
Vertical TW Load on Pier Footing (crest):	$H_{2.UN2} = 7007.6 \cdot kN$	$H_{2.UN2.loc} = 5.43\,m$
Uplift:	$U_{UN2} = -25997.7 \cdot kN$	$U_{UN2.loc} = 10.07\,m$
Lateral Soil Load (driving):	$E_{act.UN2} = -2165.6 \cdot kN$	$E_{act.UN2.loc} = 2.00\,m$
Lateral Soil Load (resisting):	$E_{pass.UN2} = 240.62 \cdot kN$	$E_{pass.UN2.loc} = 0.67\,m$
Ice / Impact Load:	$I_{UN2} = 0.0 \cdot kN$	$I_{UN2.loc} = 3.70\,m$

STABILITY ASSESSMENT (SLIDNG, BEARING, FLOTATION AND OVERTURNING): UN2 CASE

CHECK SLIDING ALONG HORIZONTAL PLANE THRU TOE,
IGNORING BEDROCK MOBILIZED BY STRUCTURAL HEEL KEY, OR VOID BEHIND KEY

Sum of Vertical Forces:

Sum of Horizontal Forces:

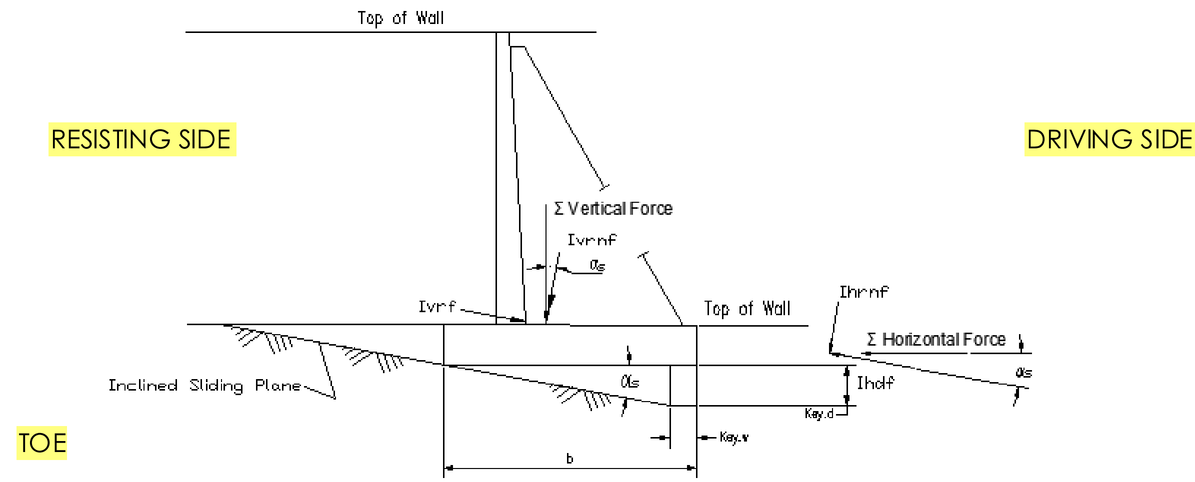
$\Sigma V_{UN2} := \Sigma V_{DL} + \Sigma V_{water.UN2} = 13692.6 \cdot kN$

$\Sigma H_{UN2} := \Sigma H_{Water.UN2} + \Sigma H_{soil.UN2} + \Sigma H_{I.UN2} = -4205.81 \cdot kN$

Sliding Factor of Safety: $FS_{HorizSliding.UN2} := \dfrac{\tan_{\phi} \cdot \Sigma V_{UN2}}{\left|\Sigma H_{UN2}\right|} = 1.59$

$FS_{HorizSliding.UN2.Check} :=$ | "OKAY" if $FS_{HorizSliding.UN2} \ge FS_{req.UN2.sl}$ = "OKAY"
| "Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !" otherwise

CHECK SLIDING ALONG INCLINED SLIDING PLANE FROM HEEL KEY TO TOE,
WITH BEDROCK MASS MOBILIZED BY REINFOCREDE CONCRETE KEY)



Ivrf=Inclined Resisting Force
Ivrnf=Inclined Resisting Normal Force
Ihrnf=Inclined Resisting Normal Force
Ihdf=Inclined Driving Force

$\alpha s = 0.11$

as degrees= $\alpha s \cdot \left(\dfrac{180}{\pi}\right) = 6.52$

$\Sigma V_{UN2} = 13692.62 \cdot kN$

$V_{rs} = 5775 \cdot kN$

Resolve $\Sigma Vert_{UN2}$ & $\Sigma Horiz_{UN2}$

$\Sigma V_{InclinedUN2} := \cos(\alpha s) \cdot \left(\Sigma V_{UN2} + V_{rs}\right) + \sin(\alpha s) \cdot \left|\Sigma H_{UN2}\right| = 19819.3 \cdot kN$

$\Sigma H_{InclinedUN2} := \cos(\alpha s) \cdot \left|\Sigma H_{UN2}\right| - \sin(\alpha s) \cdot \left(\Sigma V_{UN2} + V_{rs}\right) = 1968.1 \cdot kN$

(With properly engineered reinforced concrete Key, horizontal sliding plane thru Toe is protected, critical sliding plane is relocated to the INCLINED SLIDING PLANE FROM HEEL KEY To TOE, Bedrock Mass above this examined plane is mobilized by reinforced concrete key and combined into Structural Wedge.)

Inclined Sliding Plane Length

$L_{incline} = 18.61\ m$

Safety Factor for Sliding
Inclined Failure Plane

$FS_{InclinedISlidingUN2} := \dfrac{\Sigma V_{InclinedUN2} \cdot \tan\left(\phi_{rock} \cdot \dfrac{\pi}{180}\right)}{\left|\Sigma H_{InclinedUN2}\right|} = 4.91$

$FS_{InclinedSliding.check.UN2} :=$ | "OKAY " if $FS_{InclinedISlidingUN2} > FS_{req.UN2.sl}$ = "OKAY "
| "Revise Structure"" otherwise

$FS_{InclinedSliding.check.UN2}$ = "OKAY "

OVERTURNING STABILITY CHECK:

UN2 CASE

CHECK ECCENTRICITY

Sum of the moments:

$$\Sigma M_{UN2} := \Sigma M_{DL} + \Sigma M_{Hwater.UN2} + \Sigma M_{Vwater.UN2} + \Sigma M_{I.UN2} + \Sigma M_{soil.UN2} + \Sigma M_{soil} = 195912 \cdot kN \cdot m$$

Eccentricity:

$$e_{UN2} := \left(\frac{L_{incline}}{2}\right) - \frac{\left(\Sigma M_{UN2}\right)}{\Sigma V_{InclinedUN2}} = -0.58\,m$$

Eccentricity Check:

$$e_{check.UN2} := \begin{cases} \text{"Okay"} & \text{if } \left|e_{UN2}\right| \le Kern \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$e_{check.UN2} = \text{"Okay"}$

Foundation Bearing Checks:

Incline Plane Area: $A_{b.incline} = 279.12\,m^2$

Incline Plane Section Modulus: $S_{b.incline} = 865.63 \cdot m^3$

Bearing Pressure at Heel:

$$\sigma_{heel.UN2} := \frac{\Sigma V_{InclinedUN2}}{A_{b.incline}} - \frac{\left(\Sigma V_{InclinedUN2} \cdot e_{UN2}\right)}{S_{b.incline}} = 84.3 \cdot \frac{kN}{m^2}$$

$$\sigma_{heel.UN2.check} := \left(\begin{cases} \text{"Okay"} & \text{if } \sigma_{heel.UN2} \le \sigma_{allow.UN2} \\ \text{"Revise Structure"} & \text{if } \sigma_{heel.UN2} < 0\,\frac{kN}{m^2} \end{cases}\right)$$

$\sigma_{heel.UN2.check} = \text{"Okay"}$

Bearing Pressure at Toe:

$$\sigma_{toe.UN2} := \frac{\Sigma V_{InclinedUN2}}{A_{b.incline}} + \frac{\left(\Sigma V_{InclinedUN2} \cdot e_{UN2}\right)}{S_{b.incline}} = 57.7 \cdot \frac{kN}{m^2}$$

$$\sigma_{toe.UN2.1.check} := \begin{cases} \text{"Okay"} & \text{if } \sigma_{toe.UN2} \le \sigma_{allow.UN2} \\ \text{"Revise Structure"} & \text{if } \sigma_{toe.UN2} < 0\,\frac{kN}{m^2} \end{cases}$$

$\sigma_{toe.UN2.1.check} = \text{"Okay"}$

FLOATATION ANALYSIS:

ACCEPTANCE PARAMETERS

Required Factor of Safety: $FS_{req.FUN2} := 1.3$

VERTICAL LOADS RESISTING:

Dead Load: $\Sigma V_{DL} = 24828.6 \cdot kN$

Water Weight H1+H2: $\Sigma V_{H.FUN2} := H_{1.UN2} + H_{2.UN2} = 14861.75 \cdot kN$

Summation Vertical Resisting: $\Sigma V_{FUN2} := \Sigma V_{DL} + \Sigma V_{H.FUN2} = 39690.3 \cdot kN$

VERTICAL LOADS UPLIFT:

Uplift: $U_{UN2} = -25997.73 \cdot kN$

Factor of Safety Floatation:

$$FS_{act.FUN2} := \frac{\Sigma V_{FUN2}}{\left|U_{UN2}\right|} = 1.53$$

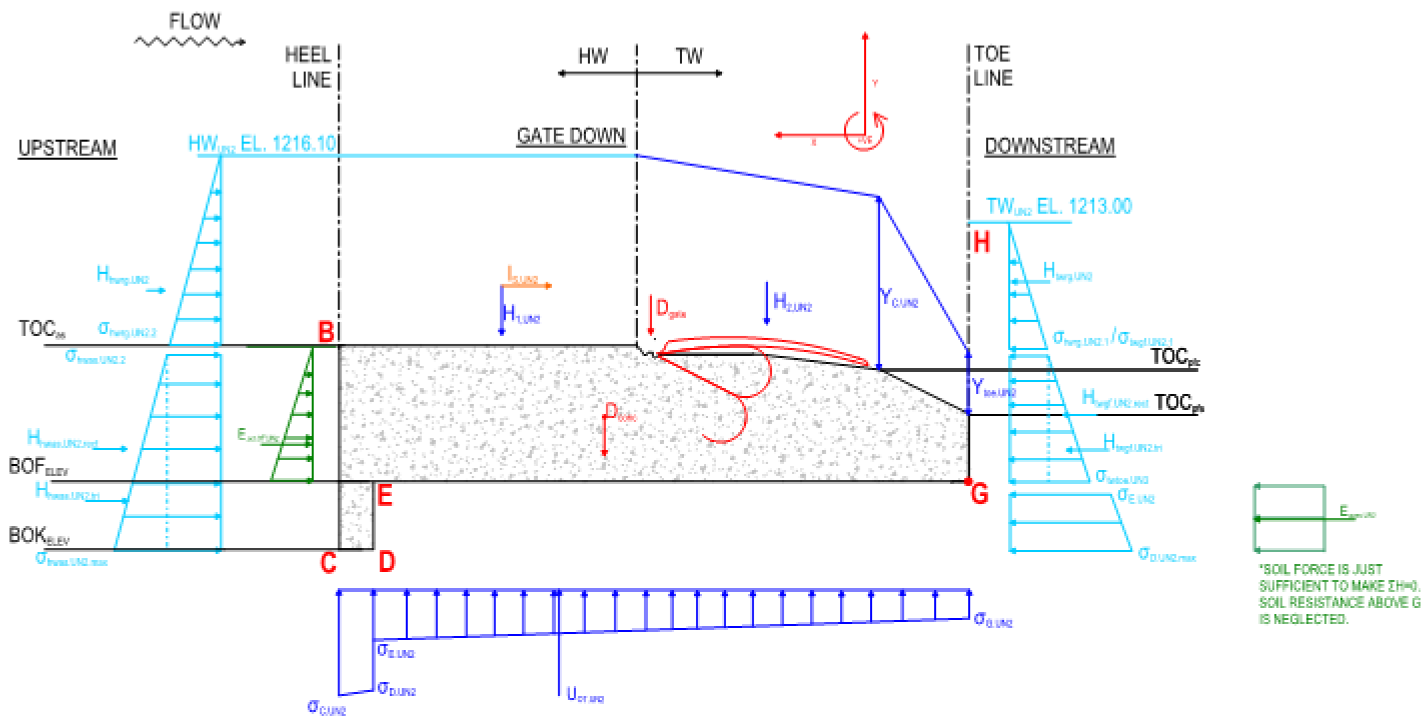
$$FS_{check.FUN2} := \begin{cases} \text{"OKAY"} & \text{if } FS_{act.FUN2} \ge FS_{req.FUN2} \\ \text{"ANCHORS REQUIRED"} & \text{if } FS_{act.FUN2} < FS_{req.FUN2} \end{cases} = \text{"OKAY"}$$

UN2 CASE

MONOLITH OVERTURNING STABILITY ANALYSIS

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.
Assumptions are made in order to compute overturning stability of indetermine forces on monolith with key;
(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.
(b) The horizontal resisting force acting on the key, P.key, is that required for static equilibrium
(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1 $Ratio_{OT.UN2.min} := 0.33$



Uplift Loads for Overturning Stability Analysis

Line of Creep:

Change in Water Head: $\Delta_{h.UN2} := HW_{UN2} - TW_{UN2} = 3.1\ m$

Length from Point C to Point G: $L_{CG} = 18.61\ m$

Length from Various Points to Points: $L_{CD} = 1\ m$ $L_{DE} = 2\ m$ $L_{EG} = 17.5\ m$

$L_{GH.UN2} := TW_{UN2} - BOF_{elev} = 7\ m$

Length from Point C, D, E to G: $L_{CDEG} = 20.5\ m$ $L_{CDE} = 3\ m$

Water Pressure at Point C: $\sigma_{C.UN2} := \sigma_{hwas.UN2.2} = -118.7 \cdot kPa$

Water Pressure at Point G: $\sigma_{G.UN2} := \sigma_{twtoe.UN2} \cdot -1 = -68.67 \cdot kPa$

Water Pressure at Point D:
$$\sigma_{D.UN2} := -\gamma_w \cdot \left[\left(HW_{UN2} - BOK_{elev} \right) - \frac{\Delta_{h.UN2} \cdot L_{CD}}{L_{CDEG}} \right] = -117.22 \cdot kPa$$

Water Pressure at Point E:
$$\sigma_{E.UN2} := -\gamma_w \cdot \left[\left(HW_{UN2} - BOF_{elev} \right) - \frac{\Delta_{h.UN2} \cdot L_{CDE}}{L_{CDEG}} \right] = -94.63 \cdot kPa$$

Uplift for Overturning Analysis on Bottom of Key:
$$U_{OT.UN2.key} := \frac{\sigma_{C.UN2} + \sigma_{D.UN2}}{2} \cdot L_{CD} \cdot W_b = -1769.39 \cdot kN$$

Acting at:
$$U_{OT.UN2.key.loc} := \frac{L_{CD} \cdot \left(2 \cdot \sigma_{C.UN2} + \sigma_{D.UN2} \right)}{3 \left(\sigma_{C.UN2} + \sigma_{D.UN2} \right)} + L_{EG} = 18\ m$$

UN2 CASE

Uplift for Overturning Analysis on Bottom of Footing:

$$U_{OT.UN2.ftg} := \frac{\sigma_{E.UN2} + \sigma_{G.UN2}}{2} \cdot L_{EG} \cdot W_b = -21433.21 \cdot kN$$

Acting at:

$$U_{OT.UN2.ftg.loc} := \frac{L_{EG} \cdot \left(\sigma_{G.UN2} + 2 \cdot \sigma_{E.UN2}\right)}{3\left(\sigma_{G.UN2} + \sigma_{E.UN2}\right)} = 9.21\,m$$

Uplift Load for Overturning Analysis:

$$U_{OT.UN2} := U_{OT.UN2.key} + U_{OT.UN2.ftg} = -23202.59 \cdot kN$$

Uplift Load Acting from Toe:

$$U_{OT.UN2.loc} := \frac{U_{OT.UN2.key} \cdot U_{OT.UN2.key.loc} + U_{OT.UN2.ftg} \cdot U_{OT.UN2.ftg.loc}}{U_{OT.UN2}} = 9.88\,m$$

All Vertical Loads Applicable to Overturning Stability Analysis

Total Concrete Dead Loads:	$D_{conc} = 24618.6 \cdot kN$	at:	$X_{conc.loc} = 10.06\,m$
Dead Load of Gate:	$D_{Gate} = 210.0 \cdot kN$		$X_{gate} = 6.60\,m$
Water Weight (HW) on Apron Slab:	$H_{1.UN2} = 7854.1 \cdot kN$		$H_{1.UN2.loc} = 14.13\,m$
Water Weight (TW) on Gate Footing:	$H_{2.UN2} = 7007.6 \cdot kN$		$H_{2.UN2.loc} = 5.43\,m$
Uplift Load for Overturning Analysis:	$U_{OT.UN2} = -23202.59 \cdot kN$		$U_{OT.UN2.loc} = 9.88 \cdot m$

Sum of All Overturning Analysis Vertical Load:

$$\Sigma V_{UN2.OT} := D_{conc} + D_{Gate} + H_{1.UN2} + H_{2.UN2} + U_{OT.UN2} = 16487.75 \cdot kN$$

Sum of All Overturning Analysis Vertical Load Moments:

$$\Sigma M_{V.UN2.OT} := D_{conc} \cdot X_{conc.loc} + D_{Gate} \cdot X_{gate} + H_{1.UN2} \cdot H_{1.UN2.loc} + H_{2.UN2} \cdot H_{2.UN2.loc} + U_{OT.UN2} \cdot U_{OT.UN2.loc} = 168606.36 \cdot kN \cdot m$$

Lateral Tailwater Loads for Overturning Stability Analysis

TW Lateral Load on Gate Footing (No Key - Overturning Values Adjusted):

$$H_{twgf.UN2} := H_{twgf.UN2.tri} + H_{twgf.UN2.rect} = 2943 \cdot kN$$

Acting at:

$$H_{twgf.UN2.loc} := \frac{\frac{h_{toe}}{3} \cdot H_{twgf.UN2.tri} + \frac{h_{toe}}{2} \cdot H_{twgf.UN2.rect}}{H_{twgf.UN2}} = 1.73\,m$$

Horizontal Tailwater Pressure Top of Key (Overturning Analysis):

$$\sigma_{twtk.OT.UN2} := \sigma_{E.UN2} \cdot -1 = 94.63 \cdot kPa$$

Horizontal Tailwater Pressure Bottom of Key (Overturning Analysis):

$$\sigma_{twbk.OT.UN2} := \sigma_{D.UN2} \cdot -1 = 117.22 \cdot kPa$$

Triangular Distribution Unit Load Acting at Key:

$$H_{twbk.OT.UN2.tri} := \frac{\left(\sigma_{twbk.OT.UN2} - \sigma_{twtk.OT.UN2}\right)}{2} \cdot d_{key} \cdot W_{tw.UN2} = 338.8 \cdot kN$$

Triangular Distribution Unit Load Acting at Key:

$$H_{twbk.OT.UN2.rect} := \sigma_{twtk.OT.UN2} \cdot d_{key} \cdot W_{tw.UN2} = 2838.92 \cdot kN$$

Total Horizontal Tailwater Load on Key (Overturning Values Adjusted):

$$H_{twkey.OT.UN2} := H_{twbk.OT.UN2.tri} + H_{twbk.OT.UN2.rect} = 3177.72 \cdot kN$$

Acting at:

$$H_{twkey.OT.UN2.loc} := \frac{H_{twbk.OT.UN2.tri} \cdot \frac{-2 \cdot d_{key}}{3} + H_{twbk.OT.UN2.rect} \cdot \frac{-d_{key}}{2}}{H_{twkey.OT.UN2}} = -1.04 \cdot m$$

UN2 CASE

Lateral Driving Earth Loads for Overturning Stability Analysis (at rest condition)

Depth of Driving Soil Loads (to top of key): $h_{E.OT.UN2} := TOC_{as} - BOF_{elev} = 4\,m$

At-Rest Soil Load: $E_{act.OT.UN2} := \dfrac{\left(K_{o.UN2} \cdot h_{E.OT.UN2}{}^{2}\right)}{2} \cdot \left(\gamma_r - \gamma_w\right) \cdot W_{hwas.UN2} \cdot -1 = -962.49 \cdot kN$

At Rest- Soil Load Acting from Toe: $E_{act.OT.UN2.loc} := \dfrac{h_{E.OT.UN2}}{3} = 1.33\,m$

All Lateral Loads Appliable to Overturning Stability Analysis

HW Lateral Load on Approach Slab:	$H_{hwas.UN2} = -8034.4 \cdot kN$	$H_{hwas.UN2.loc} = 0.67\,m$
HW Lateral Load on Reg. Gate:	$H_{hwrg.UN2} = 0.0 \cdot kN$	$H_{hwrg.UN2.loc} = 4.00\,m$
TW Lateral Load on Reg. Gate:	$H_{twrg.UN2} = 0.0 \cdot kN$	$H_{twrg.UN2.loc} = 4.00\,m$
TW Lateral Load on Gate Footing (No Key - Overturning Values Adjusted):	$H_{twgf.UN2} = 2943 \cdot kN$	$H_{twgf.UN2.loc} = 1.73\,m$
TW Lateral Load on Key:	$H_{twkey.OT.UN2} = 3177.72 \cdot kN$	$H_{twkey.OT.UN2.loc} = -1.04\,m$
Ice / Impact Load:	$I_{UN2} = 0.0 \cdot kN$	$I_{UN2.loc} = 3.70\,m$
Lateral Soil Load (driving):	$E_{act.OT.UN2} = -962.5 \cdot kN$	$E_{act.OT.UN2.loc} = 1.33\,m$

Resisting Lateral Soil Load as required to produce horizontal equilibrium:

$$E_{pas.OT.UN2} := -\left(H_{hwas.UN2} + H_{hwrg.UN2} + H_{twrg.UN2} + H_{twgf.UN2} + H_{twkey.OT.UN2} + I_{UN2} + E_{act.OT.UN2}\right) = 2876.16 \cdot kN$$

Acting at:

$$E_{pas.OT.UN2.loc} := -1 \cdot \frac{d_{key}}{2} = -1\,m$$

Sum of All Overturning Analysis Horizontal Load (ΣH=0):

$$\Sigma H_{UN2.OT} := H_{hwas.UN2} + H_{hwrg.UN2} + H_{twrg.UN2} + H_{twgf.UN2} + H_{twkey.OT.UN2} + I_{UN2} + E_{act.OT.UN2} + E_{pas.OT.UN2} = 0 \cdot kN$$

Sum of All Overturning Analysis Horizontal Load Moments:

$$\begin{aligned}\Sigma M_{H.UN2.OT} := {} & H_{hwas.UN2} \cdot H_{hwas.UN2.loc} + H_{hwrg.UN2} \cdot H_{hwrg.UN2.loc} + H_{twrg.UN2} \cdot H_{twrg.UN2.loc} \cdots = -7734.63 \cdot kN \cdot m \\ & + H_{twgf.UN2} \cdot H_{twgf.UN2.loc} + H_{twkey.OT.UN2} \cdot H_{twkey.OT.UN2.loc} + I_{UN2} \cdot I_{UN2.loc} \cdots \\ & + E_{act.OT.UN2} \cdot E_{act.OT.UN2.loc} + E_{pas.OT.UN2} \cdot E_{pas.OT.UN2.loc}\end{aligned}$$

Overturning Stability Analysis

$\Sigma M_{UN2.OT} := \Sigma M_{V.UN2.OT} + \Sigma M_{H.UN2.OT} = 160871.72 \cdot kN \cdot m$ $\quad X_{R.UN2} := \dfrac{\Sigma M_{UN2.OT}}{\Sigma V_{UN2.OT}} = 9.76\,m$ $\quad x_{OT.UN2} := X_{R.UN2} - \dfrac{L_b}{2} = 0.51\,m$

Overturning Resultant Ratio $\quad Ratio_{OT.UN2} := \dfrac{X_{R.UN2}}{L_b} = 0.53$

$$Ratio_{OT.UN2.check} := \begin{cases} \text{"OKAY"} & \text{if } Ratio_{OT.UN2} \geq Ratio_{OT.UN2.min} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

$$x_{OT.check.UN2} := \begin{cases} \text{"OKAY"} & \text{if } \left|x_{OT.UN2}\right| \leq Kern \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

CHECK FOUNDATION BEARING CAPACITY (HORIZONTAL PLANE):

UN2 CASE

Bearing Pressure Under Toe:

$$\sigma_{ToeUN2.OT} := \frac{\Sigma V_{UN2.OT}}{L_b \cdot W_b} + \frac{\left(\Sigma V_{UN2.OT} \cdot x_{OT.UN2}\right)}{S_b} = 69.2 \cdot kPa$$

$$Bearing_{ChecktoeUN2.OT} := \begin{cases} \text{"OKAY "} & \text{if } \sigma_{ToeUN2.OT} < \sigma_{allow.UN2} \\ \text{"NG""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

Bearing Pressure Under Heel:

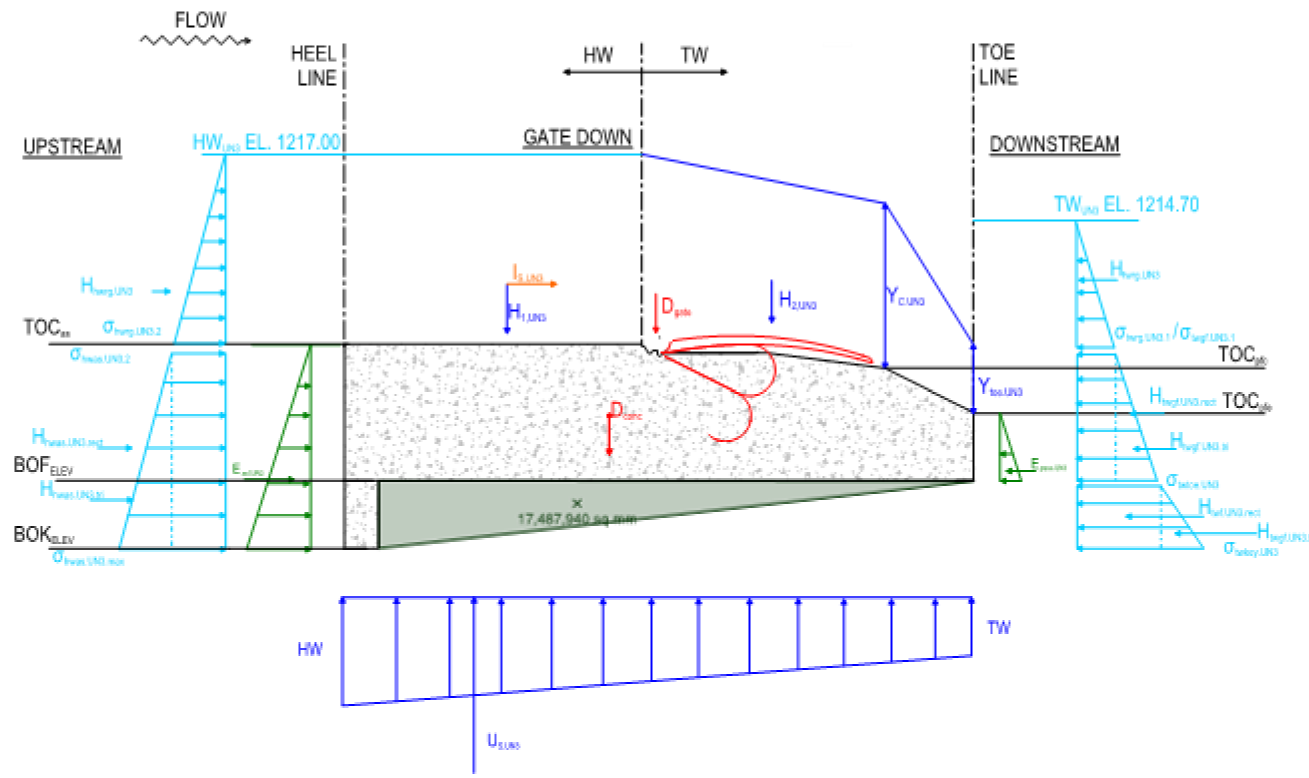
$$\sigma_{HeelUN2.OT} := \frac{\Sigma V_{UN2.OT}}{L_b \cdot W_b} - \frac{\left(\Sigma V_{UN2.OT} \cdot x_{OT.UN2}\right)}{S_b} = 49.6 \cdot kPa$$

$$Bearing_{CheckheelUN2.OT} := \left(\begin{cases} \text{"OKAY "} & \text{if } \sigma_{HeelUN2.OT} < \sigma_{allow.UN2} \wedge \sigma_{HeelUN2.OT} > 0 \\ \text{"NG""} & \text{otherwise} \end{cases} \right) = \text{"OKAY "}$$

SUMMARY OF STABILITY ASSESSMENT:

Sliding Factor of Safety: (Horizontal Plane)	$FS_{HorizSliding.UN2} = 1.59$	$FS_{HorizSliding.UN2.Check} = \text{"OKAY"}$
Sliding Factor of Safety: (Inclined Plane)	$FS_{InclinedlSlidingUN2} = 4.91$	$FS_{InclinedSliding.check.UN2} = \text{"OKAY "}$
Eccentricity: (Inclined Plane)	$e_{UN2} = -0.58\,m$	$e_{check.UN2} = \text{"Okay"}$
Bearing Pressure At Heel: (Inclined Plane)	$\sigma_{heel.UN2} = 84 \cdot kPa$	$\sigma_{heel.UN2.check} = \text{"Okay"}$
Bearing Pressure At Toe: (Inclined Plane)	$\sigma_{toe.UN2} = 58 \cdot kPa$	$\sigma_{toe.UN2.1.check} = \text{"Okay"}$
Flotation Factor of Safety (horizontal plane)	$FS_{act.FUN2} = 1.53$	$FS_{check.FUN2} = \text{"OKAY"}$
Overturning Resultant Ratio: (horizontal plane)	$Ratio_{OT.UN2} = 0.53$	$Ratio_{OT.UN2.check} = \text{"OKAY"}$
Eccentricity: (horizontal plane)	$x_{OT.UN2} = 0.51\,m$	$x_{OT.check.UN2} = \text{"OKAY"}$
Bearing Pressure At Heel: (horizontal plane)	$\sigma_{HeelUN2.OT} = 50 \cdot kPa$	$Bearing_{CheckheelUN2.OT} = \text{"OKAY "}$
Bearing Pressure At Toe: (horizontal plane)	$\sigma_{ToeUN2.OT} = 69 \cdot kPa$	$Bearing_{ChecktoeUN2.OT} = \text{"OKAY "}$

UN3 DESIGN CASE



ACCEPTANCE PARAMETERS

Required Factor of Safety for Sliding: $FS_{req.UN3.sl} := 1.3$ (Without Cohesion) (Section 8.1, Design Criteria)

Resultant Within Middle Third of Base: $e \le \frac{L_b}{6} \wedge e \ge \frac{-L_b}{6}$

Allowable Rock Bearing Pressure: $\sigma_{allow.UN3} := 1470 \cdot \frac{kN}{m^2}$ (Section 5.2, Design Criteria)

INPUT PARAMETERS

Headwater Elevation: $HW_{UN3} := 1217.0m$ (Section 8.3, Design Criteria)

Tailwater Elevation: $TW_{UN3} := 1214.70m$ (Section 8.3, Design Criteria)

Bottom of Footing Elevation: $BOF_{elev} = 1206\,m$

Approach Slab Top of Concrete Elevation at Upstream Face: $TOC_{as} = 1210\,m$

Footing Top of Concrete Elevation at Stilling Basin: $TOC_{pfe} = 1208\,m$

Footing Top of Concrete Elevation at Center of Footing: $TOC_{pfc} = 1209.3\,m$

Top of Guard/Regulating Gate Elevation: $TOP_{rg.UN3} := 1210.00m$ $TOP_{gg.UN3} := 1210.00m$

Gates are open when top of gate elevation is at 1210.00m

Gates are closed/up when top of gate elevation is at 1215.0m

Bottom of Key Elevation: $BOK_{elev} = 1204\,m$

Crestwater Elevation: Dynamic Flow $EL_{C.UN3} := 1214.67m$

$$Y_{C.UN3} := \begin{cases} \left(EL_{C.UN3} - TOC_{pfc}\right) & \text{if } TOP_{rg.UN3} \le HW_{UN3} \\ \left(TW_{UN3} - TOC_{pfc}\right) & \text{if } TOP_{rg.UN3} > HW_{UN3} \end{cases} = 5.37 \cdot m$$

Toewater Elevation: $EL_{TOE.UN3} := 1210.89m$

$$Y_{TOE.UN3} := \begin{cases} \left(EL_{TOE.UN3} - TOC_{pfe}\right) & \text{if } TOP_{rg.UN3} \le HW_{UN3} \\ \left(TW_{UN3} - TOC_{pfe}\right) & \text{if } TOP_{rg.UN3} > HW_{UN3} \end{cases} = 2.89 \cdot m$$

LATERAL WATER LOADS

UN3 CASE

HEADWATER (DRIVING):

Headwater Depth on Gate: $D_{hwg.UN3} := HW_{UN3} - TOC_{as} = 7.00\,m$

Thickness of Approach Slab (Including Key): $T_{as} = 6\,m$

Headwater Depth at Heel (U/S face): $D_{hwas.UN3} := HW_{UN3} - BOK_{elev} = 13.00\,m$

Headwater Load Unit Width on Approach Slab: $W_{hwas.UN3} := W_b = 15.00\,m$

Headwater Unit Load At Top of Approach Slab:

$$H_{hwas.UN3.1} := \frac{-\left(\gamma_w \cdot D_{hwg.UN3}{}^2\right)}{2} \cdot W_{hwas.UN3} = -3605.18 \cdot kN$$

Headwater Unit Load At Bottom of Approach Key:

$$H_{hwas.UN3.2} := \frac{-\left(\gamma_w \cdot D_{hwas.UN3}{}^2\right)}{2} \cdot W_{hwas.UN3} = -12434.2 \cdot kN$$

Headwater Line Load At Top of Approach Slab:

$$\sigma_{hwas.UN3.1} := -\left(\gamma_w \cdot D_{hwg.UN3}\right) = -68.67 \cdot kPa$$

Headwater Line Load At Bottom of Approach Key:

$$\sigma_{hwas.UN3.2} := -\left(\gamma_w \cdot D_{hwas.UN3}\right) = -127.53 \cdot kPa$$

Triangular Distribution Unit Load on Approach Slab and Key:

$$H_{hwas.UN3.2.tri} := \left(\frac{\sigma_{hwas.UN3.2} - \sigma_{hwas.UN3.1}}{2}\right) \cdot \left(T_{as} \cdot W_{hwas.UN3}\right) = -2648.7 \cdot kN$$

Rectangular Distribution Unit Load on Approach Slab and Key:

$$H_{hwas.UN3.2.rect} := \sigma_{hwas.UN3.1} \cdot \left(T_{as} \cdot W_{hwas.UN3}\right) = -6180.3 \cdot kN$$

Total Horizontal Headwater Load on Approach Slab:

$$H_{hwas.UN3} := H_{hwas.UN3.2.tri} + H_{hwas.UN3.2.rect} = -8829 \cdot kN$$

Apply Total Footing Headwater Load at:

$$H_{hwas.UN3.loc} := \frac{\left[H_{hwas.UN3.2.rect} \cdot \frac{\left(T_{as}\right)}{2} + H_{hwas.UN3.2.tri} \cdot \frac{\left(T_{as}\right)}{3}\right]}{H_{hwas.UN3.2.tri} + H_{hwas.UN3.2.rect}} - d_{key} = 0.70\,m$$

Regulating Gate (4A) Operating Condition:

Reg. Gate Down/Open Condition: $A1_{UN3} := TOP_{rg.UN3} \le TOC_{as}$

Reg. Crest Gate Up/Closed, with Top of Gate Higher than HW Elevation: $B1_{UN3} := TOP_{rg.UN3} \ge HW_{UN3} \wedge TOP_{rg.UN3} > TOC_{as}$

Reg. Crest Gate Up/Closed, with Top of Gate Lower than HW Elevation: $C1_{UN3} := TOP_{rg.UN3} > TOC_{as} \wedge HW_{UN3} > TOP_{rg.UN3}$

Reg. Crest Gate Height: $H_{rg.UN3} := TOP_{rg.UN3} - TOC_{as} = 0\,m$

Headwater Depth at Reg. Crest Gate: $D_{hwrg.UN3} := HW_{UN3} - TOC_{as} = 7.00\,m$

Reg. Crest Gate Width: $W_{hwrg.UN3} := 15.00m$

Lateral Headwater Pressure at Bottom of Reg. Crest Gate:

$$\sigma_{hwrg.UN3.1} := \begin{cases} (0.0kPa) & \text{if } A1_{UN3} \\ -(\gamma_w \cdot D_{hwrg.UN3}) & \text{if } B1_{UN3} \\ -(\gamma_w \cdot D_{hwrg.UN3}) & \text{if } C1_{UN3} \end{cases} = 0.0 \cdot kPa$$

Lateral Headwater Pressure at Top of Reg. Crest Gate: (Load at HW Elevation On Reg. Crest Gate if HW is below TOG_{rg})

$$\sigma_{hwrg.UN3.2} := \begin{cases} (0.0kPa) & \text{if } A1_{UN3} \\ 0.0kPa & \text{if } B1_{UN3} \\ -\left[\gamma_w \cdot (HW_{UN3} - TOP_{rg.UN3})\right] & \text{if } C1_{UN3} \end{cases} = 0.0 \cdot kPa$$

Average Pressure acting on Reg. Crest Gate:

$$\sigma_{hwrg.UN3.avg} := \frac{(\sigma_{hwrg.UN3.1} + \sigma_{hwrg.UN3.2})}{2} = 0 \cdot kPa$$

Total Area of Crest Gate:

$$A_{hwrg.UN3} := \begin{cases} D_{hwrg.UN3} \cdot W_{hwrg.UN3} & \text{if } A1_{UN3} \\ D_{hwrg.UN3} \cdot W_{hwrg.UN3} & \text{if } B1_{UN3} \\ H_{rg.UN3} \cdot W_{hwrg.UN3} & \text{if } C1_{UN3} \end{cases} = 105 \cdot m^2$$

Total Horizontal Headwater Load on Reg. Crest Gate: $H_{hwrg.UN3} := \sigma_{hwrg.UN3.avg} \cdot A_{hwrg.UN3} = 0.0 \cdot kN$

Apply Total Reg. Crest Gate Headwater Load at:

$$H_{hwrg.UN3.loc} := \begin{cases} (TOC_{as} - BOF_{elev}) & \text{if } A1_{UN3} \\ \left[\frac{(HW_{UN3} - TOC_{as})}{3} + (TOC_{as} - BOF_{elev})\right] & \text{if } B1_{UN3} \\ \left[\frac{\sigma_{hwrg.UN3.2} \cdot A_{hwrg.UN3} \cdot \frac{(H_{rg.UN3})}{2} + \frac{(\sigma_{hwrg.UN3.1} - \sigma_{hwrg.UN3.2})}{2} A_{hwrg.UN3} \cdot \frac{(H_{rg.UN3})}{3}}{\sigma_{hwrg.UN3.2} \cdot A_{hwrg.UN3} + \frac{(\sigma_{hwrg.UN3.1} - \sigma_{hwrg.UN3.2})}{2} \cdot A_{hwrg.UN3}} \ldots \\ + (TOC_{as} - BOF_{elev}) \right] & \text{if } C1_{UN3} \end{cases} = 4.0 \cdot m$$

LATERAL TAILWATER (RESISTING) Applied to Downstream Side of Reg. Crest Gate: UN3 CASE

Reg. Gate Down/Open Condition: $A2_{UN3} := TOP_{rg.UN3} \le TOC_{as}$

Reg. Crest Gate Up/Closed, with Top of Gate Higher than TW Elevation: $B2_{UN3} := TOP_{rg.UN3} \ge TW_{UN3} \wedge TOP_{rg.UN3} > TOC_{as}$

Reg. Crest Gate Up/Closed, with Top of Gate Lower than TW Elevation: $C2_{UN3} := TOP_{rg.UN3} > TOC_{as} \wedge TW_{UN3} > TOP_{rg.UN3}$

Tailwater Depth at Reg. Crest Gate: $D_{twrg.UN3} := TW_{UN3} - TOC_{as} = 4.70\,m$

Reg. Crest Gate Width: $W_{twrg.UN3} := 15.00m$

Lateral Water Load at Bottom of Reg. Crest Gate:

$$\sigma_{twrg.UN3.1} := \begin{cases} (0.0kPa) & \text{if } A2_{UN3} \\ (\gamma_w \cdot D_{twrg.UN3}) & \text{if } B2_{UN3} \\ (\gamma_w \cdot D_{twrg.UN3}) & \text{if } C2_{UN3} \end{cases} = 0.0 \cdot kPa$$

Lateral Water Load at Top of Reg. Crest Gate:
(Load at TW Elevation On Reg. Crest Gate if TW is below TOG_{rg})

$$\sigma_{twrg.UN3.2} := \begin{cases} (0.0kPa) & \text{if } A2_{UN3} \\ 0.0kPa & \text{if } B2_{UN3} \\ \left[\gamma_w \cdot (TW_{UN3} - TOP_{rg.UN3})\right] & \text{if } C2_{UN3} \end{cases} = 0.0 \cdot kPa$$

Average Pressure acting on Reg. Crest Gate:

$$\sigma_{twrg.UN3.avg} := \frac{(\sigma_{twrg.UN3.1} + \sigma_{twrg.UN3.2})}{2} = 0 \cdot kPa$$

Total Area water acting on Crest Gate:

$$A_{twrg.UN3} := \begin{cases} D_{twrg.UN3} \cdot W_{twrg.UN3} & \text{if } A2_{UN3} \\ D_{twrg.UN3} \cdot W_{twrg.UN3} & \text{if } B2_{UN3} \\ H_{rg.UN3} \cdot W_{twrg.UN3} & \text{if } C2_{UN3} \end{cases} = 70.5 \cdot m^2$$

Total Horizontal Tailwater Load on Reg. Crest Gate: $H_{twrg.UN3} := \sigma_{twrg.UN3.avg} \cdot A_{twrg.UN3} = 0.0 \cdot kN$

Apply Total Horiz. TW Load on Reg. Gate at:

$$H_{twrg.UN3.loc} := \begin{cases} (TOC_{as} - BOF_{elev}) & \text{if } A2_{UN3} \\ \left[\frac{(TW_{UN3} - TOC_{as})}{3} + (TOC_{as} - BOF_{elev})\right] & \text{if } B2_{UN3} \\ \left[\frac{\sigma_{twrg.UN3.2} \cdot A_{twrg.UN3} \cdot \frac{(H_{rg.UN3})}{2} + \frac{(\sigma_{twrg.UN3.1} - \sigma_{twrg.UN3.2})}{2} A_{twrg.UN3} \cdot \frac{(H_{rg.UN3})}{3}}{\sigma_{twrg.UN3.2} \cdot A_{twrg.UN3} + \frac{(\sigma_{twrg.UN3.1} - \sigma_{twrg.UN3.2})}{2} \cdot A_{twrg.UN3}} \ldots \\ + (TOC_{as} - BOF_{elev})\right] & \text{if } C2_{UN3} \end{cases} = 4.0 \cdot m$$

LATERAL WATER LOADS (continued) UN3 CASE

TAILWATER (RESISTING) Applied to Concrete Structure:

Tailwater Depth At top of Gate Base Footing Elevation: $D_{twgf.UN3} := TW_{UN3} - TOC_{as} = 4.70\,m$

Water Depth at bottom of Gate Base Footing: $D_{twtoe.UN3} := TW_{UN3} - BOF_{elev} = 8.70\,m$

Footing Thickness at Toe $h_{toe} = 4\,m$

Unit Width of D/S face of crest for application of Tailwater Load: $W_{tw.UN3} := W_b = 15.00\,m$

Tailwater Pressure At Top of Gate Footing: $\sigma_{twgf.UN3} := \left(\gamma_w \cdot D_{twgf.UN3}\right) = 46.11 \cdot kPa$

Tailwater Line Load At Bottom of Gate Footing: $\sigma_{twtoe.UN3} := \left(\gamma_w \cdot D_{twtoe.UN3}\right) = 85.35 \cdot kPa$

Triangular Distribution Unit Load on Gate Footing Base $H_{twgf.UN3.tri} := \left(\frac{\sigma_{twtoe.UN3} - \sigma_{twgf.UN3}}{2}\right) \cdot \left(h_{toe} \cdot W_{tw.UN3}\right) = 1177.2 \cdot kN$

Rectangular Distribution Unit Load on Gate Footing Base: $H_{twgf.UN3.rect} := \sigma_{twgf.UN3} \cdot \left(h_{toe} \cdot W_{tw.UN3}\right) = 2766.42 \cdot kN$

Tailwater Pressure At Bottom of Sliding Failure Plane: $\sigma_{twbk.UN3} := \left(HW_{UN3} - BOK_{elev}\right) \cdot \gamma_w = 127.53 \cdot kPa$

Triangular Distribution Unit Load Below Footing: $H_{twbk.UN3.tri} := \frac{\left(\sigma_{twbk.UN3} - \sigma_{twtoe.UN3}\right)}{2} \cdot d_{key} \cdot W_{tw.UN3} = 632.74 \cdot kN$

Rectangular Distribution Load Below Footing Base: $H_{twbk.UN3.rect} := \sigma_{twtoe.UN3} \cdot d_{key} \cdot W_{tw.UN3} = 2560.41 \cdot kN$

Total Horizontal Tailwater Load on Gate Footing (including key):

$$H_{twgk.UN3} := H_{twgf.UN3.tri} + H_{twgf.UN3.rect} + H_{twbk.UN3.tri} + H_{twbk.UN3.rect} = 7136.78 \cdot kN$$

Apply Total Gate Footing Tailwater Load at:

$$H_{twgk.UN3.loc} := \frac{\left[H_{twgf.UN3.rect} \cdot \frac{\left(h_{toe}\right)}{2} + H_{twgf.UN3.tri} \cdot \frac{\left(h_{toe}\right)}{3} + H_{twbk.UN3.tri} \cdot \left(-d_{key} \cdot \frac{2}{3}\right) + H_{twbk.UN3.rect} \cdot \left(\frac{-d_{key}}{2}\right)\right]}{H_{twgf.UN3.tri} + H_{twgf.UN3.rect} + H_{twbk.UN3.tri} + H_{twbk.UN3.rect}} = 0.52\,m$$

SUMMATION OF LATERAL WATER LOADS:

$$\Sigma H_{Water.UN3} := H_{hwas.UN3} + H_{hwrg.UN3} + H_{twgk.UN3} + H_{twrg.UN3} = -1692.22 \cdot kN$$

$$\Sigma M_{Hwater.UN3} := H_{hwas.UN3} \cdot H_{hwas.UN3.loc} + H_{hwrg.UN3} \cdot H_{hwrg.UN3.loc} \cdots + H_{twgk.UN3} \cdot H_{twgk.UN3.loc} + H_{twrg.UN3} \cdot H_{twrg.UN3.loc} = -2481.93 \cdot kN \cdot m$$

VERTICAL WATER LOADS

UN3 CASE

HEADWATER:

Water Depth on top of Approach Slab: $d_{hw.UN3} := HW_{UN3} - TOC_{as} = 7.00\,m$

Length of Approach Slab: $L_{as} = 8.75\,m$

Width of Approach Slab: $w_{as} = 15.00\,m$

Vertical Water Weight (H1) on Approach Slab: $H_{1.UN3} := \left(w_{as} \cdot d_{hw.UN3} \cdot L_{as}\right) \cdot \gamma_w = 9012.9 \cdot kN$

Moment Arm for Application of Water Weight (H1) from toe: $H_{1.UN3.loc} := L_b - \dfrac{L_{as}}{2} = 14.13\,m$

TAILWATER:

Trapezoid Volume Above Gate Footing from Approach Slab to Crest: $V_{asc.UN3} := \left(L_{gf} - L_{gfc}\right) W_b \dfrac{d_{hw.UN3} + Y_{C.UN3}}{2} = 663.34 \cdot m^3$

Trapezoid Volume Above Gate Footing Crest to End of Gate Footing: $V_{gfc.UN3} := \left(L_{gfc} \cdot W_b\right) \dfrac{Y_{C.UN3} + Y_{TOE.UN3}}{2} = 161.07 \cdot m^3$

Load Above Gate Footing from Approach Slab to Crest: $H_{2.UN3.asc} := V_{asc.UN3} \cdot \gamma_w = 6507.38 \cdot kN$

Load Acting Above Footing Crest from Toe: $H_{2.UN3.asc.loc} := \dfrac{\left(L_{gf} - L_{gfc}\right) \cdot \left(2 \cdot d_{hw.UN3} + Y_{C.UN3}\right)}{3 \cdot \left(d_{hw.UN3} + Y_{C.UN3}\right)} + L_{gfc} = 6.33\,m$

Load Above Gate Footing from Crest to End: $H_{2.UN3.gfc} := V_{gfc.UN3} \cdot \gamma_w = 1580.1 \cdot kN$

Load Acting Above Gate Footing from Crest to End: $H_{2.UN3.gfc.loc} := \dfrac{\left(L_{gfc}\right) \cdot \left(2 \cdot Y_{C.UN3} + Y_{TOE.UN3}\right)}{3 \cdot \left(Y_{C.UN3} + Y_{TOE.UN3}\right)} = 1.43\,m$

Vertical Water Weight (H2) on Gate Footing: $H_{2.UN3} := H_{2.UN3.asc} + H_{2.UN3.gfc} = 8087.47 \cdot kN$

Moment Arm for Application of Water Weight (H2) from toe: $H_{2.UN3.loc} := \dfrac{H_{2.UN3.asc} \cdot H_{2.UN3.asc.loc} + H_{2.UN3.gfc} \cdot H_{2.UN3.gfc.loc}}{H_{2.UN3}} = 5.37\,m$

UPLIFT AT INCLINE SLIDING PLANE

UN3 CASE

Uplift pressure at U/S Face (heel): $U_{HW.UN3} := D_{hwas.UN3} \cdot \gamma_w = 127.5 \cdot \frac{kN}{m^2}$

Uplift pressure at D/S Face Stilling Basin: $U_{TW.UN3} := \left(D_{twtoe.UN3}\right) \cdot \gamma_w = 85.35 \cdot \frac{kN}{m^2}$

Length from U/S of Gate Structure to D/S of Stilling Basin: $L_{overall} = 18.50\,m$

Difference between Uplift pressure at HW and TW: $U_{diff.UN3} := U_{HW.UN3} - U_{TW.UN3} = 42.18 \cdot \frac{kN}{m^2}$

Slope of difference between between Uplift pressure at HW and TW: $U_{slope.UN3} := \frac{U_{diff.UN3}}{L_{overall}} = 2.28 \cdot \frac{kN}{m^2 \cdot m}$

Tailwater Pressure at toe of Gate Structure: $U_{press.toe.gs.UN3} := U_{TW.UN3} + \left(L_{overall} - L_b\right) \cdot U_{slope.UN3} = 85.35 \cdot \frac{kN}{m^2}$

Uniform uplift force UA Under Gate Structure due to TW (rectangle): $U_{A.UN3} := U_{press.toe.gs.UN3} \cdot L_b \cdot W_b \cdot -1 = -23683.79 \cdot kN$

Moment Arm from Toe of Gate Structure for Uplift UA: $L_{A.UN3} := \left(\frac{L_b}{2}\right) = 9.25\,m$

Linearly Decreasing Uplift Force UN3B Under Gate Structure due to HW-TW Differential (triangle): $U_{B.UN3} := \frac{1}{2} \cdot \left(U_{HW.UN3} - U_{press.toe.gs.UN3}\right) \cdot L_b \cdot W_b \cdot -1 = -5852.89 \cdot kN$

Moment Arm from Toe of Gate Structure for Uplift UB: $L_{B.UN3} := \frac{2}{3} \cdot L_b = 12.33\,m$

Total Resultant Uplift force: $U_{UN3} := U_{A.UN3} + U_{B.UN3} = -29536.68 \cdot kN$

Resultant Location from Toe: $U_{UN3.loc} := \frac{\left(U_{A.UN3} \cdot L_{A.UN3} + U_{B.UN3} \cdot L_{B.UN3}\right)}{\left(U_{A.UN3} + U_{B.UN3}\right)} = 9.86\,m$

$\Sigma V_{water.UN3} := H_{1.UN3} + H_{2.UN3} + U_{UN3} = -12436.27 \cdot kN$

$\Sigma M_{Vwater.UN3} := H_{1.UN3} \cdot H_{1.UN3.loc} + H_{2.UN3} \cdot H_{2.UN3.loc} + U_{UN3} \cdot U_{UN3.loc} = -120488.41 \cdot kN \cdot m$

SOIL LOADS

UN3 CASE

Equivalent Fluid Pressure (EFP):

At rest lateral pressure coefficient: $K_{o.UN3} := 1 - \sin(\phi_{backfill}) = 0.658$ (Section 5.3, Design Criteria)

Headwater Pier Footing Unit Width: $W_{hwas.UN3} = 15.00\,m$

Tailwater Pier Footing Unit Width: $W_{tw.UN3} = 15.00\,m$

Pier Footing Thickness at Heel: $t_{hf.UN3} := TOC_{as} - BOK_{elev} = 6.00\,m$

Fixed Crest Footing Thickness at Toe: $t_{ff.UN3} := TOC_{pfe} - BOF_{elev} = 2.00\,m$

Lateral Driving Force (Headwater Side - at rest condition)

At-Rest Soil Load:

$$E_{act.UN3} := \frac{\left(K_{o.UN3} \cdot t_{hf.UN3}^{\ 2}\right)}{2} \cdot \left(\gamma_r - \gamma_w\right) \cdot W_{hwas.UN3} \cdot -1 = -2165.61 \cdot kN$$

Acting at:

$$E_{act.UN3.loc} := \frac{t_{hf.UN3}}{3} = 2.00\,m$$

Lateral Resisting Force (Tailwater Side - at rest condition)

At-rest Soil Load:

$$E_{pass.UN3} := \frac{\left(K_{o.UN3} \cdot t_{ff.UN3}^{\ 2}\right)}{2} \cdot \left(\gamma_r - \gamma_w\right) \cdot W_{tw.UN3} = 240.62 \cdot kN$$

Acting at:

$$E_{pass.UN3.loc} := \frac{t_{ff.UN3}}{3} = 0.67\,m$$

$$\Sigma H_{soil.UN3} := E_{act.UN3} + E_{pass.UN3} = -1924.99 \cdot kN$$

$$\Sigma M_{soil.UN3} := E_{act.UN3} \cdot E_{act.UN3.loc} + E_{pass.UN3} \cdot E_{pass.UN3.loc} = -4170.8 \cdot kN \cdot m$$

ICE / IMPACT LOADS (ASSUME NO ICE LOADING ON TAILWATER SIDE)

ICE & IMPACT LOADS DO NOT APPLY FOR THIS LOAD CASE

Static Ice load on Gates:

$$I_{G.UN3} := \begin{cases} 00\,\frac{kN}{m} & \text{if } TOP_{rg.UN3} \le TOC_{as} \\ 0\,\frac{kN}{m} & \text{if } TOP_{rg.UN3} > TOC_{as} \end{cases} = 0 \cdot \frac{kN}{m}$$

(Section 7.7, Design Criteria)

Ice Loading Unit Width on Reg. Gate: $W_{rg.UN3} := 15.00m$ (Input value for load case)

Total Ice Load on Structure: $I_{UN3} := -\left(I_{G.UN3} \cdot W_{rg.UN3}\right) = 0 \cdot kN$

Apply Ice load at: $I_{UN3.loc} := \left(TOP_{rg.UN3} - BOF_{elev} - 0.30m\right) = 3.70\,m$

$$\Sigma H_{I.UN3} := I_{UN3} = 0 \cdot kN$$

$$\Sigma M_{I.UN3} := I_{UN3} \cdot I_{UN3.loc} = 0 \cdot kN \cdot m$$

(SEISMIC LOAD (NOT APPLICABLE FOR THIS LOAD CASE)

UN3 CASE

SUMMARY OF LOADS

	Loads	Moment Arm
Dead load of Concrete Structure:	$D_{conc} = 24618.6 \cdot kN$	$X_{conc.loc} = 10.06\,m$
Obermyer Gate Weight:	$D_{Gate} = 210.0 \cdot kN$	$X_{gate} = 6.60\,m$
HW Lateral Load on Approach Slab:	$H_{hwas.UN3} = -8829.0 \cdot kN$	$H_{hwas.UN3.loc} = 0.70\,m$
HW Lateral Load on Reg. Gate:	$H_{hwrg.UN3} = 0.0 \cdot kN$	$H_{hwrg.UN3.loc} = 4.00\,m$
TW Lateral Load on Gate Footing (Including Key - Sliding Check Loads):	$H_{twgk.UN3} = 7136.78 \cdot kN$	$H_{twgk.UN3.loc} = 0.52\,m$
TW Lateral Load on Reg. Gate:	$H_{twrg.UN3} = 0.0 \cdot kN$	$H_{twrg.UN3.loc} = 4.00\,m$
Vertical HW Load on Approach Slab:	$H_{1.UN3} = 9012.9 \cdot kN$	$H_{1.UN3.loc} = 14.13\,m$
Vertical TW Load on Pier Footing (crest):	$H_{2.UN3} = 8087.5 \cdot kN$	$H_{2.UN3.loc} = 5.37\,m$
Uplift:	$U_{UN3} = -29536.7 \cdot kN$	$U_{UN3.loc} = 9.86\,m$
Lateral Soil Load (driving):	$E_{act.UN3} = -2165.6 \cdot kN$	$E_{act.UN3.loc} = 2.00\,m$
Lateral Soil Load (resisting):	$E_{pass.UN3} = 240.62 \cdot kN$	$E_{pass.UN3.loc} = 0.67\,m$
Ice / Impact Load:	$I_{UN3} = 0.0 \cdot kN$	$I_{UN3.loc} = 3.70\,m$

STABILITY ASSESSMENT (SLIDNG, BEARING, FLOTATION AND OVERTURNING):

CHECK SLIDING ALONG HORIZONTAL PLANE THRU TOE, IGNORING BEDROCK MOBILIZED BY STRUCTURAL HEEL KEY, OR VOID BEHIND KEY

UN3 CASE

Sum of Vertical Forces:

$\Sigma V_{UN3} := \Sigma V_{DL} + \Sigma V_{water.UN3} = 12392.3 \cdot kN$

Sum of Horizontal Forces:

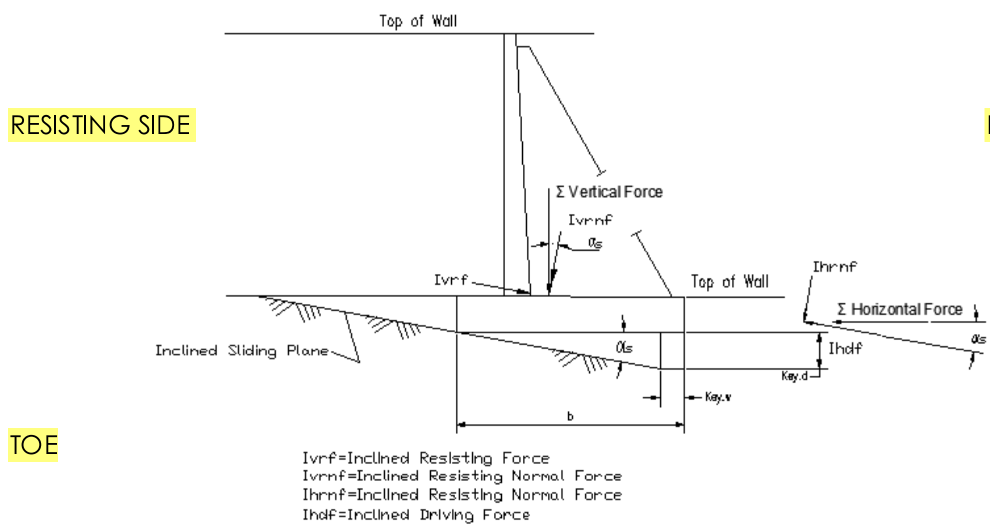
$\Sigma H_{UN3} := \Sigma H_{Water.UN3} + \Sigma H_{soil.UN3} + \Sigma H_{I.UN3} = -3617.21 \cdot kN$

Sliding Factor of Safety: $FS_{HorizSliding.UN3} := \dfrac{\tan_{\phi} \cdot \Sigma V_{UN3}}{|\Sigma H_{UN3}|} = 1.67$

$FS_{HorizSliding.UN3.Check} :=$ | "OKAY" if $FS_{HorizSliding.UN3} \geq FS_{req.UN3.sl}$ | "Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !" otherwise

= "OKAY"

CHECK SLIDING ALONG INCLINED SLIDING PLANE FROM HEEL KEY TO TOE, WITH BEDROCK MASS MOBILIZED BY REINFOCREDE CONCRETE KEY)



$\Sigma V_{UN3} = 12392.33 \cdot kN$

$V_{rs} = 5775 \cdot kN$

$\alpha s = 0.11$

as degrees= $\alpha s \cdot \left(\dfrac{180}{\pi}\right) = 6.52$

Resolve $\Sigma Vert_{UN3}$ & $\Sigma Horiz_{UN3}$

$\Sigma V_{InclinedUN3} := \cos(\alpha s) \cdot \left(\Sigma V_{UN3} + V_{rs}\right) + \sin(\alpha s) \cdot |\Sigma H_{UN3}| = 18460.6 \cdot kN$

$\Sigma H_{InclinedUN3} := \cos(\alpha s) \cdot |\Sigma H_{UN3}| - \sin(\alpha s) \cdot \left(\Sigma V_{UN3} + V_{rs}\right) = 1531.0 \cdot kN$

(With properly engineered reinforced concrete Key, horizontal sliding plane thru Toe is protected, critical sliding plane is relocated to the INCLINED SLIDING PLANE FROM HEEL KEY To TOE, Bedrock Mass above this examined plane is mobilized by reinforced concrete key and combined into Structural Wedge.)

Inclined Sliding Plane Length

$L_{incline} = 18.61 \, m$

Safety Factor for Sliding Inclined Failure Plane

$FS_{InclinedlSlidingUN3} := \dfrac{\Sigma V_{InclinedUN3} \cdot \tan\left(\phi_{rock} \cdot \dfrac{\pi}{180}\right)}{|\Sigma H_{InclinedUN3}|} = 5.88$

$FS_{InclinedSliding.check.UN3} :=$ | "OKAY " if $FS_{InclinedlSlidingUN3} > FS_{req.UN3.sl}$ | "Revise Structure"" otherwise

= "OKAY "

$FS_{InclinedSliding.check.UN3} =$ "OKAY "

OVERTURNING STABILITY CHECK:

UN3 CASE

CHECK ECCENTRICITY

Sum of the moments:

$$\Sigma M_{UN3} := \Sigma M_{DL} + \Sigma M_{Hwater.UN3} + \Sigma M_{Vwater.UN3} + \Sigma M_{I.UN3} + \Sigma M_{soil.UN3} + \Sigma M_{soil} = 189178 \cdot kN \cdot m$$

Eccentricity:

$$e_{UN3} := \left(\frac{L_{incline}}{2}\right) - \frac{\left(\Sigma M_{UN3}\right)}{\Sigma V_{InclinedUN3}} = -0.94\,m$$

Eccentricity Check:

$$e_{check.UN3} := \begin{cases} \text{"Okay"} & \text{if } \left|e_{UN3}\right| \le Kern \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$e_{check.UN3} = \text{"Okay"}$

Foundation Bearing Checks:

Incline Plane Area:

$A_{b.incline} = 279.12\,m^2$

Incline Plane Section Modulus:

$S_{b.incline} = 865.63 \cdot m^3$

Bearing Pressure at Heel:

$$\sigma_{heel.UN3} := \frac{\Sigma V_{InclinedUN3}}{A_{b.incline}} - \frac{\left(\Sigma V_{InclinedUN3} \cdot e_{UN3}\right)}{S_{b.incline}} = 86.3 \cdot \frac{kN}{m^2}$$

$$\sigma_{heel.UN3.check} := \left(\begin{cases} \text{"Okay"} & \text{if } \sigma_{heel.UN3} \le \sigma_{allow.UN3} \\ \text{"Revise Structure"} & \text{if } \sigma_{heel.UN3} < 0\,\frac{kN}{m^2} \end{cases}\right)$$

$\sigma_{heel.UN3.check} = \text{"Okay"}$

Bearing Pressure at Toe:

$$\sigma_{toe.UN3} := \frac{\Sigma V_{InclinedUN3}}{A_{b.incline}} + \frac{\left(\Sigma V_{InclinedUN3} \cdot e_{UN3}\right)}{S_{b.incline}} = 46.0 \cdot \frac{kN}{m^2}$$

$$\sigma_{toe.UN3.1.check} := \begin{cases} \text{"Okay"} & \text{if } \sigma_{toe.UN3} \le \sigma_{allow.UN3} \\ \text{"Revise Structure"} & \text{if } \sigma_{toe.UN3} < 0\,\frac{kN}{m^2} \end{cases}$$

$\sigma_{toe.UN3.1.check} = \text{"Okay"}$

FLOATATION ANALYSIS:

ACCEPTANCE PARAMETERS

Required Factor of Safety: $FS_{req.FUN3} := 1.3$

VERTICAL LOADS RESISTING:

Dead Load: $\Sigma V_{DL} = 24828.6 \cdot kN$

Water Weight H1+H2: $\Sigma V_{H.FUN3} := H_{1.UN3} + H_{2.UN3} = 17100.41 \cdot kN$

Summation Vertical Resisting: $\Sigma V_{FUN3} := \Sigma V_{DL} + \Sigma V_{H.FUN3} = 41929.0 \cdot kN$

VERTICAL LOADS UPLIFT:

Uplift: $U_{UN3} = -29536.68 \cdot kN$

Factor of Safety Floatatio

$$FS_{act.FUN3} := \frac{\Sigma V_{FUN3}}{\left|U_{UN3}\right|} = 1.42$$

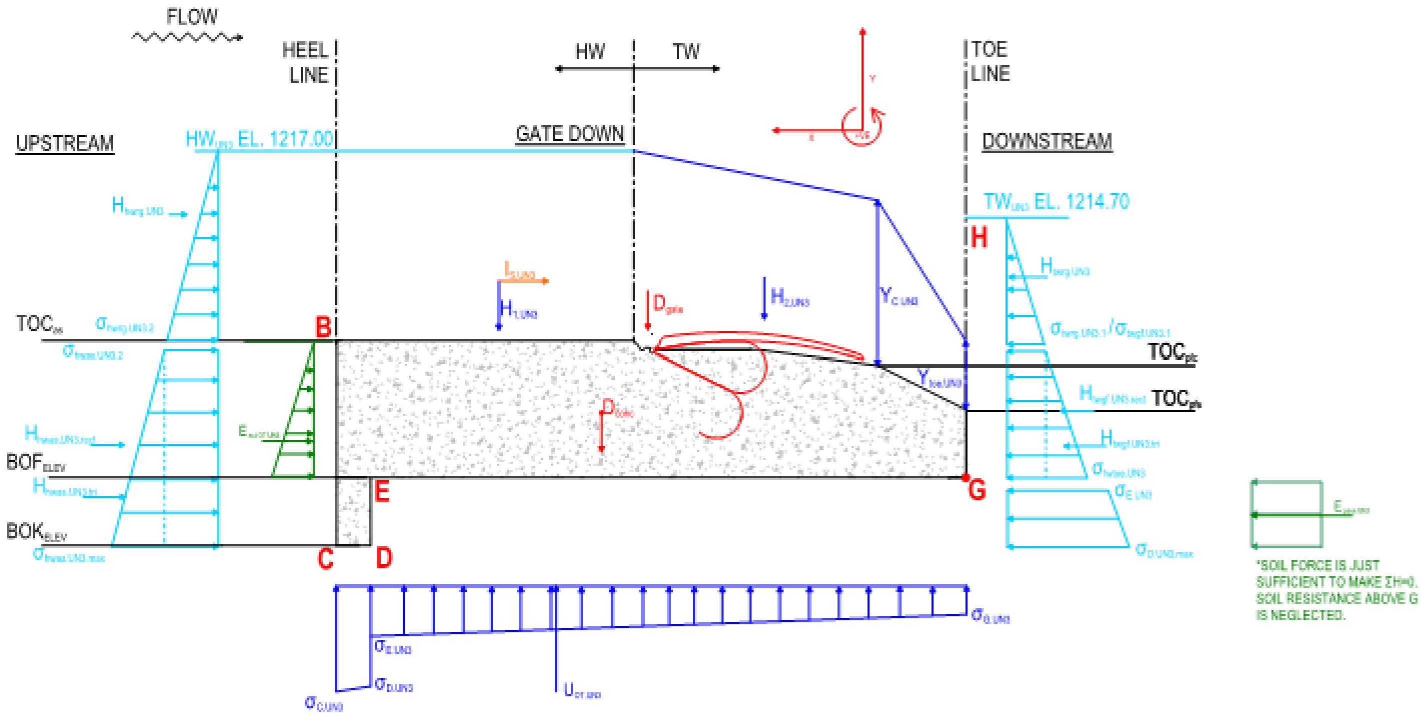
$$FS_{check.FUN3} := \begin{cases} \text{"OKAY"} & \text{if } FS_{act.FUN3} \ge FS_{req.FUN3} \\ \text{"ANCHORS REQUIRED"} & \text{if } FS_{act.FUN3} < FS_{req.FUN3} \end{cases} = \text{"OKAY"}$$

UN3 CASE

MONOLITH OVERTURNING STABILITY ANALYSIS

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.
Assumptions are made in order to compute overturning stability of indetermine forces on monolith with key;
(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.
(b) The horizontal resisting force acting on the key, P.key, is that required for static equilibrium
(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1 $Ratio_{OT.UN3.min} := 0.33$



Uplift Loads for Overturning Stability Analysis

Line of Creep:

Change in Water Head: $\Delta_{h.UN3} := HW_{UN3} - TW_{UN3} = 2.3\,m$

Length from Point C to Point G: $L_{CG} = 18.61\,m$

Length from Various Points to Points: $L_{CD} = 1\,m$ $L_{DE} = 2\,m$ $L_{EG} = 17.5\,m$

$L_{GH.UN3} := TW_{UN3} - BOF_{elev} = 8.7\,m$

Length from Point C, D, E to G: $L_{CDEG} = 20.5\,m$ $L_{CDE} = 3\,m$

Water Pressure at Point C: $\sigma_{C.UN3} := \sigma_{hwas.UN3.2} = -127.53 \cdot kPa$

Water Pressure at Point G: $\sigma_{G.UN3} := \sigma_{twtoe.UN3} \cdot -1 = -85.35 \cdot kPa$

Water Pressure at Point D: $\sigma_{D.UN3} := -\gamma_w \cdot \left[\left(HW_{UN3} - BOK_{elev} \right) - \dfrac{\Delta_{h.UN3} \cdot L_{CD}}{L_{CDEG}} \right] = -126.43 \cdot kPa$

Water Pressure at Point E: $\sigma_{E.UN3} := -\gamma_w \cdot \left[\left(HW_{UN3} - BOF_{elev} \right) - \dfrac{\Delta_{h.UN3} \cdot L_{CDE}}{L_{CDEG}} \right] = -104.61 \cdot kPa$

Uplift for Overturning Analysis on Bottom of Key: $U_{OT.UN3.key} := \dfrac{\sigma_{C.UN3} + \sigma_{D.UN3}}{2} \cdot L_{CD} \cdot W_b = -1904.7 \cdot kN$

Acting at: $U_{OT.UN3.key.loc} := \dfrac{L_{CD} \cdot \left(2 \cdot \sigma_{C.UN3} + \sigma_{D.UN3}\right)}{3 \left(\sigma_{C.UN3} + \sigma_{D.UN3}\right)} + L_{EG} = 18\,m$

UN3 CASE

Uplift for Overturning Analysis on Bottom of Footing:
$$U_{OT.UN3.ftg} := \frac{\sigma_{E.UN3} + \sigma_{G.UN3}}{2} \cdot L_{EG} \cdot W_b = -24931.61 \cdot kN$$

Acting at:
$$U_{OT.UN3.ftg.loc} := \frac{L_{EG} \cdot \left(\sigma_{G.UN3} + 2 \cdot \sigma_{E.UN3}\right)}{3\left(\sigma_{G.UN3} + \sigma_{E.UN3}\right)} = 9.05\,m$$

Uplift Load for Overturning Analysis:
$$U_{OT.UN3} := U_{OT.UN3.key} + U_{OT.UN3.ftg} = -26836.3 \cdot kN$$

Uplift Load Acting from Toe:
$$U_{OT.UN3.loc} := \frac{U_{OT.UN3.key} \cdot U_{OT.UN3.key.loc} + U_{OT.UN3.ftg} \cdot U_{OT.UN3.ftg.loc}}{U_{OT.UN3}} = 9.68\,m$$

<u>All Vertical Loads Applicable to Overturning Stability Analysis</u>

Total Concrete Dead Loads: $D_{conc} = 24618.6 \cdot kN$ at: $X_{conc.loc} = 10.06\,m$

Dead Load of Gate: $D_{Gate} = 210.0 \cdot kN$ $X_{gate} = 6.60\,m$

Water Weight (HW) on Apron Slab: $H_{1.UN3} = 9012.9 \cdot kN$ $H_{1.UN3.loc} = 14.13\,m$

Water Weight (TW) on Gate Footing: $H_{2.UN3} = 8087.5 \cdot kN$ $H_{2.UN3.loc} = 5.37\,m$

Uplift Load for Overturning Analysis: $U_{OT.UN3} = -26836.3 \cdot kN$ $U_{OT.UN3.loc} = 9.68 \cdot m$

Sum of All Overturning Analysis Vertical Load:
$$\Sigma V_{UN3.OT} := D_{conc} + D_{Gate} + H_{1.UN3} + H_{2.UN3} + U_{OT.UN3} = 15092.71 \cdot kN$$

Sum of All Overturning Analysis Vertical Load Moments:
$$\Sigma M_{V.UN3.OT} := D_{conc} \cdot X_{conc.loc} + D_{Gate} \cdot X_{gate} + H_{1.UN3} \cdot H_{1.UN3.loc} + H_{2.UN3} \cdot H_{2.UN3.loc} + U_{OT.UN3} \cdot U_{OT.UN3.loc} = 159905.29 \cdot kN \cdot m$$

<u>Lateral Tailwater Loads for Overturning Stability Analysis</u>

TW Lateral Load on Gate Footing (No Key - Overturning Values Adjusted):
$$H_{twgf.UN3} := H_{twgf.UN3.tri} + H_{twgf.UN3.rect} = 3943.62 \cdot kN$$

Acting at:
$$H_{twgf.UN3.loc} := \frac{\frac{h_{toe}}{3} \cdot H_{twgf.UN3.tri} + \frac{h_{toe}}{2} \cdot H_{twgf.UN3.rect}}{H_{twgf.UN3}} = 1.8\,m$$

Horizontal Tailwater Pressure Top of Key (Overturning Analysis):
$$\sigma_{twtk.OT.UN3} := \sigma_{E.UN3} \cdot -1 = 104.61 \cdot kPa$$

Horizontal Tailwater Pressure Bottom of Key (Overturning Analysis):
$$\sigma_{twbk.OT.UN3} := \sigma_{D.UN3} \cdot -1 = 126.43 \cdot kPa$$

Triangular Distribution Unit Load Acting at Key:
$$H_{twbk.OT.UN3.tri} := \frac{\left(\sigma_{twbk.OT.UN3} - \sigma_{twtk.OT.UN3}\right)}{2} \cdot d_{key} \cdot W_{tw.UN3} = 327.32 \cdot kN$$

Triangular Distribution Unit Load Acting at Key:
$$H_{twbk.OT.UN3.rect} := \sigma_{twtk.OT.UN3} \cdot d_{key} \cdot W_{tw.UN3} = 3138.24 \cdot kN$$

Total Horizontal Tailwater Load on Key (Overturning Values Adjusted):
$$H_{twkey.OT.UN3} := H_{twbk.OT.UN3.tri} + H_{twbk.OT.UN3.rect} = 3465.56 \cdot kN$$

Acting at:
$$H_{twkey.OT.UN3.loc} := \frac{H_{twbk.OT.UN3.tri} \cdot \frac{-2 \cdot d_{key}}{3} + H_{twbk.OT.UN3.rect} \cdot \frac{-d_{key}}{2}}{H_{twkey.OT.UN3}} = -1.03 \cdot m$$

Lateral Driving Earth Loads for Overturning Stability Analysis (at rest condition)

UN3 CASE

Depth of Driving Soil Loads (to top of key): $h_{E.OT.UN3} := TOC_{as} - BOF_{elev} = 4\,m$

At-Rest Soil Load: $E_{act.OT.UN3} := \dfrac{\left(K_{o.UN3} \cdot h_{E.OT.UN3}{}^{2}\right)}{2} \cdot \left(\gamma_r - \gamma_w\right) \cdot W_{hwas.UN3} \cdot -1 = -962.49 \cdot kN$

At Rest- Soil Load Acting from Toe: $E_{act.OT.UN3.loc} := \dfrac{h_{E.OT.UN3}}{3} = 1.33\,m$

All Lateral Loads Appliable to Overturning Stability Analysis

HW Lateral Load on Approach Slab:	$H_{hwas.UN3} = -8829.0 \cdot kN$	$H_{hwas.UN3.loc} = 0.70\,m$
HW Lateral Load on Reg. Gate:	$H_{hwrg.UN3} = 0.0 \cdot kN$	$H_{hwrg.UN3.loc} = 4.00\,m$
TW Lateral Load on Reg. Gate:	$H_{twrg.UN3} = 0.0 \cdot kN$	$H_{twrg.UN3.loc} = 4.00\,m$
TW Lateral Load on Gate Footing (No Key - Overturning Values Adjusted):	$H_{twgf.UN3} = 3943.62 \cdot kN$	$H_{twgf.UN3.loc} = 1.8\,m$
TW Lateral Load on Key:	$H_{twkey.OT.UN3} = 3465.56 \cdot kN$	$H_{twkey.OT.UN3.loc} = -1.03\,m$
Ice / Impact Load:	$I_{UN3} = 0.0 \cdot kN$	$I_{UN3.loc} = 3.70\,m$
Lateral Soil Load (driving):	$E_{act.OT.UN3} = -962.5 \cdot kN$	$E_{act.OT.UN3.loc} = 1.33\,m$

Resisting Lateral Soil Load as required to produce horizontal equilibrium:

$$E_{pas.OT.UN3} := -\left(H_{hwas.UN3} + H_{hwrg.UN3} + H_{twrg.UN3} + H_{twgf.UN3} + H_{twkey.OT.UN3} + I_{UN3} + E_{act.OT.UN3}\right) = 2382.31 \cdot kN$$

Acting at:

$$E_{pas.OT.UN3.loc} := -1 \cdot \frac{d_{key}}{2} = -1\,m$$

Sum of All Overturning Analysis Horizontal Load (ΣH=0):

$$\Sigma H_{UN3.OT} := H_{hwas.UN3} + H_{hwrg.UN3} + H_{twrg.UN3} + H_{twgf.UN3} + H_{twkey.OT.UN3} + I_{UN3} + E_{act.OT.UN3} + E_{pas.OT.UN3} = 0 \cdot kN$$

Sum of All Overturning Analysis Horizontal Load Moments:

$$\begin{aligned}\Sigma M_{H.UN3.OT} := {} & H_{hwas.UN3} \cdot H_{hwas.UN3.loc} + H_{hwrg.UN3} \cdot H_{hwrg.UN3.loc} + H_{twrg.UN3} \cdot H_{twrg.UN3.loc} \cdots = -6318.16 \cdot kN \cdot m \\ & + H_{twgf.UN3} \cdot H_{twgf.UN3.loc} + H_{twkey.OT.UN3} \cdot H_{twkey.OT.UN3.loc} + I_{UN3} \cdot I_{UN3.loc} \cdots \\ & + E_{act.OT.UN3} \cdot E_{act.OT.UN3.loc} + E_{pas.OT.UN3} \cdot E_{pas.OT.UN3.loc}\end{aligned}$$

Overturning Stability Analysis

$\Sigma M_{UN3.OT} := \Sigma M_{V.UN3.OT} + \Sigma M_{H.UN3.OT} = 153587.12 \cdot kN \cdot m$ $\quad X_{R.UN3} := \dfrac{\Sigma M_{UN3.OT}}{\Sigma V_{UN3.OT}} = 10.18\,m$ $\quad x_{OT.UN3} := X_{R.UN3} - \dfrac{L_b}{2} = 0.93\,m$

Overturning Resultant Ratio $\quad Ratio_{OT.UN3} := \dfrac{X_{R.UN3}}{L_b} = 0.55$

$$Ratio_{OT.UN3.check} := \begin{cases} \text{"OKAY"} & \text{if } Ratio_{OT.UN3} \ge Ratio_{OT.UN3.min} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

$$x_{OT.check.UN3} := \begin{cases} \text{"OKAY"} & \text{if } \left|x_{OT.UN3}\right| \le Kern \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

CHECK FOUNDATION BEARING CAPACITY (HORIZONTAL PLANE):

Bearing Pressure Under Toe:

$$\sigma_{ToeUN3.OT} := \frac{\Sigma V_{UN3.OT}}{L_b \cdot W_b} + \frac{\left(\Sigma V_{UN3.OT} \cdot x_{OT.UN3}\right)}{S_b} = 70.7 \cdot kPa$$

$$Bearing_{ChecktoeUN3.OT} := \begin{array}{|l} \text{"OKAY "} \;\; \text{if} \;\; \sigma_{ToeUN3.OT} < \sigma_{allow.UN3} \\ \text{"NG""} \;\; \text{otherwise} \end{array} = \text{"OKAY "}$$

Bearing Pressure Under Heel:

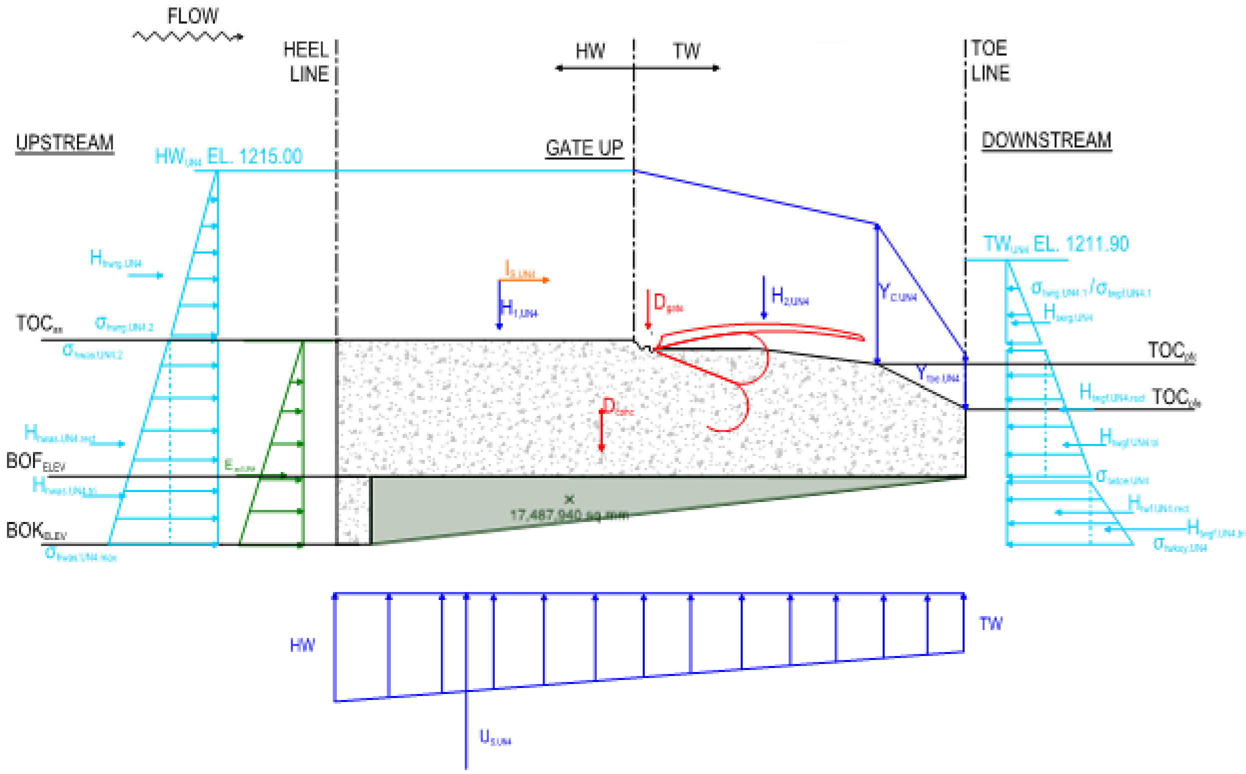
$$\sigma_{HeelUN3.OT} := \frac{\Sigma V_{UN3.OT}}{L_b \cdot W_b} - \frac{\left(\Sigma V_{UN3.OT} \cdot x_{OT.UN3}\right)}{S_b} = 38.0 \cdot kPa$$

$$Bearing_{CheckheelUN3.OT} := \left(\begin{array}{|l} \text{"OKAY "} \;\; \text{if} \;\; \sigma_{HeelUN3.OT} < \sigma_{allow.UN3} \wedge \sigma_{HeelUN3.OT} > 0 \\ \text{"NG""} \;\; \text{otherwise} \end{array}\right) = \text{"OKAY "}$$

SUMMARY OF STABILITY ASSESSMENT:

Sliding Factor of Safety: (Horizontal Plane)	$FS_{HorizSliding.UN3} = 1.67$	$FS_{HorizSliding.UN3.Check} = \text{"OKAY"}$
Sliding Factor of Safety: (Inclined Plane)	$FS_{InclinedlSlidingUN3} = 5.88$	$FS_{InclinedSliding.check.UN3} = \text{"OKAY "}$
Eccentricity: (Inclined Plane)	$e_{UN3} = -0.94\,m$	$e_{check.UN3} = \text{"Okay"}$
Bearing Pressure At Heel: (Inclined Plane)	$\sigma_{heel.UN3} = 86 \cdot kPa$	$\sigma_{heel.UN3.check} = \text{"Okay"}$
Bearing Pressure At Toe: (Inclined Plane)	$\sigma_{toe.UN3} = 46 \cdot kPa$	$\sigma_{toe.UN3.1.check} = \text{"Okay"}$
Flotation Factor of Safety (horizontal plane)	$FS_{act.FUN3} = 1.42$	$FS_{check.FUN3} = \text{"OKAY"}$
Overturning Resultant Ratio: (horizontal plane)	$Ratio_{OT.UN3} = 0.55$	$Ratio_{OT.UN3.check} = \text{"OKAY"}$
Eccentricity: (horizontal plane)	$x_{OT.UN3} = 0.93\,m$	$x_{OT.check.UN3} = \text{"OKAY"}$
Bearing Pressure At Heel: (horizontal plane)	$\sigma_{HeelUN3.OT} = 38 \cdot kPa$	$Bearing_{CheckheelUN3.OT} = \text{"OKAY "}$
Bearing Pressure At Toe: (horizontal plane)	$\sigma_{ToeUN3.OT} = 71 \cdot kPa$	$Bearing_{ChecktoeUN3.OT} = \text{"OKAY "}$

UN4 DESIGN CASE



ACCEPTANCE PARAMETERS

Required Factor of Safety for Sliding: $FS_{req.UN4.sl} := 1.3$ (Without Cohesion)

(Section 8.1, Design Criteria)

Resultant Within Middle Third of Base: $e \le \frac{L_b}{6} \wedge e \ge \frac{-L_b}{6}$

Allowable Rock Bearing Pressure: $\sigma_{allow.UN4} := 1470 \cdot \frac{kN}{m^2}$ (Section 5.2, Design Criteria)

INPUT PARAMETERS

Headwater Elevation: $HW_{UN4} := 1215.00m$ (Section 8.3, Design Criteria)

Tailwater Elevation: $TW_{UN4} := 1211.90m$ (Section 8.3, Design Criteria)

Bottom of Footing Elevation: $BOF_{elev} = 1206\,m$

Approach Slab Top of Concrete Elevation at Upstream Face: $TOC_{as} = 1210\,m$

Footing Top of Concrete Elevation at Stilling Basin: $TOC_{pfe} = 1208\,m$

Footing Top of Concrete Elevation at Center of Footing: $TOC_{pfc} = 1209.3\,m$

Top of Guard/Regulating Gate Elevation: $TOP_{rg.UN4} := 1210.00m$ $TOP_{gg.UN4} := 1215.00m$

Gates are open when top of gate elevation is at 1210.00m

Gates are closed/up when top of gate elevation is at 1215.0m

Bottom of Key Elevation: $BOK_{elev} = 1204\,m$

Crestwater Elevation: Dynamic Flow $EL_{C.UN4} := 1213.63m$

$$Y_{C.UN4} := \begin{cases} (EL_{C.UN4} - TOC_{pfc}) & \text{if } TOP_{rg.UN4} \le HW_{UN4} \\ (TW_{UN4} - TOC_{pfc}) & \text{if } TOP_{rg.UN4} > HW_{UN4} \end{cases} = 4.33 \cdot m$$

Toewater Elevation: $EL_{TOE.UN4} := 1209.23m$

$$Y_{TOE.UN4} := \begin{cases} (EL_{TOE.UN4} - TOC_{pfe}) & \text{if } TOP_{rg.UN4} \le HW_{UN4} \\ (TW_{UN4} - TOC_{pfe}) & \text{if } TOP_{rg.UN4} > HW_{UN4} \end{cases} = 1.23 \cdot m$$

UN4 CASE

This load case is the Construction / Maintenance / Single Gate Bay Dewatered Load Case. One bay is open, while the other has been blocked off for gate maintenance. Calculation highlighted in Orange where calculation is affected.

CREST GATE (OBERMEYER)

Dead Load of Gates: $D_{Gate.UN4} := \frac{D_{Gate}}{2} = 105 \cdot kN$ Vendor supplied on Q-200 Series Dwg.

DEAD LOAD SUMMATION:

$\Sigma V_{DL.UN4} := D_{conc} + D_{Gate} = 24828.6 \cdot kN$

$\Sigma M_{DL.UN4} := D_{conc} \cdot X_{conc.loc} + D_{Gate.UN4} \cdot X_{gate} = 248250.79 \cdot kN \cdot m$

LATERAL WATER LOADS

HEADWATER (DRIVING):

Headwater Depth on Pier: $D_{hwg.UN4} := HW_{UN4} - TOC_{as} = 5.00\,m$

Thickness of Approach Slab (Including Key): $T_{as} = 6\,m$

Headwater Depth at Heel (U/S face): $D_{hwas.UN4} := HW_{UN4} - BOK_{elev} = 11.00\,m$

Headwater Load Unit Width on Approach Slab: $W_{hwas.UN4} := W_b = 15.00\,m$

Headwater Unit Load At Top of Approach Slab:

$$H_{hwas.UN4.1} := \frac{-\left(\gamma_w \cdot D_{hwg.UN4}^{\;2}\right)}{2} \cdot W_{hwas.UN4} = -1839.38 \cdot kN$$

Headwater Unit Load At Bottom of Approach Key:

$$H_{hwas.UN4.2} := \frac{-\left(\gamma_w \cdot D_{hwas.UN4}^{\;2}\right)}{2} \cdot W_{hwas.UN4} = -8902.6 \cdot kN$$

Headwater Line Load At Top of Approach Slab: $\sigma_{hwas.UN4.1} := -\left(\gamma_w \cdot D_{hwg.UN4}\right) = -49.05 \cdot kPa$

Headwater Line Load At Bottom of Approach Key: $\sigma_{hwas.UN4.2} := -\left(\gamma_w \cdot D_{hwas.UN4}\right) = -107.91 \cdot kPa$

Triangular Distribution Unit Load on Approach Slab and Key:

$$H_{hwas.UN4.2.tri} := \left(\frac{\sigma_{hwas.UN4.2} - \sigma_{hwas.UN4.1}}{2}\right) \cdot \left(T_{as} \cdot W_{hwas.UN4}\right) = -2648.7 \cdot kN$$

Rectangular Distribution Unit Load on Approach Slab and Key:

$$H_{hwas.UN4.2.rect} := \sigma_{hwas.UN4.1} \cdot \left(T_{as} \cdot W_{hwas.UN4}\right) = -4414.5 \cdot kN$$

Total Horizontal Headwater Load on Approach Slab:

$$H_{hwas.UN4} := H_{hwas.UN4.2.tri} + H_{hwas.UN4.2.rect} = -7063.2 \cdot kN$$

Apply Total Footing Headwater Load at:

$$H_{hwas.UN4.loc} := \frac{\left[H_{hwas.UN4.2.rect} \cdot \frac{\left(T_{as}\right)}{2} + H_{hwas.UN4.2.tri} \cdot \frac{\left(T_{as}\right)}{3}\right]}{H_{hwas.UN4.2.tri} + H_{hwas.UN4.2.rect}} - d_{key} = 0.63\,m$$

Regulating Gate (4A) Operating Condition:

Reg. Gate Down/Open Condition: $A1_{UN4} := TOP_{rg.UN4} \le TOC_{as}$

Reg. Crest Gate Up/Closed, with Top of Gate Higher than HW Elevation: $B1_{UN4} := TOP_{rg.UN4} \ge HW_{UN4} \wedge TOP_{rg.UN4} > TOC_{as}$

Reg. Crest Gate Up/Closed, with Top of Gate Lower than HW Elevation: $C1_{UN4} := TOP_{rg.UN4} > TOC_{as} \wedge HW_{UN4} > TOP_{rg.UN4} = 0$

Reg. Crest Gate Height: $H_{rg.UN4} := TOP_{rg.UN4} - TOC_{as} = 0\,m$

Headwater Depth at Reg. Crest Gate: $D_{hwrg.UN4} := HW_{UN4} - TOC_{as} = 5.00\,m$

Reg. Crest Gate Width: $W_{hwrg.UN4} := 15.00m$

Lateral Headwater Pressure at Bottom of Reg. Crest Gate:

$$\sigma_{hwrg.UN4.1} := \begin{cases} (0.0kPa) & \text{if } A1_{UN4} \\ -(\gamma_w \cdot D_{hwrg.UN4}) & \text{if } B1_{UN4} \\ -(\gamma_w \cdot D_{hwrg.UN4}) & \text{if } C1_{UN4} \end{cases} = 0.0 \cdot kPa$$

Lateral Headwater Pressure at Top of Reg. Crest Gate: (Load at HW Elevation On Reg. Crest Gate if HW is below TOG_{rg})

$$\sigma_{hwrg.UN4.2} := \begin{cases} (0.0kPa) & \text{if } A1_{UN4} \\ 0.0kPa & \text{if } B1_{UN4} \\ -\left[\gamma_w \cdot (HW_{UN4} - TOP_{rg.UN4})\right] & \text{if } C1_{UN4} \end{cases} = 0.0 \cdot kPa$$

Average Pressure acting on Reg. Crest Gate:

$$\sigma_{hwrg.UN4.avg} := \frac{(\sigma_{hwrg.UN4.1} + \sigma_{hwrg.UN4.2})}{2} = 0 \cdot kPa$$

Total Area of Crest Gate:

$$A_{hwrg.UN4} := \begin{cases} D_{hwrg.UN4} \cdot W_{hwrg.UN4} & \text{if } A1_{UN4} \\ D_{hwrg.UN4} \cdot W_{hwrg.UN4} & \text{if } B1_{UN4} \\ H_{rg.UN4} \cdot W_{hwrg.UN4} & \text{if } C1_{UN4} \end{cases} = 75 \cdot m^2$$

Total Horizontal Headwater Load on Reg. Crest Gate: $H_{hwrg.UN4} := \sigma_{hwrg.UN4.avg} \cdot A_{hwrg.UN4} = 0.0 \cdot kN$

Apply Total Reg. Crest Gate Headwater Load at:

$$H_{hwrg.UN4.loc} := \begin{cases} (TOC_{as} - BOF_{elev}) & \text{if } A1_{UN4} \\ \left[\frac{(HW_{UN4} - TOC_{as})}{3} + (TOC_{as} - BOF_{elev})\right] & \text{if } B1_{UN4} \\ \left[\frac{\sigma_{hwrg.UN4.2} \cdot A_{hwrg.UN4} \cdot \frac{(H_{rg.UN4})}{2} + \frac{(\sigma_{hwrg.UN4.1} - \sigma_{hwrg.UN4.2})}{2} \cdot A_{hwrg.UN4} \cdot \frac{(H_{rg.UN4})}{3}}{\sigma_{hwrg.UN4.2} \cdot A_{hwrg.UN4} + \frac{(\sigma_{hwrg.UN4.1} - \sigma_{hwrg.UN4.2})}{2} \cdot A_{hwrg.UN4}} \ldots \\ + (TOC_{as} - BOF_{elev})\right] & \text{if } C1_{UN4} \end{cases} = 4.0 \cdot m$$

LATERAL TAILWATER (RESISTING) Applied to Downstream Side of Reg. Crest Gate: UN4 CASE

Reg. Gate Down/Open Condition: $A2_{UN4} := TOP_{rg.UN4} \le TOC_{as}$

Reg. Crest Gate Up/Closed, with Top of Gate Higher than TW Elevation: $B2_{UN4} := TOP_{rg.UN4} \ge TW_{UN4} \wedge TOP_{rg.UN4} > TOC_{as} = 0$

Reg. Crest Gate Up/Closed, with Top of Gate Lower than TW Elevation: $C2_{UN4} := TOP_{rg.UN4} > TOC_{as} \wedge TW_{UN4} > TOP_{rg.UN4} = 0$

Tailwater Depth at Reg. Crest Gate: $D_{twrg.UN4} := TW_{UN4} - TOC_{as} = 1.90\,m$

Reg. Crest Gate Width: $W_{twrg.UN4} := 15.00m$

Lateral Water Load at Bottom of Reg. Crest Gate:

$$\sigma_{twrg.UN4.1} := \begin{cases} (0.0kPa) & \text{if } A2_{UN4} \\ (\gamma_w \cdot D_{twrg.UN4}) & \text{if } B2_{UN4} \\ (\gamma_w \cdot D_{twrg.UN4}) & \text{if } C2_{UN4} \end{cases} = 0.0 \cdot kPa$$

Lateral Water Load at Top of Reg. Crest Gate:
(Load at TW Elevation On Reg. Crest Gate if TW is below TOG_{rg})

$$\sigma_{twrg.UN4.2} := \begin{cases} (0.0kPa) & \text{if } A2_{UN4} \\ 0.0kPa & \text{if } B2_{UN4} \\ \left[\gamma_w \cdot \left(TW_{UN4} - TOP_{rg.UN4}\right)\right] & \text{if } C2_{UN4} \end{cases} = 0.0 \cdot kPa$$

Average Pressure acting on Reg. Crest Gate:

$$\sigma_{twrg.UN4.avg} := \frac{\left(\sigma_{twrg.UN4.1} + \sigma_{twrg.UN4.2}\right)}{2} = 0 \cdot kPa$$

Total Area water acting on Crest Gate:

$$A_{twrg.UN4} := \begin{cases} D_{twrg.UN4} \cdot W_{twrg.UN4} & \text{if } A2_{UN4} \\ D_{twrg.UN4} \cdot W_{twrg.UN4} & \text{if } B2_{UN4} \\ H_{rg.UN4} \cdot W_{twrg.UN4} & \text{if } C2_{UN4} \end{cases} = 28.5 \cdot m^2$$

Total Horizontal Tailwater Load on Reg. Crest Gate: $H_{twrg.UN4} := \sigma_{twrg.UN4.avg} \cdot A_{twrg.UN4} = 0.0 \cdot kN$

Apply Total Horiz. TW Load on Reg. Gate at:

$$H_{twrg.UN4.loc} := \begin{cases} \left(TOC_{as} - BOF_{elev}\right) & \text{if } A2_{UN4} \\ \left[\frac{\left(TW_{UN4} - TOC_{as}\right)}{3} + \left(TOC_{as} - BOF_{elev}\right)\right] & \text{if } B2_{UN4} \\ \left[\frac{\sigma_{twrg.UN4.2} \cdot A_{twrg.UN4} \cdot \frac{\left(H_{rg.UN4}\right)}{2} + \frac{\left(\sigma_{twrg.UN4.1} - \sigma_{twrg.UN4.2}\right)}{2} A_{twrg.UN4} \cdot \frac{\left(H_{rg.UN4}\right)}{3}}{\sigma_{twrg.UN4.2} \cdot A_{twrg.UN4} + \frac{\left(\sigma_{twrg.UN4.1} - \sigma_{twrg.UN4.2}\right)}{2} \cdot A_{twrg.UN4}} \ldots \\ + \left(TOC_{as} - BOF_{elev}\right)\right] & \text{if } C2_{UN4} \end{cases} = 4.0 \cdot m$$

LATERAL WATER LOADS (continued)

UN4 CASE

TAILWATER (RESISTING) Applied to Concrete Structure:

Tailwater Depth At top of Gate Base Footing Elevation: $D_{twgf.UN4} := TW_{UN4} - TOC_{as} = 1.90\,m$

Water Depth at bottom of Gate Base Footing: $D_{twtoe.UN4} := TW_{UN4} - BOF_{elev} = 5.90\,m$

Footing Thickness at Toe $h_{toe} = 4\,m$

Unit Width of D/S face of crest for application of Tailwater Load: $W_{tw.UN4} := W_b = 15.00\,m$

Tailwater Pressure At Top of Gate Footing: $\sigma_{twgf.UN4} := \left(\gamma_w \cdot D_{twgf.UN4}\right) = 18.64 \cdot kPa$

Tailwater Line Load At Bottom of Gate Footing: $\sigma_{twtoe.UN4} := \left(\gamma_w \cdot D_{twtoe.UN4}\right) = 57.88 \cdot kPa$

Triangular Distribution Unit Load on Gate Footing Base $H_{twgf.UN4.tri} := \left(\dfrac{\sigma_{twtoe.UN4} - \sigma_{twgf.UN4}}{2}\right) \cdot \left(h_{toe} \cdot W_{tw.UN4}\right) = 1177.2 \cdot kN$

Rectangular Distribution Unit Load on Gate Footing Base: $H_{twgf.UN4.rect} := \sigma_{twgf.UN4} \cdot \left(h_{toe} \cdot W_{tw.UN4}\right) = 1118.34 \cdot kN$

Tailwater Pressure At Bottom of Sliding Failure Plane: $\sigma_{twbk.UN4} := \left(HW_{UN4} - BOK_{elev}\right) \cdot \gamma_w = 107.91 \cdot kPa$

Triangular Distribution Unit Load Below Footing: $H_{twbk.UN4.tri} := \dfrac{\left(\sigma_{twbk.UN4} - \sigma_{twtoe.UN4}\right)}{2} \cdot d_{key} \cdot W_{tw.UN4} = 750.46 \cdot kN$

Rectangular Distribution Load Below Footing Base: $H_{twbk.UN4.rect} := \sigma_{twtoe.UN4} \cdot d_{key} \cdot W_{tw.UN4} = 1736.37 \cdot kN$

Total Horizontal Tailwater Load on Gate Footing (including key):

$$H_{twgk.UN4} := H_{twgf.UN4.tri} + H_{twgf.UN4.rect} + H_{twbk.UN4.tri} + H_{twbk.UN4.rect} = 4782.38 \cdot kN$$

Apply Total Gate Footing Tailwater Load at:

$$H_{twgk.UN4.loc} := \frac{\left[H_{twgf.UN4.rect} \cdot \dfrac{\left(h_{toe}\right)}{2} + H_{twgf.UN4.tri} \cdot \dfrac{\left(h_{toe}\right)}{3} + H_{twbk.UN4.tri} \cdot \left(-d_{key} \cdot \dfrac{2}{3}\right) + H_{twbk.UN4.rect} \cdot \left(\dfrac{-d_{key}}{2}\right)\right]}{H_{twgf.UN4.tri} + H_{twgf.UN4.rect} + H_{twbk.UN4.tri} + H_{twbk.UN4.rect}} = 0.22\,m$$

SUMMATION OF LATERAL WATER LOADS:

$$\Sigma H_{Water.UN4} := H_{hwas.UN4} + H_{hwrg.UN4} + H_{twgk.UN4} + H_{twrg.UN4} = -2280.82 \cdot kN$$

$$\Sigma M_{Hwater.UN4} := H_{hwas.UN4} \cdot H_{hwas.UN4.loc} + H_{hwrg.UN4} \cdot H_{hwrg.UN4.loc} \cdots + H_{twgk.UN4} \cdot H_{twgk.UN4.loc} + H_{twrg.UN4} \cdot H_{twrg.UN4.loc} = -3345.21 \cdot kN \cdot m$$

VERTICAL WATER LOADS

UN4 CASE

HEADWATER:

Water Depth on top of Approach Slab: $d_{hw.UN4} := HW_{UN4} - TOC_{as} = 5.00\,m$

Length of Approach Slab: $L_{as} = 8.75\,m$

Width of Approach Slab: $w_{as} = 15.00\,m$

Weight on Apron is required for stability. Coffer U/S of pier nose must include fill to offset reduced water load.

Vertical Water Weight (H1) on Approach Slab: $H_{1.UN4} := \left(w_{as} \cdot d_{hw.UN4} \cdot L_{as}\right) \cdot \gamma_w \cdot \frac{3}{4} = 4828.4 \cdot kN$

Moment Arm for Application of Water Weight (H1) from toe: $H_{1.UN4.loc} := L_b - \frac{L_{as}}{2} = 14.13\,m$

TAILWATER:

Trapezoid Volume Above Gate Footing from Approach Slab to Crest: $V_{asc.UN4} := \left(L_{gf} - L_{gfc}\right) W_b \frac{d_{hw.UN4} + Y_{C.UN4}}{2} = 500.32 \cdot m^3$

Trapezoid Volume Above Gate Footing Crest to End of Gate Footing: $V_{gfc.UN4} := \left(L_{gfc} \cdot W_b\right) \frac{Y_{C.UN4} + Y_{TOE.UN4}}{2} = 108.42 \cdot m^3$

Load Above Gate Footing from Approach Slab to Crest: $H_{2.UN4.asc} := V_{asc.UN4} \cdot \gamma_w = 4908.15 \cdot kN$

Load Acting Above Footing Crest from Toe: $H_{2.UN4.asc.loc} := \frac{\left(L_{gf} - L_{gfc}\right) \cdot \left(2 \cdot d_{hw.UN4} + Y_{C.UN4}\right)}{3 \cdot \left(d_{hw.UN4} + Y_{C.UN4}\right)} + L_{gfc} = 6.26\,m$

Load Above Gate Footing from Crest to End: $H_{2.UN4.gfc} := V_{gfc.UN4} \cdot \gamma_w = 1063.6 \cdot kN$

Load Acting Above Gate Footing from Crest to End: $H_{2.UN4.gfc.loc} := \frac{\left(L_{gfc}\right) \cdot \left(2 \cdot Y_{C.UN4} + Y_{TOE.UN4}\right)}{3 \cdot \left(Y_{C.UN4} + Y_{TOE.UN4}\right)} = 1.54\,m$

Vertical Water Weight (H2) on Gate Footing: $H_{2.UN4} := H_{2.UN4.asc} + H_{2.UN4.gfc} = 5971.75 \cdot kN$

Moment Arm for Application of Water Weight (H2) from toe: $H_{2.UN4.loc} := \frac{H_{2.UN4.asc} \cdot H_{2.UN4.asc.loc} + H_{2.UN4.gfc} \cdot H_{2.UN4.gfc.loc}}{H_{2.UN4}} = 5.42\,m$

UPLIFT AT INCLINE SLIDING PLANE

UN4 CASE

Uplift pressure at U/S Face (heel): $U_{HW.UN4} := D_{hwas.UN4} \cdot \gamma_w = 107.9 \cdot \frac{kN}{m^2}$

Uplift pressure at D/S Face Stilling Basin: $U_{TW.UN4} := \left(D_{twtoe.UN4}\right) \cdot \gamma_w = 57.88 \cdot \frac{kN}{m^2}$

Length from U/S of Gate Structure to D/S of Stilling Basin: $L_{overall} = 18.50\,m$

Difference between Uplift pressure at HW and TW: $U_{diff.UN4} := U_{HW.UN4} - U_{TW.UN4} = 50.03 \cdot \frac{kN}{m^2}$

Slope of difference between between Uplift pressure at HW and TW: $U_{slope.UN4} := \frac{U_{diff.UN4}}{L_{overall}} = 2.70 \cdot \frac{kN}{m^2 \cdot m}$

Tailwater Pressure at toe of Gate Structure: $U_{press.toe.gs.UN4} := U_{TW.UN4} + \left(L_{overall} - L_b\right) \cdot U_{slope.UN4} = 57.88 \cdot \frac{kN}{m^2}$

Uniform uplift force UA Under Gate Structure due to TW (rectangle): $U_{A.UN4} := U_{press.toe.gs.UN4} \cdot L_b \cdot W_b \cdot -1 = -16061.42 \cdot kN$

Moment Arm from Toe of Gate Structure for Uplift UA: $L_{A.UN4} := \left(\frac{L_b}{2}\right) = 9.25\,m$

Linearly Decreasing Uplift Force UN4B Under Gate Structure due to HW-TW Differential (triangle): $U_{B.UN4} := \frac{1}{2} \cdot \left(U_{HW.UN4} - U_{press.toe.gs.UN4}\right) \cdot L_b \cdot W_b \cdot -1 = -6941.8 \cdot kN$

Moment Arm from Toe of Gate Structure for Uplift UB: $L_{B.UN4} := \frac{2}{3} \cdot L_b = 12.33\,m$

Total Resultant Uplift force: $U_{UN4} := U_{A.UN4} + U_{B.UN4} = -23003.22 \cdot kN$

Resultant Location from Toe: $U_{UN4.loc} := \frac{\left(U_{A.UN4} \cdot L_{A.UN4} + U_{B.UN4} \cdot L_{B.UN4}\right)}{\left(U_{A.UN4} + U_{B.UN4}\right)} = 10.18\,m$

$\Sigma V_{water.UN4} := H_{1.UN4} + H_{2.UN4} + U_{UN4} = -12203.11 \cdot kN$

$\Sigma M_{Vwater.UN4} := H_{1.UN4} \cdot H_{1.UN4.loc} + H_{2.UN4} \cdot H_{2.UN4.loc} + U_{UN4} \cdot U_{UN4.loc} = -133615.63 \cdot kN \cdot m$

SOIL LOADS

UN4 CASE

Equivalent Fluid Pressure (EFP):

At rest lateral pressure coefficient: $K_{o.UN4} := 1 - \sin(\phi_{backfill}) = 0.658$ (Section 5.3, Design Criteria)

Headwater Pier Footing Unit Width: $W_{hwas.UN4} = 15.00\,m$

Tailwater Pier Footing Unit Width: $W_{tw.UN4} = 15.00\,m$

Pier Footing Thickness at Heel: $t_{hf.UN4} := TOC_{as} - BOK_{elev} = 6.00\,m$

Fixed Crest Footing Thickness at Toe: $t_{tf.UN4} := TOC_{pfe} - BOF_{elev} = 2.00\,m$

Lateral Driving Force (Headwater Side - at rest condition)

At-Rest Soil Load:

$$E_{act.UN4} := \frac{\left(K_{o.UN4} \cdot t_{hf.UN4}^{\;2}\right)}{2} \cdot \left(\gamma_r - \gamma_w\right) \cdot W_{hwas.UN4} \cdot -1 = -2165.61 \cdot kN$$

Acting at:

$$E_{act.UN4.loc} := \frac{t_{hf.UN4}}{3} = 2.00\,m$$

Lateral Resisting Force (Tailwater Side - at rest condition)

At-rest Soil Load:

$$E_{pass.UN4} := \frac{\left(K_{o.UN4} \cdot t_{tf.UN4}^{\;2}\right)}{2} \cdot \left(\gamma_r - \gamma_w\right) \cdot W_{tw.UN4} = 240.62 \cdot kN$$

Acting at:

$$E_{pass.UN4.loc} := \frac{t_{tf.UN4}}{3} = 0.67\,m$$

$$\Sigma H_{soil.UN4} := E_{act.UN4} + E_{pass.UN4} = -1924.99 \cdot kN$$

$$\Sigma M_{soil.UN4} := E_{act.UN4} \cdot E_{act.UN4.loc} + E_{pass.UN4} \cdot E_{pass.UN4.loc} = -4170.8 \cdot kN \cdot m$$

ICE / IMPACT LOADS (ASSUME NO ICE LOADING ON TAILWATER SIDE)

ICE & IMPACT LOADS DO NOT APPLY FOR THIS LOAD CASE

Static Ice load on Gates:

$$I_{G.UN4} := \begin{cases} 00\,\dfrac{kN}{m} & \text{if } TOP_{rg.UN4} \le TOC_{as} \\ 0\,\dfrac{kN}{m} & \text{if } TOP_{rg.UN4} > TOC_{as} \end{cases} = 0 \cdot \frac{kN}{m}$$

(Section 7.7, Design Criteria)

Ice Loading Unit Width on Reg. Gate: $W_{rg.UN4} := 15.00m$ (Input value for load case)

Total Ice Load on Structure: $I_{UN4} := -\left(I_{G.UN4} \cdot W_{rg.UN4}\right) = 0 \cdot kN$

Apply Ice load at: $I_{UN4.loc} := \left(TOP_{rg.UN4} - BOF_{elev} - 0.30m\right) = 3.70\,m$

$$\Sigma H_{I.UN4} := I_{UN4} = 0 \cdot kN$$

$$\Sigma M_{I.UN4} := I_{UN4} \cdot I_{UN4.loc} = 0 \cdot kN \cdot m$$

(SEISMIC LOAD (NOT APPLICABLE FOR THIS LOAD CASE)

UN4 CASE

SUMMARY OF LOADS

	Loads	Moment Arm
Dead load of Concrete Structure:	$D_{conc} = 24618.6 \cdot kN$	$X_{conc.loc} = 10.06\,m$
Obermyer Gate Weight:	$D_{Gate.UN4} = 105.0 \cdot kN$	$X_{gate} = 6.60\,m$
HW Lateral Load on Approach Slab:	$H_{hwas.UN4} = -7063.2 \cdot kN$	$H_{hwas.UN4.loc} = 0.63\,m$
HW Lateral Load on Reg. Gate:	$H_{hwrg.UN4} = 0.0 \cdot kN$	$H_{hwrg.UN4.loc} = 4.00\,m$
TW Lateral Load on Reg. Footing (Including Key - Sliding Check Loads):	$H_{twgk.UN4} = 4782.38 \cdot kN$	$H_{twgk.UN4.loc} = 0.22\,m$
TW Lateral Load on Reg. Gate:	$H_{twrg.UN4} = 0.0 \cdot kN$	$H_{twrg.UN4.loc} = 4.00\,m$
Vertical HW Load on Approach Slab:	$H_{1.UN4} = 4828.4 \cdot kN$	$H_{1.UN4.loc} = 14.13\,m$
Vertical TW Load on Pier Footing (crest):	$H_{2.UN4} = 5971.8 \cdot kN$	$H_{2.UN4.loc} = 5.42\,m$
Uplift:	$U_{UN4} = -23003.2 \cdot kN$	$U_{UN4.loc} = 10.18\,m$
Lateral Soil Load (driving):	$E_{act.UN4} = -2165.6 \cdot kN$	$E_{act.UN4.loc} = 2.00\,m$
Lateral Soil Load (resisting):	$E_{pass.UN4} = 240.62 \cdot kN$	$E_{pass.UN4.loc} = 0.67\,m$
Ice / Impact Load:	$I_{UN4} = 0.0 \cdot kN$	$I_{UN4.loc} = 3.70\,m$

STABILITY ASSESSMENT (SLIDNG, BEARING, FLOTATION AND OVERTURNING):

CHECK SLIDING ALONG HORIZONTAL PLANE THRU TOE, IGNORING BEDROCK MOBILIZED BY STRUCTURAL HEEL KEY, OR VOID BEHIND KEY

UN4 CASE

Sum of Vertical Forces:

$\Sigma V_{UN4} := \Sigma V_{DL} + \Sigma V_{water.UN4} = 12625.5 \cdot kN$

Sum of Horizontal Forces:

$\Sigma H_{UN4} := \Sigma H_{Water.UN4} + \Sigma H_{soil.UN4} + \Sigma H_{I.UN4} = -4205.81 \cdot kN$

Sliding Factor of Safety:

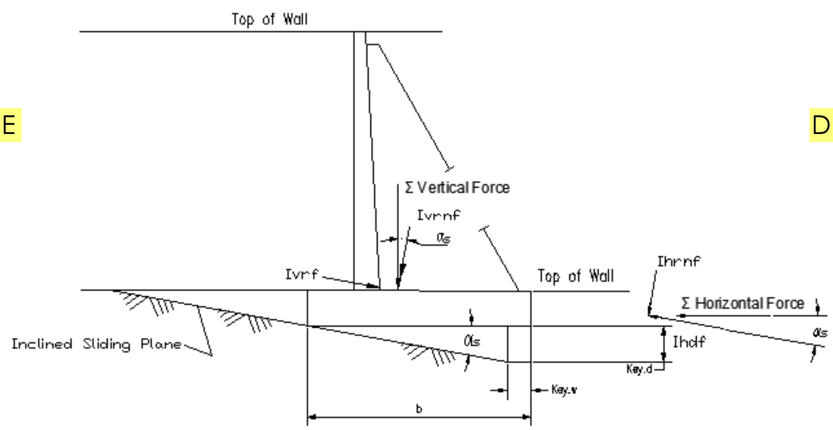
$$FS_{HorizSliding.UN4} := \frac{\tan_{\phi} \cdot \Sigma V_{UN4}}{|\Sigma H_{UN4}|} = 1.46$$

$FS_{HorizSliding.UN4.Check} :=$ | "OKAY" if $FS_{HorizSliding.UN4} \geq FS_{req.UN4.sl}$; "Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !" otherwise $=$ "OKAY"

CHECK SLIDING ALONG INCLINED SLIDING PLANE FROM HEEL KEY TO TOE, WITH BEDROCK MASS MOBILIZED BY REINFOCREDE CONCRETE KEY)

RESISTING SIDE

DRIVING SIDE



TOE

Ivrf=Inclined Resisting Force
Ivrnf=Inclined Resisting Normal Force
Ihrnf=Inclined Resisting Normal Force
Ihdf=Inclined Driving Force

$\Sigma V_{UN3} = 12392.33 \cdot kN$

$\alpha s = 0.11$ as degrees= $\alpha s \cdot \left(\frac{180}{\pi}\right) = 6.52$ $V_{rs} = 5775 \cdot kN$

Resolve $\Sigma Vert_{UN4}$ & $\Sigma Horiz_{UN4}$

$\Sigma V_{InclinedUN4} := \cos(\alpha s) \cdot \left(\Sigma V_{UN4} + V_{rs}\right) + \sin(\alpha s) \cdot |\Sigma H_{UN4}| = 18759.0 \cdot kN$

$\Sigma H_{InclinedUN4} := \cos(\alpha s) \cdot |\Sigma H_{UN4}| - \sin(\alpha s) \cdot \left(\Sigma V_{UN4} + V_{rs}\right) = 2089.3 \cdot kN$

(With properly engineered reinforced concrete Key, horizontal sliding plane thru Toe is protected, critical sliding plane is relocated to the INCLINED SLIDING PLANE FROM HEEL KEY To TOE, Bedrock Mass above this examined plane is mobilized by reinforced concrete key and combined into Structural Wedge.)

Inclined Sliding Plane Length

$L_{incline} = 18.61\ m$

Safety Factor for Sliding Inclined Failure Plane

$$FS_{InclinedISlidingUN4} := \frac{\Sigma V_{InclinedUN4} \cdot \tan\left(\phi_{rock} \cdot \frac{\pi}{180}\right)}{|\Sigma H_{InclinedUN4}|} = 4.38$$

$FS_{InclinedSliding.check.UN4} :=$ | "OKAY " if $FS_{InclinedISlidingUN4} > FS_{req.UN4.sl}$; "Revise Structure"" otherwise $=$ "OKAY "

$FS_{InclinedSliding.check.UN4} =$ "OKAY "

OVERTURNING STABILITY CHECK:

UN4 CASE

CHECK ECCENTRICITY

Sum of the moments:

$$\Sigma M_{UN4} := \Sigma M_{DL.UN4} + \Sigma M_{Hwater.UN4} + \Sigma M_{Vwater.UN4} + \Sigma M_{I.UN4} + \Sigma M_{soil.UN4} + \Sigma M_{soil} = 174494 \cdot kN \cdot m$$

Eccentricity:

$$e_{UN4} := \left(\frac{L_{incline}}{2}\right) - \frac{(\Sigma M_{UN4})}{\Sigma V_{InclinedUN4}} = 0.00\,m$$

Eccentricity Check:

$$e_{check.UN4} := \begin{cases} \text{"Okay"} & \text{if } |e_{UN4}| \le Kern \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$$e_{check.UN4} = \text{"Okay"}$$

Foundation Bearing Checks:

Incline Plane Area:

$$A_{b.incline} = 279.12\,m^2$$

Incline Plane Section Modulus:

$$S_{b.incline} = 865.63 \cdot m^3$$

Bearing Pressure at Heel:

$$\sigma_{heel.UN4} := \frac{\Sigma V_{InclinedUN4}}{A_{b.incline}} - \frac{(\Sigma V_{InclinedUN4} \cdot e_{UN4})}{S_{b.incline}} = 67.2 \cdot \frac{kN}{m^2}$$

$$\sigma_{heel.UN4.check} := \left(\begin{cases} \text{"Okay"} & \text{if } \sigma_{heel.UN4} \le \sigma_{allow.UN4} \\ \text{"Revise Structure"} & \text{if } \sigma_{heel.UN4} < 0\,\frac{kN}{m^2} \end{cases} \right)$$

$$\sigma_{heel.UN4.check} = \text{"Okay"}$$

Bearing Pressure at Toe:

$$\sigma_{toe.UN4} := \frac{\Sigma V_{InclinedUN4}}{A_{b.incline}} + \frac{(\Sigma V_{InclinedUN4} \cdot e_{UN4})}{S_{b.incline}} = 67.3 \cdot \frac{kN}{m^2}$$

$$\sigma_{toe.UN4.1.check} := \begin{cases} \text{"Okay"} & \text{if } \sigma_{toe.UN4} \le \sigma_{allow.UN4} \\ \text{"Revise Structure"} & \text{if } \sigma_{toe.UN4} < 0\,\frac{kN}{m^2} \end{cases}$$

$$\sigma_{toe.UN4.1.check} = \text{"Okay"}$$

FLOATATION ANALYSIS:

ACCEPTANCE PARAMETERS

Required Factor of Safety: $FS_{req.FUN4} := 1.3$

VERTICAL LOADS RESISTING:

Dead Load: $\Sigma V_{DL} = 24828.6 \cdot kN$

Water Weight H1+H2: $\Sigma V_{H.FUN4} := H_{1.UN4} + H_{2.UN4} = 10800.11 \cdot kN$

Summation Vertical Resisting: $\Sigma V_{FUN4} := \Sigma V_{DL} + \Sigma V_{H.FUN4} = 35628.7 \cdot kN$

VERTICAL LOADS UPLIFT:

Uplift: $U_{UN4} = -23003.22 \cdot kN$

Factor of Safety Floatation:

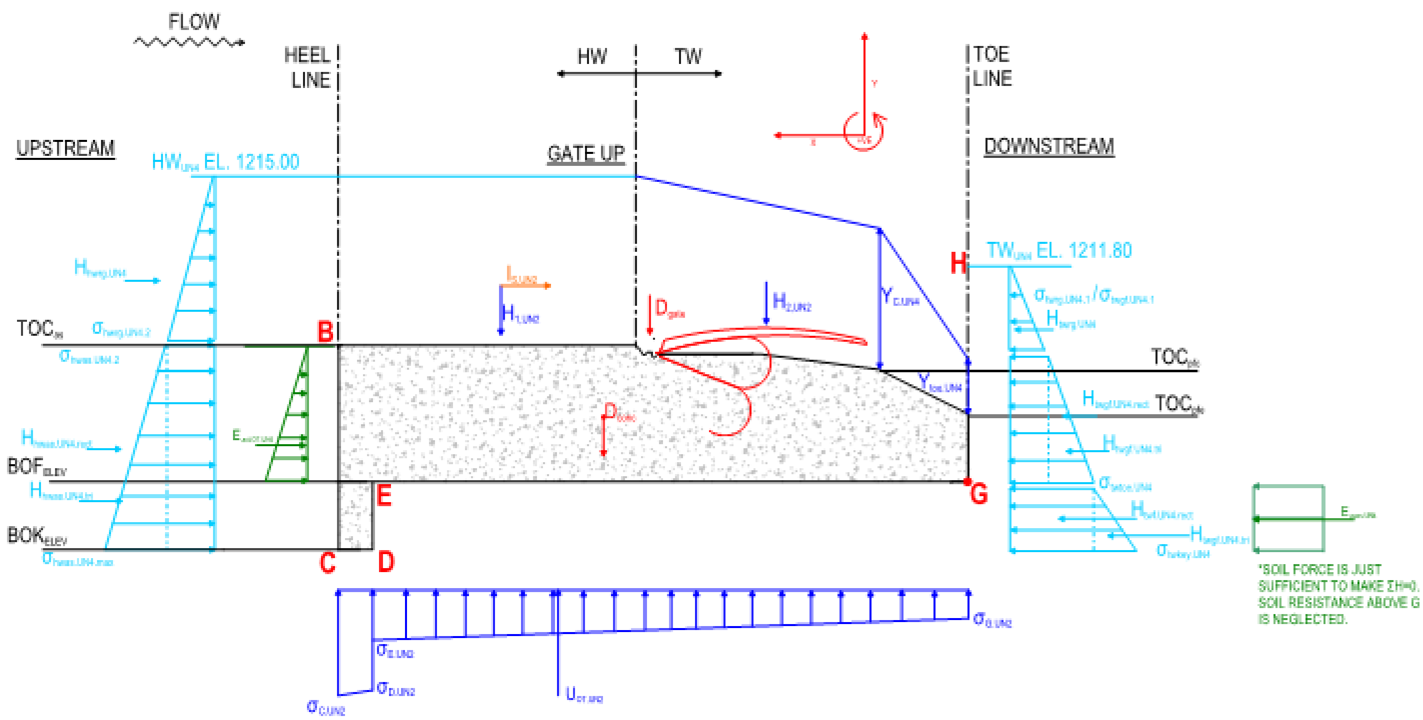
$$FS_{act.FUN4} := \frac{\Sigma V_{FUN4}}{|U_{UN4}|} = 1.55$$

$$FS_{check.FUN4} := \begin{cases} \text{"OKAY"} & \text{if } FS_{act.FUN4} \ge FS_{req.FUN4} \\ \text{"ANCHORS REQUIRED"} & \text{if } FS_{act.FUN4} < FS_{req.FUN4} \end{cases} = \text{"OKAY"}$$

MONOLITH OVERTURNING STABILITY ANALYSIS

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.
Assumptions are made in order to compute overturning stability of indetermine forces on monolith with key;
(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.
(b) The horizontal resisting force acting on the key, P.key, is that required for static equilibrium
(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1 $Ratio_{OT.UN4.min} := 0.33$



Uplift Loads for Overturning Stability Analysis

Line of Creep:

Change in Water Head: $\Delta_{h.UN4} := HW_{UN4} - TW_{UN4} = 3.1\ m$

Length from Point C to Point G: $L_{CG} = 18.61\ m$

Length from Various Points to Points: $L_{CD} = 1\ m$ $\quad L_{DE} = 2\ m$ $\quad L_{EG} = 17.5\ m$

$L_{GH.UN4} := TW_{UN4} - BOF_{elev} = 5.9\ m$

Length from Point C, D, E to G: $L_{CDEG} = 20.5\ m$ $\quad L_{CDE} = 3\ m$

Water Pressure at Point C: $\sigma_{C.UN4} := \sigma_{hwas.UN4.2} = -107.91 \cdot kPa$

Water Pressure at Point G: $\sigma_{G.UN4} := \sigma_{twtoe.UN4} \cdot -1 = -57.88 \cdot kPa$

Water Pressure at Point D:

$$\sigma_{D.UN4} := -\gamma_w \cdot \left[\left(HW_{UN4} - BOK_{elev} \right) - \frac{\Delta_{h.UN4} \cdot L_{CD}}{L_{CDEG}} \right] = -106.43 \cdot kPa$$

Water Pressure at Point E:

$$\sigma_{E.UN4} := -\gamma_w \cdot \left[\left(HW_{UN4} - BOF_{elev} \right) - \frac{\Delta_{h.UN4} \cdot L_{CDE}}{L_{CDEG}} \right] = -83.84 \cdot kPa$$

Uplift for Overturning Analysis on Bottom of Key:

$$U_{OT.UN4.key} := \frac{\sigma_{C.UN4} + \sigma_{D.UN4}}{2} \cdot L_{CD} \cdot W_b = -1607.52 \cdot kN$$

Acting at:

$$U_{OT.UN4.key.loc} := \frac{L_{CD} \cdot \left(2 \cdot \sigma_{C.UN4} + \sigma_{D.UN4} \right)}{3 \left(\sigma_{C.UN4} + \sigma_{D.UN4} \right)} + L_{EG} = 18\ m$$

UN4 CASE

Uplift for Overturning Analysis on Bottom of Footing: $U_{OT.UN4.ftg} := \frac{\sigma_{E.UN4} + \sigma_{G.UN4}}{2} \cdot L_{EG} \cdot W_b = -18600.57 \cdot kN$

Acting at: $U_{OT.UN4.ftg.loc} := \frac{L_{EG} \cdot (\sigma_{G.UN4} + 2 \cdot \sigma_{E.UN4})}{3(\sigma_{G.UN4} + \sigma_{E.UN4})} = 9.28\,m$

Uplift Load for Overturning Analysis: $U_{OT.UN4} := U_{OT.UN4.key} + U_{OT.UN4.ftg} = -20208.09 \cdot kN$

Uplift Load Acting from Toe: $U_{OT.UN4.loc} := \frac{U_{OT.UN4.key} \cdot U_{OT.UN4.key.loc} + U_{OT.UN4.ftg} \cdot U_{OT.UN4.ftg.loc}}{U_{OT.UN4}} = 9.98\,m$

<u>All Vertical Loads Applicable to Overturning Stability Analysis</u>

Total Concrete Dead Loads:	$D_{conc} = 24618.6 \cdot kN$	at:	$X_{conc.loc} = 10.06\,m$
Dead Load of Gate:	$D_{Gate} = 210.0 \cdot kN$		$X_{gate} = 6.60\,m$
Water Weight (HW) on Apron Slab:	$H_{1.UN4} = 4828.4 \cdot kN$		$H_{1.UN4.loc} = 14.13\,m$
Water Weight (TW) on Gate Footing:	$H_{2.UN4} = 5971.8 \cdot kN$		$H_{2.UN4.loc} = 5.42\,m$
Uplift Load for Overturning Analysis:	$U_{OT.UN4} = -20208.09 \cdot kN$		$U_{OT.UN4.loc} = 9.98 \cdot m$

Sum of All Overturning Analysis Vertical Load:

$$\Sigma V_{UN4.OT} := D_{conc} + D_{Gate} + H_{1.UN4} + H_{2.UN4} + U_{OT.UN4} = 15420.62 \cdot kN$$

Sum of All Overturning Analysis Vertical Load Moments:

$$\Sigma M_{V.UN4.OT} := D_{conc} \cdot X_{conc.loc} + D_{Gate} \cdot X_{gate} + H_{1.UN4} \cdot H_{1.UN4.loc} + H_{2.UN4} \cdot H_{2.UN4.loc} + U_{OT.UN4} \cdot U_{OT.UN4.loc} = 147881.57 \cdot kN \cdot m$$

<u>Lateral Tailwater Loads for Overturning Stability Analysis</u>

TW Lateral Load on Gate Footing (No Key - Overturning Values Adjusted): $H_{twgf.UN4} := H_{twgf.UN4.tri} + H_{twgf.UN4.rect} = 2295.54 \cdot kN$

Acting at: $H_{twgf.UN4.loc} := \frac{\frac{h_{toe}}{3} \cdot H_{twgf.UN4.tri} + \frac{h_{toe}}{2} \cdot H_{twgf.UN4.rect}}{H_{twgf.UN4}} = 1.66\,m$

Horizontal Tailwater Pressure Top of Key (Overturning Analysis): $\sigma_{twtk.OT.UN4} := \sigma_{E.UN4} \cdot -1 = 83.84 \cdot kPa$

Horizontal Tailwater Pressure Bottom of Key (Overturning Analysis): $\sigma_{twbk.OT.UN4} := \sigma_{D.UN4} \cdot -1 = 106.43 \cdot kPa$

Triangular Distribution Unit Load Acting at Key: $H_{twbk.OT.UN4.tri} := \frac{(\sigma_{twbk.OT.UN4} - \sigma_{twtk.OT.UN4})}{2} \cdot d_{key} \cdot W_{tw.UN4} = 338.8 \cdot kN$

Triangular Distribution Unit Load Acting at Key: $H_{twbk.OT.UN4.rect} := \sigma_{twtk.OT.UN4} \cdot d_{key} \cdot W_{tw.UN4} = 2515.19 \cdot kN$

Total Horizontal Tailwater Load on Key (Overturning Values Adjusted): $H_{twkey.OT.UN4} := H_{twbk.OT.UN4.tri} + H_{twbk.OT.UN4.rect} = 2853.99 \cdot kN$

Acting at: $H_{twkey.OT.UN4.loc} := \frac{H_{twbk.OT.UN4.tri} \cdot \frac{-2 \cdot d_{key}}{3} + H_{twbk.OT.UN4.rect} \cdot \frac{-d_{key}}{2}}{H_{twkey.OT.UN4}} = -1.04 \cdot m$

UN4 CASE

Lateral Driving Earth Loads for Overturning Stability Analysis (at rest condition)

Depth of Driving Soil Loads (to top of key): $h_{E.OT.UN4} := TOC_{as} - BOF_{elev} = 4\ m$

At-Rest Soil Load: $E_{act.OT.UN4} := \frac{\left(K_{o.UN4} \cdot h_{E.OT.UN4}^{\ 2}\right)}{2} \cdot \left(\gamma_r - \gamma_w\right) \cdot W_{hwas.UN4} \cdot -1 = -962.49 \cdot kN$

At Rest- Soil Load Acting from Toe: $E_{act.OT.UN4.loc} := \frac{h_{E.OT.UN4}}{3} = 1.33\ m$

All Lateral Loads Appliable to Overturning Stability Analysis

HW Lateral Load on Approach Slab:	$H_{hwas.UN4} = -7063.2 \cdot kN$	$H_{hwas.UN4.loc} = 0.63\ m$
HW Lateral Load on Reg. Gate:	$H_{hwrg.UN4} = 0.0 \cdot kN$	$H_{hwrg.UN4.loc} = 4.00\ m$
TW Lateral Load on Reg. Gate:	$H_{twrg.UN4} = 0.0 \cdot kN$	$H_{twrg.UN4.loc} = 4.00\ m$
TW Lateral Load on Gate Footing (No Key - Overturning Values Adjusted):	$H_{twgf.UN4} = 2295.54 \cdot kN$	$H_{twgf.UN4.loc} = 1.66\ m$
TW Lateral Load on Key:	$H_{twkey.OT.UN4} = 2853.99 \cdot kN$	$H_{twkey.OT.UN4.loc} = -1.04\ m$
Ice / Impact Load:	$I_{UN4} = 0.0 \cdot kN$	$I_{UN4.loc} = 3.70\ m$
Lateral Soil Load (driving):	$E_{act.OT.UN4} = -962.5 \cdot kN$	$E_{act.OT.UN4.loc} = 1.33\ m$

Resisting Lateral Soil Load as required to produce horizontal equilibrium:

$$E_{pas.OT.UN4} := -\left(H_{hwas.UN4} + H_{hwrg.UN4} + H_{twrg.UN4} + H_{twgf.UN4} + H_{twkey.OT.UN4} + I_{UN4} + E_{act.OT.UN4}\right) = 2876.16 \cdot kN$$

Acting at:

$$E_{pas.OT.UN4.loc} := -1 \cdot \frac{d_{key}}{2} = -1\ m$$

Sum of All Overturning Analysis Horizontal Load (ΣH=0):

$$\Sigma H_{UN4.OT} := H_{hwas.UN4} + H_{hwrg.UN4} + H_{twrg.UN4} + H_{twgf.UN4} + H_{twkey.OT.UN4} + I_{UN4} + E_{act.OT.UN4} + E_{pas.OT.UN4} = 0 \cdot kN$$

Sum of All Overturning Analysis Horizontal Load Moments:

$$\Sigma M_{H.UN4.OT} := H_{hwas.UN4} \cdot H_{hwas.UN4.loc} + H_{hwrg.UN4} \cdot H_{hwrg.UN4.loc} + H_{twrg.UN4} \cdot H_{twrg.UN4.loc} \cdots + H_{twgf.UN4} \cdot H_{twgf.UN4.loc} + H_{twkey.OT.UN4} \cdot H_{twkey.OT.UN4.loc} + I_{UN4} \cdot I_{UN4.loc} \cdots + E_{act.OT.UN4} \cdot E_{act.OT.UN4.loc} + E_{pas.OT.UN4} \cdot E_{pas.OT.UN4.loc} = -7734.63 \cdot kN \cdot m$$

Overturning Stability Analysis

$\Sigma M_{UN4.OT} := \Sigma M_{V.UN4.OT} + \Sigma M_{H.UN4.OT} = 140146.94 \cdot kN \cdot m$

$X_{R.UN4} := \frac{\Sigma M_{UN4.OT}}{\Sigma V_{UN4.OT}} = 9.09\ m$ $\quad x_{OT.UN4} := X_{R.UN4} - \frac{L_b}{2} = -0.16\ m$

Overturning Resultant Ratio $\quad Ratio_{OT.UN4} := \frac{X_{R.UN4}}{L_b} = 0.49$

$Ratio_{OT.UN4.check} :=$ "OKAY" if $Ratio_{OT.UN4} \geq Ratio_{OT.UN4.min}$; "Revise Structure" otherwise $=$ "OKAY"

$x_{OT.check.UN4} :=$ "OKAY" if $\left|x_{OT.UN4}\right| \leq Kern$; "Revise Structure" otherwise $=$ "OKAY"

CHECK FOUNDATION BEARING CAPACITY (HORIZONTAL PLANE):

UN4 CASE

Bearing Pressure Under Toe: $\sigma_{ToeUN4.OT} := \frac{\Sigma V_{UN4.OT}}{L_b \cdot W_b} + \frac{(\Sigma V_{UN4.OT} \cdot x_{OT.UN4})}{S_b} = 52.7 \cdot kPa$

$Bearing_{ChecktoeUN4.OT} := \begin{vmatrix} \text{"OKAY "} & \text{if} \quad \sigma_{ToeUN4.OT} < \sigma_{allow.UN4} \\ \text{"NG""} & \text{otherwise} \end{vmatrix} = \text{"OKAY "}$

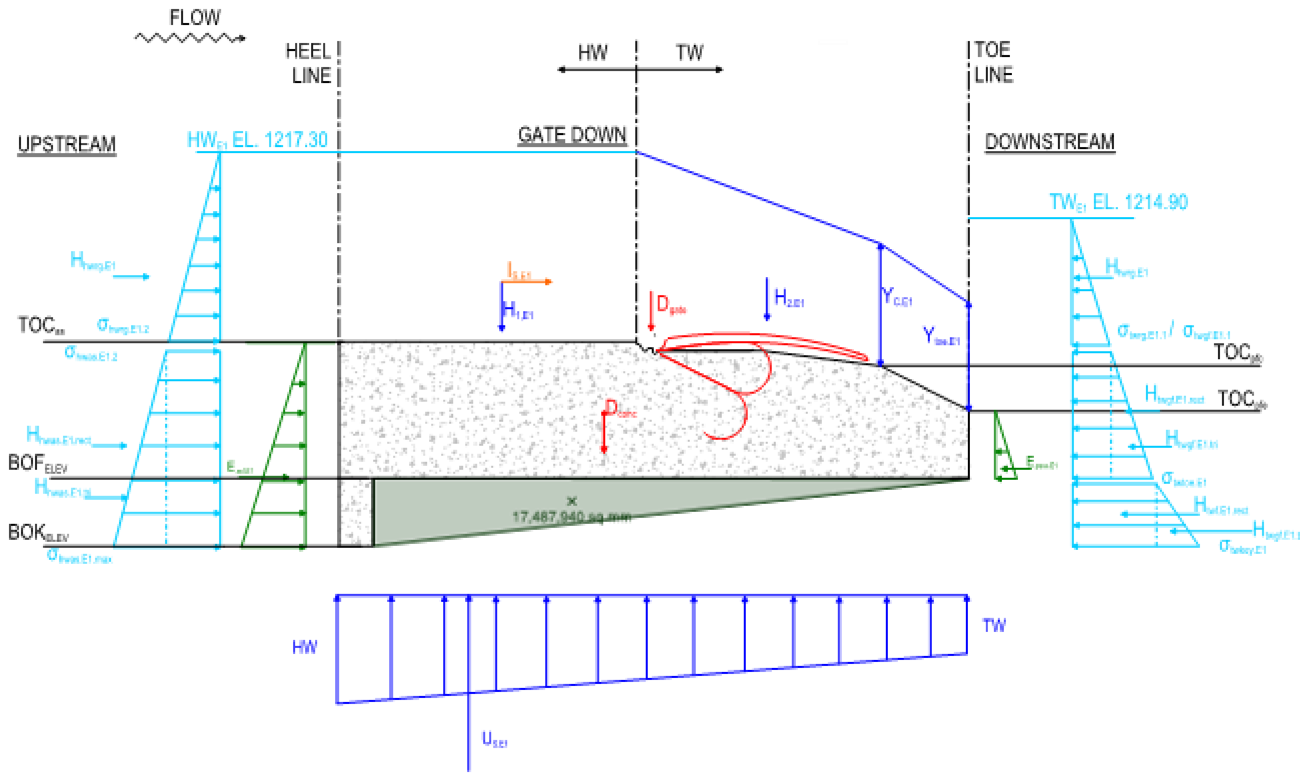
Bearing Pressure Under Heel: $\sigma_{HeelUN4.OT} := \frac{\Sigma V_{UN4.OT}}{L_b \cdot W_b} - \frac{(\Sigma V_{UN4.OT} \cdot x_{OT.UN4})}{S_b} = 58.5 \cdot kPa$

$Bearing_{CheckheelUN4.OT} := \left(\begin{vmatrix} \text{"OKAY "} & \text{if} \quad \sigma_{HeelUN4.OT} < \sigma_{allow.UN4} \wedge \sigma_{HeelUN4.OT} > 0 \\ \text{"NG""} & \text{otherwise} \end{vmatrix} \right) = \text{"OKAY "}$

SUMMARY OF STABILITY ASSESSMENT:

Sliding Factor of Safety: (Horizontal Plane)	$FS_{HorizSliding.UN4} = 1.46$	$FS_{HorizSliding.UN4.Check} = \text{"OKAY"}$
Sliding Factor of Safety: (Inclined Plane)	$FS_{InclinedlSlidingUN4} = 4.38$	$FS_{InclinedSliding.check.UN4} = \text{"OKAY "}$
Eccentricity: (Inclined Plane)	$e_{UN4} = 0.00\,m$	$e_{check.UN4} = \text{"Okay"}$
Bearing Pressure At Heel: (Inclined Plane)	$\sigma_{heel.UN4} = 67 \cdot kPa$	$\sigma_{heel.UN4.check} = \text{"Okay"}$
Bearing Pressure At Toe: (Inclined Plane)	$\sigma_{toe.UN4} = 67 \cdot kPa$	$\sigma_{toe.UN4.1.check} = \text{"Okay"}$
Flotation Factor of Safety (horizontal plane)	$FS_{act.FUN4} = 1.55$	$FS_{check.FUN4} = \text{"OKAY"}$
Overturning Resultant Ratio: (horizontal plane)	$Ratio_{OT.UN4} = 0.49$	$Ratio_{OT.UN4.check} = \text{"OKAY"}$
Eccentricity: (horizontal plane)	$x_{OT.UN4} = -0.16\,m$	$x_{OT.check.UN4} = \text{"OKAY"}$
Bearing Pressure At Heel: (horizontal plane)	$\sigma_{HeelUN4.OT} = 58 \cdot kPa$	$Bearing_{CheckheelUN4.OT} = \text{"OKAY "}$
Bearing Pressure At Toe: (horizontal plane)	$\sigma_{ToeUN4.OT} = 53 \cdot kPa$	$Bearing_{ChecktoeUN4.OT} = \text{"OKAY "}$

E1 DESIGN CASE



ACCEPTANCE PARAMETERS

Required Factor of Safety for Sliding:	$FS_{req.E1.sl} := 1.1$	(Without Cohesion) (Section 8.1, Design Criteria)
Resultant Within Middle Third of Base:	$e \le \frac{L_b}{6} \wedge e \ge \frac{-L_b}{6}$	
Allowable Rock Bearing Pressure:	$\sigma_{allow.E1} := 1740 \cdot \frac{kN}{m^2}$	(Section 5.2, Design Criteria)

INPUT PARAMETERS

Headwater Elevation:	$HW_{E1} := 1217.30m$	(Section 8.3, Design Criteria)
Tailwater Elevation:	$TW_{E1} := 1214.90m$	(Section 8.3, Design Criteria)
Bottom of Footing Elevation:	$BOF_{elev} = 1206\,m$	
Approach Slab Top of Concrete Elevation at Upstream Face:	$TOC_{as} = 1210\,m$	
Footing Top of Concrete Elevation at Stilling Basin:	$TOC_{pfe} = 1208\,m$	
Footing Top of Concrete Elevation at Center of Footing:	$TOC_{pfc} = 1209.3\,m$	
Top of Guard/Regulating Gate Elevation:	$TOP_{rg.E1} := 1210.00m$ $TOP_{gg.E1} := 1210.00m$	
Bottom of Key Elevation:	$BOK_{elev} = 1204\,m$	

Gates are open when top of gate elevation is at 1210.00m

Gates are closed/up when top of gate elevation is at 1215.0m

Crestwater Elevation: Dynamic Flow $EL_{C.E1} := 1214.87m$

$$Y_{C.E1} := \begin{cases} (EL_{C.E1} - TOC_{pfc}) & \text{if } TOP_{rg.E1} \le HW_{E1} \\ (TW_{E1} - TOC_{pfc}) & \text{if } TOP_{rg.E1} > HW_{E1} \end{cases} = 5.57 \cdot m$$

Toewater Elevation: $EL_{TOE.E1} := 1211.06m$

$$Y_{TOE.E1} := \begin{cases} (EL_{TOE.E1} - TOC_{pfe}) & \text{if } TOP_{rg.E1} \le HW_{E1} \\ (TW_{E1} - TOC_{pfe}) & \text{if } TOP_{rg.E1} > HW_{E1} \end{cases} = 3.06 \cdot m$$

LATERAL WATER LOADS

E1 CASE

HEADWATER (DRIVING):

Headwater Depth on Gate: $D_{hwg.E1} := HW_{E1} - TOC_{as} = 7.30\,m$

Thickness of Approach Slab (Including Key): $T_{as} = 6\,m$

Headwater Depth at Heel (U/S face): $D_{hwas.E1} := HW_{E1} - BOK_{elev} = 13.30\,m$

Headwater Load Unit Width on Approach Slab: $W_{hwas.E1} := W_b = 15.00\,m$

Headwater Unit Load At Top of Approach Slab:

$$H_{hwas.E1.1} := \frac{-\left(\gamma_w \cdot D_{hwg.E1}{}^2\right)}{2} \cdot W_{hwas.E1} = -3920.81 \cdot kN$$

Headwater Unit Load At Bottom of Approach Key:

$$H_{hwas.E1.2} := \frac{-\left(\gamma_w \cdot D_{hwas.E1}{}^2\right)}{2} \cdot W_{hwas.E1} = -13014.7 \cdot kN$$

Headwater Line Load At Top of Approach Slab: $\sigma_{hwas.E1.1} := -\left(\gamma_w \cdot D_{hwg.E1}\right) = -71.61 \cdot kPa$

Headwater Line Load At Bottom of Approach Key: $\sigma_{hwas.E1.2} := -\left(\gamma_w \cdot D_{hwas.E1}\right) = -130.47 \cdot kPa$

Triangular Distribution Unit Load on Approach Slab and Key:

$$H_{hwas.E1.2.tri} := \left(\frac{\sigma_{hwas.E1.2} - \sigma_{hwas.E1.1}}{2}\right) \cdot \left(T_{as} \cdot W_{hwas.E1}\right) = -2648.7 \cdot kN$$

Rectangular Distribution Unit Load on Approach Slab and Key:

$$H_{hwas.E1.2.rect} := \sigma_{hwas.E1.1} \cdot \left(T_{as} \cdot W_{hwas.E1}\right) = -6445.17 \cdot kN$$

Total Horizontal Headwater Load on Approach Slab:

$$H_{hwas.E1} := H_{hwas.E1.2.tri} + H_{hwas.E1.2.rect} = -9093.87 \cdot kN$$

Apply Total Footing Headwater Load at:

$$H_{hwas.E1.loc} := \frac{\left[H_{hwas.E1.2.rect} \cdot \frac{\left(T_{as}\right)}{2} + H_{hwas.E1.2.tri} \cdot \frac{\left(T_{as}\right)}{3}\right]}{H_{hwas.E1.2.tri} + H_{hwas.E1.2.rect}} - d_{key} = 0.71\,m$$

Regulating Gate (4A) Operating Condition:

Reg. Gate Down/Open Condition: $A1_{E1} := TOP_{rg.E1} \le TOC_{as}$

Reg. Crest Gate Up/Closed, with Top of Gate Higher than HW Elevation: $B1_{E1} := TOP_{rg.E1} \ge HW_{E1} \wedge TOP_{rg.E1} > TOC_{as}$

Reg. Crest Gate Up/Closed, with Top of Gate Lower than HW Elevation: $C1_{E1} := TOP_{rg.E1} > TOC_{as} \wedge HW_{E1} > TOP_{rg.E1} = 0$

Reg. Crest Gate Height: $H_{rg.E1} := TOP_{rg.E1} - TOC_{as} = 0\,m$

Headwater Depth at Reg. Crest Gate: $D_{hwrg.E1} := HW_{E1} - TOC_{as} = 7.30\,m$

Reg. Crest Gate Width: $W_{hwrg.E1} := 15.00m$

Lateral Headwater Pressure at Bottom of Reg. Crest Gate:

$$\sigma_{hwrg.E1.1} := \left| \begin{array}{l} (0.0kPa) \text{ if } A1_{E1} \\ -\left(\gamma_w \cdot D_{hwrg.E1}\right) \text{ if } B1_{E1} \\ -\left(\gamma_w \cdot D_{hwrg.E1}\right) \text{ if } C1_{E1} \end{array} \right. = 0.0 \cdot kPa$$

Lateral Headwater Pressure at Top of Reg. Crest Gate: (Load at HW Elevation On Reg. Crest Gate if HW is below TOG_{rg})

$$\sigma_{hwrg.E1.2} := \left| \begin{array}{l} (0.0kPa) \text{ if } A1_{E1} \\ 0.0kPa \text{ if } B1_{E1} \\ -\left[\gamma_w \cdot \left(HW_{E1} - TOP_{rg.E1}\right)\right] \text{ if } C1_{E1} \end{array} \right. = 0.0 \cdot kPa$$

Average Pressure acting on Reg. Crest Gate:

$$\sigma_{hwrg.E1.avg} := \frac{\left(\sigma_{hwrg.E1.1} + \sigma_{hwrg.E1.2}\right)}{2} = 0 \cdot kPa$$

Total Area of Crest Gate:

$$A_{hwrg.E1} := \left| \begin{array}{l} D_{hwrg.E1} \cdot W_{hwrg.E1} \text{ if } A1_{E1} \\ D_{hwrg.E1} \cdot W_{hwrg.E1} \text{ if } B1_{E1} \\ H_{rg.E1} \cdot W_{hwrg.E1} \text{ if } C1_{E1} \end{array} \right. = 109.5 \cdot m^2$$

Total Horizontal Headwater Load on Reg. Crest Gate: $H_{hwrg.E1} := \sigma_{hwrg.E1.avg} \cdot A_{hwrg.E1} = 0.0 \cdot kN$

Apply Total Reg. Crest Gate Headwater Load at:

$$H_{hwrg.E1.loc} := \left| \begin{array}{l} \left(TOC_{as} - BOF_{elev}\right) \text{ if } A1_{E1} \\ \left[\frac{\left(HW_{E1} - TOC_{as}\right)}{3} + \left(TOC_{as} - BOF_{elev}\right)\right] \text{ if } B1_{E1} \\ \left[\frac{\sigma_{hwrg.E1.2} \cdot A_{hwrg.E1} \cdot \frac{\left(H_{rg.E1}\right)}{2} + \frac{\left(\sigma_{hwrg.E1.1} - \sigma_{hwrg.E1.2}\right)}{2} \cdot A_{hwrg.E1} \cdot \frac{\left(H_{rg.E1}\right)}{3}}{\sigma_{hwrg.E1.2} \cdot A_{hwrg.E1} + \frac{\left(\sigma_{hwrg.E1.1} - \sigma_{hwrg.E1.2}\right)}{2} \cdot A_{hwrg.E1}} \ldots \\ + \left(TOC_{as} - BOF_{elev}\right) \right] \text{ if } C1_{E1} \end{array} \right. = 4.0 \cdot m$$

LATERAL TAILWATER (RESISTING) Applied to Downstream Side of Reg. Crest Gate: E1 CASE

Reg. Gate Down/Open Condition: $A2_{E1} := TOP_{rg.E1} \le TOC_{as}$

Reg. Crest Gate Up/Closed, with Top of Gate Higher than TW Elevation: $B2_{E1} := TOP_{rg.E1} \ge TW_{E1} \wedge TOP_{rg.E1} > TOC_{as} = 0$

Reg. Crest Gate Up/Closed, with Top of Gate Lower than TW Elevation: $C2_{E1} := TOP_{rg.E1} > TOC_{as} \wedge TW_{E1} > TOP_{rg.E1} = 0$

Tailwater Depth at Reg. Crest Gate: $D_{twrg.E1} := TW_{E1} - TOC_{as} = 4.90\,m$

Reg. Crest Gate Width: $W_{twrg.E1} := 15.00m$

Lateral Water Load at Bottom of Reg. Crest Gate:

$$\sigma_{twrg.E1.1} := \left| \begin{array}{ll} (0.0kPa) & \text{if } A2_{E1} \\ (\gamma_w \cdot D_{twrg.E1}) & \text{if } B2_{E1} \\ (\gamma_w \cdot D_{twrg.E1}) & \text{if } C2_{E1} \end{array} \right. = 0.0 \cdot kPa$$

Lateral Water Load at Top of Reg. Crest Gate:
(Load at TW Elevation On Reg. Crest Gate if TW is below TOG_{rg})

$$\sigma_{twrg.E1.2} := \left| \begin{array}{ll} (0.0kPa) & \text{if } A2_{E1} \\ 0.0kPa & \text{if } B2_{E1} \\ \left[\gamma_w \cdot (TW_{E1} - TOP_{rg.E1})\right] & \text{if } C2_{E1} \end{array} \right. = 0.0 \cdot kPa$$

Average Pressure acting on Reg. Crest Gate:

$$\sigma_{twrg.E1.avg} := \frac{(\sigma_{twrg.E1.1} + \sigma_{twrg.E1.2})}{2} = 0 \cdot kPa$$

Total Area water acting on Crest Gate:

$$A_{twrg.E1} := \left| \begin{array}{ll} D_{twrg.E1} \cdot W_{twrg.E1} & \text{if } A2_{E1} \\ D_{twrg.E1} \cdot W_{twrg.E1} & \text{if } B2_{E1} \\ H_{rg.E1} \cdot W_{twrg.E1} & \text{if } C2_{E1} \end{array} \right. = 73.5 \cdot m^2$$

Total Horizontal Tailwater Load on Reg. Crest Gate: $H_{twrg.E1} := \sigma_{twrg.E1.avg} \cdot A_{twrg.E1} = 0.0 \cdot kN$

Apply Total Horiz. TW Load on Reg. Gate at:

$$H_{twrg.E1.loc} := \left| \begin{array}{ll} (TOC_{as} - BOF_{elev}) & \text{if } A2_{E1} \\ \left[\frac{(TW_{E1} - TOC_{as})}{3} + (TOC_{as} - BOF_{elev})\right] & \text{if } B2_{E1} \\ \left[\frac{\sigma_{twrg.E1.2} \cdot A_{twrg.E1} \cdot \frac{(H_{rg.E1})}{2} + \frac{(\sigma_{twrg.E1.1} - \sigma_{twrg.E1.2})}{2} A_{twrg.E1} \cdot \frac{(H_{rg.E1})}{3}}{\sigma_{twrg.E1.2} \cdot A_{twrg.E1} + \frac{(\sigma_{twrg.E1.1} - \sigma_{twrg.E1.2})}{2} \cdot A_{twrg.E1}} \ldots \\ + (TOC_{as} - BOF_{elev})\right] & \text{if } C2_{E1} \end{array} \right. = 4.0 \cdot m$$

TAILWATER (RESISTING) Applied to Concrete Structure:

Tailwater Depth At top of Gate Base Footing Elevation: $D_{twgf.E1} := TW_{E1} - TOC_{as} = 4.90\,m$

Water Depth at bottom of Gate Base Footing: $D_{twtoe.E1} := TW_{E1} - BOF_{elev} = 8.90\,m$

Footing Thickness at Toe $h_{toe} = 4\,m$

Unit Width of D/S face of crest for application of Tailwater Load: $W_{tw.E1} := W_b = 15.00\,m$

Tailwater Pressure At Top of Gate Footing: $\sigma_{twgf.E1} := \left(\gamma_w \cdot D_{twgf.E1}\right) = 48.07 \cdot kPa$

Tailwater Line Load At Bottom of Gate Footing: $\sigma_{twtoe.E1} := \left(\gamma_w \cdot D_{twtoe.E1}\right) = 87.31 \cdot kPa$

Triangular Distribution Unit Load on Gate Footing Base $H_{twgf.E1.tri} := \left(\frac{\sigma_{twtoe.E1} - \sigma_{twgf.E1}}{2}\right) \cdot \left(h_{toe} \cdot W_{tw.E1}\right) = 1177.2 \cdot kN$

Rectangular Distribution Unit Load on Gate Footing Base: $H_{twgf.E1.rect} := \sigma_{twgf.E1} \cdot \left(h_{toe} \cdot W_{tw.E1}\right) = 2884.14 \cdot kN$

Tailwater Pressure At Bottom of Sliding Failure Plane: $\sigma_{twbk.E1} := \left(HW_{E1} - BOK_{elev}\right) \cdot \gamma_w = 130.47 \cdot kPa$

Triangular Distribution Unit Load Below Footing: $H_{twbk.E1.tri} := \frac{\left(\sigma_{twbk.E1} - \sigma_{twtoe.E1}\right)}{2} \cdot d_{key} \cdot W_{tw.E1} = 647.46 \cdot kN$

Rectangular Distribution Load Below Footing Base: $H_{twbk.E1.rect} := \sigma_{twtoe.E1} \cdot d_{key} \cdot W_{tw.E1} = 2619.27 \cdot kN$

Total Horizontal Tailwater Load on Gate Footing (including key):

$$H_{twgk.E1} := H_{twgf.E1.tri} + H_{twgf.E1.rect} + H_{twbk.E1.tri} + H_{twbk.E1.rect} = 7328.07 \cdot kN$$

Apply Total Gate Footing Tailwater Load at:

$$H_{twgk.E1.loc} := \frac{\left[H_{twgf.E1.rect} \cdot \frac{\left(h_{toe}\right)}{2} + H_{twgf.E1.tri} \cdot \frac{\left(h_{toe}\right)}{3} + H_{twbk.E1.tri} \cdot \left(-d_{key} \cdot \frac{2}{3}\right) + H_{twbk.E1.rect} \cdot \left(\frac{-d_{key}}{2}\right)\right]}{H_{twgf.E1.tri} + H_{twgf.E1.rect} + H_{twbk.E1.tri} + H_{twbk.E1.rect}} = 0.53\,m$$

SUMMATION OF LATERAL WATER LOADS:

$$\Sigma H_{Water.E1} := H_{hwas.E1} + H_{hwrg.E1} + H_{twgk.E1} + H_{twrg.E1} = -1765.8 \cdot kN$$

$$\Sigma M_{Hwater.E1} := H_{hwas.E1} \cdot H_{hwas.E1.loc} + H_{hwrg.E1} \cdot H_{hwrg.E1.loc} \cdots + H_{twgk.E1} \cdot H_{twgk.E1.loc} + H_{twrg.E1} \cdot H_{twrg.E1.loc} = -2589.84 \cdot kN \cdot m$$

VERTICAL WATER LOADS

E1 CASE

HEADWATER:

Water Depth on top of Approach Slab: $d_{hw.E1} := HW_{E1} - TOC_{as} = 7.30\,m$

Length of Approach Slab: $L_{as} = 8.75\,m$

Width of Approach Slab: $w_{as} = 15.00\,m$

Vertical Water Weight (H1) on Approach Slab: $H_{1.E1} := \left(w_{as} \cdot d_{hw.E1} \cdot L_{as}\right) \cdot \gamma_w = 9399.2 \cdot kN$

Moment Arm for Application of Water Weight (H1) from toe: $H_{1.E1.loc} := L_b - \dfrac{L_{as}}{2} = 14.13\,m$

TAILWATER:

Trapezoid Volume Above Gate Footing from Approach Slab to Crest: $V_{asc.E1} := \left(L_{gf} - L_{gfc}\right) W_b \dfrac{d_{hw.E1} + Y_{C.E1}}{2} = 690.15 \cdot m^3$

Trapezoid Volume Above Gate Footing Crest to End of Gate Footing: $V_{gfc.E1} := \left(L_{gfc} \cdot W_b\right) \dfrac{Y_{C.E1} + Y_{TOE.E1}}{2} = 168.28 \cdot m^3$

Load Above Gate Footing from Approach Slab to Crest: $H_{2.E1.asc} := V_{asc.E1} \cdot \gamma_w = 6770.41 \cdot kN$

Load Acting Above Footing Crest from Toe: $H_{2.E1.asc.loc} := \dfrac{\left(L_{gf} - L_{gfc}\right) \cdot \left(2 \cdot d_{hw.E1} + Y_{C.E1}\right)}{3 \cdot \left(d_{hw.E1} + Y_{C.E1}\right)} + L_{gfc} = 6.34\,m$

Load Above Gate Footing from Crest to End: $H_{2.E1.gfc} := V_{gfc.E1} \cdot \gamma_w = 1650.88 \cdot kN$

Load Acting Above Gate Footing from Crest to End: $H_{2.E1.gfc.loc} := \dfrac{\left(L_{gfc}\right) \cdot \left(2 \cdot Y_{C.E1} + Y_{TOE.E1}\right)}{3 \cdot \left(Y_{C.E1} + Y_{TOE.E1}\right)} = 1.43\,m$

Vertical Water Weight (H2) on Gate Footing: $H_{2.E1} := H_{2.E1.asc} + H_{2.E1.gfc} = 8421.28 \cdot kN$

Moment Arm for Application of Water Weight (H2) from toe: $H_{2.E1.loc} := \dfrac{H_{2.E1.asc} \cdot H_{2.E1.asc.loc} + H_{2.E1.gfc} \cdot H_{2.E1.gfc.loc}}{H_{2.E1}} = 5.37\,m$

UPLIFT AT INCLINE SLIDING PLANE

E1 CASE

Uplift pressure at U/S Face (heel):	$U_{HW.E1} := D_{hwas.E1} \cdot \gamma_w = 130.5 \cdot \frac{kN}{m^2}$
Uplift pressure at D/S Face Stilling Basin:	$U_{TW.E1} := \left(D_{twtoe.E1}\right) \cdot \gamma_w = 87.31 \cdot \frac{kN}{m^2}$
Length from U/S of Gate Structure to D/S of Stilling Basin:	$L_{overall} = 18.50\,m$
Difference between Uplift pressure at HW and TW:	$U_{diff.E1} := U_{HW.E1} - U_{TW.E1} = 43.16 \cdot \frac{kN}{m^2}$
Slope of difference between between Uplift pressure at HW and TW:	$U_{slope.E1} := \frac{U_{diff.E1}}{L_{overall}} = 2.33 \cdot \frac{kN}{m^2 \cdot m}$
Tailwater Pressure at toe of Gate Structure:	$U_{press.toe.gs.E1} := U_{TW.E1} + \left(L_{overall} - L_b\right) \cdot U_{slope.E1} = 87.31 \cdot \frac{kN}{m^2}$
Uniform uplift force UA Under Gate Structure due to TW (rectangle):	$U_{A.E1} := U_{press.toe.gs.E1} \cdot L_b \cdot W_b \cdot -1 = -24228.25 \cdot kN$
Moment Arm from Toe of Gate Structure for Uplift UA:	$L_{A.E1} := \left(\frac{L_b}{2}\right) = 9.25\,m$
Linearly Decreasing Uplift Force E1B Under Gate Structure due to HW-TW Differential (triangle):	$U_{B.E1} := \frac{1}{2} \cdot \left(U_{HW.E1} - U_{press.toe.gs.E1}\right) \cdot L_b \cdot W_b \cdot -1 = -5989 \cdot kN$
Moment Arm from Toe of Gate Structure for Uplift UB:	$L_{B.E1} := \frac{2}{3} \cdot L_b = 12.33\,m$
Total Resultant Uplift force:	$U_{E1} := U_{A.E1} + U_{B.E1} = -30217.25 \cdot kN$
Resultant Location from Toe:	$U_{E1.loc} := \frac{\left(U_{A.E1} \cdot L_{A.E1} + U_{B.E1} \cdot L_{B.E1}\right)}{\left(U_{A.E1} + U_{B.E1}\right)} = 9.86\,m$

$\Sigma V_{water.E1} := H_{1.E1} + H_{2.E1} + U_{E1} = -12396.76 \cdot kN$

$\Sigma M_{Vwater.E1} := H_{1.E1} \cdot H_{1.E1.loc} + H_{2.E1} \cdot H_{2.E1.loc} + U_{E1} \cdot U_{E1.loc} = -119965.9 \cdot kN \cdot m$

SOIL LOADS

E1 CASE

Equivalent Fluid Pressure (EFP):

At rest lateral pressure coefficient: $K_{o.E1} := 1 - \sin(\phi_{backfill}) = 0.658$ (Section 5.3, Design Criteria)

Headwater Pier Footing Unit Width: $W_{hwas.E1} = 15.00\,m$

Tailwater Pier Footing Unit Width: $W_{tw.E1} = 15.00\,m$

Pier Footing Thickness at Heel: $t_{hf.E1} := TOC_{as} - BOK_{elev} = 6.00\,m$

Fixed Crest Footing Thickness at Toe: $t_{tf.E1} := TOC_{pfe} - BOF_{elev} = 2.00\,m$

Lateral Driving Force (Headwater Side - at rest condition)

At-Rest Soil Load: $E_{act.E1} := \frac{\left(K_{o.E1} \cdot t_{hf.E1}{}^{2}\right)}{2} \cdot (\gamma_r - \gamma_w) \cdot W_{hwas.E1} \cdot -1 = -2165.61 \cdot kN$

Acting at: $E_{act.E1.loc} := \frac{t_{hf.E1}}{3} = 2.00\,m$

Lateral Resisting Force (Tailwater Side - at rest condition)

At-rest Soil Load: $E_{pass.E1} := \frac{\left(K_{o.E1} \cdot t_{tf.E1}{}^{2}\right)}{2} \cdot (\gamma_r - \gamma_w) \cdot W_{tw.E1} = 240.62 \cdot kN$

Acting at: $E_{pass.E1.loc} := \frac{t_{tf.E1}}{3} = 0.67\,m$

$\Sigma H_{soil.E1} := E_{act.E1} + E_{pass.E1} = -1924.99 \cdot kN$

$\Sigma M_{soil.E1} := E_{act.E1} \cdot E_{act.E1.loc} + E_{pass.E1} \cdot E_{pass.E1.loc} = -4170.8 \cdot kN \cdot m$

ICE / IMPACT LOADS (ASSUME NO ICE LOADING ON TAILWATER SIDE)

Static Ice load on Gates:

$$I_{G.E1} := \begin{cases} 00 \frac{kN}{m} & \text{if } TOP_{rg.E1} \le TOC_{as} \\ 0.0 \frac{kN}{m} & \text{if } TOP_{rg.E1} > TOC_{as} \end{cases} = 0 \cdot \frac{kN}{m}$$

(Section 7.7, Design Criteria)

Ice Loading Unit Width on Reg. Gate: $W_{rg.E1} := 15.00m$ (Input value for load case)

Total Ice Load on Structure: $I_{E1} := -\left(I_{G.E1} \cdot W_{rg.E1}\right) = 0 \cdot kN$

Apply Ice load at: $I_{E1.loc} := \left(TOP_{rg.E1} - BOF_{elev} - 0.30m\right) = 3.70\,m$

$\Sigma H_{I.E1} := I_{E1} = 0 \cdot kN$

$\Sigma M_{I.E1} := I_{E1} \cdot I_{E1.loc} = 0 \cdot kN \cdot m$

(SEISMIC LOAD (NOT APPLICABLE FOR THIS LOAD CASE)

E1 CASE

SUMMARY OF LOADS

	Loads	Moment Arm
Dead load of Concrete Structure:	$D_{conc} = 24618.6 \cdot kN$	$X_{conc.loc} = 10.06\,m$
Obermyer Gate Weight:	$D_{Gate} = 210.0 \cdot kN$	$X_{gate} = 6.60\,m$
HW Lateral Load on Approach Slab:	$H_{hwas.E1} = -9093.9 \cdot kN$	$H_{hwas.E1.loc} = 0.71\,m$
HW Lateral Load on Reg. Gate:	$H_{hwrg.E1} = 0.0 \cdot kN$	$H_{hwrg.E1.loc} = 4.00\,m$
TW Lateral Load on Reg. Footing (Including Key - Sliding Check Loads):	$H_{twgk.E1} = 7328.07 \cdot kN$	$H_{twgk.E1.loc} = 0.53\,m$
TW Lateral Load on Reg. Gate:	$H_{twrg.E1} = 0.0 \cdot kN$	$H_{twrg.E1.loc} = 4.00\,m$
Vertical HW Load on Approach Slab:	$H_{1.E1} = 9399.2 \cdot kN$	$H_{1.E1.loc} = 14.13\,m$
Vertical TW Load on Pier Footing (crest):	$H_{2.E1} = 8421.3 \cdot kN$	$H_{2.E1.loc} = 5.37\,m$
Uplift:	$U_{E1} = -30217.3 \cdot kN$	$U_{E1.loc} = 9.86\,m$
Lateral Soil Load (driving):	$E_{act.E1} = -2165.6 \cdot kN$	$E_{act.E1.loc} = 2.00\,m$
Lateral Soil Load (resisting):	$E_{pass.E1} = 240.62 \cdot kN$	$E_{pass.E1.loc} = 0.67\,m$
Ice / Impact Load:	$I_{E1} = 0.0 \cdot kN$	$I_{E1.loc} = 3.70\,m$

STABILITY ASSESSMENT (SLIDNG, BEARING, FLOTATION AND OVERTURNING): E1 CASE

CHECK SLIDING ALONG HORIZONTAL PLANE THRU TOE,
IGNORING BEDROCK MOBILIZED BY STRUCTURAL HEEL KEY, OR VOID BEHIND KEY

Sum of Vertical Forces:

$\Sigma V_{E1} := \Sigma V_{DL} + \Sigma V_{water.E1} = 12431.8 \cdot kN$

Sum of Horizontal Forces:

$\Sigma H_{E1} := \Sigma H_{Water.E1} + \Sigma H_{soil.E1} + \Sigma H_{I.E1} = -3690.79 \cdot kN$

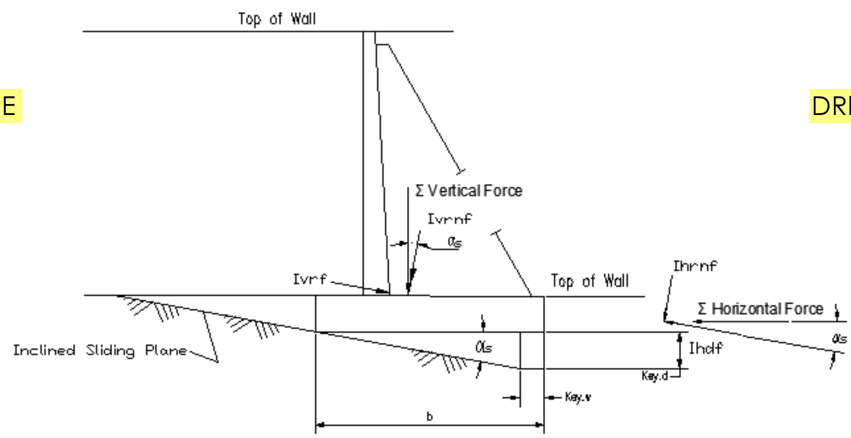
Sliding Factor of Safety: $FS_{HorizSliding.E1} := \dfrac{\tan_{\phi} \cdot \Sigma V_{E1}}{|\Sigma H_{E1}|} = 1.64$

$$FS_{HorizSliding.E1.Check} := \begin{cases} \text{"OKAY"} & \text{if } FS_{HorizSliding.E1} \ge FS_{req.E1.sl} \\ \text{"Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

CHECK SLIDING ALONG INCLINED SLIDING PLANE FROM HEEL KEY TO TOE,
WITH BEDROCK MASS MOBILIZED BY REINFOCREDE CONCRETE KEY)

RESISTING SIDE

DRIVING SIDE



TOE

Ivrf=Inclined Resisting Force
Ivrnf=Inclined Resisting Normal Force
Ihrnf=Inclined Resisting Normal Force
Ihdf=Inclined Driving Force

$\alpha s = 0.11$ as degrees= $\alpha s \cdot \left(\dfrac{180}{\pi}\right) = 6.52$ $\Sigma V_{UN3} = 12392.33 \cdot kN$ $V_{rs} = 5775 \cdot kN$

Resolve $\Sigma Vert_{E1}$ & $\Sigma Horiz_{E1}$

$\Sigma V_{InclinedE1} := \cos(\alpha s) \cdot (\Sigma V_{E1} + V_{rs}) + \sin(\alpha s) \cdot |\Sigma H_{E1}| = 18508.2 \cdot kN$

$\Sigma H_{InclinedE1} := \cos(\alpha s) \cdot |\Sigma H_{E1}| - \sin(\alpha s) \cdot (\Sigma V_{E1} + V_{rs}) = 1599.6 \cdot kN$

(With properly engineered reinforced concrete Key, horizontal sliding plane thru Toe is protected, critical sliding plane is relocated to the INCLINED SLIDING PLANE FROM HEEL KEY To TOE, Bedrock Mass above this examined plane is mobilized by reinforced concrete key and combined into Structural Wedge.)

Inclined Sliding Plane Length

$L_{incline} = 18.61 \, m$

Safety Factor for Sliding Inclined Failure Plane

$$FS_{InclinedlSlidingE1} := \frac{\Sigma V_{InclinedE1} \cdot \tan\left(\phi_{rock} \cdot \frac{\pi}{180}\right)}{|\Sigma H_{InclinedE1}|} = 5.64$$

$$FS_{InclinedSliding.check.E1} := \begin{cases} \text{"OKAY "} & \text{if } FS_{InclinedlSlidingE1} > FS_{req.E1.sl} \\ \text{"Revise Structure""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

$\boxed{FS_{InclinedSliding.check.E1} = \text{"OKAY "}}$

OVERTURNING STABILITY CHECK:

E1 CASE

CHECK ECCENTRICITY

Sum of the moments:

$$\Sigma M_{E1} := \Sigma M_{DL} + \Sigma M_{Hwater.E1} + \Sigma M_{Vwater.E1} + \Sigma M_{I.E1} + \Sigma M_{soil.E1} + \Sigma M_{soil} = 189592 \cdot kN \cdot m$$

Eccentricity:

$$e_{E1} := \left(\frac{L_{incline}}{2}\right) - \frac{(\Sigma M_{E1})}{\Sigma V_{InclinedE1}} = -0.94\,m$$

Eccentricity Check:

$$e_{check.E1} := \begin{cases} \text{"Okay"} & \text{if } |e_{E1}| \le Kern \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$e_{check.E1} = \text{"Okay"}$

Foundation Bearing Checks:

Incline Plane Area: $A_{b.incline} = 279.12\,m^2$

Incline Plane Section Modulus: $S_{b.incline} = 865.63 \cdot m^3$

Bearing Pressure at Heel:

$$\sigma_{heel.E1} := \frac{\Sigma V_{InclinedE1}}{A_{b.incline}} - \frac{(\Sigma V_{InclinedE1} \cdot e_{E1})}{S_{b.incline}} = 86.4 \cdot \frac{kN}{m^2}$$

$$\sigma_{heel.E1.check} := \left(\begin{cases} \text{"Okay"} & \text{if } \sigma_{heel.E1} \le \sigma_{allow.E1} \\ \text{"Revise Structure"} & \text{if } \sigma_{heel.E1} < 0\,\frac{kN}{m^2} \end{cases} \right)$$

$\sigma_{heel.E1.check} = \text{"Okay"}$

Bearing Pressure at Toe:

$$\sigma_{toe.E1} := \frac{\Sigma V_{InclinedE1}}{A_{b.incline}} + \frac{(\Sigma V_{InclinedE1} \cdot e_{E1})}{S_{b.incline}} = 46.2 \cdot \frac{kN}{m^2}$$

$$\sigma_{toe.E1.1.check} := \begin{cases} \text{"Okay"} & \text{if } \sigma_{toe.E1} \le \sigma_{allow.E1} \\ \text{"Revise Structure"} & \text{if } \sigma_{toe.E1} < 0\,\frac{kN}{m^2} \end{cases}$$

$\sigma_{toe.E1.1.check} = \text{"Okay"}$

FLOATATION ANALYSIS:

ACCEPTANCE PARAMETERS

Required Factor of Safety: $FS_{req.FE1} := 1.1$

VERTICAL LOADS RESISTING:

Dead Load: $\Sigma V_{DL} = 24828.6 \cdot kN$

Water Weight H1+H2: $\Sigma V_{H.FE1} := H_{1.E1} + H_{2.E1} = 17820.49 \cdot kN$

Summation Vertical Resisting: $\Sigma V_{FE1} := \Sigma V_{DL} + \Sigma V_{H.FE1} = 42649.1 \cdot kN$

VERTICAL LOADS UPLIFT:

Uplift: $U_{E1} = -30217.25 \cdot kN$

Factor of Safety Floatation:

$$FS_{act.FE1} := \frac{\Sigma V_{FE1}}{|U_{E1}|} = 1.41$$

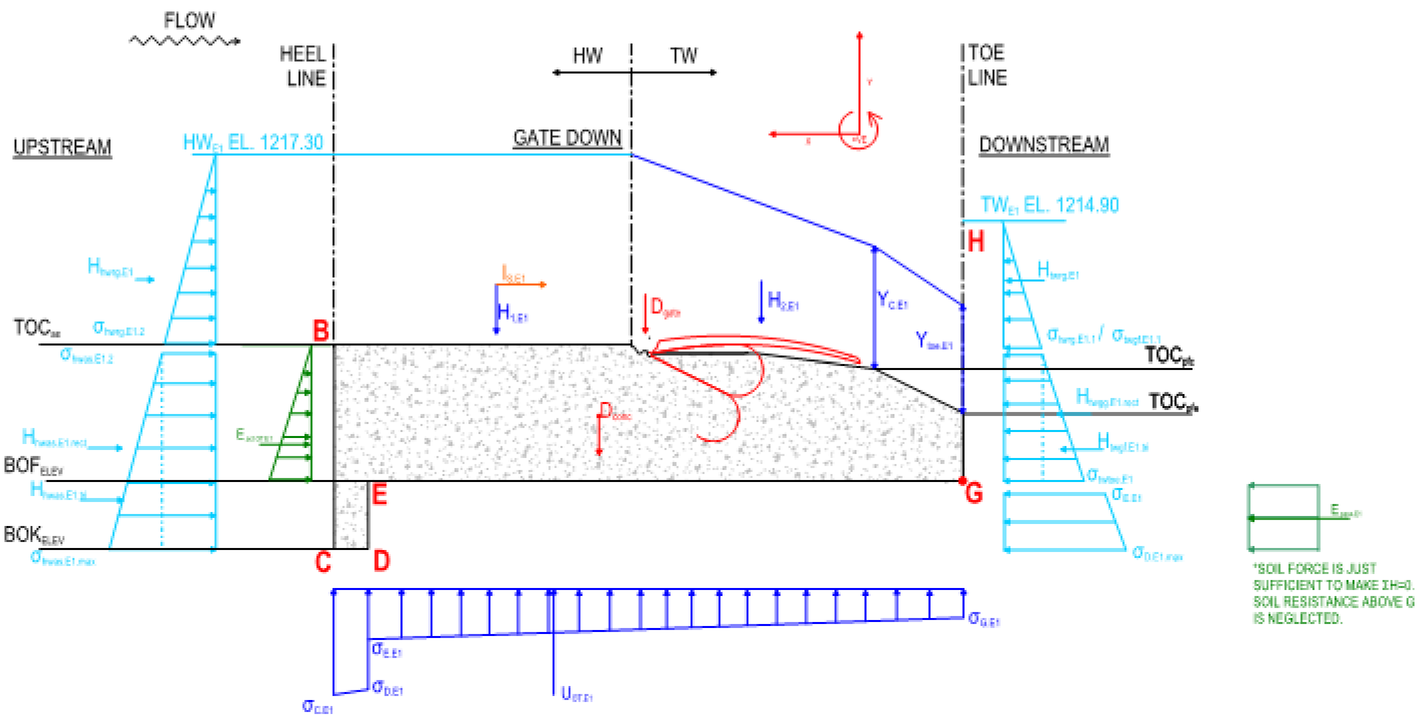
$$FS_{check.FE1} := \begin{cases} \text{"OKAY"} & \text{if } FS_{act.FE1} \ge FS_{req.FE1} \\ \text{"ANCHORS REQUIRED"} & \text{if } FS_{act.FE1} < FS_{req.FE1} \end{cases} = \text{"OKAY"}$$

MONOLITH OVERTURNING STABILITY ANALYSIS

E1 CASE

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.
Assumptions are made in order to compute overturning stability of indetermine forces on monolith with key;
(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.
(b) The horizontal resisting force acting on the key, P.key, is that required for static equilibrium
(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1 $\quad Ratio_{OT.E1.min} := 0.25$



Uplift Loads for Overturning Stability Analysis

Line of Creep:

Change in Water Head: $\Delta_{h.E1} := HW_{E1} - TW_{E1} = 2.4\,m$

Length from Point C to Point G: $L_{CG} = 18.61\ m$

Length from Various Points to Points: $L_{CD} = 1\ m \quad L_{DE} = 2\ m \quad L_{EG} = 17.5\,m$

$L_{GH.E1} := TW_{E1} - BOF_{elev} = 8.9\ m$

Length from Point C, D, E to G: $L_{CDEG} = 20.5\,m \quad L_{CDE} = 3\,m$

Water Pressure at Point C: $\sigma_{C.E1} := \sigma_{hwas.E1.2} = -130.47 \cdot kPa$

Water Pressure at Point G: $\sigma_{G.E1} := \sigma_{twtoe.E1} \cdot -1 = -87.31 \cdot kPa$

Water Pressure at Point D: $\sigma_{D.E1} := -\gamma_w \cdot \left[\left(HW_{E1} - BOK_{elev} \right) - \frac{\Delta_{h.E1} \cdot L_{CD}}{L_{CDEG}} \right] = -129.32 \cdot kPa$

Water Pressure at Point E: $\sigma_{E.E1} := -\gamma_w \cdot \left[\left(HW_{E1} - BOF_{elev} \right) - \frac{\Delta_{h.E1} \cdot L_{CDE}}{L_{CDEG}} \right] = -107.41 \cdot kPa$

Uplift for Overturning Analysis on Bottom of Key: $U_{OT.E1.key} := \frac{\sigma_{C.E1} + \sigma_{D.E1}}{2} \cdot L_{CD} \cdot W_b = -1948.48 \cdot kN$

Acting at: $U_{OT.E1.key.loc} := \frac{L_{CD} \cdot \left(2 \cdot \sigma_{C.E1} + \sigma_{D.E1} \right)}{3 \left(\sigma_{C.E1} + \sigma_{D.E1} \right)} + L_{EG} = 18\,m$

E1 CASE

Uplift for Overturning Analysis on Bottom of Footing:
$$U_{OT.E1.ftg} := \frac{\sigma_{E.E1} + \sigma_{G.E1}}{2} \cdot L_{EG} \cdot W_b = -25556.55 \cdot kN$$

Acting at:
$$U_{OT.E1.ftg.loc} := \frac{L_{EG} \cdot \left(\sigma_{G.E1} + 2 \cdot \sigma_{E.E1}\right)}{3\left(\sigma_{G.E1} + \sigma_{E.E1}\right)} = 9.05\,m$$

Uplift Load for Overturning Analysis:
$$U_{OT.E1} := U_{OT.E1.key} + U_{OT.E1.ftg} = -27505.03 \cdot kN$$

Uplift Load Acting from Toe:
$$U_{OT.E1.loc} := \frac{U_{OT.E1.key} \cdot U_{OT.E1.key.loc} + U_{OT.E1.ftg} \cdot U_{OT.E1.ftg.loc}}{U_{OT.E1}} = 9.69\,m$$

All Vertical Loads Applicable to Overturning Stability Analysis

		at:	
Total Concrete Dead Loads:	$D_{conc} = 24618.6 \cdot kN$		$X_{conc.loc} = 10.06\,m$
Dead Load of Gate:	$D_{Gate} = 210.0 \cdot kN$		$X_{gate} = 6.60\,m$
Water Weight (HW) on Apron Slab:	$H_{1.E1} = 9399.2 \cdot kN$		$H_{1.E1.loc} = 14.13\,m$
Water Weight (TW) on Gate Footing:	$H_{2.E1} = 8421.3 \cdot kN$		$H_{2.E1.loc} = 5.37\,m$
Uplift Load for Overturning Analysis:	$U_{OT.E1} = -27505.03 \cdot kN$		$U_{OT.E1.loc} = 9.69 \cdot m$

Sum of All Overturning Analysis Vertical Load:
$$\Sigma V_{E1.OT} := D_{conc} + D_{Gate} + H_{1.E1} + H_{2.E1} + U_{OT.E1} = 15144.06 \cdot kN$$

Sum of All Overturning Analysis Vertical Load Moments:
$$\Sigma M_{V.E1.OT} := D_{conc} \cdot X_{conc.loc} + D_{Gate} \cdot X_{gate} + H_{1.E1} \cdot H_{1.E1.loc} + H_{2.E1} \cdot H_{2.E1.loc} + U_{OT.E1} \cdot U_{OT.E1.loc} = 160565.73 \cdot kN \cdot m$$

Lateral Tailwater Loads for Overturning Stability Analysis

TW Lateral Load on Gate Footing (No Key - Overturning Values Adjusted):
$$H_{twgf.E1} := H_{twgf.E1.tri} + H_{twgf.E1.rect} = 4061.34 \cdot kN$$

Acting at:
$$H_{twgf.E1.loc} := \frac{\frac{h_{toe}}{3} \cdot H_{twgf.E1.tri} + \frac{h_{toe}}{2} \cdot H_{twgf.E1.rect}}{H_{twgf.E1}} = 1.81\,m$$

Horizontal Tailwater Pressure Top of Key (Overturning Analysis):
$$\sigma_{twtk.OT.E1} := \sigma_{E.E1} \cdot -1 = 107.41 \cdot kPa$$

Horizontal Tailwater Pressure Bottom of Key (Overturning Analysis):
$$\sigma_{twbk.OT.E1} := \sigma_{D.E1} \cdot -1 = 129.32 \cdot kPa$$

Triangular Distribution Unit Load Acting at Key:
$$H_{twbk.OT.E1.tri} := \frac{\left(\sigma_{twbk.OT.E1} - \sigma_{twtk.OT.E1}\right)}{2} \cdot d_{key} \cdot W_{tw.E1} = 328.75 \cdot kN$$

Triangular Distribution Unit Load Acting at Key:
$$H_{twbk.OT.E1.rect} := \sigma_{twtk.OT.E1} \cdot d_{key} \cdot W_{tw.E1} = 3222.23 \cdot kN$$

Total Horizontal Tailwater Load on Key (Overturning Values Adjusted):
$$H_{twkey.OT.E1} := H_{twbk.OT.E1.tri} + H_{twbk.OT.E1.rect} = 3550.98 \cdot kN$$

Acting at:
$$H_{twkey.OT.E1.loc} := \frac{H_{twbk.OT.E1.tri} \cdot \frac{-2 \cdot d_{key}}{3} + H_{twbk.OT.E1.rect} \cdot \frac{-d_{key}}{2}}{H_{twkey.OT.E1}} = -1.03 \cdot m$$

E1 CASE

Lateral Driving Earth Loads for Overturning Stability Analysis (at rest condition)

Depth of Driving Soil Loads (to top of key): $h_{E.OT.E1} := TOC_{as} - BOF_{elev} = 4\,m$

At-Rest Soil Load: $E_{act.OT.E1} := \frac{K_{o.E1} \cdot h_{E.OT.E1}^{2}}{2} \cdot (\gamma_r - \gamma_w) \cdot W_{hwas.E1} \cdot -1 = -962.49 \cdot kN$

At Rest- Soil Load Acting from Toe: $E_{act.OT.E1.loc} := \frac{h_{E.OT.E1}}{3} = 1.33\,m$

All Lateral Loads Appliable to Overturning Stability Analysis

HW Lateral Load on Approach Slab:	$H_{hwas.E1} = -9093.9 \cdot kN$	$H_{hwas.E1.loc} = 0.71\,m$
HW Lateral Load on Reg. Gate:	$H_{hwrg.E1} = 0.0 \cdot kN$	$H_{hwrg.E1.loc} = 4.00\,m$
TW Lateral Load on Reg. Gate:	$H_{twrg.E1} = 0.0 \cdot kN$	$H_{twrg.E1.loc} = 4.00\,m$
TW Lateral Load on Gate Footing (No Key - Overturning Values Adjusted):	$H_{twgf.E1} = 4061.34 \cdot kN$	$H_{twgf.E1.loc} = 1.81\,m$
TW Lateral Load on Key:	$H_{twkey.OT.E1} = 3550.98 \cdot kN$	$H_{twkey.OT.E1.loc} = -1.03\,m$
Ice / Impact Load:	$I_{E1} = 0.0 \cdot kN$	$I_{E1.loc} = 3.70\,m$
Lateral Soil Load (driving):	$E_{act.OT.E1} = -962.5 \cdot kN$	$E_{act.OT.E1.loc} = 1.33\,m$

Resisting Lateral Soil Load as required to produce horizontal equilibrium:

$$E_{pas.OT.E1} := -\left(H_{hwas.E1} + H_{hwrg.E1} + H_{twrg.E1} + H_{twgf.E1} + H_{twkey.OT.E1} + I_{E1} + E_{act.OT.E1}\right) = 2444.04 \cdot kN$$

Acting at:

$$E_{pas.OT.E1.loc} := -1 \cdot \frac{d_{key}}{2} = -1\,m$$

Sum of All Overturning Analysis Horizontal Load (ΣH=0):

$$\Sigma H_{E1.OT} := H_{hwas.E1} + H_{hwrg.E1} + H_{twrg.E1} + H_{twgf.E1} + H_{twkey.OT.E1} + I_{E1} + E_{act.OT.E1} + E_{pas.OT.E1} = 0 \cdot kN$$

Sum of All Overturning Analysis Horizontal Load Moments:

$$\Sigma M_{H.E1.OT} := H_{hwas.E1} \cdot H_{hwas.E1.loc} + H_{hwrg.E1} \cdot H_{hwrg.E1.loc} + H_{twrg.E1} \cdot H_{twrg.E1.loc} \cdots + H_{twgf.E1} \cdot H_{twgf.E1.loc} + H_{twkey.OT.E1} \cdot H_{twkey.OT.E1.loc} + I_{E1} \cdot I_{E1.loc} \cdots + E_{act.OT.E1} \cdot E_{act.OT.E1.loc} + E_{pas.OT.E1} \cdot E_{pas.OT.E1.loc} = -6495.22 \cdot kN \cdot m$$

Overturning Stability Analysis

$\Sigma M_{E1.OT} := \Sigma M_{V.E1.OT} + \Sigma M_{H.E1.OT} = 154070.51 \cdot kN \cdot m$

$X_{R.E1} := \frac{\Sigma M_{E1.OT}}{\Sigma V_{E1.OT}} = 10.17\,m$

$x_{OT.E1} := X_{R.E1} - \frac{L_b}{2} = 0.92\,m$

Overturning Resultant Ratio

$Ratio_{OT.E1} := \frac{X_{R.E1}}{L_b} = 0.55$

$$Ratio_{OT.E1.check} := \begin{cases} \text{"OKAY"} & \text{if } Ratio_{OT.E1} \geq Ratio_{OT.E1.min} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

$$x_{OT.check.E1} := \begin{cases} \text{"OKAY"} & \text{if } \left|x_{OT.E1}\right| \leq Kern \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

CHECK FOUNDATION BEARING CAPACITY (HORIZONTAL PLANE):

E1 CASE

Bearing Pressure Under Toe:

$$\sigma_{ToeE1.OT} := \frac{\Sigma V_{E1.OT}}{L_b \cdot W_b} + \frac{\left(\Sigma V_{E1.OT} \cdot x_{OT.E1}\right)}{S_b} = 70.9 \cdot kPa$$

$$Bearing_{ChecktoeE1.OT} := \begin{cases} \text{"OKAY "} & \text{if } \sigma_{ToeE1.OT} < \sigma_{allow.E1} \\ \text{"NG""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

Bearing Pressure Under Heel:

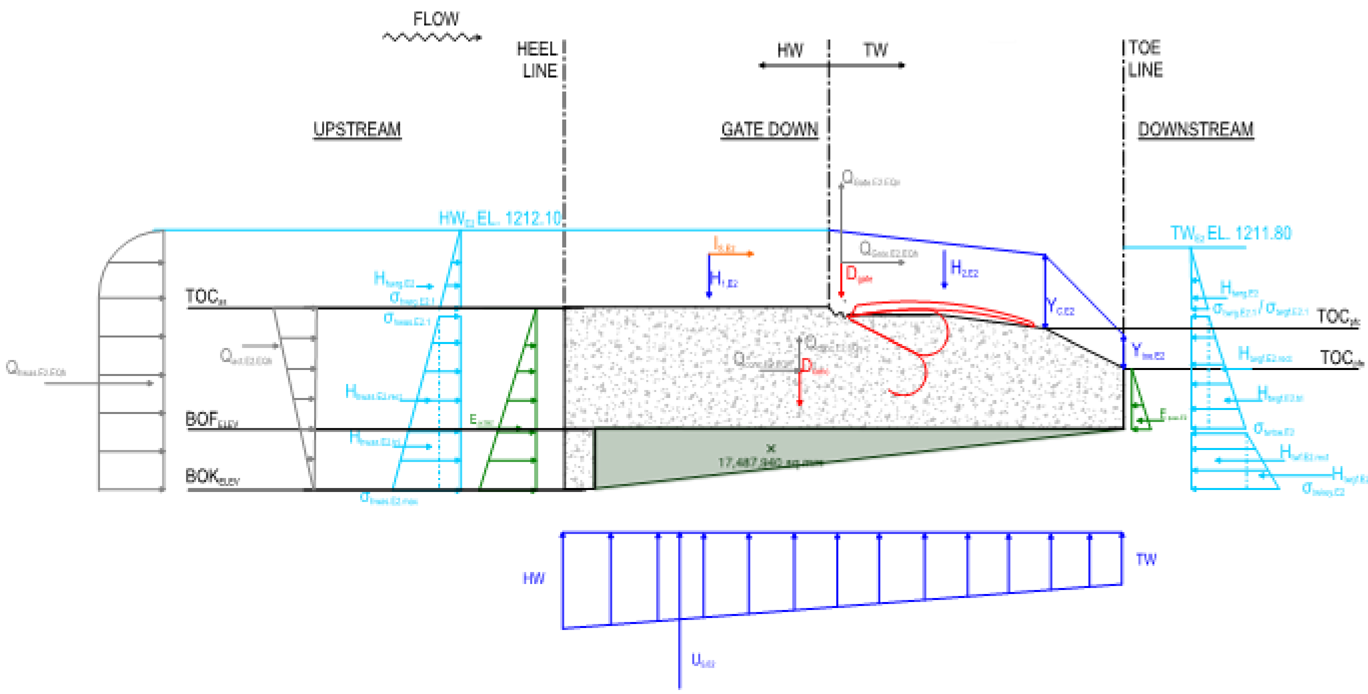
$$\sigma_{HeelE1.OT} := \frac{\Sigma V_{E1.OT}}{L_b \cdot W_b} - \frac{\left(\Sigma V_{E1.OT} \cdot x_{OT.E1}\right)}{S_b} = 38.2 \cdot kPa$$

$$Bearing_{CheckheelE1.OT} := \left(\begin{cases} \text{"OKAY "} & \text{if } \sigma_{HeelE1.OT} < \sigma_{allow.E1} \wedge \sigma_{HeelE1.OT} > 0 \\ \text{"NG""} & \text{otherwise} \end{cases} \right) = \text{"OKAY "}$$

SUMMARY OF STABILITY ASSESSMENT:

Sliding Factor of Safety: (Horizontal Plane)	$FS_{HorizSliding.E1} = 1.64$	$FS_{HorizSliding.E1.Check} = \text{"OKAY"}$
Sliding Factor of Safety: (Inclined Plane)	$FS_{InclinedlSlidingE1} = 5.64$	$FS_{InclinedSliding.check.E1} = \text{"OKAY "}$
Eccentricity: (Inclined Plane)	$e_{E1} = -0.94 m$	$e_{check.E1} = \text{"Okay"}$
Bearing Pressure At Heel: (Inclined Plane)	$\sigma_{heel.E1} = 86 \cdot kPa$	$\sigma_{heel.E1.check} = \text{"Okay"}$
Bearing Pressure At Toe: (Inclined Plane)	$\sigma_{toe.E1} = 46 \cdot kPa$	$\sigma_{toe.E1.1.check} = \text{"Okay"}$
Flotation Factor of Safety (horizontal plane)	$FS_{act.FE1} = 1.41$	$FS_{check.FE1} = \text{"OKAY"}$
Overturning Resultant Ratio: (horizontal plane)	$Ratio_{OT.E1} = 0.55$	$Ratio_{OT.E1.check} = \text{"OKAY"}$
Eccentricity: (horizontal plane)	$x_{OT.E1} = 0.92 m$	$x_{OT.check.E1} = \text{"OKAY"}$
Bearing Pressure At Heel: (horizontal plane)	$\sigma_{HeelE1.OT} = 38 \cdot kPa$	$Bearing_{CheckheelE1.OT} = \text{"OKAY "}$
Bearing Pressure At Toe: (horizontal plane)	$\sigma_{ToeE1.OT} = 71 \cdot kPa$	$Bearing_{ChecktoeE1.OT} = \text{"OKAY "}$

E2 DESIGN CASE



U1 CASE PLUS SEISMIC

ACCEPTANCE PARAMETERS

Required Factor of Safety for Sliding: $FS_{req.E2.sl} := 1.0$ (Without Cohesion) (Section 8.1, Design Criteria)

Resultant Within Middle Third of Base: $e \le \frac{L_b}{6} \wedge e \ge \frac{-L_b}{6}$

Allowable Rock Bearing Pressure: $\sigma_{allow.E2} := 1740 \cdot \frac{kN}{m^2}$ (Section 5.2, Design Criteria)

INPUT PARAMETERS

Headwater Elevation: $HW_{E2} := 1212.10m$ (Section 8.3, Design Criteria)

Tailwater Elevation: $TW_{E2} := 1211.80m$ (Section 8.3, Design Criteria)

Bottom of Footing Elevation: $BOF_{elev} = 1206\,m$

Approach Slab Top of Concrete Elevation at Upstream Face: $TOC_{as} = 1210\,m$

Footing Top of Concrete Elevation at Stilling Basin: $TOC_{pfe} = 1208\,m$

Footing Top of Concrete Elevation at Center of Footing: $TOC_{pfc} = 1209.3\,m$

Top of Guard/Regulating Gate Elevation: $TOP_{rg.U1} = 1210\,m$ $TOP_{gg.U1} = 1210.00\,m$

Gates are open when top of gate elevation is at 1210.00m

Gates are closed/up when top of gate elevation is at 1215.0m

Bottom of Key Elevation: $BOK_{elev} = 1204\,m$

Crestwater Elevation: Dynamic Flow $EL_{C.E2} := 1211.40m$

$$Y_{C.E2} := \begin{cases} (EL_{C.E2} - TOC_{pfc}) & \text{if } TOP_{rg.U1} \le HW_{E2} \\ (TW_{E2} - TOC_{pfc}) & \text{if } TOP_{rg.U1} > HW_{E2} \end{cases} = 2.1 \cdot m$$

Toewater Elevation: $EL_{TOE.E2} := 1208.46m$

$$Y_{TOE.E2} := \begin{cases} (EL_{TOE.E2} - TOC_{pfe}) & \text{if } TOP_{rg.U1} \le HW_{E2} \\ (TW_{E2} - TOC_{pfe}) & \text{if } TOP_{rg.U1} > HW_{E2} \end{cases} = 0.46 \cdot m$$

SEISMIC LOAD (Three combinations of E_h and E_v considered)

E2.1 CASE

Seismic Case $Q_{E2.1}$ - 100% Horizontal Seismic Force, No Vertical

Include Seismic Load in Analysis? $Eq_{E2.1} := 1$

Horizontal Seismic Coefficient: $K_{h.E2.1} := -0.17$

Vertical Seismic Coefficient: $K_{v.E2.1} := -0.00$

HORIZONTAL SEISMIC LOADS	Loads	Moment Arm
Horiz Seismic Component of Concrete:	$Q_{conc.E2.EQh.1} := D_{conc} \cdot K_{h.E2.1} \cdot Eq_{E2.1} = -4185.2 \cdot kN$	$Y_{conc.loc} = 1.87\,m$
Horiz Seismic Component of Gates:	$Q_{Gate.E2.EQh.1} := D_{Gate} \cdot K_{h.E2.1} \cdot Eq_{E2.1} = -35.7 \cdot kN$	$Y_{gate} = 3.90\,m$
Horizontal Seismic Component of Headwater - Sliding:	$Q_{hwas.E2.EQh.1} := \left(\frac{7}{12}\right) \cdot K_{h.E2.1} \cdot \gamma_w \cdot \left(HW_{U1} - BOK_{elev}\right)^2 \cdot W_{hwas.U1} \cdot Eq_{E2.1} = -957.4 \cdot kN$	$Y_{HWg.E2} := 0.4 \cdot \left(HW_{U1} - BOK_{elev}\right) = 3.24\,m$
Horizontal Seismic Component of Soil (Woods Method) - Overturning:	$Q_{act.E2.EQh.1.OT} := \left(\gamma_r - \gamma_w\right) \cdot \left(TOC_{as} - BOK_{elev}\right)^2 \cdot K_{h.E2.1} \cdot W_{hwas.U1} \cdot Eq_{E2.1} = -1119.0 \cdot kN$	$Y_{E.act.E2.OT} := 0.63 \cdot \left(TOC_{as} - BOK_{elev}\right) = 3.78\,m$
Horizontal Seismic Component of Soil (Woods Method)	$Q_{act.E2.EQh.1} := \left(\gamma_r - \gamma_w\right) \cdot \left(TOC_{as} - BOF_{elev}\right)^2 \cdot K_{h.E2.1} \cdot W_{hwas.U1} \cdot Eq_{E2.1} = -497.4 \cdot kN$	$Y_{E.act.E2} := 0.63 \cdot \left(TOC_{as} - BOF_{elev}\right) = 2.52\,m$

VERTICAL SEISMIC LOADS	Loads	Moment Arm
Vertical Component of Concrete:	$Q_{conc.E2.EQv.1} := D_{conc} \cdot K_{v.E2.1} \cdot Eq_{E2.1} = 0.0 \cdot kN$	$X_{conc.loc} = 10.06\,m$
Vertical Component of Gate:	$Q_{Gate.E2.EQv.1} := D_{Gate} \cdot K_{v.E2.1} \cdot Eq_{E2.1} = 0.0 \cdot kN$	$X_{gate} = 6.60\,m$
Vertical Seismic Component of Headwater over Apron Slab:	$Q_{H1.E2.EQv.1} := K_{v.E2.1} \cdot H_{1.U1} \cdot Eq_{E2.1} = 0.0 \cdot kN$	$H_{1.U1.loc} = 14.13\,m$
Vertical Seismic Component of Headwater over Pier Footing:	$Q_{H2.E2.EQv.1} := K_{v.E2.1} \cdot H_{2.U1} \cdot Eq_{E2.1} = 0.0 \cdot kN$	$H_{2.U1.loc} = 5.34\,m$

$$\Sigma H_{Q.E2.EQh.1} := Q_{conc.E2.EQh.1} + Q_{Gate.E2.EQh.1} + Q_{hwas.E2.EQh.1} + Q_{act.E2.EQh.1} = -5675.62 \cdot kN$$

$$\Sigma H_{Q.E2.EQh.1.OT} := Q_{conc.E2.EQh.1} + Q_{Gate.E2.EQh.1} + Q_{hwas.E2.EQh.1} + Q_{act.E2.EQh.1.OT} = -6297.31 \cdot kN$$

$$\Sigma V_{Q.E2.EQv.1} := Q_{conc.E2.EQv.1} + Q_{Gate.E2.EQv.1} + Q_{H1.E2.EQv.1} + Q_{H2.E2.EQv.1} = 0.0 \cdot kN$$

$$\begin{aligned}\Sigma M_{Q.E2.1} := {} & Q_{conc.E2.EQh.1} \cdot Y_{conc.loc} + Q_{Gate.E2.EQh.1} \cdot Y_{gate} + Q_{hwas.E2.EQh.1} \cdot Y_{HWg.E2} \cdots \\ & + Q_{act.E2.EQh.1.OT} \cdot Y_{E.act.E2.OT} + Q_{conc.E2.EQv.1} \cdot X_{conc.loc} + Q_{Gate.E2.EQv.1} \cdot X_{gate} \cdots \\ & + Q_{H1.E2.EQv.1} \cdot H_{1.U1.loc} + Q_{H2.E2.EQv.1} \cdot H_{2.U1.loc}\end{aligned} = -15290.5 \cdot kN \cdot m$$

STABILITY ASSESSMENT (SLIDNG, BEARING, FLOTATION AND OVERTURNING):

E2.1 CASE

CHECK SLIDING ALONG HORIZONTAL PLANE THRU TOE,
IGNORING BEDROCK MOBILIZED BY STRUCTURAL HEEL KEY, OR VOID BEHIND KEY

Sum of Vertical Forces:

$\Sigma V_{E2.1} := \Sigma V_{U1} + \Sigma V_{Q.E2.EQv.1} = 11311.8 \cdot kN$

Sum of Horizontal Forces:

$\Sigma H_{E2.1} := \Sigma H_{U1} - I_{U1} + \Sigma H_{Q.E2.EQh.1} = -7821.33 \cdot kN$

Sliding Factor of Safety: $FS_{HorizSliding.E2.1} := \dfrac{\tan_{\phi} \cdot \Sigma V_{E2.1}}{\left|\Sigma H_{E2.1}\right|} = 0.71$

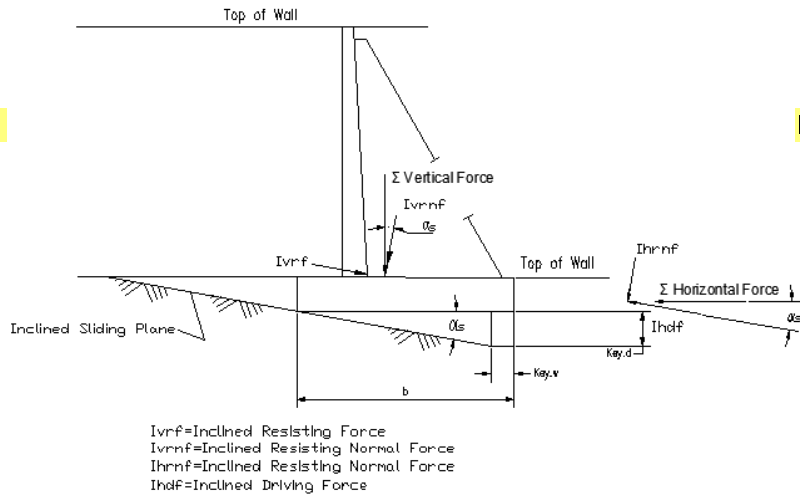
$FS_{HorizSliding.E2.1.Check} :=$ | "OKAY" if $FS_{HorizSliding.E2.1} \geq FS_{req.E2.sl}$
"Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !" otherwise

$FS_{HorizSliding.E2.1.Check}$ = "Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !"

CHECK SLIDING ALONG INCLINED SLIDING PLANE FROM HEEL KEY TO TOE,
WITH BEDROCK MASS MOBILIZED BY REINFOCREDE CONCRETE KEY)

RESISTING SIDE

DRIVING SIDE



TOE

$V_{rs} = 5775 \cdot kN$

$\alpha s = 0.11$ as degrees= $\alpha s \cdot \left(\dfrac{180}{\pi}\right) = 6.52$

Resolve $\Sigma Vert_{E2.1}$ & $\Sigma Horiz_{E2.1}$

$\Sigma V_{InclinedE2.1} := \cos(\alpha s) \cdot \left(\Sigma V_{E2.1} + V_{rs}\right) + \sin(\alpha s) \cdot \left|\Sigma H_{E2.1}\right| = 17864.4 \cdot kN$

$\Sigma H_{InclinedE2.1} := \cos(\alpha s) \cdot \left|\Sigma H_{E2.1}\right| - \sin(\alpha s) \cdot \left(\Sigma V_{E2.1} + V_{rs}\right) = 5830.6 \cdot kN$

Inclined Sliding Plane Length $L_{incline} = 18.61\ m$

Safety Factor for Sliding
Inclined Failure Plane

$FS_{InclinedlSlidingE2.1} := \dfrac{\Sigma V_{InclinedE2.1} \cdot \tan\left(\phi_{rock} \cdot \dfrac{\pi}{180}\right)}{\left|\Sigma H_{InclinedE2.1}\right|} = 1.49$

$FS_{InclinedSliding.check.E2.1} :=$ | "OKAY " if $FS_{InclinedlSlidingE2.1} > FS_{req.E2.sl}$ = "OKAY "
"Revise Structure"" otherwise

$FS_{InclinedSliding.check.E2.1}$ = "OKAY "

OVERTURNING STABILITY CHECK:

CHECK ECCENTRICITY - OBSOLETE

Sum of the moments:

$$\Sigma M_{E2.1} := \left(\Sigma M_{U1} + \Sigma M_{Q.E2.1}\right) = 168812 \cdot kN \cdot m$$

Eccentricity:

$$e_{E2.1} := \left(\frac{L_{incline}}{2}\right) - \frac{\left(\Sigma M_{E2.1}\right)}{\Sigma V_{InclinedE2.1}} = -0.15\,m$$

Eccentricity Check:

$$e_{check.E2.1} := \begin{cases} \text{"Okay"} & \text{if } e_{E2.1} \le Midhalf \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$$e_{check.E2.1} = \text{"Okay"}$$

Foundation Bearing Checks:

Bearing Pressure at Heel:

$$\sigma_{heel.E2.1} := \frac{\Sigma V_{InclinedE2.1}}{A_{b.incline}} - \frac{\left(\Sigma V_{InclinedE2.1} \cdot e_{E2.1}\right)}{S_{b.incline}} = 67.0 \cdot \frac{kN}{m^2}$$

$$\sigma_{heel.E2.1.check} := \left(\begin{cases} \text{"Okay"} & \text{if } \sigma_{heel.E2.1} \le \sigma_{allow.E2} \\ \text{"Revise Structure"} & \text{if } \sigma_{heel.E2.1} < 0 \frac{kN}{m^2} \end{cases}\right)$$

$$\sigma_{heel.E2.1.check} = \text{"Okay"}$$

Bearing Pressure at Toe:

$$\sigma_{toe.E2.1} := \frac{\Sigma V_{InclinedE2.1}}{A_{b.incline}} + \frac{\left(\Sigma V_{InclinedE2.1} \cdot e_{E2.1}\right)}{S_{b.incline}} = 61.0 \cdot \frac{kN}{m^2}$$

$$\sigma_{toe.E2.1.check.1} := \begin{cases} \text{"Okay"} & \text{if } \sigma_{toe.E2.1} \le \sigma_{allow.E2} \\ \text{"Revise Structure"} & \text{if } \sigma_{toe.E2.1} < 0 \frac{kN}{m^2} \end{cases}$$

$$\sigma_{toe.E2.1.check.1} = \text{"Okay"}$$

FLOATATION ANALYSIS:

ACCEPTANCE PARAMETERS

Required Factor of Safety: $FS_{req.FE2.1} := 1.1$

VERTICAL LOADS RESISTING:

Dead Load: $\Sigma V_{DL} = 24828.6 \cdot kN$

Water Weight H1+H2: $\Sigma V_{H.FE2.1} := \Sigma V_{H.FU1} + \Sigma V_{Q.E2.EQv.1} = 5403.05 \cdot kN$

Summation Vertical Resisting: $\Sigma V_{FE2.1} := \Sigma V_{DL} + \Sigma V_{H.FE2.1} = 30231.7 \cdot kN$

VERTICAL LOADS UPLIFT:

Uplift: $U_{S.U1} = -18919.81 \cdot kN$

Factor of Safety Floatation:

$$FS_{act.FE2.1} := \frac{\Sigma V_{FE2.1}}{\left|U_{S.U1}\right|} = 1.60$$

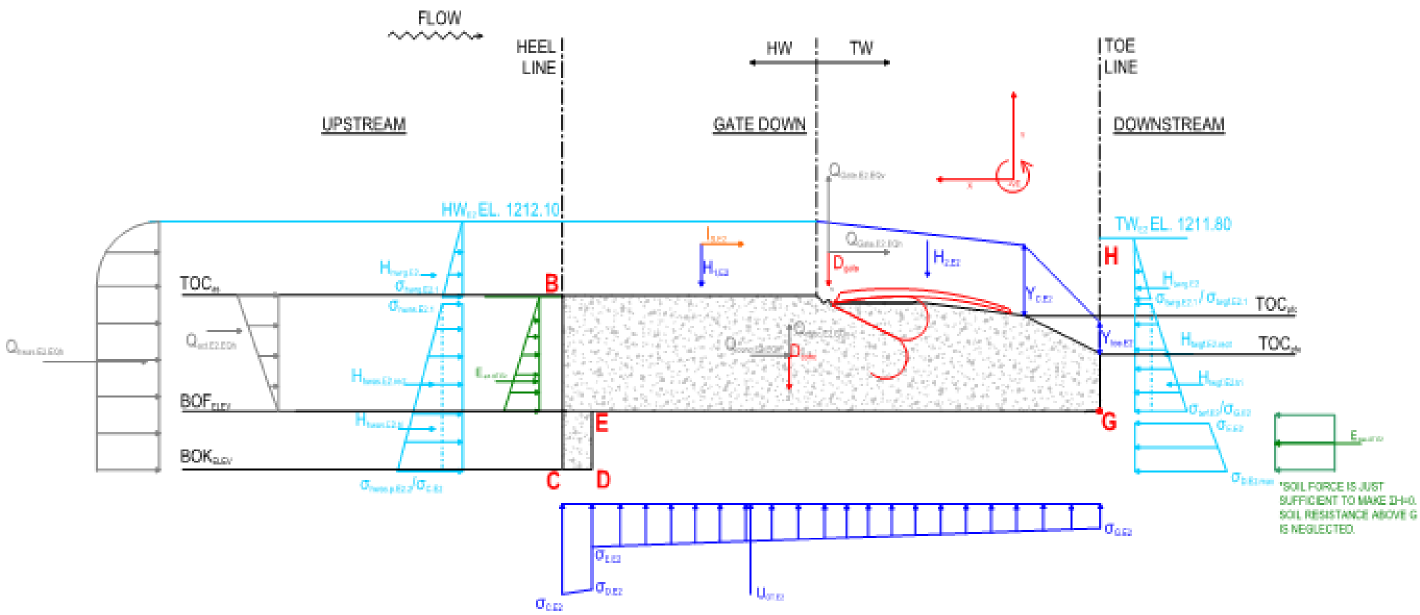
$$FS_{check.FE2.1} := \begin{cases} \text{"OKAY"} & \text{if } FS_{act.FE2.1} \ge FS_{req.FE2.1} \\ \text{"ANCHORS REQUIRED"} & \text{if } FS_{act.FE2.1} < FS_{req.FE2.1} \end{cases} = \text{"OKAY"}$$

MONOLITH OVERTURNING STABILITY ANALYSIS

Seismic Case $Q_{E2.1}$: 100% Horizontal Seismic Force, No Vertical

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.
Assumptions are made in order to compute overturning stability of indetermine forces on monolith with key;
(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.
(b) The horizontal resisting force acting on the key, P.key, is that required for static equilibrium
(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1 $Ratio_{overturning.allow.Extreme} := 0.25$ Resultant within Base



All Vertical Loads Appliable to Overturning Stability Analysis

Total Concrete Dead Loads:	$D_{conc} = 24618.6 \cdot kN$	at:	$X_{conc.loc} = 10.06\,m$
Dead Load of Gate:	$D_{Gate} = 210.0 \cdot kN$		$X_{gate} = 6.60\,m$
Water Weight (HW) on Apron Slab:	$H_{1.U1} = 2703.9 \cdot kN$		$H_{1.U1.loc} = 14.13\,m$
Water Weight (TW) on Gate Footing:	$H_{2.U1} = 2699.2 \cdot kN$		$H_{2.U1.loc} = 5.34\,m$
Uplift Load for Overturning Analysis:	$U_{OT.U1} = -16456.3 \cdot kN$		$U_{OT.U1.loc} = 9.48 \cdot m$
Vertical Seismic Component of Concrete Structure:	$Q_{conc.E2.EQv.1} = 0$		$X_{conc.loc} = 10.06\,m$
Vertical Seismic Component of Crest Gate:	$Q_{Gate.E2.EQv.1} = 0$		$X_{gate} = 6.60\,m$
Vertical Seismic Component of Headwater over Apron Slab:	$Q_{H1.E2.EQv.1} = 0$		$H_{1.U2.loc} = 14.13\,m$
Vertical Seismic Component of Headwater over Fixed Crest Slab:	$Q_{H2.E2.EQv.1} = 0$		$H_{2.U2.loc} = 5.43\,m$

Sum of All Overturning Analysis Vertical Load:

$$\Sigma V_{E2.OT.1} := D_{conc} + D_{Gate} + H_{1.U1} + H_{2.U1} + U_{OT.U1} + \Sigma V_{Q.E2.EQv.1} = 13775.35 \cdot kN$$

Sum of All Overturning Analysis Vertical Load Moments:

$$\Sigma M_{V.E2.OT.1} := D_{conc} \cdot X_{conc.loc} + D_{Gate} \cdot X_{gate} + H_{1.U1} \cdot H_{1.U1.loc} + H_{2.U1} \cdot H_{2.U1.loc} + U_{OT.U1} \cdot U_{OT.U1.loc} = 145582.24 \cdot kN \cdot m$$

Lateral Driving Earth Loads for Overturning Stability Analysis (at rest condition)

E2.1 CASE

Depth of Driving Soil Loads (to top of key): $h_{E.OT.E2.1} := TOC_{as} - BOF_{elev} = 4\,m$

At-Rest Soil Load: $E_{act.OT.E2.1} := \frac{\left(K_{o.U1} \cdot h_{E.OT.U1}^{\;2}\right)}{2} \cdot \left(\gamma_r - \gamma_w\right) \cdot W_{hwas.U1} \cdot -1 = -962.49 \cdot kN$

At Rest- Soil Load Acting from Toe: $E_{act.OT.E2.1.loc} := \frac{h_{E.OT.U1}}{3} = 1.33\,m$

All Lateral Loads Appliable to Overturning Stability Analysis

HW Lateral Load on Approach Slab:	$H_{hwas.U1} = -4502.8 \cdot kN$	$H_{hwas.U1.loc} = 0.41\,m$
HW Lateral Load on Reg. Gate:	$H_{hwrg.U1} = 0.0 \cdot kN$	$H_{hwrg.U1.loc} = 4.00\,m$
TW Lateral Load on Reg. Gate:	$H_{twrg.U1} = 0.0 \cdot kN$	$H_{twrg.U1.loc} = 4.00\,m$
TW Lateral Load on Gate Footing (No Key - Overturning Values Adjusted):	$H_{twgf.U1} = 2236.68 \cdot kN$	$H_{twgf.U1.loc} = 1.65\,m$
TW Lateral Load on Key:	$H_{twkey.OT.U1} = 2080.92 \cdot kN$	$H_{twkey.OT.U1.loc} = -1.05\,m$
Ice / Impact Load:	$I_{U1} = 0.0 \cdot kN$	$I_{U1.loc} = 3.70\,m$
Lateral Soil Load (driving):	$E_{act.OT.U1} = -962.5 \cdot kN$	$E_{act.OT.U1.loc} = 1.33\,m$
Horizontal Seismic Component of Concrete Structure:	$Q_{conc.E2.EQh.1} = -4185.16 \cdot kN$	$Y_{conc.loc} = 1.87\,m$
Horizontal Seismic Component of Vertical Lift Gate:	$Q_{Gate.E2.EQh.1} = -35.7 \cdot kN$	$Y_{gate} = 3.90\,m$
Horizontal Seismic Component of Headwater on Gate:	$Q_{hwas.E2.EQh.1} = -957.41 \cdot kN$	$Y_{HWg.E2} = 3.24\,m$
Horizontal Seismic Component of Active Soil: (Section 5-5, USACE EM_1110-2-2100)	$Q_{act.E2.EQh.1} = -497352\,N$	$Y_{E.act.E2} = 2.52\,m$

Resisting Lateral Soil Load as required to produce horizontal equilibrium:

$$E_{pas.OT.E2.1} := -\left(H_{hwas.U1} + H_{hwrg.U1} + H_{twrg.U1} + H_{twgf.U1} + H_{twkey.OT.U1} + I_{U1} + E_{act.OT.U1} + \Sigma H_{Q.E2.EQh.1.OT}\right) = 7445 \cdot kN$$

Acting at: $E_{pas.OT.E2.1.loc} := -1 \cdot \frac{d_{key}}{2} = -1\,m$

Sum of All Overturning Analysis Horizontal Load (ΣH=0):

$$\Sigma H_{E2.OT.1} := H_{hwas.U1} + H_{hwrg.U1} + H_{twrg.U1} + H_{twgf.U1} + H_{twkey.OT.U1} + I_{U1} + E_{act.OT.U1} + E_{pas.OT.E2.1} + \Sigma H_{Q.E2.EQh.1.OT} = 0 \cdot kN$$

Sum of All Overturning Analysis Horizontal Load Moments:

$$\begin{aligned}\Sigma M_{H.E2.OT.1} := {} & H_{hwas.U1} \cdot H_{hwas.U1.loc} + H_{hwrg.U1} \cdot H_{hwrg.U1.loc} + H_{twrg.U1} \cdot H_{twrg.U1.loc} \cdots = -18067.5 \cdot kN \cdot m \\ & + H_{twgf.U1} \cdot H_{twgf.U1.loc} + H_{twkey.OT.U1} \cdot H_{twkey.OT.U1.loc} + I_{U1} \cdot I_{U1.loc} \cdots \\ & + E_{act.OT.U1} \cdot E_{act.OT.U1.loc} + E_{pas.OT.U1} \cdot E_{pas.OT.U1.loc} + \Sigma M_{Q.E2.1}\end{aligned}$$

Overturning Stability Analysis

$$\Sigma M_{E2.OT.1} := \Sigma M_{V.E2.OT.1} + \Sigma M_{H.E2.OT.1} = 127514.74 \cdot kN \cdot m$$

$X_{R.E2.1} := \frac{\Sigma M_{E2.OT.1}}{\Sigma V_{E2.OT.1}} = 9.26\,m$ $\quad x_{OT.E2.1} := X_{R.E2.1} - \frac{L_b}{2} = 0.01\,m$

Overturning Resultant Ratio

$$Ratio_{OT.E2.1} := \frac{X_{R.E2.1}}{L_b} = 0.5$$

$$Ratio_{OT.E2.1.check} := \begin{cases} \text{"OKAY"} & \text{if } Ratio_{OT.E2.1} \geq Ratio_{overturning.allow.Extreme} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

$$x_{OT.check.E2.1} := \begin{cases} \text{"OKAY"} & \text{if } \left|x_{OT.E2.1}\right| \leq Kern \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

Seismic Case $Q_{E2.2}$ - 100% Horizontal Seismic Force, 30% Vertical

E2.2 CASE

Include Seismic Load in Analysis? $Eq_{E2.2} := 1$

Horizontal Seismic Coefficient: $K_{h.E2.2} := -0.17$

Vertical Seismic Coefficient: $K_{v.E2.2} := -0.03$

HORIZONTAL SEISMIC LOADS	Loads	Moment Arm
Horiz Seismic Component of Concrete:	$Q_{conc.E2.EQh.2} := D_{conc} \cdot K_{h.E2.2} \cdot Eq_{E2.2} = -4185.2 \cdot kN$	$Y_{conc.loc} = 1.87\,m$
Horiz Seismic Component of Gates:	$Q_{Gate.E2.EQh.2} := D_{Gate} \cdot K_{h.E2.2} \cdot Eq_{E2.2} = -35.7 \cdot kN$	$Y_{gate} = 3.90\,m$
Horizontal Seismic Component of Headwater - Sliding:	$Q_{hwas.E2.EQh.2} := \left(\frac{7}{12}\right) \cdot K_{h.E2.2} \cdot \gamma_w \cdot \left(HW_{U1} - BOK_{elev}\right)^2 \cdot W_{hwas.U1} \cdot Eq_{E2.2} = -957.4 \cdot kN$	$Y_{HWg.E2} = 3.24\,m$
Horizontal Seismic Component of Soil (Woods Method) - Overturning:	$Q_{act.E2.EQh.2.OT} := \left(\gamma_r - \gamma_w\right) \cdot \left(TOC_{as} - BOK_{elev}\right)^2 \cdot K_{h.E2.2} \cdot W_{hwas.U1} \cdot Eq_{E2.2} = -1119.0 \cdot kN$	$Y_{E.act.E2.OT} = 3.78\,m$
Horizontal Seismic Component of Soil (Woods Method):	$Q_{act.E2.EQh.2} := \left(\gamma_r - \gamma_w\right) \cdot \left(TOC_{as} - BOF_{elev}\right)^2 \cdot K_{h.E2.2} \cdot W_{hwas.U1} \cdot Eq_{E2.2} = -497.4 \cdot kN$	$Y_{E.act.E2} = 2.52\,m$

VERTICAL SEISMIC LOADS	Loads	Moment Arm
Vertical Component of Concrete:	$Q_{conc.E2.EQv.2} := D_{conc} \cdot K_{v.E2.2} \cdot Eq_{E2.2} = -738.6 \cdot kN$	$X_{conc.loc} = 10.06\,m$
Vertical Component of Gate:	$Q_{Gate.E2.EQv.2} := D_{Gate} \cdot K_{v.E2.2} \cdot Eq_{E2.2} = -6.3 \cdot kN$	$X_{gate} = 6.60\,m$
Vertical Seismic Component of Headwater over Apron Slab:	$Q_{H1.E2.EQv.2} := K_{v.E2.2} \cdot H_{1.U1} \cdot Eq_{E2.2} = -81.1 \cdot kN$	$H_{1.U1.loc} = 14.13\,m$
Vertical Seismic Component of Headwater over Pier Footing:	$Q_{H2.E2.EQv.2} := K_{v.E2.2} \cdot H_{2.U1} \cdot Eq_{E2.2} = -81.0 \cdot kN$	$H_{2.U1.loc} = 5.34\,m$

$$\Sigma H_{Q.E2.EQh.2} := Q_{conc.E2.EQh.2} + Q_{Gate.E2.EQh.2} + Q_{hwas.E2.EQh.2} + Q_{act.E2.EQh.2} = -5675.62 \cdot kN$$

$$\Sigma H_{Q.E2.EQh.2.OT} := Q_{conc.E2.EQh.2} + Q_{Gate.E2.EQh.2} + Q_{hwas.E2.EQh.2} + Q_{act.E2.EQh.2.OT} = -6297.31 \cdot kN$$

$$\Sigma V_{Q.E2.EQv.2} := Q_{conc.E2.EQv.2} + Q_{Gate.E2.EQv.2} + Q_{H1.E2.EQv.2} + Q_{H2.E2.EQv.2} = -906.9 \cdot kN$$

$$\begin{aligned}\Sigma M_{Q.E2.2} := {} & Q_{conc.E2.EQh.2} \cdot Y_{conc.loc} + Q_{Gate.E2.EQh.2} \cdot Y_{gate} + Q_{hwas.E2.EQh.2} \cdot Y_{HWg.E2} \cdots \\ & + Q_{act.E2.EQh.2.OT} \cdot Y_{E.act.E2.OT} + Q_{conc.E2.EQv.2} \cdot X_{conc.loc} + Q_{Gate.E2.EQv.2} \cdot X_{gate} \cdots \\ & + Q_{H1.E2.EQv.2} \cdot H_{1.U1.loc} + Q_{H2.E2.EQv.2} \cdot H_{2.U1.loc}\end{aligned} = -24337.07 \cdot kN \cdot m$$

STABILITY ASSESSMENT (SLIDNG, BEARING, FLOTATION AND OVERTURNING): E2.2 CASE

CHECK SLIDING ALONG HORIZONTAL PLANE THRU TOE,
IGNORING BEDROCK MOBILIZED BY STRUCTURAL HEEL KEY, OR VOID BEHIND KEY

Sum of Vertical Forces:

$\Sigma V_{E2.2} := \Sigma V_{U1} + \Sigma V_{Q.E2.EQv.2} = 10404.9 \cdot kN$

Sum of Horizontal Forces:

$\Sigma H_{E2.2} := \Sigma H_{U1} - I_{U1} + \Sigma H_{Q.E2.EQh.2} = -7821.33 \cdot kN$

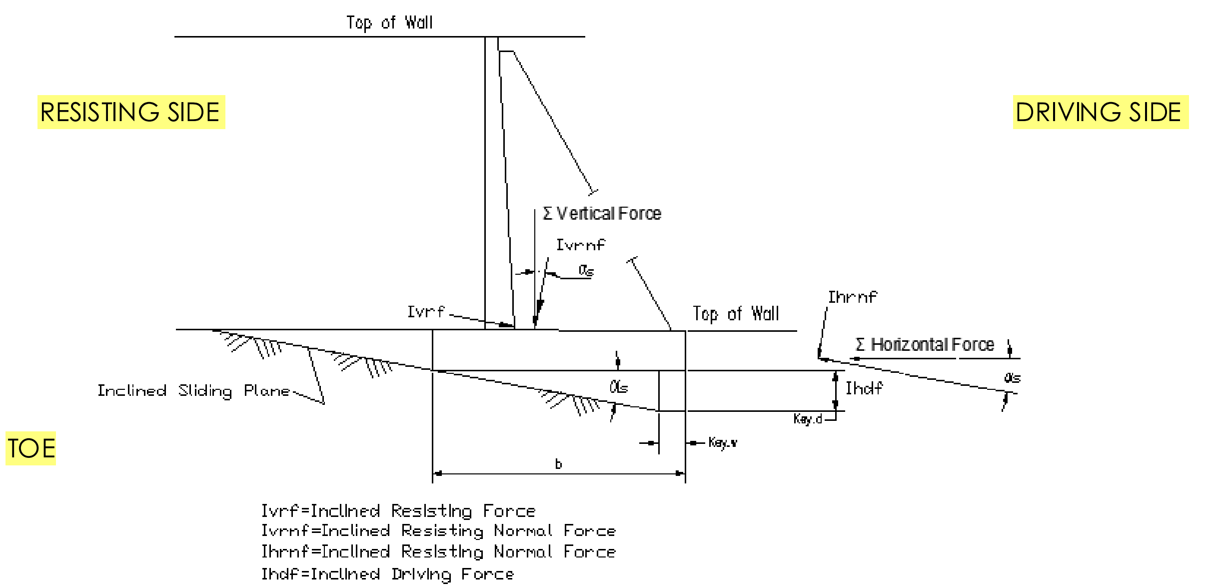
Sliding Factor of Safety:

$$FS_{HorizSliding.E2.2} := \frac{\tan_{\phi} \cdot \Sigma V_{E2.2}}{\left|\Sigma H_{E2.2}\right|} = 0.65$$

$FS_{HorizSliding.E2.2.Check} :=$ | "OKAY" if $FS_{HorizSliding.E2.2} \geq FS_{req.E2.sl}$
"Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !" otherwise

$FS_{HorizSliding.E2.2.Check} =$ "Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !"

CHECK SLIDING ALONG INCLINED SLIDING PLANE FROM HEEL KEY TO TOE,
WITH BEDROCK MASS MOBILIZED BY REINFOCREDE CONCRETE KEY)



$\alpha s = 0.11$ as degrees= $\alpha s \cdot \left(\frac{180}{\pi}\right) = 6.52$ $\Sigma V_{E2.2} = 10404.89 \cdot kN$

$V_{rs} = 5775 \cdot kN$

Resolve $\Sigma Vert_{E2.2}$ & $\Sigma Horiz_{E2.2}$

$\Sigma V_{InclinedE2.2} := \cos(\alpha s) \cdot \left(\Sigma V_{E2.2} + V_{rs}\right) + \sin(\alpha s) \cdot \left|\Sigma H_{E2.2}\right| = 16963.3 \cdot kN$

$\Sigma H_{InclinedE2.2} := \cos(\alpha s) \cdot \left|\Sigma H_{E2.2}\right| - \sin(\alpha s) \cdot \left(\Sigma V_{E2.2} + V_{rs}\right) = 5933.6 \cdot kN$

(With properly engineered reinforced concrete Key, horizontal sliding plane thru Toe is protected, critical sliding plane is relocated to the INCLINED SLIDING PLANE FROM HEEL KEY To TOE, Bedrock Mass above this examined plane is mobilized by reinforced concrete key and combined into Structural Wedge.)

Inclined Sliding Plane Length $L_{incline} = 18.61\ m$

Safety Factor for Sliding
Inclined Failure Plane

$$FS_{InclinedlSlidingE2.2} := \frac{\Sigma V_{InclinedE2.2} \cdot \tan\left(\phi_{rock} \cdot \frac{\pi}{180}\right)}{\left|\Sigma H_{InclinedE2.2}\right|} = 1.39$$

$FS_{InclinedSliding.check.E2.2} :=$ | "OKAY " if $FS_{InclinedlSlidingE2.2} > FS_{req.E2.sl}$ = "OKAY "
"Revise Structure"" otherwise

$FS_{InclinedSliding.check.E2.2} =$ "OKAY "

OVERTURNING STABILITY CHECK:

E2.2 CASE

CHECK ECCENTRICITY - OBSOLETE

Sum of the moments:

$$\Sigma M_{E2.2} := \left(\Sigma M_{U1} + \Sigma M_{Q.E2.2}\right) = 159766 \cdot kN \cdot m$$

Eccentricity:

$$e_{E2.2} := \left(\frac{L_{incline}}{2}\right) - \frac{\left(\Sigma M_{E2.2}\right)}{\Sigma V_{InclinedE2.2}} = -0.11\, m$$

Eccentricity Check:

$$e_{check.E2.2} := \begin{cases} \text{"Okay"} & \text{if } e_{E2.2} \le Midhalf \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$$e_{check.E2.2} = \text{"Okay"}$$

Foundation Bearing Checks:

Bearing Pressure at Heel:

$$\sigma_{heel.E2.2} := \frac{\Sigma V_{InclinedE2.2}}{A_{b.incline}} - \frac{\left(\Sigma V_{InclinedE2.2} \cdot e_{E2.2}\right)}{S_{b.incline}} = 63.0 \cdot \frac{kN}{m^2}$$

$$\sigma_{heel.E2.2.check} := \left(\begin{cases} \text{"Okay"} & \text{if } \sigma_{heel.E2.2} \le \sigma_{allow.E2} \\ \text{"Revise Structure"} & \text{if } \sigma_{heel.E2.2} < 0 \frac{kN}{m^2} \end{cases}\right)$$

$$\sigma_{heel.E2.2.check} = \text{"Okay"}$$

Bearing Pressure at Toe:

$$\sigma_{toe.E2.2} := \frac{\Sigma V_{InclinedE2.2}}{A_{b.incline}} + \frac{\left(\Sigma V_{InclinedE2.2} \cdot e_{E2.2}\right)}{S_{b.incline}} = 58.5 \cdot \frac{kN}{m^2}$$

$$\sigma_{toe.E2.2.check.1} := \begin{cases} \text{"Okay"} & \text{if } \sigma_{toe.E2.2} \le \sigma_{allow.E2} \\ \text{"Revise Structure"} & \text{if } \sigma_{toe.E2.2} < 0 \frac{kN}{m^2} \end{cases}$$

$$\sigma_{toe.E2.2.check.1} = \text{"Okay"}$$

FLOATATION ANALYSIS:

ACCEPTANCE PARAMETERS

Required Factor of Safety: $FS_{req.FE2.2} := 1.1$

VERTICAL LOADS RESISTING:

Dead Load: $\Sigma V_{DL} = 24828.6 \cdot kN$

Water Weight H1+H2: $\Sigma V_{H.FE2.2} := \Sigma V_{H.FU1} + \Sigma V_{Q.E2.EQv.2} = 4496.1 \cdot kN$

Summation Vertical Resisting: $\Sigma V_{FE2.2} := \Sigma V_{DL} + \Sigma V_{H.FE2.2} = 29324.7 \cdot kN$

VERTICAL LOADS UPLIFT:

Uplift: $U_{S.U1} = -18919.81 \cdot kN$

Factor of Safety Floatation:

$$FS_{act.FE2.2} := \frac{\Sigma V_{FE2.2}}{\left|U_{S.U1}\right|} = 1.55$$

$$FS_{check.FE2.2} := \begin{cases} \text{"OKAY"} & \text{if } FS_{act.FE2.2} \ge FS_{req.FE2.2} \\ \text{"ANCHORS REQUIRED"} & \text{if } FS_{act.FE2.2} < FS_{req.FE2.2} \end{cases} = \text{"OKAY"}$$

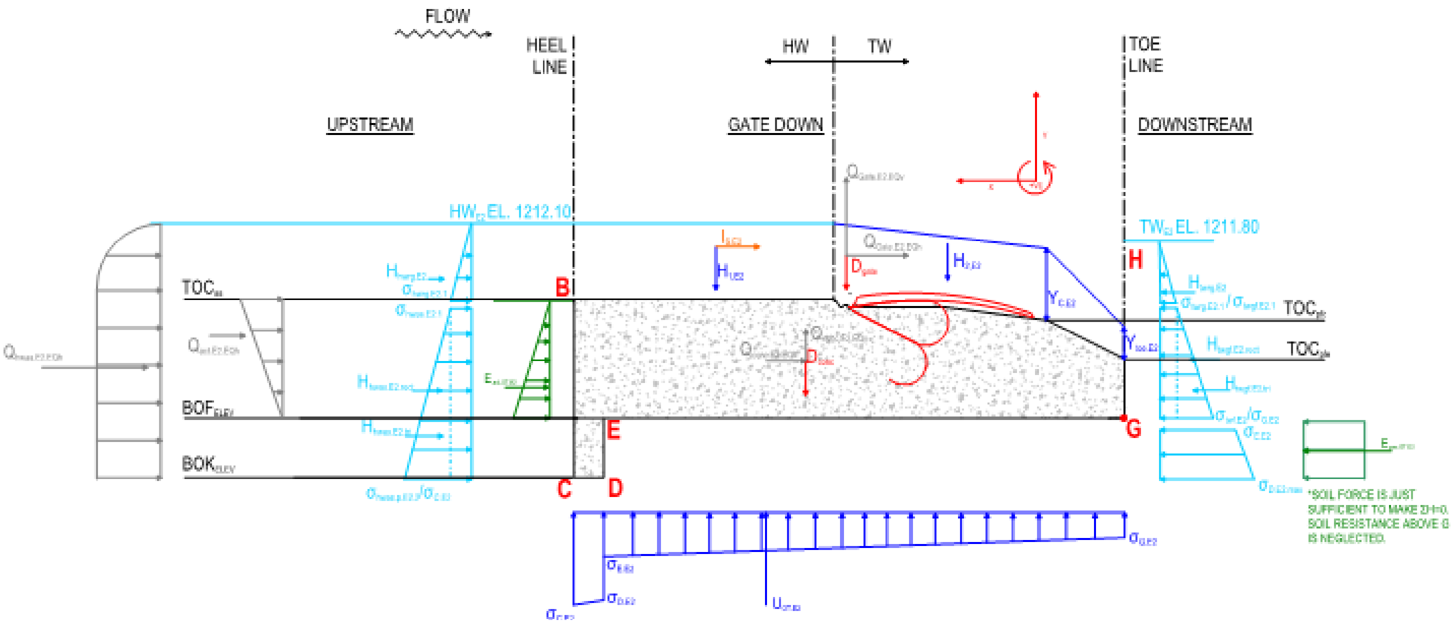
MONOLITH OVERTURNING STABILITY ANALYSIS

E2.2 CASE

Seismic Case $Q_{E2.2}$: 100% Horizontal Seismic Force, 30% Vertical

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.
Assumptions are made in order to compute overturning stability of indetermine forces on monolith with key;
(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.
(b) The horizontal resisting force acting on the key, P.key, is that required for static equilibrium
(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1 $Ratio_{overturning.allow.Extreme} = 0.25$ Resultant within Base



All Vertical Loads Appliable to Overturning Stability Analysis

Total Concrete Dead Loads:	$D_{conc} = 24618.6 \cdot kN$	at:	$X_{conc.loc} = 10.06\,m$
Dead Load of Gate:	$D_{Gate} = 210.0 \cdot kN$		$X_{gate} = 6.60\,m$
Water Weight (HW) on Apron Slab:	$H_{1.U1} = 2703.9 \cdot kN$		$H_{1.U1.loc} = 14.13\,m$
Water Weight (TW) on Gate Footing:	$H_{2.U1} = 2699.2 \cdot kN$		$H_{2.U1.loc} = 5.34\,m$
Uplift Load for Overturning Analysis:	$U_{OT.U1} = -16456.3 \cdot kN$		$U_{OT.U1.loc} = 9.48 \cdot m$
Vertical Seismic Component of Concrete Structure:	$Q_{conc.E2.EQv.2} = -738.56 \cdot kN$		$X_{conc.loc} = 10.06\,m$
Vertical Seismic Component of Crest Gate:	$Q_{Gate.E2.EQv.2} = -6.3 \cdot kN$		$X_{gate} = 6.60\,m$
Vertical Seismic Component of Headwater over Apron Slab:	$Q_{H1.E2.EQv.2} = -81.12 \cdot kN$		$H_{1.U1.loc} = 14.13\,m$
Vertical Seismic Component of Headwater over Fixed Crest Slab:	$Q_{H2.E2.EQv.2} = -80.98 \cdot kN$		$H_{2.U1.loc} = 5.34\,m$

Sum of All Overtuming Analysis Vertical Load:

$$\Sigma V_{E2.OT.2} := D_{conc} + D_{Gate} + H_{1.U1} + H_{2.U1} + U_{OT.U1} + \Sigma V_{Q.E2.EQv.2} = 12868.4 \cdot kN$$

Sum of All Overtuming Analysis Vertical Load Moments:

$$\Sigma M_{V.E2.OT.2} := D_{conc} \cdot X_{conc.loc} + D_{Gate} \cdot X_{gate} + H_{1.U1} \cdot H_{1.U1.loc} + H_{2.U1} \cdot H_{2.U1.loc} + U_{OT.U1} \cdot U_{OT.U1.loc} = 145582.24 \cdot kN \cdot m$$

Lateral Driving Earth Loads for Overturning Stability Analysis (at rest condition)

E2.2 CASE

Depth of Driving Soil Loads (to top of key): $h_{E.OT.E2.2} := TOC_{as} - BOF_{elev} = 4\ m$

static equilibrium Soil Load: $E_{act.OT.E2.2} := \frac{K_{o.U1} \cdot h_{E.OT.U1}^{2}}{2} \cdot (\gamma_r - \gamma_w) \cdot W_{hwas.U1} \cdot -1 = -962.49 \cdot kN$

At Rest- Soil Load Acting from Toe: $E_{act.OT.E2.2.loc} := \frac{h_{E.OT.U1}}{3} = 1.33\ m$

All Lateral Loads Appliable to Overturning Stability Analysis

HW Lateral Load on Approach Slab:	$H_{hwas.U1} = -4502.8 \cdot kN$	$H_{hwas.U1.loc} = 0.41\ m$
HW Lateral Load on Reg. Gate:	$H_{hwrg.U1} = 0.0 \cdot kN$	$H_{hwrg.U1.loc} = 4.00\ m$
TW Lateral Load on Reg. Gate:	$H_{twrg.U1} = 0.0 \cdot kN$	$H_{twrg.U1.loc} = 4.00\ m$
TW Lateral Load on Gate Footing (No Key - Overturning Values Adjusted):	$H_{twgf.U1} = 2236.68 \cdot kN$	$H_{twgf.U1.loc} = 1.65\ m$
TW Lateral Load on Key:	$H_{twkey.OT.U1} = 2080.92 \cdot kN$	$H_{twkey.OT.U1.loc} = -1.05\ m$
Ice / Impact Load:	$I_{U1} = 0.0 \cdot kN$	$I_{U1.loc} = 3.70\ m$
Lateral Soil Load (driving):	$E_{act.OT.U1} = -962.5 \cdot kN$	$E_{act.OT.U1.loc} = 1.33\ m$
Horizontal Seismic Component of Concrete Structure:	$Q_{conc.E2.EQh.2} = -4185.16 \cdot kN$	$Y_{conc.loc} = 1.87\ m$
Horizontal Seismic Component of Vertical Lift Gate:	$Q_{Gate.E2.EQh.2} = -35.7 \cdot kN$	$Y_{gate} = 3.90\ m$
Horizontal Seismic Component of Headwater on Gate:	$Q_{hwas.E2.EQh.2} = -957.41 \cdot kN$	$Y_{HWg.E2} = 3.24\ m$
Horizontal Seismic Component of Active Soil: (Section 5-5, USACE EM_1110-2-2100)	$Q_{act.E2.EQh.2} = -497.35 \cdot kN$	$Y_{E.act.E2} = 2.52\ m$

Resisting Lateral Soil Load as required to produce horizontal equilibrium:

$$E_{pas.OT.E2.2} := -\left(H_{hwas.U1} + H_{hwrg.U1} + H_{twrg.U1} + H_{twgf.U1} + H_{twkey.OT.U1} + I_{U1} + E_{act.OT.U1} + \Sigma H_{Q.E2.EQh.2.OT}\right) = 7445 \cdot kN$$

Acting at: $E_{pas.OT.E2.2.loc} := -1 \cdot \frac{d_{key}}{2} = -1\ m$

Sum of All Overturning Analysis Horizontal Load (ΣH=0):

$$\Sigma H_{E2.OT.2} := H_{hwas.U1} + H_{hwrg.U1} + H_{twrg.U1} + H_{twgf.U1} + H_{twkey.OT.U1} + I_{U1} + E_{act.OT.U1} + E_{pas.OT.E2.2} + \Sigma H_{Q.E2.EQh.2.OT} = 0 \cdot kN$$

Sum of All Overturning Analysis Horizontal Load Moments:

$$\begin{aligned}\Sigma M_{H.E2.OT.2} := {} & H_{hwas.U1} \cdot H_{hwas.U1.loc} + H_{hwrg.U1} \cdot H_{hwrg.U1.loc} + H_{twrg.U1} \cdot H_{twrg.U1.loc} \cdots = -27114.06 \cdot kN \cdot m \\ & + H_{twgf.U1} \cdot H_{twgf.U1.loc} + H_{twkey.OT.U1} \cdot H_{twkey.OT.U1.loc} + I_{U1} \cdot I_{U1.loc} \cdots \\ & + E_{act.OT.U1} \cdot E_{act.OT.U1.loc} + E_{pas.OT.U1} \cdot E_{pas.OT.U1.loc} + \Sigma M_{Q.E2.2}\end{aligned}$$

Overturning Stability Analysis

$$\Sigma M_{E2.OT.2} := \Sigma M_{V.E2.OT.2} + \Sigma M_{H.E2.OT.2} = 118468.18 \cdot kN \cdot m$$

$$X_{R.E2.2} := \frac{\Sigma M_{E2.OT.2}}{\Sigma V_{E2.OT.2}} = 9.21\ m \qquad x_{OT.E2.2} := X_{R.E2.2} - \frac{L_b}{2} = -0.04\ m$$

Overturning Resultant Ratio $Ratio_{OT.E2.2} := \frac{X_{R.E2.2}}{L_b} = 0.5$

$$Ratio_{OT.E2.2.check} := \begin{cases} \text{"OKAY"} & \text{if } Ratio_{OT.E2.2} \ge Ratio_{overturning.allow.Extreme} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

$$x_{OT.check.E2.2} := \begin{cases} \text{"OKAY"} & \text{if } \left|x_{OT.E2.2}\right| \le Kern \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

Seismic Case $Q_{E2.3}$ - 30% Horizontal Seismic Force, 100% Vertical

E2.3 CASE

Include Seismic Load in Analysis?	$Eq_{E2.3} := 1$	0 = No, 1 = Yes
Horizontal Seismic Coefficient:	$K_{h.E2.3} := -0.05$	
Vertical Seismic Coefficient:	$K_{v.E2.3} := -0.10$	

HORIZONTAL SEISMIC LOADS	**Loads**	**Moment Arm**
Horiz Seismic Component of Concrete:	$Q_{conc.E2.EQh.3} := D_{conc} \cdot K_{h.E2.3} \cdot Eq_{E2.3} = -1230.9 \cdot kN$	$Y_{conc.loc} = 1.87\,m$
Horiz Seismic Component of Gates:	$Q_{Gate.E2.EQh.3} := D_{Gate} \cdot K_{h.E2.3} \cdot Eq_{E2.3} = -10.5 \cdot kN$	$Y_{gate} = 3.90\,m$
Horizontal Seismic Component of Headwater - Sliding:	$Q_{hwas.E2.EQh.3} := \left(\frac{7}{12}\right) \cdot K_{h.E2.3} \cdot \gamma_w \cdot \left(HW_{U1} - BOK_{elev}\right)^2 \cdot W_{hwas.U1} \cdot Eq_{E2.3} = -281.6 \cdot kN$	$Y_{HWg.E2} = 3.24\,m$
Horizontal Seismic Component of Soil (Woods Method)-Overturning:	$Q_{act.E2.EQh.3.OT} := \left(\gamma_r - \gamma_w\right) \cdot \left(TOC_{as} - BOK_{elev}\right)^2 \cdot K_{h.E2.3} \cdot W_{hwas.U1} \cdot Eq_{E2.3} = -329.1 \cdot kN$	$Y_{E.act.E2.OT} = 3.78\,m$
Horizontal Seismic Component of Soil (Woods Method):	$Q_{act.E2.EQh.3} := \left(\gamma_r - \gamma_w\right) \cdot \left(TOC_{as} - BOF_{elev}\right)^2 \cdot K_{h.E2.3} \cdot W_{hwas.U1} \cdot Eq_{E2.3} = -146.3 \cdot kN$	$Y_{E.act.E2} = 2.52\,m$

VERTICAL SEISMIC LOADS	**Loads**	**Moment Arm**
Vertical Component of Concrete:	$Q_{conc.E2.EQv.3} := D_{conc} \cdot K_{v.E2.2} \cdot Eq_{E2.2} = -738.6 \cdot kN$	$X_{conc.loc} = 10.06\,m$
Vertical Component of Gate:	$Q_{Gate.E2.EQv.3} := D_{Gate} \cdot K_{v.E2.2} \cdot Eq_{E2.2} = -6.3 \cdot kN$	$X_{gate} = 6.60\,m$
Vertical Seismic Component of Headwater over Apron Slab:	$Q_{H1.E2.EQv.3} := K_{v.E2.2} \cdot H_{1.U1} \cdot Eq_{E2.2} = -81.1 \cdot kN$	$H_{1.U1.loc} = 14.13\,m$
Vertical Seismic Component of Headwater over Pier Footing:	$Q_{H2.E2.EQv.3} := K_{v.E2.2} \cdot H_{2.U1} \cdot Eq_{E2.2} = -81.0 \cdot kN$	$H_{2.U1.loc} = 5.34\,m$

$$\Sigma H_{Q.E2.EQh.3} := Q_{conc.E2.EQh.3} + Q_{Gate.E2.EQh.3} + Q_{hwas.E2.EQh.3} + Q_{act.E2.EQh.3} = -1669.3 \cdot kN$$

$$\Sigma H_{Q.E2.EQh.3.OT} := Q_{conc.E2.EQh.3} + Q_{Gate.E2.EQh.3} + Q_{hwas.E2.EQh.3} + Q_{act.E2.EQh.3.OT} = -1852.15 \cdot kN$$

$$\Sigma V_{Q.E2.EQv.3} := Q_{conc.E2.EQv.3} + Q_{Gate.E2.EQv.3} + Q_{H1.E2.EQv.3} + Q_{H2.E2.EQv.3} = -906.9 \cdot kN$$

$$\begin{aligned}\Sigma M_{Q.E2.3} := {} & Q_{conc.E2.EQh.3} \cdot Y_{conc.loc} + Q_{Gate.E2.EQh.3} \cdot Y_{gate} + Q_{hwas.E2.EQh.3} \cdot Y_{HWg.E2} \cdots \\ & + Q_{act.E2.EQh.3.OT} \cdot Y_{E.act.E2.OT} + Q_{conc.E2.EQv.3} \cdot X_{conc.loc} + Q_{Gate.E2.EQv.3} \cdot X_{gate} \cdots \\ & + Q_{H1.E2.EQv.3} \cdot H_{1.U1.loc} + Q_{H2.E2.EQv.3} \cdot H_{2.U1.loc}\end{aligned} = -13543.77 \cdot kN \cdot m$$

STABILITY ASSESSMENT (SLIDNG, BEARING, FLOTATION AND OVERTURNING):

E2.3 CASE

CHECK SLIDING ALONG HORIZONTAL PLANE THRU TOE,
IGNORING BEDROCK MOBILIZED BY STRUCTURAL HEEL KEY, OR VOID BEHIND KEY

Sum of Vertical Forces:

$\Sigma V_{E2.3} := \Sigma V_{U1} + \Sigma V_{Q.E2.EQv.3} = 10404.9 \cdot kN$

Sum of Horizontal Forces:

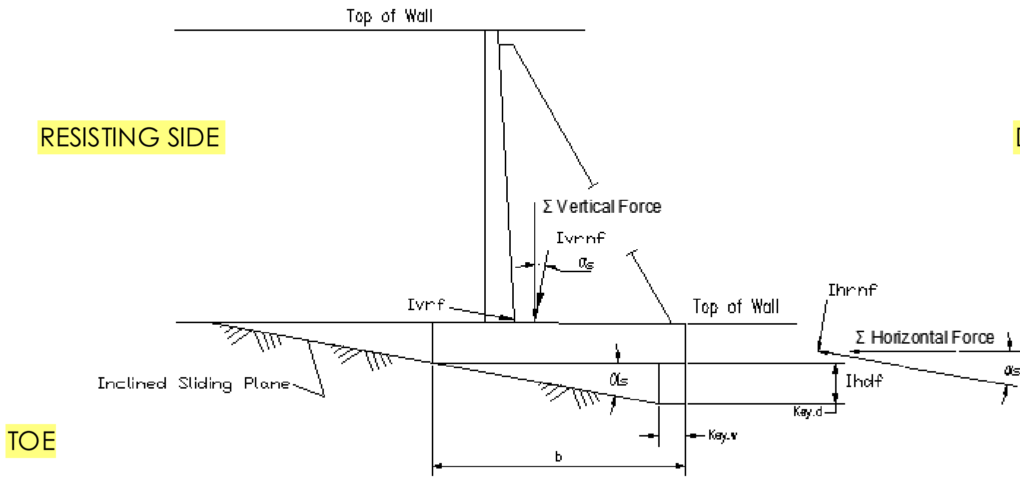
$\Sigma H_{E2.3} := \Sigma H_{U1} - I_{U1} + \Sigma H_{Q.E2.EQh.3} = -3815.01 \cdot kN$

Sliding Factor of Safety:

$$FS_{HorizSliding.E2.3} := \frac{\tan_{\phi} \cdot \Sigma V_{E2.3}}{\left|\Sigma H_{E2.3}\right|} = 1.33$$

$FS_{HorizSliding.E2.3.Check} :=$ | "OKAY" if $FS_{HorizSliding.E2.3} \geq FS_{req.E2.sl}$; "Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !" otherwise $=$ "OKAY"

CHECK SLIDING ALONG INCLINED SLIDING PLANE FROM HEEL KEY TO TOE,
WITH BEDROCK MASS MOBILIZED BY REINFOCREDE CONCRETE KEY)



Ivrf=Inclined Resisting Force
Ivrnf=Inclined Resisting Normal Force
Ihrnf=Inclined Resisting Normal Force
Ihdf=Inclined Driving Force

$\alpha s = 0.11$

as degrees= $\alpha s \cdot \left(\frac{180}{\pi}\right) = 6.52$

$\Sigma V_{E2.3} = 10404.89 \cdot kN$

$V_{rs} = 5775 \cdot kN$

Resolve $\Sigma Vert_{E2.3}$ & $\Sigma Horiz_{E2.3}$

$$\Sigma V_{InclinedE2.3} := \cos(\alpha s) \cdot \left(\Sigma V_{E2.3} + V_{rs}\right) + \sin(\alpha s) \cdot \left|\Sigma H_{E2.3}\right| = 16508.4 \cdot kN$$

$$\Sigma H_{InclinedE2.3} := \cos(\alpha s) \cdot \left|\Sigma H_{E2.3}\right| - \sin(\alpha s) \cdot \left(\Sigma V_{E2.3} + V_{rs}\right) = 1953.2 \cdot kN$$

(With properly engineered reinforced concrete Key, horizontal sliding plane thru Toe is protected, critical sliding plane is relocated to the INCLINED SLIDING PLANE FROM HEEL KEY To TOE, Bedrock Mass above this examined plane is mobilized by reinforced concrete key and combined into Structural Wedge.)

Inclined Sliding Plane Length $L_{incline} = 18.61\ m$

Safety Factor for Sliding
Inclined Failure Plane

$$FS_{InclinedlSlidingE2.3} := \frac{\Sigma V_{InclinedE2.3} \cdot \tan\left(\phi_{rock} \cdot \frac{\pi}{180}\right)}{\left|\Sigma H_{InclinedE2.3}\right|} = 4.12$$

$FS_{InclinedSliding.check.E2.3} :=$ | "OKAY " if $FS_{InclinedlSlidingE2.3} > FS_{req.E2.sl}$; "Revise Structure"" otherwise $=$ "OKAY "

$FS_{InclinedSliding.check.E2.3} =$ "OKAY "

OVERTURNING STABILITY CHECK:

E2.3 CASE

CHECK ECCENTRICITY

Sum of the moments:

$$\Sigma M_{E2.3} := \left(\Sigma M_{U1} + \Sigma M_{Q.E2.3}\right) = 170559 \cdot kN \cdot m$$

Eccentricity:

$$e_{E2.3} := \left(\frac{L_{incline}}{2}\right) - \frac{\left(\Sigma M_{E2.3}\right)}{\Sigma V_{InclinedE2.3}} = -1.03\, m$$

Eccentricity Check:

$$e_{check.E2.3} := \begin{cases} \text{"Okay"} & \text{if } e_{E2.3} \le Midhalf \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$$e_{check.E2.3} = \text{"Okay"}$$

Foundation Bearing Checks:

Bearing Pressure at Heel:

$$\sigma_{heel.E2.3} := \frac{\Sigma V_{InclinedE2.3}}{A_{b.incline}} - \frac{\left(\Sigma V_{InclinedE2.3} \cdot e_{E2.3}\right)}{S_{b.incline}} = 78.7 \cdot \frac{kN}{m^2}$$

$$\sigma_{heel.E2.3.check} := \left(\begin{cases} \text{"Okay"} & \text{if } \sigma_{heel.E2.3} \le \sigma_{allow.E2} \\ \text{"Revise Structure"} & \text{if } \sigma_{heel.E2.3} < 0 \frac{kN}{m^2} \end{cases}\right)$$

$$\sigma_{heel.E2.3.check} = \text{"Okay"}$$

Bearing Pressure at Toe:

$$\sigma_{toe.E2.3} := \frac{\Sigma V_{InclinedE2.3}}{A_{b.incline}} + \frac{\left(\Sigma V_{InclinedE2.3} \cdot e_{E2.3}\right)}{S_{b.incline}} = 39.5 \cdot \frac{kN}{m^2}$$

$$\sigma_{toe.E2.3.check.1} := \begin{cases} \text{"Okay"} & \text{if } \sigma_{toe.E2.3} \le \sigma_{allow.E2} \\ \text{"Revise Structure"} & \text{if } \sigma_{toe.E2.3} < 0 \frac{kN}{m^2} \end{cases}$$

$$\sigma_{toe.E2.3.check.1} = \text{"Okay"}$$

FLOATATION ANALYSIS:

ACCEPTANCE PARAMETERS

Required Factor of Safety: $FS_{req.FE2.3} := 1.1$

VERTICAL LOADS RESISTING:

Dead Load: $\Sigma V_{DL} = 24828.6 \cdot kN$

Water Weight H1+H2: $\Sigma V_{H.FE2.3} := \Sigma V_{H.FU1} + \Sigma V_{Q.E2.EQv.3} = 4496.1 \cdot kN$

Summation Vertical Resisting: $\Sigma V_{FE2.3} := \Sigma V_{DL} + \Sigma V_{H.FE2.3} = 29324.7 \cdot kN$

VERTICAL LOADS UPLIFT:

Uplift: $U_{S.U1} = -18919.81 \cdot kN$

Factor of Safety Floatation:

$$FS_{act.FE2.3} := \frac{\Sigma V_{FE2.3}}{\left|U_{S.U1}\right|} = 1.55$$

$$FS_{check.FE2.3} := \begin{cases} \text{"OKAY"} & \text{if } FS_{act.FE2.3} \ge FS_{req.FE2.3} \\ \text{"ANCHORS REQUIRED"} & \text{if } FS_{act.FE2.3} < FS_{req.FE2.3} \end{cases} = \text{"OKAY"}$$

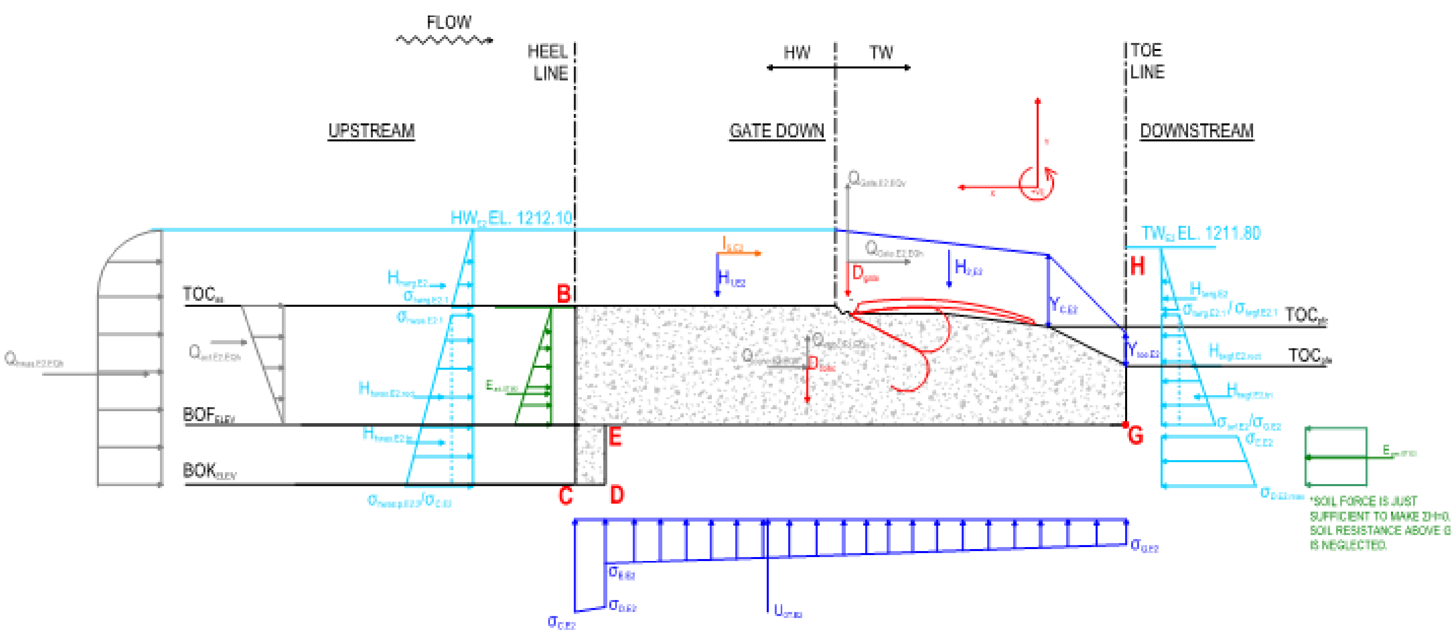
E2.3 CASE

MONOLITH OVERTURNING STABILITY ANALYSIS

Seismic Case $Q_{E2.3}$: 30% Horizontal Seismic Force, 100% Vertical

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.
Assumptions are made in order to compute overturning stability of indetermine forces on monolith with key;
(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.
(b) The horizontal resisting force acting on the key, P.key, is that required for static equilibrium
(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1 $Ratio_{overturning.allow.Extreme} = 0.25$ Resultant within Base



<u>All Vertical Loads Applicable to Overturning Stability Analysis</u>

Total Concrete Dead Loads: $D_{conc} = 24618.6 \cdot kN$ at: $X_{conc.loc} = 10.06\,m$

Dead Load of Gate: $D_{Gate} = 210.0 \cdot kN$ $X_{gate} = 6.60\,m$

Water Weight (HW) on Apron Slab: $H_{1.U1} = 2703.9 \cdot kN$ $H_{1.U1.loc} = 14.13\,m$

Water Weight (TW) on Gate Footing: $H_{2.U1} = 2699.2 \cdot kN$ $H_{2.U1.loc} = 5.34\,m$

Uplift Load for Overturning Analysis: $U_{OT.U1} = -16456.3 \cdot kN$ $U_{OT.U1.loc} = 9.48 \cdot m$

Vertical Seismic Component of Concrete Structure: $Q_{conc.E2.EQv.3} = -738.56 \cdot kN$ $X_{conc.loc} = 10.06\,m$

Vertical Seismic Component of Crest Gate: $Q_{Gate.E2.EQv.3} = -6.3 \cdot kN$ $X_{gate} = 6.60\,m$

Vertical Seismic Component of Headwater over Apron Slab: $Q_{H1.E2.EQv.3} = -81.12 \cdot kN$ $H_{1.U1.loc} = 14.13\,m$

Vertical Seismic Component of Headwater over Fixed Crest Slab: $Q_{H2.E2.EQv.3} = -80.98 \cdot kN$ $H_{2.U1.loc} = 5.34\,m$

Sum of All Overturning Analysis Vertical Load:

$$\Sigma V_{E2.OT.3} := D_{conc} + D_{Gate} + H_{1.U1} + H_{2.U1} + U_{OT.U1} + \Sigma V_{Q.E2.EQv.3} = 12868.4 \cdot kN$$

Sum of All Overturning Analysis Vertical Load Moments:

$$\Sigma M_{V.E2.OT.3} := D_{conc} \cdot X_{conc.loc} + D_{Gate} \cdot X_{gate} + H_{1.U1} \cdot H_{1.U1.loc} + H_{2.U1} \cdot H_{2.U1.loc} + U_{OT.U1} \cdot U_{OT.U1.loc} = 145582.24 \cdot kN \cdot m$$

Lateral Driving Earth Loads for Overturning Stability Analysis (at rest condition)

E2.3 CASE

Depth of Driving Soil Loads (to top of key): $h_{E.OT.E2.3} := TOC_{as} - BOF_{elev} = 4\,m$

Applicable Soil Load: $E_{act.OT.E2.3} := \dfrac{\left(K_{o.U1} \cdot h_{E.OT.U1}^{\;2}\right)}{2} \cdot \left(\gamma_r - \gamma_w\right) \cdot W_{hwas.U1} \cdot -1 = -962.49 \cdot kN$

At Rest- Soil Load Acting from Toe: $E_{act.OT.E2.3.loc} := \dfrac{h_{E.OT.U1}}{3} = 1.33\,m$

All Lateral Loads Applicable to Overturning Stability Analysis

HW Lateral Load on Approach Slab:	$H_{hwas.U1} = -4502.8 \cdot kN$	$H_{hwas.U1.loc} = 0.41\,m$
HW Lateral Load on Reg. Gate:	$H_{hwrg.U1} = 0.0 \cdot kN$	$H_{hwrg.U1.loc} = 4.00\,m$
TW Lateral Load on Reg. Gate:	$H_{twrg.U1} = 0.0 \cdot kN$	$H_{twrg.U1.loc} = 4.00\,m$
TW Lateral Load on Gate Footing (No Key - Overturning Values Adjusted):	$H_{twgf.U1} = 2236.68 \cdot kN$	$H_{twgf.U1.loc} = 1.65\,m$
TW Lateral Load on Key:	$H_{twkey.OT.U1} = 2080.92 \cdot kN$	$H_{twkey.OT.U1.loc} = -1.05\,m$
Ice / Impact Load:	$I_{U1} = 0.0 \cdot kN$	$I_{U1.loc} = 3.70\,m$
Lateral Soil Load (driving):	$E_{act.OT.U1} = -962.5 \cdot kN$	$E_{act.OT.U1.loc} = 1.33\,m$
Horizontal Seismic Component of Concrete Structure:	$Q_{conc.E2.EQh.3} = -1230.93 \cdot kN$	$Y_{conc.loc} = 1.87\,m$
Horizontal Seismic Component of Vertical Lift Gate:	$Q_{Gate.E2.EQh.3} = -10.5 \cdot kN$	$Y_{gate} = 3.90\,m$
Horizontal Seismic Component of Headwater on Gate:	$Q_{hwas.E2.EQh.3} = -281.59 \cdot kN$	$Y_{HWg.E2} = 3.24\,m$
Horizontal Seismic Component of Active Soil: (Section 5-5, USACE EM_1110-2-2100)	$Q_{act.E2.EQh.3} = -146.28 \cdot kN$	$Y_{E.act.E2} = 2.52\,m$

Resisting Lateral Soil Load as required to produce horizontal equilibrium:

$$E_{pas.OT.E2.3} := -\left(H_{hwas.U1} + H_{hwrg.U1} + H_{twrg.U1} + H_{twgf.U1} + H_{twkey.OT.U1} + I_{U1} + E_{act.OT.U1} + \Sigma H_{Q.E2.EQh.3.OT}\right) = 2999.84 \cdot kN$$

$$E_{pas.OT.E2.3.loc} := -1 \cdot \frac{d_{key}}{2} = -1\,m$$

Sum of All Overturning Analysis Horizontal Load (ΣH=0): Acting at:

$$\Sigma H_{E2.OT.3} := H_{hwas.U1} + H_{hwrg.U1} + H_{twrg.U1} + H_{twgf.U1} + H_{twkey.OT.U1} + I_{U1} + E_{act.OT.U1} + E_{pas.OT.E2.3} + \Sigma H_{Q.E2.EQh.3.OT} = 0 \cdot kN$$

Sum of All Overturning Analysis Horizontal Load Moments:

$$\Sigma M_{H.E2.OT.3} := H_{hwas.U1} \cdot H_{hwas.U1.loc} + H_{hwrg.U1} \cdot H_{hwrg.U1.loc} + H_{twrg.U1} \cdot H_{twrg.U1.loc} \cdots + H_{twgf.U1} \cdot H_{twgf.U1.loc} + H_{twkey.OT.U1} \cdot H_{twkey.OT.U1.loc} + I_{U1} \cdot I_{U1.loc} \cdots + E_{act.OT.U1} \cdot E_{act.OT.U1.loc} + E_{pas.OT.U1} \cdot E_{pas.OT.U1.loc} + \Sigma M_{Q.E2.3} = -16320.76 \cdot kN \cdot m$$

Overturning Stability Analysis

$$\Sigma M_{E2.OT.3} := \Sigma M_{V.E2.OT.3} + \Sigma M_{H.E2.OT.3} = 129261.48 \cdot kN \cdot m$$

$$X_{R.E2.3} := \frac{\Sigma M_{E2.OT.3}}{\Sigma V_{E2.OT.3}} = 10.04\,m \qquad x_{OT.E2.3} := X_{R.E2.3} - \frac{L_b}{2} = 0.79\,m$$

Overturning Resultant Ratio

$$Ratio_{OT.E2.3} := \frac{X_{R.E2.3}}{L_b} = 0.54$$

$$Ratio_{OT.E2.3.check} := \begin{cases} \text{"OKAY"} & \text{if } Ratio_{OT.E2.3} \ge Ratio_{overturning.allow.Extreme} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

$$x_{OT.check.E2.3} := \begin{cases} \text{"OKAY"} & \text{if } \left|x_{OT.E2.3}\right| \le Kern \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

Summary of Results

E2 CASE

E2.1 Case

Sliding Factor of Safety: (Horizontal Plane)	$FS_{HorizSliding.E2.1} = 0.71$	
	$FS_{HorizSliding.E2.1.Check}$ = "Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !"	
Sliding Factor of Safety: (Inclined Plane)	$FS_{InclinedlSlidingE2.1} = 1.49$	$FS_{InclinedSliding.check.E2.1}$ = "OKAY "
Eccentricity: (Inclined Plane)	$e_{E2.1} = -0.15\,m$	$e_{check.E2.1}$ = "Okay"
Bearing Pressure At Heel: (Inclined Plane)	$\sigma_{heel.E2.1} = 67 \cdot kPa$	$\sigma_{heel.E2.1.check}$ = "Okay"
Bearing Pressure At Toe: (Inclined Plane)	$\sigma_{toe.E2.1} = 61 \cdot kPa$	$\sigma_{toe.E2.1.check.1}$ = "Okay"
Flotation Factor of Safety (horizontal plane)	$FS_{act.FE2.1} = 1.6$	$FS_{check.FE2.1}$ = "OKAY"
Overturning Resultant Ratio: (horizontal plane)	$Ratio_{OT.E2.1} = 0.5$	$Ratio_{OT.E2.1.check}$ = "OKAY"
Eccentricity: (horizontal plane)	$x_{OT.E2.1} = 0.01\,m$	$x_{OT.check.E2.1}$ = "OKAY"

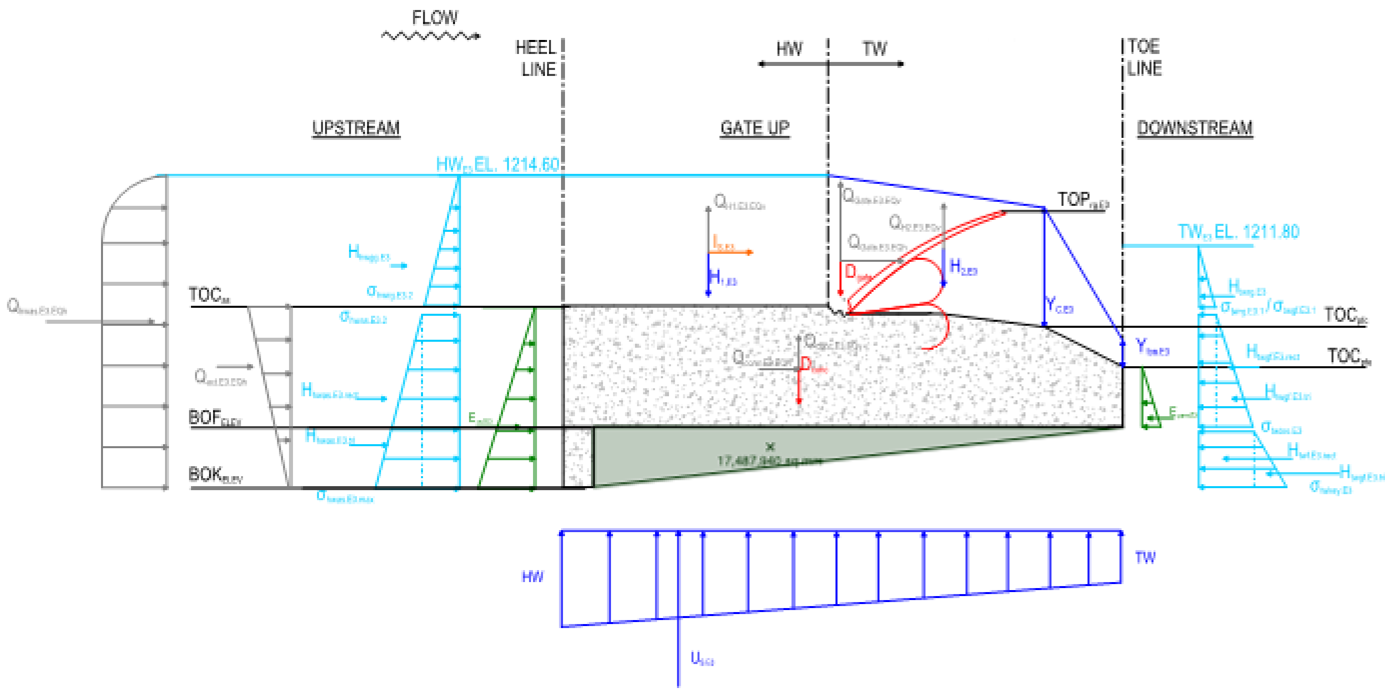
E2.2 Case

Sliding Factor of Safety: (Horizontal Plane)	$FS_{HorizSliding.E2.2} = 0.65$	
	$FS_{HorizSliding.E2.2.Check}$ = "Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !"	
Sliding Factor of Safety: (Inclined Plane)	$FS_{InclinedlSlidingE2.2} = 1.39$	$FS_{InclinedSliding.check.E2.2}$ = "OKAY "
Eccentricity: (Inclined Plane)	$e_{E2.2} = -0.11\,m$	$e_{check.E2.2}$ = "Okay"
Bearing Pressure At Heel: (Inclined Plane)	$\sigma_{heel.E2.2} = 63 \cdot kPa$	$\sigma_{heel.E2.2.check}$ = "Okay"
Bearing Pressure At Toe: (Inclined Plane)	$\sigma_{toe.E2.2} = 59 \cdot kPa$	$\sigma_{toe.E2.2.check.1}$ = "Okay"
Flotation Factor of Safety (horizontal plane)	$FS_{act.FE2.2} = 1.55$	$FS_{check.FE2.2}$ = "OKAY"
Overturning Resultant Ratio: (horizontal plane)	$Ratio_{OT.E2.2} = 0.5$	$Ratio_{OT.E2.2.check}$ = "OKAY"
Eccentricity: (horizontal plane)	$x_{OT.E2.2} = -0.04\,m$	$x_{OT.check.E2.2}$ = "OKAY"

E2.3 Case

Sliding Factor of Safety: (Horizontal Plane)	$FS_{HorizSliding.E2.3} = 1.33$	
	$FS_{HorizSliding.E2.3.Check} = \text{"OKAY"}$	
Sliding Factor of Safety: (Inclined Plane)	$FS_{InclinedlSlidingE2.3} = 4.12$	$FS_{InclinedSliding.check.E2.3} = \text{"OKAY "}$
Eccentricity: (Inclined Plane)	$e_{E2.3} = -1.03\,m$	$e_{check.E2.3} = \text{"Okay"}$
Bearing Pressure At Heel: (Inclined Plane)	$\sigma_{heel.E2.3} = 79 \cdot kPa$	$\sigma_{heel.E2.3.check} = \text{"Okay"}$
Bearing Pressure At Toe: (Inclined Plane)	$\sigma_{toe.E2.3} = 40 \cdot kPa$	$\sigma_{toe.E2.3.check.1} = \text{"Okay"}$
Flotation Factor of Safety (horizontal plane)	$FS_{act.FE2.3} = 1.55$	$FS_{check.FE2.3} = \text{"OKAY"}$
Overturning Resultant Ratio: (horizontal plane)	$Ratio_{OT.E2.3} = 0.54$	$Ratio_{OT.E2.3.check} = \text{"OKAY"}$
Eccentricity: (horizontal plane)	$x_{OT.E2.3} = 0.79\,m$	$x_{OT.check.E2.3} = \text{"OKAY"}$

E3 DESIGN CASE



U2 CASE PLUS SEISMIC

ACCEPTANCE PARAMETERS

Required Factor of Safety for Sliding:	$FS_{req.E3.sl} := 1.0$	(Without Cohesion) (Section 8.1, Design Criteria)
Resultant Within Middle Third of Base:	$e \le \frac{L_b}{6} \wedge e \ge \frac{-L_b}{6}$	
Allowable Rock Bearing Pressure:	$\sigma_{allow.E3} := 1740 \cdot \frac{kN}{m^2}$	(Section 5.2, Design Criteria)

INPUT PARAMETERS

Headwater Elevation:	$HW_{E3} := 1214.60m$	(Section 8.3, Design Criteria)
Tailwater Elevation:	$TW_{E3} := 1211.80m$	(Section 8.3, Design Criteria)
Bottom of Footing Elevation:	$BOF_{elev} = 1206\,m$	
Approach Slab Top of Concrete Elevation at Upstream Face:	$TOC_{as} = 1210\,m$	
Footing Top of Concrete Elevation at Stilling Basin:	$TOC_{pfe} = 1208\,m$	
Footing Top of Concrete Elevation at Center of Footing:	$TOC_{pfc} = 1209.3\,m$	Gates are open when top of gate elevation is at 1210.00m
Top of Guard/Regulating Gate Elevation:	$TOP_{rg.U2} = 1212.1\,m$ $TOP_{gg.U2} = 1215.00\,m$	Gates are closed/up when top of gate elevation is at 1215.0m
Bottom of Key Elevation:	$BOK_{elev} = 1204\,m$	

Crestwater Elevation: Dynamic Flow $EL_{C.E3} := 1213.76m$

$$Y_{C.E3} := \begin{cases} (EL_{C.E3} - TOC_{pfc}) & \text{if } TOP_{rg.U2} \le HW_{E3} \\ (TW_{E3} - TOC_{pfc}) & \text{if } TOP_{rg.U2} > HW_{E3} \end{cases} = 4.46 \cdot m$$

Toewater Elevation: $EL_{TOE.E3} := 1208.58m$

$$Y_{TOE.E3} := \begin{cases} (EL_{TOE.E3} - TOC_{pfe}) & \text{if } TOP_{rg.U2} \le HW_{E3} \\ (TW_{E3} - TOC_{pfe}) & \text{if } TOP_{rg.U2} > HW_{E3} \end{cases} = 0.58 \cdot m$$

SEISMIC LOAD (Three combinations of E_h and E_v considered)

E3.1 CASE

Seismic Case $Q_{E2.1}$ - 100% Horizontal Seismic Force, No Vertical

Include Seismic Load in Analysis? $Eq_{E3.1} := 1$

Horizontal Seismic Coefficient: $K_{h.E3.1} := -0.17$

Vertical Seismic Coefficient: $K_{v.E3.1} := -0.00$

HORIZONTAL SEISMIC LOADS	Loads	Moment Arm
Horiz Seismic Component of Concrete:	$Q_{conc.E3.EQh.1} := D_{conc} \cdot K_{h.E3.1} \cdot Eq_{E3.1} = -4185.2 \cdot kN$	$Y_{conc.loc} = 1.87\,m$
Horiz Seismic Component of Gates:	$Q_{Gate.E3.EQh.1} := D_{Gate} \cdot K_{h.E3.1} \cdot Eq_{E3.1} = -35.7 \cdot kN$	$Y_{gate} = 3.90\,m$
Horizontal Seismic Component of Headwater - Sliding:	$Q_{hwas.E3.EQh.1} := \left(\frac{7}{12}\right) \cdot K_{h.E3.1} \cdot \gamma_w \cdot \left(HW_{U2} - BOK_{elev}\right)^2 \cdot W_{hwas.U2} \cdot Eq_{E3.1} = -1639.6 \cdot kN$ $Y_{HWg.E3} := 0.4 \cdot \left(HW_{U2} - BOK_{elev}\right) = 4.24\,m$	
Horizontal Seismic Component of Soil (Woods Method)- Overturning:	$Q_{act.E3.EQh.1.OT} := \left(\gamma_r - \gamma_w\right) \cdot \left(TOC_{as} - BOK_{elev}\right)^2 \cdot K_{h.E3.1} \cdot W_{hwas.U2} \cdot Eq_{E3.1} = -1119.0 \cdot kN$ $Y_{E.act.E3.OT} := 0.63 \cdot \left(TOC_{as} - BOK_{elev}\right) = 3.78\,m$	
Horizontal Seismic Component of Soil (Woods Method)	$Q_{act.E3.EQh.1} := \left(\gamma_r - \gamma_w\right) \cdot \left(TOC_{as} - BOF_{elev}\right)^2 \cdot K_{h.E3.1} \cdot W_{hwas.U2} \cdot Eq_{E3.1} = -497.4 \cdot kN$ $Y_{E.act.E3} := 0.63 \cdot \left(TOC_{as} - BOF_{elev}\right) = 2.52\,m$	

VERTICAL SEISMIC LOADS	Loads	Moment Arm
Vertical Component of Concrete:	$Q_{conc.E3.EQv.1} := D_{conc} \cdot K_{v.E3.1} \cdot Eq_{E3.1} = 0.0 \cdot kN$	$X_{conc.loc} = 10.06\,m$
Vertical Component of Gate:	$Q_{Gate.E3.EQv.1} := D_{Gate} \cdot K_{v.E3.1} \cdot Eq_{E3.1} = 0.0 \cdot kN$	$X_{gate} = 6.60\,m$
Vertical Seismic Component of Headwater over Apron Slab:	$Q_{H1.E3.EQv.1} := K_{v.E3.1} \cdot H_{1.U2} \cdot Eq_{E3.1} = 0.0 \cdot kN$	$H_{1.U2.loc} = 14.13\,m$
Vertical Seismic Component of Headwater over Pier Footing:	$Q_{H2.E3.EQv.1} := K_{v.E3.1} \cdot H_{2.U2} \cdot Eq_{E3.1} = 0.0 \cdot kN$	$H_{2.U2.loc} = 5.43\,m$

$$\Sigma H_{Q.E3.EQh.1} := Q_{conc.E3.EQh.1} + Q_{Gate.E3.EQh.1} + Q_{hwas.E3.EQh.1} + Q_{act.E3.EQh.1} = -6357.81 \cdot kN$$

$$\Sigma H_{Q.E3.EQh.1.OT} := Q_{conc.E3.EQh.1} + Q_{Gate.E3.EQh.1} + Q_{hwas.E3.EQh.1} + Q_{act.E3.EQh.1.OT} = -6979.5 \cdot kN$$

$$\Sigma V_{Q.E3.EQv.1} := Q_{conc.E3.EQv.1} + Q_{Gate.E3.EQv.1} + Q_{H1.E3.EQv.1} + Q_{H2.E3.EQv.1} = 0.0 \cdot kN$$

$$\Sigma M_{Q.E3.1} := Q_{conc.E3.EQh.1} \cdot Y_{conc.loc} + Q_{Gate.E3.EQh.1} \cdot Y_{gate} + Q_{hwas.E3.EQh.1} \cdot Y_{HWg.E3} \cdots + Q_{act.E3.EQh.1.OT} \cdot Y_{E.act.E3.OT} + Q_{conc.E3.EQv.1} \cdot X_{conc.loc} + Q_{Gate.E3.EQv.1} \cdot X_{gate} \cdots + Q_{H1.E3.EQv.1} \cdot H_{1.U2.loc} + Q_{H2.E3.EQv.1} \cdot H_{2.U2.loc} = -19140.41 \cdot kN \cdot m$$

STABILITY ASSESSMENT (SLIDNG, BEARING, FLOTATION AND OVERTURNING):

CHECK SLIDING ALONG HORIZONTAL PLANE THRU TOE, IGNORING BEDROCK MOBILIZED BY STRUCTURAL HEEL KEY, OR VOID BEHIND KEY

E3.1 CASE

Sum of Vertical Forces:

$\Sigma V_{E3.1} := \Sigma V_{U2} + \Sigma V_{Q.E3.EQv.1} = 14159.0 \cdot kN$

Sum of Horizontal Forces:

$\Sigma H_{E3.1} := \Sigma H_{U2} - I_{U2} + \Sigma H_{Q.E3.EQh.1} = -11201.52 \cdot kN$

Sliding Factor of Safety:

$$FS_{HorizSliding.E3.1} := \frac{\tan_{\phi} \cdot \Sigma V_{E3.1}}{\left|\Sigma H_{E3.1}\right|} = 0.62$$

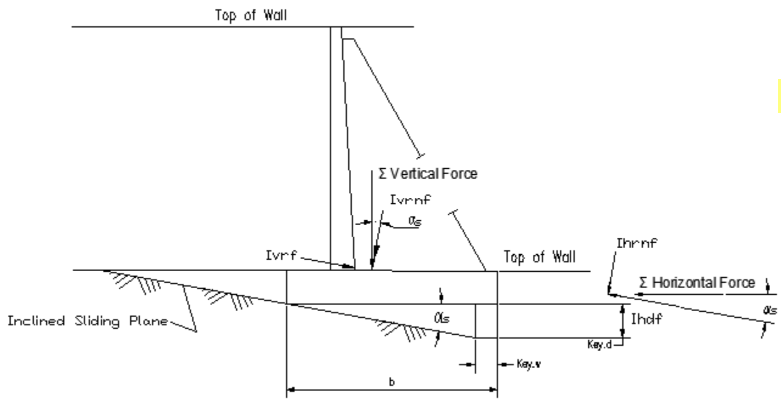
$FS_{HorizSliding.E3.1.Check} :=$ | "OKAY" if $FS_{HorizSliding.E3.1} \geq FS_{req.E3.sl}$
"Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !" otherwise

$FS_{HorizSliding.E3.1.Check}$ = "Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !"

CHECK SLIDING ALONG INCLINED SLIDING PLANE FROM HEEL KEY TO TOE, WITH BEDROCK MASS MOBILIZED BY REINFOCREDE CONCRETE KEY)

RESISTING SIDE

DRIVING SIDE



TOE

HEEL

Ivrf=Inclined Resisting Force
Ivrnf=Inclined Resisting Normal Force
Ihrnf=Inclined Resisting Normal Force
Ihdf=Inclined Driving Force

$V_{rs} = 5775 \cdot kN$

$\alpha s = 0.11$

as degrees= $\alpha s \cdot \left(\frac{180}{\pi}\right) = 6.52$

Resolve $\Sigma Vert_{E3.1}$ & $\Sigma Horiz_{E3.1}$

$\Sigma V_{InclinedE3.1} := \cos(\alpha s) \cdot \left(\Sigma V_{E3.1} + V_{rs}\right) + \sin(\alpha s) \cdot \left|\Sigma H_{E3.1}\right| = 21076.9 \cdot kN$

$\Sigma H_{InclinedE3.1} := \cos(\alpha s) \cdot \left|\Sigma H_{E3.1}\right| - \sin(\alpha s) \cdot \left(\Sigma V_{E3.1} + V_{rs}\right) = 8865.6 \cdot kN$

Inclined Sliding Plane Length

$L_{incline} = 18.61\ m$

Safety Factor for Sliding Inclined Failure Plane

$$FS_{InclinedISlidingE3.1} := \frac{\Sigma V_{InclinedE3.1} \cdot \tan\left(\phi_{rock} \cdot \frac{\pi}{180}\right)}{\left|\Sigma H_{InclinedE3.1}\right|} = 1.16$$

$FS_{InclinedSliding.check.E3.1} :=$ | "OKAY " if $FS_{InclinedISlidingE3.1} > FS_{req.E3.sl}$
"Revise Structure"" otherwise

= "OKAY "

$FS_{InclinedSliding.check.E3.1}$ = "OKAY "

OVERTURNING STABILITY CHECK:

CHECK ECCENTRICITY - OBSOLETE

Sum of the moments:

$$\Sigma M_{E3.1} := \left(\Sigma M_{U2} + \Sigma M_{Q.E3.1}\right) = 167255 \cdot kN \cdot m$$

Eccentricity:

$$e_{E3.1} := \left(\frac{L_{incline}}{2}\right) - \frac{\left(\Sigma M_{E3.1}\right)}{\Sigma V_{InclinedE3.1}} = 1.37\,m$$

Eccentricity Check:

$$e_{check.E3.1} := \begin{cases} \text{"Okay"} & \text{if } e_{E3.1} \le Midhalf \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$$e_{check.E3.1} = \text{"Okay"}$$

Foundation Bearing Checks:

Bearing Pressure at Heel:

$$\sigma_{heel.E3.1} := \frac{\Sigma V_{InclinedE3.1}}{A_{b.incline}} - \frac{\left(\Sigma V_{InclinedE3.1} \cdot e_{E3.1}\right)}{S_{b.incline}} = 42.2 \cdot \frac{kN}{m^2}$$

$$\sigma_{heel.E3.1.check} := \left(\begin{cases} \text{"Okay"} & \text{if } \sigma_{heel.E3.1} \le \sigma_{allow.E2} \\ \text{"Revise Structure"} & \text{if } \sigma_{heel.E3.1} < 0 \frac{kN}{m^2} \end{cases}\right)$$

$$\sigma_{heel.E3.1.check} = \text{"Okay"}$$

Bearing Pressure at Toe:

$$\sigma_{toe.E3.1} := \frac{\Sigma V_{InclinedE3.1}}{A_{b.incline}} + \frac{\left(\Sigma V_{InclinedE3.1} \cdot e_{E3.1}\right)}{S_{b.incline}} = 108.8 \cdot \frac{kN}{m^2}$$

$$\sigma_{toe.E3.1.check.1} := \begin{cases} \text{"Okay"} & \text{if } \sigma_{toe.E3.1} \le \sigma_{allow.E2} \\ \text{"Revise Structure"} & \text{if } \sigma_{toe.E3.1} < 0 \frac{kN}{m^2} \end{cases}$$

$$\sigma_{toe.E3.1.check.1} = \text{"Okay"}$$

FLOATATION ANALYSIS:

ACCEPTANCE PARAMETERS

Required Factor of Safety: $FS_{req.FE3.1} := 1.1$

VERTICAL LOADS RESISTING:

Dead Load: $\Sigma V_{DL} = 24828.6 \cdot kN$

Water Weight H1+H2: $\Sigma V_{H.FE3.1} := \Sigma V_{H.FU2} + \Sigma V_{Q.E3.EQv.1} = 11653.03 \cdot kN$

Summation Vertical Resisting: $\Sigma V_{FE3.1} := \Sigma V_{DL} + \Sigma V_{H.FE3.1} = 36481.6 \cdot kN$

VERTICAL LOADS UPLIFT:

Uplift: $U_{U2} = -22322.65 \cdot kN$

Factor of Safety Floatation:

$$FS_{act.FE3.1} := \frac{\Sigma V_{FE3.1}}{\left|U_{U2}\right|} = 1.63$$

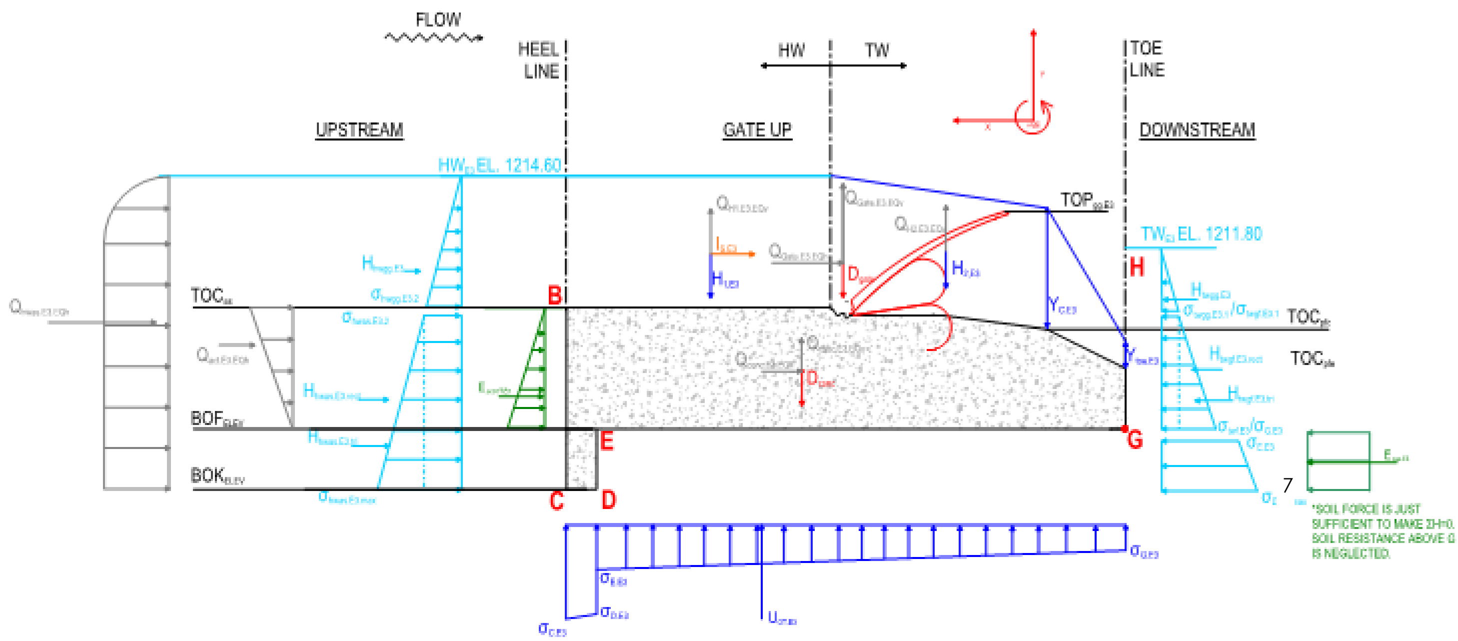
$$FS_{check.FE3.1} := \begin{cases} \text{"OKAY"} & \text{if } FS_{act.FE3.1} \ge FS_{req.FE3.1} \\ \text{"ANCHORS REQUIRED"} & \text{if } FS_{act.FE3.1} < FS_{req.FE3.1} \end{cases} = \text{"OKAY"}$$

MONOLITH OVERTURNING STABILITY ANALYSIS

Seismic Case $Q_{E3.1}$: 100% Horizontal Seismic Force, No Vertical

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.
Assumptions are made in order to compute overturning stability of indetermine forces on monolith with key;
(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.
(b) The horizontal resisting force acting on the key, P.key, is that required for static equilibrium
(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1 $Ratio_{overturning.allow.Extreme} = 0.25$ Resultant within Base



All Vertical Loads Appliable to Overturning Stability Analysis

Total Concrete Dead Loads:	$D_{conc} = 24618.6 \cdot kN$	at:	$X_{conc.loc} = 10.06\,m$
Dead Load of Gate:	$D_{Gate} = 210.0 \cdot kN$		$X_{gate} = 6.60\,m$
Water Weight (HW) on Apron Slab:	$H_{1.U2} = 5922.8 \cdot kN$		$H_{1.U2.loc} = 14.13\,m$
Water Weight (TW) on Gate Footing:	$H_{2.U2} = 5730.2 \cdot kN$		$H_{2.U2.loc} = 5.43\,m$
Uplift Load for Overturning Analysis:	$U_{OT.U2} = -19563.05 \cdot kN$		$U_{OT.U2.loc} = 9.94 \cdot m$
Vertical Seismic Component of Concrete Structure:	$Q_{conc.E3.EQv.1} = 0$		$X_{conc.loc} = 10.06\,m$
Vertical Seismic Component of Crest Gate:	$Q_{Gate.E3.EQv.1} = 0$		$X_{gate} = 6.60\,m$
Vertical Seismic Component of Headwater over Apron Slab:	$Q_{H1.E3.EQv.1} = 0$		$H_{1.U2.loc} = 14.13\,m$
Vertical Seismic Component of Headwater over Fixed Crest Slab:	$Q_{H2.E3.EQv.1} = 0$		$H_{2.U2.loc} = 5.43\,m$

Sum of All Overturning Analysis Vertical Load:

$$\Sigma V_{E3.OT.1} := D_{conc} + D_{Gate} + H_{1.U2} + H_{2.U2} + U_{OT.U2} + \Sigma V_{Q.E3.EQv.1} = 16918.58 \cdot kN$$

Sum of All Overturning Analysis Vertical Load Moments:

$$\Sigma M_{V.E3.OT.1} := D_{conc} \cdot X_{conc.loc} + D_{Gate} \cdot X_{gate} + H_{1.U2} \cdot H_{1.U2.loc} + H_{2.U2} \cdot H_{2.U2.loc} + U_{OT.U2} \cdot U_{OT.U2.loc} = 169206.88 \cdot kN \cdot m$$

E3.1 CASE

Lateral Driving Earth Loads for Overturning Stability Analysis (at rest condition)

Depth of Driving Soil Loads (to top of key): $h_{E.OT.E3.1} := TOC_{as} - BOF_{elev} = 4\,m$

At-Rest Soil Load: $E_{act.OT.E3.1} := \dfrac{\left(K_{o.U2} \cdot h_{E.OT.U2}{}^2\right)}{2} \cdot \left(\gamma_r - \gamma_w\right) \cdot W_{hwas.U2} \cdot -1 = -962.49 \cdot kN$

At Rest- Soil Load Acting from Toe: $E_{act.OT.E3.1.loc} := \dfrac{h_{E.OT.U2}}{3} = 1.33\,m$

All Lateral Loads Appliable to Overturning Stability Analysis

HW Lateral Load on Approach Slab:	$H_{hwas.U1} = -4502.8 \cdot kN$	$H_{hwas.U1.loc} = 0.41\,m$
HW Lateral Load on Reg. Gate:	$H_{hwrg.U1} = 0.0 \cdot kN$	$H_{hwrg.U1.loc} = 4.00\,m$
TW Lateral Load on Reg. Gate:	$H_{twrg.E1} = 0.0 \cdot kN$	$H_{twrg.E1.loc} = 4.00\,m$
TW Lateral Load on Gate Footing (No Key - Overturning Values Adjusted):	$H_{twgf.E1} = 4061.34 \cdot kN$	$H_{twgf.E1.loc} = 1.81\,m$
TW Lateral Load on Key:	$H_{twkey.OT.E1} = 3550.98 \cdot kN$	$H_{twkey.OT.E1.loc} = -1.03\,m$
Ice / Impact Load:	$I_{E1} = 0.0 \cdot kN$	$I_{E1.loc} = 3.70\,m$
Lateral Soil Load (driving):	$E_{act.OT.E1} = -962.5 \cdot kN$	$E_{act.OT.E1.loc} = 1.33\,m$
Horizontal Seismic Component of Concrete Structure:	$Q_{conc.E3.EQh.1} = -4185.16 \cdot kN$	$Y_{conc.loc} = 1.87\,m$
Horizontal Seismic Component of Vertical Lift Gate:	$Q_{Gate.E3.EQh.1} = -35.7 \cdot kN$	$Y_{gate} = 3.90\,m$
Horizontal Seismic Component of Headwater on Gate:	$Q_{hwas.E3.EQh.1} = -1639.6 \cdot kN$	$Y_{HWg.E3} = 4.24\,m$
Horizontal Seismic Component of Active Soil: (Section 5-5, USACE EM_1110-2-2100)	$Q_{act.E3.EQh.1} = -497352\,N$	$Y_{E.act.E3} = 2.52\,m$

Resisting Lateral Soil Load as required to produce horizontal equilibrium:

$$E_{pas.OT.E3.1} := -\left(H_{hwas.U2} + H_{hwrg.U2} + H_{twrg.U2} + H_{twgf.U2} + H_{twkey.OT.U2} + I_{U2} + E_{act.OT.U2} + \Sigma H_{Q.E3.EQh.1}\right) = 11032.4 \cdot kN$$

Acting at: $E_{pas.OT.E3.1.loc} := -1 \cdot \dfrac{d_{key}}{2} = -1\,m$

Sum of All Overturning Analysis Horizontal Load (ΣH=0):

$$\Sigma H_{E3.OT.1} := H_{hwas.U2} + H_{hwrg.U2} + H_{twrg.U2} + H_{twgf.U2} + H_{twkey.OT.U2} + I_{U2} + E_{act.OT.U2} + E_{pas.OT.E3.1} + \Sigma H_{Q.E3.EQh.1} = 0 \cdot kN$$

Sum of All Overturning Analysis Horizontal Load Moments:

$$\Sigma M_{H.E3.OT.1} := H_{hwas.U2} \cdot H_{hwas.E1.loc} + H_{hwrg.E1} \cdot H_{hwrg.E1.loc} + H_{twrg.E1} \cdot H_{twrg.E1.loc} \cdots + H_{twgf.E1} \cdot H_{twgf.E1.loc} + H_{twkey.OT.E1} \cdot H_{twkey.OT.E1.loc} + I_{E1} \cdot I_{E1.loc} \cdots + E_{act.OT.E1} \cdot E_{act.OT.E1.loc} + E_{pas.OT.E1} \cdot E_{pas.OT.E1.loc} + \Sigma M_{Q.E3.1} = -23946.12 \cdot kN \cdot m$$

Overturning Stability Analysis

$\Sigma M_{E3.OT.1} := \Sigma M_{V.E1.OT} + \Sigma M_{H.E1.OT} = 154070.51 \cdot kN \cdot m$

$X_{R.E3.1} := \dfrac{\Sigma M_{E3.OT.1}}{\Sigma V_{E3.OT.1}} = 9.11\,m$ $\qquad x_{OT.E3.1} := X_{R.E3.1} - \dfrac{L_b}{2} = -0.14\,m$

Overturning Resultant Ratio $\quad Ratio_{OT.E3.1} := \dfrac{X_{R.E3.1}}{L_b} = 0.49$

$Ratio_{OT.E3.1.check} :=$ | "OKAY" if $Ratio_{OT.E3.1} \geq Ratio_{overturning.allow.Extreme}$; "Revise Structure" otherwise $=$ "OKAY"

$x_{OT.check.E3.1} :=$ | "OKAY" if $\left|x_{OT.E3.1}\right| \leq Kern$; "Revise Structure" otherwise $=$ "OKAY"

Seismic Case $Q_{E2.2}$ - 100% Horizontal Seismic Force, 30% Vertical

E3.2 CASE

Include Seismic Load in Analysis? $Eq_{E3.2} := 1$

Horizontal Seismic Coefficient: $K_{h.E3.2} := -0.17$

Vertical Seismic Coefficient: $K_{v.E3.2} := -0.03$

HORIZONTAL SEISMIC LOADS	Loads	Moment Arm
Horiz Seismic Component of Concrete:	$Q_{conc.E3.EQh.2} := D_{conc} \cdot K_{h.E3.2} \cdot Eq_{E3.2} = -4185.2 \cdot kN$	$Y_{conc.loc} = 1.87\,m$
Horiz Seismic Component of Gates:	$Q_{Gate.E3.EQh.2} := D_{Gate} \cdot K_{h.E3.2} \cdot Eq_{E3.2} = -35.7 \cdot kN$	$Y_{gate} = 3.90\,m$
Horizontal Seismic Component of Headwater - Sliding:	$Q_{hwas.E3.EQh.2} := \left(\frac{7}{12}\right) \cdot K_{h.E3.2} \cdot \gamma_w \cdot \left(HW_{U2} - BOK_{elev}\right)^2 \cdot W_{hwas.U2} \cdot Eq_{E3.2} = -1639.6 \cdot kN$	$Y_{HWg.E3} = 4.24\,m$
Horizontal Seismic Component of Soil (Woods Method)-Overturning:	$Q_{act.E3.EQh.2.OT} := \left(\gamma_r - \gamma_w\right) \cdot \left(TOC_{as} - BOK_{elev}\right)^2 \cdot K_{h.E3.2} \cdot W_{hwas.U2} \cdot Eq_{E3.2} = -1119.0 \cdot kN$	$Y_{E.act.E3.OT} = 3.78\,m$
Horizontal Seismic Component of Soil (Woods Method)	$Q_{act.E3.EQh.2} := \left(\gamma_r - \gamma_w\right) \cdot \left(TOC_{as} - BOF_{elev}\right)^2 \cdot K_{h.E3.2} \cdot W_{hwas.U2} \cdot Eq_{E3.2} = -497.4 \cdot kN$	$Y_{E.act.E3} = 2.52\,m$

VERTICAL SEISMIC LOADS	Loads	Moment Arm
Vertical Component of Concrete:	$Q_{conc.E3.EQv.2} := D_{conc} \cdot K_{v.E3.2} \cdot Eq_{E3.2} = -738.6 \cdot kN$	$X_{conc.loc} = 10.06\,m$
Vertical Component of Gate:	$Q_{Gate.E3.EQv.2} := D_{Gate} \cdot K_{v.E3.2} \cdot Eq_{E3.2} = -6.3 \cdot kN$	$X_{gate} = 6.60\,m$
Vertical Seismic Component of Headwater over Apron Slab:	$Q_{H1.E3.EQv.2} := K_{v.E3.2} \cdot H_{1.U1} \cdot Eq_{E3.2} = -81.1 \cdot kN$	$H_{1.U2.loc} = 14.13\,m$
Vertical Seismic Component of Headwater over Pier Footing:	$Q_{H2.E3.EQv.2} := K_{v.E3.2} \cdot H_{2.U1} \cdot Eq_{E3.2} = -81.0 \cdot kN$	$H_{2.U2.loc} = 5.43\,m$

$$\Sigma H_{Q.E3.EQh.2} := Q_{conc.E3.EQh.2} + Q_{Gate.E3.EQh.2} + Q_{hwas.E3.EQh.2} + Q_{act.E2.EQh.2} = -6357.81 \cdot kN$$

$$\Sigma H_{Q.E3.EQh.2.OT} := Q_{conc.E3.EQh.2} + Q_{Gate.E3.EQh.2} + Q_{hwas.E3.EQh.2} + Q_{act.E3.EQh.2.OT} = -6979.5 \cdot kN$$

$$\Sigma V_{Q.E3.EQv.2} := Q_{conc.E3.EQv.2} + Q_{Gate.E3.EQv.2} + Q_{H1.E3.EQv.2} + Q_{H2.E3.EQv.2} = -906.9 \cdot kN$$

$$\begin{aligned}\Sigma M_{Q.E3.2} := {} & Q_{conc.E3.EQh.2} \cdot Y_{conc.loc} + Q_{Gate.E3.EQh.2} \cdot Y_{gate} + Q_{hwas.E3.EQh.2} \cdot Y_{HWg.E3} \cdots \\ & + Q_{act.E3.EQh.2.OT} \cdot Y_{E.act.E3.OT} + Q_{conc.E3.EQv.2} \cdot X_{conc.loc} + Q_{Gate.E3.EQv.2} \cdot X_{gate} \cdots \\ & + Q_{H1.E3.EQv.2} \cdot H_{1.U2.loc} + Q_{H2.E3.EQv.2} \cdot H_{2.U2.loc}\end{aligned} = -28193.88 \cdot kN \cdot m$$

STABILITY ASSESSMENT (SLIDNG, BEARING, FLOTATION AND OVERTURNING): E3.2 CASE

CHECK SLIDING ALONG HORIZONTAL PLANE THRU TOE,
IGNORING BEDROCK MOBILIZED BY STRUCTURAL HEEL KEY, OR VOID BEHIND KEY

Sum of Vertical Forces:

$\Sigma V_{E3.2} := \Sigma V_{U2} + \Sigma V_{Q.E3.EQv.2} = 13252.0 \cdot kN$

Sum of Horizontal Forces:

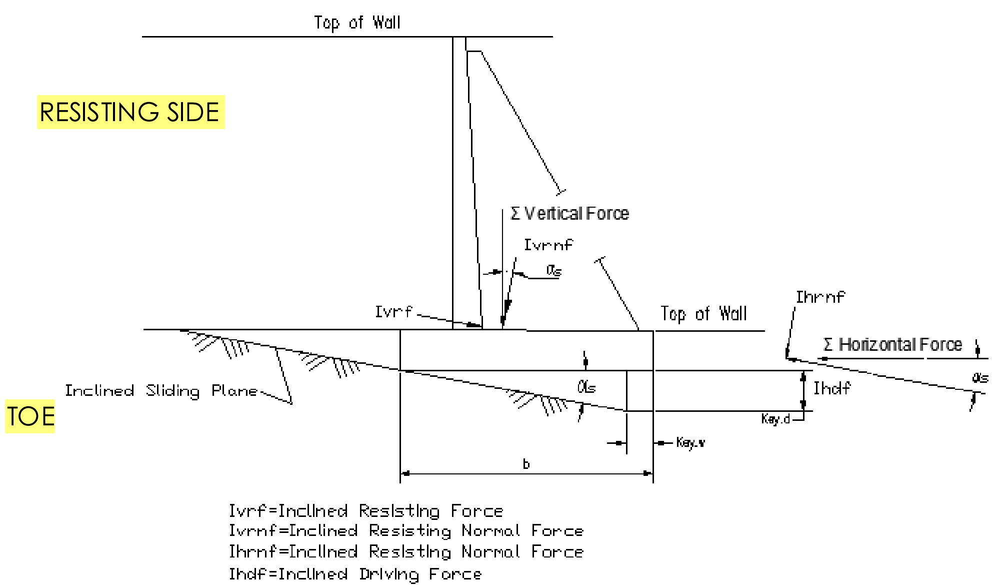
$\Sigma H_{E3.2} := \Sigma H_{U2} - I_{U2} + \Sigma H_{Q.E3.EQh.2} = -11201.52 \cdot kN$

Sliding Factor of Safety: $FS_{HorizSliding.E3.2} := \dfrac{\tan_{\phi} \cdot \Sigma V_{E3.2}}{|\Sigma H_{E3.2}|} = 0.58$

$FS_{HorizSliding.E3.2.Check} :=$ | "OKAY" if $FS_{HorizSliding.E3.2} \ge FS_{req.E3.sl}$
"Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !" otherwise

$FS_{HorizSliding.E3.2.Check} =$ "Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !"

CHECK SLIDING ALONG INCLINED SLIDING PLANE FROM HEEL KEY TO TOE,
WITH BEDROCK MASS MOBILIZED BY REINFOCREDE CONCRETE KEY)



$\alpha s = 0.11$

as degrees= $\alpha s \cdot \left(\dfrac{180}{\pi}\right) = 6.52$

$\Sigma V_{E3.2} = 13252.02 \cdot kN$

$V_{rs} = 5775 \cdot kN$

Resolve $\Sigma Vert_{E3.2}$ & $\Sigma Horiz_{E3.2}$

$\Sigma V_{InclinedE3.2} := \cos(\alpha s) \cdot \left(\Sigma V_{E3.2} + V_{rs}\right) + \sin(\alpha s) \cdot |\Sigma H_{E3.2}| = 20175.9 \cdot kN$

$\Sigma H_{InclinedE3.2} := \cos(\alpha s) \cdot |\Sigma H_{E3.2}| - \sin(\alpha s) \cdot \left(\Sigma V_{E3.2} + V_{rs}\right) = 8968.6 \cdot kN$

(With properly engineered reinforced concrete Key, horizontal sliding plane thru Toe is protected, critical sliding plane is relocated to the INCLINED SLIDING PLANE FROM HEEL KEY To TOE, Bedrock Mass above this examined plane is mobilized by reinforced concrete key and combined into Structural Wedge.)

Inclined Sliding Plane Length $L_{incline} = 18.61\ m$

Safety Factor for Sliding
Inclined Failure Plane

$FS_{InclinedlSlidingE3.2} := \dfrac{\Sigma V_{InclinedE3.2} \cdot \tan\left(\phi_{rock} \cdot \dfrac{\pi}{180}\right)}{|\Sigma H_{InclinedE3.2}|} = 1.10$

$FS_{InclinedSliding.check.E3.2} :=$ | "OKAY " if $FS_{InclinedlSlidingE3.2} > FS_{req.E3.sl}$ = "OKAY "
"Revise Structure"" otherwise

$FS_{InclinedSliding.check.E3.2} =$ "OKAY "

OVERTURNING STABILITY CHECK:

E3.2 CASE

CHECK ECCENTRICITY - OBSOLETE

Sum of the moments:

$$\Sigma M_{E3.2} := \left(\Sigma M_{U2} + \Sigma M_{Q.E3.2}\right) = 158201 \cdot kN \cdot m$$

Eccentricity:

$$e_{E3.2} := \left(\frac{L_{incline}}{2}\right) - \frac{\left(\Sigma M_{E3.2}\right)}{\Sigma V_{InclinedE3.2}} = 1.46\,m$$

Eccentricity Check:

$$e_{check.E3.2} := \begin{cases} \text{"Okay"} & \text{if } e_{E3.2} \le Midhalf \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$e_{check.E3.2} = \text{"Okay"}$

Foundation Bearing Checks:

Bearing Pressure at Heel:

$$\sigma_{heel.E3.2} := \frac{\Sigma V_{InclinedE3.2}}{A_{b.incline}} - \frac{\left(\Sigma V_{InclinedE3.2} \cdot e_{E3.2}\right)}{S_{b.incline}} = 38.2 \cdot \frac{kN}{m^2}$$

$$\sigma_{heel.E3.2.check} := \left(\begin{cases} \text{"Okay"} & \text{if } \sigma_{heel.E3.2} \le \sigma_{allow.E2} \\ \text{"Revise Structure"} & \text{if } \sigma_{heel.E3.2} < 0 \frac{kN}{m^2} \end{cases} \right)$$

$\sigma_{heel.E3.2.check} = \text{"Okay"}$

Bearing Pressure at Toe:

$$\sigma_{toe.E3.2} := \frac{\Sigma V_{InclinedE3.2}}{A_{b.incline}} + \frac{\left(\Sigma V_{InclinedE3.2} \cdot e_{E3.2}\right)}{S_{b.incline}} = 106.4 \cdot \frac{kN}{m^2}$$

$$\sigma_{toe.E3.2.check.1} := \begin{cases} \text{"Okay"} & \text{if } \sigma_{toe.E3.2} \le \sigma_{allow.E2} \\ \text{"Revise Structure"} & \text{if } \sigma_{toe.E3.2} < 0 \frac{kN}{m^2} \end{cases}$$

$\sigma_{toe.E3.2.check.1} = \text{"Okay"}$

FLOATATION ANALYSIS:

ACCEPTANCE PARAMETERS

Required Factor of Safety: $FS_{req.FE3.2} := 1.1$

VERTICAL LOADS RESISTING:

Dead Load: $\Sigma V_{DL} = 24828.6 \cdot kN$

Water Weight H1+H2: $\Sigma V_{H.FE3.2} := \Sigma V_{H.FU2} + \Sigma V_{Q.E3.EQv.2} = 10746.08 \cdot kN$

Summation Vertical Resisting: $\Sigma V_{FE3.2} := \Sigma V_{DL} + \Sigma V_{H.FE3.2} = 35574.7 \cdot kN$

VERTICAL LOADS UPLIFT:

Uplift: $U_{U2} = -22322.65 \cdot kN$

Factor of Safety Floatation:

$$FS_{act.FE3.2} := \frac{\Sigma V_{FE3.2}}{\left|U_{U2}\right|} = 1.59$$

$$FS_{check.FE3.2} := \begin{cases} \text{"OKAY"} & \text{if } FS_{act.FE3.2} \ge FS_{req.FE3.2} \\ \text{"ANCHORS REQUIRED"} & \text{if } FS_{act.FE3.2} < FS_{req.FE3.2} \end{cases} = \text{"OKAY"}$$

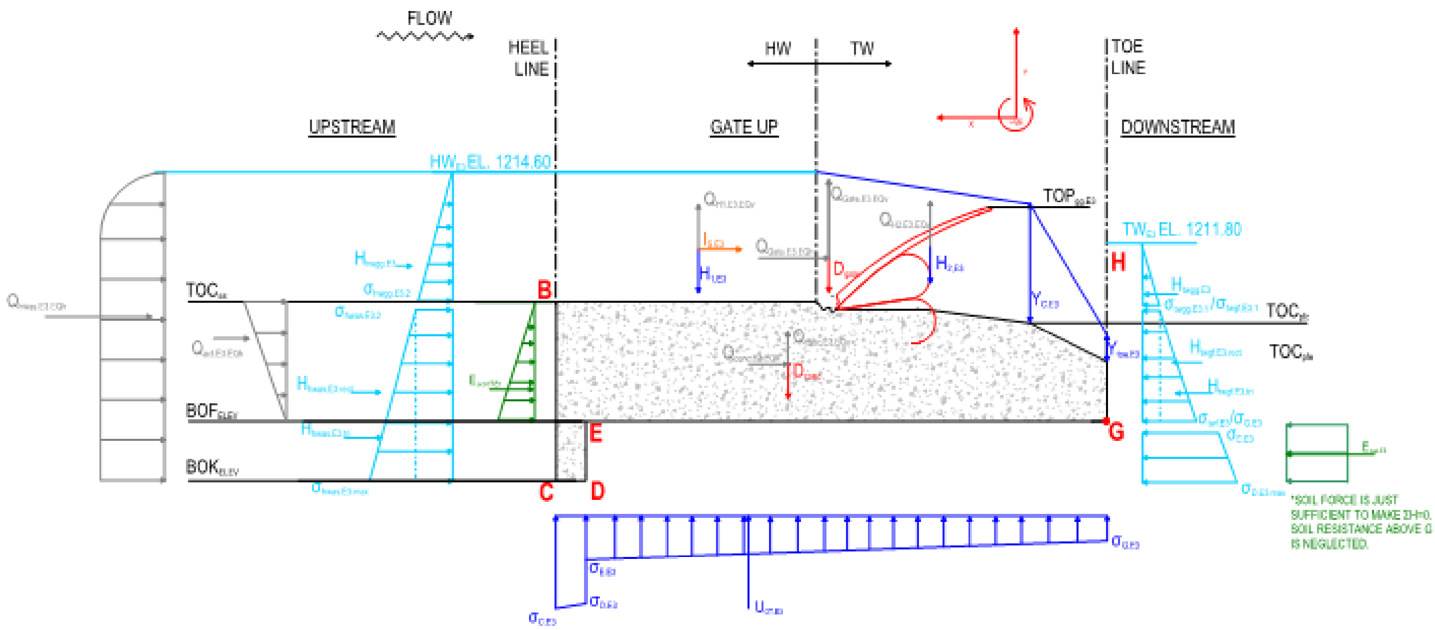
MONOLITH OVERTURNING STABILITY ANALYSIS

E3.2 CASE

Seismic Case $Q_{E3.2}$: 100% Horizontal Seismic Force, 30% Vertical

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.
Assumptions are made in order to compute overturning stability of indetermine forces on monolith with key;
(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.
(b) The horizontal resisting force acting on the key, P.key, is that required for static equilibrium
(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1 $Ratio_{overturning.allow.Extreme} = 0.25$ Resultant within Base



All Vertical Loads Appliable to Overturning Stability Analysis

Total Concrete Dead Loads:	$D_{conc} = 24618.6\cdot kN$	at:	$X_{conc.loc} = 10.06\,m$
Dead Load of Gate:	$D_{Gate} = 210.0\cdot kN$		$X_{gate} = 6.60\,m$
Water Weight (HW) on Apron Slab:	$H_{1.U2} = 5922.8\cdot kN$		$H_{1.U2.loc} = 14.13\,m$
Water Weight (TW) on Gate Footing:	$H_{2.U2} = 5730.2\cdot kN$		$H_{2.U2.loc} = 5.43\,m$
Uplift Load for Overturning Analysis:	$U_{OT.U2} = -19563.05\cdot kN$		$U_{OT.U2.loc} = 9.94\cdot m$
Vertical Seismic Component of Concrete Structure:	$Q_{conc.E3.EQv.2} = -738.56\cdot kN$		$X_{conc.loc} = 10.06\,m$
Vertical Seismic Component of Crest Gate:	$Q_{Gate.E3.EQv.2} = -6.3\cdot kN$		$X_{gate} = 6.60\,m$
Vertical Seismic Component of Headwater over Apron Slab:	$Q_{H1.E3.EQv.2} = -81.12\cdot kN$		$H_{1.U2.loc} = 14.13\,m$
Vertical Seismic Component of Headwater over Fixed Crest Slab:	$Q_{H2.E3.EQv.2} = -80.98\cdot kN$		$H_{2.U2.loc} = 5.43\,m$

Sum of All Overturning Analysis Vertical Load:

$$\Sigma V_{E3.OT.2} := D_{conc} + D_{Gate} + H_{1.U2} + H_{2.U2} + U_{OT.U2} + \Sigma V_{Q.E3.EQv.2} = 16011.63\cdot kN$$

Sum of All Overturning Analysis Vertical Load Moments:

$$\Sigma M_{V.E3.OT.2} := D_{conc}\cdot X_{conc.loc} + D_{Gate}\cdot X_{gate} + H_{1.U2}\cdot H_{1.U2.loc} + H_{2.U2}\cdot H_{2.U2.loc} + U_{OT.U2}\cdot U_{OT.U2.loc} = 169206.88\cdot kN\cdot m$$

Lateral Driving Earth Loads for Overturning Stability Analysis (at rest condition)

E3.2 CASE

Depth of Driving Soil Loads (to top of key): $h_{E.OT.E3.2} := TOC_{as} - BOF_{elev} = 4\,m$

static equilibrium Soil Load: $E_{act.OT.E3.2} := \dfrac{\left(K_{o.U1} \cdot h_{E.OT.U2}{}^{2}\right)}{2} \cdot \left(\gamma_r - \gamma_w\right) \cdot W_{hwas.U2} \cdot -1 = -962.49 \cdot kN$

At Rest- Soil Load Acting from Toe: $E_{act.OT.E3..loc} := \dfrac{h_{E.OT.U2}}{3} = 1.33\,m$

All Lateral Loads Appliable to Overturning Stability Analysis

HW Lateral Load on Approach Slab:	$H_{hwas.U2} = -6710.0 \cdot kN$	$H_{hwas.U2.loc} = 0.61\,m$
HW Lateral Load on Reg. Gate:	$H_{hwrg.U2} = -1097.0 \cdot kN$	$H_{hwrg.U2.loc} = 4.95\,m$
TW Lateral Load on Reg. Gate:	$H_{twrg.U2} = 238.4 \cdot kN$	$H_{twrg.U2.loc} = 4.60\,m$
TW Lateral Load on Gate Footing (No Key - Overturning Values Adjusted):	$H_{twgf.U2} = 2236.68 \cdot kN$	$H_{twgf.U2.loc} = 1.65\,m$
TW Lateral Load on Key:	$H_{twkey.OT.U2} = 2744.89 \cdot kN$	$H_{twkey.OT.U2.loc} = -1.04\,m$
Ice / Impact Load:	$I_{U2} = -1125.0 \cdot kN$	$I_{U2.loc} = 5.80\,m$
Lateral Soil Load (driving):	$E_{act.OT.U2} = -962.5 \cdot kN$	$E_{act.OT.U1.loc} = 1.33\,m$
Horizontal Seismic Component of Concrete Structure:	$Q_{conc.E3.EQh.2} = -4185.16 \cdot kN$	$Y_{conc.loc} = 1.87\,m$
Horizontal Seismic Component of Vertical Lift Gate:	$Q_{Gate.E3.EQh.2} = -35.7 \cdot kN$	$Y_{gate} = 3.90\,m$
Horizontal Seismic Component of Headwater on Gate:	$Q_{hwas.E3.EQh.2} = -1639.6 \cdot kN$	$Y_{HWg.E3} = 4.24\,m$
Horizontal Seismic Component of Active Soil: (Section 5-5, USACE EM_1110-2-2100)	$Q_{act.E3.EQh.2} = -497.35 \cdot kN$	$Y_{E.act.E3} = 2.52\,m$

Resisting Lateral Soil Load as required to produce horizontal equilibrium:

$$E_{pas.OT.E3.2} := -\left(H_{hwas.U2} + H_{hwrg.U2} + H_{twrg.U2} + H_{twgf.U2} + H_{twkey.OT.U2} + I_{U2} + E_{act.OT.U2} + \Sigma H_{Q.E3.EQh.2.OT}\right) = 11654.09 \cdot kN$$

Acting at: $E_{pas.OT.E3.2.loc} := -1 \cdot \dfrac{d_{key}}{2} = -1\,m$

Sum of All Overturning Analysis Horizontal Load (ΣH=0):

$$\Sigma H_{E3.OT.2} := H_{hwas.U2} + H_{hwrg.U2} + H_{twrg.U2} + H_{twgf.U2} + H_{twkey.OT.U2} + I_{U2} + E_{act.OT.U2} + E_{pas.OT.E3.2} + \Sigma H_{Q.E3.EQh.2.OT} = 0 \cdot kN$$

Sum of All Overturning Analysis Horizontal Load Moments:

$$\begin{aligned}\Sigma M_{H.E3.OT.2} := {} & H_{hwas.U2} \cdot H_{hwas.U2.loc} + H_{hwrg.U2} \cdot H_{hwrg.U2.loc} + H_{twrg.U2} \cdot H_{twrg.U2.loc} \cdots = -48235.7 \cdot kN \cdot m \\ & + H_{twgf.U2} \cdot H_{twgf.U2.loc} + H_{twkey.OT.U2} \cdot H_{twkey.OT.U2.loc} + I_{U2} \cdot I_{U2.loc} \cdots \\ & + E_{act.OT.U2} \cdot E_{act.OT.U2.loc} + E_{pas.OT.U2} \cdot E_{pas.OT.U2.loc} + \Sigma M_{Q.E3.2}\end{aligned}$$

Overturning Stability Analysis

$$\Sigma M_{E3.OT.2} := \Sigma M_{V.E3.OT.2} + \Sigma M_{H.E3.OT.2} = 120971.18 \cdot kN \cdot m$$

$X_{R.E3.2} := \dfrac{\Sigma M_{E3.OT.2}}{\Sigma V_{E3.OT.2}} = 7.56\,m$ $\qquad x_{OT.E3.2} := X_{R.E3.2} - \dfrac{L_b}{2} = -1.69\,m$

Overturning Resultant Ratio

$Ratio_{OT.E3.2} := \dfrac{X_{R.E3.2}}{L_b} = 0.41$

$Ratio_{OT.E3.2.check} := \begin{array}{|l} \text{"OKAY"} \ \ \text{if} \ \ Ratio_{OT.E3.2} \geq Ratio_{overturning.allow.Extreme} \\ \text{"Revise Structure"} \ \ \text{otherwise} \end{array} = \text{"OKAY"}$

$x_{OT.check.E3.2} := \begin{array}{|l} \text{"OKAY"} \ \ \text{if} \ \ \left|x_{OT.E3.2}\right| \leq Kern \\ \text{"Revise Structure"} \ \ \text{otherwise} \end{array} = \text{"OKAY"}$

Seismic Case $Q_{E3.3}$ - 30% Horizontal Seismic Force, 100% Vertical **E3.3 CASE**

Include Seismic Load in Analysis? $Eq_{E3.3} := 1$ 0 = No, 1 = Yes

Horizontal Seismic Coefficient: $K_{h.E3.3} := -0.05$

Vertical Seismic Coefficient: $K_{v.E3.3} := -0.10$

HORIZONTAL SEISMIC LOADS	Loads	Moment Arm
Horiz Seismic Component of Concrete:	$Q_{conc.E3.EQh.3} := D_{conc} \cdot K_{h.E3.3} \cdot Eq_{E3.3} = -1230.9 \cdot kN$	$Y_{conc.loc} = 1.87\,m$
Horiz Seismic Component of Gate:	$Q_{Gate.E3.EQh.3} := D_{Gate} \cdot K_{h.E3.3} \cdot Eq_{E3.3} = -10.5 \cdot kN$	$Y_{gate} = 3.90\,m$
Horiz Seismic Component of Headwater:	$Q_{hwas.E3.EQh.3} := \left(\frac{7}{12}\right) \cdot K_{h.E3.3} \cdot \gamma_w \cdot \left(HW_{U2} - BOK_{elev}\right)^2 \cdot W_{hwas.U2} \cdot Eq_{E3.3} = -482.2 \cdot kN$	$Y_{HWg.E3} = 4.24\,m$
Horizontal Seismic Component of Soil (Woods Method) - Overturning:	$Q_{act.E3.EQh.3.OT} := \left(\gamma_r - \gamma_w\right) \cdot \left(TOC_{as} - BOK_{elev}\right)^2 \cdot K_{h.E3.3} \cdot W_{hwas.U2} \cdot Eq_{E3.3} = -329.1 \cdot kN$	$Y_{E.act.E3.OT} = 3.78\,m$
Horizontal Seismic Component of Soil (Woods Method):	$Q_{act.E3.EQh.3} := \left(\gamma_r - \gamma_w\right) \cdot \left(TOC_{as} - BOF_{elev}\right)^2 \cdot K_{h.E3.3} \cdot W_{hwas.U2} \cdot Eq_{E3.3} = -146.3 \cdot kN$	$Y_{E.act.E3} = 2.52\,m$

VERTICAL SEISMIC LOADS	Loads	Moment Arm
Vertical Component of Concrete:	$Q_{conc.E3.EQv.3} := D_{conc} \cdot K_{v.E3.3} \cdot Eq_{E3.3} = -2461.9 \cdot kN$	$X_{conc.loc} = 10.06\,m$
Vertical Component of Gate:	$Q_{Gate.E3.EQv.3} := D_{Gate} \cdot K_{v.E3.3} \cdot Eq_{E3.3} = -21.0 \cdot kN$	$X_{gate} = 6.60\,m$
Vertical Seismic Component of Headwater over Apron Slab: (Section 7.9, Design Criteria)	$Q_{H1.E3.EQv.3} := K_{v.E3.3} \cdot H_{1.U2} \cdot Eq_{E3.3} = -592.3 \cdot kN$	$H_{1.U2.loc} = 14.13\,m$
Vertical Seismic Component of Headwater over Fixed Crest Slab: (Section 7.9, Design Criteria)	$Q_{H2.E3.EQv.3} := K_{v.E3.3} \cdot H_{2.U2} \cdot Eq_{E3.3} = -573.0 \cdot kN$	$H_{2.U2.loc} = 5.43\,m$

$$\Sigma H_{Q.E3.EQh.3} := Q_{conc.E3.EQh.3} + Q_{Gate.E3.EQh.3} + Q_{hwas.E3.EQh.3} + Q_{act.E3.EQh.3} = -1869.95 \cdot kN$$

$$\Sigma H_{Q.E3.EQh.3.OT} := Q_{conc.E3.EQh.3} + Q_{Gate.E3.EQh.3} + Q_{hwas.E3.EQh.3} + Q_{act.E3.EQh.3.OT} = -2052.8 \cdot kN$$

$$\Sigma V_{Q.E3.EQv.3} := Q_{conc.E3.EQv.3} + Q_{Gate.E3.EQv.3} + Q_{H1.E3.EQv.3} + Q_{H2.E3.EQv.3} = -3648.2 \cdot kN$$

$$\begin{aligned}\Sigma M_{Q.E3.3} := {} & Q_{conc.E3.EQh.3} \cdot Y_{conc.loc} + Q_{Gate.E3.EQh.3} \cdot Y_{gate} + Q_{hwas.E3.EQh.3} \cdot Y_{HWg.E3} \cdots \\ & + Q_{act.E3.EQh.3.OT} \cdot Y_{E.act.E3.OT} + Q_{conc.E3.EQv.3} \cdot X_{conc.loc} + Q_{Gate.E3.EQv.3} \cdot X_{gate} \cdots \\ & + Q_{H1.E3.EQv.3} \cdot H_{1.U2.loc} + Q_{H2.E3.EQv.3} \cdot H_{2.U2.loc}\end{aligned} = -41999.2 \cdot kN \cdot m$$

STABILITY ASSESSMENT (SLIDNG, BEARING, FLOTATION AND OVERTURNING): E3.3 CASE

CHECK SLIDING ALONG HORIZONTAL PLANE THRU TOE,
IGNORING BEDROCK MOBILIZED BY STRUCTURAL HEEL KEY, OR VOID BEHIND KEY

Sum of Vertical Forces:

$\Sigma V_{E3.3} := \Sigma V_{U2} + \Sigma V_{Q.E3.EQv.3} = 10510.8 \cdot kN$

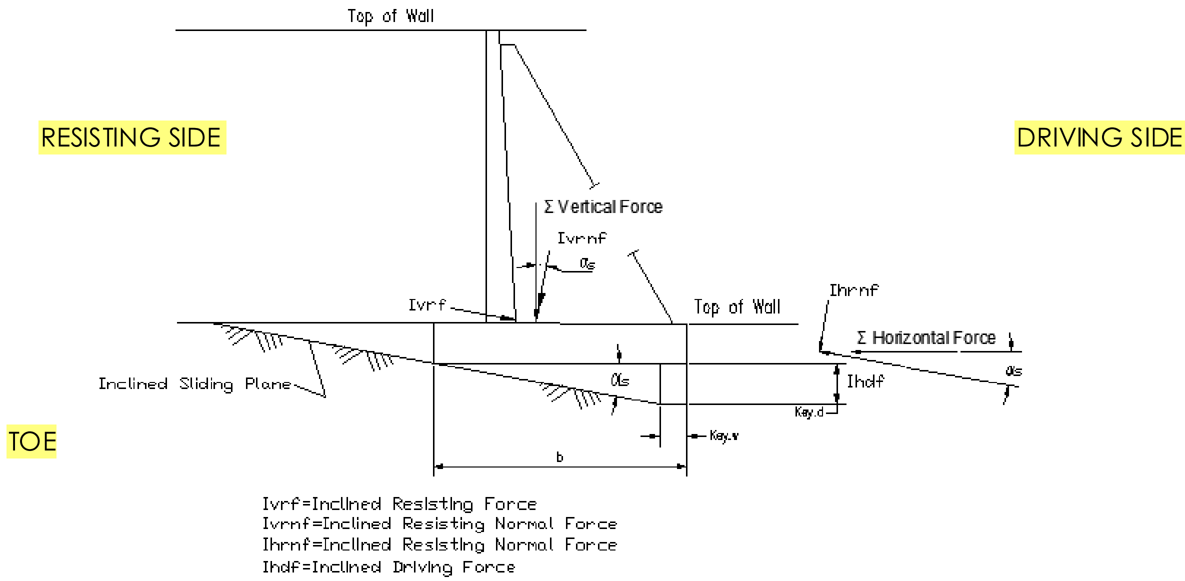
Sum of Horizontal Forces:

$\Sigma H_{E3.3} := \Sigma H_{U2} - I_{U2} + \Sigma H_{Q.E3.EQh.3} = -6713.65 \cdot kN$

Sliding Factor of Safety: $FS_{HorizSliding.E3.3} := \dfrac{\tan_{\phi} \cdot \Sigma V_{E3.3}}{|\Sigma H_{E3.3}|} = 0.76$

$FS_{HorizSliding.E3.3.Check} :=$ | "OKAY" if $FS_{HorizSliding.E3.3} \geq FS_{req.E3.sl}$; "Check Inclined Sliding Plane." otherwise = "Check Inclined Sliding Plane."

CHECK SLIDING ALONG INCLINED SLIDING PLANE FROM HEEL KEY TO TOE,
WITH BEDROCK MASS MOBILIZED BY REINFOCREDE CONCRETE KEY)



$\alpha s = 0.11$

as degrees= $\alpha s \cdot \left(\dfrac{180}{\pi}\right) = 6.52$

$\Sigma V_{E3.3} = 10510.81 \cdot kN$

$V_{rs} = 5775 \cdot kN$

Resolve $\Sigma Vert_{E3.3}$ & $\Sigma Horiz_{E3.3}$

$\Sigma V_{InclinedE3.3} := \cos(\alpha s) \cdot \left(\Sigma V_{E3.3} + V_{rs}\right) + \sin(\alpha s) \cdot |\Sigma H_{E3.3}| = 16942.8 \cdot kN$

$\Sigma H_{InclinedE3.3} := \cos(\alpha s) \cdot |\Sigma H_{E3.3}| - \sin(\alpha s) \cdot \left(\Sigma V_{E3.3} + V_{rs}\right) = 4821.0 \cdot kN$

(With properly engineered reinforced concrete Key, horizontal sliding plane thru Toe is protected, critical sliding plane is relocated to the INCLINED SLIDING PLANE FROM HEEL KEY To TOE, Bedrock Mass above this examined plane is mobilized by reinforced concrete key and combined into Structural Wedge.)

Inclined Sliding Plane Length $L_{incline} = 18.61 \ m$

Safety Factor for Sliding Inclined Failure Plane

$FS_{InclinedlSlidingE3.3} := \dfrac{\Sigma V_{InclinedE3.3} \cdot \tan\left(\phi_{rock} \cdot \dfrac{\pi}{180}\right)}{|\Sigma H_{InclinedE3.3}|} = 1.71$

$FS_{InclinedSliding.check.E3.3} :=$ | "OKAY " if $FS_{InclinedlSlidingE3.3} > FS_{req.E3.sl}$; "Revise Structure"" otherwise = "OKAY "

$FS_{InclinedSliding.check.E3.3} =$ "OKAY "

OVERTURNING STABILITY CHECK:

E3.3 CASE

CHECK ECCENTRICITY

Sum of the moments:

$$\Sigma M_{E3.3} := \left(\Sigma M_{U2} + \Sigma M_{Q.E3.3}\right) = 144396 \cdot kN \cdot m$$

Eccentricity:

$$e_{E3.3} := \left(\frac{L_{incline}}{2}\right) - \frac{\left(\Sigma M_{E3.3}\right)}{\Sigma V_{InclinedE3.3}} = 0.78\,m$$

Eccentricity Check:

$$e_{check.E3.3} := \begin{cases} \text{"Okay"} & \text{if } e_{E3.3} \le Midhalf \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$$e_{check.E3.3} = \text{"Okay"}$$

Foundation Bearing Checks:

Bearing Pressure at Heel:

$$\sigma_{heel.E3.3} := \frac{\Sigma V_{InclinedE3.3}}{A_{b.incline}} - \frac{\left(\Sigma V_{InclinedE3.3} \cdot e_{E3.3}\right)}{S_{b.incline}} = 45.4 \cdot \frac{kN}{m^2}$$

$$\sigma_{heel.E3.3.check} := \left(\begin{cases} \text{"Okay"} & \text{if } \sigma_{heel.E3.3} \le \sigma_{allow.E2} \\ \text{"Revise Structure"} & \text{if } \sigma_{heel.E3.3} < 0 \frac{kN}{m^2} \end{cases} \right)$$

$$\sigma_{heel.E3.3.check} = \text{"Okay"}$$

Bearing Pressure at Toe:

$$\sigma_{toe.E3.3} := \frac{\Sigma V_{InclinedE3.3}}{A_{b.incline}} + \frac{\left(\Sigma V_{InclinedE3.3} \cdot e_{E3.3}\right)}{S_{b.incline}} = 76.0 \cdot \frac{kN}{m^2}$$

$$\sigma_{toe.E3.3.check.1} := \begin{cases} \text{"Okay"} & \text{if } \sigma_{toe.E3.3} \le \sigma_{allow.E2} \\ \text{"Revise Structure"} & \text{if } \sigma_{toe.E3.3} < 0 \frac{kN}{m^2} \end{cases}$$

$$\sigma_{toe.E3.3.check.1} = \text{"Okay"}$$

FLOATATION ANALYSIS:

ACCEPTANCE PARAMETERS

Required Factor of Safety: $FS_{req.FE3.3} := 1.1$

VERTICAL LOADS RESISTING:

Dead Load: $\Sigma V_{DL} = 24828.6 \cdot kN$

Water Weight H1+H2: $\Sigma V_{H.FE3.3} := \Sigma V_{H.FU2} + \Sigma V_{Q.E3.EQv.3} = 8004.87 \cdot kN$

Summation Vertical Resisting: $\Sigma V_{FE3.3} := \Sigma V_{DL} + \Sigma V_{H.FE3.3} = 32833.5 \cdot kN$

VERTICAL LOADS UPLIFT:

Uplift: $U_{U2} = -22322.65 \cdot kN$

Factor of Safety Floatation:

$$FS_{act.FE3.3} := \frac{\Sigma V_{FE3.3}}{\left|U_{U2}\right|} = 1.47$$

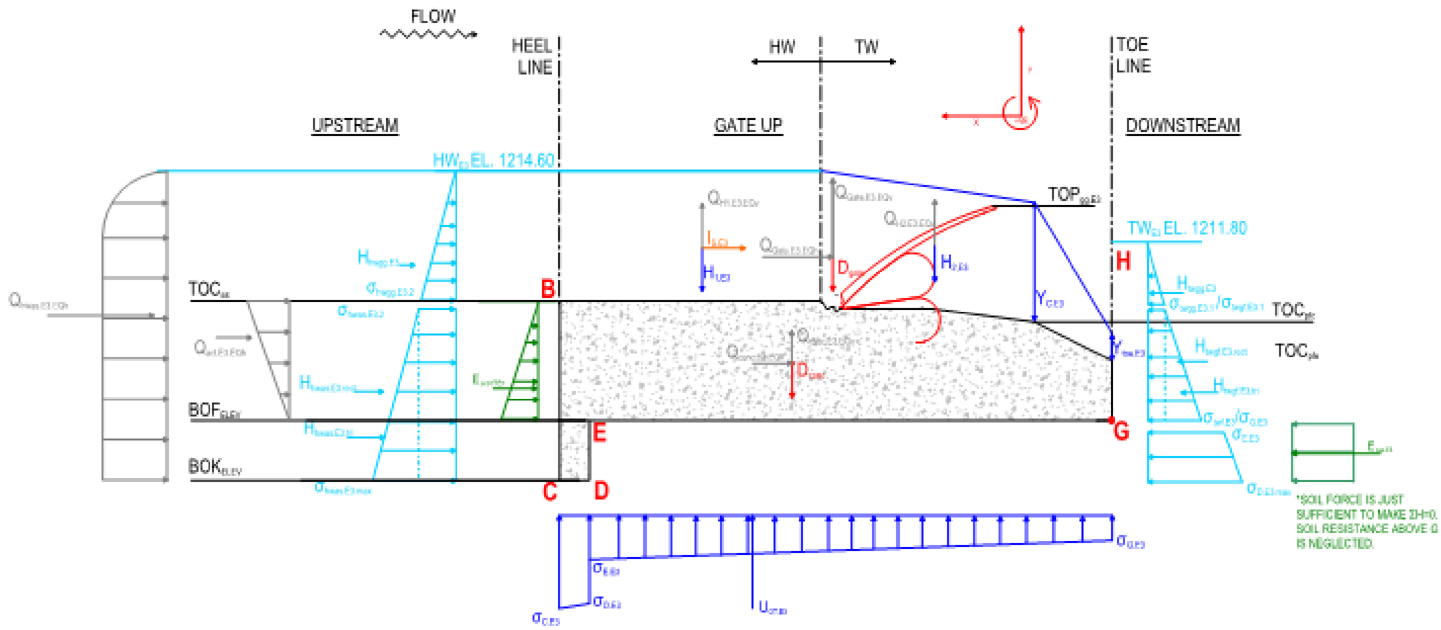
$$FS_{check.FE3.3} := \begin{cases} \text{"OKAY"} & \text{if } FS_{act.FE3.3} \ge FS_{req.FE3.3} \\ \text{"ANCHORS REQUIRED"} & \text{if } FS_{act.FE3.3} < FS_{req.FE3.3} \end{cases} = \text{"OKAY"}$$

MONOLITH OVERTURNING STABILITY ANALYSIS

Seismic Case $Q_{E3.2}$: 100% Horizontal Seismic Force, 30% Vertical

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.
Assumptions are made in order to compute overturning stability of indetermine forces on monolith with key;
(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.
(b) The horizontal resisting force acting on the key, P.key, is that required for static equilibrium
(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1 $Ratio_{overturning.allow.Extreme} = 0.25$ Resultant within Base



All Vertical Loads Applicable to Overturning Stability Analysis

Total Concrete Dead Loads:	$D_{conc} = 24618.6 \cdot kN$	at:	$X_{conc.loc} = 10.06\,m$
Dead Load of Gate:	$D_{Gate} = 210.0 \cdot kN$		$X_{gate} = 6.60\,m$
Water Weight (HW) on Apron Slab:	$H_{1.U2} = 5922.8 \cdot kN$		$H_{1.U2.loc} = 14.13\,m$
Water Weight (TW) on Gate Footing:	$H_{2.U2} = 5730.2 \cdot kN$		$H_{2.U2.loc} = 5.43\,m$
Uplift Load for Overturning Analysis:	$U_{OT.U2} = -19563.05 \cdot kN$		$U_{OT.U2.loc} = 9.94 \cdot m$
Vertical Seismic Component of Concrete Structure:	$Q_{conc.E3.EQv.3} = -2461.86 \cdot kN$		$X_{conc.loc} = 10.06\,m$
Vertical Seismic Component of Crest Gate:	$Q_{Gate.E3.EQv.3} = -21 \cdot kN$		$X_{gate} = 6.60\,m$
Vertical Seismic Component of Headwater over Apron Slab:	$Q_{H1.E3.EQv.3} = -592.28 \cdot kN$		$H_{1.U2.loc} = 14.13\,m$
Vertical Seismic Component of Headwater over Fixed Crest Slab:	$Q_{H2.E3.EQv.3} = -573.02 \cdot kN$		$H_{2.U2.loc} = 5.43\,m$

Sum of All Overturning Analysis Vertical Load:

$$\Sigma V_{E3.OT.3} := D_{conc} + D_{Gate} + H_{1.U2} + H_{2.U2} + U_{OT.U2} + \Sigma V_{Q.E3.EQv.2} = 16011.63 \cdot kN$$

Sum of All Overturning Analysis Vertical Load Moments:

$$\Sigma M_{V.E3.OT.3} := D_{conc} \cdot X_{conc.loc} + D_{Gate} \cdot X_{gate} + H_{1.U2} \cdot H_{1.U2.loc} + H_{2.U2} \cdot H_{2.U2.loc} + U_{OT.U2} \cdot U_{OT.U2.loc} = 169206.88 \cdot kN \cdot m$$

Lateral Driving Earth Loads for Overturning Stability Analysis (at rest condition)

E3.3 CASE

Depth of Driving Soil Loads (to top of key): $h_{E.OT.E3.3} := TOC_{as} - BOF_{elev} = 4\,m$

Applicable Soil Load: $E_{act.OT.E3.3} := \frac{\left(K_{o.U1} \cdot h_{E.OT.U2}{}^{2}\right)}{2} \cdot \left(\gamma_r - \gamma_w\right) \cdot W_{hwas.U2} \cdot -1 = -962.49 \cdot kN$

At Rest- Soil Load Acting from Toe: $E_{act.OT.E3..loc} = 1.33\,m$

All Lateral Loads Applicable to Overturning Stability Analysis

HW Lateral Load on Approach Slab:	$H_{hwas.U2} = -6710.0 \cdot kN$	$H_{hwas.U2.loc} = 0.61\,m$
HW Lateral Load on Reg. Gate:	$H_{hwrg.U2} = -1097.0 \cdot kN$	$H_{hwrg.U2.loc} = 4.95\,m$
TW Lateral Load on Reg. Gate:	$H_{twrg.U2} = 238.4 \cdot kN$	$H_{twrg.U2.loc} = 4.60\,m$
TW Lateral Load on Gate Footing (No Key - Overturning Values Adjusted):	$H_{twgf.U2} = 2236.68 \cdot kN$	$H_{twgf.U2.loc} = 1.65\,m$
TW Lateral Load on Key:	$H_{twkey.OT.U2} = 2744.89 \cdot kN$	$H_{twkey.OT.U2.loc} = -1.04\,m$
Ice / Impact Load:	$I_{U2} = -1125.0 \cdot kN$	$I_{U2.loc} = 5.80\,m$
Lateral Soil Load (driving):	$E_{act.OT.U2} = -962.5 \cdot kN$	$E_{act.OT.U1.loc} = 1.33\,m$
Horizontal Seismic Component of Concrete Structure:	$Q_{conc.E3.EQh.3} = -1230.93 \cdot kN$	$Y_{conc.loc} = 1.87\,m$
Horizontal Seismic Component of Vertical Lift Gate:	$Q_{Gate.E3.EQh.3} = -10.5 \cdot kN$	$Y_{gate} = 3.90\,m$
Horizontal Seismic Component of Headwater on Gate:	$Q_{hwas.E3.EQh.3} = -482.24 \cdot kN$	$Y_{HWg.E3} = 4.24\,m$
Horizontal Seismic Component of Active Soil: (Section 5-5, USACE EM_1110-2-2100)	$Q_{act.E3.EQh.3} = -146.28 \cdot kN$	$Y_{E.act.E3} = 2.52\,m$

Resisting Lateral Soil Load as required to produce horizontal equilibrium:

$$E_{pas.OT.E3.3} := -\left(H_{hwas.U2} + H_{hwrg.U2} + H_{twrg.U2} + H_{twgf.U2} + H_{twkey.OT.U2} + I_{U2} + E_{act.OT.U2} + \Sigma H_{Q.E3.EQh.3.OT}\right) = 6727.38 \cdot kN$$

Acting at: $E_{pas.OT.E3.3.loc} := -1 \cdot \frac{d_{key}}{2} = -1\,m$

Sum of All Overturning Analysis Horizontal Load (ΣH=0):

$$\Sigma H_{E3.OT.3} := H_{hwas.U2} + H_{hwrg.U2} + H_{twrg.U2} + H_{twgf.U2} + H_{twkey.OT.U2} + I_{U2} + E_{act.OT.U2} + E_{pas.OT.E3.3} + \Sigma H_{Q.E3.EQh.3.OT} = 0 \cdot kN$$

Sum of All Overturning Analysis Horizontal Load Moments:

$$\Sigma M_{H.E3.OT.3} := H_{hwas.U2} \cdot H_{hwas.U2.loc} + H_{hwrg.U2} \cdot H_{hwrg.U2.loc} + H_{twrg.U2} \cdot H_{twrg.U2.loc} \cdots + H_{twgf.U2} \cdot H_{twgf.U2.loc} + H_{twkey.OT.U2} \cdot H_{twkey.OT.U2.loc} + I_{U2} \cdot I_{U2.loc} \cdots + E_{act.OT.U2} \cdot E_{act.OT.U2.loc} + E_{pas.OT.U2} \cdot E_{pas.OT.U2.loc} + \Sigma M_{Q.E3.3} = -62041.02 \cdot kN \cdot m$$

Overturning Stability Analysis

$$\Sigma M_{E3.OT.3} := \Sigma M_{V.E3.OT.3} + \Sigma M_{H.E3.OT.3} = 107165.86 \cdot kN \cdot m$$

$X_{R.E3.3} := \frac{\Sigma M_{E3.OT.3}}{\Sigma V_{E3.OT.3}} = 6.69\,m$ $\qquad x_{OT.E3.3} := X_{R.E3.3} - \frac{L_b}{2} = -2.56\,m$

Overturning Resultant Ratio $\quad Ratio_{OT.E3.3} := \frac{X_{R.E3.2}}{L_b} = 0.41$

$$Ratio_{OT.E3.3.check} := \begin{cases} \text{"OKAY"} & \text{if } Ratio_{OT.E3.3} \geq Ratio_{overturning.allow.Extreme} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

$$x_{OT.check.E3.3} := \begin{cases} \text{"OKAY"} & \text{if } \left|x_{OT.E3.3}\right| \leq Kern \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

Summary of Results

E3 CASE

E3.1 Case

Sliding Factor of Safety: (Horizontal Plane)	$FS_{HorizSliding.E3.1} = 0.62$	
	$FS_{HorizSliding.E3.1.Check} =$ "Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !"	
Sliding Factor of Safety: (Inclined Plane)	$FS_{InclinedISlidingE3.1} = 1.16$	$FS_{InclinedSliding.check.E3.1} =$ "OKAY "
Eccentricity: (Inclined Plane)	$e_{E3.1} = 1.37\,m$	$e_{check.E3.1} =$ "Okay"
Bearing Pressure At Heel: (Inclined Plane)	$\sigma_{heel.E3.1} = 42\cdot kPa$	$\sigma_{heel.E3.1.check} =$ "Okay"
Bearing Pressure At Toe: (Inclined Plane)	$\sigma_{toe.E3.1} = 109\cdot kPa$	$\sigma_{toe.E3.1.check.1} =$ "Okay"
Flotation Factor of Safety (horizontal plane)	$FS_{act.FE3.1} = 1.63$	$FS_{check.FE3.1} =$ "OKAY"
Overturning Resultant Ratio: (horizontal plane)	$Ratio_{OT.E3.1} = 0.49$	$Ratio_{OT.E3.1.check} =$ "OKAY"
Eccentricity: (horizontal plane)	$x_{OT.E3.1} = -0.14\,m$	$x_{OT.check.E3.1} =$ "OKAY"

E3.2 Case

Sliding Factor of Safety: (Horizontal Plane)	$FS_{HorizSliding.E3.2} = 0.58$	
	$FS_{HorizSliding.E3.2.Check} =$ "Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !"	
Sliding Factor of Safety: (Inclined Plane)	$FS_{InclinedISlidingE3.2} = 1.1$	$FS_{InclinedSliding.check.E3.2} =$ "OKAY "
Eccentricity: (Inclined Plane)	$e_{E3.2} = 1.46\,m$	$e_{check.E3.2} =$ "Okay"
Bearing Pressure At Heel: (Inclined Plane)	$\sigma_{heel.E3.2} = 38\cdot kPa$	$\sigma_{heel.E3.2.check} =$ "Okay"
Bearing Pressure At Toe: (Inclined Plane)	$\sigma_{toe.E3.2} = 106\cdot kPa$	$\sigma_{toe.E3.2.check.1} =$ "Okay"
Flotation Factor of Safety (horizontal plane)	$FS_{act.FE3.2} = 1.59$	$FS_{check.FE3.2} =$ "OKAY"
Overturning Resultant Ratio: (horizontal plane)	$Ratio_{OT.E3.2} = 0.41$	$Ratio_{OT.E3.2.check} =$ "OKAY"
Eccentricity: (horizontal plane)	$x_{OT.E3.2} = -1.69\,m$	$x_{OT.check.E3.2} =$ "OKAY"

E3.3 Case

Sliding Factor of Safety: (Horizontal Plane)	$FS_{HorizSliding.E3.3} = 0.76$ $FS_{HorizSliding.E3.3.Check} =$ "Check Inclined Sliding Plane."	
Sliding Factor of Safety: (Inclined Plane)	$FS_{InclinedlSlidingE3.3} = 1.71$	$FS_{InclinedSliding.check.E3.3} =$ "OKAY "
Eccentricity: (Inclined Plane)	$e_{E3.3} = 0.78\,m$	$e_{check.E3.3} =$ "Okay"
Bearing Pressure At Heel: (Inclined Plane)	$\sigma_{heel.E3.3} = 45 \cdot kPa$	$\sigma_{heel.E3.3.check} =$ "Okay"
Bearing Pressure At Toe: (Inclined Plane)	$\sigma_{toe.E3.3} = 76 \cdot kPa$	$\sigma_{toe.E3.3.check.1} =$ "Okay"
Flotation Factor of Safety (horizontal plane)	$FS_{act.FE3.3} = 1.47$	$FS_{check.FE3.3} =$ "OKAY"
Overturning Resultant Ratio: (horizontal plane)	$Ratio_{OT.E3.3} = 0.41$	$Ratio_{OT.E3.3.check} =$ "OKAY"
Eccentricity: (horizontal plane)	$x_{OT.E3.3} = -2.56\,m$	$x_{OT.check.E3.3} =$ "OKAY"

Appendix E.2-2 STILLING BASIN

Calculation Section I

Results Summary Table (overview)

Table E.2-2.1 – Service Spillway – Stilling Basin

Load Case	Headwater/ Tailwater Elevation (m)	Vertical Force Down (kN)	Uplift Force (kN)	Floatation Safety Factor (FSF)		Anchor Force Required (kPa)
				Required	Calculated	
F1 Usual Normal Operation	1212.1 / 1211.8	22123.0	15123.5	1.50	1.46	2.1
F2 Unusual 2013 Flood	1215.8 / 1213.1	25470.6	19973.3	1.30	1.28	1.9
F3 Unusual Const./Dewatered	1214.6/ 1211.8	12337.5	14535.7	1.30	0.83	27.0
F4 Extreme Ineffective Drain	1215.8 / 1211.9	22380.5	17634.2	1.10	1.27	0.0

Notes:
1. See Appendix E.2 for definition of monolith description, analysis methodology, and stability calculations.
2. Analysis assumes inclined sliding plane, interface friction angle Φ = 26 degrees, and no cohesion.
3. Reported seismic results are controlling values for the three combinations of vertical and horizontal seismic load considered.

Calculation Section II

Results Summary Table (detailed)

SERVICE SPILLWAY STILLING BASIN FLOATATION SUMMARY (2B & 4B)					
Load Combo	Σ Vertical Forces (Down) (kN)	Σ Uplift Forces (kN)	FSF Floatation Required	FSF Floatation Actual	Required Anchor Force (kN/m2)
F1	22123.0	15123.5	1.50	1.46	2.1
F2	25470.6	19973.3	1.30	1.28	1.9
F3	12337.5	14535.7	1.30	0.83	27.0
F4	22380.5	17634.2	1.10	1.27	0.0

Calculation Section III

SS-2B/4B Stilling Basin Floatation Calculations

Project Number: 110773396

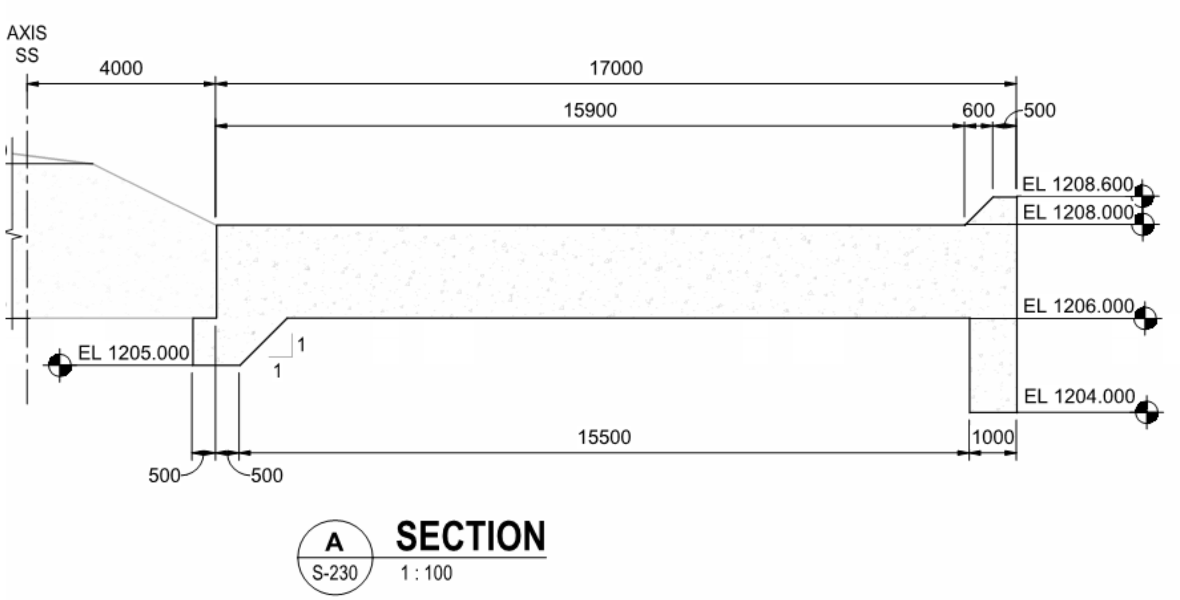
Project Title: SR1 Project

Client: Alberta Transportation

Engineer: D. CHEUK Date: 01/28/2018

Checker: Sean Xiao Date: 11/13/2018

Calculation for: Service Spillway Monolith-2B Stilling Basin Floatation Check



BASE SECTION PROPERTIES

Gate Structure Base Width: $L_b := 18.50m$

Base Length: $L_{sb} := 17.50m$ $\quad$ $Kern := \frac{L_{sb}}{6} = 2.92\,m$

Base Width: $W_{sb} := 15.00m$

Area of Base: $A_{sb} := L_{sb} \cdot W_{sb} = 262.5\,m^2$

Section Modulus of Base: $S_{sb} := \frac{\left(W_{sb} \cdot L_{sb}^2\right)}{6} = 765.6\,m^3$

Top of Concrete Elevation: $TOC := 1208.00m$

Bottom of Concrete Elevation: $BOF_{elev} := 1206.00m$

FOOTINGS

Stilling Basin Footing Thickness: $h_{sb} := 2.00m$

Stilling Basin Footing Width: $W_{sb} = 15.00\,m$

Stilling Basin Footing Length: $L_{sb} = 17.50\,m$

Total Apron Slab Footing Volume: $V_{sb} := h_{sb} \cdot W_{sb} \cdot L_{sb} = 525.0 \cdot m^3$

MATERIAL PROPERTIES

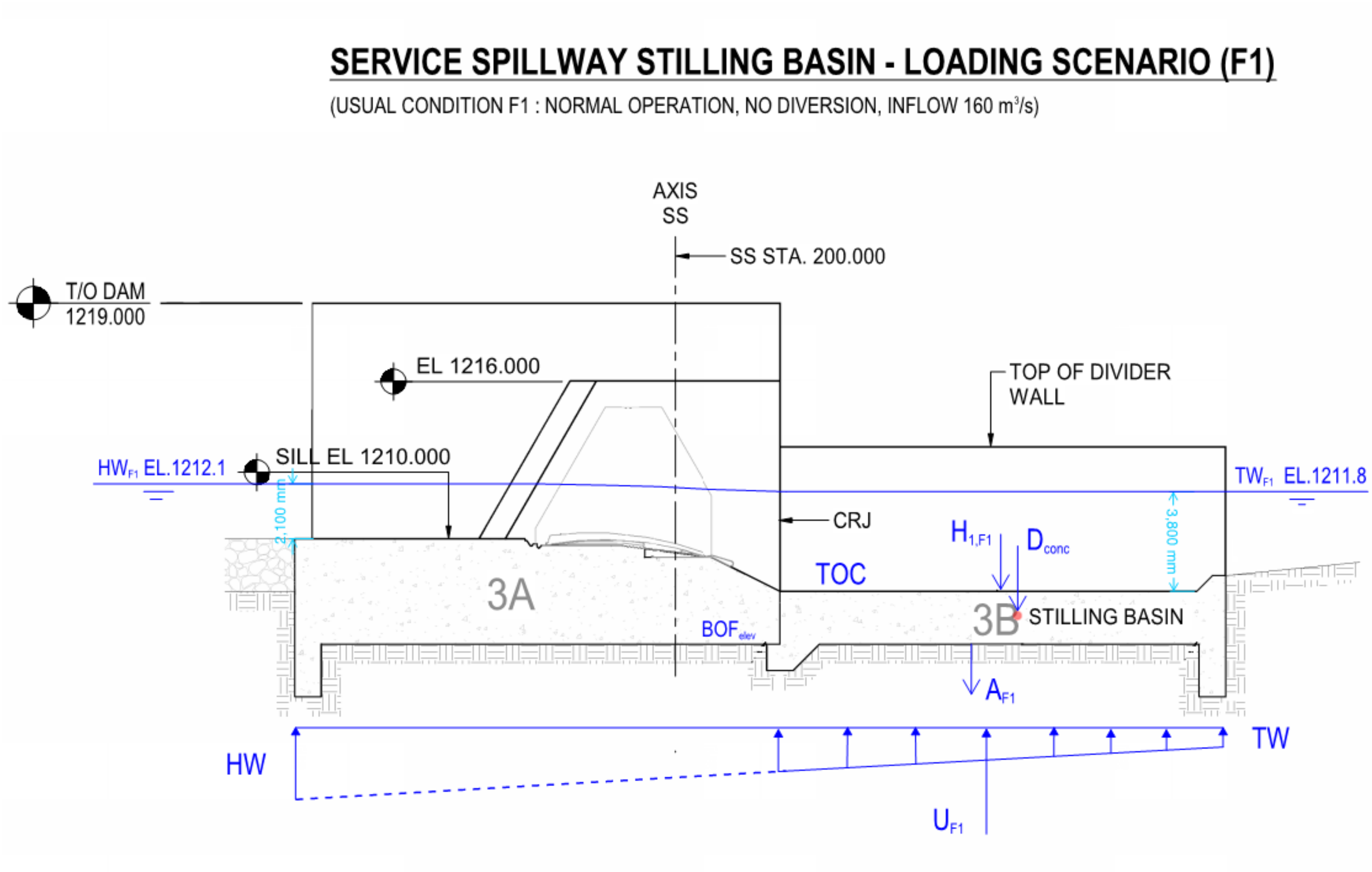
Unit Weight of Concrete: $\gamma_c := 23.5 \frac{kN}{m^3}$ (Section 7.1, Design Criteria)

Unit Weight of Water: $\gamma_w := 9.81 \frac{kN}{m^3}$ (Section 7.2, Design Criteria)

CONCRETE DEAD LOADS

Total Concrete Dead Loads: $D_{conc} := V_{sb} \cdot \gamma_c = 12337.5 \cdot kN$

F1 DESIGN CASE



ACCEPTANCE PARAMETERS

Required Factor of Safety: $FS_{req.F1} := 1.5$ (Without Cohesion)

(Section 8.1, Design Criteria)

VERTICAL WATER LOADS

Headwater Elevation: $H_{hw.F1} := 1212.10m$

Tailwater Elevation: $H_{tw.F1} := 1211.80m$

Include Vertical Water Load in Analysis?: $n_{F1} := 1$ n=1 Yes; n=0 No

Vertical Tailwater Load: $H_{1.F1} := \gamma_w \cdot L_{sb} \cdot W_{sb} \cdot \left(H_{tw.F1} - TOC\right) \cdot n_{F1} = 9785.5 \cdot kN$

WATER UPLIFT

F1 CASE

Uplift pressure at heel of Gated Structure: $U_{HW.F1} := \left(H_{hw.F1} - BOF_{elev}\right) \cdot \gamma_w = 59.8 \cdot \frac{kN}{m^2}$

Uplift pressure at Toe of Stilling Basin: $U_{TW.F1} := \left(H_{tw.F1} - BOF_{elev}\right) \cdot \gamma_w = 56.9 \cdot \frac{kN}{m^2}$

Length from Heel of Gate Structure to Toe of Stilling Basin: $L_{overall.F1} := L_b + L_{sb} = 36.00\, m$

Difference between Uplift pressure at Heel of Gate Structure and Uplift Pressure at Toe of Stilling Basin: $U_{diff.F1} := U_{HW.F1} - U_{TW.F1} = 2.9 \cdot \frac{kN}{m^2}$

Slope of difference between Uplift pressure at Heel of Gate Structure and Uplift Pressure at Toe of Stilling Basin: $U_{slope.F1} := \frac{U_{diff.F1}}{L_{overall.F1}} = 0.08 \cdot \frac{kN}{m^2 \cdot m}$

Tailwater Pressure at toe of Gate Structure / Heel of Stilling Basin: $U_{press.heel.sb.F1} := U_{TW.F1} + \left(L_{sb}\right) \cdot U_{slope.F1} = 58.3 \cdot \frac{kN}{m^2}$

Uniform uplift force: $U_{A.F1} := U_{TW.F1} \cdot L_{sb} \cdot W_{sb} \cdot -1 = -14935.7 \cdot kN$

Triangular uplift force: $U_{B.F1} := \frac{1}{2} \cdot \left(U_{press.heel.sb.F1} - U_{TW.F1}\right) \cdot L_{sb} \cdot W_{sb} \cdot -1 = -187.8 \cdot kN$

Total Resultant Uplift force: $U_{F1} := U_{A.F1} + U_{B.F1} = -15123.5 \cdot kN$

$\Sigma V_{water.F1} := H_{1.F1} + U_{F1} = -5338 \cdot kN$

FLOATATION ANALYSIS:

$\Sigma DL_{F1} := D_{conc} = 12337.5 \cdot kN$

$\Sigma H_{vert.F1} := H_{1.F1} = 9785.5 \cdot kN$

$VtForceDown_{F1} := \Sigma DL_{F1} + \Sigma H_{vert.F1} = 22123 \cdot kN$

$\Sigma Up_{F1} := U_{F1} = -15123.5 \cdot kN$

$\Sigma Fy_{F1} := \Sigma DL_{F1} + \Sigma H_{vert.F1} + \Sigma Up_{F1} = 6999.5 \cdot kN$

Factor of Safety: $FS_{act.F1} := \frac{\left(\Sigma DL_{F1} + \Sigma H_{vert.F1}\right)}{\left|\Sigma Up_{F1}\right|} = 1.46$

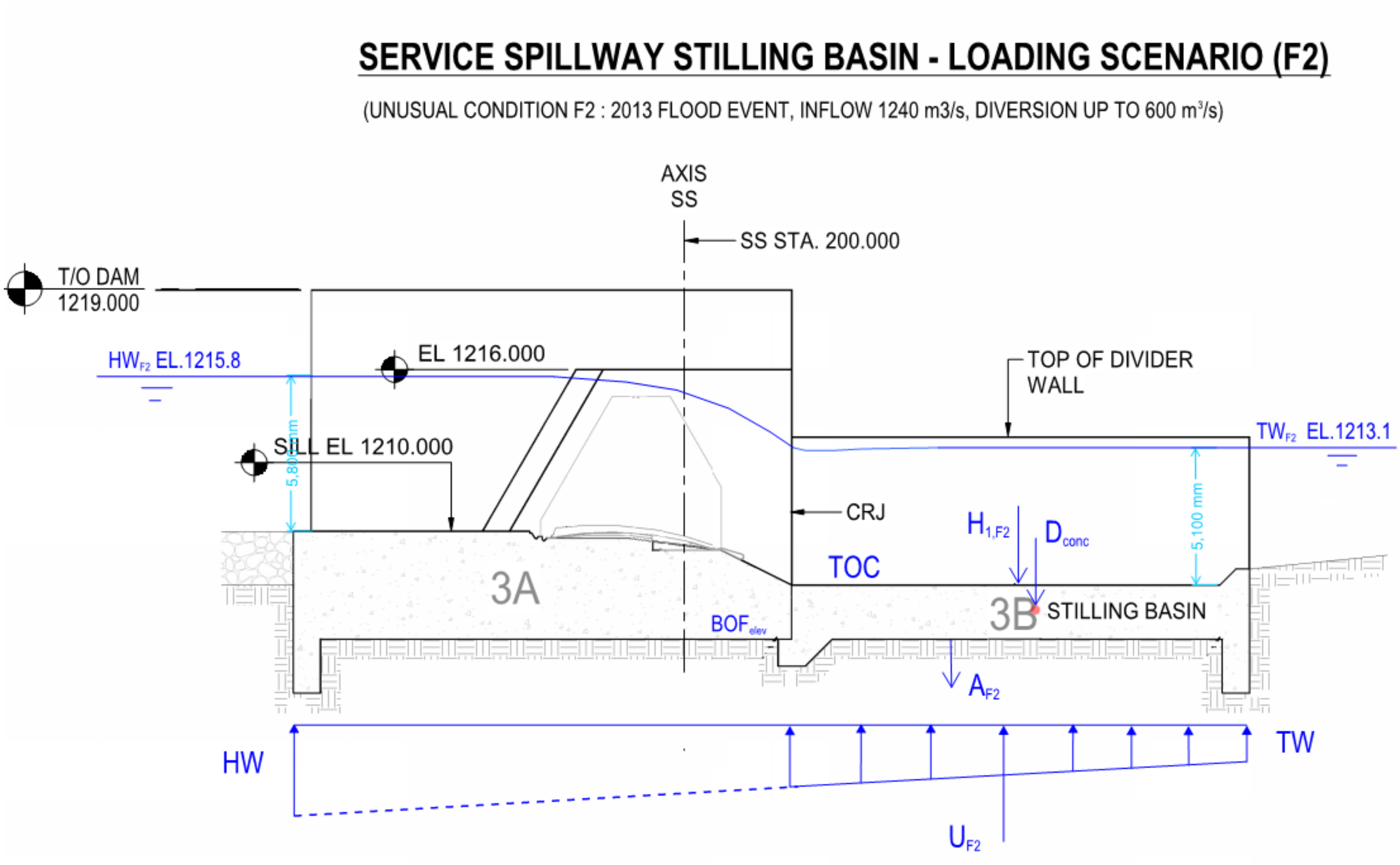
$$FS_{check.F1} := \begin{cases} \text{"OKAY"} & \text{if } FS_{act.F1} \ge FS_{req.F1} \\ \text{"ANCHORS REQUIRED"} & \text{if } FS_{act.F1} < FS_{req.F1} \end{cases} = \text{"ANCHORS REQUIRED"}$$

Anchor Force Required to Meet Factor of Safety Requirements:

$$A_{F1} := \begin{cases} (0.0kN) & \text{if } FS_{act.F1} \ge FS_{req.F1} \\ \left(\left|\Sigma Up_{F1}\right| \cdot FS_{req.F1} - \Sigma DL_{F1} - \Sigma H_{vert.F1}\right) & \text{if } FS_{act.F1} < FS_{req.F1} \end{cases} = 562.3 \cdot kN$$

Required anchor force over stilling basin Area: $A_{F1.Area} := \frac{A_{F1}}{\left(L_{sb} \cdot W_{sb}\right)} = 2.1 \cdot \frac{kN}{m^2}$

F2 DESIGN CASE



ACCEPTANCE PARAMETERS

Required Factor of Safety: $FS_{req.F2} := 1.3$ (Without Cohesion)

(Section 8.1, Design Criteria)

VERTICAL WATER LOADS

Headwater Elevation: $H_{hw.F2} := 1215.80m$

Tailwater Elevation: $H_{tw.F2} := 1213.10m$

Include Vertical Water Load in Analysis?: $n_{F2} := 1$ n=1 Yes; n=0 No

Vertical Tailwater Load: $H_{1.F2} := \gamma_w \cdot L_{sb} \cdot W_{sb} \cdot \left(H_{tw.F2} - TOC\right) \cdot n_{F2} = 13133.1 \cdot kN$

WATER UPLIFT

F2 CASE

Uplift pressure at heel of Gated Structure: $U_{HW.F2} := \left(H_{hw.F2} - BOF_{elev}\right)\cdot \gamma_w = 96.1\cdot \frac{kN}{m^2}$

Uplift pressure at Toe of Stilling Basin: $U_{TW.F2} := \left(H_{tw.F2} - BOF_{elev}\right)\cdot \gamma_w = 69.7\cdot \frac{kN}{m^2}$

Length from Heel of Gate Structure to Toe of Stilling Basin: $L_{overall.F2} := L_b + L_{sb} = 36.00\,m$

Difference between Uplift pressure at Heel of Gate Structure and Uplift Pressure at Toe of Stilling Basin: $U_{diff.F2} := U_{HW.F2} - U_{TW.F2} = 26.5\cdot \frac{kN}{m^2}$

Slope of difference between Uplift pressure at Heel of Gate Structure and Uplift Pressure at Toe of Stilling Basin: $U_{slope.F2} := \frac{U_{diff.F2}}{L_{overall.F2}} = 0.74\cdot \frac{kN}{m^2\cdot m}$

Tailwater Pressure at toe of Gate Structure / Heel of Stilling Basin: $U_{press.heel.sb.F2} := U_{TW.F2} + \left(L_{sb}\right)\cdot U_{slope.F2} = 82.5\cdot \frac{kN}{m^2}$

Uniform uplift force: $U_{A.F2} := U_{TW.F2}\cdot L_{sb}\cdot W_{sb}\cdot -1 = -18283.4\cdot kN$

Triangular uplift force: $U_{B.F2} := \frac{1}{2}\cdot\left(U_{press.heel.sb.F2} - U_{TW.F2}\right)\cdot L_{sb}\cdot W_{sb}\cdot -1 = -1689.9\cdot kN$

Total Resultant Uplift force: $U_{F2} := U_{A.F2} + U_{B.F2} = -19973.3\cdot kN$

$\Sigma V_{water.F2} := H_{1.F2} + U_{F2} = -6840.2\cdot kN$

FLOATATION ANALYSIS:

$\Sigma DL_{F2} := D_{conc} = 12337.5\cdot kN$

$\Sigma H_{vert.F2} := H_{1.F2} = 13133.1\cdot kN$ $\qquad VtForceDown_{F2} := \Sigma DL_{F2} + \Sigma H_{vert.F2} = 25470.6\cdot kN$

$\Sigma Up_{F2} := U_{F2} = -19973.3\cdot kN$

$\Sigma Fy_{F2} := \Sigma DL_{F2} + \Sigma H_{vert.F2} + \Sigma Up_{F2} = 5497.3\cdot kN$

Factor of Safety: $FS_{act.F2} := \frac{\left(\Sigma DL_{F2} + \Sigma H_{vert.F2}\right)}{\left|\Sigma Up_{F2}\right|} = 1.28$

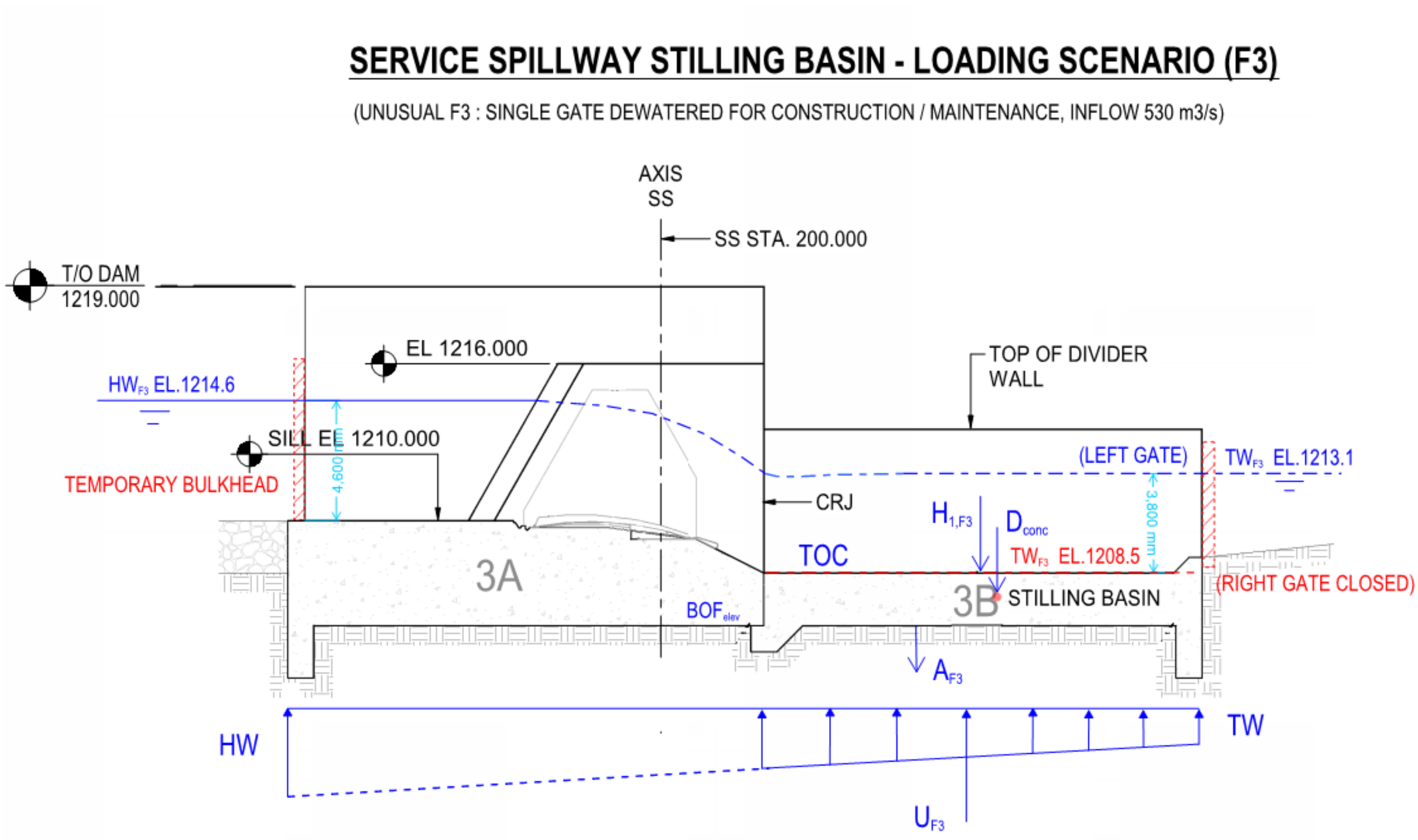
$$FS_{check.F2} := \begin{cases} \text{"OKAY"} & \text{if } FS_{act.F2} \ge FS_{req.F2} \\ \text{"ANCHORS REQUIRED"} & \text{if } FS_{act.F2} < FS_{req.F2} \end{cases} = \text{"ANCHORS REQUIRED"}$$

Anchor Force Required to Meet Factor of Safety Requirements:

$$A_{F2} := \begin{cases} (0.0kN) & \text{if } FS_{act.F2} \ge FS_{req.F2} \\ \left(\left|\Sigma Up_{F2}\right|\cdot FS_{req.F2} - \Sigma DL_{F2} - \Sigma H_{vert.F2}\right) & \text{if } FS_{act.F2} < FS_{req.F2} \end{cases} = 494.7\cdot kN$$

Required anchor force over stilling basin Area: $A_{F2.Area} := \frac{A_{F2}}{\left(L_{sb}\cdot W_{sb}\right)} = 1.9\cdot \frac{kN}{m^2}$

F3 DESIGN CASE



ACCEPTANCE PARAMETERS

Required Factor of Safety: $FS_{req.F3} := 1.3$ (Without Cohesion)

(Section 8.1, Design Criteria)

VERTICAL WATER LOADS

Headwater Elevation: $H_{hw.F3} := 1214.60m$

Tailwater Elevation: $H_{tw.F3} := 1211.80m$

Include Vertical Water Load in Analysis?: $n_{F3} := 0$ n=1 Yes; n=0 No

Vertical Tailwater Load: $H_{1.F3} := \gamma_w \cdot L_{sb} \cdot W_{sb} \cdot \left(H_{tw.F3} - TOC\right) \cdot n_{F3} = 0.0 \cdot kN$

WATER UPLIFT

F3 CASE

Uplift pressure at heel of Gated Structure: $U_{HW.F3} := \left(H_{hw.F3} - BOF_{elev}\right)\cdot\gamma_w = 84.4\cdot\frac{kN}{m^2}$

Uplift pressure at Toe of Stilling Basin: $U_{TW.F3} := \left(H_{tw.F3} - BOF_{elev}\right)\cdot\gamma_w = 56.9\cdot\frac{kN}{m^2}$

Length from Heel of Gate Structure to Toe of Stilling Basin: $L_{overall.F3} := L_b + L_{sb} = 36.00\,m$

Difference between Uplift pressure at Heel of Gate Structure and Uplift Pressure at Toe of Stilling Basin: $U_{diff.F3} := U_{HW.F3} - U_{TW.F3} = 27.5\cdot\frac{kN}{m^2}$

Slope of difference between Uplift pressure at Heel of Gate Structure and Uplift Pressure at Toe of Stilling Basin: $U_{slope.F3} := \frac{U_{diff.F3}}{L_{overall.F3}} = 0.76\cdot\frac{kN}{m^2\cdot m}$

Tailwater Pressure at toe of Gate Structure / Heel of Stilling Basin: $U_{press.heel.sb.F3} := U_{TW.F3} + \left(L_{sb}\right)\cdot U_{slope.F3} = 70.3\cdot\frac{kN}{m^2}$

Uniform uplift force: $U_{A.F3} := U_{TW.F3}\cdot L_{sb}\cdot W_{sb}\cdot -1 = -14935.7\cdot kN$

Triangular uplift force: $U_{B.F3} := \frac{1}{2}\cdot\left(U_{press.heel.sb.F3} - U_{TW.F3}\right)\cdot L_{sb}\cdot W_{sb}\cdot -1 = -1752.5\cdot kN$

Total Resultant Uplift force: $U_{F3} := U_{A.F3} + U_{B.F3} = -16688.2\cdot kN$

$\Sigma V_{water.F3} := H_{1.F3} + U_{F3} = -16688.2\cdot kN$

FLOATATION ANALYSIS:

$\Sigma DL_{F3} := D_{conc} = 12337.5\cdot kN$

$\Sigma H_{vert.F3} := H_{1.F3} = 0.0\cdot kN$ $\qquad VtForceDown_{F3} := \Sigma DL_{F3} + \Sigma H_{vert.F3} = 12337.5\cdot kN$

$\Sigma Up_{F3} := U_{F3} = -16688.2\cdot kN$

$\Sigma Fy_{F3} := \Sigma DL_{F3} + \Sigma H_{vert.F3} + \Sigma Up_{F3} = -4350.7\cdot kN$

Factor of Safety: $FS_{act.F3} := \frac{\left(\Sigma DL_{F3} + \Sigma H_{vert.F3}\right)}{\left|\Sigma Up_{F3}\right|} = 0.74$

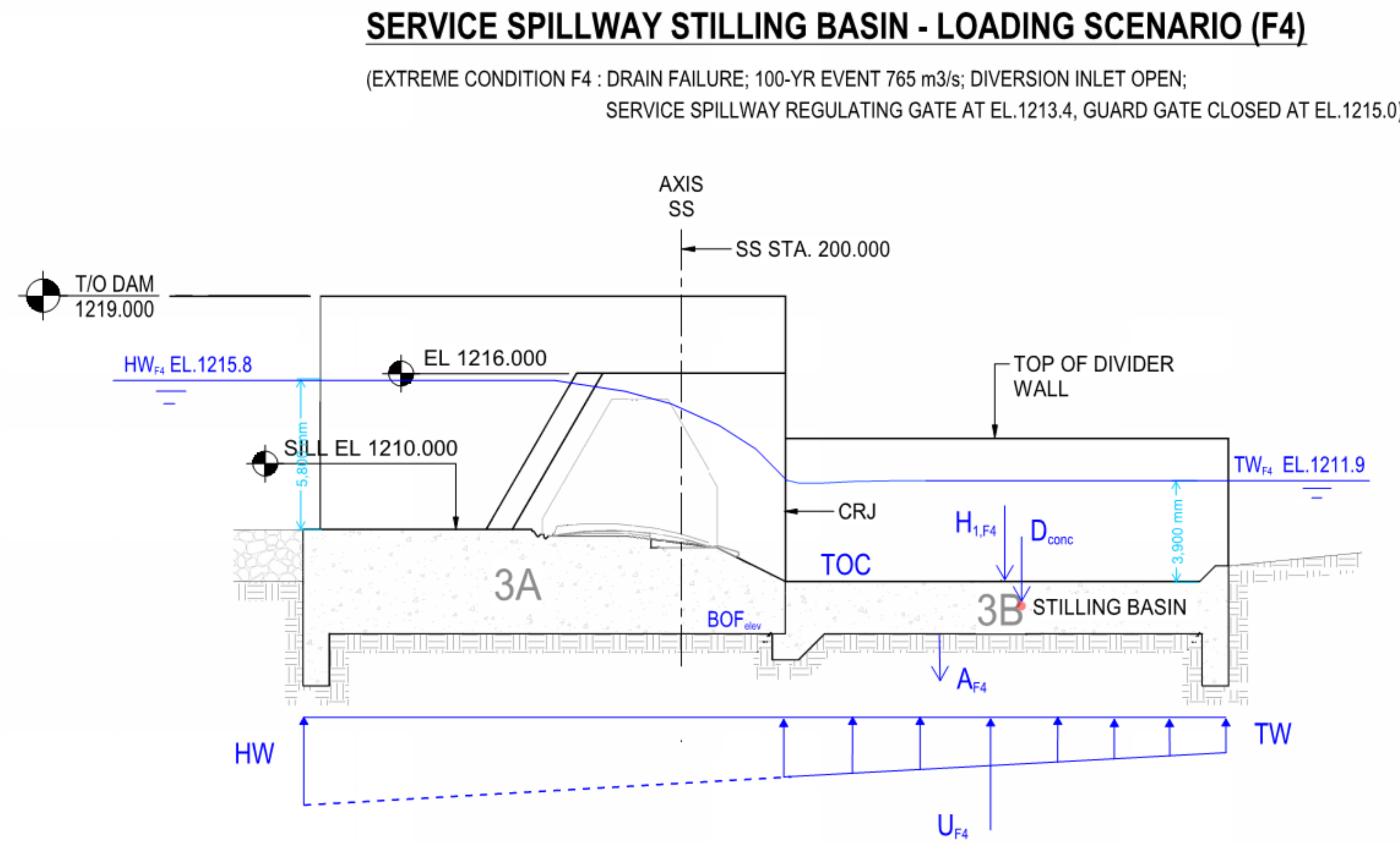
$$FS_{check.F3} := \begin{cases} \text{"OKAY"} & \text{if } FS_{act.F3} \geq FS_{req.F3} \\ \text{"ANCHORS REQUIRED"} & \text{if } FS_{act.F3} < FS_{req.F3} \end{cases} = \text{"ANCHORS REQUIRED"}$$

Anchor Force Required to Meet Factor of Safety Requirements:

$$A_{F3} := \begin{cases} (0.0kN) & \text{if } FS_{act.F3} \geq FS_{req.F3} \\ \left(\left|\Sigma Up_{F3}\right|\cdot FS_{req.F3} - \Sigma DL_{F3} - \Sigma H_{vert.F3}\right) & \text{if } FS_{act.F3} < FS_{req.F3} \end{cases} = 9357.2\cdot kN$$

Required anchor force over stilling basin Area: $A_{F3.Area} := \frac{A_{F3}}{\left(L_{sb}\cdot W_{sb}\right)} = 35.6\cdot\frac{kN}{m^2}$

F4 DESIGN CASE



ACCEPTANCE PARAMETERS

Required Factor of Safety: $FS_{req.F4} := 1.1$ (Without Cohesion)

(Section 8.1, Design Criteria)

VERTICAL WATER LOADS

Headwater Elevation: $H_{hw.F4} := 1215.80m$

Tailwater Elevation: $H_{tw.F4} := 1211.90m$

Include Vertical Water Load in Analysis?: $n_{F4} := 1$ n=1 Yes, n=0 No

Vertical Tailwater Load: $H_{1.F4} := \gamma_w \cdot L_{sb} \cdot W_{sb} \cdot \left(H_{tw.F4} - TOC\right) \cdot n_{F4} = 10043.0 \cdot kN$

WATER UPLIFT

F4 CASE

Uplift pressure at heel of Gated Structure: $U_{HW.F4} := \left(H_{hw.F4} - BOF_{elev}\right)\cdot\gamma_w = 96.1\cdot\frac{kN}{m^2}$

Uplift pressure at Toe of Stilling Basin: $U_{TW.F4} := \left(H_{tw.F4} - BOF_{elev}\right)\cdot\gamma_w = 57.9\cdot\frac{kN}{m^2}$

Length from Heel of Gate Structure to Toe of Stilling Basin: $L_{overall.F4} := L_b + L_{sb} = 36.00\,m$

Difference between Uplift pressure at Heel of Gate Structure and Uplift Pressure at Toe of Stilling Basin: $U_{diff.F4} := U_{HW.F4} - U_{TW.F4} = 38.3\cdot\frac{kN}{m^2}$

Slope of difference between Uplift pressure at Heel of Gate Structure and Uplift Pressure at Toe of Stilling Basin: $U_{slope.F4} := \frac{U_{diff.F4}}{L_{overall.F4}} = 1.06\cdot\frac{kN}{m^2\cdot m}$

Tailwater Pressure at toe of Gate Structure / Heel of Stilling Basin: $U_{press.heel.sb.F4} := U_{TW.F4} + \left(L_{sb}\right)\cdot U_{slope.F4} = 76.5\cdot\frac{kN}{m^2}$

Uniform uplift force: $U_{A.F4} := U_{TW.F4}\cdot L_{sb}\cdot W_{sb}\cdot -1 = -15193.2\cdot kN$

Triangular uplift force: $U_{B.F4} := \frac{1}{2}\cdot\left(U_{press.heel.sb.F4} - U_{TW.F4}\right)\cdot L_{sb}\cdot W_{sb}\cdot -1 = -2441.0\cdot kN$

Total Resultant Uplift force: $U_{F4} := U_{A.F4} + U_{B.F4} = -17634.2\cdot kN$

$\Sigma V_{water.F4} := H_{1.F4} + U_{F4} = -7591.3\cdot kN$

FLOATATION ANALYSIS:

$\Sigma DL_{F4} := D_{conc} = 12337.5\cdot kN$

$\Sigma H_{vert.F4} := H_{1.F4} = 10043.0\cdot kN$ $\quad VtForceDown_{F4} := \Sigma DL_{F4} + \Sigma H_{vert.F4} = 22380.5\cdot kN$

$\Sigma Up_{F4} := U_{F4} = -17634.2\cdot kN$

$\Sigma Fy_{F4} := \Sigma DL_{F4} + \Sigma H_{vert.F4} + \Sigma Up_{F4} = 4746.2\cdot kN$

Factor of Safety: $FS_{act.F4} := \frac{\left(\Sigma DL_{F4} + \Sigma H_{vert.F4}\right)}{\left|\Sigma Up_{F4}\right|} = 1.27$

$FS_{check.F4} := \begin{cases} \text{"OKAY"} & \text{if } FS_{act.F4} \geq FS_{req.F4} \\ \text{"ANCHORS REQUIRED"} & \text{if } FS_{act.F4} < FS_{req.F4} \end{cases} = \text{"OKAY"}$

Anchor Force Required to Meet Factor of Safety Requirements:

$A_{F4} := \begin{cases} (0.0kN) & \text{if } FS_{act.F4} \geq FS_{req.F4} \\ \left(\left|\Sigma Up_{F4}\right|\cdot FS_{req.F4} - \Sigma DL_{F4} - \Sigma H_{vert.F4}\right) & \text{if } FS_{act.F4} < FS_{req.F4} \end{cases} = 0.0\cdot kN$

Required anchor force over stilling basin Area: $A_{F4.Area} := \frac{A_{F4}}{\left(L_{sb}\cdot W_{sb}\right)} = 0.0\cdot\frac{kN}{m^2}$

Appendix E.2-3 RIGHT ABUTMENT PIER

Calculation Section I

Results Summary Table (overview)

Table 18 – Service Spillway Right Abutment – Stability Analysis Summary

Load Case	Headwater Elevation (m)	Tailwater Elevation (m)	Uplift Force (kN)	Floatation Safety Factor (FSF)		Sliding Safety Factor (SSF)		Foundation Bearing Stress		% Base in Compression
				Req	Calc	Req	Calc	Upstream (Heel) (kPa)	Downstream (Toe) (Kpa)	
Usual Load Cases										
U1 Normal Operation	1212.1	1211.8	16750	1.5	3.4	1.5	5.6	55	224	100
U2 Diversion Operation *50 Yr. Flood*	1214.6	1211.8	20817	1.5	2.8	1.5	5.6	42	225	100
Unusual Load Case										
UN1 Diversion Operation *2013 Flood*	1215.8	1213.1	24298	1.3	2.5	1.3	5.1	52	200	100
UN2 Diversion Operation *2013 Flood*	1216.1	1213.0	24013	1.3	2.6	1.3	4.7	86	175	100
UN3 No Diversion *1000 Yr. Flood*	1217.0	1214.7	26957	1.3	2.3	1.3	4.2	57	185	100
UN4 Construction/ Maintenance	1215.0	1211.9	21575	1.3	2.7	1.3	4.2	16	240	100
Extreme – Flood										
E1 IDF without Diversion	1217.8	1214.9	28858	1.1	2.1	1.1	4.3	73	158	100
Extreme – Earthquake used to determine Post-Seismic Condition										
E2 EDGM applied to U1	1212.1	1211.8	16750	1.1	2.0 (E2.3)	1.0	1.3 (E2.2)	24 (E2.1)	260 (E2.1)	100
E3 EDGM applied to U2	1214.6	1211.8	20817	1.1	1.6 (E3.3)	1.0	1.1 (E3.2)	8 (E3.2)	242 (E3.1)	100

Notes:
1. See Appendix E.1 for definition of monolith description, analysis methodology, and stability calculations.
2. Reported seismic results are controlling values for the three combinations of vertical and horizontal seismic load considered.

Calculation Section II

Results Summary Table (detailed)

SERVICE SPILLWAY RIGHT ABUTMENT BLOCK STABILITY SUMMARY (SS-1A)													
Load Combination	Σ Vertical (kN)	Σ Horizontal (kN)	Σ Moments x-Direction (kN*m)	Eccentricity, e x-Direction (m)	σ @ Toe (kN/m2) minimum	σ @ Heel (kN/m2) maximum	Base in Compression %	FS Sliding Required	Calculated FS Horiz	Σ Vertical Without Uplift (kN)	Σ Uplift (kN)	FS Floatation Required	FS Floatation Calculated
U1	39682.0	3432.1	310273.7	-1.30	55	224	100	1.5	5.64	56432.0	16750.0	1.5	3.37
U2	38160.6	3308.9	292946.8	-1.59	42	225	100	1.5	5.62	58977.1	20816.5	1.5	2.83
UN1	36264.8	3492.6	288150.2	-1.29	52	200	100	1.3	5.06	60562.6	24297.8	1.3	2.49
UN2	37161.6	3481.3	286934.7	-1.41	86	175	100	1.3	4.72	61174.6	24013.0	1.3	2.55
UN3	34757.3	3699.6	285450.8	-1.05	57	185	100	1.3	4.58	61714.3	26957.0	1.3	2.29
UN4	36820.6	4266.8	271848.1	-1.90	16	240	100	1.3	4.21	58395.4	21574.8	1.3	2.71
E1	32649.9	3728.6	315535.3	0.51	73	158	100	1.1	4.27	61507.5	28857.6	1.1	2.13
E2.1	22932.0	4500.0	133844.6	-2.87	24	260	100	1.0	1.41	39682.0	16750.0	1.1	2.37
E2.2	21239.0	5227.3	133844.6	-2.31	43	217	100	1.0	1.29	37989.0	16750.0	1.1	2.27
E2.3	17288.8	3360.0	165215.9	1.52	75	160	100	1.0	2.58	34038.8	16750.0	1.1	2.03
E3.1*	17344.1	5860.1	116517.7	-3.48	19	242	100	1.0	1.24	38160.6	20816.5	1.1	1.83
E3.2*	15574.8	7280.7	116517.7	-2.93	8	239	100	1.0	1.08	36391.3	20816.5	1.1	1.75
E3.3*	11446.4	4450.9	147889.0	1.08	42	179	100	1.0	2.20	32262.9	20816.5	1.1	1.55

Calculation Section III

SS-1A Right Abutment Stability Calculations

Project Number: 110773396

Project Title: SR1 Project

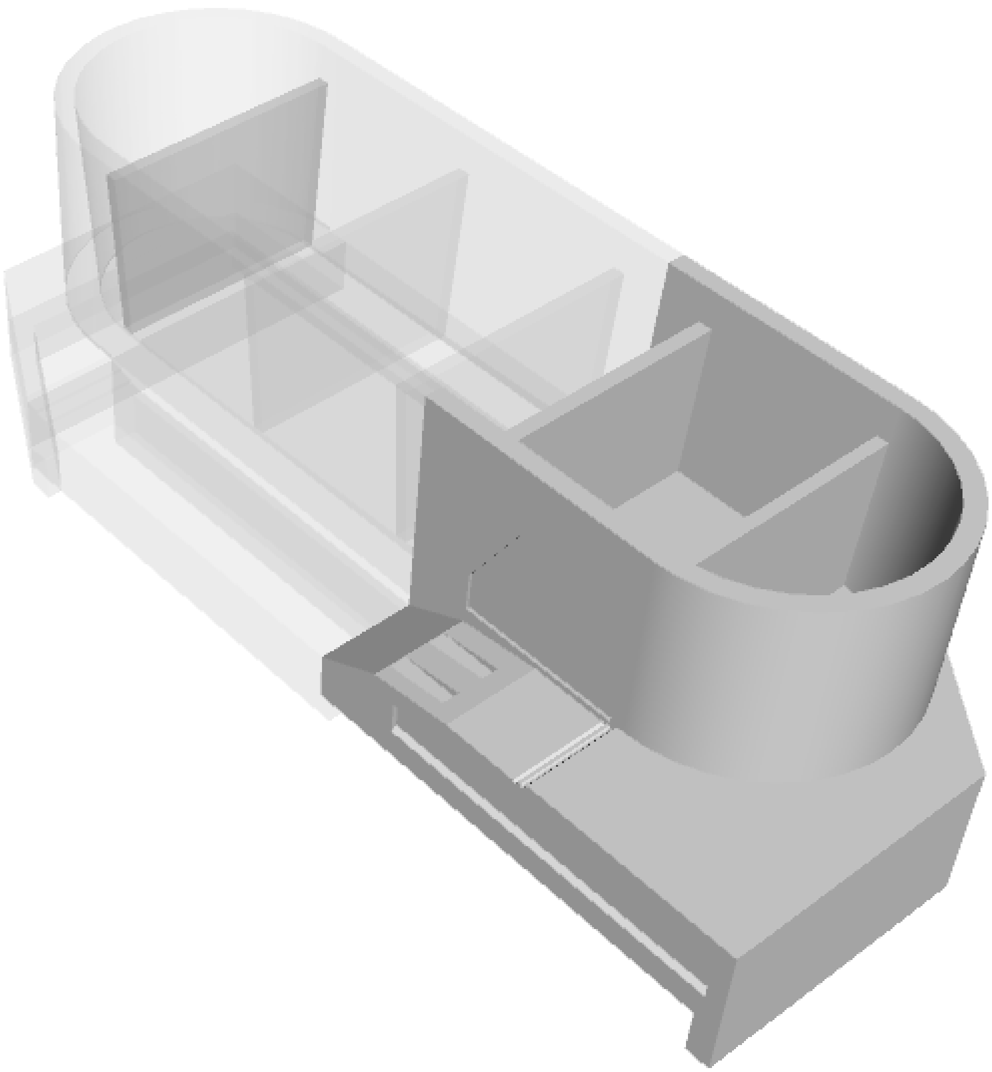
Client: Alberta Transportation

Engineer: Dave Crawford, Derek Cheuk Date: 06/25/2020

Checker: Sean Xiao Date: 06/25/2020

Calculation for: Service Spillway Right Abutment SS-1A

Structure Isometric:

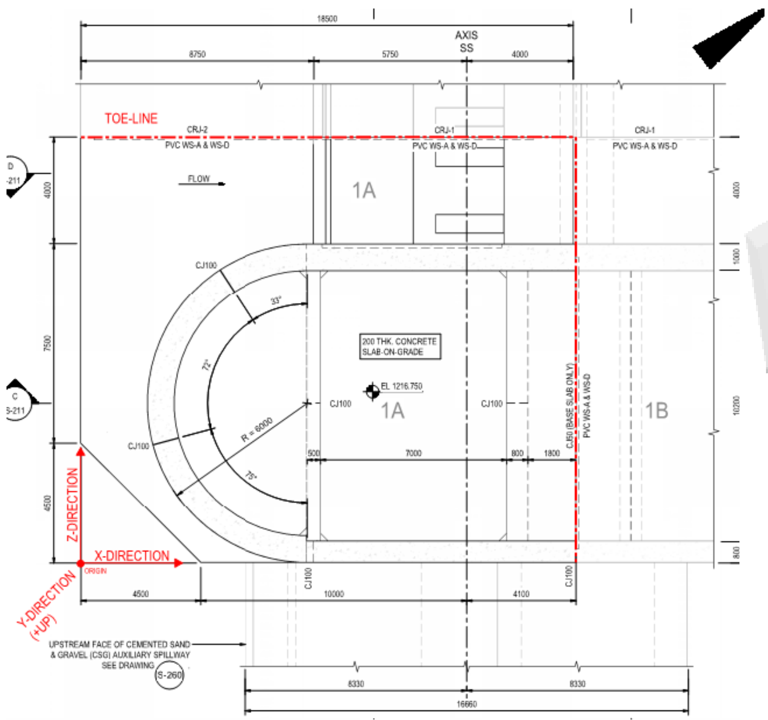


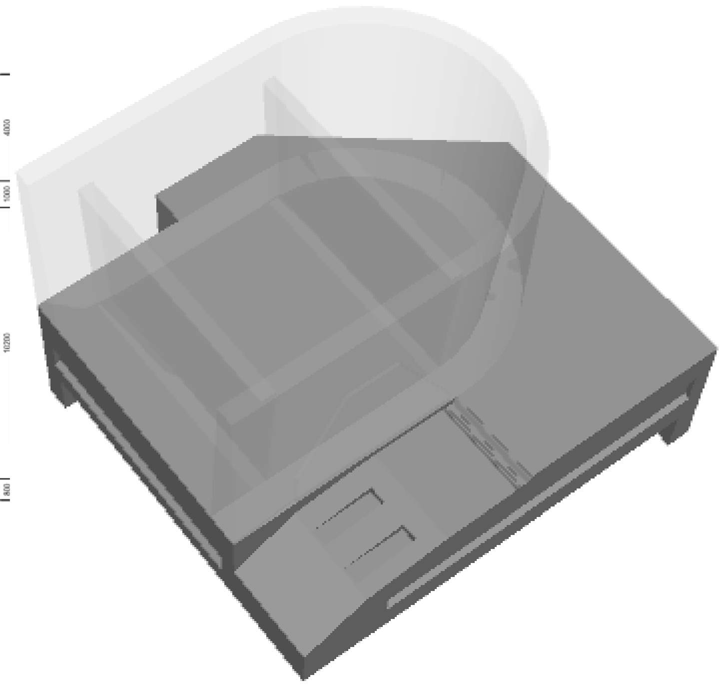
SERVICE SPILLWAY - RIGHT ABUTMENT (ABUTMENT PIER) - 1A

User Input

SERVICE SPILLWAY DEIMENSIONAL INPUT PARAMETERS

BASE SECTION PROPERTIES





Base Length: L_b Varies (See Plan)

$L_B := 18.5m$

$Kern_x := \frac{L_B}{6} = 3.08\ m$

Base Width: W_B Varies, (See Plan)

$W_B := 16.0 \cdot m$

$Kern_z := \frac{W_B}{6} = 2.67\ m$

1A Gate Water Flow Width: $W_{BG} := 4.0m$

Area of Base: $A_b := 285.875m^2$ (From Section Prop. Spreadsheet)

X Center of Gravity From Toe: $X_{BCG} := L_B - 9.5245m = 8.98\ m$ (From Section Prop. Spreadsheet)

Z Center of Gravity From Toe: $Z_{BCG} := W_B - 8.23m = 7.77\ m$

Section Modulus of Base about X-axis: (Top, Z-Direction) $S_{bz.t} := 754.248m^3$ (From Section Prop. Spreadsheet)

Section Modulus of Base: (Bottom, Z-Direction) $S_{bz.b} := 712.052m^3$

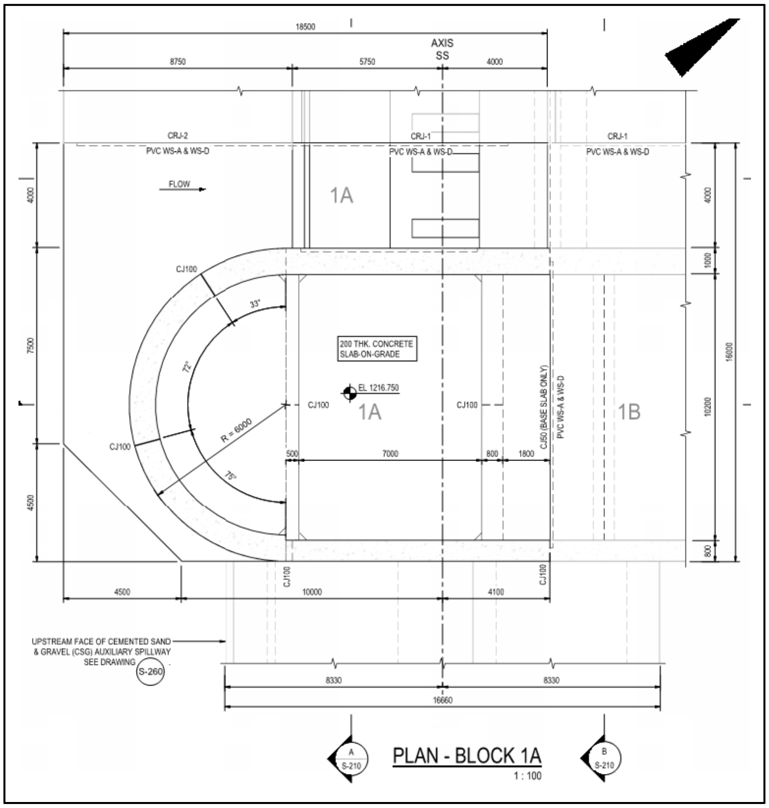
Section Modulus of Base about Z-axis: (Left, X-Direction) $S_{bx.L} := 819.058m^3$

Section Modulus of Base: (Right, X-Direction) $S_{bx.R} := 869.154m^3$

Moment of Inertia of Base: (about X-Direction) $I_{bx} := 5.860 \cdot 10^{15} mm^4 = 5860\ m^4$ (From Section Prop. Spreadsheet)

Moment of Inertia of Base: (about Y-Direction) $I_{by} := 7.801 \cdot 10^{15} mm^4 = 7801\ m^4$

ABUTMENT WALL PROPERTIES



Outside-to-Outside Wall Width: $W_{wall} := 12m$

Top of Wall Elevation: $EL_{TOP.wall} := 1218.0m$

Top of Footing Elevation: (High Point) $EL_{TOP.FTG} := 1210.0m$

Max Height of Wall: $h_w := EL_{TOP.wall} - EL_{TOP.FTG} = 8\ m$

Wall Top Width: $w_{wt} := 1.0m$

Wall Bottom Width: $w_{wb} := 1.0m$

Wall Average Width: $w_{w.avg} := \dfrac{(w_{wt} + w_{wb})}{2} = 1\ m$

Wall Cross Sectional Area: $A_{wall} := w_{wt} \cdot h_w + 0.5(w_{wb} - w_{wt}) \cdot h_w = 8\ m^2$

Radius of wall curvature: $r_{wall} := 6m$

Area of Semicircular Wall: $A_{semicircle} := \dfrac{\pi \cdot r_{wall}^2}{2} - \dfrac{\pi \cdot (r_{wall} - w_{w.avg})^2}{2} = 17.28\ m^2$

Wall Volume in Semicircle: $V_{wall.cyl} := h_w \cdot A_{semicircle} = 138.23 \cdot m^3$

Length of Straight Wall: $L_{wall} := 10.m$

Wall Volume in Straight Line: $V_{wall.s} := A_{wall} \cdot (L_{wall} \cdot 2) = 160 \cdot m^3$ (Two exterior straight walls)

Abutment Wall X C.O.G. (Semi-Cylinder):

$$X_{WC} := \frac{4 \cdot \left[r_{wall}^3 - (r_{wall} - w_{w.avg})^3 \right]}{3 \cdot \pi \cdot \left[r_{wall}^2 - (r_{wall} - w_{w.avg})^2 \right]} + L_{wall} = 13.5111\ m$$

INTERIOR WALLS

Top of Interior Wall Elevation: $EL_{TOP.i.wall} := 1216.5m$

Max Height of Interior Wall: $h_{i.w} := EL_{TOP.i.wall} - EL_{TOP.FTG} = 6.5\,m$

Width of Interior Wall 1: $w_{w1} := 0.5m$

Width of Interior Wall 2: $w_{w2} := 0.8m$

Length of Interior Walls: $L_{i.w} := W_{wall} - 2 \cdot w_{wt} - 2 \cdot \left[0.5 \cdot \left(w_{wb} - w_{wt}\right)\right] = 10\,m$

Volume of Interior Wall 1: $V_{w1} := h_{i.w} \cdot L_{i.w} \cdot w_{w1} = 32.5 \cdot m^3$

Volume of Interior Wall 2: $V_{w2} := h_{i.w} \cdot L_{i.w} \cdot w_{w2} = 52 \cdot m^3$

TOP CONCRETE CAP

Radius of Concrete Cap (Cylinder): $r_{cap.c} := 5.0m$

Area of Concrete Cap (Cylinder): $A_{cap.c} := \dfrac{\pi \cdot \left(r_{cap.c}\right)^2}{2} = 39.27\,m^2$

Width of Concrete Cap: $w_c := 10m$ (From Revit Model)

Elevation at Top of Concrete Cap: $EL_{cap.top} := 1216.7m$

Elevation at Top of Concrete Cap: $EL_{cap.bot} := 1216.5m$

Cap Thickness: $t_{cap} := EL_{cap.top} - EL_{cap.bot} = 0.2\,m$

Volume of Concrete Cap (Cylinder): $V_{cap.c} := t_{cap} \cdot A_{cap.c} = 7.85 \cdot m^3$

Volume of Concrete Cap Straight: $V_{cap.s} := t_{cap} \cdot w_c \cdot L_{wall} = 20 \cdot m^3$

FOOTINGS

Bottom of Footing (Elevation): $EL_{FTG.bot} := 1206.0m$

Top of Footing Elevation: $EL_{FTG.top} := 1210.0m$

Footing Thickness (rect): $t_{FTG} := EL_{FTG.top} - EL_{FTG.bot} = 4\,m$

Footing Cross Sectional Area: $A_{FTG} := A_b = 285.88\,m^2$

Total Footing Volume: $V_{FTG} := t_{FTG} \cdot A_{FTG} = 1143.5 \cdot m^3$

$V_{Crest} := 6.1 \cdot m^2 \cdot W_{BG} = 24.4 \cdot m^3$

$X_{Crest} := 2.91 \cdot m$ $Z_{Crest} := 2 \cdot m$

$Y_{Crest} := 1.489 \cdot m$

(To reduce concrete volume for Crest Gate, from Bluebeam Measurement)

$V_{FTG0} := V_{FTG} - V_{Crest} = 1119.1 \cdot m^3$

SHEAR KEY PROPERTIES

Key depth: $d_{key} := 2.0m$

Key width: $w_{key} := 1.0m$

FOUNDATION PARAMETERS

Granular Fill Internal Angle of Friction: $\phi := 34 \cdot \dfrac{\pi}{180} = 0.593$ Radians (Section 5.3, Design Criteria)

Friction Angle at Base Concrete / Rock Interface: $\phi_{rock} := 26 \cdot \dfrac{\pi}{180}$ (Section 5.2, Design Criteria)

Base Friction Coefficient: $\tan_{\phi} := \tan\left(\phi_{rock}\right) = 0.488$ radians

ROCK FILL PROPERTIES

Rock Fill Width (Average): $w_{fill} := W_{wall} - 2 \cdot w_{wt} - 2 \cdot \left[\frac{(w_{wb} - w_{wt})}{2} \right] = 10\,m$

Rock Fill Length 1 (Rectangle): $L_{fill.1} := 7.0m$

Rock Fill Length 2 (Rectangle): $L_{fill.2} := 1.7m$

Rock Fill Volume 1 (Box): $V_{fill.1} := w_{fill} \cdot L_{fill.1} \cdot (h_{i.w}) = 455 \cdot m^3$

Rock Fill Volume 2 (Box): $V_{fill.2} := w_{fill} \cdot L_{fill.2} \cdot (h_{i.w}) = 110.5 \cdot m^3$

Rock Fill Area 3 (Semi-Cylinder): $A_{fill.cyl} := \frac{\pi \cdot (r_{wall} - w_{w.avg})^2}{2} = 39.27\,m^2$

Rock Fill Volume 3 (Semi-Cylinder): $V_{fill.cyl} := A_{fill.cyl} \cdot h_{i.w} = 255.25 \cdot m^3$

MATERIAL PROPERTIES

Unit Weight of Concrete: $\gamma_c := 23.5 \frac{kN}{m^3}$ (Section 7.1, Design Criteria)

Unit Weight of Rock Fill: $\gamma_r := 22.0 \frac{kN}{m^3}$ (Section 5.3, Design Criteria)

$\phi_{backfill} := \left(20 \frac{\pi}{180} \right) = 0.35$ radians Assume Rip Rap Backfill

Unit Weight of Water: $\gamma_w := 9.81 \frac{kN}{m^3}$ (Section 7.2, Design Criteria)

CONCRETE DEAD LOADS

Exterior Wall (Cylinder): $D_{w.cyl} := V_{wall.cyl} \cdot \gamma_c = 3248.4 \cdot kN$

Exterior Wall (Straight): $D_{w.s} := V_{wall.s} \cdot \gamma_c = 3760 \cdot kN$

Interior Wall 1: $D_{i.w1} := V_{w1} \cdot \gamma_c = 763.8 \cdot kN$

Interior Wall 2: $D_{i.w2} := V_{w2} \cdot \gamma_c = 1222 \cdot kN$

Concrete Cap (Semicircle): $D_{c.c} := V_{cap.c} \cdot \gamma_c = 184.6 \cdot kN$

Concrete Cap (Straight): $D_{c.s} := V_{cap.s} \cdot \gamma_c = 470 \cdot kN$

Footing (rect): $D_{Fr} := V_{FTG} \cdot \gamma_c = 26872.3 \cdot kN$

Total Concrete Dead Loads: $D_{conc} := D_{w.cyl} + D_{w.s} + D_{i.w1} + D_{i.w2} + D_{c.c} + D_{c.s} + D_{Fr} - V_{Crest} \cdot \gamma_c = 35947.6 \cdot kN$

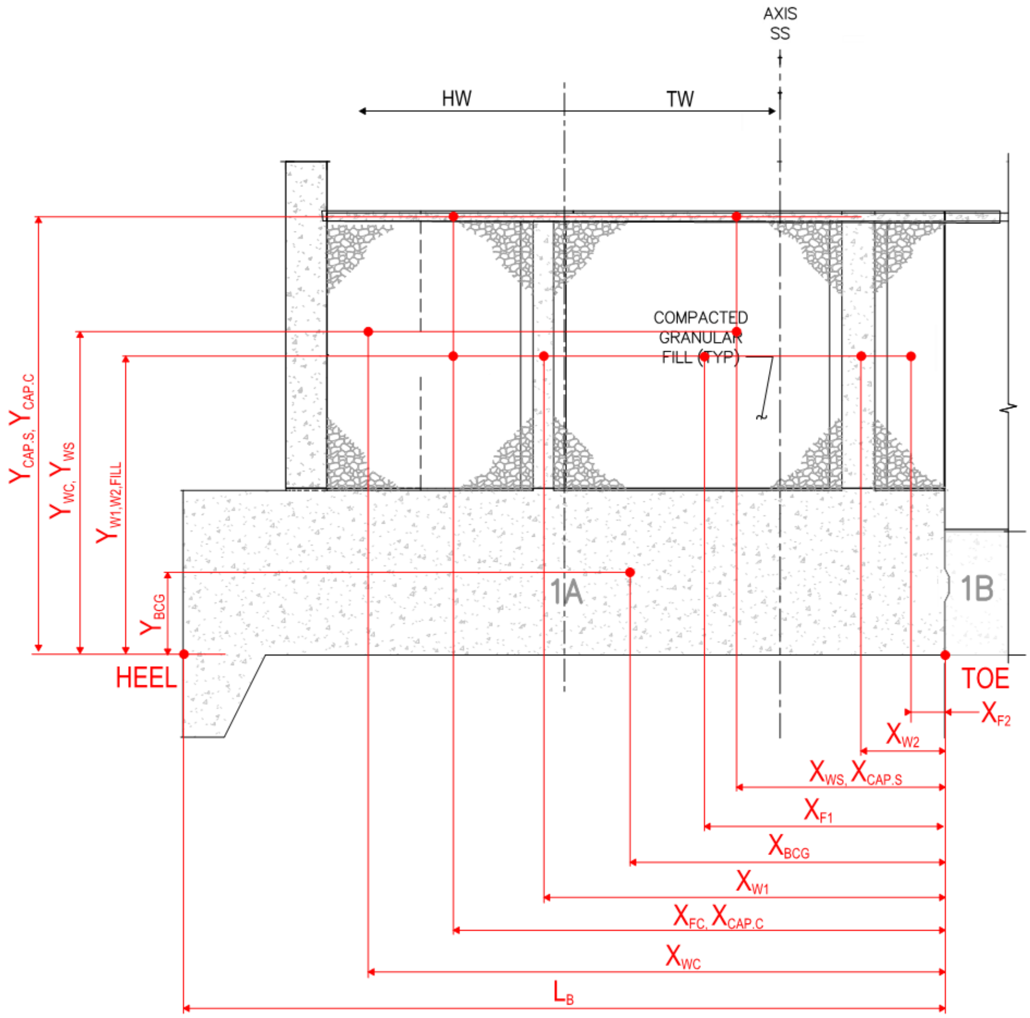
ROCK FILL DEAD LOADS

Rock Fill (Box 1): $D_{fill1} := V_{fill.1} \cdot \gamma_r = 10010 \cdot kN$

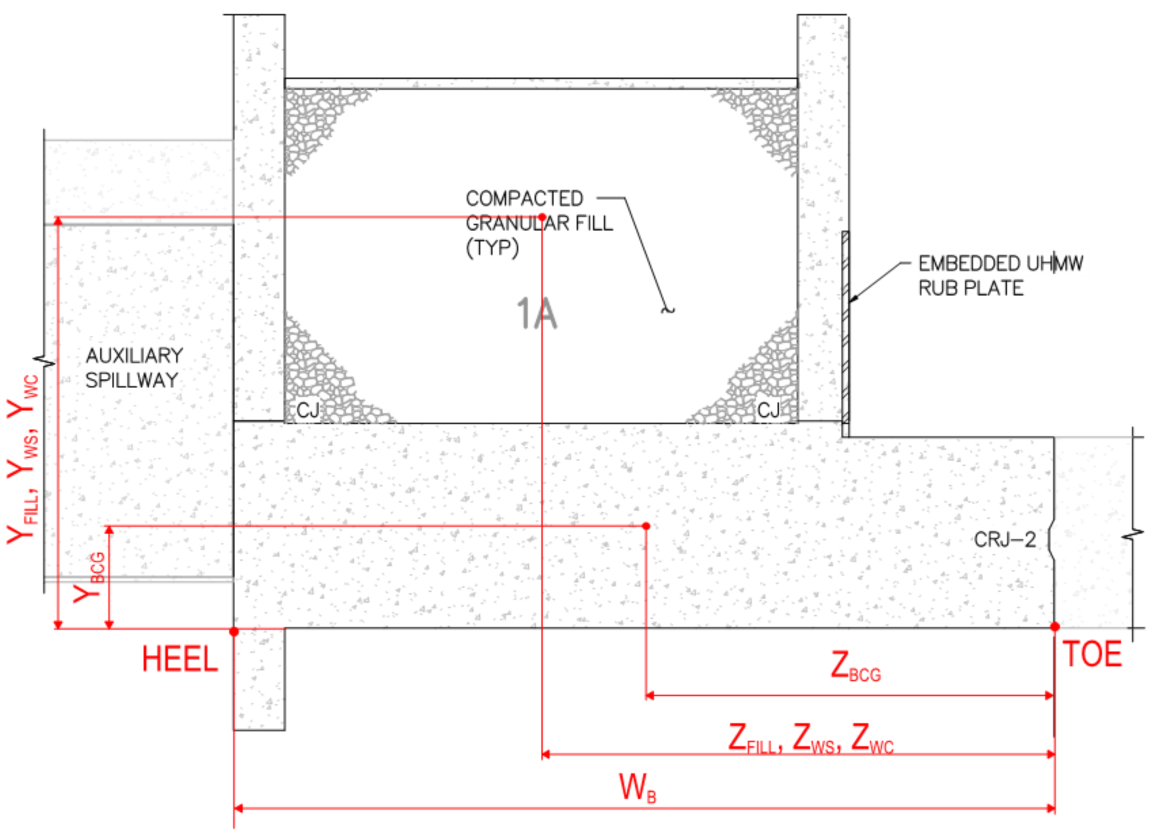
Rock Fill (Box 2): $D_{fill2} := V_{fill.2} \cdot \gamma_r = 2431 \cdot kN$

Rock Fill (Cylinder): $D_{fill.cyl} := V_{fill.cyl} \cdot \gamma_r = 5615.6 \cdot kN$

Total Rock Fill Dead Loads: $D_{fill} := D_{fill1} + D_{fill2} + D_{fill.cyl} = 18056.6 \cdot kN$



AXIS
SS
HW
TW
COMPACTED
GRANULAR
FILL (TYP)
1A
1B
HEEL
TOE
$Y_{CAP.S}, Y_{CAP.C}$
Y_{WC}, Y_{WS}
$Y_{W1,W2,FILL}$
Y_{BCG}
X_{F2}
X_{W2}
$X_{WS}, X_{CAP.S}$
X_{F1}
X_{BCG}
X_{W1}
$X_{FC}, X_{CAP.C}$
X_{WC}
L_B



COMPACTED
GRANULAR FILL
(TYP)
1A
EMBEDDED UHMW
RUB PLATE
AUXILIARY
SPILLWAY
CJ
CJ
CRJ–2
Y_{FILL}, Y_{WS}, Y_{WC}
Y_{BCG}
HEEL
TOE
Z_{BCG}
Z_{FILL}, Z_{WS}, Z_{WC}
W_B

MOMENT ARM FROM TOE TO COG OF COMPONENT (Concrete - Toe Lines in NW and NE edges)

Dist. from toe to COG Exterior Wall (Cylinder): $X_{WC} = 13.51\ m$ $\quad Z_{WC} := 4.0m + 6.0m = 10\ m$

Dist. from toe to COG Exterior Wall (Straight): $X_{WS} := 5.0m$ $\quad Z_{WS} := 10.0m$

Dist. from Toe to COG of Interior Wall 1: $X_{W1} := 9.75m$ $\quad Z_{W1} := 10.0m$

Dist. from Toe to COG of Interior Wall 2: $X_{W2} := 2.1m$ $\quad Z_{W2} := 10.0m$

Dist. from Toe to COG of Concrete Cap (Semicircle): $X_{CAP.C} := L_{wall} + \left(\frac{4 \cdot r_{cap.c}}{3 \cdot \pi}\right) = 12.12\ m$ $\quad Z_{CAP.C} := 10.0m$

Dist. from Toe to COG of Concrete Cap (Straight): $X_{CAP.S} := 5.0m$ $\quad Z_{CAP.S} := 10.0m$

Dist. from Toe to COG of Footing Base: $X_{BCG} = 8.98\ m$ $\quad Z_{BCG} = 7.77\ m$

Distance From Toe to COG of Concrete Dead Load :

$$X_{conc.loc} := \frac{\left(X_{WC} \cdot D_{w.cyl} + X_{WS} \cdot D_{w.s} + X_{W1} \cdot D_{i.w1} + X_{W2} \cdot D_{i.w2} + X_{CAP.C} \cdot D_{c.c} + X_{CAP.S} \cdot D_{c.s} + X_{BCG} \cdot D_{Fr} - X_{Crest} \cdot V_{Crest} \cdot \gamma_c\right)}{D_{conc}} = 8.81\ m$$

$$Z_{conc.loc} := \frac{\left(Z_{WC} \cdot D_{w.cyl} + Z_{WS} \cdot D_{w.s} + Z_{W1} \cdot D_{i.w1} + Z_{W2} \cdot D_{i.w2} + Z_{CAP.C} \cdot D_{c.c} + Z_{CAP.S} \cdot D_{c.s} + Z_{BCG} \cdot D_{Fr} - Z_{Crest} \cdot V_{Crest} \cdot \gamma_c\right)}{D_{conc}} = 8.46\ m$$

MOMENT ARM FROM TOE TO COG OF COMPONENT (Rock Fill)

Dist. from toe to Rock Fill (Box 1): $X_{F1} := 6.0m$ $\quad Z_{F1} := 10.0m$

Dist. from toe to Rock Fill (Box 2): $X_{F2} := 0.85m$ $\quad Z_{F2} := 10.0m$

Dist. from toe to Rock Fill (Cylinder): $X_{FC} := L_{wall} + \left(\frac{4 \cdot r_{wall} - w_{w.avg}}{3 \cdot \pi}\right) = 12.44\ m$ $\quad Z_{FC} := 10.0m$

Distance From Toe to COG of Rock Fill Dead Load :

$$X_{fill.loc} := \frac{X_{F1} \cdot D_{fill1} + X_{F2} \cdot D_{fill2} + X_{FC} \cdot D_{fill.cyl}}{D_{fill}} = 7.31\ m \qquad Z_{fill.loc} := \frac{Z_{F1} \cdot D_{fill1} + Z_{F2} \cdot D_{fill2} + Z_{FC} \cdot D_{fill.cyl}}{D_{fill}} = 10\ m$$

MOMENT ARM FROM BASE OF FOOTING TO COG OF COMPONENT (Concrete)

Dist. from Base to COG of Exterior Walls: $Y_{WALL} := \frac{h_w}{2} + 4 \cdot m = 8\ m$

Dist. from Base to COG of Interior Walls: $Y_{i.WALL} := \frac{h_{i.w}}{2} + 4 \cdot m = 7.25\ m$

Dist. from Base to COG of Concrete Cap: $Y_{CAP} := EL_{cap.top} - EL_{FTG.bot} - \frac{t_{cap}}{2} = 10.6\ m$

Dist. from Base to COG of Base Footing: $Y_{FTG} := \frac{t_{FTG}}{2} = 2\ m$

Distance Above Base to COG of Concrete Dead Load:

$$Y_{conc.loc} := \frac{\left[Y_{WALL} \cdot \left(D_{w.cyl} + D_{w.s}\right) + Y_{i.WALL} \cdot \left(D_{i.w1} + D_{i.w2}\right) + Y_{CAP} \cdot \left(D_{c.c} + D_{c.s}\right) + Y_{FTG} \cdot D_{Fr} - Y_{Crest} \cdot V_{Crest} \cdot \gamma_c\right]}{D_{conc}} = 3.62\ m$$

MOMENT ARM FROM BASE OF FOOTING TO COG OF COMPONENT (Rock Fill)

Dist. from Base to COG of Rock Fill: $Y_{fill.loc} := t_{FTG} + \frac{(EL_{cap.bot} - EL_{FTG.top})}{2} = 7.3\ m$

CREST GATE (OBERMEYER)

Dead Load of Gates: $D_{Gate} := 140kN \cdot \frac{4}{10} = 56 \cdot kN$ (Vendor supplied, Dwg. Q-200 Series)

Distance from Toe to COG of Gates: $X_{gate} := 9.50m$

Distance from Base to COG of Gates: $Y_{gate} := 4.0m$ Distance from base to right crest gate at EL 1215.0 (typ, uno), EL1213.5(UN1), EL.1210(UN3,F1)

Distance from Toe to COG of Gates: $Z_{gate} := 2.0m$

DEAD LOAD SUMMATION:

$$\Sigma V_{DL} := D_{conc} + D_{Gate} + D_{fill} = 54060.2 \cdot kN$$

$$\Sigma M_{DL.x} := D_{conc} \cdot X_{conc.loc} + D_{Gate} \cdot X_{gate} + D_{fill} \cdot X_{fill.loc} = 449331.29 \cdot kN \cdot m$$

$$\Sigma M_{DL.z} := D_{conc} \cdot Z_{conc.loc} + D_{Gate} \cdot Z_{gate} + D_{fill} \cdot Z_{fill.loc} = 484815.8 \cdot kN \cdot m$$

$$X_{mass} := \frac{\Sigma M_{DL.x}}{\Sigma V_{DL}} = 8.31\ m \qquad e_{DL.x} := X_{BCG} - \frac{\Sigma M_{DL.x}}{\Sigma V_{DL}} = 0.66\ m$$

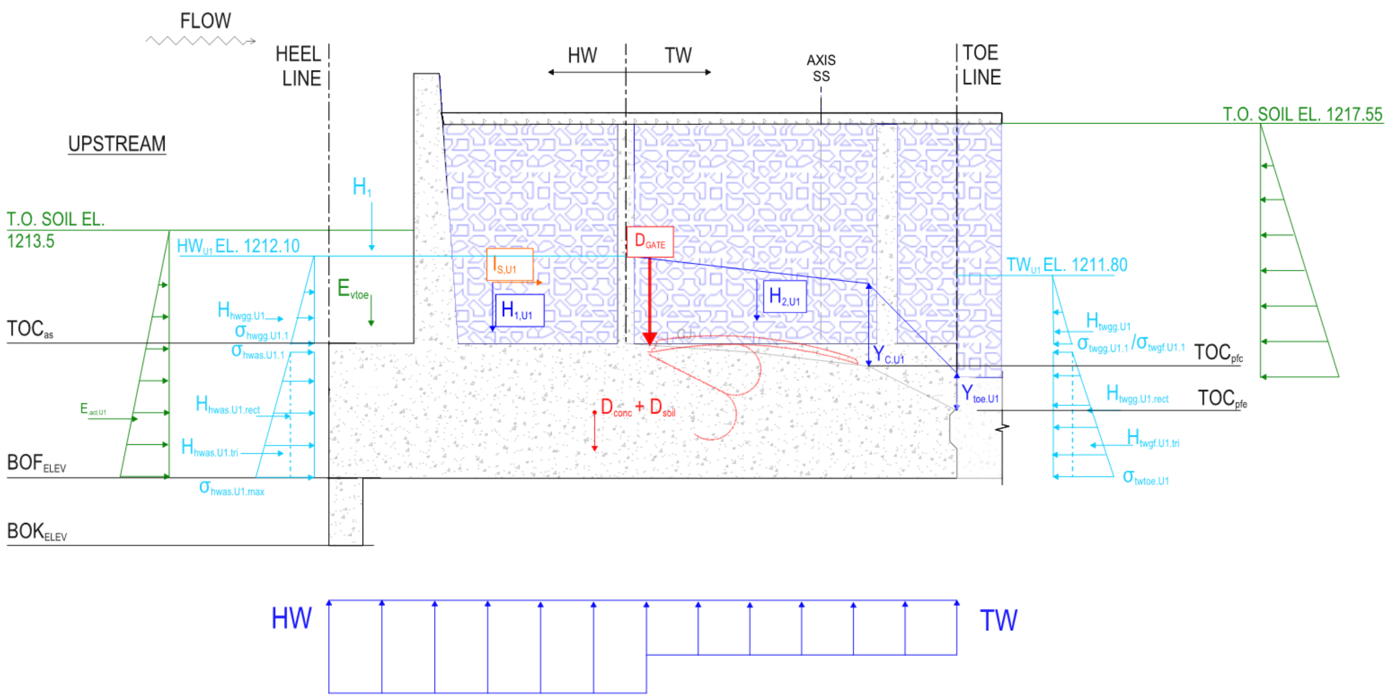
$$Z_{mass} := \frac{\Sigma M_{DL.z}}{\Sigma V_{DL}} = 8.97\ m \qquad e_{DL.z} := Z_{BCG} - \frac{\Sigma M_{DL.z}}{\Sigma V_{DL}} = -1.2\ m$$

$$\sigma_{toeheel.DL} := \frac{\Sigma V_{DL}}{A_b} - \frac{\Sigma V_{DL} \cdot e_{DL.x}}{S_{bx.L}} + \frac{\Sigma V_{DL} \cdot e_{DL.z}}{S_{bz.t}} = 59.42 \cdot kPa \qquad \sigma_{heel.DL} := \frac{\Sigma V_{DL}}{A_b} - \frac{\Sigma V_{DL} \cdot e_{DL.x}}{S_{bx.L}} - \frac{\Sigma V_{DL} \cdot e_{DL.z}}{S_{bz.b}} = 236.25 \cdot kPa$$

SERVICE SPILLWAY GATE STRUCTURE 2D HYDRAULIC MODEL RESULTS

Scenario	Total Inflow (m^3/s)	Service Spillway Discharge (m^3/s)			Headwater (m)	Service Spillway Tailwater (m)	Notes	Headwater at gate hinge (m)	Critical depth at gate lip (m)	Depth at Basin Toe (m)	SS Tailwater just passed basin end (m)*
		Left Gate	Right Gate	Total							
160 m^3/s, No Diversion, **(U1, E2-Q)**	160	91	69	160	1212.1	1211.8	Diversion Inlet gates closed and Service Spillway gates fully open	LG = RG d = 2.1 EL 1212.1	LG = RG y_c = 1.4; EL 1211.4	LG = RG, toe submerged Uplift = Use tailwater d_{toe} = 0.45; EL 1208.46	d_{tw} = 3.8 EL 1211.8
50-yr Event, Diverting up to 600 m^3/s **(U2, E3-Q)**	530	152	0	152	1214.6	1211.8	Diversion Inlet gates open, Service Spillway left crest gate at EL 1212.1 m and right crest gate at EL 1215.0 m	LG = RG d = 4.6 EL 1214.6	LG = y_c = 1.67; EL 1213.76 RG = Closed	LG = d_{toe} = 0.58; EL 1208.58 RG = Use tailwater Uplift = Use tailwater	d_{tw} = 3.8 EL 1211.8
100-yr Event, Service Spillway Construction/Maintenance, **(UN4)**	765	315	0	315	1215.0	1212.5	Diversion Inlet gates open, Service Spillway left crest gate at EL 1210.9 m and right crest gate at EL 1215.0 m	LG = RG d = 5.0 EL 1215.0	LG = y_c = 2.73; EL 1213.63 RG = Closed	LG = d_{toe} = 1.23 super; EL 1209.23 RG = Use tailwater Uplift = Use tailwater	d_{tw} = 3.9 EL 1211.9
2013 Event, Diverting up to 600 m^3/s **(UN1)**	1240	498	137	634	1215.8	1213.1	Diversion Inlet gates open; Service Spillway left crest gate at EL 1210.0 m and right crest gate at EL 1213.5 m	LG = RG d = 5.8 EL 1215.8	LG = y_c = 3.87; EL 1213.87 RG = y_c = 1.53; EL 1215.03	LG = d_{toe} = 1.95 super; EL 1209.95 RG = d_{toe} = 0.48 super; EL 1208.48 Uplift = Use tailwater	d_{tw} = 5.1 EL 1213.1
2013 Event, Diverting with One Service Spillway Crest Gate Failing to Open **(UN2)**	1240	518	44	562	1216.1	1213.0	Diversion Inlet gates open, Service Spillway left crest gate at EL 1210.0 m and right crest gate at EL 1215.0 m	LG = RG d = 6.1 EL 1216.1	LG = y_c = 4.07; EL 1214.07 RG = y_c = 0.73; EL 1215.73	LG = d_{toe} = 1.97 super; EL 1209.97 RG = Use tailwater Uplift = Use tailwater	d_{tw} = 5.0 EL 1213.0
1000-yr Event, No Diversion **(UN3)** Auxiliary Spillway cover eroded	1930	759	708	1467	1217.0	1214.7	Diversion Inlet gates closed and Service Spillway gates fully open. Auxiliary Spillway cover layer eroded	LG = RG d = 7.0 EL 1217.0	LG = RG y_c = 4.67; EL 1214.67	LG = RG d_{toe} = 2.89 super; EL 1210.89 Uplift = Use tailwater	d_{tw} = 6.7 EL 1214.7
Diversion Structure IDF Event, 1/3 Between 1000-yr and PMF, **(E1-F)** No Diversion. AS cover eroded.	2210	812	758	1570	1217.3	1214.9	Diversion Inlet gates closed and Service Spillway gates fully open. Auxiliary Spillway cover layer eroded	LG = RG d = 7.3 EL 1217.3	LG = RG y_c = 4.87; EL 1214.87	LG = RG d_{toe} = 3.06 super; EL 1211.06 Uplift = Use tailwater	d_{tw} = 6.9 EL 1214.9

U1 DESIGN CASE



ACCEPTANCE PARAMETERS

Required Factor of Safety for Sliding:	$FS_{req.U1.sl} := 1.5$	(Without Cohesion)
		(Section 8.1, Design Criteria)
Resultant Within Middle Third of Base:	$e \le \frac{L_B}{6} \wedge e \ge \frac{-L_B}{6}$	
Allowable Rock Bearing Pressure:	$\sigma_{allow.U1} := 1270 \cdot \frac{kN}{m^2}$	(Section 5.2, Design Criteria)
Required Factor of Safety for Flotation:	$FS_{req.U1.flt} := 1.5$	

INPUT PARAMETERS

Headwater Elevation:	$HW_{U1} := 1212.10m$	(Section 8.2, Design Criteria)
Tailwater Elevation:	$TW_{U1} := 1211.80m$	(Section 8.2, Design Criteria)
Bottom of Footing Elevation:	$BOF_{elev} := 1206.00m$	
Approch Slab Top of Concrete Elevation at Upstream Face:	$TOC_{as} := 1210.00m$	
Abutment Footing Top of Concrete Elevation at Stilling Basin:	$TOC_{afe} := 1208.00m$	
Abutment Footing Top of Concrete Elevation at Footing:	$TOC_{afc} := 1209.734m$	Gates are open when top of gate elevation is at 1210.00m
Abutment Footing Top of Concrete Elevation at Footing Notch:	$TOC_{afc.n} := 1209.30m$	
Top of Guard Gate Elevation:	$TOP_{gg.U1} := 1210.00m$	Gates are closed/up when top of gate elevation is at 1215.0m
Bottom of Key Elevation:	$BOK_{elev} := BOF_{elev} - d_{key} = 1204\,m$	

Water Elevation above Crest of Guard Gate:

$EL_{C.U1} := 1211.4m$

$$Y_{C.U1} := \begin{cases} (EL_{C.U1} - TOC_{afc.n}) & \text{if } TOP_{gg.U1} \le HW_{U1} \\ (TW_{U1} - TOC_{afc.n}) & \text{if } TOP_{gg.U1} > HW_{U1} \end{cases} = 2.1 \cdot m$$

Water Elevation above Guard Gate Toe: Submerged by Hydraulic 2D Model

$EL_{TOE.U1} := 1208.46m$

$$Y_{TOE.U1} := \begin{cases} (EL_{TOE.U1} - TOC_{afe}) & \text{if } TOP_{gg.U1} \le HW_{U1} \\ (TW_{U1} - TOC_{afe}) & \text{if } TOP_{gg.U1} > HW_{U1} \end{cases} = 0.46 \cdot m$$

LATERAL WATER LOADS

HEADWATER (DRIVING X-DIRECTION):

Headwater Depth on Abutment: $D_{hwa.U1} := HW_{U1} - TOC_{as} = 2.10\ m$

Headwater Load Unit Width Projected Surface Area of Abutment: $W_{hwa.U1} := 2 \cdot r_{wall} = 12.00\ m$

Total Horizontal Headwater Load on Abutment:

$$H_{hwa.U1} := \frac{-\left(\gamma_w \cdot D_{hwa.U1}^{\ 2}\right)}{2} \cdot W_{hwa.U1} = -259.6 \cdot kN$$

Apply Total Abutment Headwater Load at:

$$H_{hwa.U1.loc} := \frac{D_{hwa.U1}}{3} + \left(TOC_{as} - BOF_{elev}\right) = 4.70\ m$$

Apply Total Abutment Headwater Load at (from toe):

$H_{hwa.U1.loc.z} := 4m + r_{wall} = 10.00\ m$ (Gate Footing + Radius of Wall)

Thickness of Approach Slab: $T_{as} := \left(TOC_{as} - BOF_{elev}\right) = 4\ m$

Headwater Depth at Heel (U/S face): $D_{hwas.U1} := HW_{U1} - BOF_{elev} = 6.10\ m$

Headwater Load Unit Width on Projected Approach Slab: $W_{hwas.U1} := W_B = 16.00\ m$

Headwater Line Load At Top of Approach Slab: $\sigma_{hwas.U1.1} := -\left(\gamma_w \cdot D_{hwa.U1}\right) = -20.6 \cdot kPa$

Headwater Load At Bottom Elevation of Approach Slab: $\sigma_{hwas.U1.2} := -\left(\gamma_w \cdot D_{hwas.U1}\right) = -59.84 \cdot kPa$

Trianglular Distribution Unit Load on Approach Slab:

$$H_{hwas.U1.2.tri} := \left(\frac{\sigma_{hwas.U1.2} - \sigma_{hwas.U1.1}}{2}\right) \cdot \left(T_{as} \cdot W_{hwas.U1}\right) = -1255.68 \cdot kN$$

Rectangular Distribution Unit Load on Approach Slab:

$$H_{hwas.U1.2.rect} := \sigma_{hwas.U1.1} \cdot \left(T_{as} \cdot W_{hwas.U1}\right) = -1318.46 \cdot kN$$

Total Horizontal Headwater Load on Approach Slab:

$$H_{hwas.U1} := H_{hwas.U1.2.tri} + H_{hwas.U1.2.rect} = -2574.14 \cdot kN$$

Apply Total Footing Headwater Load at:

$$H_{hwas.U1.loc} := \frac{\left[H_{hwas.U1.2.rect} \cdot \frac{\left(T_{as}\right)}{2} + H_{hwas.U1.2.tri} \cdot \frac{\left(T_{as}\right)}{3}\right]}{H_{hwas.U1.2.tri} + H_{hwas.U1.2.rect}} = 1.67\ m$$

Apply Total Footing Headwater Load at (from toe):

$$H_{hwas.U1.loc.z} := \frac{W_B}{2} = 8.00\ m$$

Guard Gate (2A) Operating Condition: U1 - Fully Open

Guard Gate Down/Open Condition: $A1_{U1} := TOP_{gg.U1} \le TOC_{as}$

Guard Crest Gate Up/Closed, with Top of Gate Higher than HW Elevation: $B1_{U1} := TOP_{gg.U1} \ge HW_{U1} \wedge TOP_{gg.U1} > TOC_{as}$

Guard Crest Gate Up/Closed, with Top of Gate Lower than HW Elevation: $C1_{U1} := TOP_{gg.U1} > TOC_{as} \wedge HW_{U1} > TOP_{gg.U1}$

Guard Crest Gate Height: $H_{gg.U1} := TOP_{gg.U1} - TOC_{as} = 0\,m$

Headwater Depth at Guard Crest Gate: $D_{hwgg.U1} := HW_{U1} - TOC_{as} = 2.10\,m$

Guard Crest Gate Width: $W_{hwgg.U1} := 4m$

Lateral Headwater Pressure at Bottom of Guard Crest Gate:

$$\sigma_{hwgg.U1.1} := \begin{cases} (0.0kPa) & \text{if } A1_{U1} \\ -(\gamma_w \cdot D_{hwgg.U1}) & \text{if } B1_{U1} \\ -(\gamma_w \cdot D_{hwgg.U1}) & \text{if } C1_{U1} \end{cases} = 0.0 \cdot kPa$$

Lateral Headwater Pressure at Top of Guard Crest Gate: (Load at HW Elevation On Guard Crest Gate if HW is below TOG_{rg})

$$\sigma_{hwgg.U1.2} := \begin{cases} (0.0kPa) & \text{if } A1_{U1} \\ 0.0kPa & \text{if } B1_{U1} \\ -[\gamma_w \cdot (HW_{U1} - TOP_{gg.U1})] & \text{if } C1_{U1} \end{cases} = 0.0 \cdot kPa$$

Average Pressure acting on Guard Crest Gate:

$$\sigma_{hwgg.U1.avg} := \frac{(\sigma_{hwgg.U1.1} + \sigma_{hwgg.U1.2})}{2} = 0 \cdot kPa$$

Total Area water acting on Crest Gate:

$$A_{hwgg.U1} := \begin{cases} D_{hwgg.U1} \cdot W_{hwgg.U1} & \text{if } A1_{U1} \\ D_{hwgg.U1} \cdot W_{hwgg.U1} & \text{if } B1_{U1} \\ H_{gg.U1} \cdot W_{hwgg.U1} & \text{if } C1_{U1} \end{cases} = 8.4 \cdot m^2$$

Total Horizontal Headwater Load on Guard Crest Gate: $H_{hwgg.U1} := \sigma_{hwgg.U1.avg} \cdot A_{hwgg.U1} = 0.0 \cdot kN$

Apply Total Guard Crest Gate Headwater Load at:

$$H_{hwgg.U1.loc} := \begin{cases} (TOC_{as} - BOF_{elev}) & \text{if } A1_{U1} \\ \left[\frac{(HW_{U1} - TOC_{as})}{3} + (TOC_{as} - BOF_{elev})\right] & \text{if } B1_{U1} \\ \left[\frac{\sigma_{hwgg.U1.2} \cdot A_{hwgg.U1} \cdot \frac{(H_{gg.U1})}{2} + \frac{(\sigma_{hwgg.U1.1} - \sigma_{hwgg.U1.2})}{2} A_{hwgg.U1} \cdot \frac{(H_{gg.U1})}{3}}{\sigma_{hwgg.U1.2} \cdot A_{hwgg.U1} + \frac{(\sigma_{hwgg.U1.1} - \sigma_{hwgg.U1.2})}{2} \cdot A_{hwgg.U1}} \ldots + (TOC_{as} - BOF_{elev})\right] & \text{if } C1_{U1} \end{cases} = 4.0 \cdot m$$

Apply Total Guard Crest Gate Headwater Load at (From toe):

$$H_{hwgg.U1.loc.z} := \frac{W_{hwgg.U1}}{2} = 2\,m$$

LATERAL TAILWATER (RESISTING) Applied to Downstream Side of Guard Crest Gate: U1 CASE

Guard Gate Down/Open Condition: $A2_{U1} := TOP_{gg.U1} \le TOC_{as}$

Guard Crest Gate Up/Closed, with Top of Gate Higher than TW Elevation: $B2_{U1} := TOP_{gg.U1} \ge TW_{U1} \wedge TOP_{gg.U1} > TOC_{as}$

Guard Crest Gate Up/Closed, with Top of Gate Lower than TW Elevation: $C2_{U1} := TOP_{gg.U1} > TOC_{as} \wedge TW_{U1} > TOP_{gg.U1}$

Tailwater Depth at Guard Crest Gate: $D_{twgg.U1} := TW_{U1} - TOC_{as} = 1.80\ m$

Guard Crest Gate Height: $H_{gg.U1} = 0\ m$

Guard Crest Gate Width: $W_{twgg.U1} := 4.0m$

Lateral Water Load at Bottom of Guard Crest Gate:

$$\sigma_{twgg.U1.1} := \begin{vmatrix} (0.0kPa) & \text{if} & A2_{U1} \\ (\gamma_w \cdot D_{twgg.U1}) & \text{if} & B2_{U1} \\ (\gamma_w \cdot D_{twgg.U1}) & \text{if} & C2_{U1} \end{vmatrix} = 0.0 \cdot kPa$$

Lateral Water Load at Top of Guard Crest Gate:
(Load at TW Elevation On Guard Crest Gate if TW is below TOG_{gg})

$$\sigma_{twgg.U1.2} := \begin{vmatrix} (0.0kPa) & \text{if} & A2_{U1} \\ 0.0kPa & \text{if} & B2_{U1} \\ \left[\gamma_w \cdot (TW_{U1} - TOP_{gg.U1})\right] & \text{if} & C2_{U1} \end{vmatrix} = 0.0 \cdot kPa$$

Average Pressure acting on Guard Crest Gate:

$$\sigma_{twgg.U1.avg} := \frac{(\sigma_{twgg.U1.1} + \sigma_{twgg.U1.2})}{2} = 0 \cdot kPa$$

Total Area water acting on Crest Gate:

$$A_{twgg.U1} := \begin{vmatrix} D_{twgg.U1} \cdot W_{twgg.U1} & \text{if} & A2_{U1} \\ D_{twgg.U1} \cdot W_{twgg.U1} & \text{if} & B2_{U1} \\ H_{gg.U1} \cdot W_{twgg.U1} & \text{if} & C2_{U1} \end{vmatrix} = 7.2 \cdot m^2$$

Total Horizontal Headwater Load on Guard Crest Gate: $H_{twgg.U1} := \sigma_{twgg.U1.avg} \cdot A_{twgg.U1} = 0.0 \cdot kN$

Apply Total Horiz. TW Load on Guard Gate at:

$$H_{twgg.U1.loc} := \begin{vmatrix} (TOC_{as} - BOF_{elev}) & \text{if} & A2_{U1} \\ \left[\frac{(TW_{U1} - TOC_{as})}{3} + (TOC_{as} - BOF_{elev})\right] & \text{if} & B2_{U1} \\ \left[\frac{\sigma_{twgg.U1.2} \cdot A_{twgg.U1} \cdot \frac{(H_{gg.U1})}{2} + \frac{(\sigma_{twgg.U1.1} - \sigma_{twgg.U1.2})}{2} \cdot A_{twgg.U1} \cdot \frac{(H_{gg.U1})}{3}}{\sigma_{twgg.U1.2} \cdot A_{twgg.U1} + \frac{(\sigma_{twgg.U1.1} - \sigma_{twgg.U1.2})}{2} \cdot A_{twgg.U1}} \dots + (TOC_{as} - BOF_{elev})\right] & \text{if} & C2_{U1} \end{vmatrix} = 4.0 \cdot m$$

Apply Total Guard Crest Gate Headwater Load at (From toe): $H_{twgg.U1.loc.z} := \frac{W_{twgg.U1}}{2} = 2\ m$

LATERAL WATER LOADS (continued)

U1 CASE

TAILWATER (RESISTING) Applied to Concrete Strucuture:

Tailwater Depth on Top of Abutment Footing: $D_{twa.U1} := TW_{U1} - TOC_{as} = 1.80\ m$

Tailwater Load Unit Width on Abutment: $W_{twa.U1} := 2 \cdot r_{wall} = 12.00\ m$

Total Horizontal Tailwater Load on Abutment: $H_{twa.U1} := \frac{\left(\gamma_w \cdot D_{twa.U1}{}^2\right)}{2} \cdot W_{twa.U1} = 190.7 \cdot kN$

Apply Total Abutment Tailwater Load at: $H_{twa.U1.loc} := \frac{D_{twa.U1}}{3} + \left(TOC_{as} - BOF_{elev}\right) = 4.60\ m$

Apply Total Abutment Tailwater Load at (from Toe Line): $H_{twa.U1.loc.z} := W_{twgg.U1} + r_{wall} = 10\ m$

Footing Thickness for horizontal at Toe: $h_{toe} := TOC_{as} - BOF_{elev} = 4\ m$

Tailwater Depth At top of Gate Base Footing Elevation: $D_{twgf.U1} := TW_{U1} - TOC_{as} = 1.80\ m$

Water Depth at bottom of Gate Base Footing (Excluding Key): $D_{twtoe.U1} := TW_{U1} - BOF_{elev} = 5.80\ m$

Unit Width of D/S face of crest for applicaiton of Tailwater Load: $W_{tw.U1} := W_B = 16.00\ m$

Tailwater Pressure At Top of Gate Footing: $\sigma_{twgf.U1} := \left(\gamma_w \cdot D_{twgf.U1}\right) = 17.66 \cdot kPa$

Tailwater Line Load At Bottom of Gate Footing (Excluding Key): $\sigma_{twtoe.U1} := \left(\gamma_w \cdot D_{twtoe.U1}\right) = 56.9 \cdot kPa$

Trianglular Distribution Unit Load on Gate Footing Base: $H_{twgf.U1.tri} := \left(\frac{\sigma_{twtoe.U1} - \sigma_{twgf.U1}}{2}\right) \cdot \left[\left(T_{as}\right) \cdot W_{tw.U1}\right] = 1255.68 \cdot kN$

Rectangular Distribution Unit Load on Gate Footing Base: $H_{twgf.U1.rect} := \sigma_{twgf.U1} \cdot \left[\left(T_{as}\right) \cdot W_{tw.U1}\right] = 1130.11 \cdot kN$

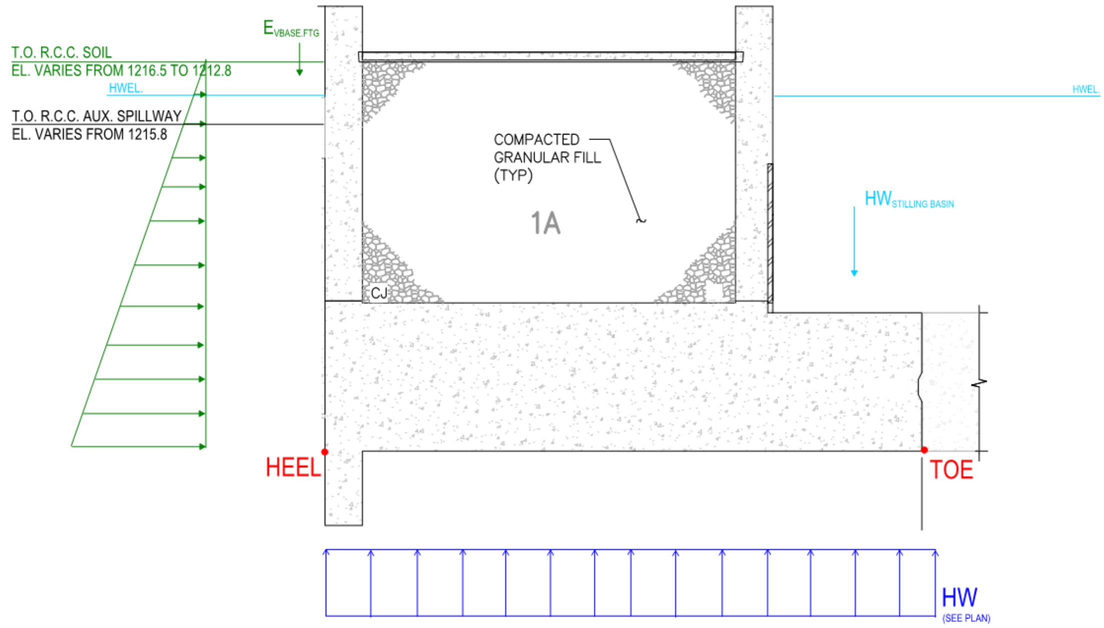
Total Horizontal Tailwater Headwater Load on Gate Footing: $H_{twgf.U1} := H_{twgf.U1.tri} + H_{twgf.U1.rect} = 2385.79 \cdot kN$

Apply Total Gate Footing Tailwater Load at:

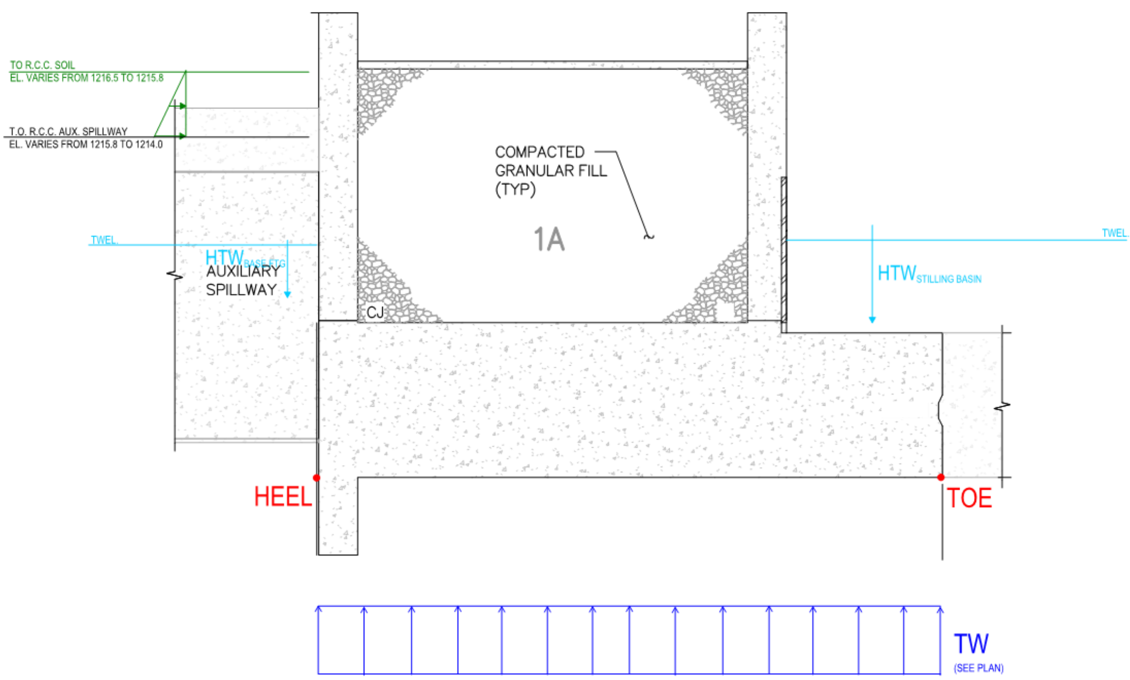
$$H_{twgf.U1.loc} := \frac{\left[H_{twgf.U1.rect} \cdot \frac{\left(T_{as}\right)}{2} + H_{twgf.U1.tri} \cdot \frac{\left(T_{as}\right)}{3}\right]}{H_{twgf.U1.tri} + H_{twgf.U1.rect}} = 1.65\ m$$

Apply Total Gate Footing Tailwater Load at (From Toe Line): $H_{twgf.U1.loc.z} := \frac{W_B}{2} = 8.00\ m$

SUMMATION OF LATERAL WATER LOADS: U1 CASE



SECTION 1A BEFORE GATES & AUX. SPILLWAY RCC



SECTION 1A AFTER GATES & AUX. SPILLWAY RCC

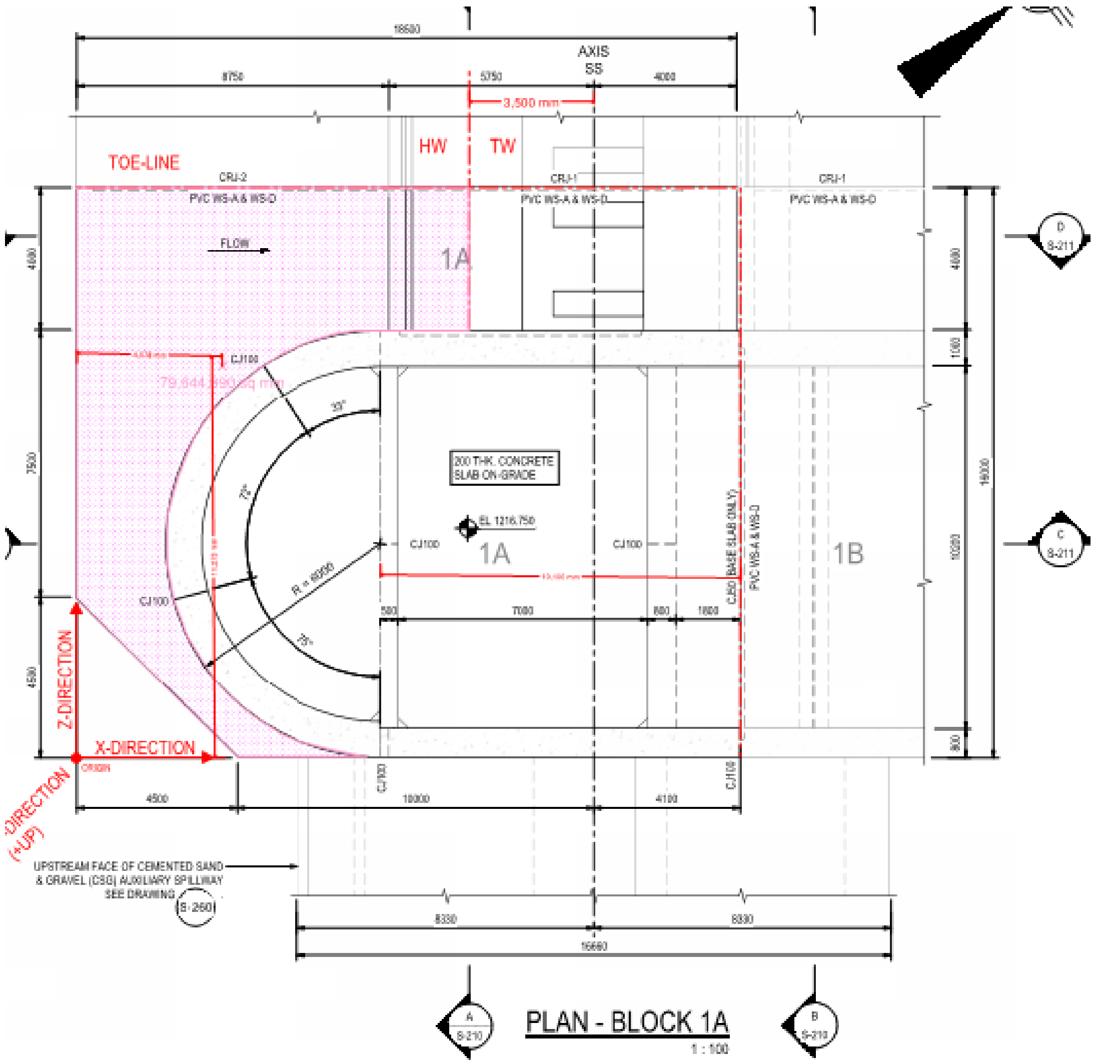
$$\Sigma H_{Water.U1.x} := H_{hwa.U1} + H_{hwas.U1} + H_{hwgg.U1} + H_{twa.U1} + H_{twgf.U1} + H_{twgg.U1} = -257.22 \cdot kN$$

$$\Sigma M_{HWater.U1.x} := H_{hwa.U1} \cdot H_{hwa.U1.loc} + H_{hwas.U1} \cdot H_{hwas.U1.loc} + H_{hwgg.U1} \cdot H_{hwgg.U1.loc} \cdots + H_{twa.U1} \cdot H_{twa.U1.loc} + H_{twgf.U1} \cdot H_{twgf.U1.loc} + H_{twgg.U1} \cdot H_{twgg.U1.loc} = -719.45 \cdot kN \cdot m$$

$\Sigma H_{Water.U1.z} := 0kN$ $\Sigma M_{HWater.U1.z} := 0 \cdot kN \cdot m$

VERTICAL WATER LOADS

U1 CASE



HEADWATER:

Water Depth on top of Approach Slab: $d_{hw.U1} := HW_{U1} - TOC_{as} = 2.10\ m$

Water Area on top of Approach Slab: $A_{as} := 79.645m^2$ (From Geom. Scaled on REVU)

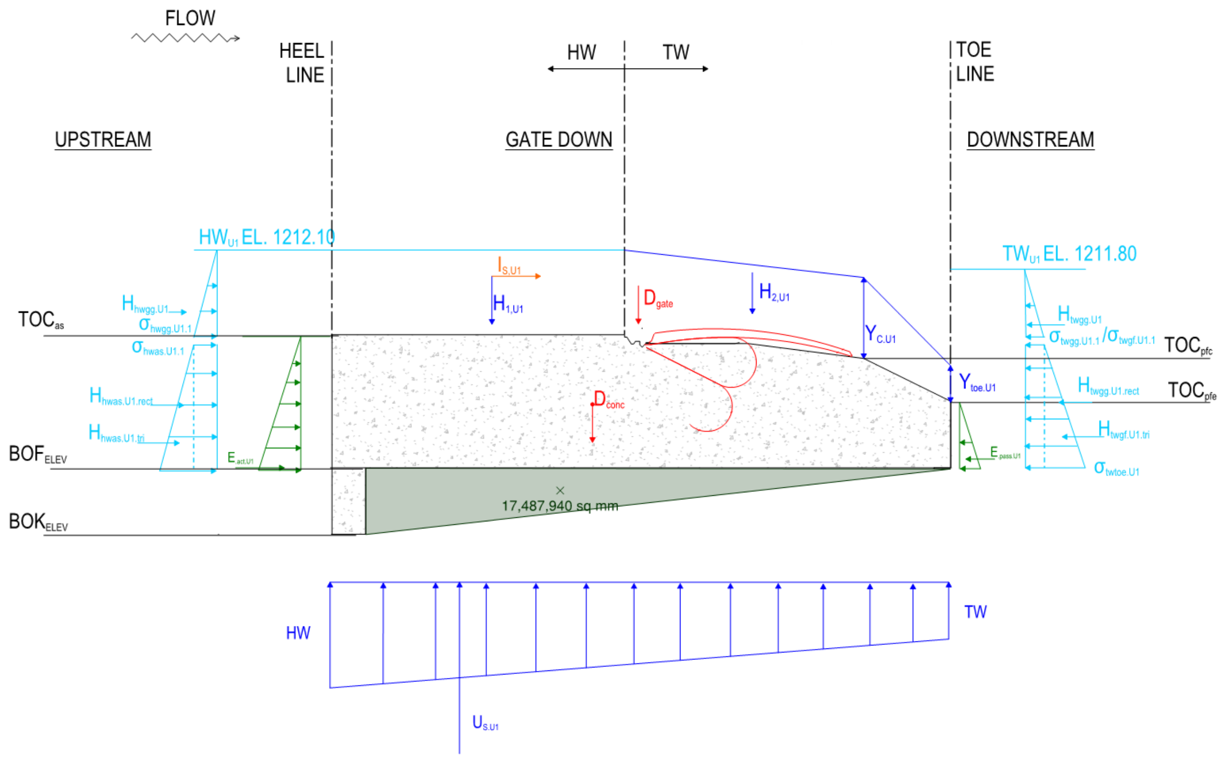
Vertical Water Weight (H1) on Approach Slab: $H_{1.U1} := \left(A_{as} \cdot d_{hw.U1}\right) \cdot \gamma_w = 1640.8 \cdot kN$

Moment Arm for Applicaiton of Water Weight (H1) from toe (X-Direction): $H_{1.U1.loc.x} := L_B - 4.078m = 14.42\ m$ (From Geom. Scaled on REVU)

Moment Arm for Applicaiton of Water Weight (H1) from toe (Z-Direction): $H_{1.U1.loc.z} := W_B - 11.273m = 4.73\ m$ (From Geom. Scaled on REVU)

VERTICAL WATER LOADS

TAILWATER:



Approach Slab Length: $L_{as} := 8.75\text{m}$

Gate Footing Length: $L_{gf} := L_B - L_{as} = 9.75\ \text{m}$

Gate Footing Crest Length: $L_{gfc} := 2.25\text{m}$

TAILWATER:

Trapezoid Volume Above Gate Footing from Approach Slab to Crest:

$$V_{asc.U1} := \left(L_{gf} - L_{gfc}\right) W_{twgg.U1} \frac{d_{hw.U1} + Y_{C.U1}}{2} = 63 \cdot m^3$$

Trapezoid Volume Above Gate Footing Crest to End of Gate Footing:

$$V_{gfc.U1} := \left(L_{gfc} \cdot W_{twgg.U1}\right) \frac{Y_{C.U1} + Y_{TOE.U1}}{2} = 11.52 \cdot m^3$$

Load Above Gate Footing from Approach Slab to Crest:

$$H_{2.U1.asc} := V_{asc.U1} \cdot \gamma_w = 618.03 \cdot kN$$

Load Acting Above Footing Crest from Toe:

$$H_{2.U1.asc.loc.x} := \frac{\left(L_{gf} - L_{gfc}\right) \cdot \left(2 \cdot d_{hw.U1} + Y_{C.U1}\right)}{3 \cdot \left(d_{hw.U1} + Y_{C.U1}\right)} + L_{gfc} = 6\ m$$

Load Above Gate Footing from Crest to End:

$$H_{2.U1.gfc} := V_{gfc.U1} \cdot \gamma_w = 113.01 \cdot kN$$

Load Acting Above Gate Footing from Crest to End:

$$H_{2.U1.gfc.loc.x} := \frac{\left(L_{gfc}\right) \cdot \left(2 \cdot Y_{C.U1} + Y_{TOE.U1}\right)}{3 \cdot \left(Y_{C.U1} + Y_{TOE.U1}\right)} = 1.37\ m$$

Vertical Water Weight (H2) on Gate Footing:

$$H_{2.U1} := H_{2.U1.asc} + H_{2.U1.gfc} = 731.04 \cdot kN$$

Moment Arm for Application of Water Weight (H2) from toe:

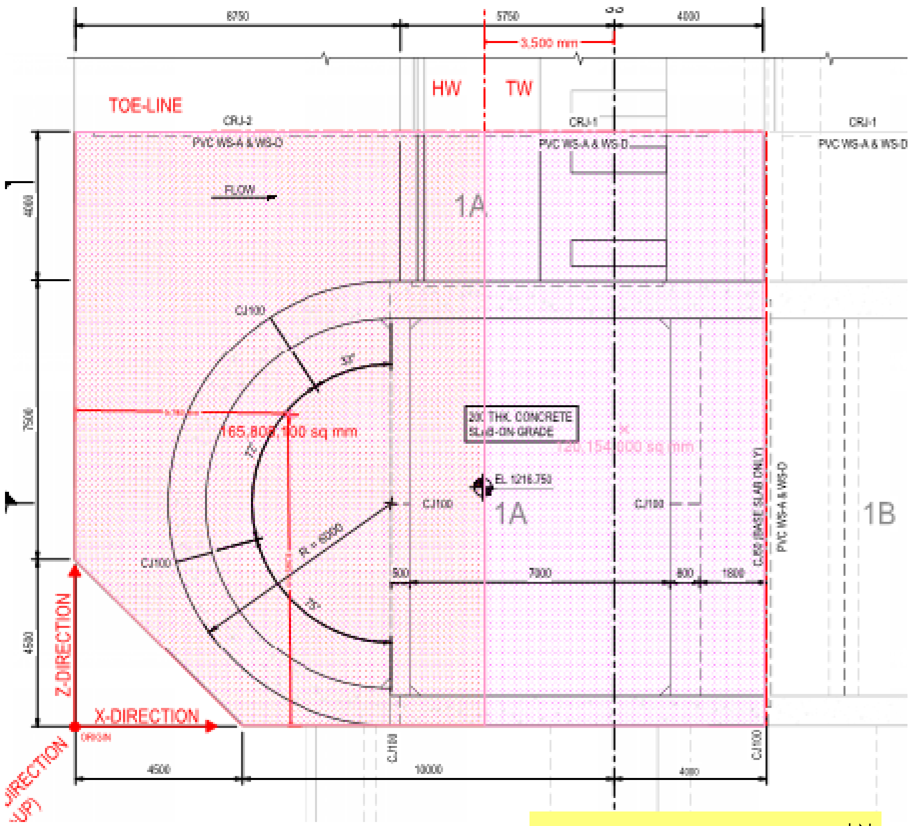
$$H_{2.U1.loc.x} := \frac{H_{2.U1.asc} \cdot H_{2.U1.asc.loc.x} + H_{2.U1.gfc} \cdot H_{2.U1.gfc.loc.x}}{H_{2.U1}} = 5.28\ m$$

Moment Arm for Applicaiton of Water Weight (H2) from toe (Z-Direction): $H_{2.U1.loc.z} := 2.0\text{m}$

UPLIFT

U1 CASE

(Assuming constant Headwater Uplift at front and constant Tailwater Uplift at back of footing base)



Uplift pressure at U/S Face (heel): $U_{HW.U1} := D_{hwas.U1} \cdot \gamma_w = 59.8 \cdot \frac{kN}{m^2}$

Uplift pressure at D/S Face Stilling Basin: $U_{TW.U1} := D_{twtoe.U1} \cdot \gamma_w = 56.9 \cdot \frac{kN}{m^2}$

Area of Uplift Force From Headwater Side: $A_{HWU.U1} := 165.81 m^2$ (From Bluebeam REVU)

Area of Uplift Force From Tailwater Side: $A_{TWU.U1} := 7.5 \cdot 16 m^2 = 120 m^2$ (From Bluebeam REVU)

Uplift Force From Headwater Side: $U_{A.U1} := -U_{HW.U1} \cdot A_{HWU.U1} = -9922.24 \cdot kN$

Uplift Force From Headwater Side: $U_{B.U1} := -U_{TW.U1} \cdot A_{TWU.U1} = -6827.76 \cdot kN$

Uplift Centroid of Area From Headwater Side to Toe: $X_{U.A} := L_B - 5.280 \cdot m = 13.22 m$ $\quad Z_{U.A} := 7.635m$ (From Bluebeam REVU)

Uplift Centroid of Area From Tailwater Side to Toe: $X_{U.B} := \frac{7.5}{2} m = 3.75 m$ $\quad Z_{U.B} := 8m$ (From Bluebeam REVU)

Total Resultant Uplift force: $U_{U1} := U_{A.U1} + U_{B.U1} = -16750 \cdot kN$

Resultant Location from Toe Rect. Load (X-Direction): $U_{U1.loc.x} := \frac{(U_{A.U1} \cdot X_{U.A} + U_{B.U1} \cdot X_{U.B})}{(U_{A.U1} + U_{B.U1})} = 9.36 m$

Resultant Location from Toe Rect. Load (Z-Direction): $U_{U1.loc.z} := \frac{[U_{A.U1} \cdot (W_B - Z_{U.A}) + U_{B.U1} \cdot (W_B - Z_{U.B})]}{(U_{A.U1} + U_{B.U1})} = 8.22 m$

$\Sigma V_{water.U1} := H_{1.U1} + H_{2.U1} + U_{U1} = -14378.19 \cdot kN$

$\Sigma M_{Vwater.U1.x} := H_{1.U1} \cdot H_{1.U1.loc.x} + H_{2.U1} \cdot H_{2.U1.loc.x} + U_{U1} \cdot U_{U1.loc.x} = -129250.46 \cdot kN \cdot m$

$\Sigma M_{Vwater.U1.z} := H_{1.U1} \cdot H_{1.U1.loc.z} + H_{2.U1} \cdot H_{2.U1.loc.z} + U_{U1} \cdot U_{U1.loc.z} = -128403.6 \cdot kN \cdot m$

SOIL LOADS

U1 CASE

Equivalent Fluid Pressure (EFP):

At rest lateral pressure coefficient: $K_{o.U1} := 1 - \sin(\phi_{backfill}) = 0.658$ (Section 5.3, Design Criteria)

$K_{o.U1.r} := 1 - \sin(\phi_{rock}) = 0.56$

Headwater Top of Soil Elevation: $TOS_{HW} := 1210.0m$

Top of Backfill Soil Elevation: $TOS_{BF} := EL_{cap.bot} = 1216.5\,m$

Driving Soil Load Unit Width Projected Surface Area of Abutment: $W_{ds.hwa.U1} := 6.0m$

Driving Soil Load Unit Width on Projected Approach Slab: $W_{hwas.U1} = 16.00\,m$

Resisting Soil Load Unit Width Projected Surface Area of Abutment: $W_{rsa.U1} := \dfrac{10.5m + 9.381m}{2} = 9.94\,m$ (From Section Cut)

Driving Soil Load Depth on Abutment: $d_{DS.a} := TOS_{HW} - EL_{FTG.top} = 0\,m$

Driving Soil Load Depth on Footing: $d_{DS.as} := TOS_{HW} - EL_{FTG.bot} = 4\,m$

Resisting Soil Load Depth on Abutment: $d_{RS.a} := TOS_{BF} - TOC_{afe} = 8.5\,m$

Thickness of Stilling Basin: $T_{sb} := TOC_{afe} - EL_{FTG.bot} = 2\,m$

Lateral X-Direction Driving Force (Headwater Side - at rest condition)

At-Rest Soil Load on Half of Abutment: $E_{act.a.U1.x} := \dfrac{\left(K_{o.U1} \cdot d_{DS.a}{}^{2}\right)}{2} \cdot (\gamma_r - \gamma_w) \cdot W_{ds.hwa.U1} \cdot -1 = 0 \cdot kN$

Acting at: $E_{act.a.U1.x.loc.y} := \dfrac{d_{DS.a}}{3} + T_{as} = 4.00\,m$

Acting at (from Toe Line): $E_{act.a.U1.x.loc.z} := W_{hwgg.U1} + r_{wall} = 10.00\,m$

At-Rest Soil Load on Top of Approach Slab: $\sigma_{DS.as.U1} := (K_{o.U1} \cdot d_{DS.a}) \cdot (\gamma_r - \gamma_w) = 0 \cdot kPa$

At-Rest Soil Load on Bottom of Approach Slab: $\sigma_{DS.key.U1} := (K_{o.U1} \cdot d_{DS.as}) \cdot (\gamma_r - \gamma_w) = 32.08 \cdot kPa$

At-Rest Soil Load on Approach Slab (Rect): $E_{act.as.rect.U1.x} := \sigma_{DS.as.U1} \cdot (T_{as}) \cdot W_{hwas.U1} \cdot -1 = 0 \cdot kN$

At-Rest Soil Load on Approach Slab(Tri): $E_{act.as.tri.U1.x} := \dfrac{(\sigma_{DS.key.U1} - \sigma_{DS.as.U1}) \cdot (T_{as})}{2} \cdot W_{hwas.U1} \cdot -1 = -1026.66 \cdot kN$

Total At-Rest Soil Load on Approach Slab : $E_{act.as.U1.x} := E_{act.as.rect.U1.x} + E_{act.as.tri.U1.x} = -1026.66 \cdot kN$

Acting at: $$E_{act.as.U1.x.loc.y} := \dfrac{\left(E_{act.as.rect.U1.x} \cdot \dfrac{T_{as}}{2} \ldots + E_{act.as.tri.U1.x} \cdot \dfrac{T_{as}}{3}\right)}{E_{act.as.U1.x}} = 1.33\,m$$

Acting at (from Toe Line): $E_{act.as.U1.x.loc.z} := \dfrac{W_B}{2} = 8.00\,m$ $d_{RS.a} = 8.5\,m$

Lateral X-Direction Resisting Force (Tailwater Side - at rest condition)

U1 CASE

At-rest Soil Load: $E_{pass.U1.x} := \frac{\left(K_{o.U1} \cdot d_{RS.a}^{2}\right)}{2} \cdot \left(\gamma_r - \gamma_w\right) \cdot W_{rsa.U1} = 2880.26 \cdot kN$

Acting at: $E_{pass.U1.x.loc.y} := \frac{d_{RS.a}}{3} + T_{sb} = 4.83\,m$

$W_{rsa.U1} = 9.94\,m$

Acting at (from Toe Line): $E_{pass.U1.x.loc.z} := W_{hwgg.U1} + r_{wall} = 10\,m$

$\Sigma H_{soil.U1.x} := \left(E_{act.a.U1.x} + E_{act.as.U1.x} + E_{pass.U1.x}\right) = 1853.61 \cdot kN$

$\Sigma M_{soil.U1.x} := E_{act.a.U1.x} \cdot E_{act.a.U1.x.loc.y} + E_{act.as.U1.x} \cdot E_{act.as.U1.x.loc.y} + E_{pass.U1.x} \cdot E_{pass.U1.x.loc.y} = 12552.4 \cdot kN \cdot m$

Lateral Z-Direction Driving Force (Headwater Side - Before Gates & Aux. Spillway RCC - at rest condition)

Max./Min. Top of R.C.C. Soil Elevation: $TOS_{RCC.max} := 1216.5m$ $TOS_{RCC.min} := 1212.8m$

Average Top of R.C.C. Soil Elevation: $TOS_{RCC} := \frac{TOS_{RCC.max} + TOS_{RCC.min}}{2} = 1214.65\,m$

Depth of R.C.C. Soil Acting on Abutment Walls: $d_{act.RCC.w} := TOS_{RCC} - EL_{FTG.top} = 4.65\,m$

Depth of R.C.C. Soil Acting on Abutment Footings: $d_{act.RCC.f} := TOS_{RCC} - BOF_{elev} = 8.65\,m$

Projected Width of soil acting on Abutment Walls: $w_{abut.RCC} := 9.45m$

Projected Width of soil acting on Abutment Footing: $w_{FTG.RCC} := 12.2m$

At-Rest Soil Load on Top of Footing Slab: $\sigma_{act.RCC.w.U1} := \left(K_{o.U1} \cdot d_{act.RCC.w}\right) \cdot \left(\gamma_r - \gamma_w\right) = 37.3 \cdot kPa$

At-Rest Soil Load on Bottom of Approach Slab: $\sigma_{act.RCC.f.U1} := \left(K_{o.U1} \cdot d_{act.RCC.f}\right) \cdot \left(\gamma_r - \gamma_w\right) = 69.38 \cdot kPa$

At-Rest Soil Load on Abutment Walls: $E_{act.a.U1.z} := \frac{\left(K_{o.U1} \cdot d_{act.RCC.w}^{2}\right)}{2} \cdot \left(\gamma_r - \gamma_w\right) \cdot w_{abut.RCC} \cdot -1 = -819.45 \cdot kN$

Acting at: $E_{act.a.U1.z.loc.y} := \frac{d_{DS.a}}{3} + T_{as} = 4.00\,m$

Acting at (from Toe Line): $E_{act.a.U1.z.loc.x} := \frac{\left(L_{wall} + r_{wall} - 6.35m\right)}{2} + 6.35m = 11.18\,m$

At-Rest Soil Load on Abutment Footing (Rect): $E_{act.as.rect.U1.z} := \sigma_{act.RCC.w.U1} \cdot \left(T_{as}\right) \cdot w_{abut.RCC} \cdot -1 = -1409.81 \cdot kN$

At-Rest Soil Load on Abutment Footing (Tri): $E_{act.as.tri.U1.z} := \frac{-\left(\sigma_{act.RCC.f.U1} - \sigma_{act.RCC.w.U1}\right) \cdot \left(T_{as}\right)}{2} \cdot w_{FTG.RCC} = -782.83 \cdot kN$

At-Rest Soil Load on Approach Slab: $E_{act.as.U1.z} := E_{act.as.rect.U1.z} + E_{act.as.tri.U1.z} = -2192.64 \cdot kN$

Acting at: $E_{act.as.U1.z.loc.y} := \frac{\left(E_{act.as.rect.U1.z} \cdot \frac{T_{as}}{2} \cdots + E_{act.as.tri.U1.z} \cdot \frac{T_{as}}{3}\right)}{E_{act.as.U1.z}} = 1.76\,m$

Acting at (from toe line): $E_{act.as.U1.z.loc.x} := \frac{\left(L_{wall} + r_{wall} - 6.35m\right)}{2} + 6.35m = 11.18\,m$

Lateral Z-Direction Driving Force (Headwater Side - After Gates & Aux. Spillway RCC - at rest condition) **U1 CASE**

Max. Top of R.C.C. Wall: $TORCC_{max} := 1215.8m$

Min. Top of R.C.C. Wall: $TORCC_{min} := 1214.0m$

Average Top of R.C.C. Wall Elevation: $TORCC := \frac{TORCC_{max} + TORCC_{min}}{2} = 1214.9\ m$

Width of Soil acting at Max. top of RCC: $w_{RCC.max} := 4.7m$

Width of Soil acting with average Top of RCC (Steps): $w_{RCC.avg} := 1.65m$

Depth of Top of Soil to Top of R.C.C. Wall: $d_{act.RCC} := TOS_{RCC.max} - TORCC_{max} = 0.7\ m$

Depth of Top of Soil to Average Top of R.C.C. Wall (Steps): $d_{act.RCC.avg} := TOS_{RCC.max} - TORCC = 1.6\ m$

At-Rest Soil Load on Abutment Walls after RCC: $E_{act.RCC.U1.z} := \frac{\left(K_{o.U1} \cdot d_{act.RCC}^{2}\right)}{2} \cdot \left(\gamma_r - \gamma_w\right) \cdot w_{RCC.max} \cdot -1 = -9.24 \cdot kN$

Acting at: $E_{act.RCC.U1.z.loc.y} := \frac{d_{act.RCC}}{3} + \left(TORCC_{max} - BOF_{elev}\right) = 10.03\ m$

Acting at (from Toe Line): $E_{act.RCC.U1.z.loc.x} := 4m$ (at SS-Axis Center Line)

At-Rest Soil Load on Abutment Walls at RCC Steps: $E_{act.RCC.s.U1.z} := \frac{\left(K_{o.U1} \cdot d_{act.RCC.avg}^{2}\right)}{2} \cdot \left(\gamma_r - \gamma_w\right) \cdot w_{RCC.avg} \cdot -1 = -16.94 \cdot kN$

Acting at: $E_{act.RCC.s.U1.z.loc.y} := \frac{d_{act.RCC.avg}}{3} + \left(TORCC - BOF_{elev}\right) = 9.43\ m$

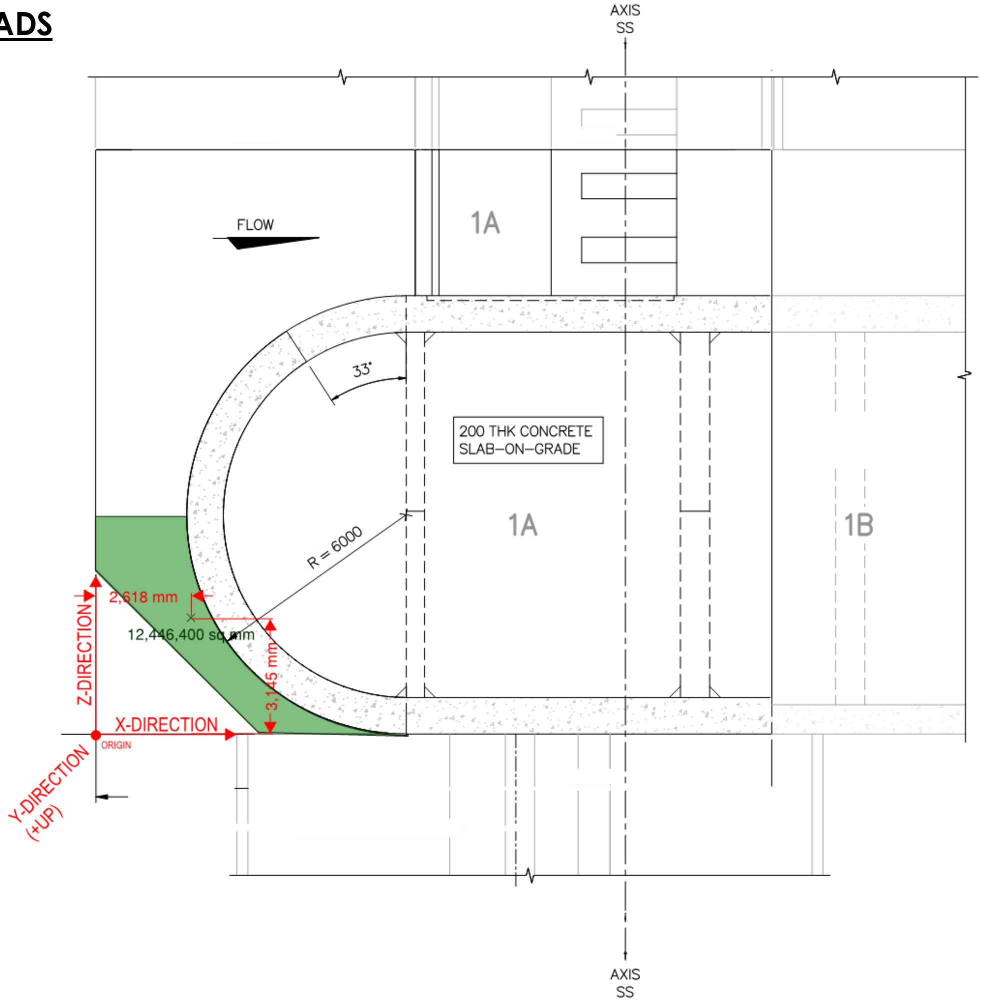
Acting at (from Toe Line): $E_{act.RCC.s.U1.z.loc.x} := \frac{4m - 2.35m}{2} = 0.83\ m$ (at Halfway point of RCC Steps)

$\Sigma H_{soil.U1.z} := \left(E_{act.a.U1.z} + E_{act.as.U1.z} + E_{act.RCC.U1.z} + E_{act.RCC.s.U1.z}\right) = -3038.27 \cdot kN$

$$\Sigma M_{soil.U1.z} := E_{act.a.U1.z} \cdot E_{act.a.U1.z.loc.y} + E_{act.as.U1.z} \cdot E_{act.as.U1.z.loc.y} \cdots + E_{act.RCC.U1.z} \cdot E_{act.RCC.U1.z.loc.y} + E_{act.RCC.s.U1.z} \cdot E_{act.RCC.s.U1.z.loc.y} = -7393.67 \cdot kN \cdot m$$

VERTICAL SOIL LOADS

U1 CASE



Average Depth on Soil above Footing: $d_{RCC.FTG} := TOS_{RCC} - EL_{FTG.top} = 4.65\ m$

Area of Footing with Soil above: $A_{ftg.soil} := 0m^2$ (From Bluebeam REVU)

Vertical Water Weight (H1) on Approach Slab: $E_{1.U1} := \left(A_{ftg.soil} \cdot d_{RCC.FTG}\right) \cdot \left(\gamma_r - \gamma_w\right) = 0.0 \cdot kN$

Moment Arm for Applicaiton of Water Weight (H1) from toe (X-Direction): $E_{1.U1.loc.x} := L_B - 5.607m = 12.89\ m$ (From Geom. Scaled on REVU)

Moment Arm for Applicaiton of Water Weight (H1) from toe (Z-Direction): $E_{1.U1.loc.z} := W_B - 3.145m = 12.86\ m$ (From Geom. Scaled on REVU)

$\Sigma E_{U1} := E_{1.U1} = 0 \cdot kN$ $\Sigma M_{E.U1.x} := E_{1.U1} \cdot E_{1.U1.loc.x} = 0 \cdot kN \cdot m$ $\Sigma M_{E.U1.z} := E_{1.U1} \cdot E_{1.U1.loc.z} = 0 \cdot kN \cdot m$

IMPACT LOADS (DEBRIS LOADING FROM MEMO)

Total Impact Load on Structure: $I_{U1} := 0kN$ (SS Abutment) - Normal Operation

Apply Ice load at: $I_{U1.loc.y} := \left(HW_{U1} - BOF_{elev} - 0.30m\right) = 5.80\ m$

$\Sigma H_{I.U1} := I_{U1} = 0 \cdot kN$

$\Sigma M_{I.U1} := I_{U1} \cdot I_{U1.loc.y} = 0 \cdot kN \cdot m$

SEISMIC LOAD (NOT APPLICABLE FOR THIS LOAD CASE)

U1 CASE

SUMMARY OF LOADS

	Loads	Moment Arm	
Dead load of Concrete Structure:	$D_{conc} = 35947.6 \cdot kN$	$X_{conc.loc} = 8.81\ m$	$Z_{conc.loc} = 8.46\ m$
Obermyer Gate Weight:	$D_{Gate} = 56.0 \cdot kN$	$X_{gate} = 9.50\ m$	$Z_{gate} = 2.00\ m$
Dead load of Fill:	$D_{fill} = 18056.6 \cdot kN$	$X_{fill.loc} = 7.31\ m$	$Z_{fill.loc} = 10.00\ m$
HW Lateral Load on Abutment:	$H_{hwa.U1} = -259.6 \cdot kN$	$H_{hwa.U1.loc} = 4.70\ m$	
HW Lateral Load on Approach Slab:	$H_{hwas.U1} = -2574.1 \cdot kN$	$H_{hwas.U1.loc} = 1.67\ m$	
HW Lateral Load on Guard Gate:	$H_{hwgg.U1} = 0.0 \cdot kN$	$H_{hwgg.U1.loc} = 4.00\ m$	
TW Lateral Load on Abutment:	$H_{twa.U1} = 190.7 \cdot kN$	$H_{twa.U1.loc} = 4.60\ m$	
TW Lateral Load on Pier Footing:	$H_{twgf.U1} = 2385.79 \cdot kN$	$H_{twgf.U1.loc} = 1.65\ m$	
TW Lateral Load on Guard Gate:	$H_{twgg.U1} = 0.0 \cdot kN$	$H_{twgg.U1.loc} = 4.00\ m$	
Vertical HW Load on Approach Slab:	$H_{1.U1} = 1640.8 \cdot kN$	$H_{1.U1.loc.x} = 14.42\ m$	$H_{1.U1.loc.z} = 4.73\ m$
Vertical TW Load on Pier Footing (crest):	$H_{2.U1} = 731.0 \cdot kN$	$H_{2.U1.loc.x} = 5.28\ m$	$H_{2.U1.loc.z} = 2.00\ m$
Uplift:	$U_{U1} = -16750.0 \cdot kN$	$U_{U1.loc.x} = 9.36\ m$	$U_{U1.loc.z} = 8.22\ m$
X-Direction Lateral Soil Load on Abutment (driving):	$E_{act.a.U1.x} = 0.0 \cdot kN$	$E_{act.a.U1.x.loc.y} = 4.00\ m$	
X-Direction Lateral Lateral Soil Load on Approach Slab (driving):	$E_{act.as.U1.x} = -1026.7 \cdot kN$	$E_{act.as.U1.x.loc.y} = 1.33\ m$	
Lateral Soil Load (resisting):	$E_{pass.U1.x} = 2880.26 \cdot kN$	$E_{pass.U1.x.loc.y} = 4.83\ m$	
Z-Direction Lateral Soil Load on Abutment Before RCC (driving):	$E_{act.a.U1.z} = -819.5 \cdot kN$	$E_{act.a.U1.z.loc.y} = 4.00\ m$	
Z-Direction Lateral Lateral Soil Load on Approach Slab Before RCC (driving):	$E_{act.as.U1.z} = -2192.6 \cdot kN$	$E_{act.as.U1.z.loc.y} = 1.76\ m$	
Z-Direction Lateral Soil Load on Abutment After RCC (driving):	$E_{act.RCC.U1.z} = -9.24 \cdot kN$	$E_{act.RCC.U1.z.loc.y} = 10.03\ m$	
Z-Direction Lateral Soil Load on Abutment at RCC Steps (driving):	$E_{act.RCC.s.U1.z} = -16.94 \cdot kN$	$E_{act.RCC.s.U1.z.loc.y} = 9.43 \cdot m$	
Vertical Soil Load on Footing:	$E_{1.U1} = 0 \cdot kN$	$E_{1.U1.loc.x} = 12.89\ m$	$E_{1.U1.loc.z} = 12.86\ m$
Ice / Impact Load:	$I_{U1} = 0.0 \cdot kN$	$I_{U1.loc.y} = 5.80\ m$	

STABILITY ASSESSMENT (SLIDNG, BEARING, FLOTATION AND OVERTURNING): U1 CASE

CHECK SLIDING (X-Direction & Z-Direction) ALONG HORIZONTAL PLANE THRU TOE, IGNORING BEDROCK MOBILIZED BY STRUCTURAL HEEL KEY, OR VOID BEHIND KEY

Sum of Vertical Forces:

$\Sigma V_{U1} := \Sigma V_{DL} + \Sigma V_{water.U1} + \Sigma E_{U1} = 39682.0 \cdot kN$

Sum of Horizontal Forces (X-Direction):

$\Sigma H_{U1.x} := \Sigma H_{Water.U1.x} + \Sigma H_{soil.U1.x} + \Sigma H_{I.U1} = 1596.39 \cdot kN$

Sum of Horizontal Forces (Z-Direction):

$\Sigma H_{U1.z} := \Sigma H_{Water.U1.z} + \Sigma H_{soil.U1.z} = -3038.27 \cdot kN$

Sum of Horizontal Forces (resultant):

$$\Sigma H_{U1} := \sqrt{\Sigma H_{U1.x}^{2} + \Sigma H_{U1.z}^{2}} = 3432.13 \cdot kN$$

Sliding Factor of Safety:

$$FS_{HorizSliding.U1.x} := \frac{\tan_{\phi} \cdot \Sigma V_{U1}}{\left|\Sigma H_{U1.x}\right|} = 12.12 \qquad FS_{HorizSliding.U1.z} := \frac{\tan_{\phi} \cdot \Sigma V_{U1}}{\left|\Sigma H_{U1.z}\right|} = 6.37$$

Sliding Factor of Safety:

$$FS_{HorizSliding.U1} := \frac{\tan_{\phi} \cdot \Sigma V_{U1}}{\sqrt{\Sigma H_{U1.x}^{2} + \Sigma H_{U1.z}^{2}}} = 5.64$$

$FS_{HorizSliding.U1.Check.x} :=$ | "OKAY" if $FS_{HorizSliding.U1.x} \geq FS_{req.U1.sl}$ = "OKAY"
| "Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !" otherwise

$FS_{HorizSliding.U1.Check.z} :=$ | "OKAY" if $FS_{HorizSliding.U1.z} \geq FS_{req.U1.sl}$ = "OKAY"
| "Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !" otherwise

$FS_{HorizSliding.U1.Check} :=$ | "OKAY" if $FS_{HorizSliding.U1} \geq FS_{req.U1.sl}$ = "OKAY"
| "Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !" otherwise

CHECK FOUNDATION BEARING CAPACITY

Sum of the Moments (X-Direction):

$\Sigma M_{U1.x} := \Sigma M_{DL.x} + \Sigma M_{HWater.U1.x} + \Sigma M_{Vwater.U1.x} + \Sigma M_{I.U1} + \Sigma M_{soil.U1.x} = 331914 \cdot kN \cdot m$

Eccentricity:

$$e_{U1.x} := X_{BCG} - \frac{\Sigma M_{U1.x}}{\Sigma V_{U1}} = 0.61\ m$$

Eccentricity Check:

$e_{check.U1.x} :=$ | "Okay" if $e_{U1.x} \leq Kern_{x}$
| "Revise Structure" otherwise

$e_{check.U1.x} =$ "Okay"

Foundation Bearing Pressures (X-Direction):

U1 CASE

Bearing Pressure at Heel:

$$\sigma_{heel.U1.x} := \frac{\Sigma V_{U1}}{A_b} - \frac{\Sigma V_{U1} \cdot e_{U1.x}}{S_{bx.L}} = 109.2 \cdot \frac{kN}{m^2}$$

$$\sigma_{heel.U1.check.x} := \left(\begin{array}{l} \text{"Okay" if } 0 \le \sigma_{heel.U1.x} \le \sigma_{allow.U1} \\ \text{"Revise Structure" otherwise} \end{array} \right) \qquad \sigma_{heel.U1.check.x} = \text{"Okay"}$$

Bearing Pressure at Toe:

$$\sigma_{toe.U1.x} := \frac{\Sigma V_{U1}}{A_b} + \frac{\Sigma V_{U1} \cdot e_{U1.x}}{S_{bx.R}} = 166.71 \cdot \frac{kN}{m^2}$$

$$\sigma_{toe.U1.check.x} := \left| \begin{array}{l} \text{"Okay" if } 0 \le \sigma_{toe.U1.x} \le \sigma_{allow.U1} \\ \text{"Revise Structure" otherwise} \end{array} \right. \qquad \sigma_{toe.U1.check.x} = \text{"Okay"}$$

Sum of the Moments (Z-Direction):

$$\Sigma M_{U1.z} := \Sigma M_{DL.z} + \Sigma M_{HWater.U1.z} + \Sigma M_{Vwater.U1.z} + \Sigma M_{soil.U1.z} = 349019 \cdot kN \cdot m$$

Eccentricity:

$$e_{U1.z} := z_{BCG} - \frac{\Sigma M_{U1.z}}{\Sigma V_{U1}} = -1.03\ m$$

Eccentricity Check:

$$e_{check.U1.z} := \left| \begin{array}{l} \text{"Okay" if } e_{U1.z} \le Kern_z \\ \text{"Revise Structure" otherwise} \end{array} \right. \qquad e_{check.U1.z} = \text{"Okay"}$$

Foundation Bearing Pressures (Z-Direction):

Bearing Pressure at Heel:

$$\sigma_{heel.U1.z} := \frac{\Sigma V_{U1}}{A_b} - \frac{\Sigma V_{U1} \cdot e_{U1.z}}{S_{bz.b}} = 195.95 \cdot \frac{kN}{m^2}$$

$$\sigma_{heel.U1.check.z} := \left(\begin{array}{l} \text{"Okay" if } 0 \le \sigma_{heel.U1.z} \le \sigma_{allow.U1} \\ \text{"Revise Structure" otherwise} \end{array} \right) \qquad \sigma_{heel.U1.check.z} = \text{"Okay"}$$

Bearing Pressure at Toe:

$$\sigma_{toe.U1.z} := \frac{\Sigma V_{U1}}{A_b} + \frac{\Sigma V_{U1} \cdot e_{U1.z}}{S_{bz.t}} = 84.86 \cdot \frac{kN}{m^2}$$

$$\sigma_{toe.U1.check.z} := \left| \begin{array}{l} \text{"Okay" if } 0 \le \sigma_{heel.U1.z} \le \sigma_{allow.U1} \\ \text{"Revise Structure" otherwise} \end{array} \right. \qquad \sigma_{toe.U1.check.z} = \text{"Okay"}$$

Foundation Bearing Pressure (Combined):

Linear pressure superimposed at Corners by both Moment_X and Moment_Z

Bearing Pressure at Heel(x)-Heel(z):

$$\sigma_{heel.U1} := \frac{\Sigma V_{U1}}{A_b} - \frac{\Sigma V_{U1} \cdot e_{U1.x}}{S_{bx.L}} - \frac{\Sigma V_{U1} \cdot e_{U1.z}}{S_{bz.b}} = 166.34 \cdot kPa$$

$$\sigma_{heel.U1.check} := \left(\begin{array}{l} \text{"Okay"} \quad \text{if } 0 \le \sigma_{heel.U1} \le \sigma_{allow.U1} \\ \text{"Revise Structure"} \quad \text{otherwise} \end{array} \right)$$

$\sigma_{heel.U1.check} = \text{"Okay"}$

Bearing Pressure at Toe(x)-Toe(z):

$$\sigma_{toe.U1} := \frac{\Sigma V_{U1}}{A_b} + \frac{\Sigma V_{U1} \cdot e_{U1.x}}{S_{bx.R}} + \frac{\Sigma V_{U1} \cdot e_{U1.z}}{S_{bz.t}} = 112.76 \cdot kPa$$

$$\sigma_{toe.U1.check} := \begin{array}{l} \text{"Okay"} \quad \text{if } 0 \le \sigma_{toe.U1} \le \sigma_{allow.U1} \\ \text{"Revise Structure"} \quad \text{otherwise} \end{array}$$

$\sigma_{toe.U1.check} = \text{"Okay"}$

Bearing Pressure at Heel(x)-Toe(z):

$$\sigma_{heeltoe.U1} := \frac{\Sigma V_{U1}}{A_b} - \frac{\Sigma V_{U1} \cdot e_{U1.x}}{S_{bx.L}} + \frac{\Sigma V_{U1} \cdot e_{U1.z}}{S_{bz.t}} = 55.25 \cdot kPa$$

$$\sigma_{heeltoe.U1.check} := \left(\begin{array}{l} \text{"Okay"} \quad \text{if } 0 \le \sigma_{heeltoe.U1} \le \sigma_{allow.U1} \\ \text{"Revise Structure"} \quad \text{otherwise} \end{array} \right)$$

$\sigma_{heeltoe.U1.check} = \text{"Okay"}$

Bearing Pressure at Toe(x)-Heel(z):

$$\sigma_{toeheel.U1} := \frac{\Sigma V_{U1}}{A_b} + \frac{\Sigma V_{U1} \cdot e_{U1.x}}{S_{bx.R}} - \frac{\Sigma V_{U1} \cdot e_{U1.z}}{S_{bz.b}} = 223.86 \cdot kPa$$

$$\sigma_{toeheel.U1.check} := \begin{array}{l} \text{"Okay"} \quad \text{if } 0 \le \sigma_{toeheel.U1} \le \sigma_{allow.U1} \\ \text{"Revise Structure"} \quad \text{otherwise} \end{array}$$

$\sigma_{toeheel.U1.check} = \text{"Okay"}$

FLOATATION ANALYSIS:

ACCEPTANCE PARAMETERS

Required Factor of Safety: $FS_{req.FU1} := 1.5$

VERTICAL LOADS RESISTING:

Dead Load: $\Sigma V_{DL} = 54060.17 \cdot kN$

Water Weight H1+H2: $\Sigma V_{H.FU1} := H_{1.U1} + H_{2.U1} = 2371.81 \cdot kN$

Summation Vertical Resisting: $\Sigma V_{FU1} := \Sigma V_{DL} + \Sigma V_{H.FU1} = 56432.0 \cdot kN$

VERTICAL LOADS UPLIFT:

Uplift: $U_{U1} = -16750 \cdot kN$

Factor of Safety Floatation:

$$FS_{act.FU1} := \frac{\Sigma V_{FU1}}{\left| U_{U1} \right|} = 3.37$$

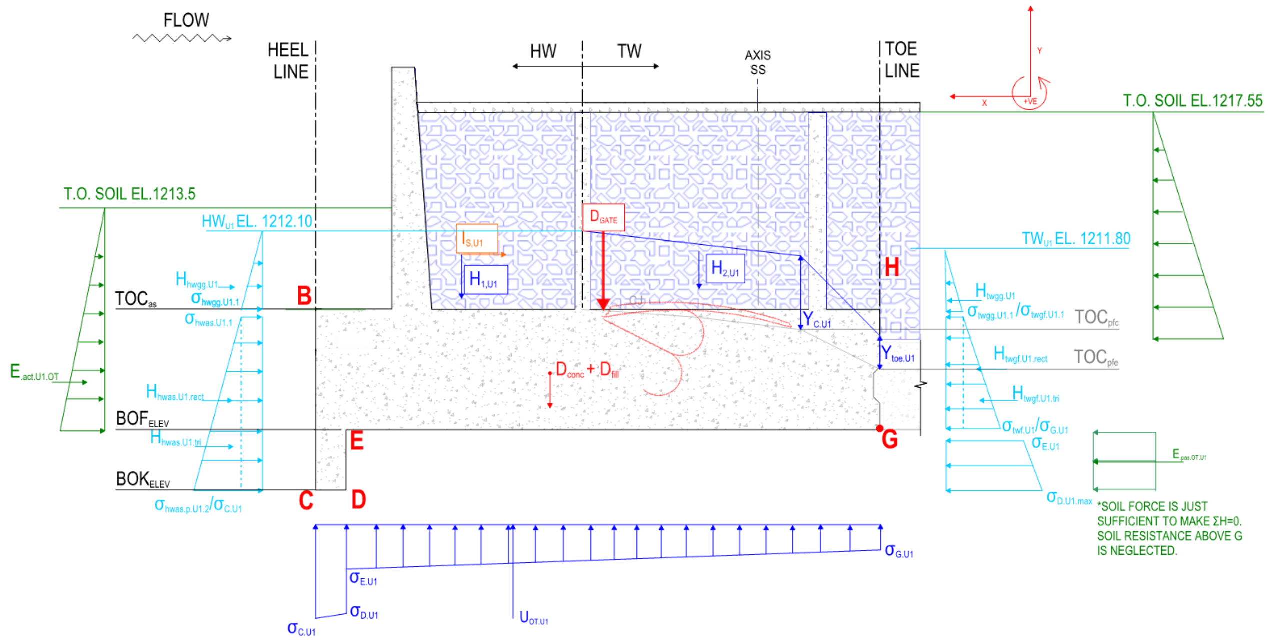
$$FS_{check.FU1} := \begin{array}{l} \text{"OKAY"} \quad \text{if } FS_{act.FU1} \ge FS_{req.FU1} \\ \text{"ANCHORS REQUIRED"} \quad \text{if } FS_{act.FU1} < FS_{req.FU1} \end{array} = \text{"OKAY"}$$

MONOLITH OVERTURNING STABILITY ANALYSIS

U1 CASE

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.
Assumptions are made in order to compute overturning stablity of indetermine forces on monolith with key;
(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.
(b) The horizontal resisting force acting on the key, P.key, is that required for staticequilibrium
(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1 $Ratio_{OT.U1.min} := 0.333$ at Rock Foundation



Uplift Loads for Overturning Stability Analysis (X-Direction)

Line of Creep:

Change in Water Head: $\Delta_{h.U1} := HW_{U1} - TW_{U1} = 0.3\ m$

Length from Point C to Point G: $L_{CG} := \sqrt{d_{key}^2 + L_B^2} = 18.61\ m$

Length from Various Points to Points: $L_{CD} := w_{key} = 1\ m$ $L_{DE} := d_{key} = 2\ m$ $L_{EG} := L_B - L_{CD} = 17.5\ m$

$L_{GH} := TW_{U1} - TOC_{afe} = 3.8\ m$

Length from Point C, D, E to G: $L_{CDEG} := L_{CD} + L_{DE} + L_{EG} = 20.5\ m$ $L_{CDE} := L_{CD} + L_{DE} = 3\ m$

Water Pressure at Point C & G: $\sigma_{C.U1} := \sigma_{hwas.U1.2} = -59.84 \cdot kPa$ $\sigma_{G.U1} := \sigma_{twtoe.U1} \cdot -1 = -56.9 \cdot kPa$

Water Pressure at Point D: $$\sigma_{D.U1} := -\gamma_w \cdot \left[\left(HW_{U1} - BOK_{elev}\right) - \frac{\Delta_{h.U1} \cdot L_{CD}}{L_{CDEG}}\right] = -79.32 \cdot kPa$$

Water Pressure at Point E: $$\sigma_{E.U1} := -\gamma_w \cdot \left[\left(HW_{U1} - BOF_{elev}\right) - \frac{\Delta_{h.U1} \cdot L_{CDE}}{L_{CDEG}}\right] = -59.41 \cdot kPa$$

Uplift for Overturning Analysis on Bottom of Key: $$U_{OT.U1.key} := \frac{\sigma_{C.U1} + \sigma_{D.U1}}{2} \cdot L_{CD} \cdot W_B = -1113.27 \cdot kN$$

Acting at: $$U_{OT.U1.key.loc} := \frac{L_{CD} \cdot \left(2 \cdot \sigma_{C.U1} + \sigma_{D.U1}\right)}{3\left(\sigma_{C.U1} + \sigma_{D.U1}\right)} + L_{EG} = 17.98\ m$$

U1 CASE

Uplift for Overturning Analysis on Bottom of Footing:

$$U_{OT.U1.ftg} := \frac{\sigma_{E.U1} + \sigma_{G.U1}}{2} \cdot L_{EG} \cdot W_B = -16283.16 \cdot kN$$

Acting at:

$$U_{OT.U1.ftg.loc} := \frac{L_{EG} \cdot \left(\sigma_{G.U1} + 2 \cdot \sigma_{E.U1}\right)}{3\left(\sigma_{G.U1} + \sigma_{E.U1}\right)} = 8.81\ m$$

Uplift Load for Overturning Analysis:

$$U_{OT.U1} := U_{OT.U1.key} + U_{OT.U1.ftg} = -17396.43 \cdot kN$$

Uplift Load Acting from Toe:

$$U_{OT.U1.loc} := \frac{U_{OT.U1.key} \cdot U_{OT.U1.key.loc} + U_{OT.U1.ftg} \cdot U_{OT.U1.ftg.loc}}{U_{OT.U1}} = 9.4\ m$$

<u>All Vertical Loads Appliable to Overturning Stability Analysis</u>

		at:	
Total Concrete Dead Loads:	$D_{conc} = 35947.58 \cdot kN$		$X_{conc.loc} = 8.81\ m$
Dead Load of Gate:	$D_{Gate} = 56.0 \cdot kN$		$X_{gate} = 9.50\ m$
Total Fill Loads:	$D_{fill} = 18056.6 \cdot kN$		$X_{fill.loc} = 7.31\ m$
Water Weight (HW) on Apron Slab:	$H_{1.U1} = 1640.8 \cdot kN$		$H_{1.U1.loc.x} = 14.42\ m$
Water Weight (TW) on Guard Gate Footing:	$H_{2.U1} = 731.0 \cdot kN$		$H_{2.U1.loc.x} = 5.28\ m$
Uplift Load for Overturning Analysis:	$U_{OT.U1} = -17396.43 \cdot kN$		$U_{OT.U1.loc} = 9.4 \cdot m$

Sum of All Overturning Analysis Vertical Load:

$$\Sigma V_{U1.OT} := D_{conc} + D_{Gate} + D_{fill} + H_{1.U1} + H_{2.U1} + U_{OT.U1} = 39035.55 \cdot kN$$

Sum of All Overturning Analysis Vertical Load Moments:

$$\Sigma M_{V.U1.OT} := \left(\begin{aligned} &D_{conc} \cdot X_{conc.loc} + D_{Gate} \cdot X_{gate} + D_{fill} \cdot X_{fill.loc} + H_{1.U1} \cdot H_{1.U1.loc.x} \ldots \\ &+ H_{2.U1} \cdot H_{2.U1.loc.x} + U_{OT.U1} \cdot U_{OT.U1.loc} \end{aligned}\right) = 313340.49 \cdot kN \cdot m$$

<u>Lateral Tailwater Loads for Overturning Stability Analysis</u>

TW Lateral Load on Gate Footing (No Key - Overturning Values Adjusted):

$$H_{twgf.U1} = 2385.79 \cdot kN$$

$$U_{OT.U1} \cdot U_{OT.U1.loc} = -163516397.85\ J$$

Acting at:

$$H_{twgf.U1.loc} = 1.65\ m$$

Horizontal Tailwater Pressure Top of Key (Overturning Analysis):

$$\sigma_{twtk.OT.U1} := \sigma_{E.U1} \cdot -1 = 59.41 \cdot kPa$$

Horizontal Tailwater Pressure Bottom of Key (Overturning Analysis):

$$\sigma_{twbk.OT.U1} := \sigma_{D.U1} \cdot -1 = 79.32 \cdot kPa$$

Triangular Distribution Unit Load Acting at Key:

$$H_{twbk.OT.U1.tri} := \frac{\left(\sigma_{twbk.OT.U1} - \sigma_{twtk.OT.U1}\right)}{2} \cdot d_{key} \cdot W_{tw.U1} = 318.51 \cdot kN$$

Triangular Distribution Unit Load Acting at Key:

$$H_{twbk.OT.U1.rect} := \sigma_{twtk.OT.U1} \cdot d_{key} \cdot W_{tw.U1} = 1901.13 \cdot kN$$

Total Horizontal Tailwater Load on Key (Overturning Values Adjusted):

$$H_{twkey.OT.U1} := H_{twbk.OT.U1.tri} + H_{twbk.OT.U1.rect} = 2219.64 \cdot kN$$

Acting at:

$$H_{twkey.OT.U1.loc} := \frac{H_{twbk.OT.U1.tri} \cdot \frac{-2 \cdot d_{key}}{3} + H_{twbk.OT.U1.rect} \cdot \frac{-d_{key}}{2}}{H_{twkey.OT.U1}} = -1.05 \cdot m$$

Lateral Driving Earth Loads for Overturning Stability Analysis (at rest condition)

U1 CASE

Depth of Driving Soil Loads (to top of key): $h_{E.OT.U1} := TOC_{as} - BOF_{elev} = 4\ m$

At-Rest Soil Load: $E_{act.OT.U1} := \dfrac{\left(K_{o.U1} \cdot h_{E.OT.U1}\right)^2}{2} \cdot \left(\gamma_r - \gamma_w\right) \cdot W_{hwas.U1} \cdot -1 = -1026.66 \cdot kN$

At Rest- Soil Load Acting from Toe: $E_{act.OT.U1.loc} := \dfrac{h_{E.OT.U1}}{3} = 1.33\ m$

All Lateral Loads Appliable to Overturning Stability Analysis (X-direction)

HW Lateral Load on Approach Slab:	$H_{hwas.U1} = -2574.1 \cdot kN$	$H_{hwas.U1.loc} = 1.67\ m$
HW Lateral Load on Guard Gate:	$H_{hwgg.U1} = 0.0 \cdot kN$	$H_{hwgg.U1.loc} = 4.00\ m$
HW Lateral Load on Abutment:	$H_{hwa.U1} = -259.6 \cdot kN$	$H_{hwa.U1.loc} = 4.70\ m$
TW Lateral Load on Abutment:	$H_{twa.U1} = 190.7 \cdot kN$	$H_{twa.U1.loc} = 4.60\ m$
TW Lateral Load on Guard Gate:	$H_{twgg.U1} = 0.0 \cdot kN$	$H_{twgg.U1.loc} = 4.00\ m$
TW Lateral Load on Gate Footing (No Key - Overturning Values Adjusted):	$H_{twgf.U1} = 2385.79 \cdot kN$	$H_{twgf.U1.loc} = 1.65\ m$
TW Lateral Load on Key:	$H_{twkey.OT.U1} = 2219.64 \cdot kN$	$H_{twkey.OT.U1.loc} = -1.05\ m$
Ice / Impact Load:	$I_{U1} = 0.0 \cdot kN$	$I_{U1.loc.y} = 5.80\ m$
Lateral Soil Load (driving):	$E_{act.OT.U1} = -1026.7 \cdot kN$	$E_{act.OT.U1.loc} = 1.33\ m$

Resisting Lateral Soil Load as required to produce horizontal equilibrium:

$$E_{pas.OT.x.U1} := -\left(\begin{array}{l} H_{hwas.U1} + H_{hwgg.U1} + H_{hwgg.U1} + H_{twgg.U1} \cdots \\ + H_{twgf.U1} + H_{twkey.OT.U1} + I_{U1} + E_{act.OT.U1} \end{array}\right) = -1004.63 \cdot kN$$

Acting at:

$$E_{pas.OT.U1.loc} := -1 \cdot \frac{d_{key}}{2} = -1\ m$$

Sum of All Overturning Analysis Horizontal Load (ΣH=0):

$$\Sigma H_{U1.OT.x} := H_{hwas.U1} + H_{hwgg.U1} + H_{twgg.U1} + H_{twgf.U1} + H_{twkey.OT.U1} + I_{U1} + E_{act.OT.U1} + E_{pas.OT.x.U1} = 0 \cdot kN$$

Sum of All Overturning Analysis Horizontal Load Moments:

$$\begin{aligned} \Sigma M_{H.U1.OT.x} := {} & H_{hwas.U1} \cdot H_{hwas.U1.loc} + H_{hwgg.U1} \cdot H_{hwgg.U1.loc} \cdots \\ & + H_{twgg.U1} \cdot H_{twgg.U1.loc} + H_{twgf.U1} \cdot H_{twgf.U1.loc} \cdots \\ & + H_{twkey.OT.U1} \cdot H_{twkey.OT.U1.loc} + I_{U1} \cdot I_{U1.loc.y} \cdots \\ & + E_{act.OT.U1} \cdot E_{act.OT.U1.loc} + E_{pas.OT.x.U1} \cdot E_{pas.OT.U1.loc} \end{aligned} = -3066.77 \cdot kN \cdot m$$

Overturning Stability Analysis (X-Direction)

$$\Sigma M_{U1.OT.x} := \Sigma M_{V.U1.OT} + \Sigma M_{H.U1.OT.x} = 310273.73 \cdot kN \cdot m$$

$$X_{R.U1} := \frac{\Sigma M_{U1.OT.x}}{\Sigma V_{U1.OT}} = 7.95\ m \qquad x_{OT.U1} := X_{R.U1} - \frac{L_B}{2} = -1.3\ m$$

Overturning Resultant Ratio

$$Ratio_{OT.x.U1} := \frac{X_{R.U1}}{L_B} = 0.43$$

$$Ratio_{OT.x.U1.check} := \begin{array}{|l} \text{"OKAY"} \ \ \text{if} \ \ Ratio_{OT.x.U1} \geq Ratio_{OT.U1.min} \\ \text{"Revise Structure"} \ \ \text{otherwise} \end{array} = \text{"OKAY"}$$

$$x_{OT.check.U1} := \begin{array}{|l} \text{"OKAY"} \ \ \text{if} \ \ \left|x_{OT.U1}\right| \leq Kern_x \\ \text{"Revise Structure"} \ \ \text{otherwise} \end{array} = \text{"OKAY"}$$

All Lateral Loads Appliable to Overturning Stability Analysis (Z-direction)

U1 CASE

Z-Direction Lateral Soil Load on Abutment Before RCC (driving): $E_{act.a.U1.z} = -819.5 \cdot kN$ $\quad E_{act.a.U1.z.loc.y} = 4.00\ m$

Z-Direction Lateral Lateral Soil Load on Approach Slab Before RCC (driving): $E_{act.as.U1.z} = -2192.6 \cdot kN$ $\quad E_{act.as.U1.z.loc.y} = 1.76\ m$

Z-Direction Lateral Soil Load on Abutment After RCC (driving): $E_{act.RCC.U1.z} = -9.24 \cdot kN$ $\quad E_{act.RCC.U1.z.loc.y} = 10.03\ m$

Z-Direction Lateral Soil Load on Abutment at RCC Steps (driving): $E_{act.RCC.s.U1.z} = -16.94 \cdot kN$ $\quad E_{act.RCC.s.U1.z.loc.y} = 9.43 \cdot m$

Resisting Lateral Soil Load as required to produce horizontal equilibrium:

$$E_{pas.OT.z.U1} := -\left(E_{act.a.U1.z} + E_{act.as.U1.z} + E_{act.RCC.U1.z} + E_{act.RCC.s.U1.z}\right) = 3038.27 \cdot kN$$

Acting at:

$$E_{pas.OT.U1.loc} = -1\ m$$

Sum of All Overturning Analysis Horizontal Load (ΣH=0):

$$\Sigma H_{U1.OT.z} := E_{act.a.U1.z} + E_{act.as.U1.z} + E_{act.RCC.U1.z} + E_{act.RCC.s.U1.z} + E_{pas.OT.z.U1} = 0 \cdot kN$$

Sum of All Overturning Analysis Horizontal Load Moments:

$$\Sigma M_{H.U1.OT.z} := E_{act.a.U1.z} \cdot E_{act.a.U1.z.loc.y} + E_{act.as.U1.z} \cdot E_{act.as.U1.z.loc.y} \cdots + E_{act.RCC.U1.z} \cdot E_{act.RCC.U1.z.loc.y} + E_{act.RCC.s.U1.z} \cdot E_{act.RCC.s.U1.z.loc.y} \cdots + E_{pas.OT.x.U1} \cdot E_{pas.OT.U1.loc} = -6389.04 \cdot kN \cdot m$$

Overturning Stability Analysis (Z-Direction)

$$\Sigma M_{U1.OT.z} := \Sigma M_{V.U1.OT} + \Sigma M_{H.U1.OT.z} = 306951.45 \cdot kN \cdot m$$

$$z_{R.U1} := \frac{\Sigma M_{U1.OT.z}}{\Sigma V_{U1.OT}} = 7.86\ m \qquad z_{OT.U1} := z_{R.U1} - \frac{W_B}{2} = -0.14\ m$$

Overturning Resultant Ratio

$$Ratio_{OT.z.U1} := \frac{z_{R.U1}}{L_B} = 0.43$$

$$Ratio_{OT.z.U1.check} := \begin{cases} \text{"OKAY"} & \text{if } Ratio_{OT.z.U1} \geq Ratio_{OT.U1.min} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

$$z_{OT.check.U1} := \begin{cases} \text{"OKAY"} & \text{if } \left|z_{OT.U1}\right| \leq Kern_z \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

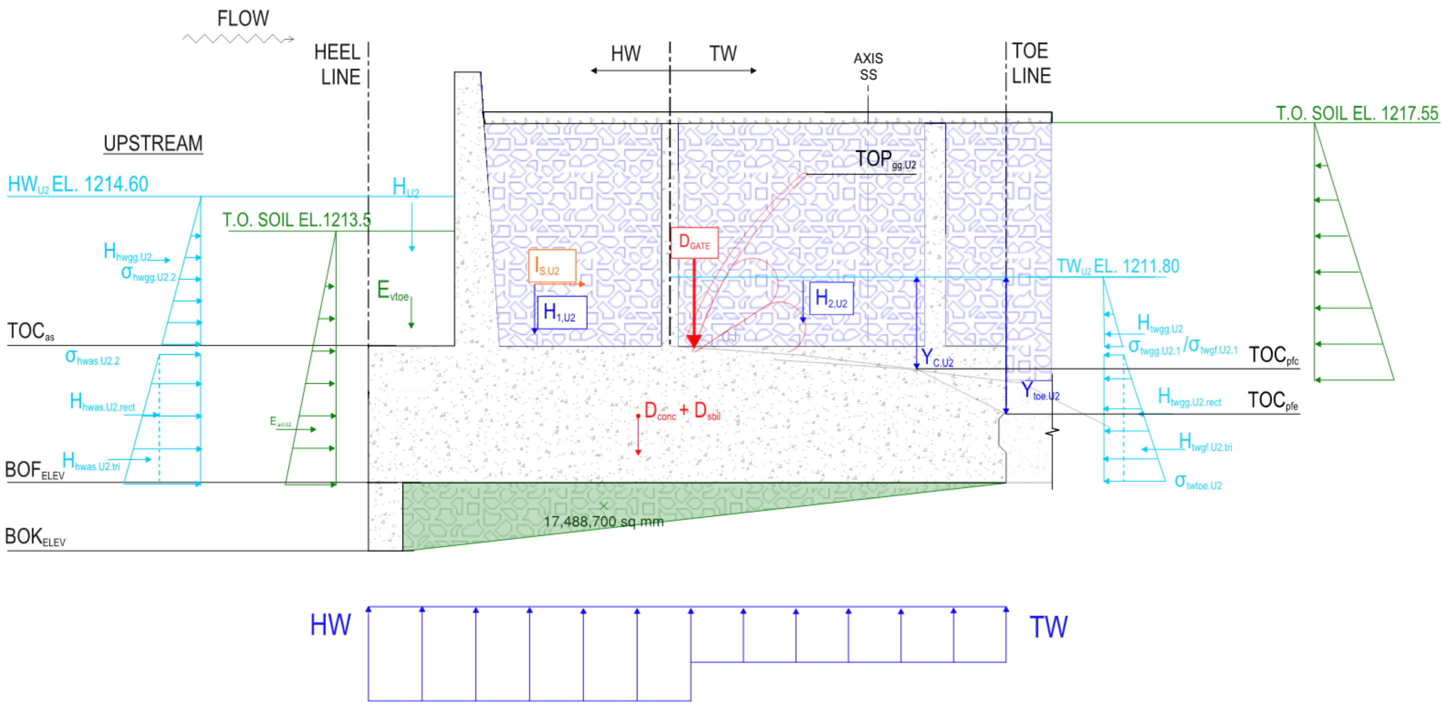
SUMMARY OF STABILITY ASSESSMENT:

U1 CASE

Sliding Factor of Safety: (Horizontal Plane)	$FS_{HorizSliding.U1} = 5.64$	$FS_{HorizSliding.U1.Check} = \text{"OKAY"}$
Flotation Factor of Safety (horizontal plane)	$FS_{act.FU1} = 3.37$	$FS_{check.FU1} = \text{"OKAY"}$
Overturning Resultant Ratio: (X-direction)	$Ratio_{OT.x.U1} = 0.43$	$Ratio_{OT.x.U1.check} = \text{"OKAY"}$
Overturning Resultant Ratio: (Z-direction)	$Ratio_{OT.z.U1} = 0.43$	$Ratio_{OT.z.U1.check} = \text{"OKAY"}$
Eccentricity: (horizontal plane)	$x_{OT.U1} = -1.30\ m$	$x_{OT.check.U1} = \text{"OKAY"}$
Eccentricity: (horizontal plane)	$z_{OT.U1} = -0.14\ m$	$z_{OT.check.U1} = \text{"OKAY"}$
Bearing Pressure At Heel(x)- Heel(z): (horizontal plane)	$\sigma_{heel.U1} = 166 \cdot kPa$	$\sigma_{heel.U1.check} = \text{"Okay"}$
Bearing Pressure At Toe(x)-Toe(z): (horizontal plane)	$\sigma_{toe.U1} = 113 \cdot kPa$	$\sigma_{toe.U1.check} = \text{"Okay"}$
Bearing Pressure at Heel(x)-Toe(z): (horizontal plane)	$\sigma_{heeltoe.U1} = 55 \cdot kPa$	$\sigma_{heeltoe.U1.check} = \text{"Okay"}$
Bearing Pressure at Toe(x)-Heel(z): (horizontal plane)	$\sigma_{toeheel.U1} = 224 \cdot kPa$	$\sigma_{toe.U1.check} = \text{"Okay"}$

Blank Pages 31-44 have been intentionally removed

U2 DESIGN CASE



ACCEPTANCE PARAMETERS

Required Factor of Safety for Sliding: $FS_{req.U2.sl} := 1.5$ (Without Cohesion)

(Section 8.1, Design Criteria)

Resultant Within Middle Third of Base: $e \le \frac{L_B}{6} \wedge e \ge \frac{-L_B}{6}$

Allowable Rock Bearing Pressure: $\sigma_{allow.U2} := 1270 \cdot \frac{kN}{m^2}$ (Section 5.2, Design Criteria)

Required Factor of Safety for Flotation: $FS_{req.U2.flt} := 1.5$

INPUT PARAMETERS

Headwater Elevation: $HW_{U2} := 1214.60m$ (Section 8.2, Design Criteria)

Tailwater Elevation: $TW_{U2} := 1211.80m$ (Section 8.2, Design Criteria)

Bottom of Footing Elevation: $BOF_{elev} = 1206\,m$

Approch Slab Top of Concrete Elevation at Upstream Face: $TOC_{as} = 1210\,m$

Abutment Footing Top of Concrete Elevation at Stilling Basin: $TOC_{afe} = 1208\,m$

Abutment Footing Top of Concrete Elevation at Footing: $TOC_{afc} = 1209.73\,m$

Abutment Footing Top of Concrete Elevation at Footing Notch: $TOC_{afc.n} = 1209.3\,m$

Gates are open when top of gate elevation is at 1210.00m

Top of Guard Gate Elevation: $TOP_{gg.U2} := 1215.00m$

Bottom of Key Elevation: $BOK_{elev} = 1204\,m$

Gates are closed/up when top of gate elevation is at 1215.0m

Water Elevation above Crest of Guard Gate:

$EL_{C.U2} := 1211.8m$

$$Y_{C.U2} := \begin{cases} (EL_{C.U2} - TOC_{afc.n}) & \text{if } TOP_{gg.U2} \le HW_{U2} \\ (TW_{U2} - TOC_{afc.n}) & \text{if } TOP_{gg.U2} > HW_{U2} \end{cases} = 2.5 \cdot m$$

Water Elevation above Guard Gate Toe:
Submerged by Hydraulic 2D Model

$EL_{TOE.U2} := 1211.8m$

$$Y_{TOE.U2} := \begin{cases} (EL_{TOE.U2} - TOC_{afe}) & \text{if } TOP_{gg.U2} \le HW_{U2} \\ (TW_{U2} - TOC_{afe}) & \text{if } TOP_{gg.U2} > HW_{U2} \end{cases} = 3.8 \cdot m$$

LATERAL WATER LOADS

HEADWATER (DRIVING X-DIRECTION):

Headwater Depth on Abutment: $D_{hwa.U2} := HW_{U2} - TOC_{as} = 4.60\ m$

Headwater Load Unit Width Projected Surface Area of Abutment: $W_{hwa.U2} := 2 \cdot r_{wall} = 12.00\ m$

Total Horizontal Headwater Load on Abutment:

$$H_{hwa.U2} := \frac{-\left(\gamma_w \cdot D_{hwa.U2}{}^2\right)}{2} \cdot W_{hwa.U2} = -1245.5 \cdot kN$$

Apply Total Abutment Headwater Load at:

$$H_{hwa.U2.loc} := \frac{D_{hwa.U2}}{3} + \left(TOC_{as} - BOF_{elev}\right) = 5.53\ m$$

Apply Total Abutment Headwater Load at (from toe): $H_{hwa.U2.loc.z} := 4m + r_{wall} = 10.00\ m$ (Gate Footing + Radius of Wall)

Thickness of Approach Slab: $T_{as} = 4\ m$

Headwater Depth at Heel (U/S face): $D_{hwas.U2} := HW_{U2} - BOF_{elev} = 8.60\ m$

Headwater Load Unit Width on Projected Approach Slab: $W_{hwas.U2} := W_B = 16.00\ m$

Headwater Line Load At Top of Approach Slab: $\sigma_{hwas.U2.1} := -\left(\gamma_w \cdot D_{hwa.U2}\right) = -45.13 \cdot kPa$

Headwater Line Load At Bottom of Approach Slab: $\sigma_{hwas.U2.2} := -\left(\gamma_w \cdot D_{hwas.U2}\right) = -84.37 \cdot kPa$

Trianglular Distribution Unit Load on Approach Slab:

$$H_{hwas.U2.2.tri} := \left(\frac{\sigma_{hwas.U2.2} - \sigma_{hwas.U2.1}}{2}\right) \cdot \left(T_{as} \cdot W_{hwas.U2}\right) = -1255.68 \cdot kN$$

Rectangular Distribution Unit Load on Approach Slab:

$$H_{hwas.U2.2.rect} := \sigma_{hwas.U2.1} \cdot \left(T_{as} \cdot W_{hwas.U2}\right) = -2888.06 \cdot kN$$

Total Horizontal Headwater Load on Approach Slab:

$$H_{hwas.U2} := H_{hwas.U2.2.tri} + H_{hwas.U2.2.rect} = -4143.74 \cdot kN$$

Apply Total Footing Headwater Load at:

$$H_{hwas.U2.loc} := \frac{\left[H_{hwas.U2.2.rect} \cdot \frac{\left(T_{as}\right)}{2} + H_{hwas.U2.2.tri} \cdot \frac{\left(T_{as}\right)}{3}\right]}{H_{hwas.U2.2.tri} + H_{hwas.U2.2.rect}} = 1.80\ m$$

Apply Total Footing Headwater Load at (from toe):

$$H_{hwas.U2.loc.z} := \frac{W_B}{2} = 8.00\ m$$

Guard Gate (2A) Operating Condition: U2- Right Crest Gate EL 1215.0

Guard Gate Down/Open Condition: $A1_{U2} := TOP_{gg.U2} \le TOC_{as}$

Guard Crest Gate Up/Closed, with Top of Gate Higher than HW Elevation: $B1_{U2} := TOP_{gg.U2} \ge HW_{U2} \wedge TOP_{gg.U2} > TOC_{as}$

Guard Crest Gate Up/Closed, with Top of Gate Lower than HW Elevation: $C1_{U2} := TOP_{gg.U2} > TOC_{as} \wedge HW_{U2} > TOP_{gg.U2}$

Guard Crest Gate Height: $H_{gg.U2} := TOP_{gg.U2} - TOC_{as} = 5\,m$

Headwater Depth at Guard Crest Gate: $D_{hwgg.U2} := HW_{U2} - TOC_{as} = 4.60\,m$

Guard Crest Gate Width: $W_{hwgg.U2} := 4.00m$

Lateral Headwater Pressure at Bottom of Guard Crest Gate:

$$\sigma_{hwgg.U2.1} := \begin{cases} (0.0kPa) & \text{if } A1_{U2} \\ -(\gamma_w \cdot D_{hwgg.U2}) & \text{if } B1_{U2} \\ -(\gamma_w \cdot D_{hwgg.U2}) & \text{if } C1_{U2} \end{cases} = -45.1 \cdot kPa$$

Lateral Headwater Pressure at Top of Guard Crest Gate:
(Load at HW Elevation On Guard Crest Gate if HW is below TOG_{rg})

$$\sigma_{hwgg.U2.2} := \begin{cases} (0.0kPa) & \text{if } A1_{U2} \\ 0.0kPa & \text{if } B1_{U2} \\ -[\gamma_w \cdot (HW_{U2} - TOP_{gg.U2})] & \text{if } C1_{U2} \end{cases} = 0.0 \cdot kPa$$

Average Pressure acting on Guard Crest Gate:

$$\sigma_{hwgg.U2.avg} := \frac{(\sigma_{hwgg.U2.1} + \sigma_{hwgg.U2.2})}{2} = -22.56 \cdot kPa$$

Total Area water acting on Crest Gate:

$$A_{hwgg.U2} := \begin{cases} D_{hwgg.U2} \cdot W_{hwgg.U2} & \text{if } A1_{U2} \\ D_{hwgg.U2} \cdot W_{hwgg.U2} & \text{if } B1_{U2} \\ H_{gg.U2} \cdot W_{hwgg.U2} & \text{if } C1_{U2} \end{cases} = 18.4 \cdot m^2$$

Total Horizontal Headwater Load on Guard Crest Gate: $H_{hwgg.U2} := \sigma_{hwgg.U2.avg} \cdot A_{hwgg.U2} = -415.2 \cdot kN$

Apply Total Guard Crest Gate Headwater Load at:

$$H_{hwgg.U2.loc} := \begin{cases} (TOC_{as} - BOF_{elev}) & \text{if } A1_{U2} \\ \left[\frac{(HW_{U2} - TOC_{as})}{3} + (TOC_{as} - BOF_{elev})\right] & \text{if } B1_{U2} \\ \left[\frac{\sigma_{hwgg.U2.2} \cdot A_{hwgg.U2} \cdot \frac{(H_{gg.U2})}{2} + \frac{(\sigma_{hwgg.U2.1} - \sigma_{hwgg.U2.2})}{2} A_{hwgg.U2} \cdot \frac{(H_{gg.U2})}{3}}{\sigma_{hwgg.U2.2} \cdot A_{hwgg.U2} + \frac{(\sigma_{hwgg.U2.1} - \sigma_{hwgg.U2.2})}{2} \cdot A_{hwgg.U2}} \cdots \\ + (TOC_{as} - BOF_{elev})\right] & \text{if } C1_{U2} \end{cases} = 5.5 \cdot m$$

Apply Total Guard Crest Gate Headwater Load at (From toe): $H_{hwgg.U2.loc.z} := \frac{W_{hwgg.U2}}{2} = 2\,m$

LATERAL TAILWATER (RESISTING) Applied to Downstream Side of Guard Crest Gate: U2 CASE

Guard Gate Down/Open Condition: $A2_{U2} := TOP_{gg.U2} \le TOC_{as}$

Guard Crest Gate Up/Closed, with Top of Gate Higher than TW Elevation: $B2_{U2} := TOP_{gg.U2} \ge TW_{U2} \wedge TOP_{gg.U2} > TOC_{as}$

Guard Crest Gate Up/Closed, with Top of Gate Lower than TW Elevation: $C2_{U2} := TOP_{gg.U2} > TOC_{as} \wedge TW_{U2} > TOP_{gg.U2}$

Tailwater Depth at Guard Crest Gate: $D_{twgg.U2} := TW_{U2} - TOC_{as} = 1.80\ m$

Guard Crest Gate Height: $H_{gg.U2} = 5\ m$

Guard Crest Gate Width: $W_{twgg.U2} := 4.00m$

Lateral Water Load at Bottom of Guard Crest Gate:

$$\sigma_{twgg.U2.1} := \begin{array}{|l} (0.0kPa) \text{ if } A2_{U2} \\ (\gamma_w \cdot D_{twgg.U2}) \text{ if } B2_{U2} \\ (\gamma_w \cdot D_{twgg.U2}) \text{ if } C2_{U2} \end{array} = 17.7 \cdot kPa$$

Lateral Water Load at Top of Guard Crest Gate:
(Load at TW Elevation On Guard Crest Gate if TW is below TOG_{gg})

$$\sigma_{twgg.U2.2} := \begin{array}{|l} (0.0kPa) \text{ if } A2_{U2} \\ 0.0kPa \text{ if } B2_{U2} \\ \left[\gamma_w \cdot (TW_{U2} - TOP_{gg.U2})\right] \text{ if } C2_{U2} \end{array} = 0.0 \cdot kPa$$

Average Pressure acting on Guard Crest Gate:

$$\sigma_{twgg.U2.avg} := \frac{(\sigma_{twgg.U2.1} + \sigma_{twgg.U2.2})}{2} = 8.83 \cdot kPa$$

Total Area water acting on Crest Gate:

$$A_{twgg.U2} := \begin{array}{|l} D_{twgg.U2} \cdot W_{twgg.U2} \text{ if } A2_{U2} \\ D_{twgg.U2} \cdot W_{twgg.U2} \text{ if } B2_{U2} \\ H_{gg.U2} \cdot W_{twgg.U2} \text{ if } C2_{U2} \end{array} = 7.2 \cdot m^2$$

Total Horizontal Headwater Load on Guard Crest Gate: $H_{twgg.U2} := \sigma_{twgg.U2.avg} \cdot A_{twgg.U2} = 63.6 \cdot kN$

Apply Total Horiz. TW Load on Guard Gate at:

$$H_{twgg.U2.loc} := \begin{array}{|l} (TOC_{as} - BOF_{elev}) \text{ if } A2_{U2} \\ \left[\frac{(TW_{U2} - TOC_{as})}{3} + (TOC_{as} - BOF_{elev})\right] \text{ if } B2_{U2} \\ \left[\frac{\sigma_{twgg.U2.2} \cdot A_{twgg.U2} \cdot \frac{(H_{gg.U2})}{2} + \frac{(\sigma_{twgg.U2.1} - \sigma_{twgg.U2.2})}{2} A_{twgg.U2} \cdot \frac{(H_{gg.U2})}{3}}{\sigma_{twgg.U2.2} \cdot A_{twgg.U2} + \frac{(\sigma_{twgg.U2.1} - \sigma_{twgg.U2.2})}{2} \cdot A_{twgg.U2}} \ldots \\ + (TOC_{as} - BOF_{elev})\right] \text{ if } C2_{U2} \end{array} = 4.6 \cdot m$$

Apply Total Guard Crest Gate Headwater Load at (From toe): $H_{twgg.U2.loc.z} := \frac{W_{twgg.U2}}{2} = 2\ m$

LATERAL WATER LOADS (continued)

U2 CASE

TAILWATER (RESISTING) Applied to Concrete Strucuture:

Tailwater Depth on Top of Abutment Footing: $D_{twa.U2} := TW_{U2} - TOC_{as} = 1.80\ m$

Tailwater Load Unit Width on Abutment: $W_{twa.U2} := 2 \cdot r_{wall} = 12.00\ m$

Total Horizontal Tailwater Load on Abutment: $H_{twa.U2} := \frac{\left(\gamma_w \cdot D_{twa.U2}^{\ 2}\right)}{2} \cdot W_{twa.U2} = 190.7 \cdot kN$

Apply Total Abutment Tailwater Load at: $H_{twa.U2.loc} := \frac{D_{twa.U2}}{3} + \left(TOC_{as} - BOF_{elev}\right) = 4.60\ m$

Apply Total Abutment Tailwater Load at (from Toe Line): $H_{twa.U2.loc.z} := W_{twgg.U2} + r_{wall} = 10\ m$

Footing Thickness for horizontal at Toe: $h_{toe} = 4\ m$

Tailwater Depth At top of Gate Base Footing Elevation: $D_{twgf.U2} := TW_{U2} - TOC_{as} = 1.80\ m$

Water Depth at bottom of Gate Base Footing (Excluding Key): $D_{twtoe.U2} := TW_{U2} - BOF_{elev} = 5.80\ m$

Water Depth at bottom of Gate Base Footing (Including Key):

Unit Width of D/S face of crest for applicaiton of Tailwater Load: $W_{tw.U2} := W_B = 16.00\ m$

Tailwater Pressure At Top of Gate Footing: $\sigma_{twgf.U2} := \left(\gamma_w \cdot D_{twgf.U2}\right) = 17.66 \cdot kPa$

Tailwater Line Load At Bottom of Gate Footing (Excluding Key): $\sigma_{twtoe.U2} := \left(\gamma_w \cdot D_{twtoe.U2}\right) = 56.9 \cdot kPa$

Trianglular Distribution Unit Load on Gate Footing Base: $H_{twgf.U2.tri} := \left(\frac{\sigma_{twtoe.U2} - \sigma_{twgf.U2}}{2}\right) \cdot \left[\left(T_{as}\right) \cdot W_{tw.U2}\right] = 1255.68 \cdot kN$

Rectangular Distribution Unit Load on Gate Footing Base: $H_{twgf.U2.rect} := \sigma_{twgf.U2} \cdot \left[\left(T_{as}\right) \cdot W_{tw.U2}\right] = 1130.11 \cdot kN$

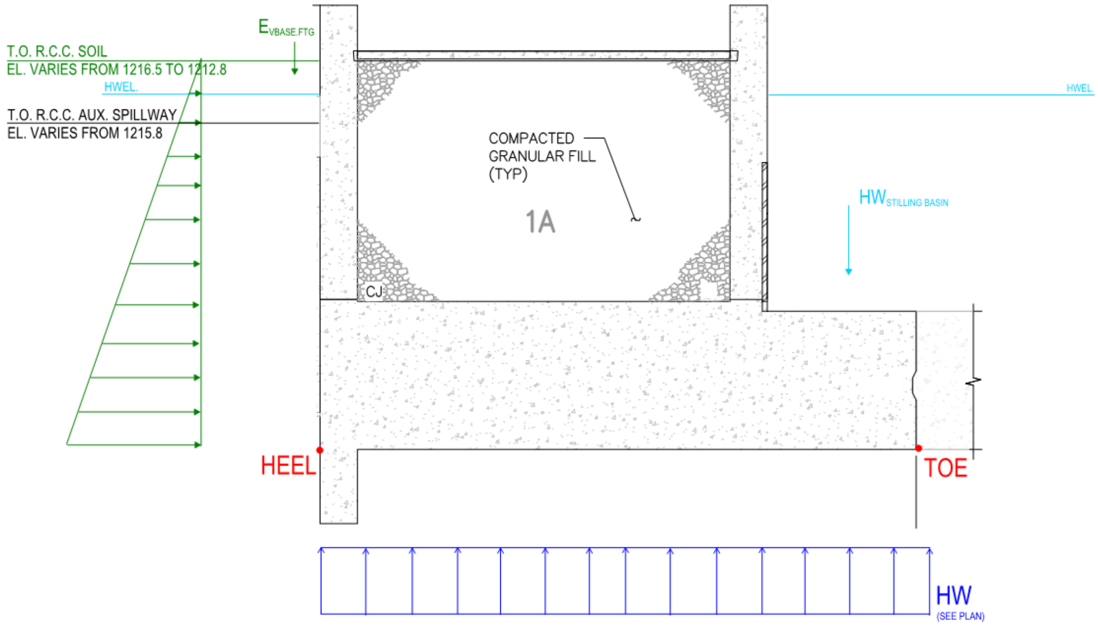
Total Horizontal Tailwater Headwater Load on Gate Footing: $H_{twgf.U2} := H_{twgf.U2.tri} + H_{twgf.U2.rect} = 2385.79 \cdot kN$

Apply Total Gate Footing Tailwater Load at:

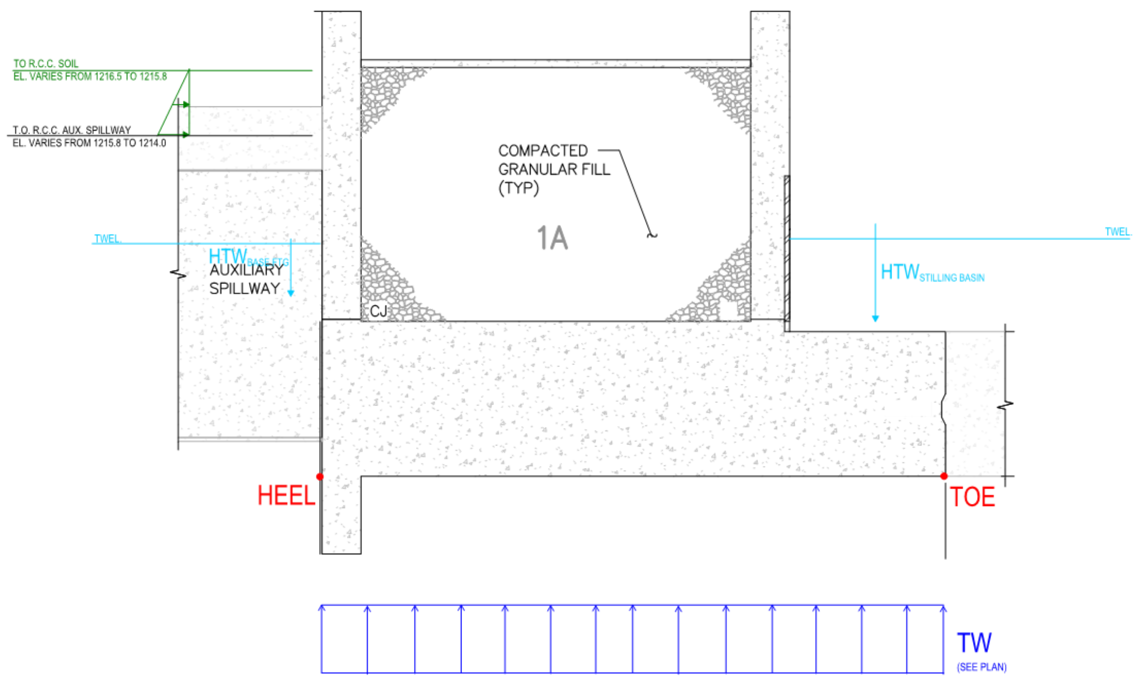
$$H_{twgf.U2.loc} := \frac{\left[H_{twgf.U2.rect} \cdot \frac{\left(T_{as}\right)}{2} + H_{twgf.U2.tri} \cdot \frac{\left(T_{as}\right)}{3}\right]}{H_{twgf.U2.tri} + H_{twgf.U2.rect}} = 1.65\ m$$

Apply Total Gate Footing Tailwater Load at (From Toe Line): $H_{twgf.U2.loc.z} := \frac{W_B}{2} = 8.00\ m$

SUMMATION OF LATERAL WATER LOADS: U2 CASE



SECTION 1A BEFORE GATES & AUX. SPILLWAY RCC

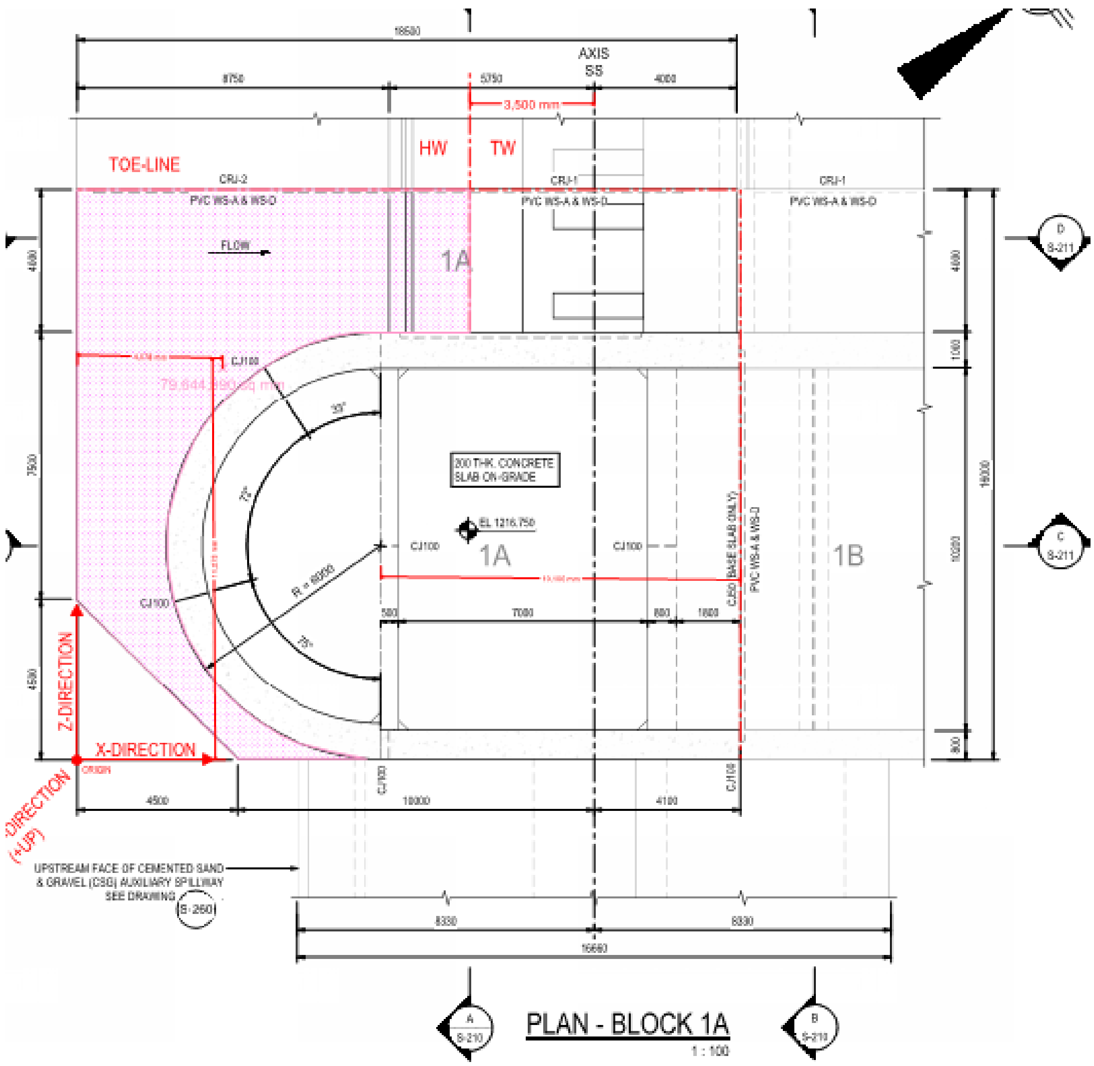


SECTION 1A AFTER GATES & AUX. SPILLWAY RCC

$$\Sigma H_{Water.U2.x} := H_{hwa.U2} + H_{hwas.U2} + H_{hwgg.U2} + H_{twa.U2} + H_{twgf.U2} + H_{twgg.U2} = -3164.31 \cdot kN$$

$$\Sigma M_{HWater.U2.x} := H_{hwa.U2} \cdot H_{hwa.U2.loc} + H_{hwas.U2} \cdot H_{hwas.U2.loc} + H_{hwgg.U2} \cdot H_{hwgg.U2.loc} \cdots = -11535.1 \cdot kN \cdot m$$
$$+ H_{twa.U2} \cdot H_{twa.U2.loc} + H_{twgf.U2} \cdot H_{twgf.U2.loc} + H_{twgg.U2} \cdot H_{twgg.U2.loc}$$

$\Sigma H_{Water.U2.z} := 0 kN$ $\Sigma M_{HWater.U2.z} := 0 \cdot kN \cdot m$



HEADWATER:

Water Depth on top of Approach Slab: $d_{hw.U2} := HW_{U2} - TOC_{as} = 4.60\ m$

Water Area on top of Approach Slab: $A_{as} = 79.64\ m^2$ (From Geom. Scaled on REVU)

Vertical Water Weight (H1) on Approach Slab: $H_{1.U2} := \left(A_{as} \cdot d_{hw.U2}\right) \cdot \gamma_w = 3594.1 \cdot kN$

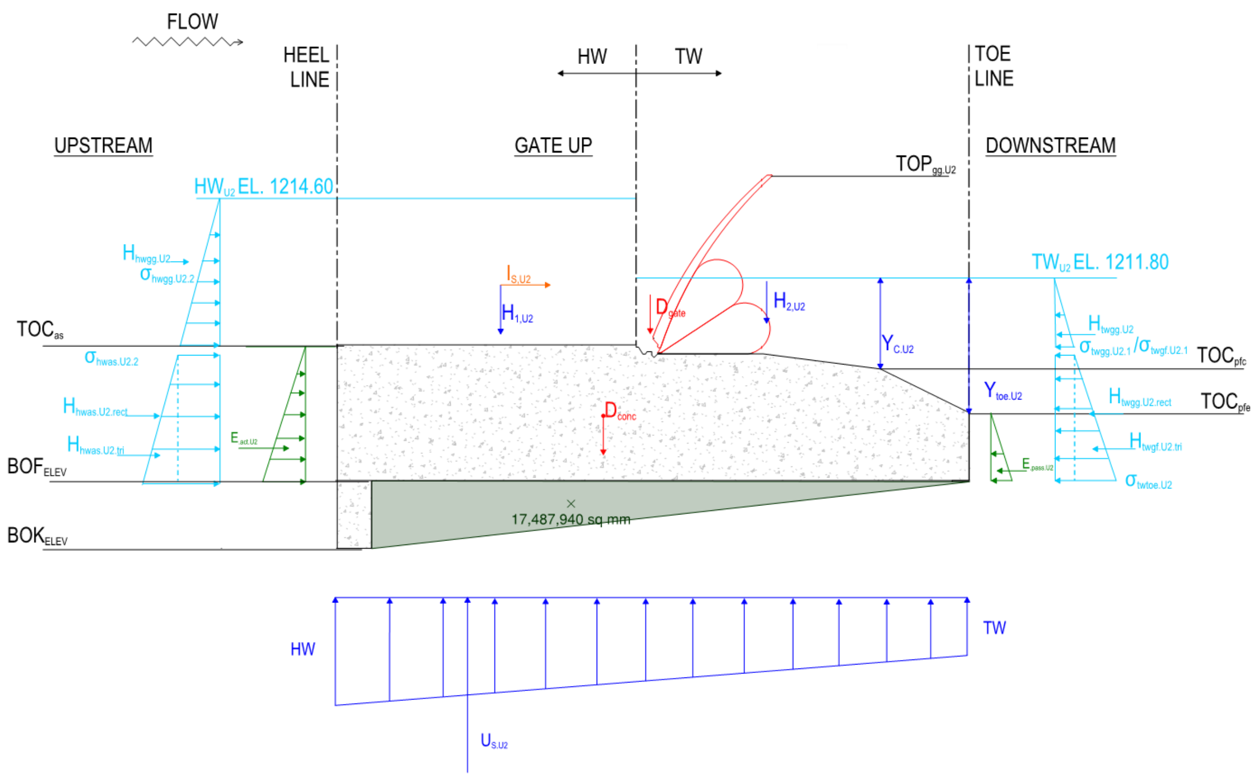
Moment Arm for Applicaiton of Water Weight (H1) from toe (X-Direction): $H_{1.U2.loc.x} := L_B - 4.078m = 14.42\ m$ (From Geom. Scaled on REVU)

Moment Arm for Applicaiton of Water Weight (H1) from toe (Z-Direction): $H_{1.U2.loc.z} := W_B - 11.273m = 4.73\ m$ (From Geom. Scaled on REVU)

VERTICAL WATER LOADS

U2 CASE

TAILWATER:



Approach Slab Length: $L_{as} = 8.75\ m$

Gate Footing Length: $L_{gf} = 9.75\ m$

Gate Footing Crest Length: $L_{gfc} = 2.25\ m$

TAILWATER:

Trapezoid Volume Above Gate Footing from Approach Slab to Crest:

$$V_{asc.U2} := (L_{gf} - L_{gfc}) W_{twgg.U2} \frac{d_{hw.U2} + Y_{C.U2}}{2} = 106.5 \cdot m^3$$

Trapezoid Volume Above Gate Footing Crest to End of Gate Footing:

$$V_{gfc.U2} := (L_{gfc} \cdot W_{twgg.U2}) \frac{Y_{C.U2} + Y_{TOE.U2}}{2} = 28.35 \cdot m^3$$

Load Above Gate Footing from Approach Slab to Crest:

$$H_{2.U2.asc} := V_{asc.U2} \cdot \gamma_w = 1044.76 \cdot kN$$

Load Acting Above Footing Crest from Toe:

$$H_{2.U2.asc.loc.x} := \frac{(L_{gf} - L_{gfc}) \cdot (2 \cdot d_{hw.U2} + Y_{C.U2})}{3 \cdot (d_{hw.U2} + Y_{C.U2})} + L_{gfc} = 6.37\ m$$

Load Above Gate Footing from Crest to End:

$$H_{2.U2.gfc} := V_{gfc.U2} \cdot \gamma_w = 278.11 \cdot kN$$

Load Acting Above Gate Footing from Crest to End:

$$H_{2.U2.gfc.loc.x} := \frac{(L_{gfc}) \cdot (2 \cdot Y_{C.U2} + Y_{TOE.U2})}{3 \cdot (Y_{C.U2} + Y_{TOE.U2})} = 1.05\ m$$

Vertical Water Weight (H2) on Gate Footing:

$$H_{2.U2} := H_{2.U2.asc} + H_{2.U2.gfc} = 1322.88 \cdot kN$$

Moment Arm for Application of Water Weight (H2) from toe:

$$H_{2.U2.loc.x} := \frac{H_{2.U2.asc} \cdot H_{2.U2.asc.loc.x} + H_{2.U2.gfc} \cdot H_{2.U2.gfc.loc.x}}{H_{2.U2}} = 5.25\ m$$

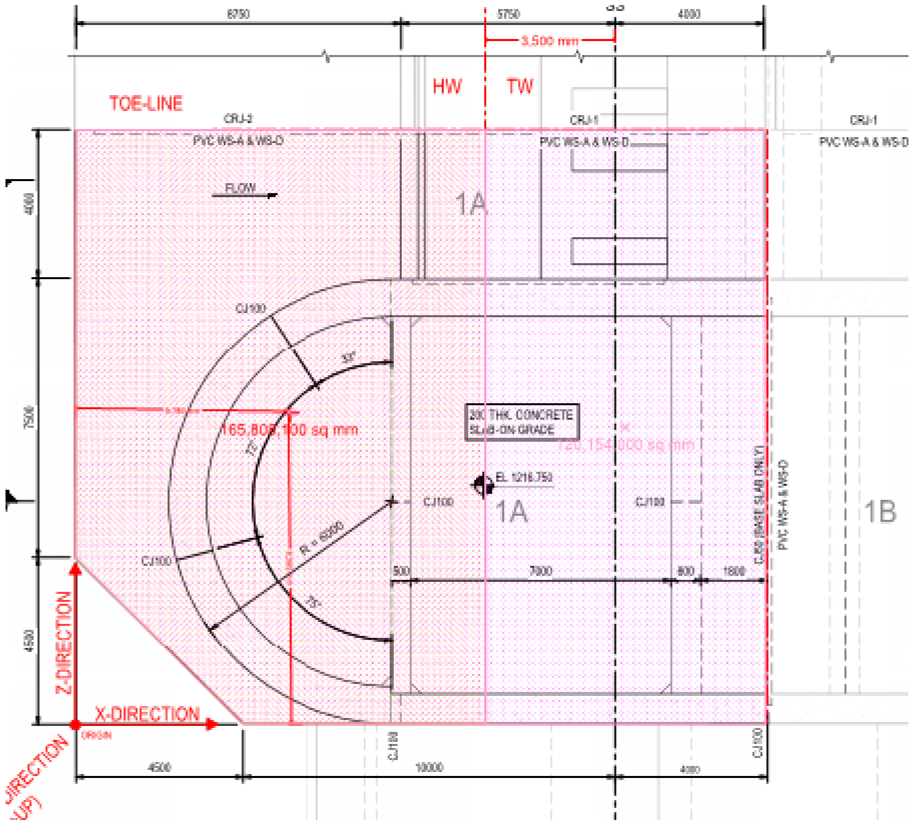
Moment Arm for Applicaiton of Water Weight (H2) from toe (Z-Direction):

$$H_{2.U2.loc.z} := 2.0m$$

UPLIFT

U2 CASE

(Assuming constant Headwater Uplift at front and constant Tailwater Uplift at back of footing base)



Uplift pressure at U/S Face (heel):	$U_{HW.U2} := D_{hwas.U2} \cdot \gamma_w = 84.4 \cdot \frac{kN}{m^2}$
Uplift pressure at D/S Face Stilling Basin:	$U_{TW.U2} := D_{twtoe.U2} \cdot \gamma_w = 56.9 \cdot \frac{kN}{m^2}$

Area of Uplift Force From Headwater Side: $A_{HWU.U2} := 165.81 m^2$ (From Bluebeam REVU)

Area of Uplift Force From Tailwater Side: $A_{TWU.U2} := 120 m^2$ (From Bluebeam REVU)

Uplift Force From Headwater Side: $U_{A.U2} := -U_{HW.U2} \cdot A_{HWU.U2} = -13988.73 \cdot kN$

Uplift Force From Headwater Side: $U_{B.U2} := -U_{TW.U2} \cdot A_{TWU.U2} = -6827.76 \cdot kN$

Uplift Centroid of Area From Headwater Side to Toe: $X_{U.A} = 13.22 m$ $\quad Z_{U.A} = 7.63 m$ (From Bluebeam REVU)

Uplift Centroid of Area From Tailwater Side to Toe: $X_{U.B} = 3.75 m$ $\quad Z_{U.B} = 8 m$ (From Bluebeam REVU)

Total Resultant Uplift force: $U_{U2} := U_{A.U2} + U_{B.U2} = -20816.49 \cdot kN$

Resultant Location from Toe Rect. Load (X-Direction):

$$U_{U2.loc.x} := \frac{\left(U_{A.U2} \cdot X_{U.A} + U_{B.U2} \cdot X_{U.B}\right)}{\left(U_{A.U2} + U_{B.U2}\right)} = 10.11 m$$

Resultant Location from Toe Rect. Load (Z-Direction):

$$U_{U2.loc.z} := \frac{\left[U_{A.U2} \cdot \left(W_B - Z_{U.A}\right) + U_{B.U2} \cdot \left(W_B - Z_{U.B}\right)\right]}{\left(U_{A.U2} + U_{B.U2}\right)} = 8.25 m$$

$$\Sigma V_{water.U2} := H_{1.U2} + H_{2.U2} + U_{U2} = -15899.55 \cdot kN$$

$$\Sigma M_{Vwater.U2.x} := H_{1.U2} \cdot H_{1.U2.loc.x} + H_{2.U2} \cdot H_{2.U2.loc.x} + U_{U2} \cdot U_{U2.loc.x} = -151755.31 \cdot kN \cdot m$$

$$\Sigma M_{Vwater.U2.z} := H_{1.U2} \cdot H_{1.U2.loc.z} + H_{2.U2} \cdot H_{2.U2.loc.z} + U_{U2} \cdot U_{U2.loc.z} = -152002.9 \cdot kN \cdot m$$

Equivalent Fluid Pressure (EFP):		
At rest lateral pressure coefficient:	$K_{o.U2} := 1 - \sin(\phi_{backfill}) = 0.658$	(Section 5.3, Design Criteria)
Headwater Top of Soil Elevation:	$TOS_{HW} = 1210\,m$	
Top of Backfill Soil Elevation:	$TOS_{BF} = 1216.5\,m$	
Driving Soil Load Unit Width Projected Surface Area of Abutment:	$W_{ds.hwa.U2} := 6.0m$	
Driving Soil Load Unit Width on Projected Approach Slab:	$W_{hwas.U2} = 16.00\,m$	
Resisting Soil Load Unit Width Projected Surface Area of Abutment:	$W_{rsa.U2} := \frac{10.5m + 9.381m}{2} = 9.94\,m$	(From Section Cut)
Driving Soil Load Depth on Abutment:	$d_{DS.a} = 0\,m$	
Driving Soil Load Depth on Footing:	$d_{DS.as} = 4\,m$	
Resisting Soil Load Depth on Abutment:	$d_{RS.a} = 8.5\,m$	
Thickness of Stilling Basin:	$T_{sb} = 2\,m$	

Lateral X-Direction Driving Force (Headwater Side - at rest condition)

At-Rest Soil Load on Half of Abutment:
$$E_{act.a.U2.x} := \frac{\left(K_{o.U2} \cdot d_{DS.a}^{\,2}\right)}{2} \cdot \left(\gamma_r - \gamma_w\right) \cdot W_{ds.hwa.U2} \cdot -1 = 0 \cdot kN$$

Acting at:
$$E_{act.a.U2.x.loc.y} := \frac{d_{DS.a}}{3} + T_{as} = 4.00\,m$$

Acting at (from Toe Line):
$$E_{act.a.U2.x.loc.z} := W_{hwgg.U2} + r_{wall} = 10.00\,m$$

At-Rest Soil Load on Top of Approach Slab:
$$\sigma_{DS.as.U2} := \left(K_{o.U2} \cdot d_{DS.a}\right) \cdot \left(\gamma_r - \gamma_w\right) = 0 \cdot kPa$$

At-Rest Soil Load on Bottom of Approach Slab:
$$\sigma_{DS.key.U2} := \left(K_{o.U2} \cdot d_{DS.as}\right) \cdot \left(\gamma_r - \gamma_w\right) = 32.08 \cdot kPa$$

At-Rest Soil Load on Approach Slab (Rect):
$$E_{act.as.rect.U2.x} := \sigma_{DS.as.U2} \cdot \left(T_{as}\right) \cdot W_{hwas.U2} \cdot -1 = 0 \cdot kN$$

At-Rest Soil Load on Approach Slab (Tri):
$$E_{act.as.tri.U2.x} := \frac{\left(\sigma_{DS.key.U2} - \sigma_{DS.as.U2}\right) \cdot \left(T_{as}\right)}{2} \cdot W_{hwas.U2} \cdot -1 = -1026.66 \cdot kN$$

At-Rest Soil Load on Approach Slab:
$$E_{act.as.U2.x} := E_{act.as.rect.U2.x} + E_{act.as.tri.U2.x} = -1026.66 \cdot kN$$

Acting at:
$$E_{act.as.U2.x.loc.y} := \frac{\left(E_{act.as.rect.U2.x} \cdot \frac{T_{as}}{2} \cdots + E_{act.as.tri.U2.x} \cdot \frac{T_{as}}{3}\right)}{E_{act.as.U2.x}} = 1.33\,m$$

Acting at (from Toe Line):
$$E_{act.as.U2.x.loc.z} := \frac{W_B}{2} = 8.00\,m$$

Lateral X-Direction Resisting Force (Tailwater Side - at rest condition)

U2 CASE

At-rest Soil Load:
$$E_{pass.U2.x} := \frac{\left(K_{o.U2} \cdot d_{RS.a}^{\;2}\right)}{2} \cdot \left(\gamma_r - \gamma_w\right) \cdot W_{rsa.U2} = 2880.26 \cdot kN$$

Acting at:
$$E_{pass.U2.x.loc.y} := \frac{d_{RS.a}}{3} + T_{sb} = 4.83\ m$$

$W_{rsa.U2} = 9.94\ m$

Acting at (from Toe Line):
$$E_{pass.U2.x.loc.z} := W_{hwgg.U2} + r_{wall} = 10\ m$$

$$\Sigma H_{soil.U2.x} := \left(E_{act.a.U2.x} + E_{act.as.U2.x} + E_{pass.U2.x}\right) = 1853.61 \cdot kN$$

$$\Sigma M_{soil.U2.x} := E_{act.a.U2.x} \cdot E_{act.a.U2.x.loc.y} + E_{act.as.U2.x} \cdot E_{act.as.U2.x.loc.y} + E_{pass.U2.x} \cdot E_{pass.U2.x.loc.y} = 12552.4 \cdot kN \cdot m$$

Lateral Z-Direction Driving Force (Headwater Side - Before Gates & Aux. Spillway RCC - at rest condition)

Max./Min. Top of R.C.C. Soil Elevation: $TOS_{RCC.max} = 1216.5\ m$ $\quad TOS_{RCC.min} = 1212.8\ m$

Average Top of R.C.C. Soil Elevation: $TOS_{RCC} = 1214.65\ m$

Depth of R.C.C. Soil Acting on Abutment Walls: $d_{act.RCC.w} = 4.65\ m$

Depth of R.C.C. Soil Acting on Abutment Footings: $d_{act.RCC.f} = 8.65\ m$

Projected Width of soil acting on Abutment Walls: $w_{abut.RCC} = 9.45\ m$

Projected Width of soil acting on Abutment Footing: $w_{FTG.RCC} = 12.2\ m$

At-Rest Soil Load on Top of Footing Slab:
$$\sigma_{act.RCC.w.U2} := \left(K_{o.U2} \cdot d_{act.RCC.w}\right) \cdot \left(\gamma_r - \gamma_w\right) = 37.3 \cdot kPa$$

At-Rest Soil Load on Bottom of Approach Slab:
$$\sigma_{act.RCC.f.U2} := \left(K_{o.U2} \cdot d_{act.RCC.f}\right) \cdot \left(\gamma_r - \gamma_w\right) = 69.38 \cdot kPa$$

At-Rest Soil Load on Abutment Walls:
$$E_{act.a.U2.z} := \frac{\left(K_{o.U2} \cdot d_{act.RCC.w}^{\;2}\right)}{2} \cdot \left(\gamma_r - \gamma_w\right) \cdot w_{abut.RCC} \cdot -1 = -819.45 \cdot kN$$

Acting at:
$$E_{act.a.U2.z.loc.y} := \frac{d_{DS.a}}{3} + T_{as} = 4.00\ m$$

Acting at (from Toe Line):
$$E_{act.a.U2.z.loc.x} := \frac{\left(L_{wall} + r_{wall} - 6.35m\right)}{2} + 6.35m = 11.18\ m$$

At-Rest Soil Load on Abutment Footing (Rect):
$$E_{act.as.rect.U2.z} := \sigma_{act.RCC.w.U2} \cdot \left(T_{as}\right) \cdot w_{abut.RCC} \cdot -1 = -1409.81 \cdot kN$$

At-Rest Soil Load on Abutment Footing (Tri):
$$E_{act.as.tri.U2.z} := \frac{-\left(\sigma_{act.RCC.f.U2} - \sigma_{act.RCC.w.U2}\right) \cdot \left(T_{as}\right)}{2} \cdot w_{FTG.RCC} = -782.83 \cdot kN$$

At-Rest Soil Load on Approach Slab:
$$E_{act.as.U2.z} := E_{act.as.rect.U2.z} + E_{act.as.tri.U2.z} = -2192.64 \cdot kN$$

Acting at:
$$E_{act.as.U2.z.loc.y} := \frac{\left(E_{act.as.rect.U2.z} \cdot \frac{T_{as}}{2} \ldots + E_{act.as.tri.U2.z} \cdot \frac{T_{as}}{3}\right)}{E_{act.as.U2.z}} = 1.76\ m$$

Acting at (from toe line):
$$E_{act.as.U2.z.loc.x} := \frac{\left(L_{wall} + r_{wall} - 6.35m\right)}{2} + 6.35m = 11.18\ m$$

Lateral Z-Direction Driving Force (Headwater Side - After Gates & Aux. Spillway RCC - at rest condition) **U2 CASE**

Max. Top of R.C.C. Wall: $TORCC_{max} = 1215.8\ m$

Min. Top of R.C.C. Wall: $TORCC_{min} = 1214\ m$

Average Top of R.C.C. Wall Elevation: $TORCC = 1214.9\ m$

Width of Soil acting at Max. top of RCC: $w_{RCC.max} = 4.7\ m$

Width of Soil acting with average Top of RCC (Steps): $w_{RCC.avg} = 1.65\ m$

Depth of Top of Soil to Top of R.C.C. Wall: $d_{act.RCC} = 0.7\ m$

Depth of Top of Soil to Average Top of R.C.C. Wall (Steps): $d_{act.RCC.avg} = 1.6\ m$

At-Rest Soil Load on Abutment Walls after RCC:

$$E_{act.RCC.U2.z} := \frac{\left(K_{o.U2} \cdot d_{act.RCC}{}^{2}\right)}{2} \cdot \left(\gamma_r - \gamma_w\right) \cdot w_{RCC.max} \cdot -1 = -9.24 \cdot kN$$

Acting at:

$$E_{act.RCC.U2.z.loc.y} := \frac{d_{act.RCC}}{3} + \left(TORCC_{max} - BOF_{elev}\right) = 10.03\ m$$

Acting at (from Toe Line): $E_{act.RCC.U2.z.loc.x} := 4m$ (at SS-Axis Center Line)

At-Rest Soil Load on Abutment Walls at RCC Steps:

$$E_{act.RCC.s.U2.z} := \frac{\left(K_{o.U2} \cdot d_{act.RCC.avg}{}^{2}\right)}{2} \cdot \left(\gamma_r - \gamma_w\right) \cdot w_{RCC.avg} \cdot -1 = -16.94 \cdot kN$$

Acting at:

$$E_{act.RCC.s.U2.z.loc.y} := \frac{d_{act.RCC.avg}}{3} + \left(TORCC - BOF_{elev}\right) = 9.43\ m$$

Acting at (from Toe Line):

$$E_{act.RCC.s.U2.z.loc.x} := \frac{4m - 2.35m}{2} = 0.83\ m$$

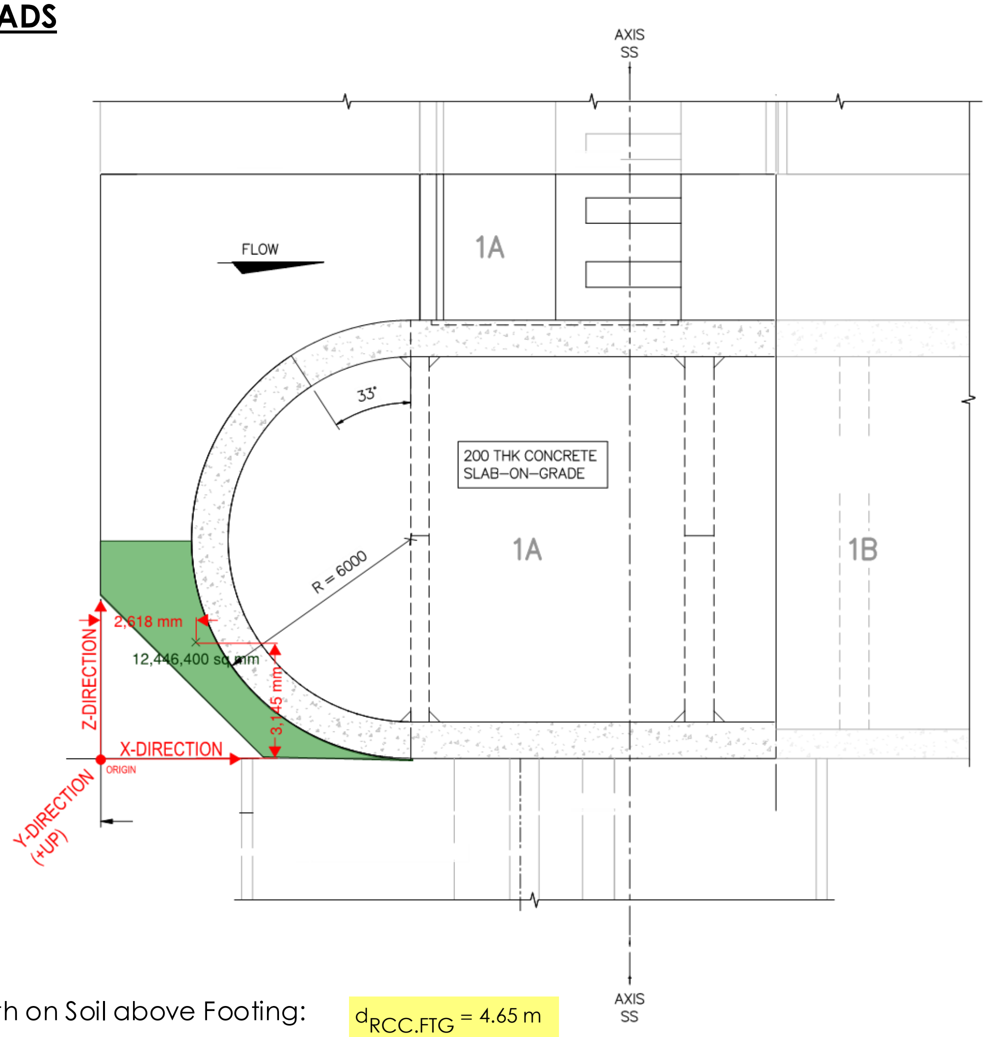
(at Halfway point of RCC Steps)

$$\Sigma H_{soil.U2.z} := \left(E_{act.a.U2.z} + E_{act.as.U2.z} + E_{act.RCC.U2.z} + E_{act.RCC.s.U2.z}\right) = -3038.27 \cdot kN$$

$$\Sigma M_{soil.U2.z} := E_{act.a.U2.z} \cdot E_{act.a.U2.z.loc.y} + E_{act.as.U2.z} \cdot E_{act.as.U2.z.loc.y} \cdots + E_{act.RCC.U2.z} \cdot E_{act.RCC.U2.z.loc.y} + E_{act.RCC.s.U2.z} \cdot E_{act.RCC.s.U2.z.loc.y} = -7393.67 \cdot kN \cdot m$$

VERTICAL SOIL LOADS

U2 CASE



Average Depth on Soil above Footing: $d_{RCC.FTG} = 4.65\ m$

Area of Footing with Soil above: $A_{ftg.soil} = 0$ (From Bluebeam REVU)

Vertical Water Weight (H1) on Approach Slab: $E_{1.U2} := (A_{ftg.soil} \cdot d_{RCC.FTG}) \cdot (\gamma_r - \gamma_w) = 0.0 \cdot kN$

Moment Arm for Applicaiton of Water Weight (H1) from toe (X-Direction): $E_{1.U2.loc.x} := L_B - 5.607m = 12.89\ m$ (From Geom. Scaled on REVU)

Moment Arm for Applicaiton of Water Weight (H1) from toe (Z-Direction): $E_{1.U2.loc.z} := W_B - 3.145m = 12.86\ m$ (From Geom. Scaled on REVU)

$\Sigma E_{U2} := E_{1.U2} = 0 \cdot kN$

$\Sigma M_{E.U2.x} := E_{1.U2} \cdot E_{1.U2.loc.x} = 0 \cdot kN \cdot m$

$\Sigma M_{E.U2.z} := E_{1.U2} \cdot E_{1.U2.loc.z} = 0 \cdot kN \cdot m$

IMPACT LOADS (DEBRIS LOADING FROM MEMO)

Total Impact Load on Structure: $I_{U2} := 0kN$ (SS Abutment) - 50 Year Flood

Apply Ice load at: $I_{U2.loc.y} := (HW_{U2} - BOF_{elev} - 0.30m) = 8.30\ m$

$\Sigma H_{I.U2} := I_{U2} = 0 \cdot kN$

$\Sigma M_{I.U2} := I_{U2} \cdot I_{U2.loc.y} = 0 \cdot kN \cdot m$

SEISMIC LOAD (NOT APPLICABLE FOR THIS LOAD CASE)

U2 CASE

SUMMARY OF LOADS

	Loads	Moment Arm	
Dead load of Concrete Structure:	$D_{conc} = 35947.6 \cdot kN$	$X_{conc.loc} = 8.81\ m$	$Z_{conc.loc} = 8.46\ m$
Obermyer Gate Weight:	$D_{Gate} = 56.0 \cdot kN$	$X_{gate} = 9.50\ m$	$Z_{gate} = 2.00\ m$
Dead load of Fill:	$D_{fill} = 18056.6 \cdot kN$	$X_{fill.loc} = 7.31\ m$	$Z_{fill.loc} = 10.00\ m$
HW Lateral Load on Abutment:	$H_{hwa.U2} = -1245.5 \cdot kN$	$H_{hwa.U2.loc} = 5.53\ m$	
HW Lateral Load on Approach Slab:	$H_{hwas.U2} = -4143.7 \cdot kN$	$H_{hwas.U2.loc} = 1.80\ m$	
HW Lateral Load on Guard Gate:	$H_{hwgg.U2} = -415.2 \cdot kN$	$H_{hwgg.U2.loc} = 5.53\ m$	
TW Lateral Load on Abutment:	$H_{twa.U2} = 190.7 \cdot kN$	$H_{twa.U2.loc} = 4.60\ m$	
TW Lateral Load on Pier Footing:	$H_{twgf.U2} = 2385.79 \cdot kN$	$H_{twgf.U2.loc} = 1.65\ m$	
TW Lateral Load on Guard Gate:	$H_{twgg.U2} = 63.6 \cdot kN$	$H_{twgg.U2.loc} = 4.60\ m$	
Vertical HW Load on Approach Slab:	$H_{1.U2} = 3594.1 \cdot kN$	$H_{1.U2.loc.x} = 14.42\ m$	$H_{1.U2.loc.z} = 4.73\ m$
Vertical TW Load on Pier Footing (crest):	$H_{2.U2} = 1322.9 \cdot kN$	$H_{2.U2.loc.x} = 5.25\ m$	$H_{2.U2.loc.z} = 2.00\ m$
Uplift:	$U_{U2} = -20816.5 \cdot kN$	$U_{U2.loc.x} = 10.11\ m$	$U_{U2.loc.z} = 8.25\ m$
X-Direction Lateral Soil Load on Abutment (driving):	$E_{act.a.U2.x} = 0.0 \cdot kN$	$E_{act.a.U2.x.loc.y} = 4.00\ m$	
X-Direction Lateral Lateral Soil Load on Approach Slab (driving):	$E_{act.as.U2.x} = -1026.7 \cdot kN$	$E_{act.as.U2.x.loc.y} = 1.33\ m$	
Lateral Soil Load (resisting):	$E_{pass.U2.x} = 2880.26 \cdot kN$	$E_{pass.U2.x.loc.y} = 4.83\ m$	
Z-Direction Lateral Soil Load on Abutment Before RCC (driving):	$E_{act.a.U2.z} = -819.5 \cdot kN$	$E_{act.a.U2.z.loc.y} = 4.00\ m$	
Z-Direction Lateral Lateral Soil Load on Approach Slab Before RCC (driving):	$E_{act.as.U2.z} = -2192.6 \cdot kN$	$E_{act.as.U2.z.loc.y} = 1.76\ m$	
Z-Direction Lateral Soil Load on Abutment After RCC (driving):	$E_{act.RCC.U2.z} = -9.24 \cdot kN$	$E_{act.RCC.U2.z.loc.y} = 10.03\ m$	
Z-Direction Lateral Soil Load on Abutment at RCC Steps (driving):	$E_{act.RCC.s.U2.z} = -16.94 \cdot kN$	$E_{act.RCC.s.U2.z.loc.y} = 9.43 \cdot m$	
Vertical Soil Load on Footing:	$E_{1.U2} = 0 \cdot kN$	$E_{1.U2.loc.x} = 12.89\ m$	$E_{1.U2.loc.z} = 12.86\ m$
Ice / Impact Load:	$I_{U2} = 0.0 \cdot kN$	$I_{U2.loc.y} = 8.30\ m$	

STABILITY ASSESSMENT (SLIDNG, BEARING, FLOTATION AND OVERTURNING): U2 CASE

CHECK SLIDING (X-Direction & Z-Direction) ALONG HORIZONTAL PLANE THRU TOE, IGNORING BEDROCK MOBILIZED BY STRUCTURAL HEEL KEY, OR VOID BEHIND KEY

Sum of Vertical Forces:

$$\Sigma V_{U2} := \Sigma V_{DL} + \Sigma V_{water.U2} + \Sigma E_{U2} = 38160.6 \cdot kN$$

Sum of Horizontal Forces (X-Direction):

$$\Sigma H_{U2.x} := \Sigma H_{Water.U2.x} + \Sigma H_{soil.U2.x} + \Sigma H_{I.U2} = -1310.71 \cdot kN$$

Sum of Horizontal Forces (Z-Direction):

$$\Sigma H_{U2.z} := \Sigma H_{Water.U2.z} + \Sigma H_{soil.U2.z} = -3038.27 \cdot kN$$

Sum of Horizontal Forces (resultant):

$$\Sigma H_{U2} := \sqrt{\Sigma H_{U2.x}^{\ 2} + \Sigma H_{U2.z}^{\ 2}} = 3308.93 \cdot kN$$

Sliding Factor of Safety:

$$FS_{HorizSliding.U2.x} := \frac{\tan_{\phi} \cdot \Sigma V_{U2}}{\left|\Sigma H_{U2.x}\right|} = 14.20 \qquad FS_{HorizSliding.U2.z} := \frac{\tan_{\phi} \cdot \Sigma V_{U2}}{\left|\Sigma H_{U2.z}\right|} = 6.13$$

Sliding Factor of Safety:

$$FS_{HorizSliding.U2} := \frac{\tan_{\phi} \cdot \Sigma V_{U2}}{\sqrt{\Sigma H_{U2.x}^{\ 2} + \Sigma H_{U2.z}^{\ 2}}} = 5.62$$

$$FS_{HorizSliding.U2.Check.x} := \begin{cases} \text{"OKAY"} & \text{if } FS_{HorizSliding.U2.x} \geq FS_{req.U2.sl} \\ \text{"Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

$$FS_{HorizSliding.U2.Check.z} := \begin{cases} \text{"OKAY"} & \text{if } FS_{HorizSliding.U2.z} \geq FS_{req.U2.sl} \\ \text{"Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

$$FS_{HorizSliding.U2.Check} := \begin{cases} \text{"OKAY"} & \text{if } FS_{HorizSliding.U2} \geq FS_{req.U2.sl} \\ \text{"Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

CHECK FOUNDATION BEARING CAPACITY

Sum of the Moments (X-Direction):

$$\Sigma M_{U2.x} := \Sigma M_{DL.x} + \Sigma M_{HWater.U2.x} + \Sigma M_{Vwater.U2.x} + \Sigma M_{I.U2} + \Sigma M_{soil.U2.x} = 298593 \cdot kN \cdot m$$

Eccentricity:

$$e_{U2.x} := X_{BCG} - \frac{\Sigma M_{U2.x}}{\Sigma V_{U2}} = 1.15\ m$$

Eccentricity Check:

$$e_{check.U2.x} := \begin{cases} \text{"Okay"} & \text{if } e_{U2.x} \leq Kern_x \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$$e_{check.U2.x} = \text{"Okay"}$$

Foundation Bearing Pressures (X-Direction):

U2 CASE

Bearing Pressure at Heel:

$$\sigma_{heel.U2.x} := \frac{\Sigma V_{U2}}{A_b} - \frac{\Sigma V_{U2} \cdot e_{U2.x}}{S_{bx.L}} = 79.87 \cdot \frac{kN}{m^2}$$

$$\sigma_{heel.U2.check.x} := \left(\begin{array}{|l} \text{"Okay"} \quad \text{if } 0 \le \sigma_{heel.U2.x} \le \sigma_{allow.U2} \\ \text{"Revise Structure"} \quad \text{otherwise} \end{array} \right)$$

$$\sigma_{heel.U2.check.x} = \text{"Okay"}$$

Bearing Pressure at Toe:

$$\sigma_{toe.U2.x} := \frac{\Sigma V_{U2}}{A_b} + \frac{\Sigma V_{U2} \cdot e_{U2.x}}{S_{bx.R}} = 184.02 \cdot \frac{kN}{m^2}$$

$$\sigma_{toe.U2.check.x} := \begin{array}{|l} \text{"Okay"} \quad \text{if } 0 \le \sigma_{toe.U2.x} \le \sigma_{allow.U2} \\ \text{"Revise Structure"} \quad \text{otherwise} \end{array}$$

$$\sigma_{toe.U2.check.x} = \text{"Okay"}$$

Sum of the Moments (Z-Direction):

$$\Sigma M_{U2.z} := \Sigma M_{DL.z} + \Sigma M_{HWater.U2.z} + \Sigma M_{Vwater.U2.z} + \Sigma M_{soil.U2.z} = 325419 \cdot kN \cdot m$$

Eccentricity:

$$e_{U2.z} := z_{BCG} - \frac{\Sigma M_{U2.z}}{\Sigma V_{U2}} = -0.76\ m$$

Eccentricity Check:

$$e_{check.U2.z} := \begin{array}{|l} \text{"Okay"} \quad \text{if } e_{U2.z} \le Kern_z \\ \text{"Revise Structure"} \quad \text{otherwise} \end{array}$$

$$e_{check.U2.z} = \text{"Okay"}$$

Foundation Bearing Pressures (Z-Direction):

Bearing Pressure at Heel:

$$\sigma_{heel.U2.z} := \frac{\Sigma V_{U2}}{A_b} - \frac{\Sigma V_{U2} \cdot e_{U2.z}}{S_{bz.b}} = 174.09 \cdot \frac{kN}{m^2}$$

$$\sigma_{heel.U2.check.z} := \left(\begin{array}{|l} \text{"Okay"} \quad \text{if } 0 \le \sigma_{heel.U2.z} \le \sigma_{allow.U2} \\ \text{"Revise Structure"} \quad \text{otherwise} \end{array} \right)$$

$$\sigma_{heel.U2.check.z} = \text{"Okay"}$$

Bearing Pressure at Toe:

$$\sigma_{toe.U2.z} := \frac{\Sigma V_{U2}}{A_b} + \frac{\Sigma V_{U2} \cdot e_{U2.z}}{S_{bz.t}} = 95.16 \cdot \frac{kN}{m^2}$$

$$\sigma_{toe.U2.check.z} := \begin{array}{|l} \text{"Okay"} \quad \text{if } 0 \le \sigma_{heel.U2.z} \le \sigma_{allow.U2} \\ \text{"Revise Structure"} \quad \text{otherwise} \end{array}$$

$$\sigma_{toe.U2.check.z} = \text{"Okay"}$$

U2 CASE

Foundation Bearing Pressure (Combined):

Linear pressure superimposed at Corners by both Moment_X and Moment_Z

Bearing Pressure at Heel(x)-Heel(z):

$$\sigma_{heel.U2} := \frac{\Sigma V_{U2}}{A_b} - \frac{\Sigma V_{U2} \cdot e_{U2.x}}{S_{bx.L}} - \frac{\Sigma V_{U2} \cdot e_{U2.z}}{S_{bz.b}} = 120.47 \cdot kPa$$

$$\sigma_{heel.U2.check} := \left(\begin{array}{ll} \text{"Okay"} & \text{if } 0 \le \sigma_{heel.U2} \le \sigma_{allow.U2} \\ \text{"Revise Structure"} & \text{otherwise} \end{array} \right)$$

$\sigma_{heel.U2.check} = \text{"Okay"}$

a

Bearing Pressure at Toe(x)-Toe(z):

$$\sigma_{toe.U2} := \frac{\Sigma V_{U2}}{A_b} + \frac{\Sigma V_{U2} \cdot e_{U2.x}}{S_{bx.R}} + \frac{\Sigma V_{U2} \cdot e_{U2.z}}{S_{bz.t}} = 145.68 \cdot kPa$$

$$\sigma_{toe.U2.check} := \begin{array}{ll} \text{"Okay"} & \text{if } 0 \le \sigma_{toe.U2} \le \sigma_{allow.U2} \\ \text{"Revise Structure"} & \text{otherwise} \end{array}$$

$\sigma_{toe.U2.check} = \text{"Okay"}$

Bearing Pressure at Heel(x)-Toe(z):

$$\sigma_{heeltoe.U2} := \frac{\Sigma V_{U2}}{A_b} - \frac{\Sigma V_{U2} \cdot e_{U2.x}}{S_{bx.L}} + \frac{\Sigma V_{U2} \cdot e_{U2.z}}{S_{bz.t}} = 41.54 \cdot kPa$$

$$\sigma_{heeltoe.U2.check} := \left(\begin{array}{ll} \text{"Okay"} & \text{if } 0 \le \sigma_{heeltoe.U2} \le \sigma_{allow.U2} \\ \text{"Revise Structure"} & \text{otherwise} \end{array} \right)$$

$\sigma_{heeltoe.U2.check} = \text{"Okay"}$

Bearing Pressure at Toe(x)-Heel(z):

$$\sigma_{toeheel.U2} := \frac{\Sigma V_{U2}}{A_b} + \frac{\Sigma V_{U2} \cdot e_{U2.x}}{S_{bx.R}} - \frac{\Sigma V_{U2} \cdot e_{U2.z}}{S_{bz.b}} = 224.62 \cdot kPa$$

$$\sigma_{toeheel.U2.check} := \begin{array}{ll} \text{"Okay"} & \text{if } 0 \le \sigma_{toeheel.U2} \le \sigma_{allow.U2} \\ \text{"Revise Structure"} & \text{otherwise} \end{array}$$

$\sigma_{toeheel.U2.check} = \text{"Okay"}$

FLOATATION ANALYSIS:

ACCEPTANCE PARAMETERS

Required Factor of Safety: $FS_{req.FU2} := 1.5$

VERTICAL LOADS RESISTING:

Dead Load: $\Sigma V_{DL} = 54060.17 \cdot kN$

Water Weight H1+H2: $\Sigma V_{H.FU2} := H_{1.U2} + H_{2.U2} = 4916.94 \cdot kN$

Summation Vertical Resisting: $\Sigma V_{FU2} := \Sigma V_{DL} + \Sigma V_{H.FU2} = 58977.1 \cdot kN$

VERTICAL LOADS UPLIFT:

Uplift: $U_{U2} = -20816.49 \cdot kN$

Factor of Safety Floatation:

$$FS_{act.FU2} := \frac{\Sigma V_{FU2}}{\left| U_{U2} \right|} = 2.83$$

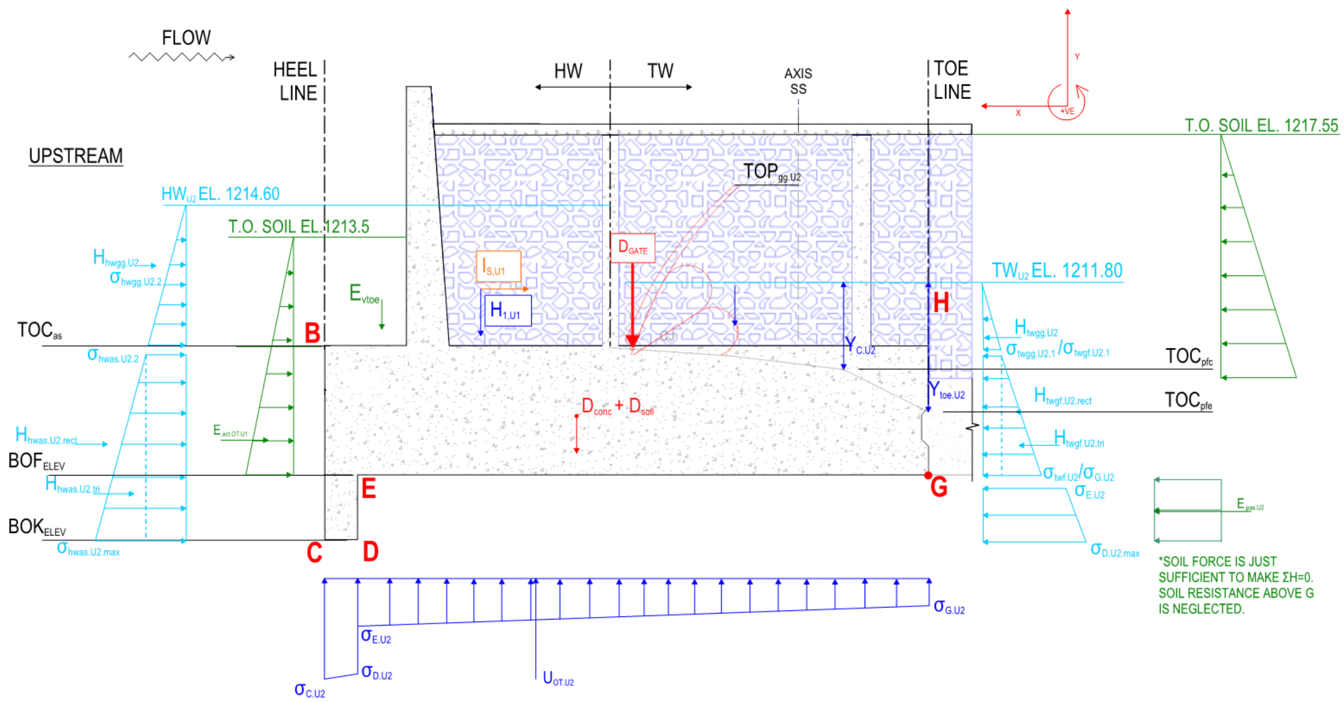
$$FS_{check.FU2} := \begin{array}{ll} \text{"OKAY"} & \text{if } FS_{act.FU2} \ge FS_{req.FU2} \\ \text{"ANCHORS REQUIRED"} & \text{if } FS_{act.FU2} < FS_{req.FU2} \end{array} = \text{"OKAY"}$$

MONOLITH OVERTURNING STABILITY ANALYSIS

U2 CASE

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.
Assumptions are made in order to compute overturning stablity of indetermine forces on monolith with key;
(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.
(b) The horizontal resisting force acting on the key, P.key, is that required for staticequilibrium
(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1 $Ratio_{OT.U2.min} := 0.333$ at Rock Foundation



Uplift Loads for Overturning Stability Analysis (X-Direction)

Line of Creep:

Change in Water Head: $\Delta_{h.U2} := HW_{U2} - TW_{U2} = 2.8\ m$

Length from Point C to Point G: $L_{CG} = 18.61\ m$

Length from Various Points to Points: $L_{CD} = 1\ m$ $L_{DE} = 2\ m$ $L_{EG} = 17.5\ m$

$L_{GH.U2} := TW_{U2} - TOC_{afe} = 3.8\ m$

Length from Point C, D, E to G: $L_{CDEG} = 20.5\ m$ $L_{CDE} = 3\ m$

Water Pressure at Point C & G: $\sigma_{C.U2} := \sigma_{hwas.U2.2} = -84.37 \cdot kPa$ $\sigma_{G.U2} := \sigma_{twtoe.U2} \cdot -1 = -56.9 \cdot kPa$

Water Pressure at Point D:

$$\sigma_{D.U2} := -\gamma_w \cdot \left[\left(HW_{U2} - BOK_{elev} \right) - \frac{\Delta_{h.U2} \cdot L_{CD}}{L_{CDEG}} \right] = -102.65 \cdot kPa$$

Water Pressure at Point E:

$$\sigma_{E.U2} := -\gamma_w \cdot \left[\left(HW_{U2} - BOF_{elev} \right) - \frac{\Delta_{h.U2} \cdot L_{CDE}}{L_{CDEG}} \right] = -80.35 \cdot kPa$$

Uplift for Overturning Analysis on Bottom of Key:

$$U_{OT.U2.key} := \frac{\sigma_{C.U2} + \sigma_{D.U2}}{2} \cdot L_{CD} \cdot W_B = -1496.1 \cdot kN$$

Acting at:

$$U_{OT.U2.key.loc} := \frac{L_{CD} \cdot \left(2 \cdot \sigma_{C.U2} + \sigma_{D.U2} \right)}{3 \left(\sigma_{C.U2} + \sigma_{D.U2} \right)} + L_{EG} = 17.98\ m$$

U2 CASE

Uplift for Overturning Analysis on Bottom of Footing:

$$U_{OT.U2.ftg} := \frac{\sigma_{E.U2} + \sigma_{G.U2}}{2} \cdot L_{EG} \cdot W_B = -19214.2 \cdot kN$$

Acting at:

$$U_{OT.U2.ftg.loc} := \frac{L_{EG} \cdot \left(\sigma_{G.U2} + 2 \cdot \sigma_{E.U2}\right)}{3\left(\sigma_{G.U2} + \sigma_{E.U2}\right)} = 9.25\ m$$

Uplift Load for Overturning Analysis:

$$U_{OT.U2} := U_{OT.U2.key} + U_{OT.U2.ftg} = -20710.3 \cdot kN$$

Uplift Load Acting from Toe:

$$U_{OT.U2.loc} := \frac{U_{OT.U2.key} \cdot U_{OT.U2.key.loc} + U_{OT.U2.ftg} \cdot U_{OT.U2.ftg.loc}}{U_{OT.U2}} = 9.88\ m$$

<u>All Vertical Loads Appliable to Overturning Stability Analysis</u>

		at:	
Total Concrete Dead Loads:	$D_{conc} = 35947.58 \cdot kN$		$X_{conc.loc} = 8.81\ m$
Dead Load of Gate:	$D_{Gate} = 56.0 \cdot kN$		$X_{gate} = 9.50\ m$
Total Fill Loads:	$D_{fill} = 18056.6 \cdot kN$		$X_{fill.loc} = 7.31\ m$
Water Weight (HW) on Apron Slab:	$H_{1.U2} = 3594.1 \cdot kN$		$H_{1.U2.loc.x} = 14.42\ m$
Water Weight (TW) on Guard Gate Footing:	$H_{2.U2} = 1322.9 \cdot kN$		$H_{2.U2.loc.x} = 5.25\ m$
Uplift Load for Overturning Analysis:	$U_{OT.U2} = -20710.3 \cdot kN$		$U_{OT.U2.loc} = 9.88 \cdot m$

Sum of All Overturning Analysis Vertical Load:

$$\Sigma V_{U2.OT} := D_{conc} + D_{Gate} + D_{fill} + H_{1.U2} + H_{2.U2} + U_{OT.U2} = 38266.81 \cdot kN$$

Sum of All Overturning Analysis Vertical Load Moments:

$$\Sigma M_{V.U2.OT} := \left(\begin{array}{l} D_{conc} \cdot X_{conc.loc} + D_{Gate} \cdot X_{gate} + D_{fill} \cdot X_{fill.loc} + H_{1.U2} \cdot H_{1.U2.loc.x} \ldots \\ + H_{2.U2} \cdot H_{2.U2.loc.x} + U_{OT.U2} \cdot U_{OT.U2.loc} \end{array}\right) = 303506.69 \cdot kN \cdot m$$

<u>Lateral Tailwater Loads for Overturning Stability Analysis</u>

TW Lateral Load on Gate Footing (No Key - Overturning Values Adjusted): $H_{twgf.U2} = 2385.79 \cdot kN$

Acting at: $H_{twgf.U2.loc} = 1.65\ m$

Horizontal Tailwater Pressure Top of Key (Overturning Analysis): $\sigma_{twtk.OT.U2} := \sigma_{E.U2} \cdot -1 = 80.35 \cdot kPa$

Horizontal Tailwater Pressure Bottom of Key (Overturning Analysis): $\sigma_{twbk.OT.U2} := \sigma_{D.U2} \cdot -1 = 102.65 \cdot kPa$

Triangular Distribution Unit Load Acting at Key:

$$H_{twbk.OT.U2.tri} := \frac{\left(\sigma_{twbk.OT.U2} - \sigma_{twtk.OT.U2}\right)}{2} \cdot d_{key} \cdot W_{tw.U2} = 356.8 \cdot kN$$

Triangular Distribution Unit Load Acting at Key:

$$H_{twbk.OT.U2.rect} := \sigma_{twtk.OT.U2} \cdot d_{key} \cdot W_{tw.U2} = 2571.08 \cdot kN$$

Total Horizontal Tailwater Load on Key (Overturning Values Adjusted):

$$H_{twkey.OT.U2} := H_{twbk.OT.U2.tri} + H_{twbk.OT.U2.rect} = 2927.88 \cdot kN$$

Acting at:

$$H_{twkey.OT.U2.loc} := \frac{H_{twbk.OT.U2.tri} \cdot \frac{-2 \cdot d_{key}}{3} + H_{twbk.OT.U2.rect} \cdot \frac{-d_{key}}{2}}{H_{twkey.OT.U2}} = -1.04 \cdot m$$

Lateral Driving Earth Loads for Overturning Stability Analysis (at rest condition)

U2 CASE

Depth of Driving Soil Loads (to top of key): $h_{E.OT.U2} := TOC_{as} - BOF_{elev} = 4\ m$

At-Rest Soil Load: $E_{act.OT.U2} := \frac{\left(K_{o.U2} \cdot h_{E.OT.U2}^{2}\right)}{2} \cdot (\gamma_r - \gamma_w) \cdot W_{hwas.U2} \cdot -1 = -1026.66 \cdot kN$

At Rest- Soil Load Acting from Toe: $E_{act.OT.U2.loc} := \frac{h_{E.OT.U2}}{3} = 1.33\ m$

All Lateral Loads Appliable to Overturning Stability Analysis (X-direction)

HW Lateral Load on Approach Slab:	$H_{hwas.U2} = -4143.7 \cdot kN$	$H_{hwas.U2.loc} = 1.80\ m$
HW Lateral Load on Guard Gate:	$H_{hwgg.U2} = -415.2 \cdot kN$	$H_{hwgg.U2.loc} = 5.53\ m$
HW Lateral Load on Abutment:	$H_{hwa.U2} = -1245.5 \cdot kN$	$H_{hwa.U2.loc} = 5.53\ m$
TW Lateral Load on Abutment:	$H_{twa.U2} = 190.7 \cdot kN$	$H_{twa.U2.loc} = 4.60\ m$
TW Lateral Load on Guard Gate:	$H_{twgg.U2} = 63.6 \cdot kN$	$H_{twgg.U2.loc} = 4.60\ m$
TW Lateral Load on Gate Footing (No Key - Overturning Values Adjusted):	$H_{twgf.U2} = 2385.79 \cdot kN$	$H_{twgf.U2.loc} = 1.65\ m$
TW Lateral Load on Key:	$H_{twkey.OT.U2} = 2927.88 \cdot kN$	$H_{twkey.OT.U2.loc} = -1.04\ m$
Ice / Impact Load:	$I_{U2} = 0.0 \cdot kN$	$I_{U2.loc.y} = 8.30\ m$
Lateral Soil Load (driving):	$E_{act.OT.U2} = -1026.7 \cdot kN$	$E_{act.OT.U2.loc} = 1.33\ m$

Resisting Lateral Soil Load as required to produce horizontal equilibrium:

$$E_{pas.OT.x.U2} := -\left(H_{hwas.U2} + H_{hwgg.U2} + H_{hwgg.U2} + H_{twgg.U2} \cdots + H_{twgf.U2} + H_{twkey.OT.U2} + I_{U2} + E_{act.OT.U2}\right) = 623.48 \cdot kN$$

Acting at:

$$E_{pas.OT.U2.loc} := -1 \cdot \frac{d_{key}}{2} = -1\ m$$

Sum of All Overturning Analysis Horizontal Load (ΣH=0):

$$\Sigma H_{U2.OT.x} := H_{hwas.U2} + H_{hwgg.U2} + H_{twgg.U2} + H_{twgf.U2} + H_{twkey.OT.U2} + I_{U2} + E_{act.OT.U2} + E_{pas.OT.x.U2} = 415.16 \cdot kN$$

Sum of All Overturning Analysis Horizontal Load Moments:

$$\Sigma M_{H.U2.OT.x} := H_{hwas.U2} \cdot H_{hwas.U2.loc} + H_{hwgg.U2} \cdot H_{hwgg.U2.loc} \cdots + H_{twgg.U2} \cdot H_{twgg.U2.loc} + H_{twgf.U2} \cdot H_{twgf.U2.loc} \cdots + H_{twkey.OT.U2} \cdot H_{twkey.OT.U2.loc} + I_{U2} \cdot I_{U2.loc.y} \cdots + E_{act.OT.U2} \cdot E_{act.OT.U2.loc} + E_{pas.OT.x.U2} \cdot E_{pas.OT.U2.loc} = -10559.87 \cdot kN \cdot m$$

Overturning Stability Analysis (X-Direction)

$$\Sigma M_{U2.OT.x} := \Sigma M_{V.U2.OT} + \Sigma M_{H.U2.OT.x} = 292946.82 \cdot kN \cdot m$$

$$X_{R.U2} := \frac{\Sigma M_{U2.OT.x}}{\Sigma V_{U2.OT}} = 7.66\ m \qquad x_{OT.U2} := X_{R.U2} - \frac{L_B}{2} = -1.59\ m$$

Overturning Resultant Ratio

$$Ratio_{OT.x.U2} := \frac{X_{R.U2}}{L_B} = 0.41$$

$$Ratio_{OT.x.U2.check} := \begin{cases} \text{"OKAY"} & \text{if } Ratio_{OT.x.U2} \geq Ratio_{OT.U2.min} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

$$x_{OT.check.U2} := \begin{cases} \text{"OKAY"} & \text{if } \left|x_{OT.U2}\right| \leq Kern_x \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

All Lateral Loads Appliable to Overturning Stability Analysis (Z-direction)

U2 CASE

Z-Direction Lateral Soil Load on Abutment Before RCC (driving): $E_{act.a.U2.z} = -819.5 \cdot kN$ $E_{act.a.U2.z.loc.y} = 4.00\ m$

Z-Direction Lateral Lateral Soil Load on Approach Slab Before RCC (driving): $E_{act.as.U2.z} = -2192.6 \cdot kN$ $E_{act.as.U2.z.loc.y} = 1.76\ m$

Z-Direction Lateral Soil Load on Abutment After RCC (driving): $E_{act.RCC.U2.z} = -9.24 \cdot kN$ $E_{act.RCC.U2.z.loc.y} = 10.03\ m$

Z-Direction Lateral Soil Load on Abutment at RCC Steps (driving): $E_{act.RCC.s.U2.z} = -16.94 \cdot kN$ $E_{act.RCC.s.U2.z.loc.y} = 9.43 \cdot m$

Resisting Lateral Soil Load as required to produce horizontal equilibrium:

$$E_{pas.OT.z.U2} := -\left(E_{act.a.U2.z} + E_{act.as.U2.z} + E_{act.RCC.U2.z} + E_{act.RCC.s.U2.z}\right) = 3038.27 \cdot kN$$

Acting at:

$$E_{pas.OT.U2.loc} = -1\ m$$

Sum of All Overturning Analysis Horizontal Load (ΣH=0):

$$\Sigma H_{U2.OT.z} := E_{act.a.U2.z} + E_{act.as.U2.z} + E_{act.RCC.U2.z} + E_{act.RCC.s.U2.z} + E_{pas.OT.z.U2} = 0 \cdot kN$$

Sum of All Overturning Analysis Horizontal Load Moments:

$$\Sigma M_{H.U2.OT.z} := E_{act.a.U2.z} \cdot E_{act.a.U2.z.loc.y} + E_{act.as.U2.z} \cdot E_{act.as.U2.z.loc.y} \cdots + E_{act.RCC.U2.z} \cdot E_{act.RCC.U2.z.loc.y} + E_{act.RCC.s.U2.z} \cdot E_{act.RCC.s.U2.z.loc.y} \cdots + E_{pas.OT.x.U2} \cdot E_{pas.OT.U2.loc} = -8017.15 \cdot kN \cdot m$$

Overturning Stability Analysis (Z-Direction)

$$\Sigma M_{U2.OT.z} := \Sigma M_{V.U2.OT} + \Sigma M_{H.U2.OT.z} = 295489.54 \cdot kN \cdot m$$

$$z_{R.U2} := \frac{\Sigma M_{U2.OT.z}}{\Sigma V_{U2.OT}} = 7.72\ m \qquad z_{OT.U2} := z_{R.U2} - \frac{W_B}{2} = -0.28\ m$$

Overturning Resultant Ratio

$$Ratio_{OT.z.U2} := \frac{z_{R.U2}}{L_B} = 0.42$$

$$Ratio_{OT.z.U2.check} := \begin{cases} \text{"OKAY"} & \text{if } Ratio_{OT.z.U2} \geq Ratio_{OT.U2.min} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

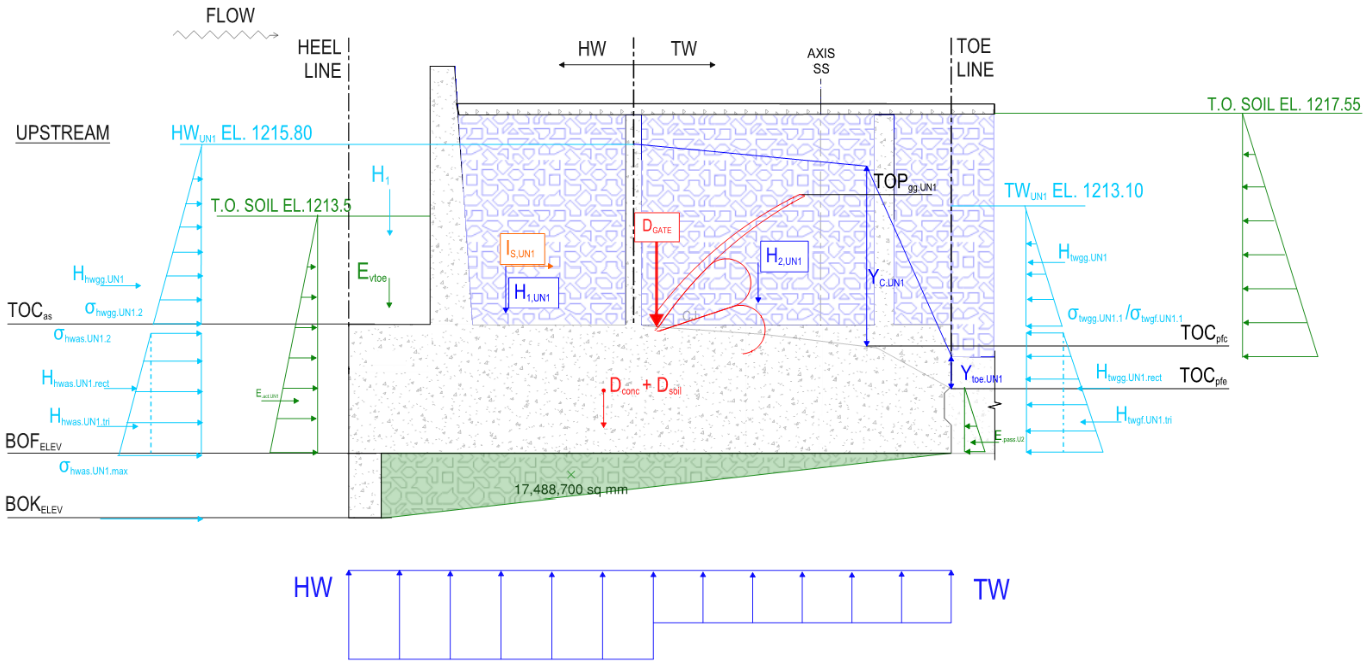
$$z_{OT.check.U2} := \begin{cases} \text{"OKAY"} & \text{if } \left|z_{OT.U2}\right| \leq Kern_z \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

SUMMARY OF STABILITY ASSESSMENT:

U2 CASE

Sliding Factor of Safety: (Horizontal Plane)	$FS_{HorizSliding.U2} = 5.62$	$FS_{HorizSliding.U2.Check} = \text{"OKAY"}$
Flotation Factor of Safety (horizontal plane)	$FS_{act.FU2} = 2.83$	$FS_{check.FU2} = \text{"OKAY"}$
Overturning Resultant Ratio: (X-direction)	$Ratio_{OT.x.U2} = 0.41$	$Ratio_{OT.x.U2.check} = \text{"OKAY"}$
Overturning Resultant Ratio: (Z-direction)	$Ratio_{OT.z.U2} = 0.42$	$Ratio_{OT.z.U2.check} = \text{"OKAY"}$
Eccentricity: (horizontal plane)	$x_{OT.U2} = -1.59\ m$	$x_{OT.check.U2} = \text{"OKAY"}$
Eccentricity: (horizontal plane)	$z_{OT.U2} = -0.28\ m$	$z_{OT.check.U2} = \text{"OKAY"}$
Bearing Pressure At Heel(x)- Heel(z): (horizontal plane)	$\sigma_{heel.U2} = 120 \cdot kPa$	$\sigma_{heel.U2.check} = \text{"Okay"}$
Bearing Pressure At Toe(x)-Toe(z): (horizontal plane)	$\sigma_{toe.U2} = 146 \cdot kPa$	$\sigma_{toe.U2.check} = \text{"Okay"}$
Bearing Pressure at Heel(x)-Toe(z): (horizontal plane)	$\sigma_{heeltoe.U2} = 42 \cdot kPa$	$\sigma_{heeltoe.U2.check} = \text{"Okay"}$
Bearing Pressure at Toe(x)-Heel(z): (horizontal plane)	$\sigma_{toeheel.U2} = 225 \cdot kPa$	$\sigma_{toe.U2.check} = \text{"Okay"}$

UN1 DESIGN CASE



ACCEPTANCE PARAMETERS

Required Factor of Safety for Sliding:	$FS_{req.UN1.sl} := 1.3$	(Without Cohesion)
		(Section 8.1, Design Criteria)
Resultant Within Middle Third of Base:	$e \le \frac{L_B}{6} \wedge e \ge \frac{-L_B}{6}$	
Allowable Rock Bearing Pressure:	$\sigma_{allow.UN1} := 1270 \cdot \frac{kN}{m^2}$	(Section 5.2, Design Criteria)
Required Factor of Safety for Flotation:	$FS_{req.UN1.flt} := 1.3$	

INPUT PARAMETERS

Headwater Elevation:	$HW_{UN1} := 1215.80m$	(Section 8.2, Design Criteria)
Tailwater Elevation:	$TW_{UN1} := 1213.10m$	(Section 8.2, Design Criteria)
Bottom of Footing Elevation:	$BOF_{elev} = 1206\,m$	
Approch Slab Top of Concrete Elevation at Upstream Face:	$TOC_{as} = 1210\,m$	
Abutment Footing Top of Concrete Elevation at Stilling Basin:	$TOC_{afe} = 1208\,m$	
Abutment Footing Top of Concrete Elevation at Footing:	$TOC_{afc} = 1209.73\,m$	Gates are open when top of gate elevation is at 1210.00m
Abutment Footing Top of Concrete Elevation at Footing Notch:	$TOC_{afc.n} = 1209.3\,m$	
Top of Guard Gate Elevation:	$TOP_{gg.UN1} := 1213.50m$	Gates are closed/up when top of gate elevation is at 1215.0m
Bottom of Key Elevation:	$BOK_{elev} = 1204\,m$	

UN1 CASE

Water Elevation above Crest of Guard Gate:

$EL_{C.UN1} := 1215.03m$

$$Y_{C.UN1} := \begin{cases} (EL_{C.UN1} - TOC_{afc.n}) & \text{if } TOP_{gg.UN1} \le HW_{UN1} \\ (TW_{UN1} - TOC_{afc.n}) & \text{if } TOP_{gg.UN1} > HW_{UN1} \end{cases} = 5.73 \cdot m$$

Water Elevation above Guard Gate Toe:
Submerged by Hydraulic 2D Model

$EL_{TOE.UN1} := 1208.48m$

$$Y_{TOE.UN1} := \begin{cases} (EL_{TOE.UN1} - TOC_{afe}) & \text{if } TOP_{gg.UN1} \le HW_{UN1} \\ (TW_{UN1} - TOC_{afe}) & \text{if } TOP_{gg.UN1} > HW_{UN1} \end{cases} = 0.48 \cdot m$$

LATERAL WATER LOADS

HEADWATER (DRIVING X-DIRECTION):

Headwater Depth on Abutment: $D_{hwa.UN1} := HW_{UN1} - TOC_{as} = 5.80\ m$

Headwater Load Unit Width Projected Surface Area of Abutment: $W_{hwa.UN1} := 2 \cdot r_{wall} = 12.00\ m$

Total Horizontal Headwater Load on Abutment:

$$H_{hwa.UN1} := \frac{-\left(\gamma_w \cdot D_{hwa.UN1}^{\ 2}\right)}{2} \cdot W_{hwa.UN1} = -1980.1 \cdot kN$$

Apply Total Abutment Headwater Load at:

$$H_{hwa.UN1.loc} := \frac{D_{hwa.UN1}}{3} + \left(TOC_{as} - BOF_{elev}\right) = 5.93\ m$$

Apply Total Abutment Headwater Load at (from toe):

$H_{hwa.UN1.loc.z} := 4m + r_{wall} = 10.00\ m$ (Gate Footing + Radius of Wall)

Thickness of Approach Slab: $T_{as} = 4\ m$

Headwater Depth at Heel (U/S face): $D_{hwas.UN1} := HW_{UN1} - BOF_{elev} = 9.80\ m$

Headwater Load Unit Width on Projected Approach Slab: $W_{hwas.UN1} := W_B = 16.00\ m$

Headwater Line Load At Top of Approach Slab:

$$\sigma_{hwas.UN1.1} := -\left(\gamma_w \cdot D_{hwa.UN1}\right) = -56.9 \cdot kPa$$

Headwater Line Load At Bottom of Approach Slab:

$$\sigma_{hwas.UN1.2} := -\left(\gamma_w \cdot D_{hwas.UN1}\right) = -96.14 \cdot kPa$$

Trianglular Distribution Unit Load on Approach Slab:

$$H_{hwas.UN1.2.tri} := \left(\frac{\sigma_{hwas.UN1.2} - \sigma_{hwas.UN1.1}}{2}\right) \cdot \left(T_{as} \cdot W_{hwas.UN1}\right) = -1255.68 \cdot kN$$

Rectangular Distribution Unit Load on Approach Slab:

$$H_{hwas.UN1.2.rect} := \sigma_{hwas.UN1.1} \cdot \left(T_{as} \cdot W_{hwas.UN1}\right) = -3641.47 \cdot kN$$

Total Horizontal Headwater Load on Approach Slab:

$$H_{hwas.UN1} := H_{hwas.UN1.2.tri} + H_{hwas.UN1.2.rect} = -4897.15 \cdot kN$$

Apply Total Footing Headwater Load at:

$$H_{hwas.UN1.loc} := \frac{\left[H_{hwas.UN1.2.rect} \cdot \frac{\left(T_{as}\right)}{2} + H_{hwas.UN1.2.tri} \cdot \frac{\left(T_{as}\right)}{3}\right]}{H_{hwas.UN1.2.tri} + H_{hwas.UN1.2.rect}} = 1.83\ m$$

Apply Total Footing Headwater Load at (from toe):

$$H_{hwas.UN1.loc.z} := \frac{W_B}{2} = 8.00\ m$$

Guard Gate (2A) Operating Condition: Right Crest Gate at EL 1213.5

Guard Gate Down/Open Condition: $A1_{UN1} := TOP_{gg.UN1} \le TOC_{as}$

Guard Crest Gate Up/Closed, with Top of Gate Higher than HW Elevation: $B1_{UN1} := TOP_{gg.UN1} \ge HW_{UN1} \wedge TOP_{gg.UN1} > TOC_{as}$

Guard Crest Gate Up/Closed, with Top of Gate Lower than HW Elevation: $C1_{UN1} := TOP_{gg.UN1} > TOC_{as} \wedge HW_{UN1} > TOP_{gg.UN1}$

Guard Crest Gate Height: $H_{gg.UN1} := TOP_{gg.UN1} - TOC_{as} = 3.5\,m$

Headwater Depth at Guard Crest Gate: $D_{hwgg.UN1} := HW_{UN1} - TOC_{as} = 5.80\,m$

Guard Crest Gate Width: $W_{hwgg.UN1} := 4.00m$

Lateral Headwater Pressure at Bottom of Guard Crest Gate:

$$\sigma_{hwgg.UN1.1} := \begin{vmatrix} (0.0kPa) & \text{if } A1_{UN1} \\ -(\gamma_w \cdot D_{hwgg.UN1}) & \text{if } B1_{UN1} \\ -(\gamma_w \cdot D_{hwgg.UN1}) & \text{if } C1_{UN1} \end{vmatrix} = -56.9 \cdot kPa$$

Lateral Headwater Pressure at Top of Guard Crest Gate: (Load at HW Elevation On Guard Crest Gate if HW is below TOG_{rg})

$$\sigma_{hwgg.UN1.2} := \begin{vmatrix} (0.0kPa) & \text{if } A1_{UN1} \\ 0.0kPa & \text{if } B1_{UN1} \\ -\left[\gamma_w \cdot (HW_{UN1} - TOP_{gg.UN1})\right] & \text{if } C1_{UN1} \end{vmatrix} = -22.6 \cdot kPa$$

Average Pressure acting on Guard Crest Gate:

$$\sigma_{hwgg.UN1.avg} := \frac{(\sigma_{hwgg.UN1.1} + \sigma_{hwgg.UN1.2})}{2} = -39.73 \cdot kPa$$

Total Area water acting on Crest Gate:

$$A_{hwgg.UN1} := \begin{vmatrix} D_{hwgg.UN1} \cdot W_{hwgg.UN1} & \text{if } A1_{UN1} \\ D_{hwgg.UN1} \cdot W_{hwgg.UN1} & \text{if } B1_{UN1} \\ H_{gg.UN1} \cdot W_{hwgg.UN1} & \text{if } C1_{UN1} \end{vmatrix} = 14 \cdot m^2$$

Total Horizontal Headwater Load on Guard Crest Gate: $H_{hwgg.UN1} := \sigma_{hwgg.UN1.avg} \cdot A_{hwgg.UN1} = -556.2 \cdot kN$

Apply Total Guard Crest Gate Headwater Load at:

$$H_{hwgg.UN1.loc} := \begin{vmatrix} (TOC_{as} - BOF_{elev}) & \text{if } A1_{UN1} \\ \left[\frac{(HW_{UN1} - TOC_{as})}{3} + (TOC_{as} - BOF_{elev})\right] & \text{if } B1_{UN1} \\ \left[\frac{\sigma_{hwgg.UN1.2} \cdot A_{hwgg.UN1} \cdot \frac{(H_{gg.UN1})}{2} + \frac{(\sigma_{hwgg.UN1.1} - \sigma_{hwgg.UN1.2})}{2} A_{hwgg.UN1} \cdot \frac{(H_{gg.UN1})}{3}}{\sigma_{hwgg.UN1.2} \cdot A_{hwgg.UN1} + \frac{(\sigma_{hwgg.UN1.1} - \sigma_{hwgg.UN1.2})}{2} \cdot A_{hwgg.UN1}} \dots \\ + (TOC_{as} - BOF_{elev}) \right] & \text{if } C1_{UN1} \end{vmatrix} = 5.5 \cdot m$$

Apply Total Guard Crest Gate Headwater Load at (From toe): $H_{hwgg.UN1.loc.z} := \frac{W_{hwgg.UN1}}{2} = 2\,m$

LATERAL TAILWATER (RESISTING) Applied to Downstream Side of Guard Crest Gate: UN1 CASE

Guard Gate Down/Open Condition: $A2_{UN1} := TOP_{gg.UN1} \le TOC_{as}$

Guard Crest Gate Up/Closed, with Top of Gate Higher than TW Elevation: $B2_{UN1} := TOP_{gg.UN1} \ge TW_{UN1} \wedge TOP_{gg.UN1} > TOC_{as}$

Guard Crest Gate Up/Closed, with Top of Gate Lower than TW Elevation: $C2_{UN1} := TOP_{gg.UN1} > TOC_{as} \wedge TW_{UN1} > TOP_{gg.UN1}$

Tailwater Depth at Guard Crest Gate: $D_{twgg.UN1} := TW_{UN1} - TOC_{as} = 3.10\ m$

Guard Crest Gate Height: $H_{gg.UN1} = 3.5\ m$

Guard Crest Gate Width: $W_{twgg.UN1} := 4.00m$

Lateral Water Load at Bottom of Guard Crest Gate:

$$\sigma_{twgg.UN1.1} := \begin{cases} (0.0kPa) & \text{if } A2_{UN1} \\ (\gamma_w \cdot D_{twgg.UN1}) & \text{if } B2_{UN1} \\ (\gamma_w \cdot D_{twgg.UN1}) & \text{if } C2_{UN1} \end{cases} = 30.4 \cdot kPa$$

Lateral Water Load at Top of Guard Crest Gate:
(Load at TW Elevation On Guard Crest Gate if TW is below TOG_{gg})

$$\sigma_{twgg.UN1.2} := \begin{cases} (0.0kPa) & \text{if } A2_{UN1} \\ 0.0kPa & \text{if } B2_{UN1} \\ \left[\gamma_w \cdot (TW_{UN1} - TOP_{gg.UN1})\right] & \text{if } C2_{UN1} \end{cases} = 0.0 \cdot kPa$$

Average Pressure acting on Guard Crest Gate:

$$\sigma_{twgg.UN1.avg} := \frac{(\sigma_{twgg.UN1.1} + \sigma_{twgg.UN1.2})}{2} = 15.21 \cdot kPa$$

Total Area water acting on Crest Gate:

$$A_{twgg.UN1} := \begin{cases} D_{twgg.UN1} \cdot W_{twgg.UN1} & \text{if } A2_{UN1} \\ D_{twgg.UN1} \cdot W_{twgg.UN1} & \text{if } B2_{UN1} \\ H_{gg.UN1} \cdot W_{twgg.UN1} & \text{if } C2_{UN1} \end{cases} = 12.4 \cdot m^2$$

Total Horizontal Headwater Load on Guard Crest Gate: $H_{twgg.UN1} := \sigma_{twgg.UN1.avg} \cdot A_{twgg.UN1} = 188.5 \cdot kN$

Apply Total Horiz. TW Load on Guard Gate at:

$$H_{twgg.UN1.loc} := \begin{cases} (TOC_{as} - BOF_{elev}) & \text{if } A2_{UN1} \\ \left[\frac{(TW_{UN1} - TOC_{as})}{3} + (TOC_{as} - BOF_{elev})\right] & \text{if } B2_{UN1} \\ \left[\frac{\sigma_{twgg.UN1.2} \cdot A_{twgg.UN1} \cdot \frac{(H_{gg.UN1})}{2} + \frac{(\sigma_{twgg.UN1.1} - \sigma_{twgg.UN1.2})}{2} A_{twgg.UN1} \cdot \frac{(H_{gg.UN1})}{3}}{\sigma_{twgg.UN1.2} \cdot A_{twgg.UN1} + \frac{(\sigma_{twgg.UN1.1} - \sigma_{twgg.UN1.2})}{2} \cdot A_{twgg.UN1}} \dots \\ + (TOC_{as} - BOF_{elev})\right] & \text{if } C2_{UN1} \end{cases} = 5.0 \cdot m$$

Apply Total Guard Crest Gate Headwater Load at (From toe): $H_{twgg.UN1.loc.z} := \frac{W_{twgg.UN1}}{2} = 2\ m$

LATERAL WATER LOADS (continued)

UN1 CASE

TAILWATER (RESISTING) Applied to Concrete Strucuture:

Tailwater Depth on Top of Abutment Footing: $D_{twa.UN1} := TW_{UN1} - TOC_{as} = 3.10\ m$

Tailwater Load Unit Width on Abutment: $W_{twa.UN1} := 2 \cdot r_{wall} = 12.00\ m$

Total Horizontal Tailwater Load on Abutment: $H_{twa.UN1} := \dfrac{\left(\gamma_w \cdot D_{twa.UN1}{}^2\right)}{2} \cdot W_{twa.UN1} = 565.6 \cdot kN$

Apply Total Abutment Tailwater Load at: $H_{twa.UN1.loc} := \dfrac{D_{twa.UN1}}{3} + \left(TOC_{as} - BOF_{elev}\right) = 5.03\ m$

Apply Total Abutment Tailwater Load at (from Toe Line): $H_{twa.UN1.loc.z} := W_{twgg.UN1} + r_{wall} = 10\ m$

Footing Thickness for horizontal at Toe: $h_{toe} = 4\ m$

Tailwater Depth At top of Gate Base Footing Elevation: $D_{twgf.UN1} := TW_{UN1} - TOC_{as} = 3.10\ m$

Water Depth at bottom of Gate Base Footing (Excluding Key): $D_{twtoe.UN1} := TW_{UN1} - BOF_{elev} = 7.10\ m$

Water Depth at bottom of Gate Base Footing (Including Key): $D_{twkey.UN1} := HW_{UN1} - BOK_{elev} = 11.80\ m$

Unit Width of D/S face of crest for applicaiton of Tailwater Load: $W_{tw.UN1} := W_B = 16.00\ m$

(Conservatively taken resisting water in front of 1.5m RCC Auxiliary Spillway as Tailwater elevation)

Tailwater Pressure At Top of Gate Footing: $\sigma_{twgf.UN1} := \left(\gamma_w \cdot D_{twgf.UN1}\right) = 30.41 \cdot kPa$

Tailwater Line Load At Bottom of Gate Footing (Excluding Key): $\sigma_{twtoe.UN1} := \left(\gamma_w \cdot D_{twtoe.UN1}\right) = 69.65 \cdot kPa$

Trianglular Distribution Unit Load on Gate Footing Base: $H_{twgf.UN1.tri} := \left(\dfrac{\sigma_{twtoe.UN1} - \sigma_{twgf.UN1}}{2}\right) \cdot \left[\left(T_{as} - d_{key}\right) \cdot W_{tw.UN1}\right] = 627.84 \cdot kN$

Rectangular Distribution Unit Load on Gate Footing Base: $H_{twgf.UN1.rect} := \sigma_{twgf.UN1} \cdot \left[\left(T_{as} - d_{key}\right) \cdot W_{tw.UN1}\right] = 973.15 \cdot kN$

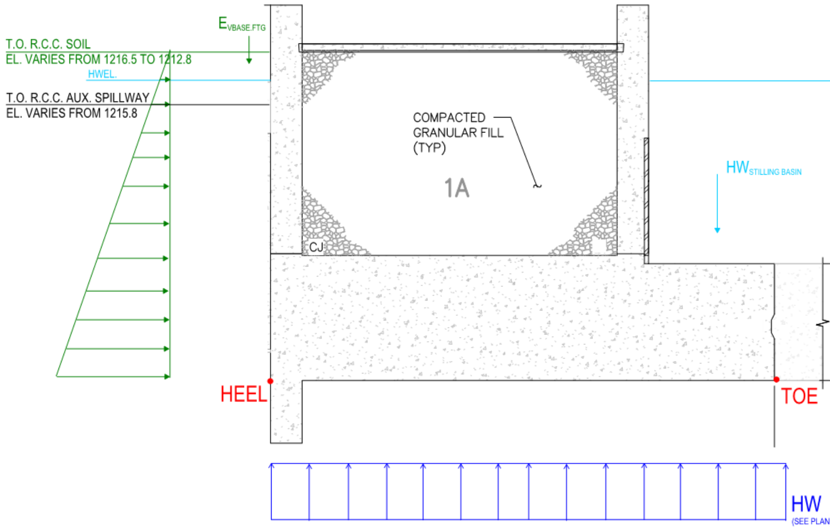
Total Horizontal Tailwater Headwater Load on Gate Footing: $H_{twgf.UN1} := H_{twgf.UN1.tri} + H_{twgf.UN1.rect} = 1600.99 \cdot kN$

Apply Total Gate Footing Tailwater Load at:

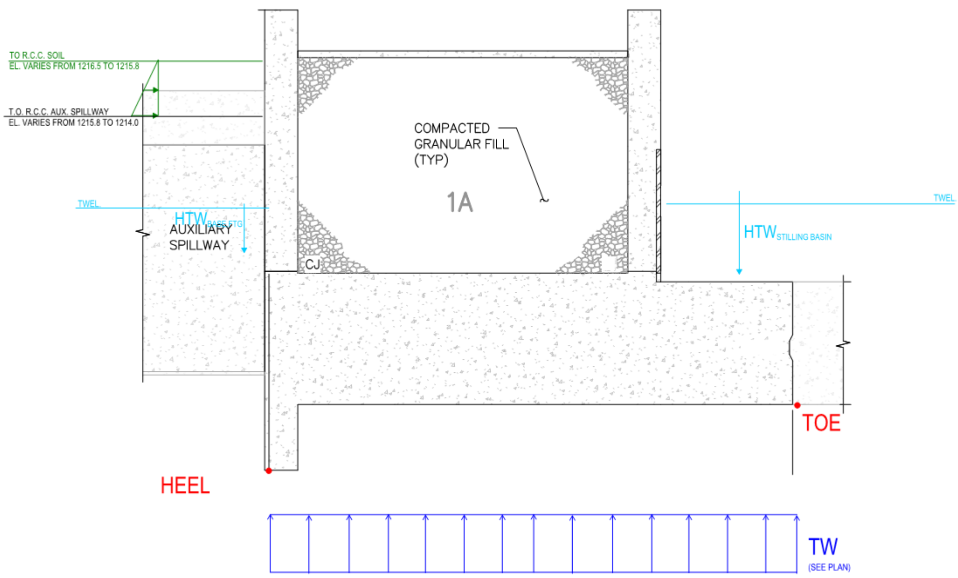
$$H_{twgf.UN1.loc} := \frac{\left[H_{twgf.UN1.rect} \cdot \dfrac{\left(T_{as}\right)}{2} + H_{twgf.UN1.tri} \cdot \dfrac{\left(T_{as}\right)}{3}\right]}{H_{twgf.UN1.tri} + H_{twgf.UN1.rect}} = 1.74\ m$$

Apply Total Gate Footing Tailwater Load at (From Toe Line): $H_{twgf.UN1.loc.z} := \dfrac{W_B}{2} = 8.00\ m$

SUMMATION OF LATERAL WATER LOADS:



SECTION 1A BEFORE GATES & AUX. SPILLWAY RCC



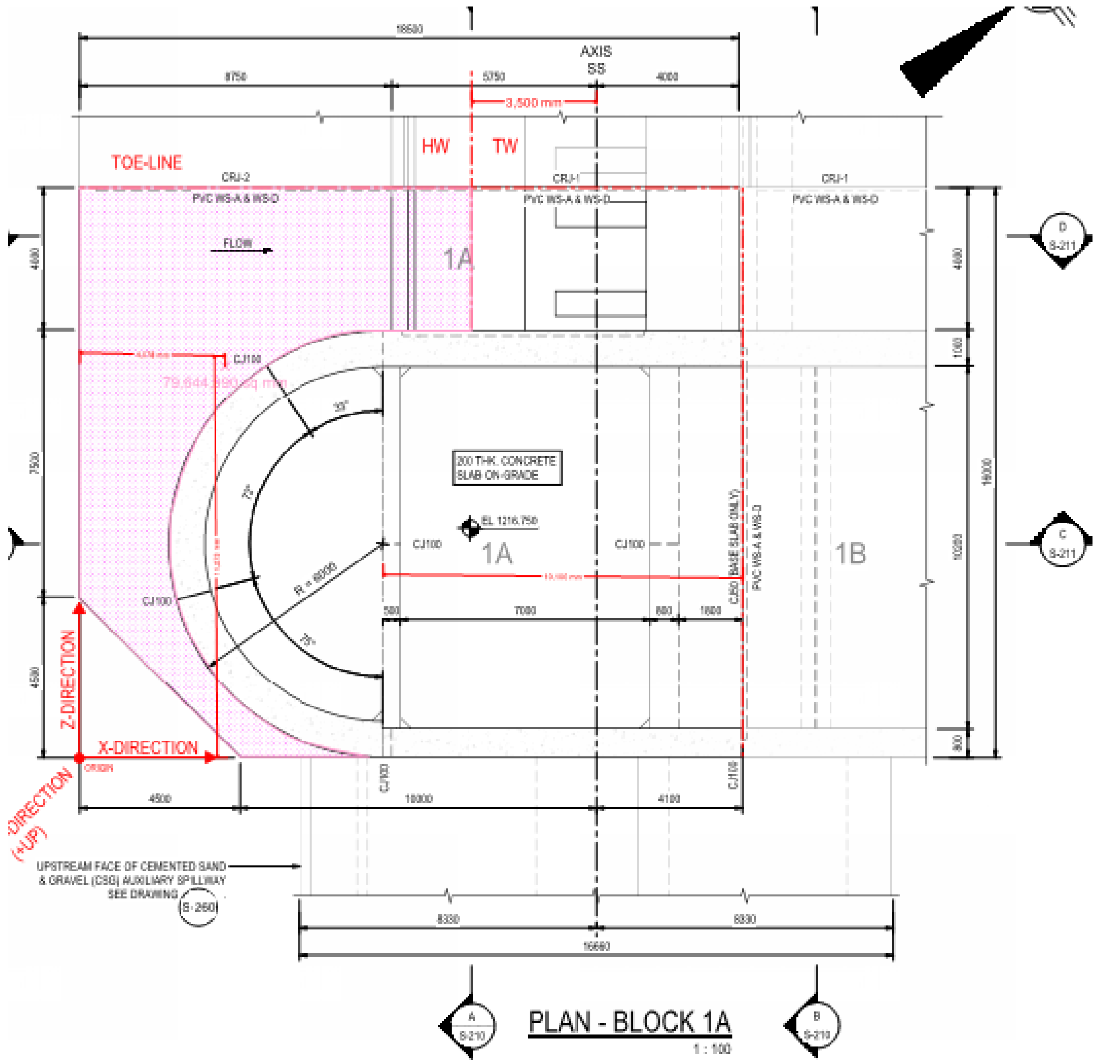
SECTION 1A AFTER GATES & AUX. SPILLWAY RCC

$\Sigma H_{Water.UN1.x} := H_{hwa.UN1} + H_{hwas.UN1} + H_{hwgg.UN1} + H_{twa.UN1} + H_{twgf.UN1} + H_{twgg.UN1} = -5078.24 \cdot kN$

$\Sigma M_{HWater.UN1.x} := H_{hwa.UN1} \cdot H_{hwa.UN1.loc} + H_{hwas.UN1} \cdot H_{hwas.UN1.loc} + H_{hwgg.UN1} \cdot H_{hwgg.UN1.loc} \ldots = -17184.06 \cdot kN \cdot m$
$+ H_{twa.UN1} \cdot H_{twa.UN1.loc} + H_{twgf.UN1} \cdot H_{twgf.UN1.loc} + H_{twgg.UN1} \cdot H_{twgg.UN1.loc}$

$\Sigma H_{Water.UN1.z} := 0kN$

$\Sigma M_{HWater.UN1.z} := 0 \cdot kN \cdot m$



HEADWATER:

Water Depth on top of Approach Slab: $d_{hw.UN1} := HW_{UN1} - TOC_{as} = 5.80\ m$

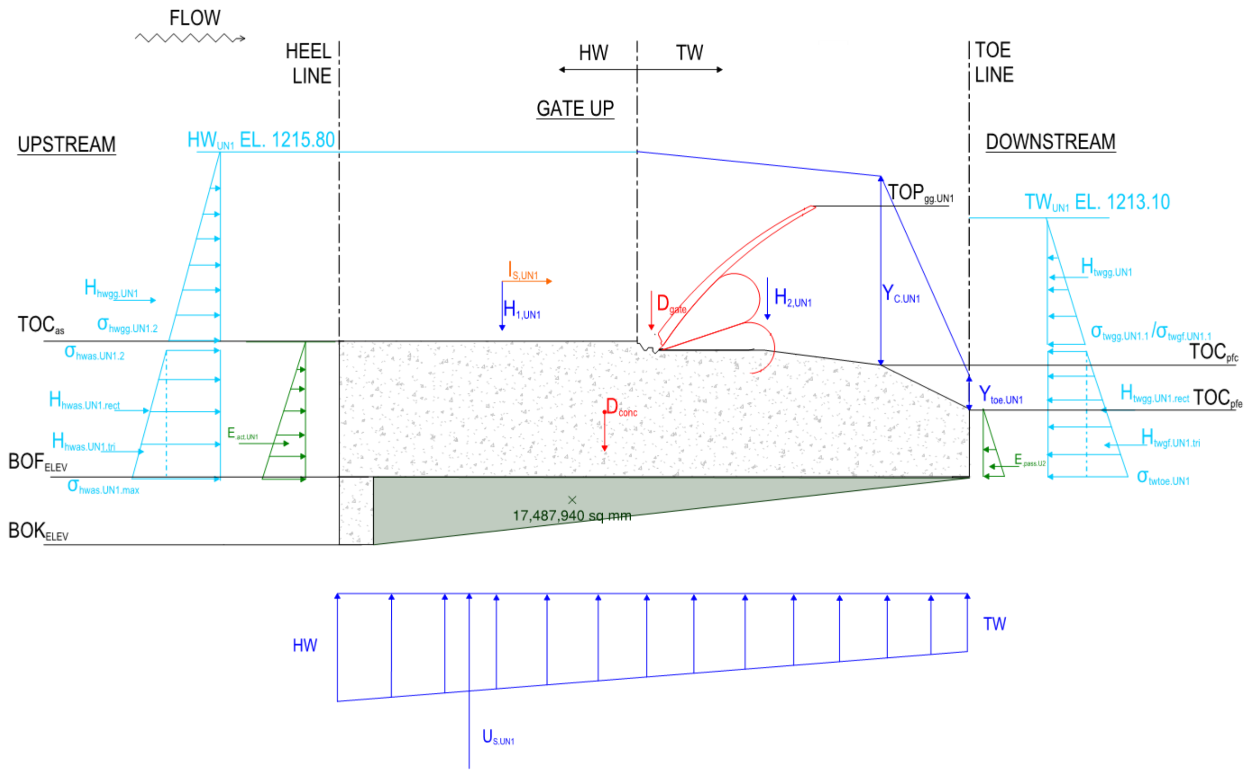
Water Area on top of Approach Slab: $A_{as} = 79.64\ m^2$ (From Geom. Scaled on REVU)

Vertical Water Weight (H1) on Approach Slab: $H_{1.UN1} := \left(A_{as} \cdot d_{hw.UN1}\right) \cdot \gamma_w = 4531.6 \cdot kN$

Moment Arm for Applicaiton of Water Weight (H1) from toe (X-Direction): $H_{1.UN1.loc.x} := L_B - 4.078m = 14.42\ m$ (From Geom. Scaled on REVU)

Moment Arm for Applicaiton of Water Weight (H1) from toe (Z-Direction): $H_{1.UN1.loc.z} := W_B - 11.273m = 4.73\ m$ (From Geom. Scaled on REVU)

TAILWATER:



Approach Slab Length: $L_{as} = 8.75\ m$

Gate Footing Length: $L_{gf} = 9.75\ m$

Gate Footing Crest Length: $L_{gfc} = 2.25\ m$

TAILWATER:

Trapezoid Volume Above Gate Footing from Approach Slab to Crest:

$$V_{asc.UN1} := \left(L_{gf} - L_{gfc}\right) W_{twgg.UN1} \frac{d_{hw.UN1} + Y_{C.UN1}}{2} = 172.95 \cdot m^3$$

Trapezoid Volume Above Gate Footing Crest to End of Gate Footing:

$$V_{gfc.UN1} := \left(L_{gfc} \cdot W_{twgg.UN1}\right) \frac{Y_{C.UN1} + Y_{TOE.UN1}}{2} = 27.95 \cdot m^3$$

Load Above Gate Footing from Approach Slab to Crest:

$$H_{2.UN1.asc} := V_{asc.UN1} \cdot \gamma_w = 1696.64 \cdot kN$$

Load Acting Above Footing Crest from Toe:

$$H_{2.UN1.asc.loc.x} := \frac{\left(L_{gf} - L_{gfc}\right) \cdot \left(2 \cdot d_{hw.UN1} + Y_{C.UN1}\right)}{3 \cdot \left(d_{hw.UN1} + Y_{C.UN1}\right)} + L_{gfc} = 6.01\ m$$

Load Above Gate Footing from Crest to End:

$$H_{2.UN1.gfc} := V_{gfc.UN1} \cdot \gamma_w = 274.14 \cdot kN$$

Load Acting Above Gate Footing from Crest to End:

$$H_{2.UN1.gfc.loc.x} := \frac{\left(L_{gfc}\right) \cdot \left(2 \cdot Y_{C.UN1} + Y_{TOE.UN1}\right)}{3 \cdot \left(Y_{C.UN1} + Y_{TOE.UN1}\right)} = 1.44\ m$$

Vertical Water Weight (H2) on Gate Footing:

$$H_{2.UN1} := H_{2.UN1.asc} + H_{2.UN1.gfc} = 1970.78 \cdot kN$$

Moment Arm for Application of Water Weight (H2) from toe:

$$H_{2.UN1.loc.x} := \frac{H_{2.UN1.asc} \cdot H_{2.UN1.asc.loc.x} + H_{2.UN1.gfc} \cdot H_{2.UN1.gfc.loc.x}}{H_{2.UN1}} = 5.37\ m$$

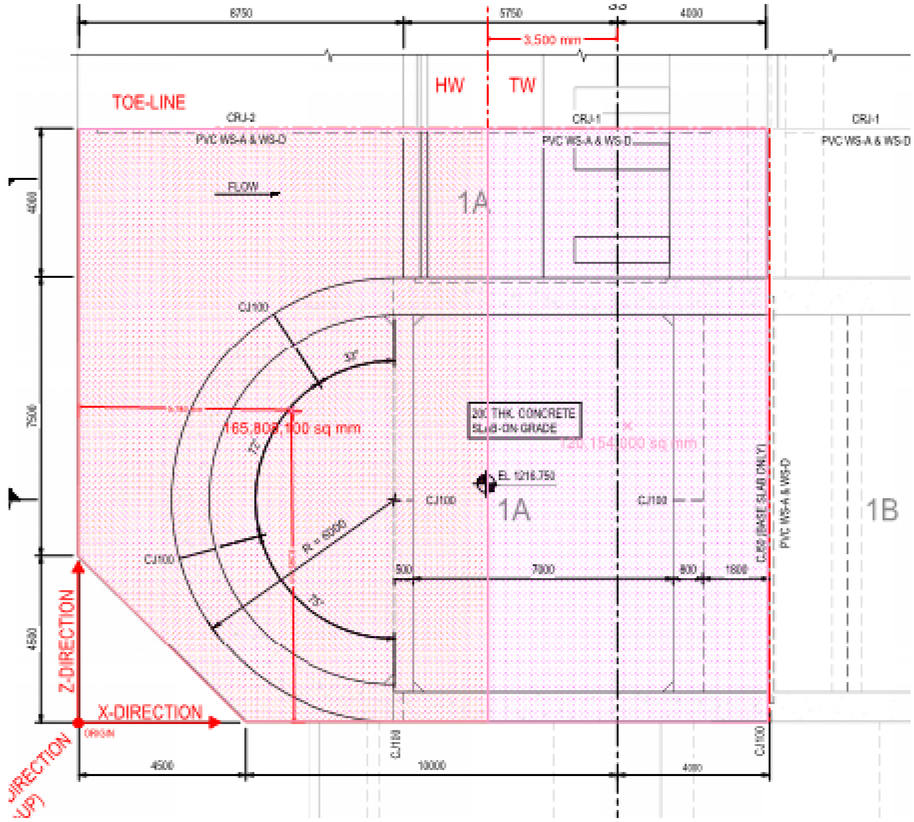
Moment Arm for Applicaiton of Water Weight (H2) from toe (Z-Direction):

$$H_{2.UN1.loc.z} := 2.0m$$

UPLIFT

UN1 CASE

(Assuming constant Headwater Uplift at front and constant Tailwater Uplift at back of footing base)



Uplift pressure at U/S Face (heel): $U_{HW.UN1} := D_{hwas.UN1} \cdot \gamma_w = 96.1 \cdot \frac{kN}{m^2}$

Uplift pressure at D/S Face Stilling Basin: $U_{TW.UN1} := D_{twtoe.UN1} \cdot \gamma_w = 69.65 \cdot \frac{kN}{m^2}$

Area of Uplift Force From Headwater Side: $A_{HWU.UN1} := 165.81 m^2$ (From Bluebeam REVU)

Area of Uplift Force From Tailwater Side: $A_{TWU.UN1} := 120 m^2$ (From Bluebeam REVU)

Uplift Force From Headwater Side: $U_{A.UN1} := -U_{HW.UN1} \cdot A_{HWU.UN1} = -15940.64 \cdot kN$

Uplift Force From Headwater Side: $U_{B.UN1} := -U_{TW.UN1} \cdot A_{TWU.UN1} = -8358.12 \cdot kN$

Uplift Centroid of Area From Headwater Side to Toe: $X_{U.A} = 13.22\,m$ $Z_{U.A} = 7.63\,m$ (From Bluebeam REVU)

Uplift Centroid of Area From Tailwater Side to Toe: $X_{U.B} = 3.75\,m$ $Z_{U.B} = 8\,m$ (From Bluebeam REVU)

Total Resultant Uplift force: $U_{UN1} := U_{A.UN1} + U_{B.UN1} = -24298.76 \cdot kN$

Resultant Location from Toe Rect. Load (X-Direction): $U_{UN1.loc.x} := \frac{(U_{A.UN1} \cdot X_{U.A} + U_{B.UN1} \cdot X_{U.B})}{(U_{A.UN1} + U_{B.UN1})} = 9.96\,m$

Resultant Location from Toe Rect. Load (Z-Direction): $U_{UN1.loc.z} := \frac{[U_{A.UN1} \cdot (W_B - Z_{U.A}) + U_{B.UN1} \cdot (W_B - Z_{U.B})]}{(U_{A.UN1} + U_{B.UN1})} = 8.24\,m$

$$\Sigma V_{water.UN1} := H_{1.UN1} + H_{2.UN1} + U_{UN1} = -17796.34 \cdot kN$$

$$\Sigma M_{Vwater.UN1.x} := H_{1.UN1} \cdot H_{1.UN1.loc.x} + H_{2.UN1} \cdot H_{2.UN1.loc.x} + U_{UN1} \cdot U_{UN1.loc.x} = -166134.87 \cdot kN \cdot m$$

$$\Sigma M_{Vwater.UN1.z} := H_{1.UN1} \cdot H_{1.UN1.loc.z} + H_{2.UN1} \cdot H_{2.UN1.loc.z} + U_{UN1} \cdot U_{UN1.loc.z} = -174845.8 \cdot kN \cdot m$$

SOIL LOADS

UN1 CASE

Equivalent Fluid Pressure (EFP): (Section 5.3, Design Criteria)

At rest lateral pressure coefficient: $K_{o.UN1} := 1 - \sin(\phi_{backfill}) = 0.658$

Headwater Top of Soil Elevation: $TOS_{HW} = 1210\,m$

Top of Backfill Soil Elevation: $TOS_{BF} = 1216.5\,m$

Driving Soil Load Unit Width Projected Surface Area of Abutment: $W_{ds.hwa.UN1} := 6.0m$

Driving Soil Load Unit Width on Projected Approach Slab + Key: $W_{hwas.UN1} = 16.00\,m$

(From Section Cut)

Resisting Soil Load Unit Width Projected Surface Area of Abutment: $W_{rsa.UN1} := \frac{10.5m + 9.381m}{2} = 9.94\,m$

Driving Soil Load Depth on Abutment: $d_{DS.a} = 0\,m$

Driving Soil Load Depth on Footing: $d_{DS.as} = 4\,m$

Resisting Soil Load Depth on Abutment: $d_{RS.a} = 8.5\,m$

Thickness of Stilling Basin: $T_{sb} = 2\,m$

Lateral X-Direction Driving Force (Headwater Side - at rest condition)

At-Rest Soil Load on Half of Abutment:

$$E_{act.a.UN1.x} := \frac{\left(K_{o.UN1} \cdot d_{DS.a}^{\;2}\right)}{2} \cdot \left(\gamma_r - \gamma_w\right) \cdot W_{ds.hwa.UN1} \cdot -1 = 0 \cdot kN$$

Acting at:

$$E_{act.a.UN1.x.loc.y} := \frac{d_{DS.a}}{3} + T_{as} - d_{key} = 2.00\,m$$

Acting at (from Toe Line):

$$E_{act.a.UN1.x.loc.z} := W_{hwgg.UN1} + r_{wall} = 10.00\,m$$

At-Rest Soil Load on Top of Approach Slab:

$$\sigma_{DS.as.UN1} := \left(K_{o.UN1} \cdot d_{DS.a}\right) \cdot \left(\gamma_r - \gamma_w\right) = 0 \cdot kPa$$

At-Rest Soil Load on Bottom of Approach Slab:

$$\sigma_{DS.key.UN1} := \left(K_{o.UN1} \cdot d_{DS.as}\right) \cdot \left(\gamma_r - \gamma_w\right) = 32.08 \cdot kPa$$

At-Rest Soil Load on Approach Slab (Rect):

$$E_{act.as.rect.UN1.x} := \sigma_{DS.as.UN1} \cdot \left(T_{as}\right) \cdot W_{hwas.UN1} \cdot -1 = 0 \cdot kN$$

At-Rest Soil Load on Approach Slab (Tri):

$$E_{act.as.tri.UN1.x} := \frac{\left(\sigma_{DS.key.UN1} - \sigma_{DS.as.UN1}\right) \cdot \left(T_{as}\right)}{2} \cdot W_{hwas.UN1} \cdot -1 = -1026.66 \cdot kN$$

At-Rest Soil Load on Approach Slab:

$$E_{act.as.UN1.x} := E_{act.as.rect.UN1.x} + E_{act.as.tri.UN1.x} = -1026.66 \cdot kN$$

Acting at:

$$E_{act.as.UN1.x.loc.y} := \frac{\left(E_{act.as.rect.UN1.x} \cdot \frac{T_{as}}{2} \; ... \; + E_{act.as.tri.UN1.x} \cdot \frac{T_{as}}{3}\right)}{E_{act.as.UN1.x}} = 1.33\,m$$

Acting at (from Toe Line):

$$E_{act.as.UN1.x.loc.z} := \frac{W_B}{2} = 8.00\,m$$

Lateral X-Direction Resisting Force (Tailwater Side - at rest condition) **UN1 CASE**

At-rest Soil Load: $E_{pass.UN1.x} := \frac{\left(K_{o.UN1} \cdot d_{RS.a}^{\,2}\right)}{2} \cdot \left(\gamma_r - \gamma_w\right) \cdot W_{rsa.UN1} = 2880.26 \cdot kN$

Acting at: $E_{pass.UN1.x.loc.y} := \frac{d_{RS.a}}{3} + T_{sb} - d_{key} = 2.83\,m$ $W_{rsa.UN1} = 9.94\,m$

Acting at (from Toe Line): $E_{pass.UN1.x.loc.z} := W_{hwgg.UN1} + r_{wall} = 10\,m$

$\Sigma H_{soil.UN1.x} := \left(E_{act.a.UN1.x} + E_{act.as.UN1.x} + E_{pass.UN1.x}\right) = 1853.61 \cdot kN$

$\Sigma M_{soil.UN1.x} := E_{act.a.UN1.x} \cdot E_{act.a.UN1.x.loc.y} + E_{act.as.UN1.x} \cdot E_{act.as.UN1.x.loc.y} + E_{pass.UN1.x} \cdot E_{pass.UN1.x.loc.y} = 6791.87 \cdot kN \cdot m$

Lateral Z-Direction Driving Force (Headwater Side - Before Gates & Aux. Spillway RCC - at rest condition)

Max./Min. Top of R.C.C. Soil Elevation: $TOS_{RCC.max} = 1216.5\,m$ $TOS_{RCC.min} = 1212.8\,m$

Average Top of R.C.C. Soil Elevation: $TOS_{RCC} = 1214.65\,m$

Depth of R.C.C. Soil Acting on Abutment Walls: $d_{act.RCC.w} = 4.65\,m$

Depth of R.C.C. Soil Acting on Abutment Footings: $d_{act.RCC.f} = 8.65\,m$

Projected Width of soil acting on Abutment Walls: $w_{abut.RCC} = 9.45\,m$

Projected Width of soil acting on Abutment Footing: $w_{FTG.RCC} = 12.2\,m$

At-Rest Soil Load on Top of Footing Slab: $\sigma_{act.RCC.w.UN1} := \left(K_{o.UN1} \cdot d_{act.RCC.w}\right) \cdot \left(\gamma_r - \gamma_w\right) = 37.3 \cdot kPa$

At-Rest Soil Load on Bottom of Approach Slab: $\sigma_{act.RCC.f.UN1} := \left(K_{o.UN1} \cdot d_{act.RCC.f}\right) \cdot \left(\gamma_r - \gamma_w\right) = 69.38 \cdot kPa$

At-Rest Soil Load on Abutment Walls: $E_{act.a.UN1.z} := \frac{\left(K_{o.UN1} \cdot d_{act.RCC.w}^{\,2}\right)}{2} \cdot \left(\gamma_r - \gamma_w\right) \cdot w_{abut.RCC} \cdot -1 = -819.45 \cdot kN$

Acting at: $E_{act.a.UN1.z.loc.y} := \frac{d_{DS.a}}{3} + T_{as} = 4.00\,m$

Acting at (from Toe Line): $E_{act.a.UN1.z.loc.x} := \frac{\left(L_{wall} + r_{wall} - 6.35m\right)}{2} + 6.35m = 11.18\,m$

At-Rest Soil Load on Abutment Footing (Rect): $E_{act.as.rect.UN1.z} := \sigma_{act.RCC.w.UN1} \cdot \left(T_{as}\right) \cdot w_{abut.RCC} \cdot -1 = -1409.81 \cdot kN$

At-Rest Soil Load on Abutment Footing (Tri): $E_{act.as.tri.UN1.z} := \frac{-\left(\sigma_{act.RCC.f.UN1} - \sigma_{act.RCC.w.UN1}\right) \cdot \left(T_{as}\right)}{2} \cdot w_{FTG.RCC} = -782.83 \cdot kN$

At-Rest Soil Load on Approach Slab: $E_{act.as.UN1.z} := E_{act.as.rect.UN1.z} + E_{act.as.tri.UN1.z} = -2192.64 \cdot kN$

Acting at: $E_{act.as.UN1.z.loc.y} := \frac{\left(E_{act.as.rect.UN1.z} \cdot \frac{T_{as}}{2} \ldots + E_{act.as.tri.UN1.z} \cdot \frac{T_{as}}{3}\right)}{E_{act.as.UN1.z}} = 1.76\,m$

Acting at (from toe line): $E_{act.as.UN1.z.loc.x} := \frac{\left(L_{wall} + r_{wall} - 6.35m\right)}{2} + 6.35m = 11.18\,m$

Lateral Z-Direction Driving Force (Headwater Side - After Gates & Aux. Spillway RCC - at rest condition) **UN1 CASE**

Max. Top of R.C.C. Wall: $TORCC_{max} = 1215.8\ m$

Min. Top of R.C.C. Wall: $TORCC_{min} = 1214\ m$

Average Top of R.C.C. Wall Elevation: $TORCC = 1214.9\ m$

Width of Soil acting at Max. top of RCC: $w_{RCC.max} = 4.7\ m$

Width of Soil acting with average Top of RCC (Steps): $w_{RCC.avg} = 1.65\ m$

Depth of Top of Soil to Top of R.C.C. Wall: $d_{act.RCC} = 0.7\ m$

Depth of Top of Soil to Average Top of R.C.C. Wall (Steps): $d_{act.RCC.avg} = 1.6\ m$

At-Rest Soil Load on Abutment Walls after RCC:

$$E_{act.RCC.UN1.z} := \frac{\left(K_{o.UN1} \cdot d_{act.RCC}^{\ 2}\right)}{2} \cdot \left(\gamma_r - \gamma_w\right) \cdot w_{RCC.max} \cdot -1 = -9.24 \cdot kN$$

Acting at:

$$E_{act.RCC.UN1.z.loc.y} := \frac{d_{act.RCC}}{3} + \left(TORCC_{max} - BOF_{elev}\right) = 10.03\ m$$

Acting at (from Toe Line): $E_{act.RCC.UN1.z.loc.x} := 4m$ (at SS-Axis Center Line)

At-Rest Soil Load on Abutment Walls at RCC Steps:

$$E_{act.RCC.s.UN1.z} := \frac{\left(K_{o.UN1} \cdot d_{act.RCC.avg}^{\ 2}\right)}{2} \cdot \left(\gamma_r - \gamma_w\right) \cdot w_{RCC.avg} \cdot -1 = -16.94 \cdot kN$$

Acting at:

$$E_{act.RCC.s.UN1.z.loc.y} := \frac{d_{act.RCC.avg}}{3} + \left(TORCC - BOF_{elev}\right) = 9.43\ m$$

Acting at (from Toe Line):

$$E_{act.RCC.s.UN1.z.loc.x} := \frac{4m - 2.35m}{2} = 0.83\ m$$

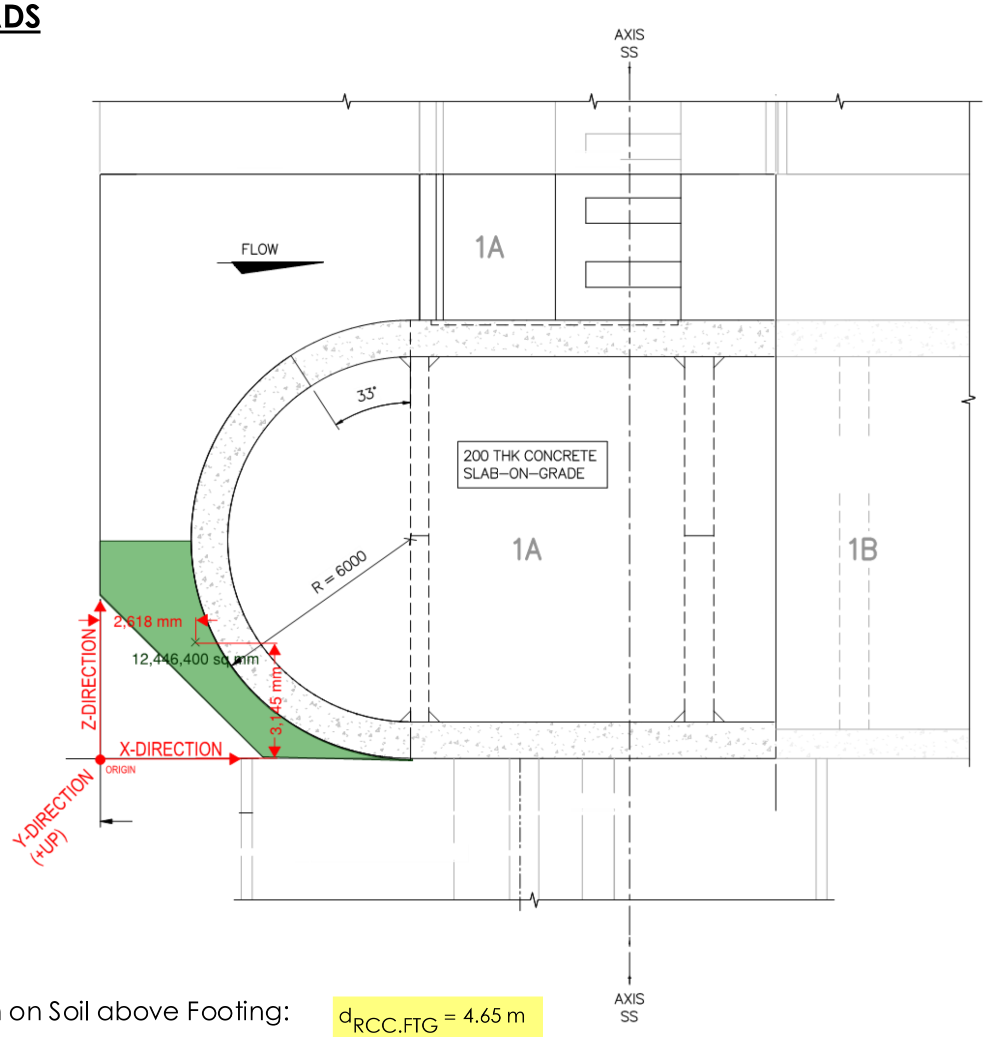
(at Halfway point of RCC Steps)

$$\Sigma H_{soil.UN1.z} := \left(E_{act.a.UN1.z} + E_{act.as.UN1.z} + E_{act.RCC.UN1.z} + E_{act.RCC.s.UN1.z}\right) = -3038.27 \cdot kN$$

$$\Sigma M_{soil.UN1.z} := E_{act.a.UN1.z} \cdot E_{act.a.UN1.z.loc.y} + E_{act.as.UN1.z} \cdot E_{act.as.UN1.z.loc.y} \cdots + E_{act.RCC.UN1.z} \cdot E_{act.RCC.UN1.z.loc.y} + E_{act.RCC.s.UN1.z} \cdot E_{act.RCC.s.UN1.z.loc.y} = -7393.67 \cdot kN \cdot m$$

VERTICAL SOIL LOADS

UN1 CASE



Average Depth on Soil above Footing: $d_{RCC.FTG} = 4.65\ m$

Area of Footing with Soil above: $A_{ftg.soil} = 0$ (From Bluebeam REVU)

Vertical Water Weight (H1) on Approach Slab: $E_{1.UN1} := \left(A_{ftg.soil} \cdot d_{RCC.FTG}\right) \cdot \left(\gamma_r - \gamma_w\right) = 0.0 \cdot kN$

Moment Arm for Applicaiton of Water Weight (H1) from toe (X-Direction): $E_{1.UN1.loc.x} := L_B - 5.607m = 12.89\ m$ (From Geom. Scaled on REVU)

Moment Arm for Applicaiton of Water Weight (H1) from toe (Z-Direction): $E_{1.UN1.loc.z} := W_B - 3.145m = 12.86\ m$ (From Geom. Scaled on REVU)

$\Sigma E_{UN1} := E_{1.UN1} = 0 \cdot kN$ $\Sigma M_{E.UN1.x} := E_{1.UN1} \cdot E_{1.UN1.loc.x} = 0 \cdot kN \cdot m$ $\Sigma M_{E.UN1.z} := E_{1.UN1} \cdot E_{1.UN1.loc.z} = 0 \cdot kN \cdot m$

IMPACT LOADS (DEBRIS LOADING FROM MEMO)

Total Impact Load on Structure: $I_{UN1} := 1502kN$ (SS Abutment) - 2013 Design Flood

Apply Ice load at: $I_{UN1.loc.y} := \left(HW_{UN1} - BOF_{elev} - 0.30m\right) = 9.50\ m$

$\Sigma H_{I.UN1} := I_{UN1} = 1502 \cdot kN$

$\Sigma M_{I.UN1} := I_{UN1} \cdot I_{UN1.loc.y} = 14269 \cdot kN \cdot m$

SEISMIC LOAD (NOT APPLICABLE FOR THIS LOAD CASE)

UN1 CASE

SUMMARY OF LOADS

	Loads	Moment Arm	
Dead load of Concrete Structure:	$D_{conc} = 35947.6 \cdot kN$	$X_{conc.loc} = 8.81\ m$	$Z_{conc.loc} = 8.46\ m$
Obermyer Gate Weight:	$D_{Gate} = 56.0 \cdot kN$	$X_{gate} = 9.50\ m$	$Z_{gate} = 2.00\ m$
Dead load of Fill:	$D_{fill} = 18056.6 \cdot kN$	$X_{fill.loc} = 7.31\ m$	$Z_{fill.loc} = 10.00\ m$
HW Lateral Load on Abutment:	$H_{hwa.UN1} = -1980.1 \cdot kN$	$H_{hwa.UN1.loc} = 5.93\ m$	
HW Lateral Load on Approach Slab:	$H_{hwas.UN1} = -4897.2 \cdot kN$	$H_{hwas.UN1.loc} = 1.83\ m$	
HW Lateral Load on Guard Gate:	$H_{hwgg.UN1} = -556.2 \cdot kN$	$H_{hwgg.UN1.loc} = 5.50\ m$	
TW Lateral Load on Abutment:	$H_{twa.UN1} = 565.6 \cdot kN$	$H_{twa.UN1.loc} = 5.03\ m$	
TW Lateral Load on Pier Footing:	$H_{twgf.UN1} = 1600.99 \cdot kN$	$H_{twgf.UN1.loc} = 1.74\ m$	
TW Lateral Load on Guard Gate:	$H_{twgg.UN1} = 188.5 \cdot kN$	$H_{twgg.UN1.loc} = 5.03\ m$	
Vertical HW Load on Approach Slab:	$H_{1.UN1} = 4531.6 \cdot kN$	$H_{1.UN1.loc.x} = 14.42\ m$	$H_{1.UN1.loc.z} = 4.73\ m$
Vertical TW Load on Pier Footing (crest):	$H_{2.UN1} = 1970.8 \cdot kN$	$H_{2.UN1.loc.x} = 5.37\ m$	$H_{2.UN1.loc.z} = 2.00\ m$
Uplift:	$U_{UN1} = -24298.8 \cdot kN$	$U_{UN1.loc.x} = 9.96\ m$	$U_{UN1.loc.z} = 8.24\ m$
X-Direction Lateral Soil Load on Abutment (driving):	$E_{act.a.UN1.x} = 0.0 \cdot kN$	$E_{act.a.UN1.x.loc.y} = 2.00\ m$	
X-Direction Lateral Lateral Soil Load on Approach Slab (driving):	$E_{act.as.UN1.x} = -1026.7 \cdot kN$	$E_{act.as.UN1.x.loc.y} = 1.33\ m$	
Lateral Soil Load (resisting):	$E_{pass.UN1.x} = 2880.26 \cdot kN$	$E_{pass.UN1.x.loc.y} = 2.83\ m$	
Z-Direction Lateral Soil Load on Abutment Before RCC (driving):	$E_{act.a.UN1.z} = -819.5 \cdot kN$	$E_{act.a.UN1.z.loc.y} = 4.00\ m$	
Z-Direction Lateral Lateral Soil Load on Approach Slab Before RCC (driving):	$E_{act.as.UN1.z} = -2192.6 \cdot kN$	$E_{act.as.UN1.z.loc.y} = 1.76\ m$	
Z-Direction Lateral Soil Load on Abutment After RCC (driving):	$E_{act.RCC.UN1.z} = -9.24 \cdot kN$	$E_{act.RCC.UN1.z.loc.y} = 10.03\ m$	
Z-Direction Lateral Soil Load on Abutment at RCC Steps (driving):	$E_{act.RCC.s.UN1.z} = -16.94 \cdot kN$	$E_{act.RCC.s.UN1.z.loc.y} = 9.43 \cdot m$	
Vertical Soil Load on Footing:	$E_{1.UN1} = 0 \cdot kN$	$E_{1.UN1.loc.x} = 12.89\ m$	$E_{1.UN1.loc.z} = 12.86\ m$
Ice / Impact Load:	$I_{UN1} = 1502.0 \cdot kN$	$I_{UN1.loc.y} = 9.50\ m$	

STABILITY ASSESSMENT (SLIDNG, BEARING, FLOTATION AND OVERTURNING): UN1 CASE

CHECK SLIDING (X-Direction & Z-Direction) ALONG HORIZONTAL PLANE THRU TOE, IGNORING BEDROCK MOBILIZED BY STRUCTURAL HEEL KEY, OR VOID BEHIND KEY

Sum of Vertical Forces:

$$\Sigma V_{UN1} := \Sigma V_{DL} + \Sigma V_{water.UN1} + \Sigma E_{UN1} = 36263.8 \cdot kN$$

Sum of Horizontal Forces (X-Direction):

$$\Sigma H_{UN1.x} := \Sigma H_{Water.UN1.x} + \Sigma H_{soil.UN1.x} + \Sigma H_{I.UN1} = -1722.64 \cdot kN$$

Sum of Horizontal Forces (Z-Direction):

$$\Sigma H_{UN1.z} := \Sigma H_{Water.UN1.z} + \Sigma H_{soil.UN1.z} = -3038.27 \cdot kN$$

Sum of Horizontal Forces (resultant):

$$\Sigma H_{UN1} := \sqrt{\Sigma H_{UN1.x}^{\ 2} + \Sigma H_{UN1.z}^{\ 2}} = 3492.64 \cdot kN$$

Sliding Factor of Safety:

$$FS_{HorizSliding.UN1.x} := \frac{\tan_{\phi} \cdot \Sigma V_{UN1}}{\left|\Sigma H_{UN1.x}\right|} = 10.27 \qquad FS_{HorizSliding.UN1.z} := \frac{\tan_{\phi} \cdot \Sigma V_{UN1}}{\left|\Sigma H_{UN1.z}\right|} = 5.82$$

Sliding Factor of Safety:

$$FS_{HorizSliding.UN1} := \frac{\tan_{\phi} \cdot \Sigma V_{UN1}}{\sqrt{\Sigma H_{UN1.x}^{\ 2} + \Sigma H_{UN1.z}^{\ 2}}} = 5.06$$

$$FS_{HorizSliding.UN1.Check.x} := \begin{cases} \text{"OKAY"} & \text{if } FS_{HorizSliding.UN1.x} \geq FS_{req.UN1.sl} \\ \text{"Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

$$FS_{HorizSliding.UN1.Check.z} := \begin{cases} \text{"OKAY"} & \text{if } FS_{HorizSliding.UN1.z} \geq FS_{req.UN1.sl} \\ \text{"Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

$$FS_{HorizSliding.UN1.Check} := \begin{cases} \text{"OKAY"} & \text{if } FS_{HorizSliding.UN1} \geq FS_{req.UN1.sl} \\ \text{"Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

CHECK FOUNDATION BEARING CAPACITY

Sum of the Moments (X-Direction):

$$\Sigma M_{UN1.x} := \Sigma M_{DL.x} + \Sigma M_{HWater.UN1.x} + \Sigma M_{Vwater.UN1.x} + \Sigma M_{I.UN1} + \Sigma M_{soil.UN1.x} = 287073 \cdot kN \cdot m$$

Eccentricity:

$$e_{UN1.x} := X_{BCG} - \frac{\Sigma M_{UN1.x}}{\Sigma V_{UN1}} = 1.06\ m$$

Eccentricity Check:

$$e_{check.UN1.x} := \begin{cases} \text{"Okay"} & \text{if } e_{UN1.x} \leq Kern_x \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$$e_{check.UN1.x} = \text{"Okay"}$$

Foundation Bearing Pressures (X-Direction):

UN1 CASE

Bearing Pressure at Heel:

$$\sigma_{heel.UN1.x} := \frac{\Sigma V_{UN1}}{A_b} - \frac{\Sigma V_{UN1} \cdot e_{UN1.x}}{S_{bx.L}} = 79.95 \cdot \frac{kN}{m^2}$$

$$\sigma_{heel.UN1.check.x} := \left(\begin{array}{ll} \text{"Okay"} & \text{if } 0 \le \sigma_{heel.UN1.x} \le \sigma_{allow.UN1} \\ \text{"Revise Structure"} & \text{otherwise} \end{array} \right) \qquad \sigma_{heel.UN1.check.x} = \text{"Okay"}$$

Bearing Pressure at Toe:

$$\sigma_{toe.UN1.x} := \frac{\Sigma V_{UN1}}{A_b} + \frac{\Sigma V_{UN1} \cdot e_{UN1.x}}{S_{bx.R}} = 171.05 \cdot \frac{kN}{m^2}$$

$$\sigma_{toe.UN1.check.x} := \left| \begin{array}{ll} \text{"Okay"} & \text{if } 0 \le \sigma_{toe.UN1.x} \le \sigma_{allow.UN1} \\ \text{"Revise Structure"} & \text{otherwise} \end{array} \right. \qquad \sigma_{toe.UN1.check.x} = \text{"Okay"}$$

Sum of the Moments (Z-Direction):

$$\Sigma M_{UN1.z} := \Sigma M_{DL.z} + \Sigma M_{HWater.UN1.z} + \Sigma M_{Vwater.UN1.z} + \Sigma M_{soil.UN1.z} = 302576 \cdot kN \cdot m$$

Eccentricity:

$$e_{UN1.z} := Z_{BCG} - \frac{\Sigma M_{UN1.z}}{\Sigma V_{UN1}} = -0.57\ m$$

Eccentricity Check:

$$e_{check.UN1.z} := \left| \begin{array}{ll} \text{"Okay"} & \text{if } e_{UN1.z} \le Kern_z \\ \text{"Revise Structure"} & \text{otherwise} \end{array} \right. \qquad e_{check.UN1.z} = \text{"Okay"}$$

Foundation Bearing Pressures (Z-Direction):

Bearing Pressure at Heel:

$$\sigma_{heel.UN1.z} := \frac{\Sigma V_{UN1}}{A_b} - \frac{\Sigma V_{UN1} \cdot e_{UN1.z}}{S_{bz.b}} = 156.07 \cdot \frac{kN}{m^2}$$

$$\sigma_{heel.UN1.check.z} := \left(\begin{array}{ll} \text{"Okay"} & \text{if } 0 \le \sigma_{heel.UN1.z} \le \sigma_{allow.UN1} \\ \text{"Revise Structure"} & \text{otherwise} \end{array} \right) \qquad \sigma_{heel.UN1.check.z} = \text{"Okay"}$$

Bearing Pressure at Toe:

$$\sigma_{toe.UN1.z} := \frac{\Sigma V_{UN1}}{A_b} + \frac{\Sigma V_{UN1} \cdot e_{UN1.z}}{S_{bz.t}} = 99.27 \cdot \frac{kN}{m^2}$$

$$\sigma_{toe.UN1.check.z} := \left| \begin{array}{ll} \text{"Okay"} & \text{if } 0 \le \sigma_{heel.UN1.z} \le \sigma_{allow.UN1} \\ \text{"Revise Structure"} & \text{otherwise} \end{array} \right. \qquad \sigma_{toe.UN1.check.z} = \text{"Okay"}$$

UN1 CASE

Foundation Bearing Pressure (Combined):

Linear pressure superimposed at Corners by both Moment_X and Moment_Z

Bearing Pressure at Heel(x)-Heel(z):

$$\sigma_{heel.UN1} := \frac{\Sigma V_{UN1}}{A_b} - \frac{\Sigma V_{UN1} \cdot e_{UN1.x}}{S_{bx.L}} - \frac{\Sigma V_{UN1} \cdot e_{UN1.z}}{S_{bz.b}} = 109.17 \cdot kPa$$

$$\sigma_{heel.UN1.check} := \left(\begin{array}{l} \text{"Okay" if } 0 \le \sigma_{heel.UN1} \le \sigma_{allow.UN1} \\ \text{"Revise Structure" otherwise} \end{array} \right)$$

$\sigma_{heel.UN1.check} = \text{"Okay"}$

Bearing Pressure at Toe(x)-Toe(z):

$$\sigma_{toe.UN1} := \frac{\Sigma V_{UN1}}{A_b} + \frac{\Sigma V_{UN1} \cdot e_{UN1.x}}{S_{bx.R}} + \frac{\Sigma V_{UN1} \cdot e_{UN1.z}}{S_{bz.t}} = 143.46 \cdot kPa$$

$$\sigma_{toe.UN1.check} := \begin{array}{l} \text{"Okay" if } 0 \le \sigma_{toe.UN1} \le \sigma_{allow.UN1} \\ \text{"Revise Structure" otherwise} \end{array}$$

$\sigma_{toe.UN1.check} = \text{"Okay"}$

Bearing Pressure at Heel(x)-Toe(z):

$$\sigma_{heeltoe.UN1} := \frac{\Sigma V_{UN1}}{A_b} - \frac{\Sigma V_{UN1} \cdot e_{UN1.x}}{S_{bx.L}} + \frac{\Sigma V_{UN1} \cdot e_{UN1.z}}{S_{bz.t}} = 52.37 \cdot kPa$$

$$\sigma_{heeltoe.UN1.check} := \left(\begin{array}{l} \text{"Okay" if } 0 \le \sigma_{heeltoe.UN1} \le \sigma_{allow.UN1} \\ \text{"Revise Structure" otherwise} \end{array} \right)$$

$\sigma_{heeltoe.UN1.check} = \text{"Okay"}$

Bearing Pressure at Toe(x)-Heel(z):

$$\sigma_{toeheel.UN1} := \frac{\Sigma V_{UN1}}{A_b} + \frac{\Sigma V_{UN1} \cdot e_{UN1.x}}{S_{bx.R}} - \frac{\Sigma V_{UN1} \cdot e_{UN1.z}}{S_{bz.b}} = 200.27 \cdot kPa$$

$$\sigma_{toeheel.UN1.check} := \begin{array}{l} \text{"Okay" if } 0 \le \sigma_{toeheel.UN1} \le \sigma_{allow.UN1} \\ \text{"Revise Structure" otherwise} \end{array}$$

$\sigma_{toeheel.UN1.check} = \text{"Okay"}$

FLOATATION ANALYSIS:

ACCEPTANCE PARAMETERS

Required Factor of Safety: $FS_{req.FUN1} := 1.3$

VERTICAL LOADS RESISTING:

Dead Load: $\Sigma V_{DL} = 54060.17 \cdot kN$

Water Weight H1+H2: $\Sigma V_{H.FUN1} := H_{1.UN1} + H_{2.UN1} = 6502.42 \cdot kN$

Summation Vertical Resisting: $\Sigma V_{FUN1} := \Sigma V_{DL} + \Sigma V_{H.FUN1} = 60562.6 \cdot kN$

VERTICAL LOADS UPLIFT:

Uplift: $U_{UN1} = -24298.76 \cdot kN$

Factor of Safety Floatation:

$$FS_{act.FUN1} := \frac{\Sigma V_{FUN1}}{\left|U_{UN1}\right|} = 2.49$$

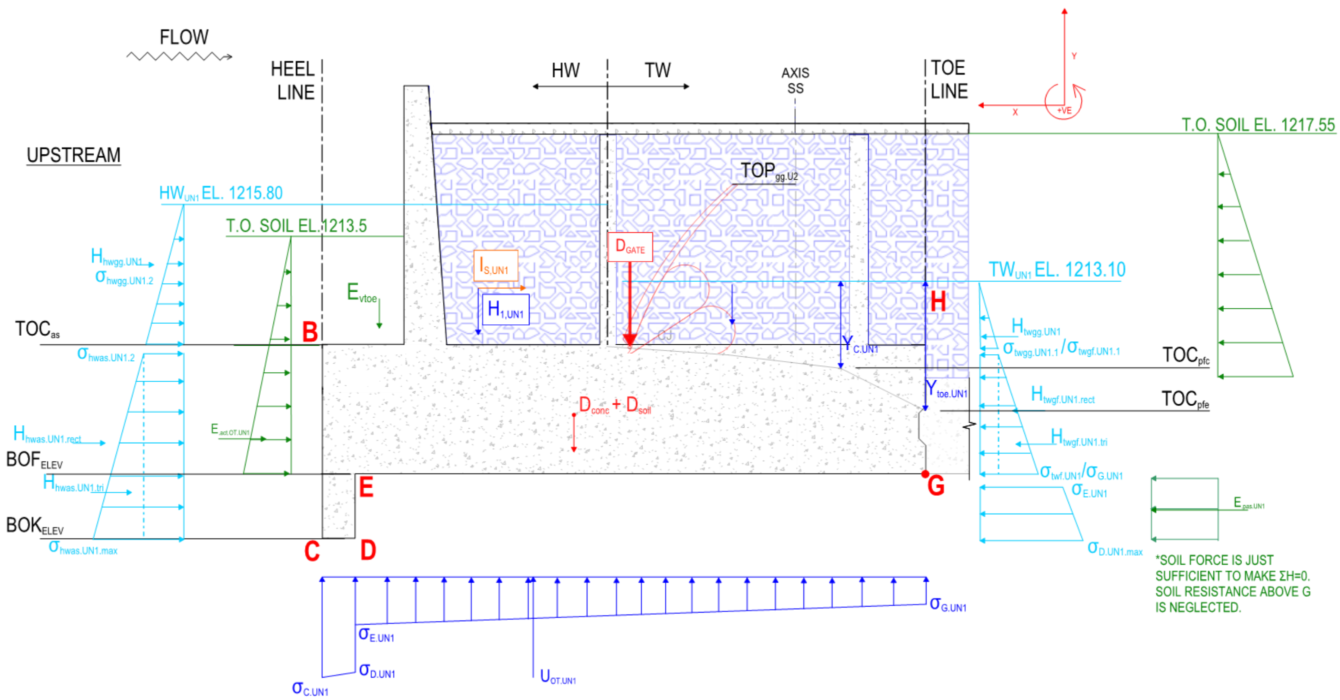
$$FS_{check.FUN1} := \begin{array}{l} \text{"OKAY" if } FS_{act.FUN1} \ge FS_{req.FUN1} \\ \text{"ANCHORS REQUIRED" if } FS_{act.FUN1} < FS_{req.FUN1} \end{array} = \text{"OKAY"}$$

MONOLITH OVERTURNING STABILITY ANALYSIS

UN1 CASE

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.
Assumptions are made in order to compute overturning stablity of indetermine forces on monolith with key;
(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.
(b) The horizontal resisting force acting on the key, P.key, is that required for staticequilibrium
(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1 $Ratio_{OT.UN1.min} := 0.333$ at Rock Foundation



Uplift Loads for Overturning Stability Analysis (X-Direction)

Line of Creep:

Change in Water Head: $\Delta_{h.UN1} := HW_{UN1} - TW_{UN1} = 2.7\ m$

Length from Point C to Point G: $L_{CG} = 18.61\ m$

Length from Various Points to Points: $L_{CD} = 1\ m$ $L_{DE} = 2\ m$ $L_{EG} = 17.5\ m$

$L_{GH.UN1} := TW_{UN1} - TOC_{afe} = 5.1\ m$

Length from Point C, D, E to G: $L_{CDEG} = 20.5\ m$ $L_{CDE} = 3\ m$

Water Pressure at Point C & G: $\sigma_{C.UN1} := \sigma_{hwas.UN1.2} = -96.14 \cdot kPa$ $\sigma_{G.UN1} := \sigma_{twtoe.UN1} \cdot -1 = -69.65 \cdot kPa$

Water Pressure at Point D:

$$\sigma_{D.UN1} := -\gamma_w \cdot \left[\left(HW_{UN1} - BOK_{elev} \right) - \frac{\Delta_{h.UN1} \cdot L_{CD}}{L_{CDEG}} \right] = -114.47 \cdot kPa$$

Water Pressure at Point E:

$$\sigma_{E.UN1} := -\gamma_w \cdot \left[\left(HW_{UN1} - BOF_{elev} \right) - \frac{\Delta_{h.UN1} \cdot L_{CDE}}{L_{CDEG}} \right] = -92.26 \cdot kPa$$

Uplift for Overturning Analysis on Bottom of Key:

$$U_{OT.UN1.key} := \frac{\sigma_{C.UN1} + \sigma_{D.UN1}}{2} \cdot L_{CD} \cdot W_B = -1684.83 \cdot kN$$

Acting at:

$$U_{OT.UN1.key.loc} := \frac{L_{CD} \cdot \left(2 \cdot \sigma_{C.UN1} + \sigma_{D.UN1} \right)}{3 \left(\sigma_{C.UN1} + \sigma_{D.UN1} \right)} + L_{EG} = 17.99\ m$$

UN1 CASE

Uplift for Overturning Analysis on Bottom of Footing:

$$U_{OT.UN1.ftg} := \frac{\sigma_{E.UN1} + \sigma_{G.UN1}}{2} \cdot L_{EG} \cdot W_B = -22667.8 \cdot kN$$

Acting at:

$$U_{OT.UN1.ftg.loc} := \frac{L_{EG} \cdot \left(\sigma_{G.UN1} + 2 \cdot \sigma_{E.UN1}\right)}{3\left(\sigma_{G.UN1} + \sigma_{E.UN1}\right)} = 9.16\ m$$

Uplift Load for Overtuming Analysis:

$$U_{OT.UN1} := U_{OT.UN1.key} + U_{OT.UN1.ftg} = -24352.63 \cdot kN$$

Uplift Load Acting from Toe:

$$U_{OT.UN1.loc} := \frac{U_{OT.UN1.key} \cdot U_{OT.UN1.key.loc} + U_{OT.UN1.ftg} \cdot U_{OT.UN1.ftg.loc}}{U_{OT.UN1}} = 9.77\ m$$

<u>All Vertical Loads Appliable to Overturning Stability Analysis</u>

Total Concrete Dead Loads:	$D_{conc} = 35947.58 \cdot kN$	at:	$X_{conc.loc} = 8.81\ m$
Dead Load of Gate:	$D_{Gate} = 56.0 \cdot kN$		$X_{gate} = 9.50\ m$
Total Fill Loads:	$D_{fill} = 18056.6 \cdot kN$		$X_{fill.loc} = 7.31\ m$
Water Weight (HW) on Apron Slab:	$H_{1.UN1} = 4531.6 \cdot kN$		$H_{1.UN1.loc.x} = 14.42\ m$
Water Weight (TW) on Guard Gate Footing:	$H_{2.UN1} = 1970.8 \cdot kN$		$H_{2.UN1.loc.x} = 5.37\ m$
Uplift Load for Overtuming Analysis:	$U_{OT.UN1} = -24352.63 \cdot kN$		$U_{OT.UN1.loc} = 9.77 \cdot m$

Sum of All Overturning Analysis Vertical Load:

$$\Sigma V_{UN1.OT} := D_{conc} + D_{Gate} + D_{fill} + H_{1.UN1} + H_{2.UN1} + U_{OT.UN1} = 36209.96 \cdot kN$$

Sum of All Overturning Analysis Vertical Load Moments:

$$\Sigma M_{V.UN1.OT} := \begin{pmatrix} D_{conc} \cdot X_{conc.loc} + D_{Gate} \cdot X_{gate} + D_{fill} \cdot X_{fill.loc} + H_{1.UN1} \cdot H_{1.UN1.loc.x} \cdots \\ + H_{2.UN1} \cdot H_{2.UN1.loc.x} + U_{OT.UN1} \cdot U_{OT.UN1.loc} \end{pmatrix} = 287396.11 \cdot kN \cdot m$$

<u>Lateral Tailwater Loads for Overturning Stability Analysis</u>

TW Lateral Load on Gate Footing (No Key - Overturning Values Adjusted):

$$H_{twgf.UN1} = 1600.99 \cdot kN$$

Acting at:

$$H_{twgf.UN1.loc} = 1.74\ m$$

Horizontal Tailwater Pressure Top of Key (Overturning Analysis):

$$\sigma_{twtk.OT.UN1} := \sigma_{E.UN1} \cdot -1 = 92.26 \cdot kPa$$

Horizontal Tailwater Pressure Bottom of Key (Overturning Analysis):

$$\sigma_{twbk.OT.UN1} := \sigma_{D.UN1} \cdot -1 = 114.47 \cdot kPa$$

Triangular Distribution Unit Load Acting at Key:

$$H_{twbk.OT.UN1.tri} := \frac{\left(\sigma_{twbk.OT.UN1} - \sigma_{twtk.OT.UN1}\right)}{2} \cdot d_{key} \cdot W_{tw.UN1} = 355.27 \cdot kN$$

Triangular Distribution Unit Load Acting at Key:

$$H_{twbk.OT.UN1.rect} := \sigma_{twtk.OT.UN1} \cdot d_{key} \cdot W_{tw.UN1} = 2952.38 \cdot kN$$

Total Horizontal Tailwater Load on Key (Overturning Values Adjusted):

$$H_{twkey.OT.UN1} := H_{twbk.OT.UN1.tri} + H_{twbk.OT.UN1.rect} = 3307.64 \cdot kN$$

Acting at:

$$H_{twkey.OT.UN1.loc} := \frac{H_{twbk.OT.UN1.tri} \cdot \frac{-2 \cdot d_{key}}{3} + H_{twbk.OT.UN1.rect} \cdot \frac{-d_{key}}{2}}{H_{twkey.OT.UN1}} = -1.04 \cdot m$$

Lateral Driving Earth Loads for Overturning Stability Analysis (at rest condition)

UN1 CASE

Depth of Driving Soil Loads (to top of key): $h_{E.OT.UN1} := TOC_{as} - BOF_{elev} = 4\ m$

At-Rest Soil Load: $E_{act.OT.UN1} := \frac{\left(K_{o.UN1} \cdot h_{E.OT.UN1}{}^2\right)}{2} \cdot \left(\gamma_r - \gamma_w\right) \cdot W_{hwas.UN1} \cdot -1 = -1026.66 \cdot kN$

At Rest- Soil Load Acting from Toe: $E_{act.OT.UN1.loc} := \frac{h_{E.OT.UN1}}{3} = 1.33\ m$

All Lateral Loads Appliable to Overturning Stability Analysis (X-direction)

HW Lateral Load on Approach Slab:	$H_{hwas.UN1} = -4897.2 \cdot kN$	$H_{hwas.UN1.loc} = 1.83\ m$
HW Lateral Load on Guard Gate:	$H_{hwgg.UN1} = -556.2 \cdot kN$	$H_{hwgg.UN1.loc} = 5.50\ m$
HW Lateral Load on Abutment:	$H_{hwa.UN1} = -1980.1 \cdot kN$	$H_{hwa.UN1.loc} = 5.93\ m$
TW Lateral Load on Abutment:	$H_{twa.UN1} = 565.6 \cdot kN$	$H_{twa.UN1.loc} = 5.03\ m$
TW Lateral Load on Guard Gate:	$H_{twgg.UN1} = 188.5 \cdot kN$	$H_{twgg.UN1.loc} = 5.03\ m$
TW Lateral Load on Gate Footing (No Key - Overturning Values Adjusted):	$H_{twgf.UN1} = 1600.99 \cdot kN$	$H_{twgf.UN1.loc} = 1.74\ m$
TW Lateral Load on Key:	$H_{twkey.OT.UN1} = 3307.64 \cdot kN$	$H_{twkey.OT.UN1.loc} = -1.04\ m$
Ice / Impact Load:	$I_{UN1} = 1502.0 \cdot kN$	$I_{UN1.loc.y} = 9.50\ m$
Lateral Soil Load (driving):	$E_{act.OT.UN1} = -1026.7 \cdot kN$	$E_{act.OT.UN1.loc} = 1.33\ m$

Resisting Lateral Soil Load as required to produce horizontal equilibrium:

$$E_{pas.OT.x.UN1} := -\left(H_{hwas.UN1} + H_{hwgg.UN1} + H_{hwgg.UN1} + H_{twgg.UN1} \cdots + H_{twgf.UN1} + H_{twkey.OT.UN1} + I_{UN1} + E_{act.OT.UN1}\right) = 437.08 \cdot kN$$

Acting at:

$$E_{pas.OT.UN1.loc} := -1 \cdot \frac{d_{key}}{2} = -1\ m$$

Sum of All Overturning Analysis Horizontal Load (ΣH=0):

$$\Sigma H_{UN1.OT.x} := H_{hwas.UN1} + H_{hwgg.UN1} + H_{twgg.UN1} + H_{twgf.UN1} + H_{twkey.OT.UN1} + I_{UN1} + E_{act.OT.UN1} + E_{pas.OT.x.UN1} = 556.23 \cdot kN$$

Sum of All Overturning Analysis Horizontal Load Moments:

$$\Sigma M_{H.UN1.OT.x} := H_{hwas.UN1} \cdot H_{hwas.UN1.loc} + H_{hwgg.UN1} \cdot H_{hwgg.UN1.loc} \cdots + H_{twgg.UN1} \cdot H_{twgg.UN1.loc} + H_{twgf.UN1} \cdot H_{twgf.UN1.loc} \cdots + H_{twkey.OT.UN1} \cdot H_{twkey.OT.UN1.loc} + I_{UN1} \cdot I_{UN1.loc.y} \cdots + E_{act.OT.UN1} \cdot E_{act.OT.UN1.loc} + E_{pas.OT.x.UN1} \cdot E_{pas.OT.UN1.loc} = 754.14 \cdot kN \cdot m$$

Overturning Stability Analysis (X-Direction)

$$\Sigma M_{UN1.OT.x} := \Sigma M_{V.UN1.OT} + \Sigma M_{H.UN1.OT.x} = 288150.24 \cdot kN \cdot m$$

$$X_{R.UN1} := \frac{\Sigma M_{UN1.OT.x}}{\Sigma V_{UN1.OT}} = 7.96\ m \qquad x_{OT.UN1} := X_{R.UN1} - \frac{L_B}{2} = -1.29\ m$$

Overturning Resultant Ratio

$$Ratio_{OT.x.UN1} := \frac{X_{R.UN1}}{L_B} = 0.43$$

$$Ratio_{OT.x.UN1.check} := \begin{cases} \text{"OKAY"} & \text{if } Ratio_{OT.x.UN1} \ge Ratio_{OT.UN1.min} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

$$x_{OT.check.UN1} := \begin{cases} \text{"OKAY"} & \text{if } \left|x_{OT.UN1}\right| \le Kern_x \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

All Lateral Loads Appliable to Overturning Stability Analysis (Z-direction)

UN1 CASE

Z-Direction Lateral Soil Load on Abutment Before RCC (driving): $E_{act.a.UN1.z} = -819.5 \cdot kN$ $E_{act.a.UN1.z.loc.y} = 4.00\ m$

Z-Direction Lateral Lateral Soil Load on Approach Slab Before RCC (driving): $E_{act.as.UN1.z} = -2192.6 \cdot kN$ $E_{act.as.UN1.z.loc.y} = 1.76\ m$

Z-Direction Lateral Soil Load on Abutment After RCC (driving): $E_{act.RCC.UN1.z} = -9.24 \cdot kN$ $E_{act.RCC.UN1.z.loc.y} = 10.03\ m$

Z-Direction Lateral Soil Load on Abutment at RCC Steps (driving): $E_{act.RCC.s.UN1.z} = -16.94 \cdot kN$ $E_{act.RCC.s.UN1.z.loc.y} = 9.43 \cdot m$

Resisting Lateral Soil Load as required to produce horizontal equilibrium:

$$E_{pas.OT.z.UN1} := -\left(E_{act.a.UN1.z} + E_{act.as.UN1.z} + E_{act.RCC.UN1.z} + E_{act.RCC.s.UN1.z}\right) = 3038.27 \cdot kN$$

Acting at:

$$E_{pas.OT.UN1.loc} = -1\ m$$

Sum of All Overturning Analysis Horizontal Load (ΣH=0):

$$\Sigma H_{UN1.OT.z} := E_{act.a.UN1.z} + E_{act.as.UN1.z} + E_{act.RCC.UN1.z} + E_{act.RCC.s.UN1.z} + E_{pas.OT.z.UN1} = 0 \cdot kN$$

Sum of All Overturning Analysis Horizontal Load Moments:

$$\begin{aligned}\Sigma M_{H.UN1.OT.z} := {} & E_{act.a.UN1.z} \cdot E_{act.a.UN1.z.loc.y} + E_{act.as.UN1.z} \cdot E_{act.as.UN1.z.loc.y} \cdots \\ & + E_{act.RCC.UN1.z} \cdot E_{act.RCC.UN1.z.loc.y} + E_{act.RCC.s.UN1.z} \cdot E_{act.RCC.s.UN1.z.loc.y} \cdots \\ & + E_{pas.OT.x.UN1} \cdot E_{pas.OT.UN1.loc}\end{aligned} = -7830.75 \cdot kN \cdot m$$

Overturning Stability Analysis (Z-Direction)

$$\Sigma M_{UN1.OT.z} := \Sigma M_{V.UN1.OT} + \Sigma M_{H.UN1.OT.z} = 279565.35 \cdot kN \cdot m$$

$$z_{R.UN1} := \frac{\Sigma M_{UN1.OT.z}}{\Sigma V_{UN1.OT}} = 7.72\ m \qquad z_{OT.UN1} := z_{R.UN1} - \frac{W_B}{2} = -0.28\ m$$

Overturning Resultant Ratio

$$Ratio_{OT.z.UN1} := \frac{z_{R.UN1}}{L_B} = 0.42$$

$$Ratio_{OT.z.UN1.check} := \begin{array}{|l} \text{"OKAY"} \quad \text{if} \quad Ratio_{OT.z.UN1} \geq Ratio_{OT.UN1.min} \\ \text{"Revise Structure"} \quad \text{otherwise} \end{array} = \text{"OKAY"}$$

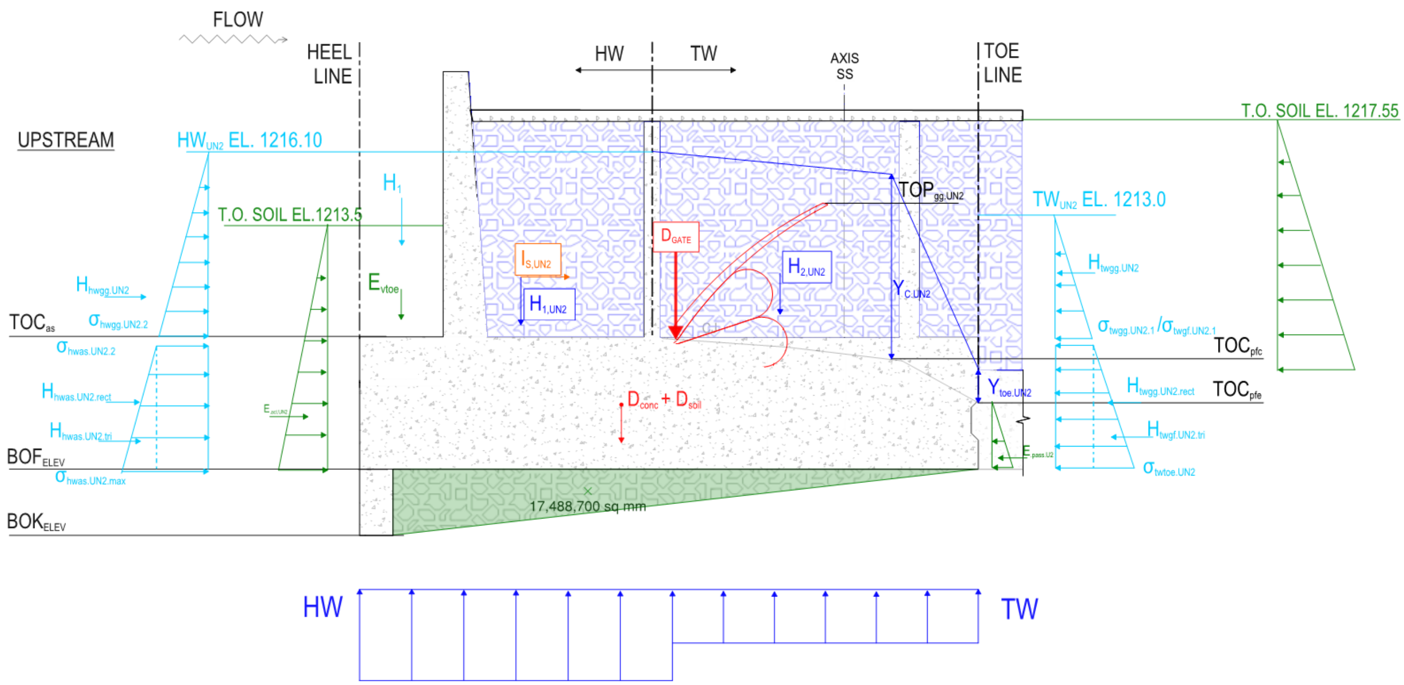
$$z_{OT.check.UN1} := \begin{array}{|l} \text{"OKAY"} \quad \text{if} \quad \left|z_{OT.UN1}\right| \leq Kern_z \\ \text{"Revise Structure"} \quad \text{otherwise} \end{array} = \text{"OKAY"}$$

SUMMARY OF STABILITY ASSESSMENT:

UN1 CASE

Sliding Factor of Safety: (Horizontal Plane)	$FS_{HorizSliding.UN1} = 5.06$	$FS_{HorizSliding.UN1.Check} = $ "OKAY"
Flotation Factor of Safety (horizontal plane)	$FS_{act.FUN1} = 2.49$	$FS_{check.FUN1} = $ "OKAY"
Overturning Resultant Ratio: (X-direction)	$Ratio_{OT.x.UN1} = 0.43$	$Ratio_{OT.x.UN1.check} = $ "OKAY"
Overturning Resultant Ratio: (Z-direction)	$Ratio_{OT.z.UN1} = 0.42$	$Ratio_{OT.z.UN1.check} = $ "OKAY"
Eccentricity: (horizontal plane)	$x_{OT.UN1} = -1.29\ m$	$x_{OT.check.UN1} = $ "OKAY"
Eccentricity: (horizontal plane)	$z_{OT.UN1} = -0.28\ m$	$z_{OT.check.UN1} = $ "OKAY"
Bearing Pressure At Heel(x)- Heel(z): (horizontal plane)	$\sigma_{heel.UN1} = 109 \cdot kPa$	$\sigma_{heel.UN1.check} = $ "Okay"
Bearing Pressure At Toe(x)-Toe(z): (horizontal plane)	$\sigma_{toe.UN1} = 143 \cdot kPa$	$\sigma_{toe.UN1.check} = $ "Okay"
Bearing Pressure at Heel(x)-Toe(z): (horizontal plane)	$\sigma_{heeltoe.UN1} = 52 \cdot kPa$	$\sigma_{heeltoe.UN1.check} = $ "Okay"
Bearing Pressure at Toe(x)-Heel(z): (horizontal plane)	$\sigma_{toeheel.UN1} = 200 \cdot kPa$	$\sigma_{toe.UN1.check} = $ "Okay"

UN2 DESIGN CASE



ACCEPTANCE PARAMETERS

Required Factor of Safety for Sliding:	$FS_{req.UN2.sl} := 1.3$	(Without Cohesion)
Resultant Within Middle Third of Base:	$e \le \frac{L_B}{6} \wedge e \ge \frac{-L_B}{6}$	(Section 8.1, Design Criteria)
Allowable Rock Bearing Pressure:	$\sigma_{allow.UN2} := 1270 \cdot \frac{kN}{m^2}$	(Section 5.2, Design Criteria)
Required Factor of Safety for Flotation:	$FS_{req.UN2.flt} := 1.3$	

INPUT PARAMETERS

Headwater Elevation:	$HW_{UN2} := 1216.10m$	(Section 8.2, Design Criteria)
Tailwater Elevation:	$TW_{UN2} := 1213.00m$	(Section 8.2, Design Criteria)
Bottom of Footing Elevation:	$BOF_{elev} = 1206\,m$	
Approch Slab Top of Concrete Elevation at Upstream Face:	$TOC_{as} = 1210\,m$	
Abutment Footing Top of Concrete Elevation at Stilling Basin:	$TOC_{afe} = 1208\,m$	
Abutment Footing Top of Concrete Elevation at Footing:	$TOC_{afc} = 1209.73\,m$	Gates are open when top of gate elevation is at 1210.00m
Abutment Footing Top of Concrete Elevation at Footing Notch:	$TOC_{afc.n} = 1209.3\,m$	
Top of Guard Gate Elevation:	$TOP_{gg.UN2} := 1215.0m$	Gates are closed/up when top of gate elevation is at 1215.0m
Bottom of Key Elevation:	$BOK_{elev} = 1204\,m$	

UN2 CASE

Water Elevation above Crest of Guard Gate:

$EL_{C.UN2} := 1215.73m$

$$Y_{C.UN2} := \begin{cases} (EL_{C.UN2} - TOC_{afc.n}) & \text{if } TOP_{gg.UN2} \le HW_{UN2} \\ (TW_{UN2} - TOC_{afc.n}) & \text{if } TOP_{gg.UN2} > HW_{UN2} \end{cases} = 6.43 \cdot m$$

Water Elevation above Guard Gate Toe: Submerged by Hydraulic 2D Model

$EL_{TOE.UN2} := 1213.0m$

$$Y_{TOE.UN2} := \begin{cases} (EL_{TOE.UN2} - TOC_{afe}) & \text{if } TOP_{gg.UN2} \le HW_{UN2} \\ (TW_{UN2} - TOC_{afe}) & \text{if } TOP_{gg.UN2} > HW_{UN2} \end{cases} = 5 \cdot m$$

LATERAL WATER LOADS

HEADWATER (DRIVING X-DIRECTION):

Headwater Depth on Abutment: $D_{hwa.UN2} := HW_{UN2} - TOC_{as} = 6.10\text{ m}$

Headwater Load Unit Width Projected Surface Area of Abutment: $W_{hwa.UN2} := 2 \cdot r_{wall} = 12.00\text{ m}$

Total Horizontal Headwater Load on Abutment:

$$H_{hwa.UN2} := \frac{-\left(\gamma_w \cdot D_{hwa.UN2}{}^2\right)}{2} \cdot W_{hwa.UN2} = -2190.2 \cdot kN$$

Apply Total Abutment Headwater Load at:

$$H_{hwa.UN2.loc} := \frac{D_{hwa.UN2}}{3} + (TOC_{as} - BOF_{elev}) = 6.03\text{ m}$$

Apply Total Abutment Headwater Load at (from toe): $H_{hwa.UN2.loc.z} := 4m + r_{wall} = 10.00\text{ m}$ (Gate Footing + Radius of Wall)

Thickness of Approach Slab: $T_{as} = 4\text{ m}$

Headwater Depth at Heel (U/S face): $D_{hwas.UN2} := HW_{UN2} - BOF_{elev} = 10.10\text{ m}$

Headwater Load Unit Width on Projected Approach Slab: $W_{hwas.UN2} := W_B = 16.00\text{ m}$

Headwater Line Load At Top of Approach Slab: $\sigma_{hwas.UN2.1} := -(\gamma_w \cdot D_{hwa.UN2}) = -59.84 \cdot kPa$

Headwater Line Load At Bottom of Approach Slab: $\sigma_{hwas.UN2.2} := -(\gamma_w \cdot D_{hwas.UN2}) = -99.08 \cdot kPa$

Trianglular Distribution Unit Load on Approach Slab:

$$H_{hwas.UN2.2.tri} := \left(\frac{\sigma_{hwas.UN2.2} - \sigma_{hwas.UN2.1}}{2}\right) \cdot (T_{as} \cdot W_{hwas.UN2}) = -1255.68 \cdot kN$$

Rectangular Distribution Unit Load on Approach Slab:

$$H_{hwas.UN2.2.rect} := \sigma_{hwas.UN2.1} \cdot (T_{as} \cdot W_{hwas.UN2}) = -3829.82 \cdot kN$$

Total Horizontal Headwater Load on Approach Slab:

$$H_{hwas.UN2} := H_{hwas.UN2.2.tri} + H_{hwas.UN2.2.rect} = -5085.5 \cdot kN$$

Apply Total Footing Headwater Load at:

$$H_{hwas.UN2.loc} := \frac{\left[H_{hwas.UN2.2.rect} \cdot \frac{(T_{as})}{2} + H_{hwas.UN2.2.tri} \cdot \frac{(T_{as})}{3}\right]}{H_{hwas.UN2.2.tri} + H_{hwas.UN2.2.rect}} = 1.84\text{ m}$$

Apply Total Footing Headwater Load at (from toe):

$$H_{hwas.UN2.loc.z} := \frac{W_B}{2} = 8.00\text{ m}$$

Guard Gate (2A) Operating Condition: Right Crest Gate at EL 1215.0

Guard Gate Down/Open Condition: $A1_{UN2} := TOP_{gg.UN2} \le TOC_{as}$

Guard Crest Gate Up/Closed, with Top of Gate Higher than HW Elevation: $B1_{UN2} := TOP_{gg.UN2} \ge HW_{UN2} \wedge TOP_{gg.UN2} > TOC_{as}$

Guard Crest Gate Up/Closed, with Top of Gate Lower than HW Elevation: $C1_{UN2} := TOP_{gg.UN2} > TOC_{as} \wedge HW_{UN2} > TOP_{gg.UN2}$

Guard Crest Gate Height: $H_{gg.UN2} := TOP_{gg.UN2} - TOC_{as} = 5\ m$

Headwater Depth at Guard Crest Gate: $D_{hwgg.UN2} := HW_{UN2} - TOC_{as} = 6.10\ m$

Guard Crest Gate Width: $W_{hwgg.UN2} := 4.00m$

Lateral Headwater Pressure at Bottom of Guard Crest Gate:

$$\sigma_{hwgg.UN2.1} := \begin{cases} (0.0kPa) & \text{if } A1_{UN2} \\ -(\gamma_w \cdot D_{hwgg.UN2}) & \text{if } B1_{UN2} \\ -(\gamma_w \cdot D_{hwgg.UN2}) & \text{if } C1_{UN2} \end{cases} = -59.8 \cdot kPa$$

Lateral Headwater Pressure at Top of Guard Crest Gate:
(Load at HW Elevation On Guard Crest Gate if HW is below TOG_{rg})

$$\sigma_{hwgg.UN2.2} := \begin{cases} (0.0kPa) & \text{if } A1_{UN2} \\ 0.0kPa & \text{if } B1_{UN2} \\ -\left[\gamma_w \cdot (HW_{UN2} - TOP_{gg.UN2})\right] & \text{if } C1_{UN2} \end{cases} = -10.8 \cdot kPa$$

Average Pressure acting on Guard Crest Gate:

$$\sigma_{hwgg.UN2.avg} := \frac{(\sigma_{hwgg.UN2.1} + \sigma_{hwgg.UN2.2})}{2} = -35.32 \cdot kPa$$

Total Area water acting on Crest Gate:

$$A_{hwgg.UN2} := \begin{cases} D_{hwgg.UN2} \cdot W_{hwgg.UN2} & \text{if } A1_{UN2} \\ D_{hwgg.UN2} \cdot W_{hwgg.UN2} & \text{if } B1_{UN2} \\ H_{gg.UN2} \cdot W_{hwgg.UN2} & \text{if } C1_{UN2} \end{cases} = 20 \cdot m^2$$

Total Horizontal Headwater Load on Guard Crest Gate: $H_{hwgg.UN2} := \sigma_{hwgg.UN2.avg} \cdot A_{hwgg.UN2} = -706.3 \cdot kN$

Apply Total Guard Crest Gate Headwater Load at:

$$H_{hwgg.UN2.loc} := \begin{cases} (TOC_{as} - BOF_{elev}) & \text{if } A1_{UN2} \\ \left[\frac{(HW_{UN2} - TOC_{as})}{3} + (TOC_{as} - BOF_{elev})\right] & \text{if } B1_{UN2} \\ \left[\frac{\sigma_{hwgg.UN2.2} \cdot A_{hwgg.UN2} \cdot \frac{(H_{gg.UN2})}{2} + \frac{(\sigma_{hwgg.UN2.1} - \sigma_{hwgg.UN2.2})}{2} A_{hwgg.UN2} \cdot \frac{(H_{gg.UN2})}{3}}{\sigma_{hwgg.UN2.2} \cdot A_{hwgg.UN2} + \frac{(\sigma_{hwgg.UN2.1} - \sigma_{hwgg.UN2.2})}{2} \cdot A_{hwgg.UN2}} \ldots \\ + (TOC_{as} - BOF_{elev})\right] & \text{if } C1_{UN2} \end{cases} = 5.9 \cdot m$$

Apply Total Guard Crest Gate Headwater Load at (From toe): $H_{hwgg.UN2.loc.z} := \frac{W_{hwgg.UN2}}{2} = 2\ m$

LATERAL TAILWATER (RESISTING) Applied to Downstream Side of Guard Crest Gate: UN2 CASE

Guard Gate Down/Open Condition: $A2_{UN2} := TOP_{gg.UN2} \le TOC_{as}$

Guard Crest Gate Up/Closed, with Top of Gate Higher than TW Elevation: $B2_{UN2} := TOP_{gg.UN2} \ge TW_{UN2} \wedge TOP_{gg.UN2} > TOC_{as}$

Guard Crest Gate Up/Closed, with Top of Gate Lower than TW Elevation: $C2_{UN2} := TOP_{gg.UN2} > TOC_{as} \wedge TW_{UN2} > TOP_{gg.UN2}$

Tailwater Depth at Guard Crest Gate: $D_{twgg.UN2} := TW_{UN2} - TOC_{as} = 3.00\,m$

Guard Crest Gate Height: $H_{gg.UN2} = 5\,m$

Guard Crest Gate Width: $W_{twgg.UN2} := 4.00m$

Lateral Water Load at Bottom of Guard Crest Gate:

$$\sigma_{twgg.UN2.1} := \begin{cases} (0.0kPa) & \text{if } A2_{UN2} \\ (\gamma_w \cdot D_{twgg.UN2}) & \text{if } B2_{UN2} \\ (\gamma_w \cdot D_{twgg.UN2}) & \text{if } C2_{UN2} \end{cases} = 29.4 \cdot kPa$$

Lateral Water Load at Top of Guard Crest Gate:
(Load at TW Elevation On Guard Crest Gate if TW is below TOG_{gg})

$$\sigma_{twgg.UN2.2} := \begin{cases} (0.0kPa) & \text{if } A2_{UN2} \\ 0.0kPa & \text{if } B2_{UN2} \\ \left[\gamma_w \cdot \left(\left(TW_{UN2} - TOP_{gg.UN2}\right)\right)\right] & \text{if } C2_{UN2} \end{cases} = 0.0 \cdot kPa$$

Average Pressure acting on Guard Crest Gate:

$$\sigma_{twgg.UN2.avg} := \frac{\left(\sigma_{twgg.UN2.1} + \sigma_{twgg.UN2.2}\right)}{2} = 14.71 \cdot kPa$$

Total Area water acting on Crest Gate:

$$A_{twgg.UN2} := \begin{cases} D_{twgg.UN2} \cdot W_{twgg.UN2} & \text{if } A2_{UN2} \\ D_{twgg.UN2} \cdot W_{twgg.UN2} & \text{if } B2_{UN2} \\ H_{gg.UN2} \cdot W_{twgg.UN2} & \text{if } C2_{UN2} \end{cases} = 12 \cdot m^2$$

Total Horizontal Headwater Load on Guard Crest Gate: $H_{twgg.UN2} := \sigma_{twgg.UN2.avg} \cdot A_{twgg.UN2} = 176.6 \cdot kN$

Apply Total Horiz. TW Load on Guard Gate at:

$$H_{twgg.UN2.loc} := \begin{cases} \left(TOC_{as} - BOF_{elev}\right) & \text{if } A2_{UN2} \\ \left[\frac{\left(TW_{UN2} - TOC_{as}\right)}{3} + \left(TOC_{as} - BOF_{elev}\right)\right] & \text{if } B2_{UN2} \\ \left[\frac{\sigma_{twgg.UN2.2} \cdot A_{twgg.UN2} \cdot \frac{\left(H_{gg.UN2}\right)}{2} + \frac{\left(\sigma_{twgg.UN2.1} - \sigma_{twgg.UN2.2}\right)}{2} A_{twgg.UN2} \cdot \frac{\left(H_{gg.UN2}\right)}{3}}{\sigma_{twgg.UN2.2} \cdot A_{twgg.UN2} + \frac{\left(\sigma_{twgg.UN2.1} - \sigma_{twgg.UN2.2}\right)}{2} \cdot A_{twgg.UN2}} \ldots \\ + \left(TOC_{as} - BOF_{elev}\right)\right] & \text{if } C2_{UN2} \end{cases} = 5.0 \cdot m$$

Apply Total Guard Crest Gate Headwater Load at (From toe): $H_{twgg.UN2.loc.z} := \frac{W_{twgg.UN2}}{2} = 2\,m$

TAILWATER (RESISTING) Applied to Concrete Strucuture:

Tailwater Depth on Top of Abutment Footing: $D_{twa.UN2} := TW_{UN2} - TOC_{as} = 3.00\ m$

Tailwater Load Unit Width on Abutment: $W_{twa.UN2} := 2 \cdot r_{wall} = 12.00\ m$

Total Horizontal Tailwater Load on Abutment: $H_{twa.UN2} := \frac{\left(\gamma_w \cdot D_{twa.UN2}{}^2\right)}{2} \cdot W_{twa.UN2} = 529.7 \cdot kN$

Apply Total Abutment Tailwater Load at: $H_{twa.UN2.loc} := \frac{D_{twa.UN2}}{3} + \left(TOC_{as} - BOF_{elev}\right) = 5.00\ m$

Apply Total Abutment Tailwater Load at (from Toe Line): $H_{twa.UN2.loc.z} := W_{twgg.UN2} + r_{wall} = 10\ m$

Footing Thickness for horizontal at Toe: $h_{toe} = 4\ m$

Tailwater Depth At top of Gate Base Footing Elevation: $D_{twgf.UN2} := TW_{UN2} - TOC_{as} = 3.00\ m$

Water Depth at bottom of Gate Base Footing (Excluding Key): $D_{twtoe.UN2} := TW_{UN2} - BOF_{elev} = 7.00\ m$

Water Depth at bottom of Gate Base Footing (Including Key): $D_{twkey.UN2} := HW_{UN2} - BOK_{elev} = 12.10\ m$

Unit Width of D/S face of crest for applicaiton of Tailwater Load: $W_{tw.UN2} := W_B = 16.00\ m$

(Conservatively taken resisting water in front of 1.5m RCC Auxiliary Spillway as Tailwater elevation)

Tailwater Pressure At Top of Gate Footing: $\sigma_{twgf.UN2} := \left(\gamma_w \cdot D_{twgf.UN2}\right) = 29.43 \cdot kPa$

Tailwater Line Load At Bottom of Gate Footing (Excluding Key): $\sigma_{twtoe.UN2} := \left(\gamma_w \cdot D_{twtoe.UN2}\right) = 68.67 \cdot kPa$

Trianglular Distribution Unit Load on Gate Footing Base: $H_{twgf.UN2.tri} := \left(\frac{\sigma_{twtoe.UN2} - \sigma_{twgf.UN2}}{2}\right) \cdot \left[\left(T_{as} - d_{key}\right) \cdot W_{tw.UN2}\right] = 627.84 \cdot kN$

Rectangular Distribution Unit Load on Gate Footing Base: $H_{twgf.UN2.rect} := \sigma_{twgf.UN2} \cdot \left[\left(T_{as} - d_{key}\right) \cdot W_{tw.UN2}\right] = 941.76 \cdot kN$

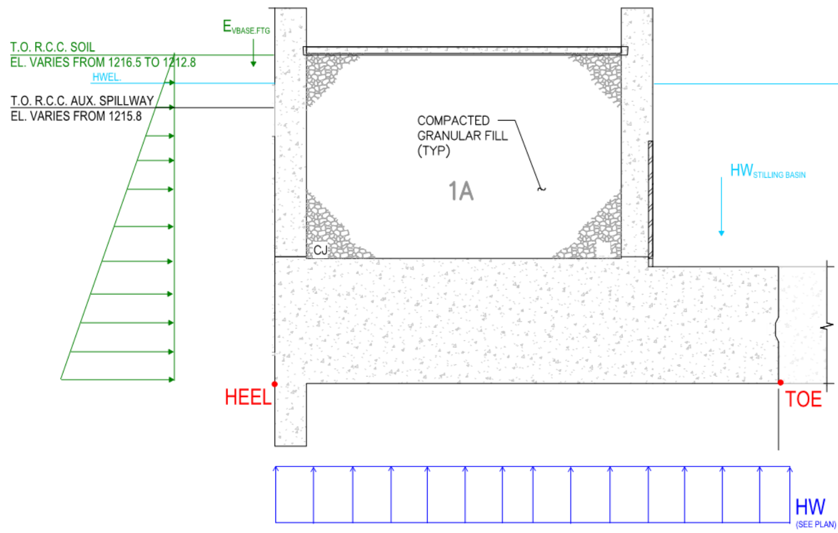
Total Horizontal Tailwater Headwater Load on Gate Footing: $H_{twgf.UN2} := H_{twgf.UN2.tri} + H_{twgf.UN2.rect} = 1569.6 \cdot kN$

Apply Total Gate Footing Tailwater Load at:

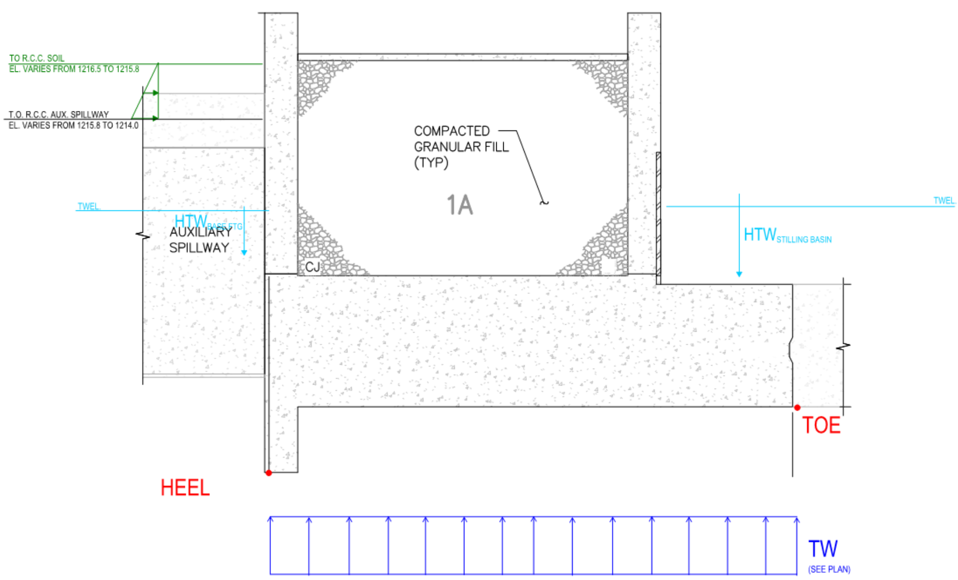
$$H_{twgf.UN2.loc} := \frac{\left[H_{twgf.UN2.rect} \cdot \frac{\left(T_{as}\right)}{2} + H_{twgf.UN2.tri} \cdot \frac{\left(T_{as}\right)}{3}\right]}{H_{twgf.UN2.tri} + H_{twgf.UN2.rect}} = 1.73\ m$$

Apply Total Gate Footing Tailwater Load at (From Toe Line): $H_{twgf.UN2.loc.z} := \frac{W_B}{2} = 8.00\ m$

SUMMATION OF LATERAL WATER LOADS:



SECTION 1A BEFORE GATES & AUX. SPILLWAY RCC

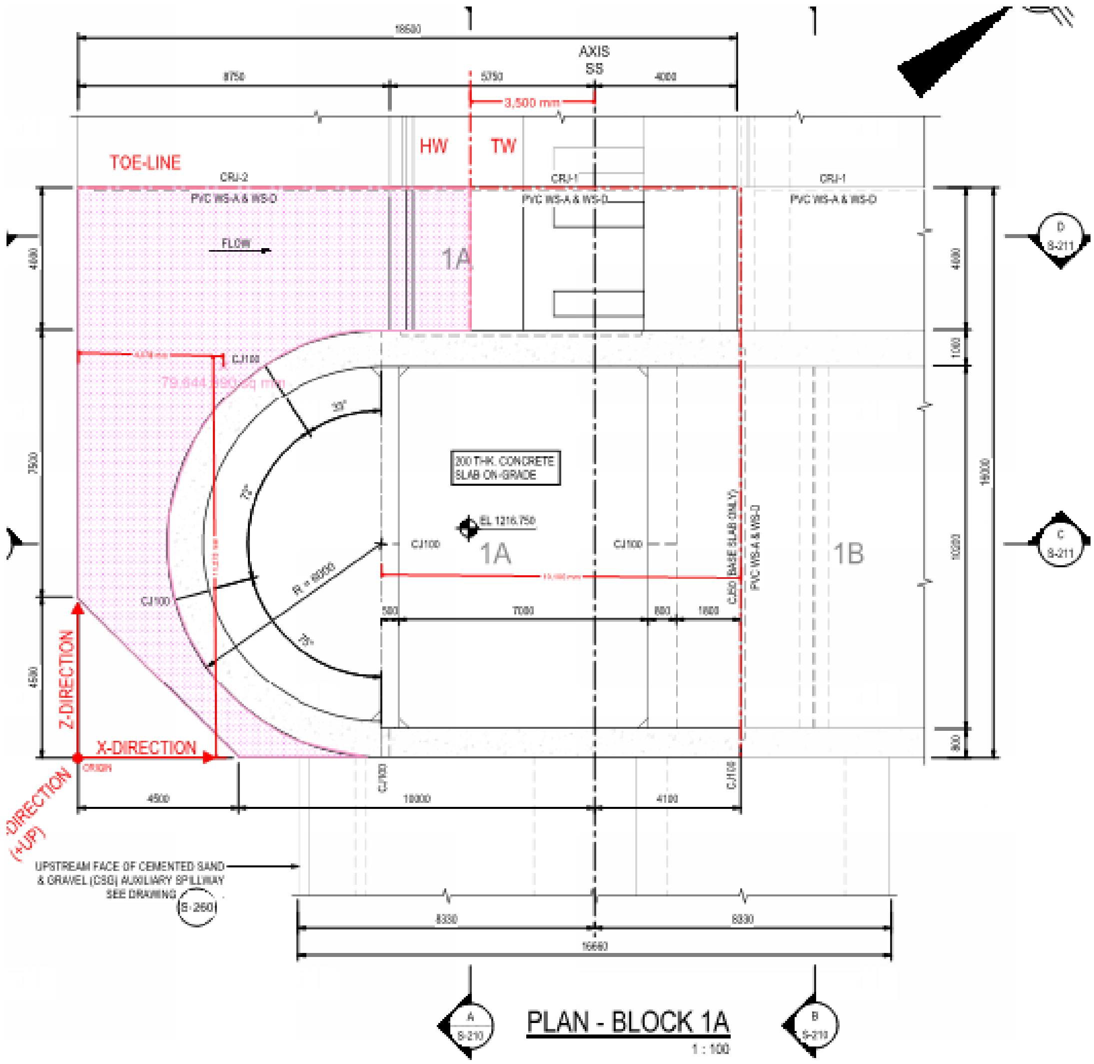


SECTION 1A AFTER GATES & AUX. SPILLWAY RCC

$$\Sigma H_{Water.UN2.x} := H_{hwa.UN2} + H_{hwas.UN2} + H_{hwgg.UN2} + H_{twa.UN2} + H_{twgf.UN2} + H_{twgg.UN2} = -5706.08 \cdot kN$$

$$\Sigma M_{HWater.UN2.x} := H_{hwa.UN2} \cdot H_{hwa.UN2.loc} + H_{hwas.UN2} \cdot H_{hwas.UN2.loc} + H_{hwgg.UN2} \cdot H_{hwgg.UN2.loc} \dots + H_{twa.UN2} \cdot H_{twa.UN2.loc} + H_{twgf.UN2} \cdot H_{twgf.UN2.loc} + H_{twgg.UN2} \cdot H_{twgg.UN2.loc} = -20478.07 \cdot kN \cdot m$$

$\Sigma H_{Water.UN2.z} := 0kN$ $\Sigma M_{HWater.UN2.z} := 0 \cdot kN \cdot m$



HEADWATER:

Water Depth on top of Approach Slab: $d_{hw.UN2} := HW_{UN2} - TOC_{as} = 6.10\ m$

Water Area on top of Approach Slab: $A_{as} = 79.64\ m^2$ (From Geom. Scaled on REVU)

Vertical Water Weight (H1) on Approach Slab: $H_{1.UN2} := \left(A_{as} \cdot d_{hw.UN2}\right) \cdot \gamma_w = 4766.0 \cdot kN$

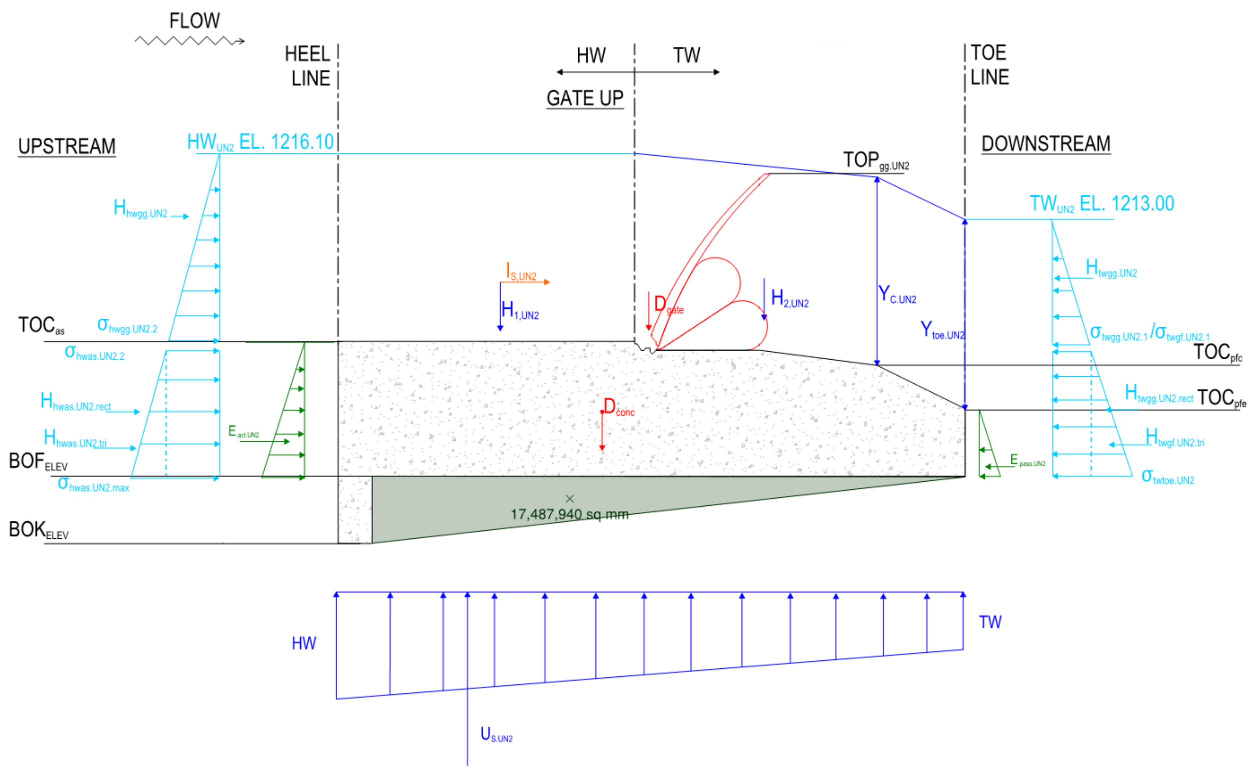
Moment Arm for Applicaiton of Water Weight (H1) from toe (X-Direction): $H_{1.UN2.loc.x} := L_B - 4.078m = 14.42\ m$ (From Geom. Scaled on REVU)

Moment Arm for Applicaiton of Water Weight (H1) from toe (Z-Direction): $H_{1.UN2.loc.z} := W_B - 11.273m = 4.73\ m$ (From Geom. Scaled on REVU)

VERTICAL WATER LOADS

UN2 CASE

TAILWATER:



Approach Slab Length: $L_{as} = 8.75\ m$

Gate Footing Length: $L_{gf} = 9.75\ m$

Gate Footing Crest Length: $L_{gfc} = 2.25\ m$

TAILWATER:

Trapezoid Volume Above Gate Footing from Approach Slab to Crest:

$$V_{asc.UN2} := \left(L_{gf} - L_{gfc}\right) W_{twgg.UN2} \frac{d_{hw.UN2} + Y_{C.UN2}}{2} = 187.95 \cdot m^3$$

Trapezoid Volume Above Gate Footing Crest to End of Gate Footing:

$$V_{gfc.UN2} := \left(L_{gfc} \cdot W_{twgg.UN2}\right) \frac{Y_{C.UN2} + Y_{TOE.UN2}}{2} = 51.44 \cdot m^3$$

Load Above Gate Footing from Approach Slab to Crest:

$$H_{2.UN2.asc} := V_{asc.UN2} \cdot \gamma_w = 1843.79 \cdot kN$$

Load Acting Above Footing Crest from Toe:

$$H_{2.UN2.asc.loc.x} := \frac{\left(L_{gf} - L_{gfc}\right) \cdot \left(2 \cdot d_{hw.UN2} + Y_{C.UN2}\right)}{3 \cdot \left(d_{hw.UN2} + Y_{C.UN2}\right)} + L_{gfc} = 5.97\ m$$

Load Above Gate Footing from Crest to End:

$$H_{2.UN2.gfc} := V_{gfc.UN2} \cdot \gamma_w = 504.58 \cdot kN$$

Load Acting Above Gate Footing from Crest to End:

$$H_{2.UN2.gfc.loc.x} := \frac{\left(L_{gfc}\right) \cdot \left(2 \cdot Y_{C.UN2} + Y_{TOE.UN2}\right)}{3 \cdot \left(Y_{C.UN2} + Y_{TOE.UN2}\right)}$$

Vertical Water Weight (H2) on Gate Footing:

$$H_{2.UN2} := H_{2.UN2.asc} + H_{2.UN2.gfc} = 2348.37 \cdot kN$$

Moment Arm for Application of Water Weight (H2) from toe:

$$H_{2.UN2.loc.x} := \frac{H_{2.UN2.asc} \cdot H_{2.UN2.asc.loc.x} + H_{2.UN2.gfc} \cdot H_{2.UN2.gfc.loc.x}}{H_{2.UN2}} = 4.94\ m$$

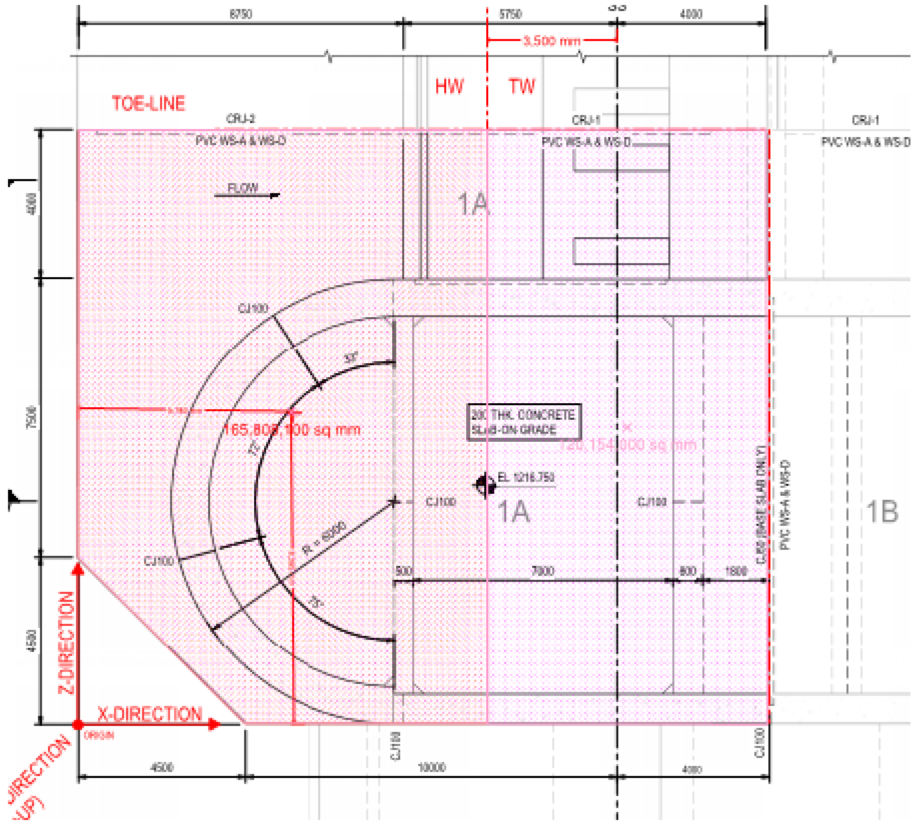
Moment Arm for Applicaiton of Water Weight (H2) from toe (Z-Direction):

$$H_{2.UN2.loc.z} := 2.0m$$

UPLIFT

UN2 CASE

(Assuming constant Headwater Uplift at front and constant Tailwater Uplift at back of footing base)



Uplift pressure at U/S Face (heel): $U_{HW.UN2} := D_{hwas.UN2} \cdot \gamma_w = 99.1 \cdot \frac{kN}{m^2}$

Uplift pressure at D/S Face Stilling Basin: $U_{TW.UN2} := D_{twtoe.UN2} \cdot \gamma_w = 68.67 \cdot \frac{kN}{m^2}$

Area of Uplift Force From Headwater Side: $A_{HWU.UN2} := 130.602 m^2$ (From Bluebeam REVU)

Area of Uplift Force From Tailwater Side: $A_{TWU.UN2} := 161.247 m^2$ (From Bluebeam REVU)

Uplift Force From Headwater Side: $U_{A.UN2} := -U_{HW.UN2} \cdot A_{HWU.UN2} = -12940.18 \cdot kN$

Uplift Force From Headwater Side: $U_{B.UN2} := -U_{TW.UN2} \cdot A_{TWU.UN2} = -11072.83 \cdot kN$

Uplift Centroid of Area From Headwater Side to Toe: $X_{U.A} = 13.22 \, m$ $Z_{U.A} = 7.63 \, m$ (From Bluebeam REVU)

Uplift Centroid of Area From Tailwater Side to Toe: $X_{U.B} = 3.75 \, m$ $Z_{U.B} = 8 \, m$ (From Bluebeam REVU)

Total Resultant Uplift force: $U_{UN2} := U_{A.UN2} + U_{B.UN2} = -24013.01 \cdot kN$

Resultant Location from Toe Rect. Load (X-Direction): $U_{UN2.loc.x} := \frac{\left(U_{A.UN2} \cdot X_{U.A} + U_{B.UN2} \cdot X_{U.B}\right)}{\left(U_{A.UN2} + U_{B.UN2}\right)} = 8.85 \, m$

Resultant Location from Toe Rect. Load (Z-Direction): $U_{UN2.loc.z} := \frac{\left[U_{A.UN2} \cdot \left(W_B - Z_{U.A}\right) + U_{B.UN2} \cdot \left(W_B - Z_{U.B}\right)\right]}{\left(U_{A.UN2} + U_{B.UN2}\right)} = 8.20 \, m$

$\Sigma V_{water.UN2} := H_{1.UN2} + H_{2.UN2} + U_{UN2} = -16898.6 \cdot kN$

$\Sigma M_{Vwater.UN2.x} := H_{1.UN2} \cdot H_{1.UN2.loc.x} + H_{2.UN2} \cdot H_{2.UN2.loc.x} + U_{UN2} \cdot U_{UN2.loc.x} = -132263.12 \cdot kN \cdot m$

$\Sigma M_{Vwater.UN2.z} := H_{1.UN2} \cdot H_{1.UN2.loc.z} + H_{2.UN2} \cdot H_{2.UN2.loc.z} + U_{UN2} \cdot U_{UN2.loc.z} = -169601.44 \cdot kN \cdot m$

Equivalent Fluid Pressure (EFP):

At rest lateral pressure coefficient: $K_{o.UN2} := 1 - \sin(\phi_{backfill}) = 0.658$ (Section 5.3, Design Criteria)

Headwater Top of Soil Elevation: $TOS_{HW} = 1210\,m$

Top of Backfill Soil Elevation: $TOS_{BF} = 1216.5\,m$

Driving Soil Load Unit Width Projected Surface Area of Abutment: $W_{ds.hwa.UN2} := 6.0m$

Driving Soil Load Unit Width on Projected Approach Slab + Key: $W_{hwas.UN2} = 16.00\,m$

Resisting Soil Load Unit Width Projected Surface Area of Abutment: $W_{rsa.UN2} := \frac{10.5m + 9.381m}{2} = 9.94\,m$ (From Section Cut)

Driving Soil Load Depth on Abutment: $d_{DS.a} = 0\,m$

Driving Soil Load Depth on Footing: $d_{DS.as} = 4\,m$

Resisting Soil Load Depth on Abutment: $d_{RS.a} = 8.5\,m$

Thickness of Stilling Basin: $T_{sb} = 2\,m$

Lateral X-Direction Driving Force (Headwater Side - at rest condition)

At-Rest Soil Load on Half of Abutment: $E_{act.a.UN2.x} := \frac{\left(K_{o.UN2} \cdot d_{DS.a}{}^{2}\right)}{2} \cdot (\gamma_r - \gamma_w) \cdot W_{ds.hwa.UN2} \cdot -1 = 0 \cdot kN$

Acting at: $E_{act.a.UN2.x.loc.y} := \frac{d_{DS.a}}{3} + T_{as} - d_{key} = 2.00\,m$

Acting at (from Toe Line): $E_{act.a.UN2.x.loc.z} := W_{hwgg.UN2} + r_{wall} = 10.00\,m$

At-Rest Soil Load on Top of Approach Slab: $\sigma_{DS.as.UN2} := \left(K_{o.UN2} \cdot d_{DS.a}\right) \cdot (\gamma_r - \gamma_w) = 0 \cdot kPa$

At-Rest Soil Load on Bottom of Approach Slab: $\sigma_{DS.key.UN2} := \left(K_{o.UN2} \cdot d_{DS.as}\right) \cdot (\gamma_r - \gamma_w) = 32.08 \cdot kPa$

At-Rest Soil Load on Approach Slab: $E_{act.as.rect.UN2.x} := \sigma_{DS.as.UN2} \cdot (T_{as}) \cdot W_{hwas.UN2} \cdot -1 = 0 \cdot kN$

At-Rest Soil Load on Approach Slab: $E_{act.as.tri.UN2.x} := \frac{(\sigma_{DS.key.UN2} - \sigma_{DS.as.UN2}) \cdot (T_{as})}{2} \cdot W_{hwas.UN2} \cdot -1 = -1026.66 \cdot kN$

At-Rest Soil Load on Approach Slab: $E_{act.as.UN2.x} := E_{act.as.rect.UN2.x} + E_{act.as.tri.UN2.x} = -1026.66 \cdot kN$

Acting at:

$$E_{act.as.UN2.x.loc.y} := \frac{\left(E_{act.as.rect.UN2.x} \cdot \frac{T_{as}}{2} \cdots + E_{act.as.tri.UN2.x} \cdot \frac{T_{as}}{3}\right)}{E_{act.as.UN2.x}} = 1.33\,m$$

Acting at (from Toe Line): $E_{act.as.UN2.x.loc.z} := \frac{W_B}{2} = 8.00\,m$

Lateral X-Direction Resisting Force (Tailwater Side - at rest condition)

UN2 CASE

At-rest Soil Load: $E_{pass.UN2.x} := \frac{\left(K_{o.UN2} \cdot d_{RS.a}^{\ 2}\right)}{2} \cdot \left(\gamma_r - \gamma_w\right) \cdot W_{rsa.UN2} = 2880.26 \cdot kN$

Acting at: $E_{pass.UN2.x.loc.y} := \frac{d_{RS.a}}{3} + T_{sb} - d_{key} = 2.83\,m$

$W_{rsa.UN2} = 9.94\,m$

Acting at (from Toe Line): $E_{pass.UN2.x.loc.z} := W_{hwgg.UN2} + r_{wall} = 10\,m$

$\Sigma H_{soil.UN2.x} := \left(E_{act.a.UN2.x} + E_{act.as.UN2.x} + E_{pass.UN2.x}\right) = 1853.61 \cdot kN$

$\Sigma M_{soil.UN2.x} := E_{act.a.UN2.x} \cdot E_{act.a.UN2.x.loc.y} + E_{act.as.UN2.x} \cdot E_{act.as.UN2.x.loc.y} + E_{pass.UN2.x} \cdot E_{pass.UN2.x.loc.y} = 6791.87 \cdot kN \cdot m$

Lateral Z-Direction Driving Force (Headwater Side - Before Gates & Aux. Spillway RCC - at rest condition)

Max./Min. Top of R.C.C. Soil Elevation: $TOS_{RCC.max} = 1216.5\,m$ $TOS_{RCC.min} = 1212.8\,m$

Average Top of R.C.C. Soil Elevation: $TOS_{RCC} = 1214.65\,m$

Depth of R.C.C. Soil Acting on Abutment Walls: $d_{act.RCC.w} = 4.65\,m$

Depth of R.C.C. Soil Acting on Abutment Footings: $d_{act.RCC.f} = 8.65\,m$

Projected Width of soil acting on Abutment Walls: $w_{abut.RCC} = 9.45\,m$

Projected Width of soil acting on Abutment Footing: $w_{FTG.RCC} = 12.2\,m$

At-Rest Soil Load on Top of Footing Slab: $\sigma_{act.RCC.w.UN2} := \left(K_{o.UN2} \cdot d_{act.RCC.w}\right) \cdot \left(\gamma_r - \gamma_w\right) = 37.3 \cdot kPa$

At-Rest Soil Load on Bottom of Approach Slab: $\sigma_{act.RCC.f.UN2} := \left(K_{o.UN2} \cdot d_{act.RCC.f}\right) \cdot \left(\gamma_r - \gamma_w\right) = 69.38 \cdot kPa$

At-Rest Soil Load on Abutment Walls: $E_{act.a.UN2.z} := \frac{\left(K_{o.UN2} \cdot d_{act.RCC.w}^{\ 2}\right)}{2} \cdot \left(\gamma_r - \gamma_w\right) \cdot w_{abut.RCC} \cdot -1 = -819.45 \cdot kN$

Acting at: $E_{act.a.UN2.z.loc.y} := \frac{d_{DS.a}}{3} + T_{as} = 4.00\,m$

Acting at (from Toe Line): $E_{act.a.UN2.z.loc.x} := \frac{\left(L_{wall} + r_{wall} - 6.35m\right)}{2} + 6.35m = 11.18\,m$

At-Rest Soil Load on Abutment Footing (Rect): $E_{act.as.rect.UN2.z} := \sigma_{act.RCC.w.UN2} \cdot \left(T_{as}\right) \cdot w_{abut.RCC} \cdot -1 = -1409.81 \cdot kN$

At-Rest Soil Load on Abutment Footing (Tri): $E_{act.as.tri.UN2.z} := \frac{-\left(\sigma_{act.RCC.f.UN2} - \sigma_{act.RCC.w.UN2}\right) \cdot \left(T_{as}\right)}{2} \cdot w_{FTG.RCC} = -782.83 \cdot kN$

At-Rest Soil Load on Approach Slab: $E_{act.as.UN2.z} := E_{act.as.rect.UN2.z} + E_{act.as.tri.UN2.z} = -2192.64 \cdot kN$

Acting at: $E_{act.as.UN2.z.loc.y} := \frac{\left(E_{act.as.rect.UN2.z} \cdot \frac{T_{as}}{2} + E_{act.as.tri.UN2.z} \cdot \frac{T_{as}}{3}\right)}{E_{act.as.UN2.z}} = 1.76\,m$

Acting at (from toe line): $E_{act.as.UN2.z.loc.x} := \frac{\left(L_{wall} + r_{wall} - 6.35m\right)}{2} + 6.35m = 11.18\,m$

Lateral Z-Direction Driving Force (Headwater Side - After Gates & Aux. Spillway RCC - at rest condition) **UN2 CASE**

Max. Top of R.C.C. Wall: $TORCC_{max} = 1215.8\ m$

Min. Top of R.C.C. Wall: $TORCC_{min} = 1214\ m$

Average Top of R.C.C. Wall Elevation: $TORCC = 1214.9\ m$

Width of Soil acting at Max. top of RCC: $w_{RCC.max} = 4.7\ m$

Width of Soil acting with average Top of RCC (Steps): $w_{RCC.avg} = 1.65\ m$

Depth of Top of Soil to Top of R.C.C. Wall: $d_{act.RCC} = 0.7\ m$

Depth of Top of Soil to Average Top of R.C.C. Wall (Steps): $d_{act.RCC.avg} = 1.6\ m$

At-Rest Soil Load on Abutment Walls after RCC:

$$E_{act.RCC.UN2.z} := \frac{\left(K_{o.UN2} \cdot d_{act.RCC}^{\ 2}\right)}{2} \cdot \left(\gamma_r - \gamma_w\right) \cdot w_{RCC.max} \cdot -1 = -9.24 \cdot kN$$

Acting at:

$$E_{act.RCC.UN2.z.loc.y} := \frac{d_{act.RCC}}{3} + \left(TORCC_{max} - BOF_{elev}\right) = 10.03\ m$$

Acting at (from Toe Line): $E_{act.RCC.UN2.z.loc.x} := 4m$ (at SS-Axis Center Line)

At-Rest Soil Load on Abutment Walls at RCC Steps:

$$E_{act.RCC.s.UN2.z} := \frac{\left(K_{o.UN2} \cdot d_{act.RCC.avg}^{\ 2}\right)}{2} \cdot \left(\gamma_r - \gamma_w\right) \cdot w_{RCC.avg} \cdot -1 = -16.94 \cdot kN$$

Acting at:

$$E_{act.RCC.s.UN2.z.loc.y} := \frac{d_{act.RCC.avg}}{3} + \left(TORCC - BOF_{elev}\right) = 9.43\ m$$

Acting at (from Toe Line):

$$E_{act.RCC.s.UN2.z.loc.x} := \frac{4m - 2.35m}{2} = 0.83\ m$$

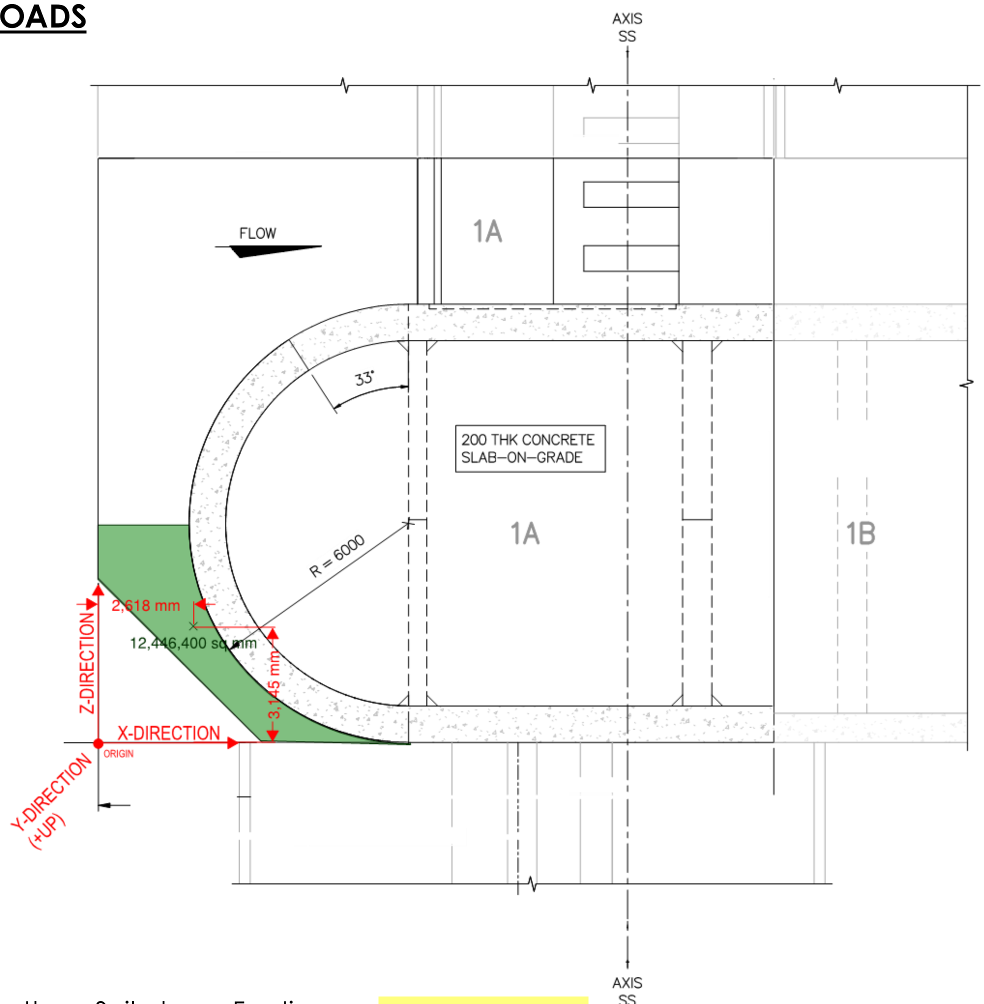
(at Halfway point of RCC Steps)

$$\Sigma H_{soil.UN2.z} := \left(E_{act.a.UN2.z} + E_{act.as.UN2.z} + E_{act.RCC.UN2.z} + E_{act.RCC.s.UN2.z}\right) = -3038.27 \cdot kN$$

$$\Sigma M_{soil.UN2.z} := E_{act.a.UN2.z} \cdot E_{act.a.UN2.z.loc.y} + E_{act.as.UN2.z} \cdot E_{act.as.UN2.z.loc.y} \cdots + E_{act.RCC.UN2.z} \cdot E_{act.RCC.UN2.z.loc.y} + E_{act.RCC.s.UN2.z} \cdot E_{act.RCC.s.UN2.z.loc.y} = -7393.67 \cdot kN \cdot m$$

VERTICAL SOIL LOADS

UN2 CASE



Average Depth on Soil above Footing: $d_{RCC.FTG} = 4.65\ m$

Area of Footing with Soil above: $A_{ftg.soil} = 0$ (From Bluebeam REVU)

Vertical Water Weight (H1) on Approach Slab: $E_{1.UN2} := (A_{ftg.soil} \cdot d_{RCC.FTG}) \cdot (\gamma_r - \gamma_w) = 0.0 \cdot kN$

Moment Arm for Applicaiton of Water Weight (H1) from toe (X-Direction): $E_{1.UN2.loc.x} := L_B - 5.607m = 12.89\ m$ (From Geom. Scaled on REVU)

Moment Arm for Applicaiton of Water Weight (H1) from toe (Z-Direction): $E_{1.UN2.loc.z} := W_B - 3.145m = 12.86\ m$ (From Geom. Scaled on REVU)

$\Sigma E_{UN2} := E_{1.UN2} = 0 \cdot kN$

$\Sigma M_{E.UN2.x} := E_{1.UN2} \cdot E_{1.UN2.loc.x} = 0 \cdot kN \cdot m$

$\Sigma M_{E.UN2.z} := E_{1.UN2} \cdot E_{1.UN2.loc.z} = 0 \cdot kN \cdot m$

IMPACT LOADS (DEBRIS LOADING FROM MEMO)

Total Impact Load on Structure: $I_{UN2} := 1502kN$ (SS Abutment) - 2013 Design Flood

Apply Ice load at: $I_{UN2.loc.y} := (HW_{UN2} - BOF_{elev} - 0.30m) = 9.80\ m$

$\Sigma H_{I.UN2} := I_{UN2} = 1502 \cdot kN$

$\Sigma M_{I.UN2} := I_{UN2} \cdot I_{UN2.loc.y} = 14719.6 \cdot kN \cdot m$

SEISMIC LOAD (NOT APPLICABLE FOR THIS LOAD CASE)

UN2 CASE

SUMMARY OF LOADS

	Loads	Moment Arm	
Dead load of Concrete Structure:	$D_{conc} = 35947.6 \cdot kN$	$X_{conc.loc} = 8.81\ m$	$Z_{conc.loc} = 8.46\ m$
Obermyer Gate Weight:	$D_{Gate} = 56.0 \cdot kN$	$X_{gate} = 9.50\ m$	$Z_{gate} = 2.00\ m$
Dead load of Fill:	$D_{fill} = 18056.6 \cdot kN$	$X_{fill.loc} = 7.31\ m$	$Z_{fill.loc} = 10.00\ m$
HW Lateral Load on Abutment:	$H_{hwa.UN2} = -2190.2 \cdot kN$	$H_{hwa.UN2.loc} = 6.03\ m$	
HW Lateral Load on Approach Slab:	$H_{hwas.UN2} = -5085.5 \cdot kN$	$H_{hwas.UN2.loc} = 1.84\ m$	
HW Lateral Load on Guard Gate:	$H_{hwgg.UN2} = -706.3 \cdot kN$	$H_{hwgg.UN2.loc} = 5.92\ m$	
TW Lateral Load on Abutment:	$H_{twa.UN2} = 529.7 \cdot kN$	$H_{twa.UN2.loc} = 5.00\ m$	
TW Lateral Load on Pier Footing:	$H_{twgf.UN2} = 1569.6 \cdot kN$	$H_{twgf.UN2.loc} = 1.73\ m$	
TW Lateral Load on Guard Gate:	$H_{twgg.UN2} = 176.6 \cdot kN$	$H_{twgg.UN2.loc} = 5.00\ m$	
Vertical HW Load on Approach Slab:	$H_{1.UN2} = 4766.0 \cdot kN$	$H_{1.UN2.loc.x} = 14.42\ m$	$H_{1.UN2.loc.z} = 4.73\ m$
Vertical TW Load on Pier Footing (crest):	$H_{2.UN2} = 2348.4 \cdot kN$	$H_{2.UN2.loc.x} = 4.94\ m$	$H_{2.UN2.loc.z} = 2.00\ m$
Uplift:	$U_{UN2} = -24013.0 \cdot kN$	$U_{UN2.loc.x} = 8.85\ m$	$U_{UN2.loc.z} = 8.20\ m$
X-Direction Lateral Soil Load on Abutment (driving):	$E_{act.a.UN2.x} = 0.0 \cdot kN$	$E_{act.a.UN2.x.loc.y} = 2.00\ m$	
X-Direction Lateral Lateral Soil Load on Approach Slab (driving):	$E_{act.as.UN2.x} = -1026.7 \cdot kN$	$E_{act.as.UN2.x.loc.y} = 1.33\ m$	
Lateral Soil Load (resisting):	$E_{pass.UN2.x} = 2880.26 \cdot kN$	$E_{pass.UN2.x.loc.y} = 2.83\ m$	
Z-Direction Lateral Soil Load on Abutment Before RCC (driving):	$E_{act.a.UN2.z} = -819.5 \cdot kN$	$E_{act.a.UN2.z.loc.y} = 4.00\ m$	
Z-Direction Lateral Lateral Soil Load on Approach Slab Before RCC (driving):	$E_{act.as.UN2.z} = -2192.6 \cdot kN$	$E_{act.as.UN2.z.loc.y} = 1.76\ m$	
Z-Direction Lateral Soil Load on Abutment After RCC (driving):	$E_{act.RCC.UN2.z} = -9.24 \cdot kN$	$E_{act.RCC.UN2.z.loc.y} = 10.03\ m$	
Z-Direction Lateral Soil Load on Abutment at RCC Steps (driving):	$E_{act.RCC.s.UN2.z} = -16.94 \cdot kN$	$E_{act.RCC.s.UN2.z.loc.y} = 9.43 \cdot m$	
Vertical Soil Load on Footing:	$E_{1.UN2} = 0 \cdot kN$	$E_{1.UN2.loc.x} = 12.89\ m$	$E_{1.UN2.loc.z} = 12.86\ m$
Ice / Impact Load:	$I_{UN2} = 1502.0 \cdot kN$	$I_{UN2.loc.y} = 9.80\ m$	

STABILITY ASSESSMENT (SLIDNG, BEARING, FLOTATION AND OVERTURNING): UN2 CASE

CHECK SLIDING (X-Direction & Z-Direction) ALONG HORIZONTAL PLANE THRU TOE, IGNORING BEDROCK MOBILIZED BY STRUCTURAL HEEL KEY, OR VOID BEHIND KEY

Sum of Vertical Forces:

$$\Sigma V_{UN2} := \Sigma V_{DL} + \Sigma V_{water.UN2} + \Sigma E_{UN2} = 37161.6 \cdot kN$$

Sum of Horizontal Forces (X-Direction):

$$\Sigma H_{UN2.x} := \Sigma H_{Water.UN2.x} + \Sigma H_{soil.UN2.x} + \Sigma H_{I.UN2} = -2350.48 \cdot kN$$

Sum of Horizontal Forces (Z-Direction):

$$\Sigma H_{UN2.z} := \Sigma H_{Water.UN2.z} + \Sigma H_{soil.UN2.z} = -3038.27 \cdot kN$$

Sum of Horizontal Forces (resultant):

$$\Sigma H_{UN2} := \sqrt{\Sigma H_{UN2.x}{}^2 + \Sigma H_{UN2.z}{}^2} = 3841.33 \cdot kN$$

Sliding Factor of Safety:

$$FS_{HorizSliding.UN2.x} := \frac{tan_{\phi} \cdot \Sigma V_{UN2}}{\left|\Sigma H_{UN2.x}\right|} = 7.71 \qquad FS_{HorizSliding.UN2.z} := \frac{tan_{\phi} \cdot \Sigma V_{UN2}}{\left|\Sigma H_{UN2.z}\right|} = 5.97$$

Sliding Factor of Safety:

$$FS_{HorizSliding.UN2} := \frac{tan_{\phi} \cdot \Sigma V_{UN2}}{\sqrt{\Sigma H_{UN2.x}{}^2 + \Sigma H_{UN2.z}{}^2}} = 4.72$$

$FS_{HorizSliding.UN2.Check.x} :=$ | "OKAY" if $FS_{HorizSliding.UN2.x} \geq FS_{req.UN2.sl}$ = "OKAY"
"Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !" otherwise

$FS_{HorizSliding.UN2.Check.z} :=$ | "OKAY" if $FS_{HorizSliding.UN2.z} \geq FS_{req.UN2.sl}$ = "OKAY"
"Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !" otherwise

$FS_{HorizSliding.UN2.Check} :=$ | "OKAY" if $FS_{HorizSliding.UN2} \geq FS_{req.UN2.sl}$ = "OKAY"
"Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !" otherwise

CHECK FOUNDATION BEARING CAPACITY

Sum of the Moments (X-Direction):

$$\Sigma M_{UN2.x} := \Sigma M_{DL.x} + \Sigma M_{HWater.UN2.x} + \Sigma M_{Vwater.UN2.x} + \Sigma M_{I.UN2} + \Sigma M_{soil.UN2.x} = 318102 \cdot kN \cdot m$$

Eccentricity:

$$e_{UN2.x} := X_{BCG} - \frac{\Sigma M_{UN2.x}}{\Sigma V_{UN2}} = 0.42\ m$$

Eccentricity Check:

$e_{check.UN2.x} :=$ | "Okay" if $e_{UN2.x} \leq Kern_x$
"Revise Structure" otherwise

$e_{check.UN2.x}$ = "Okay"

Foundation Bearing Pressures (X-Direction):

UN2 CASE

Bearing Pressure at Heel:

$$\sigma_{heel.UN2.x} := \frac{\Sigma V_{UN2}}{A_b} - \frac{\Sigma V_{UN2} \cdot e_{UN2.x}}{S_{bx.L}} = 111.14 \cdot \frac{kN}{m^2}$$

$$\sigma_{heel.UN2.check.x} := \left(\begin{array}{ll} \text{"Okay"} & \text{if } 0 \le \sigma_{heel.UN2.x} \le \sigma_{allow.UN2} \\ \text{"Revise Structure"} & \text{otherwise} \end{array} \right) \qquad \sigma_{heel.UN2.check.x} = \text{"Okay"}$$

Bearing Pressure at Toe:

$$\sigma_{toe.UN2.x} := \frac{\Sigma V_{UN2}}{A_b} + \frac{\Sigma V_{UN2} \cdot e_{UN2.x}}{S_{bx.R}} = 147.76 \cdot \frac{kN}{m^2}$$

$$\sigma_{toe.UN2.check.x} := \left| \begin{array}{ll} \text{"Okay"} & \text{if } 0 \le \sigma_{toe.UN2.x} \le \sigma_{allow.UN2} \\ \text{"Revise Structure"} & \text{otherwise} \end{array} \right. \qquad \sigma_{toe.UN2.check.x} = \text{"Okay"}$$

Sum of the Moments (Z-Direction):

$$\Sigma M_{UN2.z} := \Sigma M_{DL.z} + \Sigma M_{HWater.UN2.z} + \Sigma M_{Vwater.UN2.z} + \Sigma M_{soil.UN2.z} = 307821 \cdot kN \cdot m$$

Eccentricity:

$$e_{UN2.z} := Z_{BCG} - \frac{\Sigma M_{UN2.z}}{\Sigma V_{UN2}} = -0.51\ m$$

Eccentricity Check:

$$e_{check.UN2.z} := \left| \begin{array}{ll} \text{"Okay"} & \text{if } e_{UN2.z} \le Kern_z \\ \text{"Revise Structure"} & \text{otherwise} \end{array} \right. \qquad e_{check.UN2.z} = \text{"Okay"}$$

Foundation Bearing Pressures (Z-Direction):

Bearing Pressure at Heel:

$$\sigma_{heel.UN2.z} := \frac{\Sigma V_{UN2}}{A_b} - \frac{\Sigma V_{UN2} \cdot e_{UN2.z}}{S_{bz.b}} = 156.78 \cdot \frac{kN}{m^2}$$

$$\sigma_{heel.UN2.check.z} := \left(\begin{array}{ll} \text{"Okay"} & \text{if } 0 \le \sigma_{heel.UN2.z} \le \sigma_{allow.UN2} \\ \text{"Revise Structure"} & \text{otherwise} \end{array} \right) \qquad \sigma_{heel.UN2.check.z} = \text{"Okay"}$$

Bearing Pressure at Toe:

$$\sigma_{toe.UN2.z} := \frac{\Sigma V_{UN2}}{A_b} + \frac{\Sigma V_{UN2} \cdot e_{UN2.z}}{S_{bz.t}} = 104.7 \cdot \frac{kN}{m^2}$$

$$\sigma_{toe.UN2.check.z} := \left| \begin{array}{ll} \text{"Okay"} & \text{if } 0 \le \sigma_{heel.UN2.z} \le \sigma_{allow.UN2} \\ \text{"Revise Structure"} & \text{otherwise} \end{array} \right. \qquad \sigma_{toe.UN2.check.z} = \text{"Okay"}$$

UN2 CASE

Foundation Bearing Pressure (Combined):

Linear pressure superimposed at Corners by both Moment_X and Moment_Z

Bearing Pressure at Heel(x)-Heel(z):

$$\sigma_{heel.UN2} := \frac{\Sigma V_{UN2}}{A_b} - \frac{\Sigma V_{UN2} \cdot e_{UN2.x}}{S_{bx.L}} - \frac{\Sigma V_{UN2} \cdot e_{UN2.z}}{S_{bz.b}} = 137.93 \cdot kPa$$

$$\sigma_{heel.UN2.check} := \left(\begin{array}{|l} \text{"Okay"} \quad \text{if} \quad 0 \le \sigma_{heel.UN2} \le \sigma_{allow.UN2} \\ \text{"Revise Structure"} \quad \text{otherwise} \end{array} \right) \qquad \sigma_{heel.UN2.check} = \text{"Okay"}$$

Bearing Pressure at Toe(x)-Toe(z):

$$\sigma_{toe.UN2} := \frac{\Sigma V_{UN2}}{A_b} + \frac{\Sigma V_{UN2} \cdot e_{UN2.x}}{S_{bx.R}} + \frac{\Sigma V_{UN2} \cdot e_{UN2.z}}{S_{bz.t}} = 122.47 \cdot kPa$$

$$\sigma_{toe.UN2.check} := \begin{array}{|l} \text{"Okay"} \quad \text{if} \quad 0 \le \sigma_{toe.UN2} \le \sigma_{allow.UN2} \\ \text{"Revise Structure"} \quad \text{otherwise} \end{array} \qquad \sigma_{toe.UN2.check} = \text{"Okay"}$$

Bearing Pressure at Heel(x)-Toe(z):

$$\sigma_{heeltoe.UN2} := \frac{\Sigma V_{UN2}}{A_b} - \frac{\Sigma V_{UN2} \cdot e_{UN2.x}}{S_{bx.L}} + \frac{\Sigma V_{UN2} \cdot e_{UN2.z}}{S_{bz.t}} = 85.85 \cdot kPa$$

$$\sigma_{heeltoe.UN2.check} := \left(\begin{array}{|l} \text{"Okay"} \quad \text{if} \quad 0 \le \sigma_{heeltoe.UN2} \le \sigma_{allow.UN2} \\ \text{"Revise Structure"} \quad \text{otherwise} \end{array} \right) \qquad \sigma_{heeltoe.UN2.check} = \text{"Okay"}$$

Bearing Pressure at Toe(x)-Heel(z):

$$\sigma_{toeheel.UN2} := \frac{\Sigma V_{UN2}}{A_b} + \frac{\Sigma V_{UN2} \cdot e_{UN2.x}}{S_{bx.R}} - \frac{\Sigma V_{UN2} \cdot e_{UN2.z}}{S_{bz.b}} = 174.55 \cdot kPa$$

$$\sigma_{toeheel.UN2.check} := \begin{array}{|l} \text{"Okay"} \quad \text{if} \quad 0 \le \sigma_{toeheel.UN2} \le \sigma_{allow.UN2} \\ \text{"Revise Structure"} \quad \text{otherwise} \end{array} \qquad \sigma_{toeheel.UN2.check} = \text{"Okay"}$$

FLOATATION ANALYSIS:

ACCEPTANCE PARAMETERS

Required Factor of Safety: $FS_{req.FUN2} := 1.3$

VERTICAL LOADS RESISTING:

Dead Load: $\Sigma V_{DL} = 54060.17 \cdot kN$

Water Weight H1+H2: $\Sigma V_{H.FUN2} := H_{1.UN2} + H_{2.UN2} = 7114.4 \cdot kN$

Summation Vertical Resisting: $\Sigma V_{FUN2} := \Sigma V_{DL} + \Sigma V_{H.FUN2} = 61174.6 \cdot kN$

VERTICAL LOADS UPLIFT:

Uplift: $U_{UN2} = -24013.01 \cdot kN$

Factor of Safety Floatation:

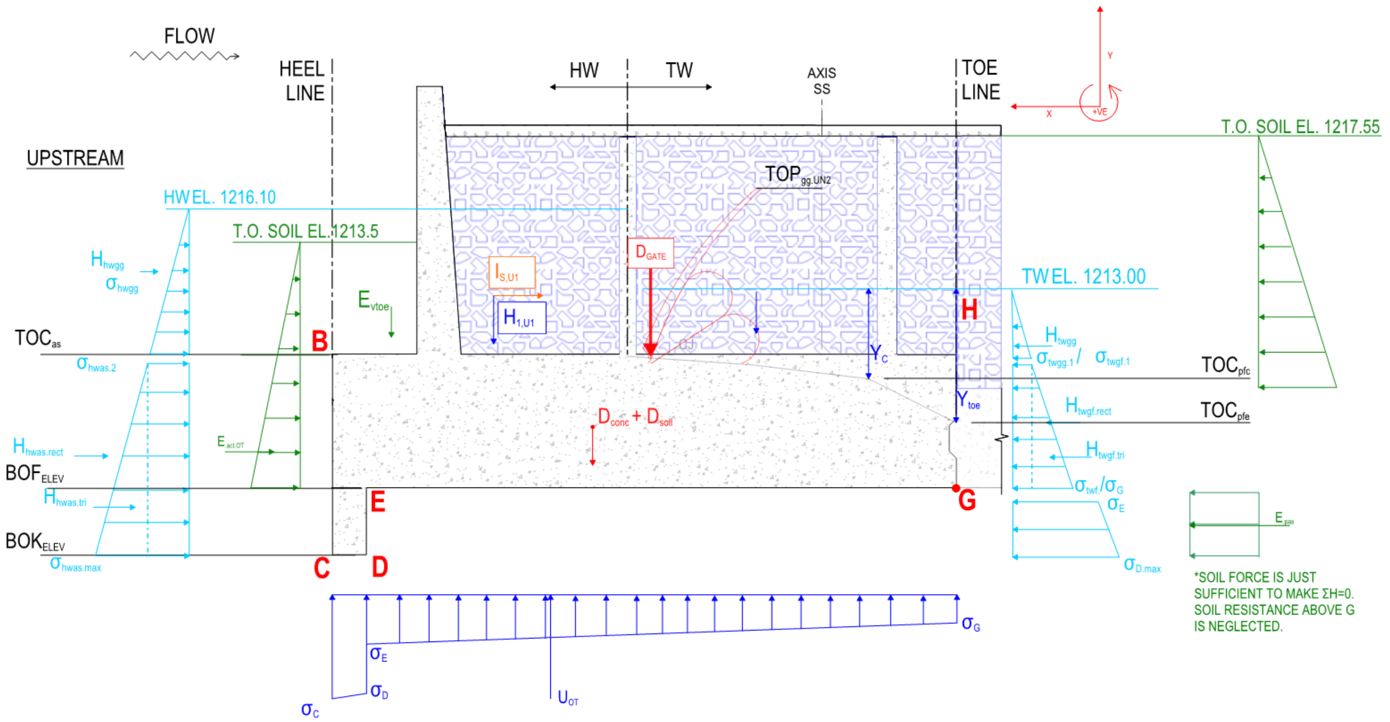
$$FS_{act.FUN2} := \frac{\Sigma V_{FUN2}}{\left| U_{UN2} \right|} = 2.55$$

$$FS_{check.FUN2} := \begin{array}{|l} \text{"OKAY"} \quad \text{if} \quad FS_{act.FUN2} \ge FS_{req.FUN2} \\ \text{"ANCHORS REQUIRED"} \quad \text{if} \quad FS_{act.FUN2} < FS_{req.FUN2} \end{array} = \text{"OKAY"}$$

MONOLITH OVERTURNING STABILITY ANALYSIS

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.
Assumptions are made in order to compute overturning stablity of indetermine forces on monolith with key;
(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.
(b) The horizontal resisting force acting on the key, P.key, is that required for staticequilibrium
(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1 $Ratio_{OT.UN2.min} := 0.333$ at Rock Foundation



Uplift Loads for Overturning Stability Analysis (X-Direction)

Line of Creep:

Change in Water Head: $\Delta_{h.UN2} := HW_{UN2} - TW_{UN2} = 3.1\ m$

Length from Point C to Point G: $L_{CG} = 18.61\ m$

Length from Various Points to Points: $L_{CD} = 1\ m$ $L_{DE} = 2\ m$ $L_{EG} = 17.5\ m$

$L_{GH.UN2} := TW_{UN2} - TOC_{afe} = 5\ m$

Length from Point C, D, E to G: $L_{CDEG} = 20.5\ m$ $L_{CDE} = 3\ m$

Water Pressure at Point C & G: $\sigma_{C.UN2} := \sigma_{hwas.UN2.2} = -99.08 \cdot kPa$ $\sigma_{G.UN2} := \sigma_{twtoe.UN2} \cdot -1 = -68.67 \cdot kPa$

Water Pressure at Point D:

$$\sigma_{D.UN2} := -\gamma_w \cdot \left[\left(HW_{UN2} - BOK_{elev} \right) - \frac{\Delta_{h.UN2} \cdot L_{CD}}{L_{CDEG}} \right] = -117.22 \cdot kPa$$

Water Pressure at Point E:

$$\sigma_{E.UN2} := -\gamma_w \cdot \left[\left(HW_{UN2} - BOF_{elev} \right) - \frac{\Delta_{h.UN2} \cdot L_{CDE}}{L_{CDEG}} \right] = -94.63 \cdot kPa$$

Uplift for Overturning Analysis on Bottom of Key:

$$U_{OT.UN2.key} := \frac{\sigma_{C.UN2} + \sigma_{D.UN2}}{2} \cdot L_{CD} \cdot W_B = -1730.39 \cdot kN$$

Acting at:

$$U_{OT.UN2.key.loc} := \frac{L_{CD} \cdot \left(2 \cdot \sigma_{C.UN2} + \sigma_{D.UN2} \right)}{3 \left(\sigma_{C.UN2} + \sigma_{D.UN2} \right)} + L_{EG} = 17.99\ m$$

Uplift for Overturning Analysis on Bottom of Footing: $U_{OT.UN2.ftg} := \frac{\sigma_{E.UN2} + \sigma_{G.UN2}}{2} \cdot L_{EG} \cdot W_B = -22862.09 \cdot kN$

UN2 CASE

Acting at: $U_{OT.UN2.ftg.loc} := \frac{L_{EG} \cdot \left(\sigma_{G.UN2} + 2 \cdot \sigma_{E.UN2}\right)}{3\left(\sigma_{G.UN2} + \sigma_{E.UN2}\right)} = 9.21\ m$

Uplift Load for Overturning Analysis: $U_{OT.UN2} := U_{OT.UN2.key} + U_{OT.UN2.ftg} = -24592.47 \cdot kN$

Uplift Load Acting from Toe: $U_{OT.UN2.loc} := \frac{U_{OT.UN2.key} \cdot U_{OT.UN2.key.loc} + U_{OT.UN2.ftg} \cdot U_{OT.UN2.ftg.loc}}{U_{OT.UN2}} = 9.83\ m$

All Vertical Loads Appliable to Overturning Stability Analysis

		at:	
Total Concrete Dead Loads:	$D_{conc} = 35947.58 \cdot kN$		$X_{conc.loc} = 8.81\ m$
Dead Load of Gate:	$D_{Gate} = 56.0 \cdot kN$		$X_{gate} = 9.50\ m$
Total Fill Loads:	$D_{fill} = 18056.6 \cdot kN$		$X_{fill.loc} = 7.31\ m$
Water Weight (HW) on Apron Slab:	$H_{1.UN2} = 4766.0 \cdot kN$		$H_{1.UN2.loc.x} = 14.42\ m$
Water Weight (TW) on Guard Gate Footing:	$H_{2.UN2} = 2348.4 \cdot kN$		$H_{2.UN2.loc.x} = 4.94\ m$
Uplift Load for Overturning Analysis:	$U_{OT.UN2} = -24592.47 \cdot kN$		$U_{OT.UN2.loc} = 9.83 \cdot m$

Sum of All Overturning Analysis Vertical Load:

$$\Sigma V_{UN2.OT} := D_{conc} + D_{Gate} + D_{fill} + H_{1.UN2} + H_{2.UN2} + U_{OT.UN2} = 36582.1 \cdot kN$$

Sum of All Overturning Analysis Vertical Load Moments:

$$\Sigma M_{V.UN2.OT} := \begin{pmatrix} D_{conc} \cdot X_{conc.loc} + D_{Gate} \cdot X_{gate} + D_{fill} \cdot X_{fill.loc} + H_{1.UN2} \cdot H_{1.UN2.loc.x} \cdots \\ + H_{2.UN2} \cdot H_{2.UN2.loc.x} + U_{OT.UN2} \cdot U_{OT.UN2.loc} \end{pmatrix} = 287893.79 \cdot kN \cdot m$$

Lateral Tailwater Loads for Overturning Stability Analysis

TW Lateral Load on Gate Footing (No Key - Overturning Values Adjusted): $H_{twgf.UN2} = 1569.6 \cdot kN$

Acting at: $H_{twgf.UN2.loc} = 1.73\ m$

Horizontal Tailwater Pressure Top of Key (Overturning Analysis): $\sigma_{twtk.OT.UN2} := \sigma_{E.UN2} \cdot -1 = 94.63 \cdot kPa$

Horizontal Tailwater Pressure Bottom of Key (Overturning Analysis): $\sigma_{twbk.OT.UN2} := \sigma_{D.UN2} \cdot -1 = 117.22 \cdot kPa$

Triangular Distribution Unit Load Acting at Key: $H_{twbk.OT.UN2.tri} := \frac{\left(\sigma_{twbk.OT.UN2} - \sigma_{twtk.OT.UN2}\right)}{2} \cdot d_{key} \cdot W_{tw.UN2} = 361.39 \cdot kN$

Triangular Distribution Unit Load Acting at Key: $H_{twbk.OT.UN2.rect} := \sigma_{twtk.OT.UN2} \cdot d_{key} \cdot W_{tw.UN2} = 3028.18 \cdot kN$

Total Horizontal Tailwater Load on Key (Overturning Values Adjusted): $H_{twkey.OT.UN2} := H_{twbk.OT.UN2.tri} + H_{twbk.OT.UN2.rect} = 3389.57 \cdot kN$

Acting at: $H_{twkey.OT.UN2.loc} := \frac{H_{twbk.OT.UN2.tri} \cdot \frac{-2 \cdot d_{key}}{3} + H_{twbk.OT.UN2.rect} \cdot \frac{-d_{key}}{2}}{H_{twkey.OT.UN2}} = -1.04 \cdot m$

Lateral Driving Earth Loads for Overturning Stability Analysis (at rest condition)

UN2 CASE

Depth of Driving Soil Loads (to top of key): $h_{E.OT.UN2} := TOC_{as} - BOF_{elev} = 4\ m$

At-Rest Soil Load: $E_{act.OT.UN2} := \frac{\left(K_{o.UN2} \cdot h_{E.OT.UN2}^{\ 2}\right)}{2} \cdot \left(\gamma_r - \gamma_w\right) \cdot W_{hwas.UN2} \cdot -1 = -1026.66 \cdot kN$

At Rest- Soil Load Acting from Toe: $E_{act.OT.UN2.loc} := \frac{h_{E.OT.UN2}}{3} = 1.33\ m$

All Lateral Loads Appliable to Overturning Stability Analysis (X-direction)

HW Lateral Load on Approach Slab:	$H_{hwas.UN2} = -5085.5 \cdot kN$	$H_{hwas.UN2.loc} = 1.84\ m$
HW Lateral Load on Guard Gate:	$H_{hwgg.UN2} = -706.3 \cdot kN$	$H_{hwgg.UN2.loc} = 5.92\ m$
HW Lateral Load on Abutment:	$H_{hwa.UN2} = -2190.2 \cdot kN$	$H_{hwa.UN2.loc} = 6.03\ m$
TW Lateral Load on Abutment:	$H_{twa.UN2} = 529.7 \cdot kN$	$H_{twa.UN2.loc} = 5.00\ m$
TW Lateral Load on Guard Gate:	$H_{twgg.UN2} = 176.6 \cdot kN$	$H_{twgg.UN2.loc} = 5.00\ m$
TW Lateral Load on Gate Footing (No Key - Overturning Values Adjusted):	$H_{twgf.UN2} = 1569.6 \cdot kN$	$H_{twgf.UN2.loc} = 1.73\ m$
TW Lateral Load on Key:	$H_{twkey.OT.UN2} = 3389.57 \cdot kN$	$H_{twkey.OT.UN2.loc} = -1.04\ m$
Ice / Impact Load:	$I_{UN2} = 1502.0 \cdot kN$	$I_{UN2.loc.y} = 9.80\ m$
Lateral Soil Load (driving):	$E_{act.OT.UN2} = -1026.7 \cdot kN$	$E_{act.OT.UN2.loc} = 1.33\ m$

Resisting Lateral Soil Load as required to produce horizontal equilibrium:

$$E_{pas.OT.x.UN2} := -\left(H_{hwas.UN2} + H_{hwgg.UN2} + H_{hwgg.UN2} + H_{twgg.UN2} \cdots \atop + H_{twgf.UN2} + H_{twkey.OT.UN2} + I_{UN2} + E_{act.OT.UN2}\right) = 887.05 \cdot kN$$

Acting at:

$$E_{pas.OT.UN2.loc} := -1 \cdot \frac{d_{key}}{2} = -1\ m$$

Sum of All Overturning Analysis Horizontal Load (ΣH=0):

$$\Sigma H_{UN2.OT.x} := H_{hwas.UN2} + H_{hwgg.UN2} + H_{twgg.UN2} + H_{twgf.UN2} + H_{twkey.OT.UN2} + I_{UN2} + E_{act.OT.UN2} + E_{pas.OT.x.UN2} = 706.32 \cdot kN$$

Sum of All Overturning Analysis Horizontal Load Moments:

$$\begin{aligned} \Sigma M_{H.UN2.OT.x} := {} & H_{hwas.UN2} \cdot H_{hwas.UN2.loc} + H_{hwgg.UN2} \cdot H_{hwgg.UN2.loc} \cdots \\ & + H_{twgg.UN2} \cdot H_{twgg.UN2.loc} + H_{twgf.UN2} \cdot H_{twgf.UN2.loc} \cdots \\ & + H_{twkey.OT.UN2} \cdot H_{twkey.OT.UN2.loc} + I_{UN2} \cdot I_{UN2.loc.y} \cdots \\ & + E_{act.OT.UN2} \cdot E_{act.OT.UN2.loc} + E_{pas.OT.x.UN2} \cdot E_{pas.OT.UN2.loc} \end{aligned} = -959.04 \cdot kN \cdot m$$

Overturning Stability Analysis (X-Direction)

$$\Sigma M_{UN2.OT.x} := \Sigma M_{V.UN2.OT} + \Sigma M_{H.UN2.OT.x} = 286934.74 \cdot kN \cdot m$$

$$X_{R.UN2} := \frac{\Sigma M_{UN2.OT.x}}{\Sigma V_{UN2.OT}} = 7.84\ m \qquad x_{OT.UN2} := X_{R.UN2} - \frac{L_B}{2} = -1.41\ m$$

Overturning Resultant Ratio

$$Ratio_{OT.x.UN2} := \frac{X_{R.UN2}}{L_B} = 0.42$$

$$Ratio_{OT.x.UN2.check} := \begin{cases} \text{"OKAY"} & \text{if } Ratio_{OT.x.UN2} \ge Ratio_{OT.UN2.min} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

$$x_{OT.check.UN2} := \begin{cases} \text{"OKAY"} & \text{if } \left|x_{OT.UN2}\right| \le Kern_x \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

All Lateral Loads Appliable to Overturning Stability Analysis (Z-direction)

UN2 CASE

Z-Direction Lateral Soil Load on Abutment Before RCC (driving): $E_{act.a.UN2.z} = -819.5 \cdot kN$ $E_{act.a.UN2.z.loc.y} = 4.00\ m$

Z-Direction Lateral Lateral Soil Load on Approach Slab Before RCC (driving): $E_{act.as.UN2.z} = -2192.6 \cdot kN$ $E_{act.as.UN2.z.loc.y} = 1.76\ m$

Z-Direction Lateral Soil Load on Abutment After RCC (driving): $E_{act.RCC.UN2.z} = -9.24 \cdot kN$ $E_{act.RCC.UN2.z.loc.y} = 10.03\ m$

Z-Direction Lateral Soil Load on Abutment at RCC Steps (driving): $E_{act.RCC.s.UN2.z} = -16.94 \cdot kN$ $E_{act.RCC.s.UN2.z.loc.y} = 9.43 \cdot m$

Resisting Lateral Soil Load as required to produce horizontal equilibrium:

$$E_{pas.OT.z.UN2} := -\left(E_{act.a.UN2.z} + E_{act.as.UN2.z} + E_{act.RCC.UN2.z} + E_{act.RCC.s.UN2.z}\right) = 3038.27 \cdot kN$$

Acting at:

$$E_{pas.OT.UN2.loc} = -1\ m$$

Sum of All Overturning Analysis Horizontal Load (ΣH=0):

$$\Sigma H_{UN2.OT.z} := E_{act.a.UN2.z} + E_{act.as.UN2.z} + E_{act.RCC.UN2.z} + E_{act.RCC.s.UN2.z} + E_{pas.OT.z.UN2} = 0 \cdot kN$$

Sum of All Overturning Analysis Horizontal Load Moments:

$$\Sigma M_{H.UN2.OT.z} := E_{act.a.UN2.z} \cdot E_{act.a.UN2.z.loc.y} + E_{act.as.UN2.z} \cdot E_{act.as.UN2.z.loc.y} \cdots + E_{act.RCC.UN2.z} \cdot E_{act.RCC.UN2.z.loc.y} + E_{act.RCC.s.UN2.z} \cdot E_{act.RCC.s.UN2.z.loc.y} \cdots + E_{pas.OT.x.UN2} \cdot E_{pas.OT.UN2.loc} = -8280.72 \cdot kN \cdot m$$

Overturning Stability Analysis (Z-Direction)

$$\Sigma M_{UN2.OT.z} := \Sigma M_{V.UN2.OT} + \Sigma M_{H.UN2.OT.z} = 279613.06 \cdot kN \cdot m$$

$$z_{R.UN2} := \frac{\Sigma M_{UN2.OT.z}}{\Sigma V_{UN2.OT}} = 7.64\ m \qquad z_{OT.UN2} := z_{R.UN2} - \frac{W_B}{2} = -0.36\ m$$

Overturning Resultant Ratio

$$Ratio_{OT.z.UN2} := \frac{z_{R.UN2}}{L_B} = 0.41$$

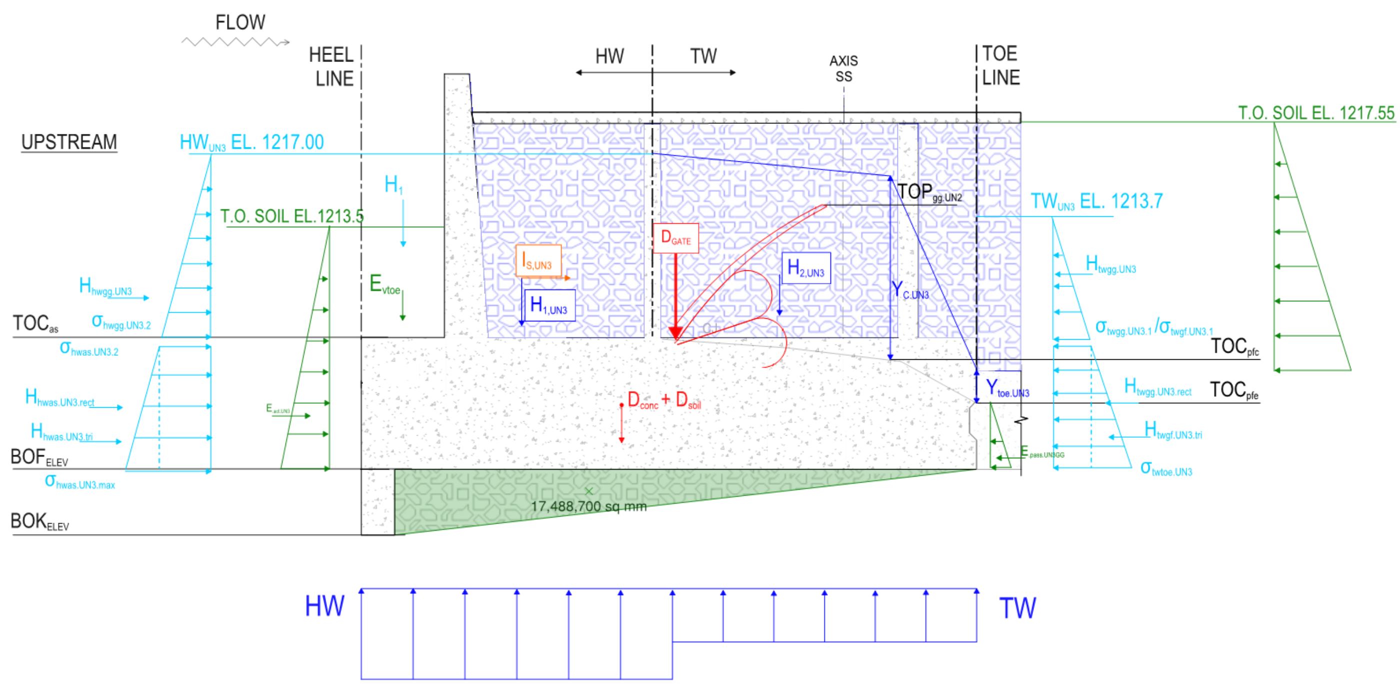
$$Ratio_{OT.z.UN2.check} := \begin{array}{|l} \text{"OKAY"} \ \text{if} \ Ratio_{OT.z.UN2} \ge Ratio_{OT.UN2.min} \\ \text{"Revise Structure"} \ \text{otherwise} \end{array} = \text{"OKAY"}$$

$$z_{OT.check.UN2} := \begin{array}{|l} \text{"OKAY"} \ \text{if} \ \left|z_{OT.UN2}\right| \le Kern_z \\ \text{"Revise Structure"} \ \text{otherwise} \end{array} = \text{"OKAY"}$$

SUMMARY OF STABILITY ASSESSMENT: UN2 CASE

Sliding Factor of Safety: (Horizontal Plane)	$FS_{HorizSliding.UN2} = 4.72$	$FS_{HorizSliding.UN2.Check}$ = "OKAY"
Flotation Factor of Safety (horizontal plane)	$FS_{act.FUN2} = 2.55$	$FS_{check.FUN2}$ = "OKAY"
Overturning Resultant Ratio: (X-direction)	$Ratio_{OT.x.UN2} = 0.42$	$Ratio_{OT.x.UN2.check}$ = "OKAY"
Overturning Resultant Ratio: (Z-direction)	$Ratio_{OT.z.UN2} = 0.41$	$Ratio_{OT.z.UN2.check}$ = "OKAY"
Eccentricity: (horizontal plane)	$x_{OT.UN2} = -1.41\ m$	$x_{OT.check.UN2}$ = "OKAY"
Eccentricity: (horizontal plane)	$z_{OT.UN2} = -0.36\ m$	$z_{OT.check.UN2}$ = "OKAY"
Bearing Pressure At Heel(x)- Heel(z): (horizontal plane)	$\sigma_{heel.UN2} = 138 \cdot kPa$	$\sigma_{heel.UN2.check}$ = "Okay"
Bearing Pressure At Toe(x)-Toe(z): (horizontal plane)	$\sigma_{toe.UN2} = 122 \cdot kPa$	$\sigma_{toe.UN2.check}$ = "Okay"
Bearing Pressure at Heel(x)-Toe(z): (horizontal plane)	$\sigma_{heeltoe.UN2} = 86 \cdot kPa$	$\sigma_{heeltoe.UN2.check}$ = "Okay"
Bearing Pressure at Toe(x)-Heel(z): (horizontal plane)	$\sigma_{toeheel.UN2} = 175 \cdot kPa$	$\sigma_{toe.UN2.check}$ = "Okay"

UN3 DESIGN CASE



ACCEPTANCE PARAMETERS

Required Factor of Safety for Sliding: $FS_{req.UN3.sl} := 1.3$ (Without Cohesion)

(Section 8.1, Design Criteria)

Resultant Within Middle Third of Base: $e \le \frac{L_B}{6} \wedge e \ge \frac{-L_B}{6}$

Allowable Rock Bearing Pressure: $\sigma_{allow.UN3} := 1270 \cdot \frac{kN}{m^2}$ (Section 5.2, Design Criteria)

Required Factor of Safety for Flotation: $FS_{req.UN3.flt} := 1.3$

INPUT PARAMETERS

Headwater Elevation: $HW_{UN3} := 1217.0m$ (Section 8.2, Design Criteria)

Tailwater Elevation: $TW_{UN3} := 1213.7m$ (Section 8.2, Design Criteria)

Bottom of Footing Elevation: $BOF_{elev} = 1206\,m$

Approch Slab Top of Concrete Elevation at Upstream Face: $TOC_{as} = 1210\,m$

Abutment Footing Top of Concrete Elevation at Stilling Basin: $TOC_{afe} = 1208\,m$

Abutment Footing Top of Concrete Elevation at Footing: $TOC_{afc} = 1209.73\,m$

Abutment Footing Top of Concrete Elevation at Footing Notch: $TOC_{afc.n} = 1209.3\,m$

Gates are open when top of gate elevation is at 1210.00m

Top of Guard Gate Elevation: $TOP_{gg.UN3} := 1210.0m$

Bottom of Key Elevation: $BOK_{elev} = 1204\,m$

Gates are closed/up when top of gate elevation is at 1215.0m

Water Elevation above Crest of Guard Gate:

$EL_{C.UN3} := 1214.67m$

$$Y_{C.UN3} := \begin{cases} (EL_{C.UN3} - TOC_{afc.n}) & \text{if } TOP_{gg.UN3} \le HW_{UN3} \\ (TW_{UN3} - TOC_{afc.n}) & \text{if } TOP_{gg.UN3} > HW_{UN3} \end{cases} = 5.37 \cdot m$$

Water Elevation above Guard Gate Toe: Submerged by Hydraulic 2D Model

$EL_{TOE.UN3} := 1210.89m$

$$Y_{TOE.UN3} := \begin{cases} (EL_{TOE.UN3} - TOC_{afe}) & \text{if } TOP_{gg.UN3} \le HW_{UN3} \\ (TW_{UN3} - TOC_{afe}) & \text{if } TOP_{gg.UN3} > HW_{UN3} \end{cases} = 2.89 \cdot m$$

LATERAL WATER LOADS

HEADWATER (DRIVING X-DIRECTION):

Headwater Depth on Abutment: $D_{hwa.UN3} := HW_{UN3} - TOC_{as} = 7.00\ m$

Headwater Load Unit Width Projected Surface Area of Abutment: $W_{hwa.UN3} := 2 \cdot r_{wall} = 12.00\ m$

Total Horizontal Headwater Load on Abutment:

$$H_{hwa.UN3} := \frac{-(\gamma_w \cdot D_{hwa.UN3}{}^2)}{2} \cdot W_{hwa.UN3} = -2884.1 \cdot kN$$

Apply Total Abutment Headwater Load at:

$$H_{hwa.UN3.loc} := \frac{D_{hwa.UN3}}{3} + (TOC_{as} - BOF_{elev}) = 6.33\ m$$

Apply Total Abutment Headwater Load at (from toe): $H_{hwa.UN3.loc.z} := 4m + r_{wall} = 10.00\ m$ (Gate Footing + Radius of Wall)

Thickness of Approach Slab: $T_{as} = 4\ m$

Headwater Depth at Heel (U/S face): $D_{hwas.UN3} := HW_{UN3} - BOF_{elev} = 11.00\ m$

Headwater Load Unit Width on Projected Approach Slab: $W_{hwas.UN3} := W_B = 16.00\ m$

Headwater Line Load At Top of Approach Slab: $\sigma_{hwas.UN3.1} := -(\gamma_w \cdot D_{hwa.UN3}) = -68.67 \cdot kPa$

Headwater Line Load At Bottom of Approach Slab: $\sigma_{hwas.UN3.2} := -(\gamma_w \cdot D_{hwas.UN3}) = -107.91 \cdot kPa$

Trianglular Distribution Unit Load on Approach Slab:

$$H_{hwas.UN3.2.tri} := \left(\frac{\sigma_{hwas.UN3.2} - \sigma_{hwas.UN3.1}}{2}\right) \cdot (T_{as} \cdot W_{hwas.UN3}) = -1255.68 \cdot kN$$

Rectangular Distribution Unit Load on Approach Slab:

$$H_{hwas.UN3.2.rect} := \sigma_{hwas.UN3.1} \cdot (T_{as} \cdot W_{hwas.UN3}) = -4394.88 \cdot kN$$

Total Horizontal Headwater Load on Approach Slab:

$$H_{hwas.UN3} := H_{hwas.UN3.2.tri} + H_{hwas.UN3.2.rect} = -5650.56 \cdot kN$$

Apply Total Footing Headwater Load at:

$$H_{hwas.UN3.loc} := \frac{\left[H_{hwas.UN3.2.rect} \cdot \frac{(T_{as})}{2} + H_{hwas.UN3.2.tri} \cdot \frac{(T_{as})}{3}\right]}{H_{hwas.UN3.2.tri} + H_{hwas.UN3.2.rect}} = 1.85\ m$$

Apply Total Footing Headwater Load at (from toe):

$$H_{hwas.UN3.loc.z} := \frac{W_B}{2} = 8.00\ m$$

Guard Gate (2A) Operating Condition: Fully Open

Guard Gate Down/Open Condition: $A1_{UN3} := TOP_{gg.UN3} \le TOC_{as}$

Guard Crest Gate Up/Closed, with Top of Gate Higher than HW Elevation: $B1_{UN3} := TOP_{gg.UN3} \ge HW_{UN3} \wedge TOP_{gg.UN3} > TOC_{as}$

Guard Crest Gate Up/Closed, with Top of Gate Lower than HW Elevation: $C1_{UN3} := TOP_{gg.UN3} > TOC_{as} \wedge HW_{UN3} > TOP_{gg.UN3}$

Guard Crest Gate Height: $H_{gg.UN3} := TOP_{gg.UN3} - TOC_{as} = 0\ m$

Headwater Depth at Guard Crest Gate: $D_{hwgg.UN3} := HW_{UN3} - TOC_{as} = 7.00\ m$

Guard Crest Gate Width: $W_{hwgg.UN3} := 4.00m$

Lateral Headwater Pressure at Bottom of Guard Crest Gate:

$$\sigma_{hwgg.UN3.1} := \begin{cases} (0.0kPa) & \text{if } A1_{UN3} \\ -(\gamma_w \cdot D_{hwgg.UN3}) & \text{if } B1_{UN3} \\ -(\gamma_w \cdot D_{hwgg.UN3}) & \text{if } C1_{UN3} \end{cases} = 0.0 \cdot kPa$$

Lateral Headwater Pressure at Top of Guard Crest Gate:
(Load at HW Elevation On Guard Crest Gate if HW is below TOG_{rg})

$$\sigma_{hwgg.UN3.2} := \begin{cases} (0.0kPa) & \text{if } A1_{UN3} \\ 0.0kPa & \text{if } B1_{UN3} \\ -\left[\gamma_w \cdot (HW_{UN3} - TOP_{gg.UN3})\right] & \text{if } C1_{UN3} \end{cases} = 0.0 \cdot kPa$$

Average Pressure acting on Guard Crest Gate:

$$\sigma_{hwgg.UN3.avg} := \frac{(\sigma_{hwgg.UN3.1} + \sigma_{hwgg.UN3.2})}{2} = 0 \cdot kPa$$

Total Area water acting on Crest Gate:

$$A_{hwgg.UN3} := \begin{cases} D_{hwgg.UN3} \cdot W_{hwgg.UN3} & \text{if } A1_{UN3} \\ D_{hwgg.UN3} \cdot W_{hwgg.UN3} & \text{if } B1_{UN3} \\ H_{gg.UN3} \cdot W_{hwgg.UN3} & \text{if } C1_{UN3} \end{cases} = 28 \cdot m^2$$

Total Horizontal Headwater Load on Guard Crest Gate:

$$H_{hwgg.UN3} := \sigma_{hwgg.UN3.avg} \cdot A_{hwgg.UN3} = 0.0 \cdot kN$$

Apply Total Guard Crest Gate Headwater Load at:

$$H_{hwgg.UN3.loc} := \begin{cases} (TOC_{as} - BOF_{elev}) & \text{if } A1_{UN3} \\ \left[\frac{(HW_{UN3} - TOC_{as})}{3} + (TOC_{as} - BOF_{elev})\right] & \text{if } B1_{UN3} \\ \left[\frac{\sigma_{hwgg.UN3.2} \cdot A_{hwgg.UN3} \cdot \frac{(H_{gg.UN3})}{2} + \frac{(\sigma_{hwgg.UN3.1} - \sigma_{hwgg.UN3.2})}{2} \cdot A_{hwgg.UN3} \cdot \frac{(H_{gg.UN3})}{3}}{\sigma_{hwgg.UN3.2} \cdot A_{hwgg.UN3} + \frac{(\sigma_{hwgg.UN3.1} - \sigma_{hwgg.UN3.2})}{2} \cdot A_{hwgg.UN3}} \ldots \\ + (TOC_{as} - BOF_{elev})\right] & \text{if } C1_{UN3} \end{cases} = 4.0 \cdot m$$

Apply Total Guard Crest Gate Headwater Load at (From toe):

$$H_{hwgg.UN3.loc.z} := \frac{W_{hwgg.UN3}}{2} = 2\ m$$

LATERAL TAILWATER (RESISTING) Applied to Downstream Side of Guard Crest Gate: UN3 CASE

Guard Gate Down/Open Condition: $A2_{UN3} := TOP_{gg.UN3} \le TOC_{as}$

Guard Crest Gate Up/Closed, with Top of Gate Higher than TW Elevation: $B2_{UN3} := TOP_{gg.UN3} \ge TW_{UN3} \wedge TOP_{gg.UN3} > TOC_{as}$

Guard Crest Gate Up/Closed, with Top of Gate Lower than TW Elevation: $C2_{UN3} := TOP_{gg.UN3} > TOC_{as} \wedge TW_{UN3} > TOP_{gg.UN3}$

Tailwater Depth at Guard Crest Gate: $D_{twgg.UN3} := TW_{UN3} - TOC_{as} = 3.70\ m$

Guard Crest Gate Height: $H_{gg.UN3} = 0\ m$

Guard Crest Gate Width: $W_{twgg.UN3} := 4.00m$

Lateral Water Load at Bottom of Guard Crest Gate:

$$\sigma_{twgg.UN3.1} := \begin{vmatrix} (0.0kPa) & \text{if} & A2_{UN3} \\ (\gamma_w \cdot D_{twgg.UN3}) & \text{if} & B2_{UN3} \\ (\gamma_w \cdot D_{twgg.UN3}) & \text{if} & C2_{UN3} \end{vmatrix} = 0.0 \cdot kPa$$

Lateral Water Load at Top of Guard Crest Gate:
(Load at TW Elevation On Guard Crest Gate if TW is below TOG_{gg})

$$\sigma_{twgg.UN3.2} := \begin{vmatrix} (0.0kPa) & \text{if} & A2_{UN3} \\ 0.0kPa & \text{if} & B2_{UN3} \\ \left[\gamma_w \cdot \left(\left(TW_{UN3} - TOP_{gg.UN3}\right)\right)\right] & \text{if} & C2_{UN3} \end{vmatrix} = 0.0 \cdot kPa$$

Average Pressure acting on Guard Crest Gate:

$$\sigma_{twgg.UN3.avg} := \frac{\left(\sigma_{twgg.UN3.1} + \sigma_{twgg.UN3.2}\right)}{2} = 0 \cdot kPa$$

Total Area water acting on Crest Gate:

$$A_{twgg.UN3} := \begin{vmatrix} D_{twgg.UN3} \cdot W_{twgg.UN3} & \text{if} & A2_{UN3} \\ D_{twgg.UN3} \cdot W_{twgg.UN3} & \text{if} & B2_{UN3} \\ H_{gg.UN3} \cdot W_{twgg.UN3} & \text{if} & C2_{UN3} \end{vmatrix} = 14.8 \cdot m^2$$

Total Horizontal Headwater Load on Guard Crest Gate: $H_{twgg.UN3} := \sigma_{twgg.UN3.avg} \cdot A_{twgg.UN3} = 0.0 \cdot kN$

Apply Total Horiz. TW Load on Guard Gate at:

$$H_{twgg.UN3.loc} := \begin{vmatrix} \left(TOC_{as} - BOF_{elev}\right) & \text{if} & A2_{UN3} \\ \left[\frac{\left(TW_{UN3} - TOC_{as}\right)}{3} + \left(TOC_{as} - BOF_{elev}\right)\right] & \text{if} & B2_{UN3} \\ \left[\frac{\sigma_{twgg.UN3.2} \cdot A_{twgg.UN3} \cdot \frac{\left(H_{gg.UN3}\right)}{2} + \frac{\left(\sigma_{twgg.UN3.1} - \sigma_{twgg.UN3.2}\right)}{2} \cdot A_{twgg.UN3} \cdot \frac{\left(H_{gg.UN3}\right)}{3}}{\sigma_{twgg.UN3.2} \cdot A_{twgg.UN3} + \frac{\left(\sigma_{twgg.UN3.1} - \sigma_{twgg.UN3.2}\right)}{2} \cdot A_{twgg.UN3}} \ldots \atop + \left(TOC_{as} - BOF_{elev}\right)\right] & \text{if} & C2_{UN3} \end{vmatrix} = 4.0 \cdot m$$

Apply Total Guard Crest Gate Headwater Load at (From toe): $H_{twgg.UN3.loc.z} := \frac{W_{twgg.UN3}}{2} = 2\ m$

LATERAL WATER LOADS (continued)

UN3 CASE

TAILWATER (RESISTING) Applied to Concrete Strucuture:

Tailwater Depth on Top of Abutment Footing: $D_{twa.UN3} := TW_{UN3} - TOC_{as} = 3.70\ m$

Tailwater Load Unit Width on Abutment: $W_{twa.UN3} := 2 \cdot r_{wall} = 12.00\ m$

Total Horizontal Tailwater Load on Abutment: $H_{twa.UN3} := \dfrac{\left(\gamma_w \cdot D_{twa.UN3}{}^2\right)}{2} \cdot W_{twa.UN3} = 805.8 \cdot kN$

Apply Total Abutment Tailwater Load at: $H_{twa.UN3.loc} := \dfrac{D_{twa.UN3}}{3} + \left(TOC_{as} - BOF_{elev}\right) = 5.23\ m$

Apply Total Abutment Tailwater Load at (from Toe Line): $H_{twa.UN3.loc.z} := W_{twgg.UN3} + r_{wall} = 10\ m$

Footing Thickness for horizontal at Toe: $h_{toe} = 4\ m$

Tailwater Depth At top of Gate Base Footing Elevation: $D_{twgf.UN3} := TW_{UN3} - TOC_{as} = 3.70\ m$

Water Depth at bottom of Gate Base Footing (Excluding Key): $D_{twtoe.UN3} := TW_{UN3} - BOF_{elev} = 7.70\ m$

Water Depth at bottom of Gate Base Footing (Including Key): $D_{twkey.UN3} := HW_{UN3} - BOK_{elev} = 13.00\ m$

Unit Width of D/S face of crest for applicaiton of Tailwater Load: $W_{tw.UN3} := W_B = 16.00\ m$

(Conservatively taken resisting water in front of 1.5m RCC Auxiliary Spillway as Tailwater elevation)

Tailwater Pressure At Top of Gate Footing: $\sigma_{twgf.UN3} := \left(\gamma_w \cdot D_{twgf.UN3}\right) = 36.3 \cdot kPa$

Tailwater Line Load At Bottom of Gate Footing (Excluding Key): $\sigma_{twtoe.UN3} := \left(\gamma_w \cdot D_{twtoe.UN3}\right) = 75.54 \cdot kPa$

Trianglular Distribution Unit Load on Gate Footing Base: $H_{twgf.UN3.tri} := \left(\dfrac{\sigma_{twtoe.UN3} - \sigma_{twgf.UN3}}{2}\right) \cdot \left[\left(T_{as} - d_{key}\right) \cdot W_{tw.UN3}\right] = 627.84 \cdot kN$

Rectangular Distribution Unit Load on Gate Footing Base: $H_{twgf.UN3.rect} := \sigma_{twgf.UN3} \cdot \left[\left(T_{as} - d_{key}\right) \cdot W_{tw.UN3}\right] = 1161.5 \cdot kN$

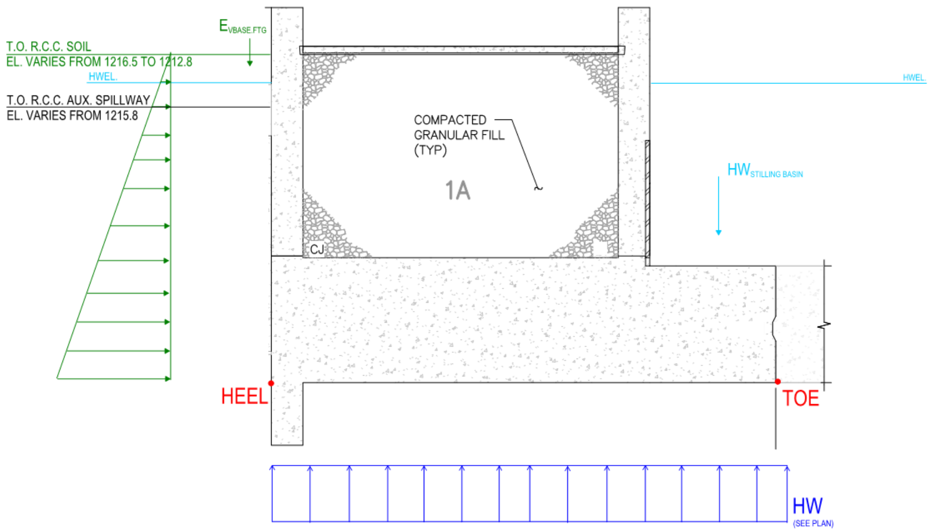
Total Horizontal Tailwater Headwater Load on Gate Footing: $H_{twgf.UN3} := H_{twgf.UN3.tri} + H_{twgf.UN3.rect} = 1789.34 \cdot kN$

Apply Total Gate Footing Tailwater Load at:

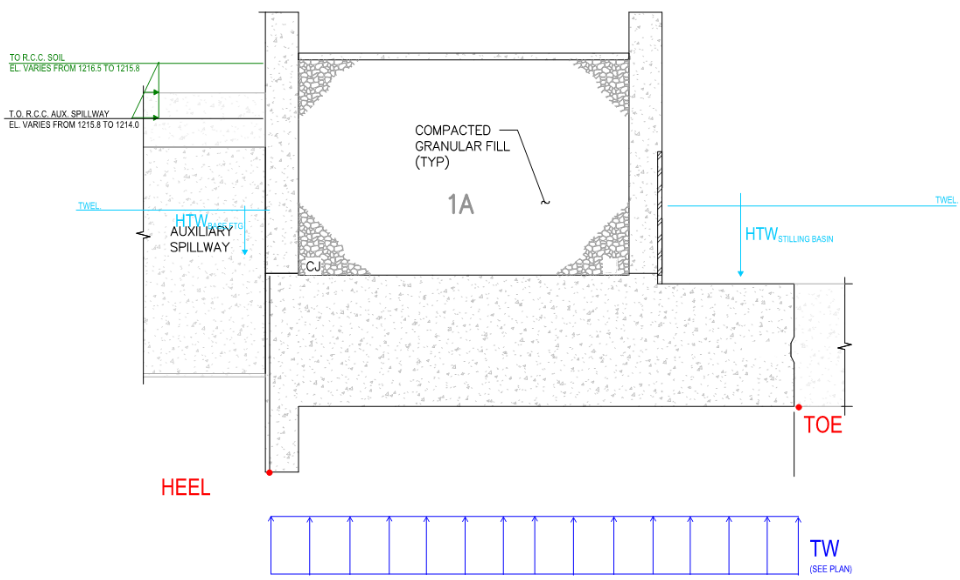
$$H_{twgf.UN3.loc} := \frac{\left[H_{twgf.UN3.rect} \cdot \frac{\left(T_{as}\right)}{2} + H_{twgf.UN3.tri} \cdot \frac{\left(T_{as}\right)}{3}\right]}{H_{twgf.UN3.tri} + H_{twgf.UN3.rect}} = 1.77\ m$$

Apply Total Gate Footing Tailwater Load at (From Toe Line): $H_{twgf.UN3.loc.z} := \dfrac{W_B}{2} = 8.00\ m$

SUMMATION OF LATERAL WATER LOADS:



SECTION 1A BEFORE GATES & AUX. SPILLWAY RCC

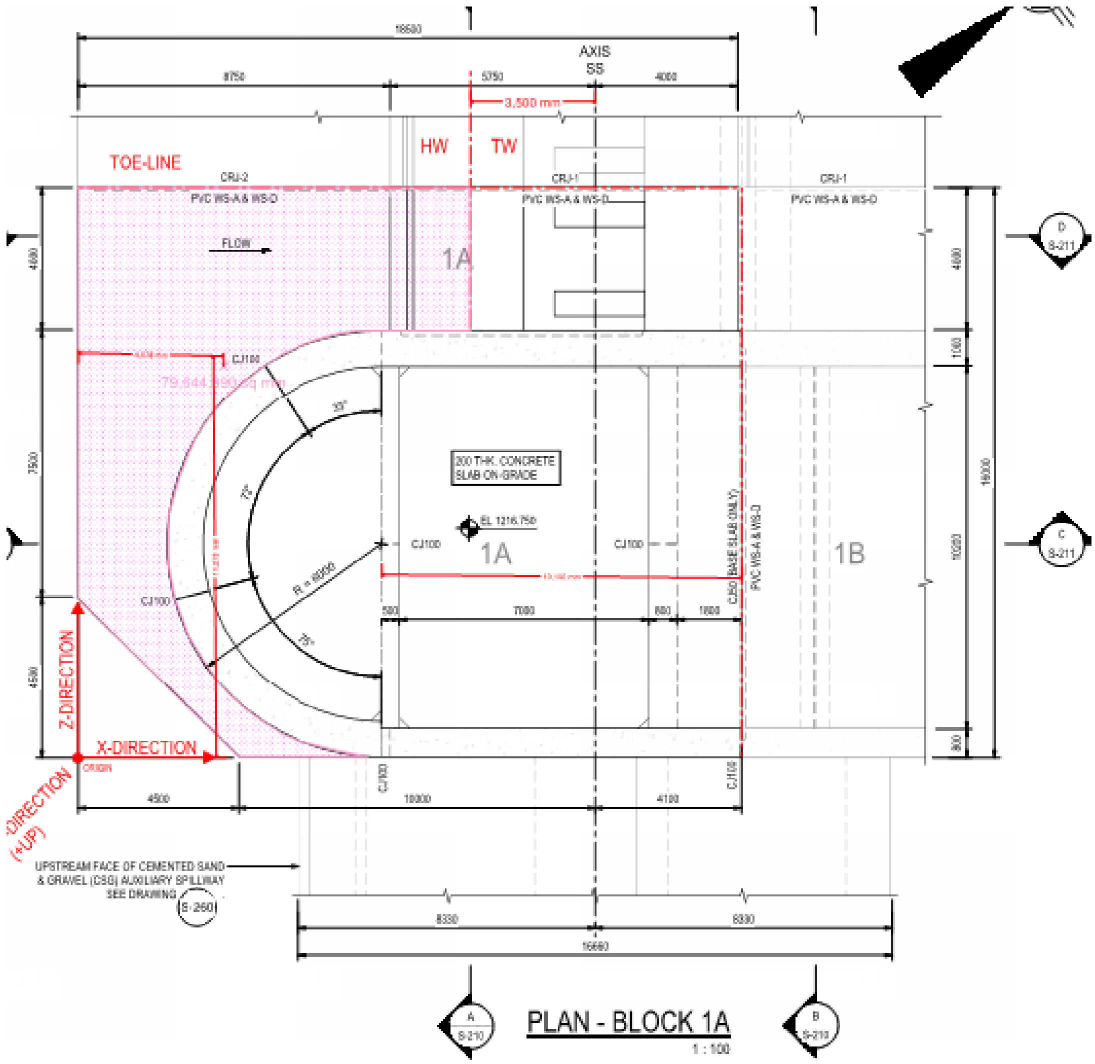


SECTION 1A AFTER GATES & AUX. SPILLWAY RCC

$$\Sigma H_{Water.UN3.x} := H_{hwa.UN3} + H_{hwas.UN3} + H_{hwgg.UN3} + H_{twa.UN3} + H_{twgf.UN3} + H_{twgg.UN3} = -5939.56 \cdot kN$$

$$\Sigma M_{HWater.UN3.x} := H_{hwa.UN3} \cdot H_{hwa.UN3.loc} + H_{hwas.UN3} \cdot H_{hwas.UN3.loc} + H_{hwgg.UN3} \cdot H_{hwgg.UN3.loc} \cdots + H_{twa.UN3} \cdot H_{twa.UN3.loc} + H_{twgf.UN3} \cdot H_{twgf.UN3.loc} + H_{twgg.UN3} \cdot H_{twgg.UN3.loc} = -21353.11 \cdot kN \cdot m$$

$$\Sigma H_{Water.UN3.z} := 0kN \qquad \Sigma M_{HWater.UN3.z} := 0 \cdot kN \cdot m$$



HEADWATER:

Water Depth on top of Approach Slab: $d_{hw.UN3} := HW_{UN3} - TOC_{as} = 7.00\ m$

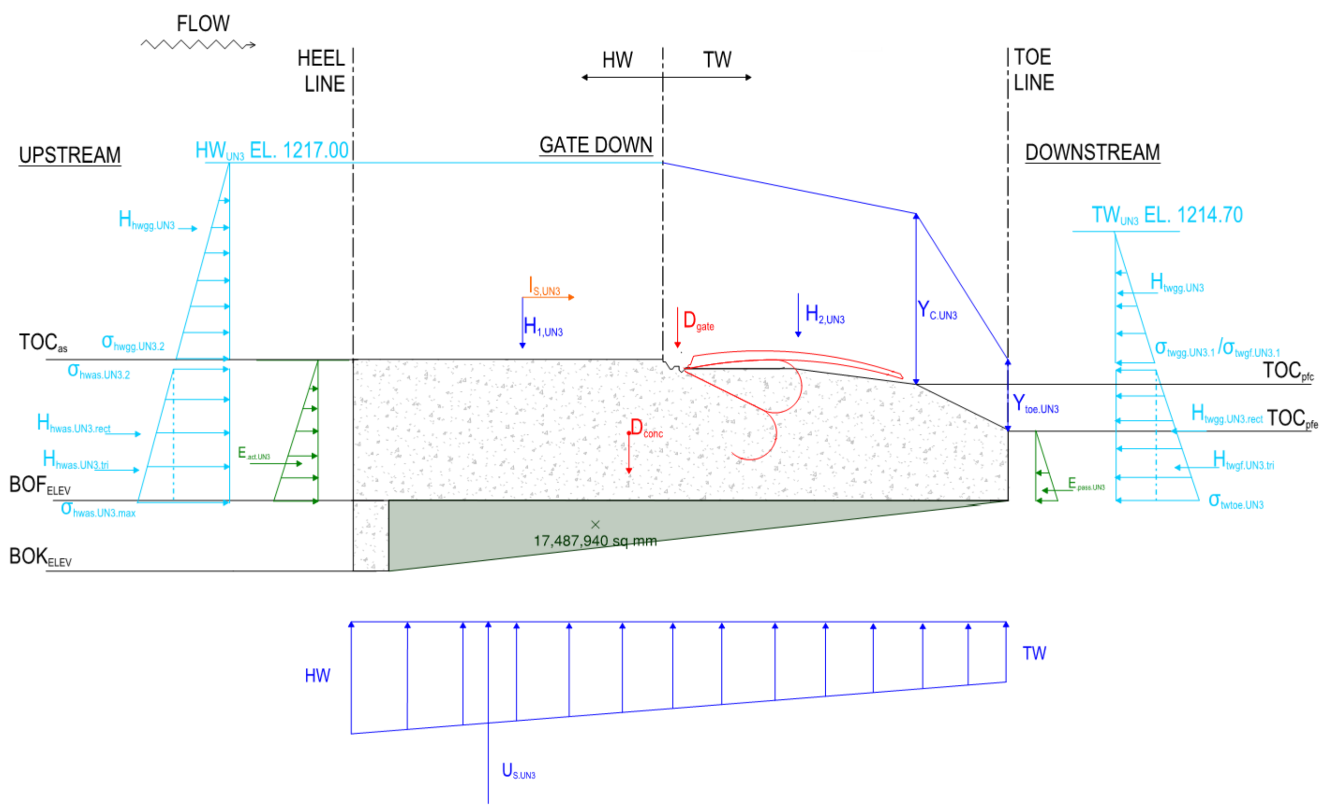
Water Area on top of Approach Slab: $A_{as} = 79.64\ m^2$ (From Geom. Scaled on REVU)

Vertical Water Weight (H1) on Approach Slab: $H_{1.UN3} := \left(A_{as} \cdot d_{hw.UN3}\right) \cdot \gamma_w = 5469.2 \cdot kN$

Moment Arm for Applicaiton of Water Weight (H1) from toe (X-Direction): $H_{1.UN3.loc.x} := L_B - 4.078m = 14.42\ m$ (From Geom. Scaled on REVU)

Moment Arm for Applicaiton of Water Weight (H1) from toe (Z-Direction): $H_{1.UN3.loc.z} := W_B - 11.273m = 4.73\ m$ (From Geom. Scaled on REVU)

TAILWATER:



Approach Slab Length: $L_{as} = 8.75\,m$

Gate Footing Length: $L_{gf} = 9.75\,m$

Gate Footing Crest Length: $L_{gfc} = 2.25\,m$

TAILWATER:

Trapezoid Volume Above Gate Footing from Approach Slab to Crest:

$$V_{asc.UN3} := \left(L_{gf} - L_{gfc}\right) W_{twgg.UN3} \frac{d_{hw.UN3} + Y_{C.UN3}}{2} = 185.55 \cdot m^3$$

Trapezoid Volume Above Gate Footing Crest to End of Gate Footing:

$$V_{gfc.UN3} := \left(L_{gfc} \cdot W_{twgg.UN3}\right) \frac{Y_{C.UN3} + Y_{TOE.UN3}}{2} = 37.17 \cdot m^3$$

Load Above Gate Footing from Approach Slab to Crest:

$$H_{2.UN3.asc} := V_{asc.UN3} \cdot \gamma_w = 1820.25 \cdot kN$$

Load Acting Above Footing Crest from Toe:

$$H_{2.UN3.asc.loc.x} := \frac{\left(L_{gf} - L_{gfc}\right) \cdot \left(2 \cdot d_{hw.UN3} + Y_{C.UN3}\right)}{3 \cdot \left(d_{hw.UN3} + Y_{C.UN3}\right)} + L_{gfc} = 6.16\,m$$

Load Above Gate Footing from Crest to End:

$$H_{2.UN3.gfc} := V_{gfc.UN3} \cdot \gamma_w = 364.64 \cdot kN$$

Load Acting Above Gate Footing from Crest to End:

$$H_{2.UN3.gfc.loc.x} := \frac{\left(L_{gfc}\right) \cdot \left(2 \cdot Y_{C.UN3} + Y_{TOE.UN3}\right)}{3 \cdot \left(Y_{C.UN3} + Y_{TOE.UN3}\right)}$$

Vertical Water Weight (H2) on Gate Footing:

$$H_{2.UN3} := H_{2.UN3.asc} + H_{2.UN3.gfc} = 2184.88 \cdot kN$$

Moment Arm for Application of Water Weight (H2) from toe:

$$H_{2.UN3.loc.x} := \frac{H_{2.UN3.asc} \cdot H_{2.UN3.asc.loc.x} + H_{2.UN3.gfc} \cdot H_{2.UN3.gfc.loc.x}}{H_{2.UN3}} = 5.34\,m$$

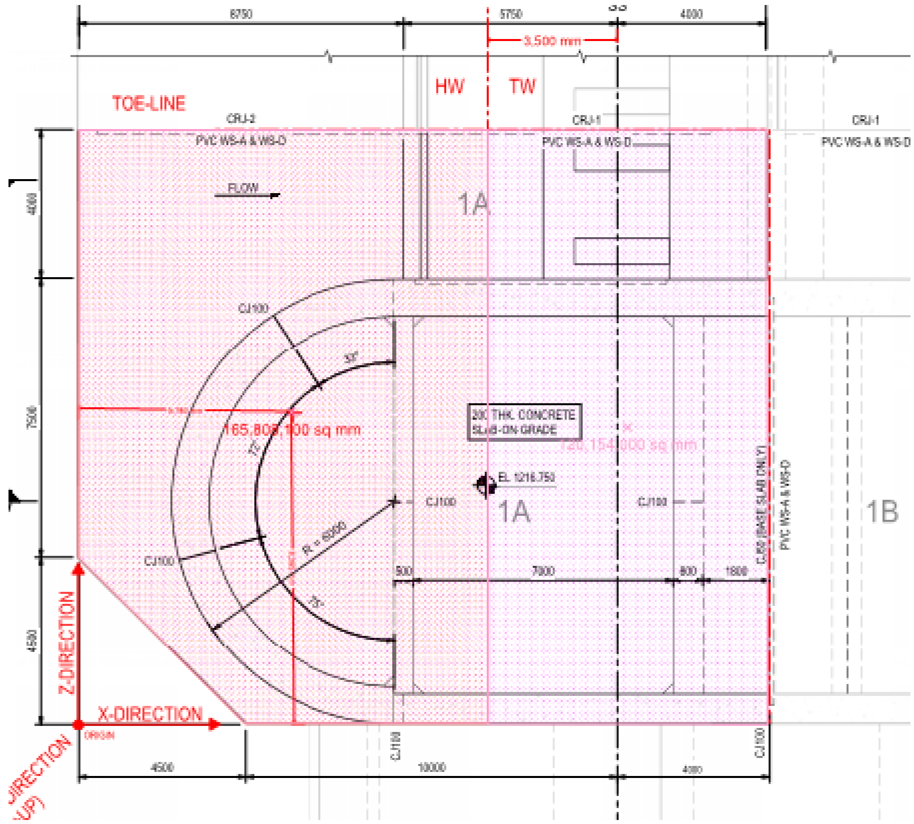
Moment Arm for Applicaiton of Water Weight (H2) from toe (Z-Direction):

$$H_{2.UN3.loc.z} := 2.0m$$

UPLIFT

UN3 CASE

(Assuming constant Headwater Uplift at front and constant Tailwater Uplift at back of footing base)



Uplift pressure at U/S Face (heel): $U_{HW.UN3} := D_{hwas.UN3} \cdot \gamma_w = 107.9 \cdot \frac{kN}{m^2}$

Uplift pressure at D/S Face Stilling Basin: $U_{TW.UN3} := D_{twtoe.UN3} \cdot \gamma_w = 75.54 \cdot \frac{kN}{m^2}$

Area of Uplift Force From Headwater Side: $A_{HWU.UN3} := 165.81 m^2$ (From Bluebeam REVU)

Area of Uplift Force From Tailwater Side: $A_{TWU.UN3} := 120 m^2$ (From Bluebeam REVU)

Uplift Force From Headwater Side: $U_{A.UN3} := -U_{HW.UN3} \cdot A_{HWU.UN3} = -17892.56 \cdot kN$

Uplift Force From Headwater Side: $U_{B.UN3} := -U_{TW.UN3} \cdot A_{TWU.UN3} = -9064.44 \cdot kN$

Uplift Centroid of Area From Headwater Side to Toe: $X_{U.A} = 13.22 m$ $Z_{U.A} = 7.63 m$ (From Bluebeam REVU)

Uplift Centroid of Area From Tailwater Side to Toe: $X_{U.B} = 3.75 m$ $Z_{U.B} = 8 m$ (From Bluebeam REVU)

Total Resultant Uplift force: $U_{UN3} := U_{A.UN3} + U_{B.UN3} = -26957 \cdot kN$

Resultant Location from Toe Rect. Load (X-Direction): $U_{UN3.loc.x} := \frac{\left(U_{A.UN3} \cdot X_{U.A} + U_{B.UN3} \cdot X_{U.B}\right)}{\left(U_{A.UN3} + U_{B.UN3}\right)} = 10.04 m$

Resultant Location from Toe Rect. Load (Z-Direction): $U_{UN3.loc.z} := \frac{\left[U_{A.UN3} \cdot \left(W_B - Z_{U.A}\right) + U_{B.UN3} \cdot \left(W_B - Z_{U.B}\right)\right]}{\left(U_{A.UN3} + U_{B.UN3}\right)} = 8.24 m$

$\Sigma V_{water.UN3} := H_{1.UN3} + H_{2.UN3} + U_{UN3} = -19302.89 \cdot kN$

$\Sigma M_{Vwater.UN3.x} := H_{1.UN3} \cdot H_{1.UN3.loc.x} + H_{2.UN3} \cdot H_{2.UN3.loc.x} + U_{UN3} \cdot U_{UN3.loc.x} = -179981.57 \cdot kN \cdot m$

$\Sigma M_{Vwater.UN3.z} := H_{1.UN3} \cdot H_{1.UN3.loc.z} + H_{2.UN3} \cdot H_{2.UN3.loc.z} + U_{UN3} \cdot U_{UN3.loc.z} = -191963.98 \cdot kN \cdot m$

Equivalent Fluid Pressure (EFP):

At rest lateral pressure coefficient: $K_{o.UN3} := 1 - \sin(\phi_{backfill}) = 0.658$ (Section 5.3, Design Criteria)

Headwater Top of Soil Elevation: $TOS_{HW} = 1210\,m$

Top of Backfill Soil Elevation: $TOS_{BF} = 1216.5\,m$

Driving Soil Load Unit Width Projected Surface Area of Abutment: $W_{ds.hwa.UN3} := 6.0m$

Driving Soil Load Unit Width on Projected Approach Slab + Key: $W_{hwas.UN3} = 16.00\,m$

Resisting Soil Load Unit Width Projected Surface Area of Abutment: $W_{rsa.UN3} := \dfrac{10.5m + 9.381m}{2} = 9.94\,m$ (From Section Cut)

Driving Soil Load Depth on Abutment: $d_{DS.a} = 0\,m$

Driving Soil Load Depth on Footing: $d_{DS.as} = 4\,m$

Resisting Soil Load Depth on Abutment: $d_{RS.a} = 8.5\,m$

Thickness of Stilling Basin: $T_{sb} = 2\,m$

Lateral X-Direction Driving Force (Headwater Side - at rest condition)

At-Rest Soil Load on Half of Abutment: $E_{act.a.UN3.x} := \dfrac{\left(K_{o.UN3} \cdot d_{DS.a}{}^{2}\right)}{2} \cdot (\gamma_r - \gamma_w) \cdot W_{ds.hwa.UN3} \cdot -1 = 0 \cdot kN$

Acting at: $E_{act.a.UN3.x.loc.y} := \dfrac{d_{DS.a}}{3} + T_{as} - d_{key} = 2.00\,m$

Acting at (from Toe Line): $E_{act.a.UN3.x.loc.z} := W_{hwgg.UN3} + r_{wall} = 10.00\,m$

At-Rest Soil Load on Top of Approach Slab: $\sigma_{DS.as.UN3} := \left(K_{o.UN3} \cdot d_{DS.a}\right) \cdot (\gamma_r - \gamma_w) = 0 \cdot kPa$

At-Rest Soil Load on Bottom of Approach Slab: $\sigma_{DS.key.UN3} := \left(K_{o.UN3} \cdot d_{DS.as}\right) \cdot (\gamma_r - \gamma_w) = 32.08 \cdot kPa$

At-Rest Soil Load on Approach Slab (Rect): $E_{act.as.rect.UN3.x} := \sigma_{DS.as.UN3} \cdot (T_{as}) \cdot W_{hwas.UN3} \cdot -1 = 0 \cdot kN$

At-Rest Soil Load on Approach Slab (Tri): $E_{act.as.tri.UN3.x} := \dfrac{\left(\sigma_{DS.key.UN3} - \sigma_{DS.as.UN3}\right) \cdot (T_{as})}{2} \cdot W_{hwas.UN3} \cdot -1 = -1026.66 \cdot kN$

At-Rest Soil Load on Approach Slab: $E_{act.as.UN3.x} := E_{act.as.rect.UN3.x} + E_{act.as.tri.UN3.x} = -1026.66 \cdot kN$

Acting at:

$$E_{act.as.UN3.x.loc.y} := \frac{\left(E_{act.as.rect.UN3.x} \cdot \frac{T_{as}}{2} \cdots + E_{act.as.tri.UN3.x} \cdot \frac{T_{as}}{3}\right)}{E_{act.as.UN3.x}} = 1.33\,m$$

Acting at (from Toe Line): $E_{act.as.UN3.x.loc.z} := \dfrac{W_B}{2} = 8.00\,m$

Lateral X-Direction Resisting Force (Tailwater Side - at rest condition)

UN3 CASE

At-rest Soil Load: $E_{pass.UN3.x} := \frac{\left(K_{o.UN3} \cdot d_{RS.a}^{2}\right)}{2} \cdot \left(\gamma_r - \gamma_w\right) \cdot W_{rsa.UN3} = 2880.26 \cdot kN$

Acting at: $E_{pass.UN3.x.loc.y} := \frac{d_{RS.a}}{3} + T_{sb} - d_{key} = 2.83\ m$ $W_{rsa.UN3} = 9.94\ m$

Acting at (from Toe Line): $E_{pass.UN3.x.loc.z} := W_{hwgg.UN3} + r_{wall} = 10\ m$

$\Sigma H_{soil.UN3.x} := \left(E_{act.a.UN3.x} + E_{act.as.UN3.x} + E_{pass.UN3.x}\right) = 1853.61 \cdot kN$

$\Sigma M_{soil.UN3.x} := E_{act.a.UN3.x} \cdot E_{act.a.UN3.x.loc.y} + E_{act.as.UN3.x} \cdot E_{act.as.UN3.x.loc.y} + E_{pass.UN3.x} \cdot E_{pass.UN3.x.loc.y} = 6791.87 \cdot kN \cdot m$

Lateral Z-Direction Driving Force (Headwater Side - Before Gates & Aux. Spillway RCC - at rest condition)

Max./Min. Top of R.C.C. Soil Elevation: $TOS_{RCC.max} = 1216.5\ m$ $TOS_{RCC.min} = 1212.8\ m$

Average Top of R.C.C. Soil Elevation: $TOS_{RCC} = 1214.65\ m$

Depth of R.C.C. Soil Acting on Abutment Walls: $d_{act.RCC.w} = 4.65\ m$

Depth of R.C.C. Soil Acting on Abutment Footings: $d_{act.RCC.f} = 8.65\ m$

Projected Width of soil acting on Abutment Walls: $w_{abut.RCC} = 9.45\ m$

Projected Width of soil acting on Abutment Footing: $w_{FTG.RCC} = 12.2\ m$

At-Rest Soil Load on Top of Footing Slab: $\sigma_{act.RCC.w.UN3} := \left(K_{o.UN3} \cdot d_{act.RCC.w}\right) \cdot \left(\gamma_r - \gamma_w\right) = 37.3 \cdot kPa$

At-Rest Soil Load on Bottom of Approach Slab: $\sigma_{act.RCC.f.UN3} := \left(K_{o.UN3} \cdot d_{act.RCC.f}\right) \cdot \left(\gamma_r - \gamma_w\right) = 69.38 \cdot kPa$

At-Rest Soil Load on Abutment Walls: $E_{act.a.UN3.z} := \frac{\left(K_{o.UN3} \cdot d_{act.RCC.w}^{2}\right)}{2} \cdot \left(\gamma_r - \gamma_w\right) \cdot w_{abut.RCC} \cdot -1 = -819.45 \cdot kN$

Acting at: $E_{act.a.UN3.z.loc.y} := \frac{d_{DS.a}}{3} + T_{as} = 4.00\ m$

Acting at (from Toe Line): $E_{act.a.UN3.z.loc.x} := \frac{\left(L_{wall} + r_{wall} - 6.35m\right)}{2} + 6.35m = 11.18\ m$

At-Rest Soil Load on Abutment Footing (Rect): $E_{act.as.rect.UN3.z} := \sigma_{act.RCC.w.UN3} \cdot \left(T_{as}\right) \cdot w_{abut.RCC} \cdot -1 = -1409.81 \cdot kN$

At-Rest Soil Load on Abutment Footing (Tri): $E_{act.as.tri.UN3.z} := \frac{-\left(\sigma_{act.RCC.f.UN3} - \sigma_{act.RCC.w.UN3}\right) \cdot \left(T_{as}\right)}{2} \cdot w_{FTG.RCC} = -782.83 \cdot kN$

At-Rest Soil Load on Approach Slab: $E_{act.as.UN3.z} := E_{act.as.rect.UN3.z} + E_{act.as.tri.UN3.z} = -2192.64 \cdot kN$

Acting at: $E_{act.as.UN3.z.loc.y} := \frac{\left(E_{act.as.rect.UN3.z} \cdot \frac{T_{as}}{2} \ldots + E_{act.as.tri.UN3.z} \cdot \frac{T_{as}}{3}\right)}{E_{act.as.UN3.z}} = 1.76\ m$

Acting at (from toe line): $E_{act.as.UN3.z.loc.x} := \frac{\left(L_{wall} + r_{wall} - 6.35m\right)}{2} + 6.35m = 11.18\ m$

Lateral Z-Direction Driving Force (Headwater Side - After Gates & Aux. Spillway RCC - at rest condition) **UN3 CASE**

Max. Top of R.C.C. Wall: $TORCC_{max} = 1215.8\ m$

Min. Top of R.C.C. Wall: $TORCC_{min} = 1214\ m$

Average Top of R.C.C. Wall Elevation: $TORCC = 1214.9\ m$

Width of Soil acting at Max. top of RCC: $w_{RCC.max} = 4.7\ m$

Width of Soil acting with average Top of RCC (Steps): $w_{RCC.avg} = 1.65\ m$

Depth of Top of Soil to Top of R.C.C. Wall: $d_{act.RCC} = 0.7\ m$

Depth of Top of Soil to Average Top of R.C.C. Wall (Steps): $d_{act.RCC.avg} = 1.6\ m$

At-Rest Soil Load on Abutment Walls after RCC:

$$E_{act.RCC.UN3.z} := \frac{\left(K_{o.UN3} \cdot d_{act.RCC}^{\ 2}\right)}{2} \cdot \left(\gamma_r - \gamma_w\right) \cdot w_{RCC.max} \cdot -1 = -9.24 \cdot kN$$

Acting at:

$$E_{act.RCC.UN3.z.loc.y} := \frac{d_{act.RCC}}{3} + \left(TORCC_{max} - BOF_{elev}\right) = 10.03\ m$$

Acting at (from Toe Line): $E_{act.RCC.UN3.z.loc.x} := 4m$ (at SS-Axis Center Line)

At-Rest Soil Load on Abutment Walls at RCC Steps:

$$E_{act.RCC.s.UN3.z} := \frac{\left(K_{o.UN3} \cdot d_{act.RCC.avg}^{\ 2}\right)}{2} \cdot \left(\gamma_r - \gamma_w\right) \cdot w_{RCC.avg} \cdot -1 = -16.94 \cdot kN$$

Acting at:

$$E_{act.RCC.s.UN3.z.loc.y} := \frac{d_{act.RCC.avg}}{3} + \left(TORCC - BOF_{elev}\right) = 9.43\ m$$

Acting at (from Toe Line):

$$E_{act.RCC.s.UN3.z.loc.x} := \frac{4m - 2.35m}{2} = 0.83\ m$$

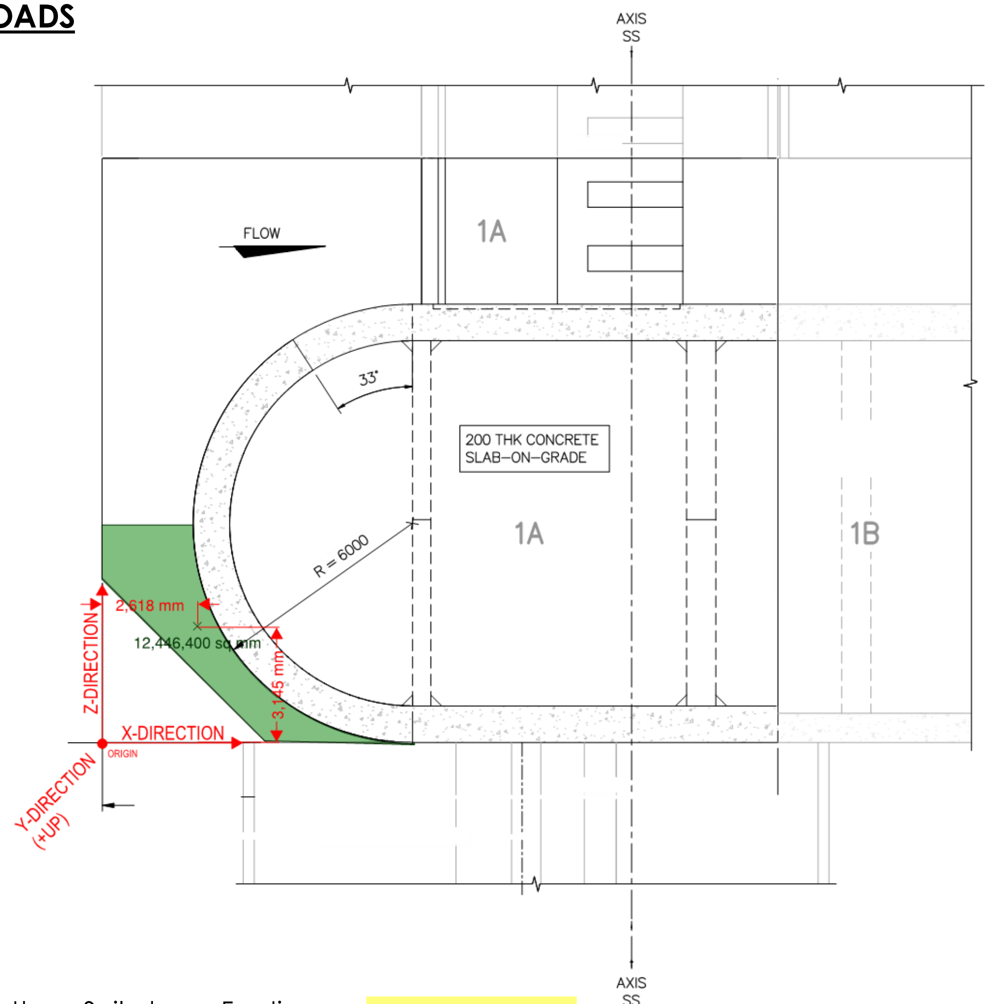
(at Halfway point of RCC Steps)

$$\Sigma H_{soil.UN3.z} := \left(E_{act.a.UN3.z} + E_{act.as.UN3.z} + E_{act.RCC.UN3.z} + E_{act.RCC.s.UN3.z}\right) = -3038.27 \cdot kN$$

$$\Sigma M_{soil.UN3.z} := E_{act.a.UN3.z} \cdot E_{act.a.UN3.z.loc.y} + E_{act.as.UN3.z} \cdot E_{act.as.UN3.z.loc.y} \cdots + E_{act.RCC.UN3.z} \cdot E_{act.RCC.UN3.z.loc.y} + E_{act.RCC.s.UN3.z} \cdot E_{act.RCC.s.UN3.z.loc.y} = -7393.67 \cdot kN \cdot m$$

VERTICAL SOIL LOADS

UN3 CASE



Average Depth on Soil above Footing: $d_{RCC.FTG} = 4.65\ m$

Area of Footing with Soil above: $A_{ftg.soil} = 0$ (From Bluebeam REVU)

Vertical Water Weight (H1) on Approach Slab: $E_{1.UN3} := \left(A_{ftg.soil} \cdot d_{RCC.FTG}\right) \cdot \left(\gamma_r - \gamma_w\right) = 0.0 \cdot kN$

Moment Arm for Applicaiton of Water Weight (H1) from toe (X-Direction): $E_{1.UN3.loc.x} := L_B - 5.607m = 12.89\ m$ (From Geom. Scaled on REVU)

Moment Arm for Applicaiton of Water Weight (H1) from toe (Z-Direction): $E_{1.UN3.loc.z} := W_B - 3.145m = 12.86\ m$ (From Geom. Scaled on REVU)

$\Sigma E_{UN3} := E_{1.UN3} = 0 \cdot kN$ $\Sigma M_{E.UN3.x} := E_{1.UN3} \cdot E_{1.UN3.loc.x} = 0 \cdot kN \cdot m$ $\Sigma M_{E.UN3.z} := E_{1.UN3} \cdot E_{1.UN3.loc.z} = 0 \cdot kN \cdot m$

IMPACT LOADS (DEBRIS LOADING FROM MEMO)

Total Impact Load on Structure: $I_{UN3} := 1975kN$ (SS Abutment) - 1000 Year Design Flood

Apply Ice load at: $I_{UN3.loc.y} := \left(HW_{UN3} - BOF_{elev} - 0.30m\right) = 10.70\ m$

$\Sigma H_{I.UN3} := I_{UN3} = 1975 \cdot kN$

$\Sigma M_{I.UN3} := I_{UN3} \cdot I_{UN3.loc.y} = 21132.5 \cdot kN \cdot m$

SEISMIC LOAD (NOT APPLICABLE FOR THIS LOAD CASE)

UN3 CASE

SUMMARY OF LOADS

	Loads	Moment Arm	
Dead load of Concrete Structure:	$D_{conc} = 35947.6 \cdot kN$	$X_{conc.loc} = 8.81\ m$	$Z_{conc.loc} = 8.46\ m$
Obermyer Gate Weight:	$D_{Gate} = 56.0 \cdot kN$	$X_{gate} = 9.50\ m$	$Z_{gate} = 2.00\ m$
Dead load of Fill:	$D_{fill} = 18056.6 \cdot kN$	$X_{fill.loc} = 7.31\ m$	$Z_{fill.loc} = 10.00\ m$
HW Lateral Load on Abutment:	$H_{hwa.UN3} = -2884.1 \cdot kN$	$H_{hwa.UN3.loc} = 6.33\ m$	
HW Lateral Load on Approach Slab:	$H_{hwas.UN3} = -5650.6 \cdot kN$	$H_{hwas.UN3.loc} = 1.85\ m$	
HW Lateral Load on Guard Gate:	$H_{hwgg.UN3} = 0.0 \cdot kN$	$H_{hwgg.UN3.loc} = 4.00\ m$	
TW Lateral Load on Abutment:	$H_{twa.UN3} = 805.8 \cdot kN$	$H_{twa.UN3.loc} = 5.23\ m$	
TW Lateral Load on Pier Footing:	$H_{twgf.UN3} = 1789.34 \cdot kN$	$H_{twgf.UN3.loc} = 1.77\ m$	
TW Lateral Load on Guard Gate:	$H_{twgg.UN3} = 0.0 \cdot kN$	$H_{twgg.UN3.loc} = 4.00\ m$	
Vertical HW Load on Approach Slab:	$H_{1.UN3} = 5469.2 \cdot kN$	$H_{1.UN3.loc.x} = 14.42\ m$	$H_{1.UN3.loc.z} = 4.73\ m$
Vertical TW Load on Pier Footing (crest):	$H_{2.UN3} = 2184.9 \cdot kN$	$H_{2.UN3.loc.x} = 5.34\ m$	$H_{2.UN3.loc.z} = 2.00\ m$
Uplift:	$U_{UN3} = -26957.0 \cdot kN$	$U_{UN3.loc.x} = 10.04\ m$	$U_{UN3.loc.z} = 8.24\ m$
X-Direction Lateral Soil Load on Abutment (driving):	$E_{act.a.UN3.x} = 0.0 \cdot kN$	$E_{act.a.UN3.x.loc.y} = 2.00\ m$	
X-Direction Lateral Lateral Soil Load on Approach Slab (driving):	$E_{act.as.UN3.x} = -1026.7 \cdot kN$	$E_{act.as.UN3.x.loc.y} = 1.33\ m$	
Lateral Soil Load (resisting):	$E_{pass.UN3.x} = 2880.26 \cdot kN$	$E_{pass.UN3.x.loc.y} = 2.83\ m$	
Z-Direction Lateral Soil Load on Abutment Before RCC (driving):	$E_{act.a.UN3.z} = -819.5 \cdot kN$	$E_{act.a.UN3.z.loc.y} = 4.00\ m$	
Z-Direction Lateral Lateral Soil Load on Approach Slab Before RCC (driving):	$E_{act.as.UN3.z} = -2192.6 \cdot kN$	$E_{act.as.UN3.z.loc.y} = 1.76\ m$	
Z-Direction Lateral Soil Load on Abutment After RCC (driving):	$E_{act.RCC.UN3.z} = -9.24 \cdot kN$	$E_{act.RCC.UN3.z.loc.y} = 10.03\ m$	
Z-Direction Lateral Soil Load on Abutment at RCC Steps (driving):	$E_{act.RCC.s.UN3.z} = -16.94\ kN$	$E_{act.RCC.s.UN3.z.loc.y} = 9.43 \cdot m$	
Vertical Soil Load on Footing:	$E_{1.UN3} = 0 \cdot kN$	$E_{1.UN3.loc.x} = 12.89\ m$	$E_{1.UN3.loc.z} = 12.86\ m$
Ice / Impact Load:	$I_{UN3} = 1975.0 \cdot kN$	$I_{UN3.loc.y} = 10.70\ m$	

STABILITY ASSESSMENT (SLIDNG, BEARING, FLOTATION AND OVERTURNING): UN3 CASE

CHECK SLIDING (X-Direction & Z-Direction) ALONG HORIZONTAL PLANE THRU TOE, IGNORING BEDROCK MOBILIZED BY STRUCTURAL HEEL KEY, OR VOID BEHIND KEY

Sum of Vertical Forces:

$$\Sigma V_{UN3} := \Sigma V_{DL} + \Sigma V_{water.UN3} + \Sigma E_{UN3} = 34757.3 \cdot kN$$

Sum of Horizontal Forces (X-Direction):

$$\Sigma H_{UN3.x} := \Sigma H_{Water.UN3.x} + \Sigma H_{soil.UN3.x} + \Sigma H_{I.UN3} = -2110.96 \cdot kN$$

Sum of Horizontal Forces (Z-Direction):

$$\Sigma H_{UN3.z} := \Sigma H_{Water.UN3.z} + \Sigma H_{soil.UN3.z} = -3038.27 \cdot kN$$

Sum of Horizontal Forces (resultant):

$$\Sigma H_{UN3} := \sqrt{\Sigma H_{UN3.x}{}^2 + \Sigma H_{UN3.z}{}^2} = 3699.62 \cdot kN$$

Sliding Factor of Safety:

$$FS_{HorizSliding.UN3.x} := \frac{\tan_{\phi} \cdot \Sigma V_{UN3}}{\left|\Sigma H_{UN3.x}\right|} = 8.03 \qquad FS_{HorizSliding.UN3.z} := \frac{\tan_{\phi} \cdot \Sigma V_{UN3}}{\left|\Sigma H_{UN3.z}\right|} = 5.58$$

Sliding Factor of Safety:

$$FS_{HorizSliding.UN3} := \frac{\tan_{\phi} \cdot \Sigma V_{UN3}}{\sqrt{\Sigma H_{UN3.x}{}^2 + \Sigma H_{UN3.z}{}^2}} = 4.58$$

$$FS_{HorizSliding.UN3.Check.x} := \begin{cases} \text{"OKAY"} & \text{if } FS_{HorizSliding.UN3.x} \geq FS_{req.UN3.sl} \\ \text{"Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

$$FS_{HorizSliding.UN3.Check.z} := \begin{cases} \text{"OKAY"} & \text{if } FS_{HorizSliding.UN3.z} \geq FS_{req.UN3.sl} \\ \text{"Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

$$FS_{HorizSliding.UN3.Check} := \begin{cases} \text{"OKAY"} & \text{if } FS_{HorizSliding.UN3} \geq FS_{req.UN3.sl} \\ \text{"Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

CHECK FOUNDATION BEARING CAPACITY

Sum of the Moments (X-Direction):

$$\Sigma M_{UN3.x} := \Sigma M_{DL.x} + \Sigma M_{HWater.UN3.x} + \Sigma M_{Vwater.UN3.x} + \Sigma M_{I.UN3} + \Sigma M_{soil.UN3.x} = 275921 \cdot kN \cdot m$$

Eccentricity:

$$e_{UN3.x} := X_{BCG} - \frac{\Sigma M_{UN3.x}}{\Sigma V_{UN3}} = 1.04\ m$$

Eccentricity Check:

$$e_{check.UN3.x} := \begin{cases} \text{"Okay"} & \text{if } e_{UN3.x} \leq Kern_x \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} \qquad e_{check.UN3.x} = \text{"Okay"}$$

Foundation Bearing Pressures (X-Direction):

UN3 CASE

Bearing Pressure at Heel:

$$\sigma_{heel.UN3.x} := \frac{\Sigma V_{UN3}}{A_b} - \frac{\Sigma V_{UN3} \cdot e_{UN3.x}}{S_{bx.L}} = 77.58 \cdot \frac{kN}{m^2}$$

$$\sigma_{heel.UN3.check.x} := \left(\begin{array}{ll} \text{"Okay"} & \text{if } 0 \le \sigma_{heel.UN3.x} \le \sigma_{allow.UN3} \\ \text{"Revise Structure"} & \text{otherwise} \end{array} \right)$$

$$\sigma_{heel.UN3.check.x} = \text{"Okay"}$$

Bearing Pressure at Toe:

$$\sigma_{toe.UN3.x} := \frac{\Sigma V_{UN3}}{A_b} + \frac{\Sigma V_{UN3} \cdot e_{UN3.x}}{S_{bx.R}} = 163.05 \cdot \frac{kN}{m^2}$$

$$\sigma_{toe.UN3.check.x} := \begin{array}{ll} \text{"Okay"} & \text{if } 0 \le \sigma_{toe.UN3.x} \le \sigma_{allow.UN3} \\ \text{"Revise Structure"} & \text{otherwise} \end{array}$$

$$\sigma_{toe.UN3.check.x} = \text{"Okay"}$$

Sum of the Moments (Z-Direction):

$$\Sigma M_{UN3.z} := \Sigma M_{DL.z} + \Sigma M_{HWater.UN3.z} + \Sigma M_{Vwater.UN3.z} + \Sigma M_{soil.UN3.z} = 285458 \cdot kN \cdot m$$

Eccentricity:

$$e_{UN3.z} := Z_{BCG} - \frac{\Sigma M_{UN3.z}}{\Sigma V_{UN3}} = -0.44\ m$$

Eccentricity Check:

$$e_{check.UN3.z} := \begin{array}{ll} \text{"Okay"} & \text{if } e_{UN3.z} \le Kern_z \\ \text{"Revise Structure"} & \text{otherwise} \end{array}$$

$$e_{check.UN3.z} = \text{"Okay"}$$

Foundation Bearing Pressures (Z-Direction):

Bearing Pressure at Heel:

$$\sigma_{heel.UN3.z} := \frac{\Sigma V_{UN3}}{A_b} - \frac{\Sigma V_{UN3} \cdot e_{UN3.z}}{S_{bz.b}} = 143.2 \cdot \frac{kN}{m^2}$$

$$\sigma_{heel.UN3.check.z} := \left(\begin{array}{ll} \text{"Okay"} & \text{if } 0 \le \sigma_{heel.UN3.z} \le \sigma_{allow.UN3} \\ \text{"Revise Structure"} & \text{otherwise} \end{array} \right)$$

$$\sigma_{heel.UN3.check.z} = \text{"Okay"}$$

Bearing Pressure at Toe:

$$\sigma_{toe.UN3.z} := \frac{\Sigma V_{UN3}}{A_b} + \frac{\Sigma V_{UN3} \cdot e_{UN3.z}}{S_{bz.t}} = 101.17 \cdot \frac{kN}{m^2}$$

$$\sigma_{toe.UN3.check.z} := \begin{array}{ll} \text{"Okay"} & \text{if } 0 \le \sigma_{heel.UN3.z} \le \sigma_{allow.UN3} \\ \text{"Revise Structure"} & \text{otherwise} \end{array}$$

$$\sigma_{toe.UN3.check.z} = \text{"Okay"}$$

UN3 CASE

Foundation Bearing Pressure (Combined):

Linear pressure superimposed at Corners by both Moment_X and Moment_Z

Bearing Pressure at Heel(x)-Heel(z):

$$\sigma_{heel.UN3} := \frac{\Sigma V_{UN3}}{A_b} - \frac{\Sigma V_{UN3} \cdot e_{UN3.x}}{S_{bx.L}} - \frac{\Sigma V_{UN3} \cdot e_{UN3.z}}{S_{bz.b}} = 99.2 \cdot kPa$$

$$\sigma_{heel.UN3.check} := \begin{cases} \text{"Okay"} & \text{if } 0 \le \sigma_{heel.UN3} \le \sigma_{allow.UN3} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$\sigma_{heel.UN3.check} = \text{"Okay"}$

Bearing Pressure at Toe(x)-Toe(z):

$$\sigma_{toe.UN3} := \frac{\Sigma V_{UN3}}{A_b} + \frac{\Sigma V_{UN3} \cdot e_{UN3.x}}{S_{bx.R}} + \frac{\Sigma V_{UN3} \cdot e_{UN3.z}}{S_{bz.t}} = 142.64 \cdot kPa$$

$$\sigma_{toe.UN3.check} := \begin{cases} \text{"Okay"} & \text{if } 0 \le \sigma_{toe.UN3} \le \sigma_{allow.UN3} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$\sigma_{toe.UN3.check} = \text{"Okay"}$

Bearing Pressure at Heel(x)-Toe(z):

$$\sigma_{heeltoe.UN3} := \frac{\Sigma V_{UN3}}{A_b} - \frac{\Sigma V_{UN3} \cdot e_{UN3.x}}{S_{bx.L}} + \frac{\Sigma V_{UN3} \cdot e_{UN3.z}}{S_{bz.t}} = 57.17 \cdot kPa$$

$$\sigma_{heeltoe.UN3.check} := \begin{cases} \text{"Okay"} & \text{if } 0 \le \sigma_{heeltoe.UN3} \le \sigma_{allow.UN3} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$\sigma_{heeltoe.UN3.check} = \text{"Okay"}$

Bearing Pressure at Toe(x)-Heel(z):

$$\sigma_{toeheel.UN3} := \frac{\Sigma V_{UN3}}{A_b} + \frac{\Sigma V_{UN3} \cdot e_{UN3.x}}{S_{bx.R}} - \frac{\Sigma V_{UN3} \cdot e_{UN3.z}}{S_{bz.b}} = 184.67 \cdot kPa$$

$$\sigma_{toeheel.UN3.check} := \begin{cases} \text{"Okay"} & \text{if } 0 \le \sigma_{toeheel.UN3} \le \sigma_{allow.UN3} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$\sigma_{toeheel.UN3.check} = \text{"Okay"}$

FLOATATION ANALYSIS:

ACCEPTANCE PARAMETERS

Required Factor of Safety: $FS_{req.FUN3} := 1.3$

VERTICAL LOADS RESISTING:

Dead Load: $\Sigma V_{DL} = 54060.17 \cdot kN$

Water Weight H1+H2: $\Sigma V_{H.FUN3} := H_{1.UN3} + H_{2.UN3} = 7654.11 \cdot kN$

Summation Vertical Resisting: $\Sigma V_{FUN3} := \Sigma V_{DL} + \Sigma V_{H.FUN3} = 61714.3 \cdot kN$

VERTICAL LOADS UPLIFT:

Uplift: $U_{UN3} = -26956.997 \cdot kN$

Factor of Safety Floatation:

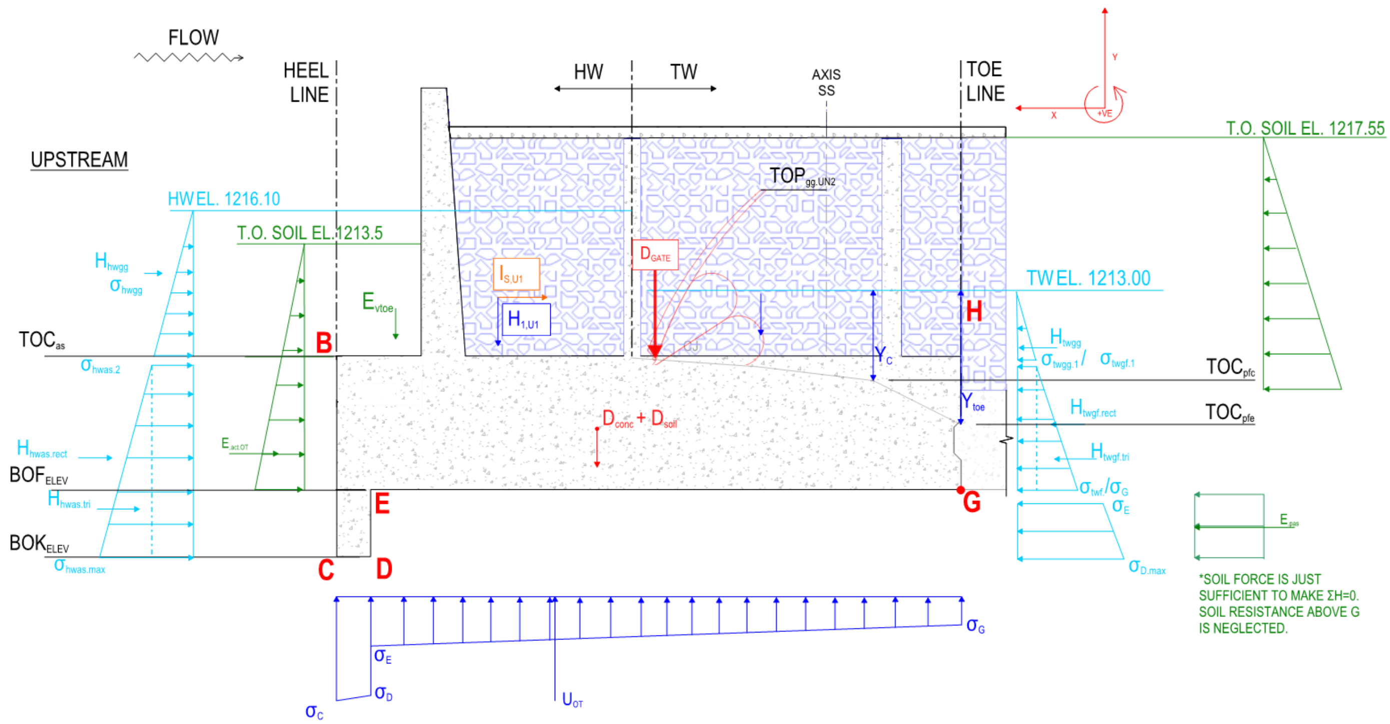
$$FS_{act.FUN3} := \frac{\Sigma V_{FUN3}}{\left| U_{UN3} \right|} = 2.29$$

$$FS_{check.FUN3} := \begin{cases} \text{"OKAY"} & \text{if } FS_{act.FUN3} \ge FS_{req.FUN3} \\ \text{"ANCHORS REQUIRED"} & \text{if } FS_{act.FUN3} < FS_{req.FUN3} \end{cases} = \text{"OKAY"}$$

MONOLITH OVERTURNING STABILITY ANALYSIS

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.
Assumptions are made in order to compute overturning stablity of indetermine forces on monolith with key;
(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.
(b) The horizontal resisting force acting on the key, P.key, is that required for staticequilibrium
(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1 $Ratio_{OT.UN3.min} := 0.333$ at Rock Foundation



Uplift Loads for Overturning Stability Analysis (X-Direction)

Line of Creep:

Change in Water Head: $\Delta_{h.UN3} := HW_{UN3} - TW_{UN3} = 3.3\,m$

Length from Point C to Point G: $L_{CG} = 18.61\,m$

Length from Various Points to Points: $L_{CD} = 1\,m$ $L_{DE} = 2\,m$ $L_{EG} = 17.5\,m$

$L_{GH.UN3} := TW_{UN3} - TOC_{afe} = 5.7\,m$

Length from Point C, D, E to G: $L_{CDEG} = 20.5\,m$ $L_{CDE} = 3\,m$

Water Pressure at Point C & G: $\sigma_{C.UN3} := \sigma_{hwas.UN3.2} = -107.91 \cdot kPa$ $\sigma_{G.UN3} := \sigma_{twtoe.UN3} \cdot -1 = -75.54 \cdot kPa$

Water Pressure at Point D:

$$\sigma_{D.UN3} := -\gamma_w \cdot \left[\left(HW_{UN3} - BOK_{elev}\right) - \frac{\Delta_{h.UN3} \cdot L_{CD}}{L_{CDEG}}\right] = -125.95 \cdot kPa$$

Water Pressure at Point E:

$$\sigma_{E.UN3} := -\gamma_w \cdot \left[\left(HW_{UN3} - BOF_{elev}\right) - \frac{\Delta_{h.UN3} \cdot L_{CDE}}{L_{CDEG}}\right] = -103.17 \cdot kPa$$

Uplift for Overturning Analysis on Bottom of Key:

$$U_{OT.UN3.key} := \frac{\sigma_{C.UN3} + \sigma_{D.UN3}}{2} \cdot L_{CD} \cdot W_B = -1870.89 \cdot kN$$

Acting at:

$$U_{OT.UN3.key.loc} := \frac{L_{CD} \cdot \left(2 \cdot \sigma_{C.UN3} + \sigma_{D.UN3}\right)}{3\left(\sigma_{C.UN3} + \sigma_{D.UN3}\right)} + L_{EG} = 17.99\,m$$

Uplift for Overturning Analysis on Bottom of Footing:

$$U_{OT.UN3.ftg} := \frac{\sigma_{E.UN3} + \sigma_{G.UN3}}{2} \cdot L_{EG} \cdot W_B = -25019.33 \cdot kN$$

UN3 CASE

Acting at:

$$U_{OT.UN3.ftg.loc} := \frac{L_{EG} \cdot \left(\sigma_{G.UN3} + 2 \cdot \sigma_{E.UN3}\right)}{3\left(\sigma_{G.UN3} + \sigma_{E.UN3}\right)} = 9.2\,m$$

Uplift Load for Overtuming Analysis:

$$U_{OT.UN3} := U_{OT.UN3.key} + U_{OT.UN3.ftg} = -26890.21 \cdot kN$$

Uplift Load Acting from Toe:

$$U_{OT.UN3.loc} := \frac{U_{OT.UN3.key} \cdot U_{OT.UN3.key.loc} + U_{OT.UN3.ftg} \cdot U_{OT.UN3.ftg.loc}}{U_{OT.UN3}} = 9.81\,m$$

All Vertical Loads Appliable to Overturning Stability Analysis

Total Concrete Dead Loads:	$D_{conc} = 35947.58 \cdot kN$	at:	$X_{conc.loc} = 8.81\,m$
Dead Load of Gate:	$D_{Gate} = 56.0 \cdot kN$		$X_{gate} = 9.50\,m$
Total Fill Loads:	$D_{fill} = 18056.6 \cdot kN$		$X_{fill.loc} = 7.31\,m$
Water Weight (HW) on Apron Slab:	$H_{1.UN3} = 5469.2 \cdot kN$		$H_{1.UN3.loc.x} = 14.42\,m$
Water Weight (TW) on Guard Gate Footing:	$H_{2.UN3} = 2184.9 \cdot kN$		$H_{2.UN3.loc.x} = 5.34\,m$
Uplift Load for Overtuming Analysis:	$U_{OT.UN3} = -26890.21 \cdot kN$		$U_{OT.UN3.loc} = 9.81 \cdot m$

Sum of All Overturning Analysis Vertical Load:

$$\Sigma V_{UN3.OT} := D_{conc} + D_{Gate} + D_{fill} + H_{1.UN3} + H_{2.UN3} + U_{OT.UN3} = 34824.06 \cdot kN$$

Sum of All Overturning Analysis Vertical Load Moments:

$$\Sigma M_{V.UN3.OT} := \begin{pmatrix} D_{conc} \cdot X_{conc.loc} + D_{Gate} \cdot X_{gate} + D_{fill} \cdot X_{fill.loc} + H_{1.UN3} \cdot H_{1.UN3.loc.x} \cdots \\ + H_{2.UN3} \cdot H_{2.UN3.loc.x} + U_{OT.UN3} \cdot U_{OT.UN3.loc} \end{pmatrix} = 276025.45 \cdot kN \cdot m$$

Lateral Tailwater Loads for Overturning Stability Analysis

TW Lateral Load on Gate Footing (No Key - Overturning Values Adjusted):

$$H_{twgf.UN3} = 1789.34 \cdot kN$$

Acting at:

$$H_{twgf.UN3.loc} = 1.77\,m$$

Horizontal Tailwater Pressure Top of Key (Overturning Analysis):

$$\sigma_{twtk.OT.UN3} := \sigma_{E.UN3} \cdot -1 = 103.17 \cdot kPa$$

Horizontal Tailwater Pressure Bottom of Key (Overturning Analysis):

$$\sigma_{twbk.OT.UN3} := \sigma_{D.UN3} \cdot -1 = 125.95 \cdot kPa$$

Triangular Distribution Unit Load Acting at Key:

$$H_{twbk.OT.UN3.tri} := \frac{\left(\sigma_{twbk.OT.UN3} - \sigma_{twtk.OT.UN3}\right)}{2} \cdot d_{key} \cdot W_{tw.UN3} = 364.45 \cdot kN$$

Triangular Distribution Unit Load Acting at Key:

$$H_{twbk.OT.UN3.rect} := \sigma_{twtk.OT.UN3} \cdot d_{key} \cdot W_{tw.UN3} = 3301.52 \cdot kN$$

Total Horizontal Tailwater Load on Key (Overturning Values Adjusted):

$$H_{twkey.OT.UN3} := H_{twbk.OT.UN3.tri} + H_{twbk.OT.UN3.rect} = 3665.97 \cdot kN$$

Acting at:

$$H_{twkey.OT.UN3.loc} := \frac{H_{twbk.OT.UN3.tri} \cdot \frac{-2 \cdot d_{key}}{3} + H_{twbk.OT.UN3.rect} \cdot \frac{-d_{key}}{2}}{H_{twkey.OT.UN3}} = -1.03 \cdot m$$

Lateral Driving Earth Loads for Overturning Stability Analysis (at rest condition)

UN3 CASE

Depth of Driving Soil Loads (to top of key): $h_{E.OT.UN3} := TOC_{as} - BOF_{elev} = 4\,m$

At-Rest Soil Load: $E_{act.OT.UN3} := \dfrac{\left(K_{o.UN3} \cdot h_{E.OT.UN3}^{2}\right)}{2} \cdot (\gamma_r - \gamma_w) \cdot W_{hwas.UN3} \cdot -1 = -1026.66 \cdot kN$

At Rest- Soil Load Acting from Toe: $E_{act.OT.UN3.loc} := \dfrac{h_{E.OT.UN3}}{3} = 1.33\,m$

All Lateral Loads Appliable to Overturning Stability Analysis (X-direction)

HW Lateral Load on Approach Slab:	$H_{hwas.UN3} = -5650.6 \cdot kN$	$H_{hwas.UN3.loc} = 1.85\,m$
HW Lateral Load on Guard Gate:	$H_{hwgg.UN3} = 0.0 \cdot kN$	$H_{hwgg.UN3.loc} = 4.00\,m$
HW Lateral Load on Abutment:	$H_{hwa.UN3} = -2884.1 \cdot kN$	$H_{hwa.UN3.loc} = 6.33\,m$
TW Lateral Load on Abutment:	$H_{twa.UN3} = 805.8 \cdot kN$	$H_{twa.UN3.loc} = 5.23\,m$
TW Lateral Load on Guard Gate:	$H_{twgg.UN3} = 0.0 \cdot kN$	$H_{twgg.UN3.loc} = 4.00\,m$
TW Lateral Load on Gate Footing (No Key - Overturning Values Adjusted):	$H_{twgf.UN3} = 1789.34 \cdot kN$	$H_{twgf.UN3.loc} = 1.77\,m$
TW Lateral Load on Key:	$H_{twkey.OT.UN3} = 3665.97 \cdot kN$	$H_{twkey.OT.UN3.loc} = -1.03\,m$
Ice / Impact Load:	$I_{UN3} = 1975.0 \cdot kN$	$I_{UN3.loc.y} = 10.70\,m$
Lateral Soil Load (driving):	$E_{act.OT.UN3} = -1026.7 \cdot kN$	$E_{act.OT.UN3.loc} = 1.33\,m$

Resisting Lateral Soil Load as required to produce horizontal equilibrium:

$$E_{pas.OT.x.UN3} := -\left(H_{hwas.UN3} + H_{hwgg.UN3} + H_{hwgg.UN3} + H_{twgg.UN3} \cdots + H_{twgf.UN3} + H_{twkey.OT.UN3} + I_{UN3} + E_{act.OT.UN3}\right) = -753.1 \cdot kN$$

Acting at:

$$E_{pas.OT.UN3.loc} := -1 \cdot \frac{d_{key}}{2} = -1\,m$$

Sum of All Overturning Analysis Horizontal Load (ΣH=0):

$$\Sigma H_{UN3.OT.x} := H_{hwas.UN3} + H_{hwgg.UN3} + H_{twgg.UN3} + H_{twgf.UN3} + H_{twkey.OT.UN3} + I_{UN3} + E_{act.OT.UN3} + E_{pas.OT.x.UN3} = -0 \cdot kN$$

Sum of All Overturning Analysis Horizontal Load Moments:

$$\begin{aligned}\Sigma M_{H.UN3.OT.x} := {} & H_{hwas.UN3} \cdot H_{hwas.UN3.loc} + H_{hwgg.UN3} \cdot H_{hwgg.UN3.loc} \cdots \\ & + H_{twgg.UN3} \cdot H_{twgg.UN3.loc} + H_{twgf.UN3} \cdot H_{twgf.UN3.loc} \cdots \\ & + H_{twkey.OT.UN3} \cdot H_{twkey.OT.UN3.loc} + I_{UN3} \cdot I_{UN3.loc.y} \cdots \\ & + E_{act.OT.UN3} \cdot E_{act.OT.UN3.loc} + E_{pas.OT.x.UN3} \cdot E_{pas.OT.UN3.loc} = 9425.39 \cdot kN \cdot m\end{aligned}$$

Overturning Stability Analysis (X-Direction)

$$\Sigma M_{UN3.OT.x} := \Sigma M_{V.UN3.OT} + \Sigma M_{H.UN3.OT.x} = 285450.84 \cdot kN \cdot m$$

$$X_{R.UN3} := \frac{\Sigma M_{UN3.OT.x}}{\Sigma V_{UN3.OT}} = 8.2\,m \qquad x_{OT.UN3} := X_{R.UN3} - \frac{L_B}{2} = -1.05\,m$$

Overturning Resultant Ratio

$$Ratio_{OT.x.UN3} := \frac{X_{R.UN3}}{L_B} = 0.44$$

$$Ratio_{OT.x.UN3.check} := \begin{cases} \text{"OKAY"} & \text{if } Ratio_{OT.x.UN3} \ge Ratio_{OT.UN3.min} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

$$x_{OT.check.UN3} := \begin{cases} \text{"OKAY"} & \text{if } \left|x_{OT.UN3}\right| \le Kern_x \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

All Lateral Loads Appliable to Overturning Stability Analysis (Z-direction)

UN3 CASE

Z-Direction Lateral Soil Load on Abutment Before RCC (driving): $E_{act.a.UN3.z} = -819.5 \cdot kN$ $E_{act.a.UN3.z.loc.y} = 4.00\ m$

Z-Direction Lateral Lateral Soil Load on Approach Slab Before RCC (driving): $E_{act.as.UN3.z} = -2192.6 \cdot kN$ $E_{act.as.UN3.z.loc.y} = 1.76\ m$

Z-Direction Lateral Soil Load on Abutment After RCC (driving): $E_{act.RCC.UN3.z} = -9.24 \cdot kN$ $E_{act.RCC.UN3.z.loc.y} = 10.03\ m$

Z-Direction Lateral Soil Load on Abutment at RCC Steps (driving): $E_{act.RCC.s.UN3.z} = -16.94 \cdot kN$ $E_{act.RCC.s.UN3.z.loc.y} = 9.43 \cdot m$

Resisting Lateral Soil Load as required to produce horizontal equilibrium:

$$E_{pas.OT.z.UN3} := -\left(E_{act.a.UN3.z} + E_{act.as.UN3.z} + E_{act.RCC.UN3.z} + E_{act.RCC.s.UN3.z}\right) = 3038.27 \cdot kN$$

Acting at:

$$E_{pas.OT.UN3.loc} = -1\ m$$

Sum of All Overturning Analysis Horizontal Load (ΣH=0):

$$\Sigma H_{UN3.OT.z} := E_{act.a.UN3.z} + E_{act.as.UN3.z} + E_{act.RCC.UN3.z} + E_{act.RCC.s.UN3.z} + E_{pas.OT.z.UN3} = 0 \cdot kN$$

Sum of All Overturning Analysis Horizontal Load Moments:

$$\Sigma M_{H.UN3.OT.z} := E_{act.a.UN3.z} \cdot E_{act.a.UN3.z.loc.y} + E_{act.as.UN3.z} \cdot E_{act.as.UN3.z.loc.y} \cdots + E_{act.RCC.UN3.z} \cdot E_{act.RCC.UN3.z.loc.y} + E_{act.RCC.s.UN3.z} \cdot E_{act.RCC.s.UN3.z.loc.y} \cdots + E_{pas.OT.x.UN3} \cdot E_{pas.OT.UN3.loc} = -6640.57 \cdot kN \cdot m$$

Overturning Stability Analysis (Z-Direction)

$$\Sigma M_{UN3.OT.z} := \Sigma M_{V.UN3.OT} + \Sigma M_{H.UN3.OT.z} = 269384.88 \cdot kN \cdot m$$

$$z_{R.UN3} := \frac{\Sigma M_{UN3.OT.z}}{\Sigma V_{UN3.OT}} = 7.74\ m \qquad z_{OT.UN3} := z_{R.UN3} - \frac{W_B}{2} = -0.26\ m$$

Overturning Resultant Ratio

$$Ratio_{OT.z.UN3} := \frac{z_{R.UN3}}{L_B} = 0.42$$

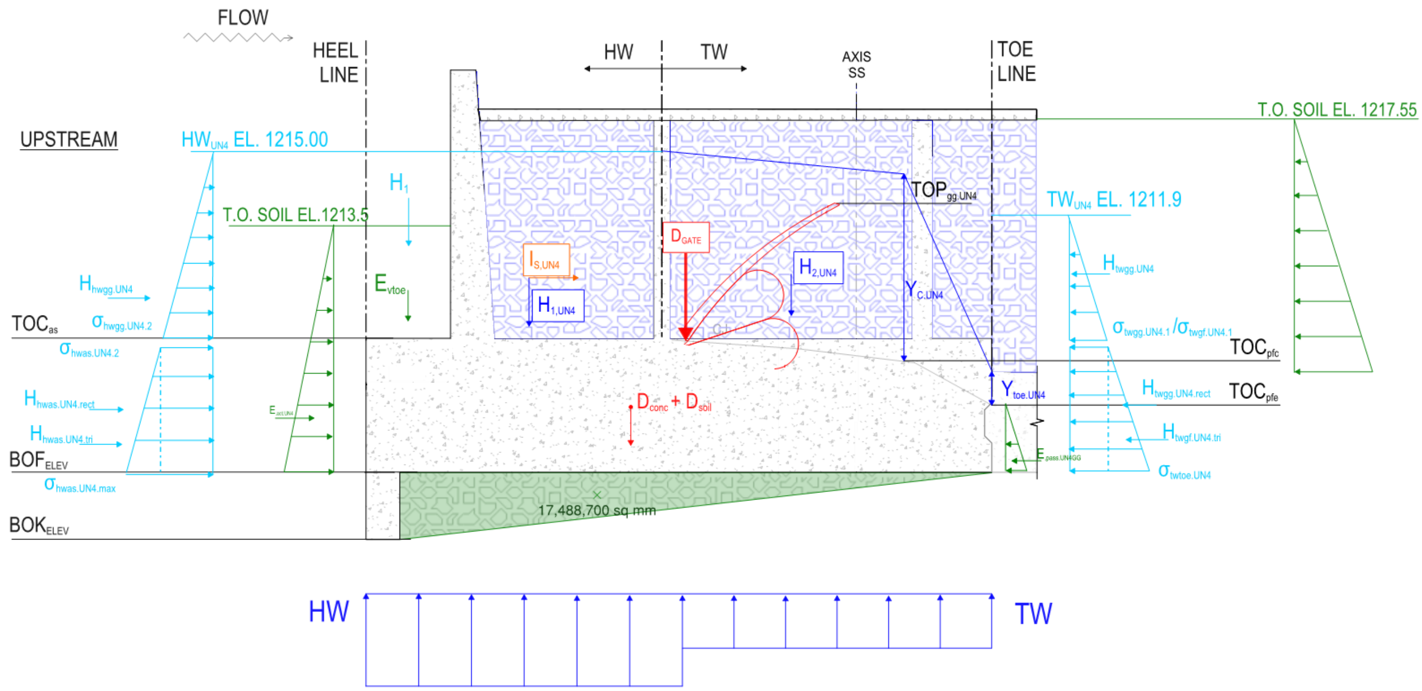
$$Ratio_{OT.z.UN3.check} := \begin{cases} \text{"OKAY"} & \text{if } Ratio_{OT.z.UN3} \geq Ratio_{OT.UN3.min} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

$$z_{OT.check.UN3} := \begin{cases} \text{"OKAY"} & \text{if } \left|z_{OT.UN3}\right| \leq Kern_z \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

SUMMARY OF STABILITY ASSESSMENT: UN3 CASE

Sliding Factor of Safety: (Horizontal Plane)	$FS_{HorizSliding.UN3} = 4.58$	$FS_{HorizSliding.UN3.Check}$ = "OKAY"
Flotation Factor of Safety (horizontal plane)	$FS_{act.FUN3} = 2.29$	$FS_{check.FUN3}$ = "OKAY"
Overturning Resultant Ratio: (X-direction)	$Ratio_{OT.x.UN3} = 0.44$	$Ratio_{OT.x.UN3.check}$ = "OKAY"
Overturning Resultant Ratio: (Z-direction)	$Ratio_{OT.z.UN3} = 0.42$	$Ratio_{OT.z.UN3.check}$ = "OKAY"
Eccentricity: (horizontal plane)	$x_{OT.UN3} = -1.05\ m$	$x_{OT.check.UN3}$ = "OKAY"
Eccentricity: (horizontal plane)	$z_{OT.UN3} = -0.26\ m$	$z_{OT.check.UN3}$ = "OKAY"
Bearing Pressure At Heel(x)- Heel(z): (horizontal plane)	$\sigma_{heel.UN3} = 99 \cdot kPa$	$\sigma_{heel.UN3.check}$ = "Okay"
Bearing Pressure At Toe(x)-Toe(z): (horizontal plane)	$\sigma_{toe.UN3} = 143 \cdot kPa$	$\sigma_{toe.UN3.check}$ = "Okay"
Bearing Pressure at Heel(x)-Toe(z): (horizontal plane)	$\sigma_{heeltoe.UN3} = 57 \cdot kPa$	$\sigma_{heeltoe.UN3.check}$ = "Okay"
Bearing Pressure at Toe(x)-Heel(z): (horizontal plane)	$\sigma_{toeheel.UN3} = 185 \cdot kPa$	$\sigma_{toe.UN3.check}$ = "Okay"

UN4 DESIGN CASE



ACCEPTANCE PARAMETERS

Required Factor of Safety for Sliding:	$FS_{req.UN4.sl} := 1.3$	(Without Cohesion)
		(Section 8.1, Design Criteria)
Resultant Within Middle Third of Base:	$e \leq \frac{L_B}{6} \wedge e \geq \frac{-L_B}{6}$	
Allowable Rock Bearing Pressure:	$\sigma_{allow.UN4} := 1270 \cdot \frac{kN}{m^2}$	(Section 5.2, Design Criteria)
Required Factor of Safety for Flotation:	$FS_{req.UN4.flt} := 1.3$	

INPUT PARAMETERS

Headwater Elevation:	$HW_{UN4} := 1215.0m$	(Section 8.2, Design Criteria)
Tailwater Elevation:	$TW_{UN4} := 1211.9m$	(Section 8.2, Design Criteria)
Bottom of Footing Elevation:	$BOF_{elev} = 1206\,m$	
Approch Slab Top of Concrete Elevation at Upstream Face:	$TOC_{as} = 1210\,m$	
Abutment Footing Top of Concrete Elevation at Stilling Basin:	$TOC_{afe} = 1208\,m$	
Abutment Footing Top of Concrete Elevation at Footing:	$TOC_{afc} = 1209.73\,m$	Gates are open when top of gate elevation is at 1210.00m
Abutment Footing Top of Concrete Elevation at Footing Notch:	$TOC_{afc.n} = 1209.3\,m$	
Top of Guard Gate Elevation:	$TOP_{gg.UN4} := 1215.0m$	Gates are closed/up when top of gate elevation is at 1215.0m
Bottom of Key Elevation:	$BOK_{elev} = 1204\,m$	

UN4 CASE

Water Elevation above Crest of Guard Gate:

$EL_{C.UN4} := 1211.9m$

$$Y_{C.UN4} := \begin{cases} (EL_{C.UN4} - TOC_{afc.n}) & \text{if } TOP_{gg.UN4} \le HW_{UN4} \\ (TW_{UN4} - TOC_{afc.n}) & \text{if } TOP_{gg.UN4} > HW_{UN4} \end{cases} = 2.6 \cdot m$$

Water Elevation above Guard Gate Toe: Submerged by Hydraulic 2D Model

$EL_{TOE.UN4} := 1211.9m$

$$Y_{TOE.UN4} := \begin{cases} (EL_{TOE.UN4} - TOC_{afe}) & \text{if } TOP_{gg.UN4} \le HW_{UN4} \\ (TW_{UN4} - TOC_{afe}) & \text{if } TOP_{gg.UN4} > HW_{UN4} \end{cases} = 3.9 \cdot m$$

This load case is the Construction / Maintenance / Single Gate Bay Dewatered Load Case. One bay is open, while the other has been blocked off for gate maintenance.

CREST GATE (OBERMEYER)

Dead Load of Gates: $D_{Gate.UN4} := 70kN$ Vendor dwgs. Q-200 Series

DEAD LOAD SUMMATION:

$\Sigma V_{DL.UN4} := D_{conc} + D_{Gate.UN4} = 36017.6 \cdot kN$

$\Sigma M_{DL.UN4} := D_{conc} \cdot X_{conc.loc} + D_{Gate.UN4} \cdot X_{gate} = 317477.8 \cdot kN \cdot m$

LATERAL WATER LOADS

HEADWATER (DRIVING X-DIRECTION):

Headwater Depth on Abutment: $D_{hwa.UN4} := HW_{UN4} - TOC_{as} = 5.00\ m$

Headwater Load Unit Width Projected Surface Area of Abutment: $W_{hwa.UN4} := 2 \cdot r_{wall} = 12.00\ m$

Total Horizontal Headwater Load on Abutment:

$$H_{hwa.UN4} := \frac{-\left(\gamma_w \cdot D_{hwa.UN4}{}^2\right)}{2} \cdot W_{hwa.UN4} = -1471.5 \cdot kN$$

Apply Total Abutment Headwater Load at:

$$H_{hwa.UN4.loc} := \frac{D_{hwa.UN4}}{3} + \left(TOC_{as} - BOF_{elev}\right) = 5.67\ m$$

Apply Total Abutment Headwater Load at (from toe):

$H_{hwa.UN4.loc.z} := 4m + r_{wall} = 10.00\ m$ (Gate Footing + Radius of Wall)

Thickness of Approach Slab: $T_{as} = 4\ m$

Headwater Depth at Heel (U/S face): $D_{hwas.UN4} := HW_{UN4} - BOF_{elev} = 9.00\ m$

Headwater Load Unit Width on Projected Approach Slab: $W_{hwas.UN4} := W_B = 16.00\ m$

Headwater Line Load At Top of Approach Slab: $\sigma_{hwas.UN4.1} := -\left(\gamma_w \cdot D_{hwa.UN4}\right) = -49.05 \cdot kPa$

Headwater Line Load At Bottom of Approach Slab: $\sigma_{hwas.UN4.2} := -\left(\gamma_w \cdot D_{hwas.UN4}\right) = -88.29 \cdot kPa$

Trianglular Distribution Unit Load on Approach Slab:

$$H_{hwas.UN4.2.tri} := \left(\frac{\sigma_{hwas.UN4.2} - \sigma_{hwas.UN4.1}}{2}\right) \cdot \left(T_{as} \cdot W_{hwas.UN4}\right) = -1255.68 \cdot kN$$

Rectangular Distribution Unit Load on Approach Slab and Key:

$$H_{hwas.UN4.2.rect} := \sigma_{hwas.UN4.1} \cdot \left(T_{as} \cdot W_{hwas.UN4}\right) = -3139.2 \cdot kN$$

Total Horizontal Headwater Load on Approach Slab:

$$H_{hwas.UN4} := H_{hwas.UN4.2.tri} + H_{hwas.UN4.2.rect} = -4394.88 \cdot kN$$

Apply Total Footing Headwater Load at:

$$H_{hwas.UN4.loc} := \frac{\left[H_{hwas.UN4.2.rect} \cdot \frac{\left(T_{as}\right)}{2} + H_{hwas.UN4.2.tri} \cdot \frac{\left(T_{as}\right)}{3}\right]}{H_{hwas.UN4.2.tri} + H_{hwas.UN4.2.rect}} = 1.81\ m$$

Apply Total Footing Headwater Load at (from toe):

$$H_{hwas.UN4.loc.z} := \frac{W_B}{2} = 8.00\ m$$

Guard Gate (2A) Operating Condition: Right Gate at EL 1215.0

Guard Gate Down/Open Condition: $A1_{UN4} := TOP_{gg.UN4} \le TOC_{as}$

Guard Crest Gate Up/Closed, with Top of Gate Higher than HW Elevation: $B1_{UN4} := TOP_{gg.UN4} \ge HW_{UN4} \wedge TOP_{gg.UN4} > TOC_{as}$

Guard Crest Gate Up/Closed, with Top of Gate Lower than HW Elevation: $C1_{UN4} := TOP_{gg.UN4} > TOC_{as} \wedge HW_{UN4} > TOP_{gg.UN4}$

Guard Crest Gate Height: $H_{gg.UN4} := TOP_{gg.UN4} - TOC_{as} = 5\ m$

Headwater Depth at Guard Crest Gate: $D_{hwgg.UN4} := HW_{UN4} - TOC_{as} = 5.00\ m$

Guard Crest Gate Width: $W_{hwgg.UN4} := 4.00m$

Lateral Headwater Pressure at Bottom of Guard Crest Gate:

$$\sigma_{hwgg.UN4.1} := \begin{vmatrix} (0.0kPa) & \text{if } A1_{UN4} \\ -(\gamma_w \cdot D_{hwgg.UN4}) & \text{if } B1_{UN4} \\ -(\gamma_w \cdot D_{hwgg.UN4}) & \text{if } C1_{UN4} \end{vmatrix} = -49.0 \cdot kPa$$

Lateral Headwater Pressure at Top of Guard Crest Gate:
(Load at HW Elevation On Guard Crest Gate if HW is below TOG_{rg})

$$\sigma_{hwgg.UN4.2} := \begin{vmatrix} (0.0kPa) & \text{if } A1_{UN4} \\ 0.0kPa & \text{if } B1_{UN4} \\ -[\gamma_w \cdot (HW_{UN4} - TOP_{gg.UN4})] & \text{if } C1_{UN4} \end{vmatrix} = 0.0 \cdot kPa$$

Average Pressure acting on Guard Crest Gate:

$$\sigma_{hwgg.UN4.avg} := \frac{(\sigma_{hwgg.UN4.1} + \sigma_{hwgg.UN4.2})}{2} = -24.52 \cdot kPa$$

Total Area water acting on Crest Gate:

$$A_{hwgg.UN4} := \begin{vmatrix} D_{hwgg.UN4} \cdot W_{hwgg.UN4} & \text{if } A1_{UN4} \\ D_{hwgg.UN4} \cdot W_{hwgg.UN4} & \text{if } B1_{UN4} \\ H_{gg.UN4} \cdot W_{hwgg.UN4} & \text{if } C1_{UN4} \end{vmatrix} = 20 \cdot m^2$$

Total Horizontal Headwater Load on Guard Crest Gate: $H_{hwgg.UN4} := \sigma_{hwgg.UN4.avg} \cdot A_{hwgg.UN4} = -490.5 \cdot kN$

Apply Total Guard Crest Gate Headwater Load at:

$$H_{hwgg.UN4.loc} := \begin{vmatrix} (TOC_{as} - BOF_{elev}) & \text{if } A1_{UN4} \\ \left[\frac{(HW_{UN4} - TOC_{as})}{3} + (TOC_{as} - BOF_{elev})\right] & \text{if } B1_{UN4} \\ \left[\frac{\sigma_{hwgg.UN4.2} \cdot A_{hwgg.UN4} \cdot \frac{(H_{gg.UN4})}{2} + \frac{(\sigma_{hwgg.UN4.1} - \sigma_{hwgg.UN4.2})}{2} A_{hwgg.UN4} \cdot \frac{(H_{gg.UN4})}{3}}{\sigma_{hwgg.UN4.2} \cdot A_{hwgg.UN4} + \frac{(\sigma_{hwgg.UN4.1} - \sigma_{hwgg.UN4.2})}{2} \cdot A_{hwgg.UN4}} \dots \\ + (TOC_{as} - BOF_{elev})\right] & \text{if } C1_{UN4} \end{vmatrix} = 5.7 \cdot m$$

Apply Total Guard Crest Gate Headwater Load at (From toe): $H_{hwgg.UN4.loc.z} := \frac{W_{hwgg.UN4}}{2} = 2\ m$

LATERAL TAILWATER (RESISTING) Applied to Downstream Side of Guard Crest Gate: UN4 CASE

Guard Gate Down/Open Condition: $A2_{UN4} := TOP_{gg.UN4} \le TOC_{as}$

Guard Crest Gate Up/Closed, with Top of Gate Higher than TW Elevation: $B2_{UN4} := TOP_{gg.UN4} \ge TW_{UN4} \wedge TOP_{gg.UN4} > TOC_{as}$

Guard Crest Gate Up/Closed, with Top of Gate Lower than TW Elevation: $C2_{UN4} := TOP_{gg.UN4} > TOC_{as} \wedge TW_{UN4} > TOP_{gg.UN4}$

Tailwater Depth at Guard Crest Gate: $D_{twgg.UN4} := TW_{UN4} - TOC_{as} = 1.90\ m$

Guard Crest Gate Height: $H_{gg.UN4} = 5\ m$

Guard Crest Gate Width: $W_{twgg.UN4} := 4.00m$

Lateral Water Load at Bottom of Guard Crest Gate:

$$\sigma_{twgg.UN4.1} := \begin{cases} (0.0kPa) & \text{if } A2_{UN4} \\ (\gamma_w \cdot D_{twgg.UN4}) & \text{if } B2_{UN4} \\ (\gamma_w \cdot D_{twgg.UN4}) & \text{if } C2_{UN4} \end{cases} = 18.6 \cdot kPa$$

Lateral Water Load at Top of Guard Crest Gate:
(Load at TW Elevation On Guard Crest Gate if TW is below TOG_{gg})

$$\sigma_{twgg.UN4.2} := \begin{cases} (0.0kPa) & \text{if } A2_{UN4} \\ 0.0kPa & \text{if } B2_{UN4} \\ \left[\gamma_w \cdot \left(\left(TW_{UN4} - TOP_{gg.UN4}\right)\right)\right] & \text{if } C2_{UN4} \end{cases} = 0.0 \cdot kPa$$

Average Pressure acting on Guard Crest Gate:

$$\sigma_{twgg.UN4.avg} := \frac{\left(\sigma_{twgg.UN4.1} + \sigma_{twgg.UN4.2}\right)}{2} = 9.32 \cdot kPa$$

Total Area water acting on Crest Gate:

$$A_{twgg.UN4} := \begin{cases} D_{twgg.UN4} \cdot W_{twgg.UN4} & \text{if } A2_{UN4} \\ D_{twgg.UN4} \cdot W_{twgg.UN4} & \text{if } B2_{UN4} \\ H_{gg.UN4} \cdot W_{twgg.UN4} & \text{if } C2_{UN4} \end{cases} = 7.6 \cdot m^2$$

Total Horizontal Headwater Load on Guard Crest Gate: $H_{twgg.UN4} := \sigma_{twgg.UN4.avg} \cdot A_{twgg.UN4} = 70.8 \cdot kN$

Apply Total Horiz. TW Load on Guard Gate at:

$$H_{twgg.UN4.loc} := \begin{cases} \left(TOC_{as} - BOF_{elev}\right) & \text{if } A2_{UN4} \\ \left[\frac{\left(TW_{UN4} - TOC_{as}\right)}{3} + \left(TOC_{as} - BOF_{elev}\right)\right] & \text{if } B2_{UN4} \\ \left[\frac{\sigma_{twgg.UN4.2} \cdot A_{twgg.UN4} \cdot \frac{\left(H_{gg.UN4}\right)}{2} + \frac{\left(\sigma_{twgg.UN4.1} - \sigma_{twgg.UN4.2}\right)}{2} A_{twgg.UN4} \cdot \frac{\left(H_{gg.UN4}\right)}{3}}{\sigma_{twgg.UN4.2} \cdot A_{twgg.UN4} + \frac{\left(\sigma_{twgg.UN4.1} - \sigma_{twgg.UN4.2}\right)}{2} \cdot A_{twgg.UN4}} \ldots \\ + \left(TOC_{as} - BOF_{elev}\right)\right] & \text{if } C2_{UN4} \end{cases} = 4.6 \cdot m$$

Apply Total Guard Crest Gate Headwater Load at (From toe): $H_{twgg.UN4.loc.z} := \frac{W_{twgg.UN4}}{2} = 2\ m$

TAILWATER (RESISTING) Applied to Concrete Strucuture:

Tailwater Depth on Top of Abutment Footing: $D_{twa.UN4} := TW_{UN4} - TOC_{as} = 1.90\ m$

Tailwater Load Unit Width on Abutment: $W_{twa.UN4} := 2 \cdot r_{wall} = 12.00\ m$

Total Horizontal Tailwater Load on Abutment: $H_{twa.UN4} := \frac{\left(\gamma_w \cdot D_{twa.UN4}{}^2\right)}{2} \cdot W_{twa.UN4} = 212.5 \cdot kN$

Apply Total Abutment Tailwater Load at: $H_{twa.UN4.loc} := \frac{D_{twa.UN4}}{3} + \left(TOC_{as} - BOF_{elev}\right) = 4.63\ m$

Apply Total Abutment Tailwater Load at (from Toe Line): $H_{twa.UN4.loc.z} := W_{twgg.UN4} + r_{wall} = 10\ m$

Footing Thickness for horizontal at Toe: $h_{toe} = 4\ m$

Tailwater Depth At top of Gate Base Footing Elevation: $D_{twgf.UN4} := TW_{UN4} - TOC_{as} = 1.90\ m$

Water Depth at bottom of Gate Base Footing (Excluding Key): $D_{twtoe.UN4} := TW_{UN4} - BOF_{elev} = 5.90\ m$

Water Depth at bottom of Gate Base Footing (Including Key): $D_{twkey.UN4} := HW_{UN4} - BOK_{elev} = 11.00\ m$

Unit Width of D/S face of crest for applicaiton of Tailwater Load: $W_{tw.UN4} := W_B = 16.00\ m$

(Conservatively taken resisting water in front of 1.5m RCC Auxiliary Spillway as Tailwater elevation)

Tailwater Pressure At Top of Gate Footing: $\sigma_{twgf.UN4} := \left(\gamma_w \cdot D_{twgf.UN4}\right) = 18.64 \cdot kPa$

Tailwater Line Load At Bottom of Gate Footing (Excluding Key): $\sigma_{twtoe.UN4} := \left(\gamma_w \cdot D_{twtoe.UN4}\right) = 57.88 \cdot kPa$

Trianglular Distribution Unit Load on Gate Footing Base: $H_{twgf.UN4.tri} := \left(\frac{\sigma_{twtoe.UN4} - \sigma_{twgf.UN4}}{2}\right) \cdot \left[\left(T_{as} - d_{key}\right) \cdot W_{tw.UN4}\right] = 627.84 \cdot kN$

Rectangular Distribution Unit Load on Gate Footing Base: $H_{twgf.UN4.rect} := \sigma_{twgf.UN4} \cdot \left[\left(T_{as} - d_{key}\right) \cdot W_{tw.UN4}\right] = 596.45 \cdot kN$

Total Horizontal Tailwater Headwater Load on Gate Footing: $H_{twgf.UN4} := H_{twgf.UN4.tri} + H_{twgf.UN4.rect} = 1224.29 \cdot kN$

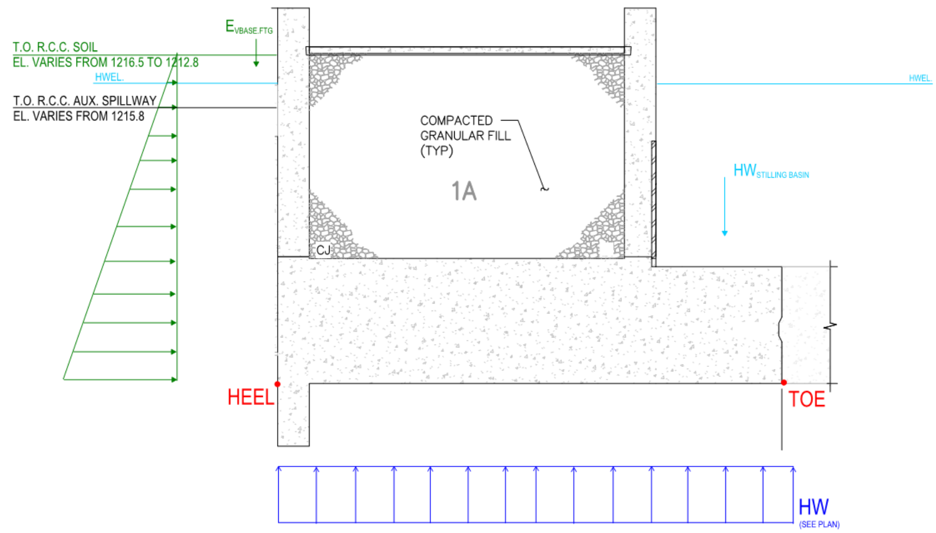
Apply Total Gate Footing Tailwater Load at:

$$H_{twgf.UN4.loc} := \frac{\left[H_{twgf.UN4.rect} \cdot \frac{\left(T_{as}\right)}{2} + H_{twgf.UN4.tri} \cdot \frac{\left(T_{as}\right)}{3}\right]}{H_{twgf.UN4.tri} + H_{twgf.UN4.rect}} = 1.66\ m$$

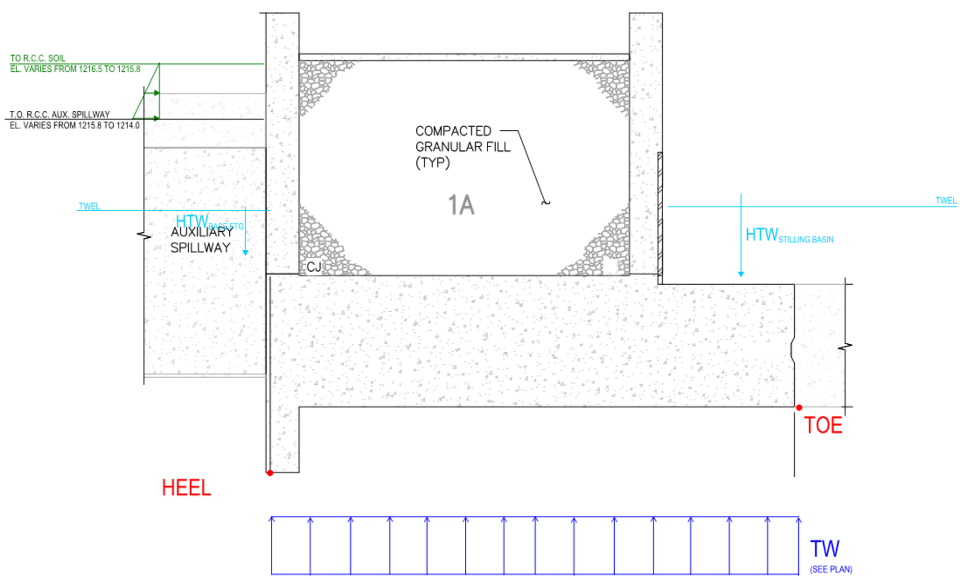
Apply Total Gate Footing Tailwater Load at (From Toe Line): $H_{twgf.UN4.loc.z} := \frac{W_B}{2} = 8.00\ m$

UN4 CASE

SUMMATION OF LATERAL WATER LOADS:



SECTION 1A BEFORE GATES & AUX. SPILLWAY RCC



SECTION 1A AFTER GATES & AUX. SPILLWAY RCC

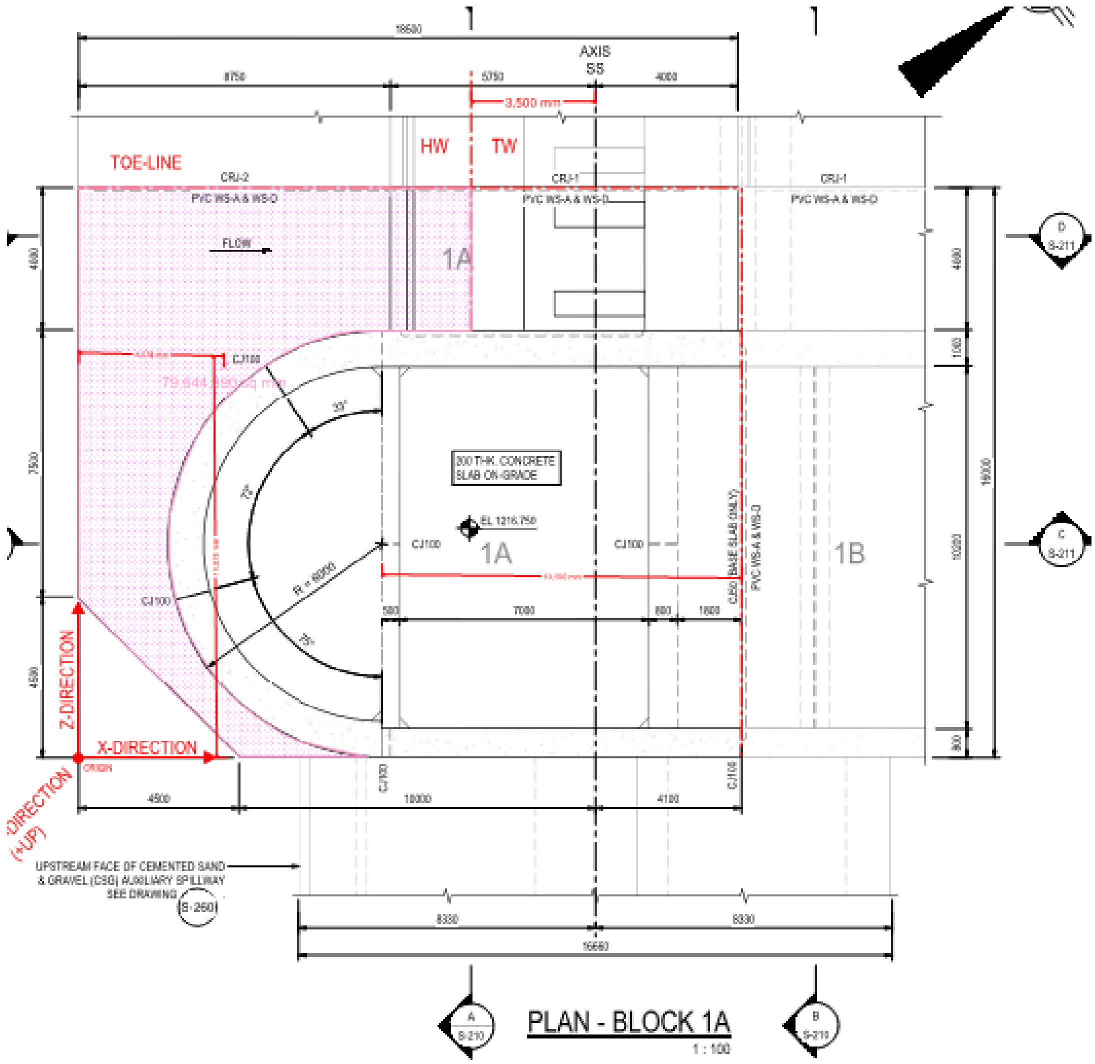
$$\Sigma H_{Water.UN4.x} := H_{hwa.UN4} + H_{hwas.UN4} + H_{hwgg.UN4} + H_{twa.UN4} + H_{twgf.UN4} + H_{twgg.UN4} = -4849.28 \cdot kN$$

$$\Sigma M_{HWater.UN4.x} := H_{hwa.UN4} \cdot H_{hwa.UN4.loc} + H_{hwas.UN4} \cdot H_{hwas.UN4.loc} + H_{hwgg.UN4} \cdot H_{hwgg.UN4.loc} \cdots + H_{twa.UN4} \cdot H_{twa.UN4.loc} + H_{twgf.UN4} \cdot H_{twgf.UN4.loc} + H_{twgg.UN4} \cdot H_{twgg.UN4.loc} = -15727.94 \cdot kN \cdot m$$

$\Sigma H_{Water.UN4.z} := 0kN$ $\Sigma M_{HWater.UN4.z} := 0 \cdot kN \cdot m$

VERTICAL WATER LOADS

UN4 CASE



HEADWATER:

Water Depth on top of Approach Slab: $d_{hw.UN4} := HW_{UN4} - TOC_{as} = 5.00\ m$

Water Area on top of Approach Slab: $A_{as} = 79.64\ m^2$ (From Geom. Scaled on REVU)

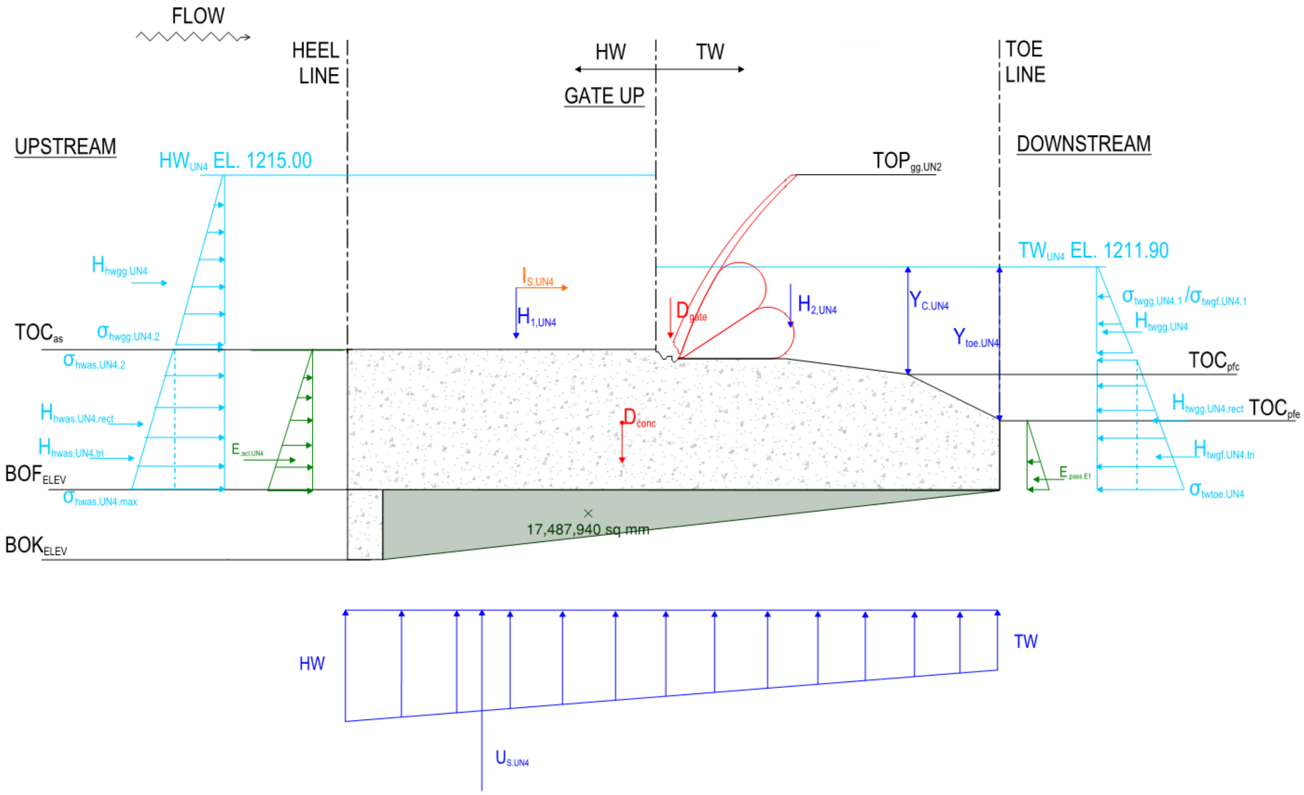
Vertical Water Weight (H1) on Approach Slab: $H_{1.UN4} := \left(A_{as} \cdot d_{hw.UN4}\right) \cdot \gamma_w \cdot \frac{3}{4} = 2929.9 \cdot kN$

Weight on Apron is req for stability. Coffer U/S of pier nose must include fill to offset reduced water load.

Moment Arm for Applicaiton of Water Weight (H1) from toe (X-Direction): $H_{1.UN4.loc.x} := L_B - 4.078m = 14.42\ m$ (From Geom. Scaled on REVU)

Moment Arm for Applicaiton of Water Weight (H1) from toe (Z-Direction): $H_{1.UN4.loc.z} := W_B - 11.273m = 4.73\ m$ (From Geom. Scaled on REVU)

TAILWATER:



Approach Slab Length: $L_{as} = 8.75\ m$

Gate Footing Length: $L_{gf} = 9.75\ m$

Gate Footing Crest Length: $L_{gfc} = 2.25\ m$

TAILWATER:

Trapezoid Volume Above Gate Footing from Approach Slab to Crest:

$$V_{asc.UN4} := \left(L_{gf} - L_{gfc}\right) W_{twgg.UN4} \frac{d_{hw.UN4} + Y_{C.UN4}}{2} = 114 \cdot m^3$$

Trapezoid Volume Above Gate Footing Crest to End of Gate Footing:

$$V_{gfc.UN4} := \left(L_{gfc} \cdot W_{twgg.UN4}\right) \frac{Y_{C.UN4} + Y_{TOE.UN4}}{2} = 29.25 \cdot m^3$$

Load Above Gate Footing from Approach Slab to Crest:

$$H_{2.UN4.asc} := V_{asc.UN4} \cdot \gamma_w = 1118.34 \cdot kN$$

Load Acting Above Footing Crest from Toe:

$$H_{2.UN4.asc.loc.x} := \frac{\left(L_{gf} - L_{gfc}\right) \cdot \left(2 \cdot d_{hw.UN4} + Y_{C.UN4}\right)}{3 \cdot \left(d_{hw.UN4} + Y_{C.UN4}\right)} + L_{gfc} = 6.39\ m$$

Load Above Gate Footing from Crest to End:

$$H_{2.UN4.gfc} := V_{gfc.UN4} \cdot \gamma_w = 286.94 \cdot kN$$

Load Acting Above Gate Footing from Crest to End:

$$H_{2.UN4.gfc.loc.x} := \frac{\left(L_{gfc}\right) \cdot \left(2 \cdot Y_{C.UN4} + Y_{TOE.UN4}\right)}{3 \cdot \left(Y_{C.UN4} + Y_{TOE.UN4}\right)}$$

Vertical Water Weight (H2) on Gate Footing:

$$H_{2.UN4} := H_{2.UN4.asc} + H_{2.UN4.gfc} = 1405.28 \cdot kN$$

Moment Arm for Application of Water Weight (H2) from toe:

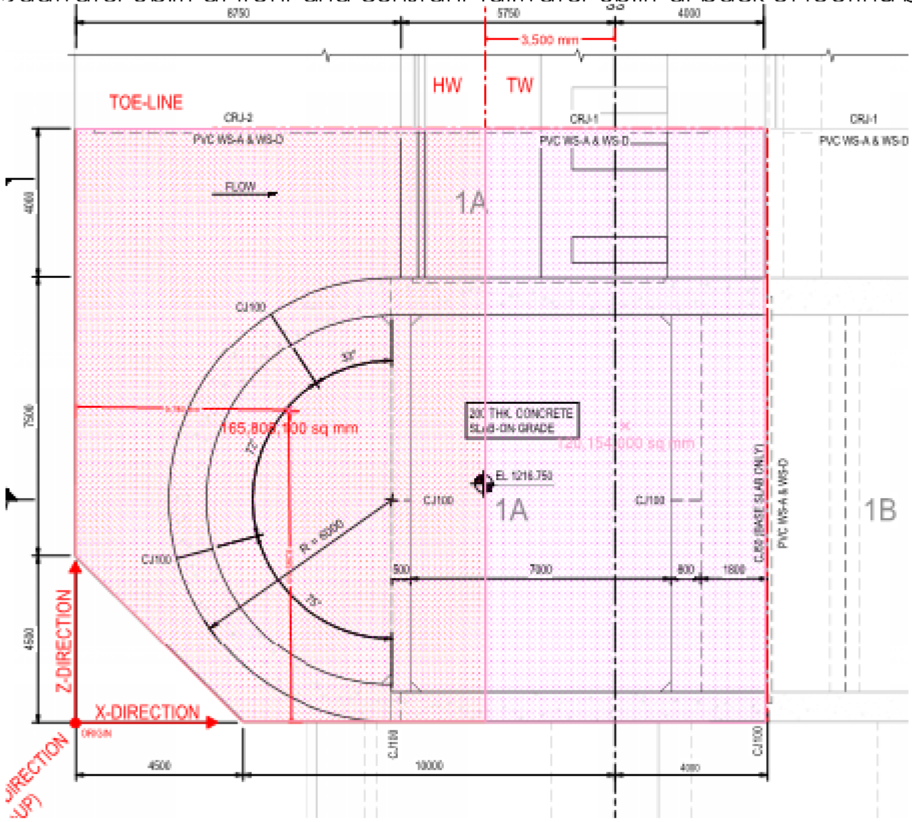
$$H_{2.UN4.loc.x} := \frac{H_{2.UN4.asc} \cdot H_{2.UN4.asc.loc.x} + H_{2.UN4.gfc} \cdot H_{2.UN4.gfc.loc.x}}{H_{2.UN4}} = 5.3\ m$$

Moment Arm for Applicaiton of Water Weight (H2) from toe (Z-Direction):

$$H_{2.UN4.loc.z} := 2.0m$$

UPLIFT

(Assuming constant Headwater Uplift at front and constant Tailwater Uplift at back of footing base)



Uplift pressure at U/S Face (heel): $U_{HW.UN4} := D_{hwas.UN4} \cdot \gamma_w = 88.3 \cdot \frac{kN}{m^2}$

Uplift pressure at D/S Face Stilling Basin: $U_{TW.UN4} := D_{twtoe.UN4} \cdot \gamma_w = 57.88 \cdot \frac{kN}{m^2}$

Area of Uplift Force From Headwater Side: $A_{HWU.UN4} := 165.81 m^2$ (From Bluebeam REVU)

Area of Uplift Force From Tailwater Side: $A_{TWU.UN4} := 120 m^2$ (From Bluebeam REVU)

Uplift Force From Headwater Side: $U_{A.UN4} := -U_{HW.UN4} \cdot A_{HWU.UN4} = -14639.36 \cdot kN$

Uplift Force From Headwater Side: $U_{B.UN4} := -U_{TW.UN4} \cdot A_{TWU.UN4} = -6945.48 \cdot kN$

Uplift Centroid of Area From Headwater Side to Toe: $X_{U.A} = 13.22 m$ $Z_{U.A} = 7.63 m$ (From Bluebeam REVU)

Uplift Centroid of Area From Tailwater Side to Toe: $X_{U.B} = 3.75 m$ $Z_{U.B} = 8 m$ (From Bluebeam REVU)

Total Resultant Uplift force: $U_{UN4} := U_{A.UN4} + U_{B.UN4} = -21584.84 \cdot kN$

Resultant Location from Toe Rect. Load (X-Direction):

$$U_{UN4.loc.x} := \frac{\left(U_{A.UN4} \cdot X_{U.A} + U_{B.UN4} \cdot X_{U.B}\right)}{\left(U_{A.UN4} + U_{B.UN4}\right)} = 10.17 m$$

Resultant Location from Toe Rect. Load (Z-Direction):

$$U_{UN4.loc.z} := \frac{\left[U_{A.UN4} \cdot \left(W_B - Z_{U.A}\right) + U_{B.UN4} \cdot \left(W_B - Z_{U.B}\right)\right]}{\left(U_{A.UN4} + U_{B.UN4}\right)} = 8.25 m$$

$$\Sigma V_{water.UN4} := H_{1.UN4} + H_{2.UN4} + U_{UN4} = -17249.62 \cdot kN$$

$$\Sigma M_{Vwater.UN4.x} := H_{1.UN4} \cdot H_{1.UN4.loc.x} + H_{2.UN4} \cdot H_{2.UN4.loc.x} + U_{UN4} \cdot U_{UN4.loc.x} = -169869.57 \cdot kN \cdot m$$

$$\Sigma M_{Vwater.UN4.z} := H_{1.UN4} \cdot H_{1.UN4.loc.z} + H_{2.UN4} \cdot H_{2.UN4.loc.z} + U_{UN4} \cdot U_{UN4.loc.z} = -161361.73 \cdot kN \cdot m$$

Equivalent Fluid Pressure (EFP):

At rest lateral pressure coefficient: $K_{o.UN4} := 1 - \sin(\phi_{backfill}) = 0.658$ (Section 5.3, Design Criteria)

Headwater Top of Soil Elevation: $TOS_{HW} = 1210\,m$

Top of Backfill Soil Elevation: $TOS_{BF} = 1216.5\,m$

Driving Soil Load Unit Width Projected Surface Area of Abutment: $W_{ds.hwa.UN4} := 6.0m$

Driving Soil Load Unit Width on Projected Approach Slab + Key: $W_{hwas.UN4} = 16.00\,m$

Resisting Soil Load Unit Width Projected Surface Area of Abutment: $W_{rsa.UN4} := \frac{10.5m + 9.381m}{2} = 9.94\,m$ (From Section Cut)

Driving Soil Load Depth on Abutment: $d_{DS.a} = 0\,m$

Driving Soil Load Depth on Footing: $d_{DS.as} = 4\,m$

Resisting Soil Load Depth on Abutment: $d_{RS.a} = 8.5\,m$

Thickness of Stilling Basin: $T_{sb} = 2\,m$

Lateral X-Direction Driving Force (Headwater Side - at rest condition)

At-Rest Soil Load on Half of Abutment: $E_{act.a.UN4.x} := \frac{\left(K_{o.UN4} \cdot d_{DS.a}^{\,2}\right)}{2} \cdot (\gamma_r - \gamma_w) \cdot W_{ds.hwa.UN4} \cdot -1 = 0 \cdot kN$

Acting at: $E_{act.a.UN4.x.loc.y} := \frac{d_{DS.a}}{3} + T_{as} - d_{key} = 2.00\,m$

Acting at (from Toe Line): $E_{act.a.UN4.x.loc.z} := W_{hwgg.UN4} + r_{wall} = 10.00\,m$

At-Rest Soil Load on Top of Approach Slab: $\sigma_{DS.as.UN4} := \left(K_{o.UN4} \cdot d_{DS.a}\right) \cdot (\gamma_r - \gamma_w) = 0 \cdot kPa$

At-Rest Soil Load on Bottom of Approach Slab: $\sigma_{DS.key.UN4} := \left(K_{o.UN4} \cdot d_{DS.as}\right) \cdot (\gamma_r - \gamma_w) = 32.08 \cdot kPa$

At-Rest Soil Load on Approach Slab (Rect): $E_{act.as.rect.UN4.x} := \sigma_{DS.as.UN4} \cdot (T_{as}) \cdot W_{hwas.UN4} \cdot -1 = 0 \cdot kN$

At-Rest Soil Load on Approach Slab (Tri): $E_{act.as.tri.UN4.x} := \frac{\left(\sigma_{DS.key.UN4} - \sigma_{DS.as.UN4}\right) \cdot (T_{as})}{2} \cdot W_{hwas.UN4} \cdot -1 = -1026.66 \cdot kN$

At-Rest Soil Load on Approach Slab: $E_{act.as.UN4.x} := E_{act.as.rect.UN4.x} + E_{act.as.tri.UN4.x} = -1026.66 \cdot kN$

Acting at:

$$E_{act.as.UN4.x.loc.y} := \frac{\left(E_{act.as.rect.UN4.x} \cdot \frac{T_{as}}{2} \dots + E_{act.as.tri.UN4.x} \cdot \frac{T_{as}}{3}\right)}{E_{act.as.UN4.x}} = 1.33\,m$$

Acting at (from Toe Line): $E_{act.as.UN4.x.loc.z} := \frac{W_B}{2} = 8.00\,m$

Lateral X-Direction Resisting Force (Tailwater Side - at rest condition)

UN4 CASE

At-rest Soil Load: $E_{pass.UN4.x} := \frac{\left(K_{o.UN4} \cdot d_{RS.a}^{\ 2}\right)}{2} \cdot \left(\gamma_r - \gamma_w\right) \cdot W_{rsa.UN4} = 2880.26 \cdot kN$

Acting at: $E_{pass.UN4.x.loc.y} := \frac{d_{RS.a}}{3} + T_{sb} - d_{key} = 2.83\,m$

$W_{rsa.UN4} = 9.94\,m$

Acting at (from Toe Line): $E_{pass.UN4.x.loc.z} := W_{hwgg.UN4} + r_{wall} = 10\,m$

$\Sigma H_{soil.UN4.x} := \left(E_{act.a.UN4.x} + E_{act.as.UN4.x} + E_{pass.UN4.x}\right) = 1853.61 \cdot kN$

$\Sigma M_{soil.UN4.x} := E_{act.a.UN4.x} \cdot E_{act.a.UN4.x.loc.y} + E_{act.as.UN4.x} \cdot E_{act.as.UN4.x.loc.y} + E_{pass.UN4.x} \cdot E_{pass.UN4.x.loc.y} = 6791.87 \cdot kN \cdot m$

Lateral Z-Direction Driving Force (Headwater Side - Before Gates & Aux. Spillway RCC - at rest condition)

Max./Min. Top of R.C.C. Soil Elevation: $TOS_{RCC.max} = 1216.5\,m$ $TOS_{RCC.min} = 1212.8\,m$

Average Top of R.C.C. Soil Elevation: $TOS_{RCC} = 1214.65\,m$

Depth of R.C.C. Soil Acting on Abutment Walls: $d_{act.RCC.w} = 4.65\,m$

Depth of R.C.C. Soil Acting on Abutment Footings: $d_{act.RCC.f} = 8.65\,m$

Projected Width of soil acting on Abutment Walls: $w_{abut.RCC} = 9.45\,m$

Projected Width of soil acting on Abutment Footing: $w_{FTG.RCC} = 12.2\,m$

At-Rest Soil Load on Top of Footing Slab: $\sigma_{act.RCC.w.UN4} := \left(K_{o.UN4} \cdot d_{act.RCC.w}\right) \cdot \left(\gamma_r - \gamma_w\right) = 37.3 \cdot kPa$

At-Rest Soil Load on Bottom of Approach Slab: $\sigma_{act.RCC.f.UN4} := \left(K_{o.UN4} \cdot d_{act.RCC.f}\right) \cdot \left(\gamma_r - \gamma_w\right) = 69.38 \cdot kPa$

At-Rest Soil Load on Abutment Walls: $E_{act.a.UN4.z} := \frac{\left(K_{o.UN4} \cdot d_{act.RCC.w}^{\ 2}\right)}{2} \cdot \left(\gamma_r - \gamma_w\right) \cdot w_{abut.RCC} \cdot -1 = -819.45 \cdot kN$

Acting at: $E_{act.a.UN4.z.loc.y} := \frac{d_{DS.a}}{3} + T_{as} = 4.00\,m$

Acting at (from Toe Line): $E_{act.a.UN4.z.loc.x} := \frac{\left(L_{wall} + r_{wall} - 6.35m\right)}{2} + 6.35m = 11.18\,m$

At-Rest Soil Load on Abutment Footing (Rect): $E_{act.as.rect.UN4.z} := \sigma_{act.RCC.w.UN4} \cdot \left(T_{as}\right) \cdot w_{abut.RCC} \cdot -1 = -1409.81 \cdot kN$

At-Rest Soil Load on Abutment Footing (Tri): $E_{act.as.tri.UN4.z} := \frac{-\left(\sigma_{act.RCC.f.UN4} - \sigma_{act.RCC.w.UN4}\right) \cdot \left(T_{as}\right)}{2} \cdot w_{FTG.RCC} = -782.83 \cdot kN$

At-Rest Soil Load on Approach Slab: $E_{act.as.UN4.z} := E_{act.as.rect.UN4.z} + E_{act.as.tri.UN4.z} = -2192.64 \cdot kN$

Acting at: $E_{act.as.UN4.z.loc.y} := \frac{\left(E_{act.as.rect.UN4.z} \cdot \frac{T_{as}}{2} \ldots + E_{act.as.tri.UN4.z} \cdot \frac{T_{as}}{3}\right)}{E_{act.as.UN4.z}} = 1.76\,m$

Acting at (from toe line): $E_{act.as.UN4.z.loc.x} := \frac{\left(L_{wall} + r_{wall} - 6.35m\right)}{2} + 6.35m = 11.18\,m$

Lateral Z-Direction Driving Force (Headwater Side - After Gates & Aux. Spillway RCC - at rest condition) **UN4 CASE**

Max. Top of R.C.C. Wall: $TORCC_{max} = 1215.8\ m$

Min. Top of R.C.C. Wall: $TORCC_{min} = 1214\ m$

Average Top of R.C.C. Wall Elevation: $TORCC = 1214.9\ m$

Width of Soil acting at Max. top of RCC: $w_{RCC.max} = 4.7\ m$

Width of Soil acting with average Top of RCC (Steps): $w_{RCC.avg} = 1.65\ m$

Depth of Top of Soil to Top of R.C.C. Wall: $d_{act.RCC} = 0.7\ m$

Depth of Top of Soil to Average Top of R.C.C. Wall (Steps): $d_{act.RCC.avg} = 1.6\ m$

At-Rest Soil Load on Abutment Walls after RCC:

$$E_{act.RCC.UN4.z} := \frac{\left(K_{o.UN4} \cdot d_{act.RCC}^{\ 2}\right)}{2} \cdot \left(\gamma_r - \gamma_w\right) \cdot w_{RCC.max} \cdot -1 = -9.24 \cdot kN$$

Acting at:

$$E_{act.RCC.UN4.z.loc.y} := \frac{d_{act.RCC}}{3} + \left(TORCC_{max} - BOF_{elev}\right) = 10.03\ m$$

Acting at (from Toe Line): $E_{act.RCC.UN4.z.loc.x} := 4m$ (at SS-Axis Center Line)

At-Rest Soil Load on Abutment Walls at RCC Steps:

$$E_{act.RCC.s.UN4.z} := \frac{\left(K_{o.UN4} \cdot d_{act.RCC.avg}^{\ 2}\right)}{2} \cdot \left(\gamma_r - \gamma_w\right) \cdot w_{RCC.avg} \cdot -1 = -16.94 \cdot kN$$

Acting at:

$$E_{act.RCC.s.UN4.z.loc.y} := \frac{d_{act.RCC.avg}}{3} + \left(TORCC - BOF_{elev}\right) = 9.43\ m$$

Acting at (from Toe Line):

$$E_{act.RCC.s.UN4.z.loc.x} := \frac{4m - 2.35m}{2} = 0.83\ m$$

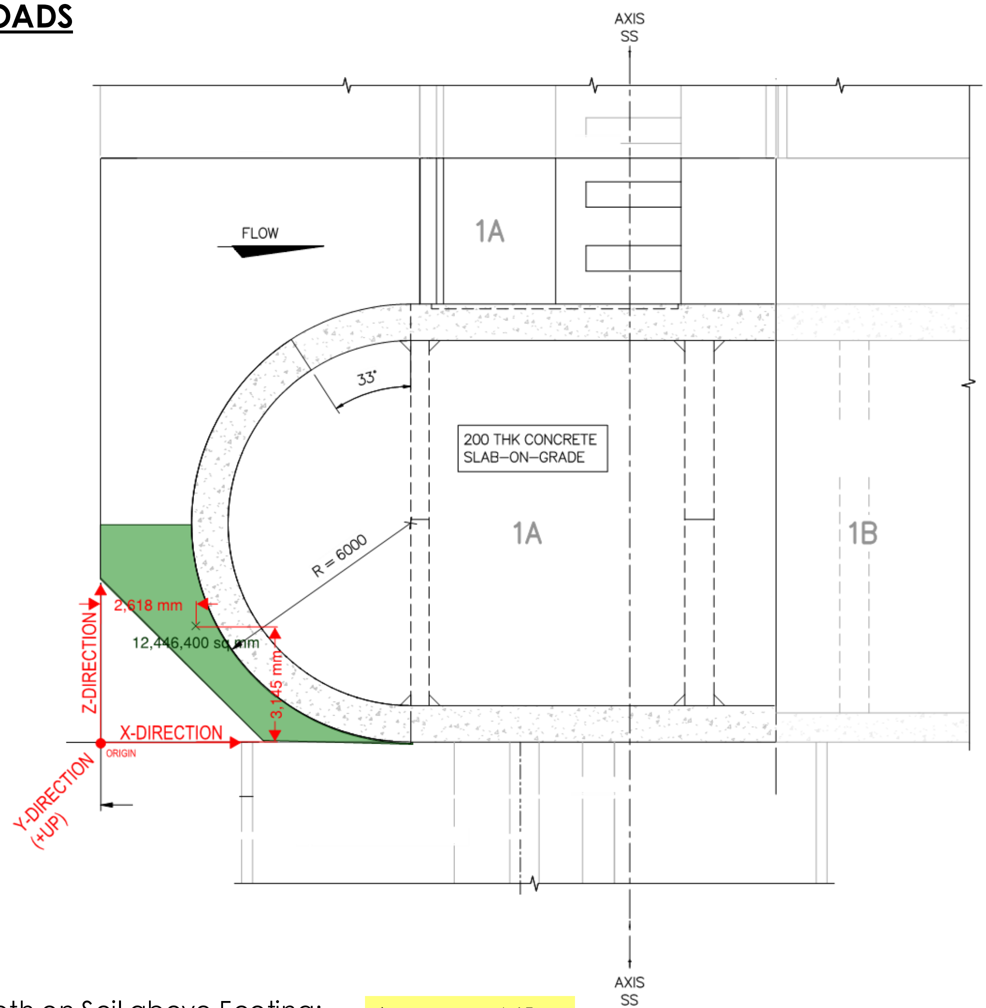
(at Halfway point of RCC Steps)

$$\Sigma H_{soil.UN4.z} := \left(E_{act.a.UN4.z} + E_{act.as.UN4.z} + E_{act.RCC.UN4.z} + E_{act.RCC.s.UN4.z}\right) = -3038.27 \cdot kN$$

$$\Sigma M_{soil.UN4.z} := E_{act.a.UN4.z} \cdot E_{act.a.UN4.z.loc.y} + E_{act.as.UN4.z} \cdot E_{act.as.UN4.z.loc.y} \cdots + E_{act.RCC.UN4.z} \cdot E_{act.RCC.UN4.z.loc.y} + E_{act.RCC.s.UN4.z} \cdot E_{act.RCC.s.UN4.z.loc.y} = -7393.67 \cdot kN \cdot m$$

VERTICAL SOIL LOADS

UN4 CASE



Average Depth on Soil above Footing: $d_{RCC.FTG} = 4.65\ m$

Area of Footing with Soil above: $A_{ftg.soil} = 0$ (From Bluebeam REVU)

Vertical Water Weight (H1) on Approach Slab: $E_{1.UN4} := \left(A_{ftg.soil} \cdot d_{RCC.FTG}\right) \cdot \left(\gamma_r - \gamma_w\right) = 0.0 \cdot kN$

Moment Arm for Applicaiton of Water Weight (H1) from toe (X-Direction): $E_{1.UN4.loc.x} := L_B - 5.607m = 12.89\ m$ (From Geom. Scaled on REVU)

Moment Arm for Applicaiton of Water Weight (H1) from toe (Z-Direction): $E_{1.UN4.loc.z} := W_B - 3.145m = 12.86\ m$ (From Geom. Scaled on REVU)

$\Sigma E_{UN4} := E_{1.UN4} = 0 \cdot kN$ $\Sigma M_{E.UN4.x} := E_{1.UN4} \cdot E_{1.UN4.loc.x} = 0 \cdot kN \cdot m$ $\Sigma M_{E.UN4.z} := E_{1.UN4} \cdot E_{1.UN4.loc.z} = 0 \cdot kN \cdot m$

IMPACT LOADS (DEBRIS LOADING FROM MEMO)

Total Impact Load on Structure: $I_{UN4} := 0kN$ (SS Abutment) - Construction/Maintenance

Apply Ice load at: $I_{UN4.loc.y} := \left(HW_{UN4} - BOF_{elev} - 0.30m\right) = 8.70\ m$

$\Sigma H_{I.UN4} := I_{UN4} = 0 \cdot kN$

$\Sigma M_{I.UN4} := I_{UN4} \cdot I_{UN4.loc.y} = 0 \cdot kN \cdot m$

SEISMIC LOAD (NOT APPLICABLE FOR THIS LOAD CASE)

UN4 CASE

SUMMARY OF LOADS

	Loads	Moment Arm	
Dead load of Concrete Structure:	$D_{conc} = 35947.6 \cdot kN$	$X_{conc.loc} = 8.81\ m$	$Z_{conc.loc} = 8.46\ m$
Obermyer Gate Weight:	$D_{Gate} = 56.0 \cdot kN$	$X_{gate} = 9.50\ m$	$Z_{gate} = 2.00\ m$
Dead load of Fill:	$D_{fill} = 18056.6 \cdot kN$	$X_{fill.loc} = 7.31\ m$	$Z_{fill.loc} = 10.00\ m$
HW Lateral Load on Abutment:	$H_{hwa.UN4} = -1471.5 \cdot kN$	$H_{hwa.UN4.loc} = 5.67\ m$	
HW Lateral Load on Approach Slab:	$H_{hwas.UN4} = -4394.9 \cdot kN$	$H_{hwas.UN4.loc} = 1.81\ m$	
HW Lateral Load on Guard Gate:	$H_{hwgg.UN4} = -490.5 \cdot kN$	$H_{hwgg.UN4.loc} = 5.67\ m$	
TW Lateral Load on Abutment:	$H_{twa.UN4} = 212.5 \cdot kN$	$H_{twa.UN4.loc} = 4.63\ m$	
TW Lateral Load on Pier Footing:	$H_{twgf.UN4} = 1224.29 \cdot kN$	$H_{twgf.UN4.loc} = 1.66\ m$	
TW Lateral Load on Guard Gate:	$H_{twgg.UN4} = 70.8 \cdot kN$	$H_{twgg.UN4.loc} = 4.63\ m$	
Vertical HW Load on Approach Slab:	$H_{1.UN4} = 2929.9 \cdot kN$	$H_{1.UN4.loc.x} = 14.42\ m$	$H_{1.UN4.loc.z} = 4.73\ m$
Vertical TW Load on Pier Footing (crest):	$H_{2.UN4} = 1405.3 \cdot kN$	$H_{2.UN4.loc.x} = 5.30\ m$	$H_{2.UN4.loc.z} = 2.00\ m$
Uplift:	$U_{UN4} = -21584.8 \cdot kN$	$U_{UN4.loc.x} = 10.17\ m$	$U_{UN4.loc.z} = 8.25\ m$
X-Direction Lateral Soil Load on Abutment (driving):	$E_{act.a.UN4.x} = 0.0 \cdot kN$	$E_{act.a.UN4.x.loc.y} = 2.00\ m$	
X-Direction Lateral Lateral Soil Load on Approach Slab (driving):	$E_{act.as.UN4.x} = -1026.7 \cdot kN$	$E_{act.as.UN4.x.loc.y} = 1.33\ m$	
Lateral Soil Load (resisting):	$E_{pass.UN4.x} = 2880.26 \cdot kN$	$E_{pass.UN4.x.loc.y} = 2.83\ m$	
Z-Direction Lateral Soil Load on Abutment Before RCC (driving):	$E_{act.a.UN4.z} = -819.5 \cdot kN$	$E_{act.a.UN4.z.loc.y} = 4.00\ m$	
Z-Direction Lateral Lateral Soil Load on Approach Slab Before RCC (driving):	$E_{act.as.UN4.z} = -2192.6 \cdot kN$	$E_{act.as.UN4.z.loc.y} = 1.76\ m$	
Z-Direction Lateral Soil Load on Abutment After RCC (driving):	$E_{act.RCC.UN4.z} = -9.24 \cdot kN$	$E_{act.RCC.UN4.z.loc.y} = 10.03\ m$	
Z-Direction Lateral Soil Load on Abutment at RCC Steps (driving):	$E_{act.RCC.s.UN4.z} = -16.94 \cdot kN$	$E_{act.RCC.s.UN4.z.loc.y} = 9.43 \cdot m$	
Vertical Soil Load on Footing:	$E_{1.UN4} = 0 \cdot kN$	$E_{1.UN4.loc.x} = 12.89\ m$	$E_{1.UN4.loc.z} = 12.86\ m$
Ice / Impact Load:	$I_{UN4} = 0.0 \cdot kN$	$I_{UN4.loc.y} = 8.70\ m$	

STABILITY ASSESSMENT (SLIDNG, BEARING, FLOTATION AND OVERTURNING): UN4 CASE

CHECK SLIDING (X-Direction & Z-Direction) ALONG HORIZONTAL PLANE THRU TOE, IGNORING BEDROCK MOBILIZED BY STRUCTURAL HEEL KEY, OR VOID BEHIND KEY

Sum of Vertical Forces:

$\Sigma V_{UN4} := \Sigma V_{DL} + \Sigma V_{water.UN4} + \Sigma E_{UN4} = 36810.6 \cdot kN$

Sum of Horizontal Forces (X-Direction):

$\Sigma H_{UN4.x} := \Sigma H_{Water.UN4.x} + \Sigma H_{soil.UN4.x} + \Sigma H_{I.UN4} = -2995.67 \cdot kN$

Sum of Horizontal Forces (Z-Direction):

$\Sigma H_{UN4.z} := \Sigma H_{Water.UN4.z} + \Sigma H_{soil.UN4.z} = -3038.27 \cdot kN$

Sum of Horizontal Forces (resultant):

$$\Sigma H_{UN4} := \sqrt{\Sigma H_{UN4.x}^{\;2} + \Sigma H_{UN4.z}^{\;2}} = 4266.75 \cdot kN$$

Sliding Factor of Safety:

$$FS_{HorizSliding.UN4.x} := \frac{\tan_{\phi} \cdot \Sigma V_{UN4}}{\left|\Sigma H_{UN4.x}\right|} = 5.99 \qquad FS_{HorizSliding.UN4.z} := \frac{\tan_{\phi} \cdot \Sigma V_{UN4}}{\left|\Sigma H_{UN4.z}\right|} = 5.91$$

Sliding Factor of Safety:

$$FS_{HorizSliding.UN4} := \frac{\tan_{\phi} \cdot \Sigma V_{UN4}}{\sqrt{\Sigma H_{UN4.x}^{\;2} + \Sigma H_{UN4.z}^{\;2}}} = 4.21$$

$$FS_{HorizSliding.UN4.Check.x} := \begin{array}{|l} \text{"OKAY" if } FS_{HorizSliding.UN4.x} \geq FS_{req.UN4.sl} \\ \text{"Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !" otherwise} \end{array} = \text{"OKAY"}$$

$$FS_{HorizSliding.UN4.Check.z} := \begin{array}{|l} \text{"OKAY" if } FS_{HorizSliding.UN4.z} \geq FS_{req.UN4.sl} \\ \text{"Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !" otherwise} \end{array} = \text{"OKAY"}$$

$$FS_{HorizSliding.UN4.Check} := \begin{array}{|l} \text{"OKAY" if } FS_{HorizSliding.UN4} \geq FS_{req.UN4.sl} \\ \text{"Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !" otherwise} \end{array} = \text{"OKAY"}$$

CHECK FOUNDATION BEARING CAPACITY

Sum of the Moments (X-Direction):

$$\Sigma M_{UN4.x} := \Sigma M_{DL.x} + \Sigma M_{HWater.UN4.x} + \Sigma M_{Vwater.UN4.x} + \Sigma M_{I.UN4} + \Sigma M_{soil.UN4.x} = 270526 \cdot kN \cdot m$$

Eccentricity:

$$e_{UN4.x} := X_{BCG} - \frac{\Sigma M_{UN4.x}}{\Sigma V_{UN4}} = 1.63\ m$$

Eccentricity Check:

$$e_{check.UN4.x} := \begin{array}{|l} \text{"Okay" if } e_{UN4.x} \leq Kern_x \\ \text{"Revise Structure" otherwise} \end{array}$$

$e_{check.UN4.x} = \text{"Okay"}$

Foundation Bearing Pressures (X-Direction):

UN4 CASE

Bearing Pressure at Heel:

$$\sigma_{heel.UN4.x} := \frac{\Sigma V_{UN4}}{A_b} - \frac{\Sigma V_{UN4} \cdot e_{UN4.x}}{S_{bx.L}} = 55.67 \cdot \frac{kN}{m^2}$$

$$\sigma_{heel.UN4.check.x} := \left(\begin{array}{ll} \text{"Okay"} & \text{if } 0 \le \sigma_{heel.UN4.x} \le \sigma_{allow.UN4} \\ \text{"Revise Structure"} & \text{otherwise} \end{array} \right) \qquad \sigma_{heel.UN4.check.x} = \text{"Okay"}$$

Bearing Pressure at Toe:

$$\sigma_{toe.UN4.x} := \frac{\Sigma V_{UN4}}{A_b} + \frac{\Sigma V_{UN4} \cdot e_{UN4.x}}{S_{bx.R}} = 197.64 \cdot \frac{kN}{m^2}$$

$$\sigma_{toe.UN4.check.x} := \begin{array}{|ll} \text{"Okay"} & \text{if } 0 \le \sigma_{toe.UN4.x} \le \sigma_{allow.UN4} \\ \text{"Revise Structure"} & \text{otherwise} \end{array} \qquad \sigma_{toe.UN4.check.x} = \text{"Okay"}$$

Sum of the Moments (Z-Direction):

$$\Sigma M_{UN4.z} := \Sigma M_{DL.z} + \Sigma M_{HWater.UN4.z} + \Sigma M_{Vwater.UN4.z} + \Sigma M_{soil.UN4.z} = 316060 \cdot kN \cdot m$$

Eccentricity:

$$e_{UN4.z} := Z_{BCG} - \frac{\Sigma M_{UN4.z}}{\Sigma V_{UN4}} = -0.82\ m$$

Eccentricity Check:

$$e_{check.UN4.z} := \begin{array}{|ll} \text{"Okay"} & \text{if } e_{UN4.z} \le Kern_z \\ \text{"Revise Structure"} & \text{otherwise} \end{array} \qquad e_{check.UN4.z} = \text{"Okay"}$$

Foundation Bearing Pressures (Z-Direction):

Bearing Pressure at Heel:

$$\sigma_{heel.UN4.z} := \frac{\Sigma V_{UN4}}{A_b} - \frac{\Sigma V_{UN4} \cdot e_{UN4.z}}{S_{bz.b}} = 170.96 \cdot \frac{kN}{m^2}$$

$$\sigma_{heel.UN4.check.z} := \left(\begin{array}{ll} \text{"Okay"} & \text{if } 0 \le \sigma_{heel.UN4.z} \le \sigma_{allow.UN4} \\ \text{"Revise Structure"} & \text{otherwise} \end{array} \right) \qquad \sigma_{heel.UN4.check.z} = \text{"Okay"}$$

Bearing Pressure at Toe:

$$\sigma_{toe.UN4.z} := \frac{\Sigma V_{UN4}}{A_b} + \frac{\Sigma V_{UN4} \cdot e_{UN4.z}}{S_{bz.t}} = 88.93 \cdot \frac{kN}{m^2}$$

$$\sigma_{toe.UN4.check.z} := \begin{array}{|ll} \text{"Okay"} & \text{if } 0 \le \sigma_{heel.UN4.z} \le \sigma_{allow.UN4} \\ \text{"Revise Structure"} & \text{otherwise} \end{array} \qquad \sigma_{toe.UN4.check.z} = \text{"Okay"}$$

UN4 CASE

Foundation Bearing Pressure (Combined):

Linear pressure superimposed at Corners by both Moment_X and Moment_Z

Bearing Pressure at Heel(x)-Heel(z):

$$\sigma_{heel.UN4} := \frac{\Sigma V_{UN4}}{A_b} - \frac{\Sigma V_{UN4} \cdot e_{UN4.x}}{S_{bx.L}} - \frac{\Sigma V_{UN4} \cdot e_{UN4.z}}{S_{bz.b}} = 97.86 \cdot kPa$$

$$\sigma_{heel.UN4.check} := \left(\begin{array}{l} \text{"Okay"} \quad \text{if} \quad 0 \le \sigma_{heel.UN4} \le \sigma_{allow.UN4} \\ \text{"Revise Structure"} \quad \text{otherwise} \end{array} \right)$$

$\sigma_{heel.UN4.check} = \text{"Okay"}$

Bearing Pressure at Toe(x)-Toe(z):

$$\sigma_{toe.UN4} := \frac{\Sigma V_{UN4}}{A_b} + \frac{\Sigma V_{UN4} \cdot e_{UN4.x}}{S_{bx.R}} + \frac{\Sigma V_{UN4} \cdot e_{UN4.z}}{S_{bz.t}} = 157.81 \cdot kPa$$

$$\sigma_{toe.UN4.check} := \begin{array}{|l} \text{"Okay"} \quad \text{if} \quad 0 \le \sigma_{toe.UN4} \le \sigma_{allow.UN4} \\ \text{"Revise Structure"} \quad \text{otherwise} \end{array}$$

$\sigma_{toe.UN4.check} = \text{"Okay"}$

Bearing Pressure at Heel(x)-Toe(z):

$$\sigma_{heeltoe.UN4} := \frac{\Sigma V_{UN4}}{A_b} - \frac{\Sigma V_{UN4} \cdot e_{UN4.x}}{S_{bx.L}} + \frac{\Sigma V_{UN4} \cdot e_{UN4.z}}{S_{bz.t}} = 15.84 \cdot kPa$$

$$\sigma_{heeltoe.UN4.check} := \left(\begin{array}{l} \text{"Okay"} \quad \text{if} \quad 0 \le \sigma_{heeltoe.UN4} \le \sigma_{allow.UN4} \\ \text{"Revise Structure"} \quad \text{otherwise} \end{array} \right)$$

$\sigma_{heeltoe.UN4.check} = \text{"Okay"}$

Bearing Pressure at Toe(x)-Heel(z):

$$\sigma_{toeheel.UN4} := \frac{\Sigma V_{UN4}}{A_b} + \frac{\Sigma V_{UN4} \cdot e_{UN4.x}}{S_{bx.R}} - \frac{\Sigma V_{UN4} \cdot e_{UN4.z}}{S_{bz.b}} = 239.84 \cdot kPa$$

$$\sigma_{toeheel.UN4.check} := \begin{array}{|l} \text{"Okay"} \quad \text{if} \quad 0 \le \sigma_{toeheel.UN4} \le \sigma_{allow.UN4} \\ \text{"Revise Structure"} \quad \text{otherwise} \end{array}$$

$\sigma_{toeheel.UN4.check} = \text{"Okay"}$

FLOATATION ANALYSIS:

ACCEPTANCE PARAMETERS

Required Factor of Safety: $FS_{req.FUN4} := 1.3$

VERTICAL LOADS RESISTING:

Dead Load: $\Sigma V_{DL} = 54060.17 \cdot kN$

Water Weight H1+H2: $\Sigma V_{H.FUN4} := H_{1.UN4} + H_{2.UN4} = 4335.22 \cdot kN$

Summation Vertical Resisting: $\Sigma V_{FUN4} := \Sigma V_{DL} + \Sigma V_{H.FUN4} = 58395.4 \cdot kN$

VERTICAL LOADS UPLIFT:

Uplift: $U_{UN4} = -21584.84 \cdot kN$

Factor of Safety Floatation:

$$FS_{act.FUN4} := \frac{\Sigma V_{FUN4}}{|U_{UN4}|} = 2.71$$

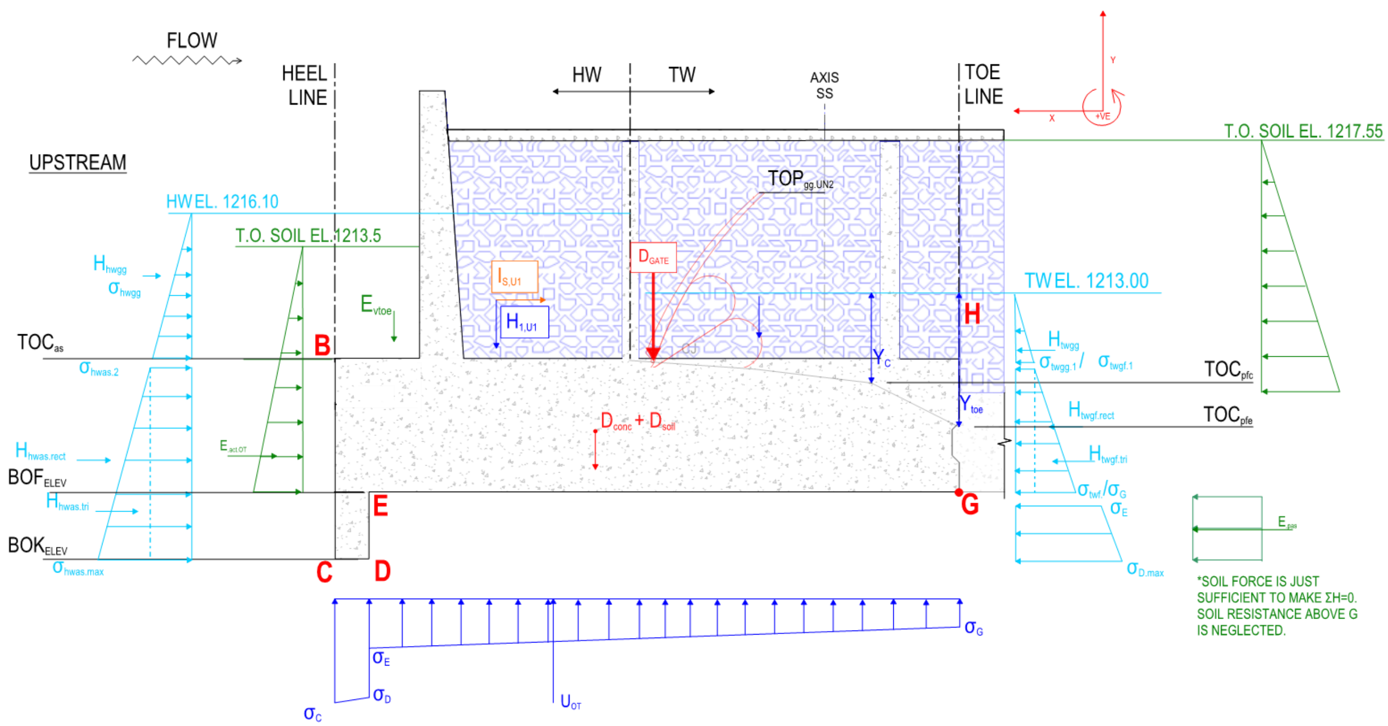
$$FS_{check.FUN4} := \begin{array}{|l} \text{"OKAY"} \quad \text{if} \quad FS_{act.FUN4} \ge FS_{req.FUN4} \\ \text{"ANCHORS REQUIRED"} \quad \text{if} \quad FS_{act.FUN4} < FS_{req.FUN4} \end{array} = \text{"OKAY"}$$

MONOLITH OVERTURNING STABILITY ANALYSIS

UN4 CASE

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.
Assumptions are made in order to compute overturning stablity of indetermine forces on monolith with key;
(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.
(b) The horizontal resisting force acting on the key, P.key, is that required for staticequilibrium
(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1 $Ratio_{OT.UN4.min} := 0.333$ at Rock Foundation



Uplift Loads for Overturning Stability Analysis (X-Direction)

Line of Creep:

Change in Water Head: $\Delta_{h.UN4} := HW_{UN4} - TW_{UN4} = 3.1\ m$

Length from Point C to Point G: $L_{CG} = 18.61\ m$

Length from Various Points to Points: $L_{CD} = 1\ m$ $L_{DE} = 2\ m$ $L_{EG} = 17.5\ m$

$L_{GH.UN4} := TW_{UN4} - TOC_{afe} = 3.9\ m$

Length from Point C, D, E to G: $L_{CDEG} = 20.5\ m$ $L_{CDE} = 3\ m$

Water Pressure at Point C & G: $\sigma_{C.UN4} := \sigma_{hwas.UN4.2} = -88.29 \cdot kPa$ $\sigma_{G.UN4} := \sigma_{twtoe.UN4} \cdot -1 = -57.88 \cdot kPa$

Water Pressure at Point D:
$$\sigma_{D.UN4} := -\gamma_w \cdot \left[\left(HW_{UN4} - BOK_{elev} \right) - \frac{\Delta_{h.UN4} \cdot L_{CD}}{L_{CDEG}} \right] = -106.43 \cdot kPa$$

Water Pressure at Point E:
$$\sigma_{E.UN4} := -\gamma_w \cdot \left[\left(HW_{UN4} - BOF_{elev} \right) - \frac{\Delta_{h.UN4} \cdot L_{CDE}}{L_{CDEG}} \right] = -83.84 \cdot kPa$$

Uplift for Overturning Analysis on Bottom of Key:
$$U_{OT.UN4.key} := \frac{\sigma_{C.UN4} + \sigma_{D.UN4}}{2} \cdot L_{CD} \cdot W_B = -1557.73 \cdot kN$$

Acting at:
$$U_{OT.UN4.key.loc} := \frac{L_{CD} \cdot \left(2 \cdot \sigma_{C.UN4} + \sigma_{D.UN4} \right)}{3 \left(\sigma_{C.UN4} + \sigma_{D.UN4} \right)} + L_{EG} = 17.98\ m$$

UN4 CASE

Uplift for Overturning Analysis on Bottom of Footing: $U_{OT.UN4.ftg} := \frac{\sigma_{E.UN4} + \sigma_{G.UN4}}{2} \cdot L_{EG} \cdot W_B = -19840.61 \cdot kN$

Acting at: $U_{OT.UN4.ftg.loc} := \frac{L_{EG} \cdot \left(\sigma_{G.UN4} + 2 \cdot \sigma_{E.UN4}\right)}{3\left(\sigma_{G.UN4} + \sigma_{E.UN4}\right)} = 9.28\ m$

Uplift Load for Overtuming Analysis: $U_{OT.UN4} := U_{OT.UN4.key} + U_{OT.UN4.ftg} = -21398.34 \cdot kN$

Uplift Load Acting from Toe: $U_{OT.UN4.loc} := \frac{U_{OT.UN4.key} \cdot U_{OT.UN4.key.loc} + U_{OT.UN4.ftg} \cdot U_{OT.UN4.ftg.loc}}{U_{OT.UN4}} = 9.92\ m$

<u>All Vertical Loads Appliable to Overturning Stability Analysis</u>

Total Concrete Dead Loads:	$D_{conc} = 35947.58 \cdot kN$	at:	$X_{conc.loc} = 8.81\ m$
Dead Load of Gate:	$D_{Gate} = 56.0 \cdot kN$		$X_{gate} = 9.50\ m$
Total Fill Loads:	$D_{fill} = 18056.6 \cdot kN$		$X_{fill.loc} = 7.31\ m$
Water Weight (HW) on Apron Slab:	$H_{1.UN4} = 2929.9 \cdot kN$		$H_{1.UN4.loc.x} = 14.42\ m$
Water Weight (TW) on Guard Gate Footing:	$H_{2.UN4} = 1405.3 \cdot kN$		$H_{2.UN4.loc.x} = 5.30\ m$
Uplift Load for Overtuming Analysis:	$U_{OT.UN4} = -21398.34 \cdot kN$		$U_{OT.UN4.loc} = 9.92 \cdot m$

Sum of All Overturning Analysis Vertical Load:

$$\Sigma V_{UN4.OT} := D_{conc} + D_{Gate} + D_{fill} + H_{1.UN4} + H_{2.UN4} + U_{OT.UN4} = 36997.06 \cdot kN$$

Sum of All Overturning Analysis Vertical Load Moments:

$$\Sigma M_{V.UN4.OT} := \begin{pmatrix} D_{conc} \cdot X_{conc.loc} + D_{Gate} \cdot X_{gate} + D_{fill} \cdot X_{fill.loc} + H_{1.UN4} \cdot H_{1.UN4.loc.x} \cdots \\ + H_{2.UN4} \cdot H_{2.UN4.loc.x} + U_{OT.UN4} \cdot U_{OT.UN4.loc} \end{pmatrix} = 286818.79 \cdot kN \cdot m$$

<u>Lateral Tailwater Loads for Overturning Stability Analysis</u>

TW Lateral Load on Gate Footing (No Key - Overturning Values Adjusted): $H_{twgf.UN4} = 1224.29 \cdot kN$

Acting at: $H_{twgf.UN4.loc} = 1.66\ m$

Horizontal Tailwater Pressure Top of Key (Overturning Analysis): $\sigma_{twtk.OT.UN4} := \sigma_{E.UN4} \cdot -1 = 83.84 \cdot kPa$

Horizontal Tailwater Pressure Bottom of Key (Overturning Analysis): $\sigma_{twbk.OT.UN4} := \sigma_{D.UN4} \cdot -1 = 106.43 \cdot kPa$

Triangular Distribution Unit Load Acting at Key: $H_{twbk.OT.UN4.tri} := \frac{\left(\sigma_{twbk.OT.UN4} - \sigma_{twtk.OT.UN4}\right)}{2} \cdot d_{key} \cdot W_{tw.UN4} = 361.39 \cdot kN$

Triangular Distribution Unit Load Acting at Key: $H_{twbk.OT.UN4.rect} := \sigma_{twtk.OT.UN4} \cdot d_{key} \cdot W_{tw.UN4} = 2682.87 \cdot kN$

Total Horizontal Tailwater Load on Key (Overturning Values Adjusted): $H_{twkey.OT.UN4} := H_{twbk.OT.UN4.tri} + H_{twbk.OT.UN4.rect} = 3044.26 \cdot kN$

Acting at: $H_{twkey.OT.UN4.loc} := \frac{H_{twbk.OT.UN4.tri} \cdot \frac{-2 \cdot d_{key}}{3} + H_{twbk.OT.UN4.rect} \cdot \frac{-d_{key}}{2}}{H_{twkey.OT.UN4}} = -1.04 \cdot m$

Lateral Driving Earth Loads for Overturning Stability Analysis (at rest condition)

UN4 CASE

Depth of Driving Soil Loads (to top of key): $h_{E.OT.UN4} := TOC_{as} - BOF_{elev} = 4\ m$

At-Rest Soil Load: $E_{act.OT.UN4} := \frac{\left(K_{o.UN4} \cdot h_{E.OT.UN4}{}^{2}\right)}{2} \cdot \left(\gamma_r - \gamma_w\right) \cdot W_{hwas.UN4} \cdot -1 = -1026.66 \cdot kN$

At Rest- Soil Load Acting from Toe: $E_{act.OT.UN4.loc} := \frac{h_{E.OT.UN4}}{3} = 1.33\ m$

All Lateral Loads Appliable to Overturning Stability Analysis (X-direction)

HW Lateral Load on Approach Slab:	$H_{hwas.UN4} = -4394.9 \cdot kN$	$H_{hwas.UN4.loc} = 1.81\ m$
HW Lateral Load on Guard Gate:	$H_{hwgg.UN4} = -490.5 \cdot kN$	$H_{hwgg.UN4.loc} = 5.67\ m$
HW Lateral Load on Abutment:	$H_{hwa.UN4} = -1471.5 \cdot kN$	$H_{hwa.UN4.loc} = 5.67\ m$
TW Lateral Load on Abutment:	$H_{twa.UN4} = 212.5 \cdot kN$	$H_{twa.UN4.loc} = 4.63\ m$
TW Lateral Load on Guard Gate:	$H_{twgg.UN4} = 70.8 \cdot kN$	$H_{twgg.UN4.loc} = 4.63\ m$
TW Lateral Load on Gate Footing (No Key - Overturning Values Adjusted):	$H_{twgf.UN4} = 1224.29 \cdot kN$	$H_{twgf.UN4.loc} = 1.66\ m$
TW Lateral Load on Key:	$H_{twkey.OT.UN4} = 3044.26 \cdot kN$	$H_{twkey.OT.UN4.loc} = -1.04\ m$
Ice / Impact Load:	$I_{UN4} = 0.0 \cdot kN$	$I_{UN4.loc.y} = 8.70\ m$
Lateral Soil Load (driving):	$E_{act.OT.UN4} = -1026.7 \cdot kN$	$E_{act.OT.UN4.loc} = 1.33\ m$

Resisting Lateral Soil Load as required to produce horizontal equilibrium:

$$E_{pas.OT.x.UN4} := -\left(\begin{array}{l} H_{hwas.UN4} + H_{hwgg.UN4} + H_{hwgg.UN4} + H_{twgg.UN4} \cdots \\ + H_{twgf.UN4} + H_{twkey.OT.UN4} + I_{UN4} + E_{act.OT.UN4} \end{array}\right) = 2063.16 \cdot kN$$

Acting at:

$$E_{pas.OT.UN4.loc} := -1 \cdot \frac{d_{key}}{2} = -1\ m$$

Sum of All Overturning Analysis Horizontal Load (ΣH=0):

$$\Sigma H_{UN4.OT.x} := H_{hwas.UN4} + H_{hwgg.UN4} + H_{twgg.UN4} + H_{twgf.UN4} + H_{twkey.OT.UN4} + I_{UN4} + E_{act.OT.UN4} + E_{pas.OT.x.UN4} = 490.5 \cdot kN$$

Sum of All Overturning Analysis Horizontal Load Moments:

$$\begin{aligned} \Sigma M_{H.UN4.OT.x} := {} & H_{hwas.UN4} \cdot H_{hwas.UN4.loc} + H_{hwgg.UN4} \cdot H_{hwgg.UN4.loc} \cdots \\ & + H_{twgg.UN4} \cdot H_{twgg.UN4.loc} + H_{twgf.UN4} \cdot H_{twgf.UN4.loc} \cdots \\ & + H_{twkey.OT.UN4} \cdot H_{twkey.OT.UN4.loc} + I_{UN4} \cdot I_{UN4.loc.y} \cdots \\ & + E_{act.OT.UN4} \cdot E_{act.OT.UN4.loc} + E_{pas.OT.x.UN4} \cdot E_{pas.OT.UN4.loc} \end{aligned} = -14970.72 \cdot kN \cdot m$$

Overturning Stability Analysis (X-Direction)

$$\Sigma M_{UN4.OT.x} := \Sigma M_{V.UN4.OT} + \Sigma M_{H.UN4.OT.x} = 271848.07 \cdot kN \cdot m$$

$$X_{R.UN4} := \frac{\Sigma M_{UN4.OT.x}}{\Sigma V_{UN4.OT}} = 7.35\ m \qquad x_{OT.UN4} := X_{R.UN4} - \frac{L_B}{2} = -1.9\ m$$

Overturning Resultant Ratio

$$Ratio_{OT.x.UN4} := \frac{X_{R.UN4}}{L_B} = 0.4$$

$$Ratio_{OT.x.UN4.check} := \left| \begin{array}{l} \text{"OKAY"} \quad \text{if} \quad Ratio_{OT.x.UN4} \ge Ratio_{OT.UN4.min} \\ \text{"Revise Structure"} \quad \text{otherwise} \end{array} \right. = \text{"OKAY"}$$

$$x_{OT.check.UN4} := \left| \begin{array}{l} \text{"OKAY"} \quad \text{if} \quad \left| x_{OT.UN4} \right| \le Kern_x \\ \text{"Revise Structure"} \quad \text{otherwise} \end{array} \right. = \text{"OKAY"}$$

All Lateral Loads Appliable to Overturning Stability Analysis (Z-direction)

UN4 CASE

Z-Direction Lateral Soil Load on Abutment Before RCC (driving): $E_{act.a.UN4.z} = -819.5 \cdot kN$ $E_{act.a.UN4.z.loc.y} = 4.00\ m$

Z-Direction Lateral Lateral Soil Load on Approach Slab Before RCC (driving): $E_{act.as.UN4.z} = -2192.6 \cdot kN$ $E_{act.as.UN4.z.loc.y} = 1.76\ m$

Z-Direction Lateral Soil Load on Abutment After RCC (driving): $E_{act.RCC.UN4.z} = -9.24 \cdot kN$ $E_{act.RCC.UN4.z.loc.y} = 10.03\ m$

Z-Direction Lateral Soil Load on Abutment at RCC Steps (driving): $E_{act.RCC.s.UN4.z} = -16.94 \cdot kN$ $E_{act.RCC.s.UN4.z.loc.y} = 9.43 \cdot m$

Resisting Lateral Soil Load as required to produce horizontal equilibrium:

$$E_{pas.OT.z.UN4} := -\left(E_{act.a.UN4.z} + E_{act.as.UN4.z} + E_{act.RCC.UN4.z} + E_{act.RCC.s.UN4.z}\right) = 3038.27 \cdot kN$$

Acting at:

$$E_{pas.OT.UN4.loc} = -1\ m$$

Sum of All Overturning Analysis Horizontal Load (ΣH=0):

$$\Sigma H_{UN4.OT.z} := E_{act.a.UN4.z} + E_{act.as.UN4.z} + E_{act.RCC.UN4.z} + E_{act.RCC.s.UN4.z} + E_{pas.OT.z.UN4} = 0 \cdot kN$$

Sum of All Overturning Analysis Horizontal Load Moments:

$$\Sigma M_{H.UN4.OT.z} := E_{act.a.UN4.z} \cdot E_{act.a.UN4.z.loc.y} + E_{act.as.UN4.z} \cdot E_{act.as.UN4.z.loc.y} \cdots + E_{act.RCC.UN4.z} \cdot E_{act.RCC.UN4.z.loc.y} + E_{act.RCC.s.UN4.z} \cdot E_{act.RCC.s.UN4.z.loc.y} \cdots + E_{pas.OT.x.UN4} \cdot E_{pas.OT.UN4.loc} = -9456.84 \cdot kN \cdot m$$

Overturning Stability Analysis (Z-Direction)

$$\Sigma M_{UN4.OT.z} := \Sigma M_{V.UN4.OT} + \Sigma M_{H.UN4.OT.z} = 277361.95 \cdot kN \cdot m$$

$$Z_{R.UN4} := \frac{\Sigma M_{UN4.OT.z}}{\Sigma V_{UN4.OT}} = 7.5\ m \qquad z_{OT.UN4} := Z_{R.UN4} - \frac{W_B}{2} = -0.5\ m$$

Overturning Resultant Ratio

$$Ratio_{OT.z.UN4} := \frac{Z_{R.UN4}}{L_B} = 0.41$$

$$Ratio_{OT.z.UN4.check} := \begin{cases} \text{"OKAY"} & \text{if } Ratio_{OT.z.UN4} \geq Ratio_{OT.UN4.min} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

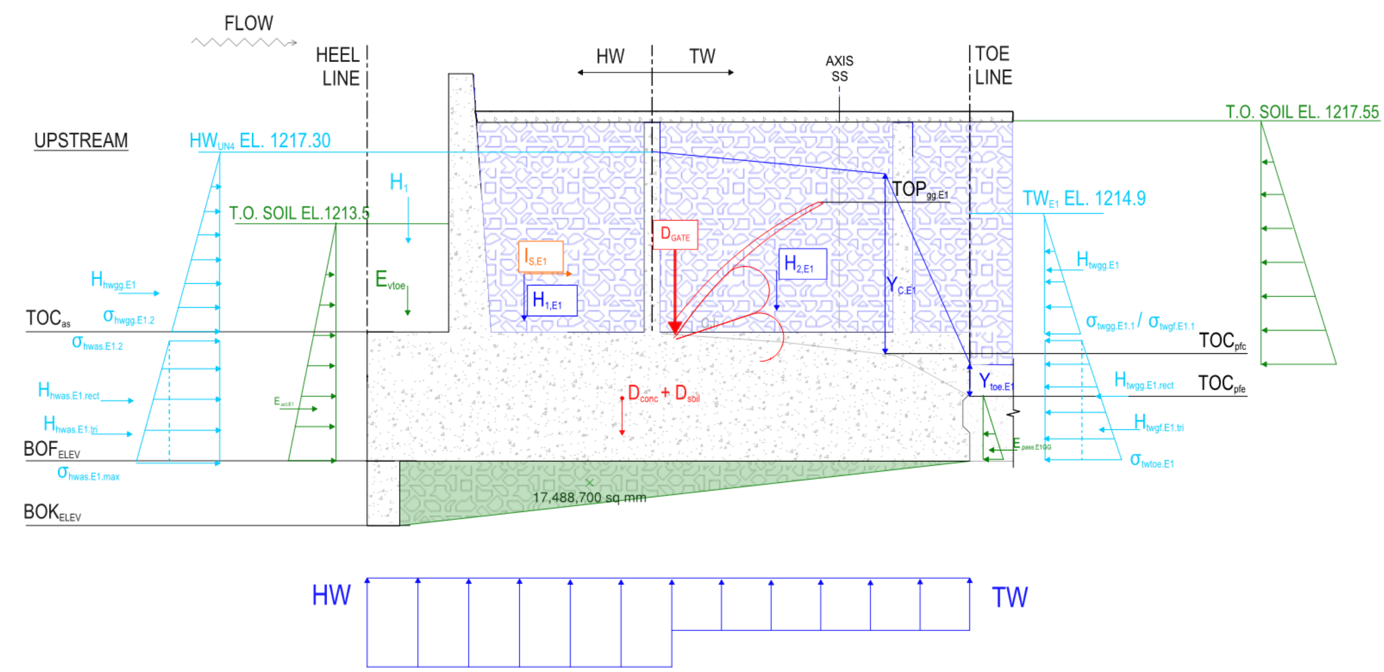
$$z_{OT.check.UN4} := \begin{cases} \text{"OKAY"} & \text{if } \left|z_{OT.UN4}\right| \leq Kern_z \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

SUMMARY OF STABILITY ASSESSMENT:

UN4 CASE

Sliding Factor of Safety: (Horizontal Plane)	$FS_{HorizSliding.UN4} = 4.21$	$FS_{HorizSliding.UN4.Check} =$ "OKAY"
Flotation Factor of Safety (horizontal plane)	$FS_{act.FUN4} = 2.71$	$FS_{check.FUN4} =$ "OKAY"
Overturning Resultant Ratio: (X-direction)	$Ratio_{OT.x.UN4} = 0.4$	$Ratio_{OT.x.UN4.check} =$ "OKAY"
Overturning Resultant Ratio: (Z-direction)	$Ratio_{OT.z.UN4} = 0.41$	$Ratio_{OT.z.UN4.check} =$ "OKAY"
Eccentricity: (horizontal plane)	$x_{OT.UN4} = -1.90\ m$	$x_{OT.check.UN4} =$ "OKAY"
Eccentricity: (horizontal plane)	$z_{OT.UN4} = -0.50\ m$	$z_{OT.check.UN4} =$ "OKAY"
Bearing Pressure At Heel(x)- Heel(z): (horizontal plane)	$\sigma_{heel.UN4} = 98 \cdot kPa$	$\sigma_{heel.UN4.check} =$ "Okay"
Bearing Pressure At Toe(x)-Toe(z): (horizontal plane)	$\sigma_{toe.UN4} = 158 \cdot kPa$	$\sigma_{toe.UN4.check} =$ "Okay"
Bearing Pressure at Heel(x)-Toe(z): (horizontal plane)	$\sigma_{heeltoe.UN4} = 16 \cdot kPa$	$\sigma_{heeltoe.UN4.check} =$ "Okay"
Bearing Pressure at Toe(x)-Heel(z): (horizontal plane)	$\sigma_{toeheel.UN4} = 240 \cdot kPa$	$\sigma_{toe.UN4.check} =$ "Okay"

E1 DESIGN CASE



ACCEPTANCE PARAMETERS

Required Factor of Safety for Sliding:	$FS_{req.E1.sl} := 1.0$	(Without Cohesion)
		(Section 8.1, Design Criteria)
Resultant Within Middle Third of Base:	$e \le \frac{L_B}{6} \wedge e \ge \frac{-L_B}{6}$	
Allowable Rock Bearing Pressure:	$\sigma_{allow.E1} := 1740 \cdot \frac{kN}{m^2}$	(Section 5.2, Design Criteria)
Required Factor of Safety for Flotation:	$FS_{req.E1.flt} := 1.1$	

INPUT PARAMETERS

Headwater Elevation:	$HW_{E1} := 1217.3m$	(Section 8.2, Design Criteria)
Tailwater Elevation:	$TW_{E1} := 1214.9m$	(Section 8.2, Design Criteria)
Bottom of Footing Elevation:	$BOF_{elev} = 1206\,m$	
Approch Slab Top of Concrete Elevation at Upstream Face:	$TOC_{as} = 1210\,m$	
Abutment Footing Top of Concrete Elevation at Stilling Basin:	$TOC_{afe} = 1208\,m$	
Abutment Footing Top of Concrete Elevation at Footing:	$TOC_{afc} = 1209.73\,m$	Gates are open when top of gate elevation is at 1210.00m
Abutment Footing Top of Concrete Elevation at Footing Notch:	$TOC_{afc.n} = 1209.3\,m$	
Top of Guard Gate Elevation:	$TOP_{gg.E1} := 1210.0m$	Gates are closed/up when top of gate elevation is at 1215.0m
Bottom of Key Elevation:	$BOK_{elev} = 1204\,m$	

E1 CASE

Water Elevation above Crest of Guard Gate:

$EL_{C.E1} := 1211.9m$

$$Y_{C.E1} := \begin{cases} (EL_{C.E1} - TOC_{afc.n}) & \text{if } TOP_{gg.E1} \le HW_{E1} \\ (TW_{E1} - TOC_{afc.n}) & \text{if } TOP_{gg.E1} > HW_{E1} \end{cases} = 2.6 \cdot m$$

Water Elevation above Guard Gate Toe: Submerged by Hydraulic 2D Model

$EL_{TOE.E1} := 1211.9m$

$$Y_{TOE.E1} := \begin{cases} (EL_{TOE.E1} - TOC_{afe}) & \text{if } TOP_{gg.E1} \le HW_{E1} \\ (TW_{E1} - TOC_{afe}) & \text{if } TOP_{gg.E1} > HW_{E1} \end{cases} = 3.9 \cdot m$$

LATERAL WATER LOADS

HEADWATER (DRIVING X-DIRECTION):

Headwater Depth on Abutment: $D_{hwa.E1} := HW_{E1} - TOC_{as} = 7.30\ m$

Headwater Load Unit Width Projected Surface Area of Abutment: $W_{hwa.E1} := 2 \cdot r_{wall} = 12.00\ m$

Total Horizontal Headwater Load on Abutment:

$$H_{hwa.E1} := \frac{-\left(\gamma_w \cdot D_{hwa.E1}{}^2\right)}{2} \cdot W_{hwa.E1} = -3136.6 \cdot kN$$

Apply Total Abutment Headwater Load at:

$$H_{hwa.E1.loc} := \frac{D_{hwa.E1}}{3} + \left(TOC_{as} - BOF_{elev}\right) = 6.43\ m$$

Apply Total Abutment Headwater Load at (from toe):

$H_{hwa.E1.loc.z} := 4m + r_{wall} = 10.00\ m$ (Gate Footing + Radius of Wall)

Thickness of Approach Slab: $T_{as} = 4\ m$

Headwater Depth at Heel (U/S face): $D_{hwas.E1} := HW_{E1} - BOF_{elev} = 11.30\ m$

Headwater Load Unit Width on Projected Approach Slab: $W_{hwas.E1} := W_B = 16.00\ m$

Headwater Line Load At Top of Approach Slab: $\sigma_{hwas.E1.1} := -\left(\gamma_w \cdot D_{hwa.E1}\right) = -71.61 \cdot kPa$

Headwater Line Load At Bottom of Approach Slab: $\sigma_{hwas.E1.2} := -\left(\gamma_w \cdot D_{hwas.E1}\right) = -110.85 \cdot kPa$

Trianglular Distribution Unit Load on Approach Slab:

$$H_{hwas.E1.2.tri} := \left(\frac{\sigma_{hwas.E1.2} - \sigma_{hwas.E1.1}}{2}\right) \cdot \left(T_{as} \cdot W_{hwas.E1}\right) = -1255.68 \cdot kN$$

Rectangular Distribution Unit Load on Approach Slab:

$$H_{hwas.E1.2.rect} := \sigma_{hwas.E1.1} \cdot \left(T_{as} \cdot W_{hwas.E1}\right) = -4583.23 \cdot kN$$

Total Horizontal Headwater Load on Approach Slab:

$$H_{hwas.E1} := H_{hwas.E1.2.tri} + H_{hwas.E1.2.rect} = -5838.91 \cdot kN$$

Apply Total Footing Headwater Load at:

$$H_{hwas.E1.loc} := \frac{\left[H_{hwas.E1.2.rect} \cdot \frac{\left(T_{as}\right)}{2} + H_{hwas.E1.2.tri} \cdot \frac{\left(T_{as}\right)}{3}\right]}{H_{hwas.E1.2.tri} + H_{hwas.E1.2.rect}} = 1.86\ m$$

Apply Total Footing Headwater Load at (from toe):

$$H_{hwas.E1.loc.z} := \frac{W_B}{2} = 8.00\ m$$

Guard Gate (2A) Operating Condition: Fully Open

Guard Gate Down/Open Condition: $A1_{E1} := TOP_{gg.E1} \le TOC_{as}$

Guard Crest Gate Up/Closed, with Top of Gate Higher than HW Elevation: $B1_{E1} := TOP_{gg.E1} \ge HW_{E1} \wedge TOP_{gg.E1} > TOC_{as}$

Guard Crest Gate Up/Closed, with Top of Gate Lower than HW Elevation: $C1_{E1} := TOP_{gg.E1} > TOC_{as} \wedge HW_{E1} > TOP_{gg.E1}$

Guard Crest Gate Height: $H_{gg.E1} := TOP_{gg.E1} - TOC_{as} = 0\ m$

Headwater Depth at Guard Crest Gate: $D_{hwgg.E1} := HW_{E1} - TOC_{as} = 7.30\ m$

Guard Crest Gate Width: $W_{hwgg.E1} := 4.0m$

Lateral Headwater Pressure at Bottom of Guard Crest Gate:

$$\sigma_{hwgg.E1.1} := \begin{cases} (0.0kPa) & \text{if } A1_{E1} \\ -(\gamma_w \cdot D_{hwgg.E1}) & \text{if } B1_{E1} \\ -(\gamma_w \cdot D_{hwgg.E1}) & \text{if } C1_{E1} \end{cases} = 0.0 \cdot kPa$$

Lateral Headwater Pressure at Top of Guard Crest Gate: (Load at HW Elevation On Guard Crest Gate if HW is below TOG_{rg})

$$\sigma_{hwgg.E1.2} := \begin{cases} (0.0kPa) & \text{if } A1_{E1} \\ 0.0kPa & \text{if } B1_{E1} \\ -\left[\gamma_w \cdot (HW_{E1} - TOP_{gg.E1})\right] & \text{if } C1_{E1} \end{cases} = 0.0 \cdot kPa$$

Average Pressure acting on Guard Crest Gate:

$$\sigma_{hwgg.E1.avg} := \frac{(\sigma_{hwgg.E1.1} + \sigma_{hwgg.E1.2})}{2} = 0 \cdot kPa$$

Total Area water acting on Crest Gate:

$$A_{hwgg.E1} := \begin{cases} D_{hwgg.E1} \cdot W_{hwgg.E1} & \text{if } A1_{E1} \\ D_{hwgg.E1} \cdot W_{hwgg.E1} & \text{if } B1_{E1} \\ H_{gg.E1} \cdot W_{hwgg.E1} & \text{if } C1_{E1} \end{cases} = 29.2 \cdot m^2$$

Total Horizontal Headwater Load on Guard Crest Gate: $H_{hwgg.E1} := \sigma_{hwgg.E1.avg} \cdot A_{hwgg.E1} = 0.0\ kN$

Apply Total Guard Crest Gate Headwater Load at:

$$H_{hwgg.E1.loc} := \begin{cases} (TOC_{as} - BOF_{elev}) & \text{if } A1_{E1} \\ \left[\frac{(HW_{E1} - TOC_{as})}{3} + (TOC_{as} - BOF_{elev})\right] & \text{if } B1_{E1} \\ \left[\frac{\sigma_{hwgg.E1.2} \cdot A_{hwgg.E1} \cdot \frac{(H_{gg.E1})}{2} + \frac{(\sigma_{hwgg.E1.1} - \sigma_{hwgg.E1.2})}{2} A_{hwgg.E1} \cdot \frac{(H_{gg.E1})}{3}}{\sigma_{hwgg.E1.2} \cdot A_{hwgg.E1} + \frac{(\sigma_{hwgg.E1.1} - \sigma_{hwgg.E1.2})}{2} \cdot A_{hwgg.E1}} \ldots \\ + (TOC_{as} - BOF_{elev})\right] & \text{if } C1_{E1} \end{cases} = 4.0 \cdot m$$

Apply Total Guard Crest Gate Headwater Load at (From toe): $H_{hwgg.E1.loc.z} := \frac{W_{hwgg.E1}}{2} = 2\ m$

LATERAL TAILWATER (RESISTING) Applied to Downstream Side of Guard Crest Gate: **E1-F CASE**

Guard Gate Down/Open Condition: $A2_{E1} := TOP_{gg.E1} \le TOC_{as}$

Guard Crest Gate Up/Closed, with Top of Gate Higher than TW Elevation: $B2_{E1} := TOP_{gg.E1} \ge TW_{E1} \wedge TOP_{gg.E1} > TOC_{as}$

Guard Crest Gate Up/Closed, with Top of Gate Lower than TW Elevation: $C2_{E1} := TOP_{gg.E1} > TOC_{as} \wedge TW_{E1} > TOP_{gg.E1}$

Tailwater Depth at Guard Crest Gate: $D_{twgg.E1} := TW_{E1} - TOC_{as} = 4.90\ m$

Guard Crest Gate Height: $H_{gg.E1} = 0\ m$

Guard Crest Gate Width: $W_{twgg.E1} := 4.0m$

Lateral Water Load at Bottom of Guard Crest Gate:

$$\sigma_{twgg.E1.1} := \begin{cases} (0.0kPa) & \text{if } A2_{E1} \\ (\gamma_w \cdot D_{twgg.E1}) & \text{if } B2_{E1} \\ (\gamma_w \cdot D_{twgg.E1}) & \text{if } C2_{E1} \end{cases} = 0.0 \cdot kPa$$

Lateral Water Load at Top of Guard Crest Gate:
(Load at TW Elevation On Guard Crest Gate if TW is below TOG_{gg})

$$\sigma_{twgg.E1.2} := \begin{cases} (0.0kPa) & \text{if } A2_{E1} \\ 0.0kPa & \text{if } B2_{E1} \\ \left[\gamma_w \cdot \left(\left(TW_{E1} - TOP_{gg.E1}\right)\right)\right] & \text{if } C2_{E1} \end{cases} = 0.0 \cdot kPa$$

Average Pressure acting on Guard Crest Gate:

$$\sigma_{twgg.E1.avg} := \frac{(\sigma_{twgg.E1.1} + \sigma_{twgg.E1.2})}{2} = 0 \cdot kPa$$

Total Area water acting on Crest Gate:

$$A_{twgg.E1} := \begin{cases} D_{twgg.E1} \cdot W_{twgg.E1} & \text{if } A2_{E1} \\ D_{twgg.E1} \cdot W_{twgg.E1} & \text{if } B2_{E1} \\ H_{gg.E1} \cdot W_{twgg.E1} & \text{if } C2_{E1} \end{cases} = 19.6 \cdot m^2$$

Total Horizontal Headwater Load on Guard Crest Gate: $H_{twgg.E1} := \sigma_{twgg.E1.avg} \cdot A_{twgg.E1} = 0.0 \cdot kN$

Apply Total Horiz. TW Load on Guard Gate at:

$$H_{twgg.E1.loc} := \begin{cases} (TOC_{as} - BOF_{elev}) & \text{if } A2_{E1} \\ \left[\frac{(TW_{E1} - TOC_{as})}{3} + (TOC_{as} - BOF_{elev})\right] & \text{if } B2_{E1} \\ \left[\frac{\sigma_{twgg.E1.2} \cdot A_{twgg.E1} \cdot \frac{(H_{gg.E1})}{2} + \frac{(\sigma_{twgg.E1.1} - \sigma_{twgg.E1.2})}{2} \cdot A_{twgg.E1} \cdot \frac{(H_{gg.E1})}{3}}{\sigma_{twgg.E1.2} \cdot A_{twgg.E1} + \frac{(\sigma_{twgg.E1.1} - \sigma_{twgg.E1.2})}{2} \cdot A_{twgg.E1}} \cdots \right. \\ \left. + (TOC_{as} - BOF_{elev}) \right] & \text{if } C2_{E1} \end{cases} = 4.0 \cdot m$$

Apply Total Guard Crest Gate Headwater Load at (From toe): $H_{twgg.E1.loc.z} := \frac{W_{twgg.E1}}{2} = 2\ m$

LATERAL WATER LOADS (continued)

E1 CASE

TAILWATER (RESISTING) Applied to Concrete Strucuture:

Tailwater Depth on Top of Abutment Footing: $D_{twa.E1} := TW_{E1} - TOC_{as} = 4.90\ m$

Tailwater Load Unit Width on Abutment: $W_{twa.E1} := 2 \cdot r_{wall} = 12.00\ m$

Total Horizontal Tailwater Load on Abutment: $H_{twa.E1} := \frac{\left(\gamma_w \cdot D_{twa.E1}{}^2\right)}{2} \cdot W_{twa.E1} = 1413.2 \cdot kN$

Apply Total Abutment Tailwater Load at: $H_{twa.E1.loc} := \frac{D_{twa.E1}}{3} + \left(TOC_{as} - BOF_{elev}\right) = 5.63\ m$

Apply Total Abutment Tailwater Load at (from Toe Line): $H_{twa.E1.loc.z} := W_{twgg.E1} + r_{wall} = 10\ m$

Footing Thickness for horizontal at Toe: $h_{toe} = 4\ m$

Tailwater Depth At top of Gate Base Footing Elevation: $D_{twgf.E1} := TW_{E1} - TOC_{as} = 4.90\ m$

Water Depth at bottom of Gate Base Footing (Excluding Key): $D_{twtoe.E1} := TW_{E1} - BOF_{elev} = 8.90\ m$

Water Depth at bottom of Gate Base Footing (Including Key): $D_{twkey.E1} := HW_{E1} - BOK_{elev} = 13.30\ m$

Unit Width of D/S face of crest for applicaiton of Tailwater Load: $W_{tw.E1} := W_B = 16.00\ m$

(Conservatively taken resisting water in front of 1.5m RCC Auxiliary Spillway as Tailwater elevation)

Tailwater Pressure At Top of Gate Footing: $\sigma_{twgf.E1} := \left(\gamma_w \cdot D_{twgf.E1}\right) = 48.07 \cdot kPa$

Tailwater Line Load At Bottom of Gate Footing (Excluding Key): $\sigma_{twtoe.E1} := \left(\gamma_w \cdot D_{twtoe.E1}\right) = 87.31 \cdot kPa$

Trianglular Distribution Unit Load on Gate Footing Base: $H_{twgf.E1.tri} := \left(\frac{\sigma_{twtoe.E1} - \sigma_{twgf.E1}}{2}\right) \cdot \left[\left(T_{as} - d_{key}\right) \cdot W_{tw.E1}\right] = 627.84 \cdot kN$

Rectangular Distribution Unit Load on Gate Footing Base: $H_{twgf.E1.rect} := \sigma_{twgf.E1} \cdot \left[\left(T_{as} - d_{key}\right) \cdot W_{tw.E1}\right] = 1538.21 \cdot kN$

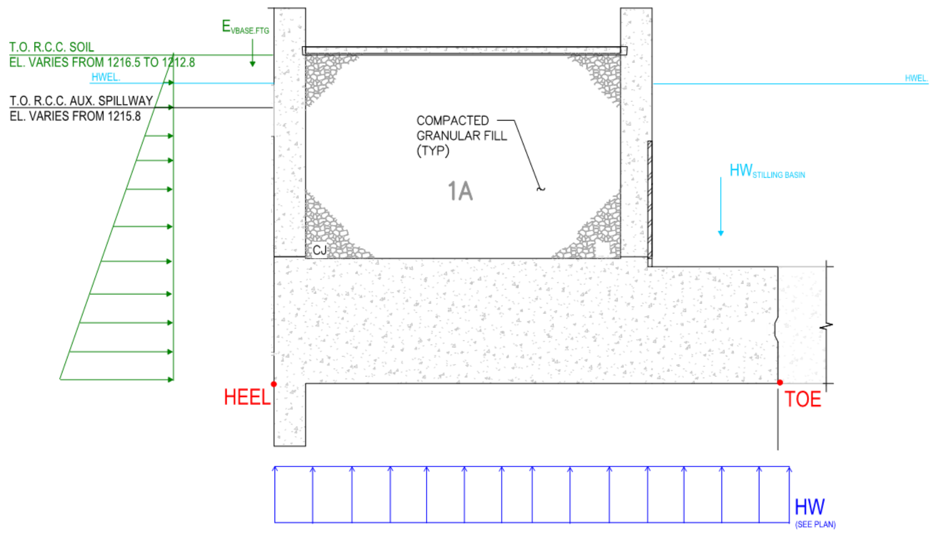
Total Horizontal Tailwater Headwater Load on Gate Footing: $H_{twgf.E1} := H_{twgf.E1.tri} + H_{twgf.E1.rect} = 2166.05 \cdot kN$

Apply Total Gate Footing Tailwater Load at:

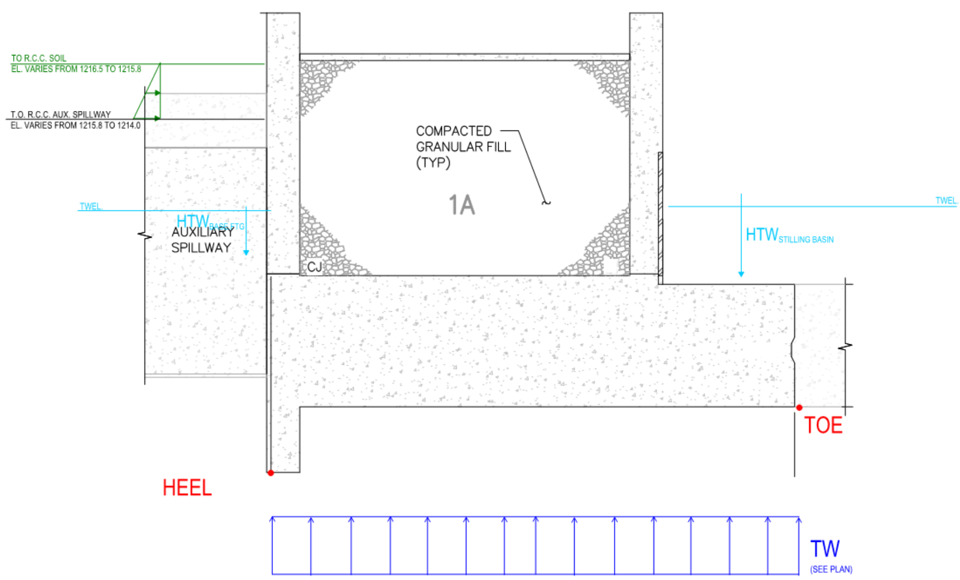
$$H_{twgf.E1.loc} := \frac{\left[H_{twgf.E1.rect} \cdot \frac{\left(T_{as}\right)}{2} + H_{twgf.E1.tri} \cdot \frac{\left(T_{as}\right)}{3}\right]}{H_{twgf.E1.tri} + H_{twgf.E1.rect}} = 1.81\ m$$

Apply Total Gate Footing Tailwater Load at (From Toe Line): $H_{twgf.E1.loc.z} := \frac{W_B}{2} = 8.00\ m$

SUMMATION OF LATERAL WATER LOADS:



SECTION 1A BEFORE GATES & AUX. SPILLWAY RCC



SECTION 1A AFTER GATES & AUX. SPILLWAY RCC

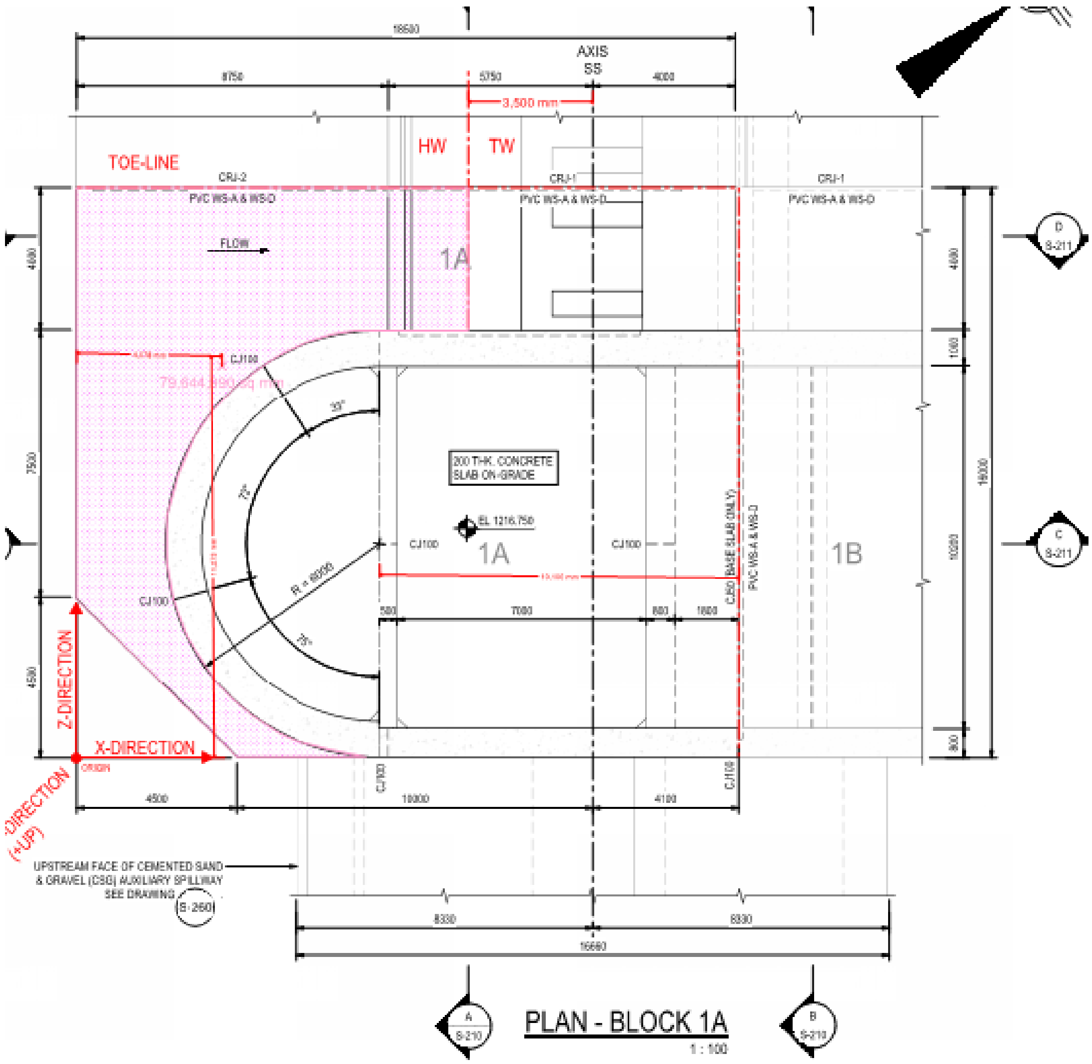
$$\Sigma H_{Water.E1.x} := H_{hwa.E1} + H_{hwas.E1} + H_{hwgg.E1} + H_{twa.E1} + H_{twgf.E1} + H_{twgg.E1} = -5396.28 \cdot kN$$

$$\Sigma M_{HWater.E1.x} := H_{hwa.E1} \cdot H_{hwa.E1.loc} + H_{hwas.E1} \cdot H_{hwas.E1.loc} + H_{hwgg.E1} \cdot H_{hwgg.E1.loc} \dots + H_{twa.E1} \cdot H_{twa.E1.loc} + H_{twgf.E1} \cdot H_{twgf.E1.loc} + H_{twgg.E1} \cdot H_{twgg.E1.loc} = -19145.09 \cdot kN \cdot m$$

$\Sigma H_{Water.E1.z} := 0kN$ $\Sigma M_{HWater.E1.z} := 0 \cdot kN \cdot m$

VERTICAL WATER LOADS

E1 CASE



HEADWATER:

Water Depth on top of Approach Slab: $d_{hw.E1} := HW_{E1} - TOC_{as} = 7.30\ m$

Water Area on top of Approach Slab: $A_{as} = 79.64\ m^2$ (From Geom. Scaled on REVU)

Vertical Water Weight (H1) on Approach Slab: $H_{1.E1} := \left(A_{as} \cdot d_{hw.E1}\right) \cdot \gamma_w = 5703.6 \cdot kN$

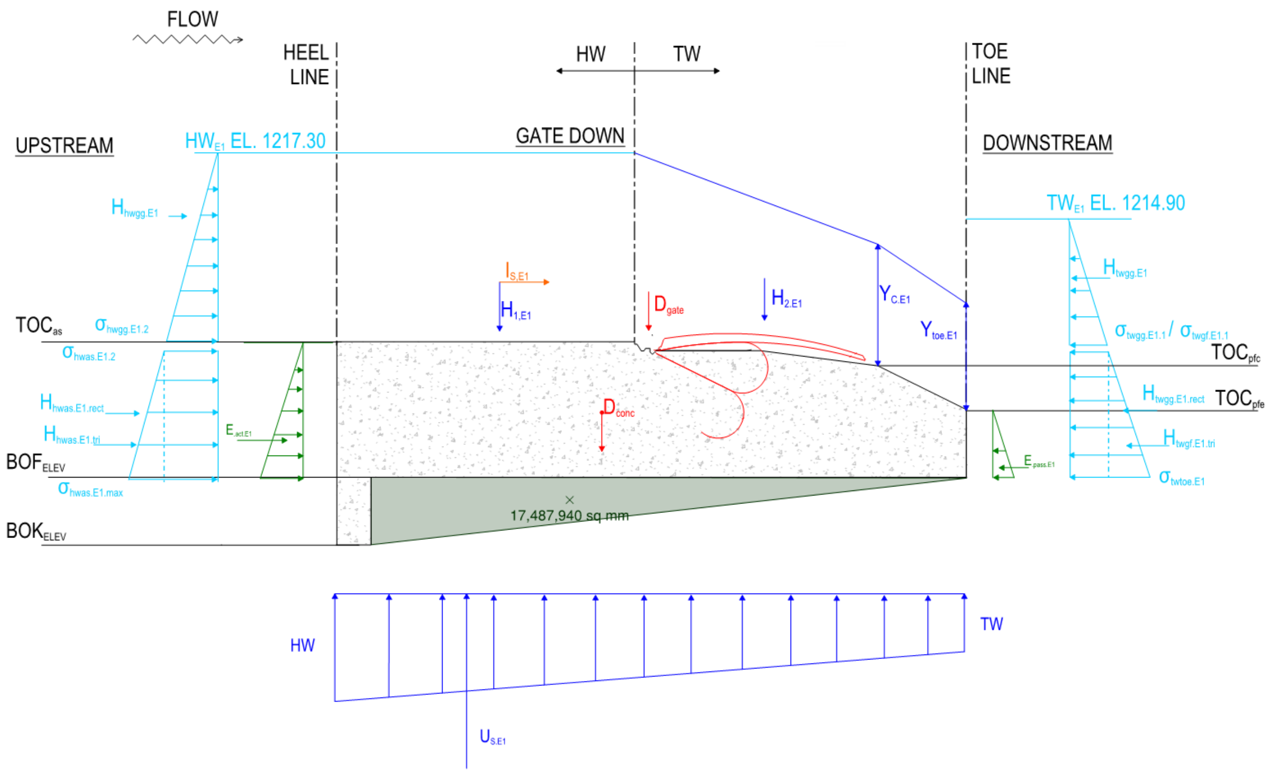
Moment Arm for Applicaiton of Water Weight (H1) from toe (X-Direction): $H_{1.E1.loc.x} := L_B - 4.078m = 14.42\ m$ (From Geom. Scaled on REVU)

Moment Arm for Applicaiton of Water Weight (H1) from toe (Z-Direction): $H_{1.E1.loc.z} := W_B - 11.273m = 4.73\ m$ (From Geom. Scaled on REVU)

VERTICAL WATER LOADS

E1 CASE

TAILWATER:



Approach Slab Length: $L_{as} = 8.75\ m$

Gate Footing Length: $L_{gf} = 9.75\ m$

Gate Footing Crest Length: $L_{gfc} = 2.25\ m$

TAILWATER:

Trapezoid Volume Above Gate Footing from Approach Slab to Crest:

$$V_{asc.E1} := \left(L_{gf} - L_{gfc}\right) W_{twgg.E1} \frac{d_{hw.E1} + Y_{C.E1}}{2} = 148.5 \cdot m^3$$

Trapezoid Volume Above Gate Footing Crest to End of Gate Footing:

$$V_{gfc.E1} := \left(L_{gfc} \cdot W_{twgg.E1}\right) \frac{Y_{C.E1} + Y_{TOE.E1}}{2} = 29.25 \cdot m^3$$

Load Above Gate Footing from Approach Slab to Crest:

$$H_{2.E1.asc} := V_{asc.E1} \cdot \gamma_w = 1456.79 \cdot kN$$

Load Acting Above Footing Crest from Toe:

$$H_{2.E1.asc.loc.x} := \frac{\left(L_{gf} - L_{gfc}\right) \cdot \left(2 \cdot d_{hw.E1} + Y_{C.E1}\right)}{3 \cdot \left(d_{hw.E1} + Y_{C.E1}\right)} + L_{gfc} = 6.59\ m$$

Load Above Gate Footing from Crest to End:

$$H_{2.E1.gfc} := V_{gfc.E1} \cdot \gamma_w = 286.94 \cdot kN$$

Load Acting Above Gate Footing from Crest to End:

$$H_{2.E1.gfc.loc.x} := \frac{\left(L_{gfc}\right) \cdot \left(2 \cdot Y_{C.E1} + Y_{TOE.E1}\right)}{3 \cdot \left(Y_{C.E1} + Y_{TOE.E1}\right)}$$

Vertical Water Weight (H2) on Gate Footing:

$$H_{2.E1} := H_{2.E1.asc} + H_{2.E1.gfc} = 1743.73 \cdot kN$$

Moment Arm for Application of Water Weight (H2) from toe:

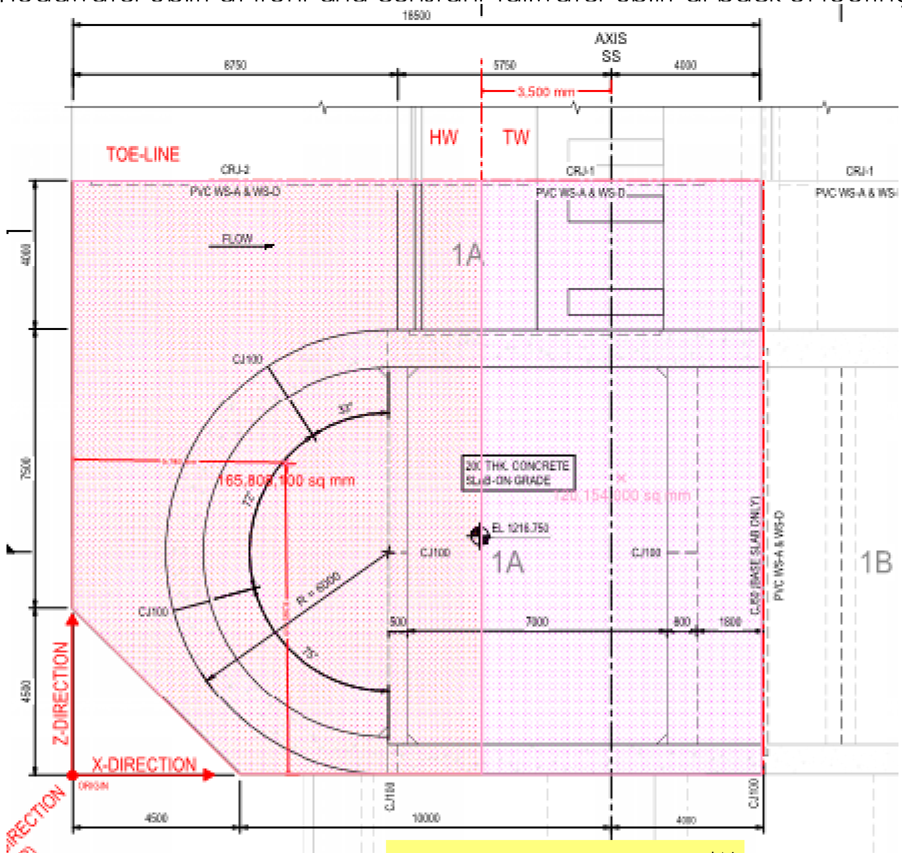
$$H_{2.E1.loc.x} := \frac{H_{2.E1.asc} \cdot H_{2.E1.asc.loc.x} + H_{2.E1.gfc} \cdot H_{2.E1.gfc.loc.x}}{H_{2.E1}} = 5.68\ m$$

Moment Arm for Applicaiton of Water Weight (H2) from toe (Z-Direction):

$$H_{2.E1.loc.z} := 2.0m$$

UPLIFT

(Assuming constant Headwater Uplift at front and constant Tailwater Uplift at back of footing base)



Uplift pressure at U/S Face (heel): $U_{HW.E1} := D_{hwas.E1} \cdot \gamma_w = 110.9 \cdot \frac{kN}{m^2}$

Uplift pressure at D/S Face Stilling Basin: $U_{TW.E1} := D_{twtoe.E1} \cdot \gamma_w = 87.31 \cdot \frac{kN}{m^2}$

Area of Uplift Force From Headwater Side: $A_{HWU.E1} := 165.81 m^2$ (From Bluebeam REVU)

Area of Uplift Force From Tailwater Side: $A_{TWU.E1} := 120.0 m^2$ (From Bluebeam REVU)

Uplift Force From Headwater Side: $U_{A.E1} := -U_{HW.E1} \cdot A_{HWU.E1} = -18380.54 \cdot kN$

Uplift Force From Headwater Side: $U_{B.E1} := -U_{TW.E1} \cdot A_{TWU.E1} = -10477.08 \cdot kN$

Uplift Centroid of Area From Headwater Side to Toe: $X_{U.A} = 13.22 m$ $Z_{U.A} = 7.63 m$ (From Bluebeam REVU)

Uplift Centroid of Area From Tailwater Side to Toe: $X_{U.B} = 3.75 m$ $Z_{U.B} = 8 m$ (From Bluebeam REVU)

Total Resultant Uplift force: $U_{E1} := U_{A.E1} + U_{B.E1} = -28857.62 \cdot kN$

Resultant Location from Toe Rect. Load (X-Direction): $U_{E1.loc.x} := \frac{\left(U_{A.E1} \cdot X_{U.A} + U_{B.E1} \cdot X_{U.B}\right)}{\left(U_{A.E1} + U_{B.E1}\right)} = 9.78 m$

Resultant Location from Toe Rect. Load (Z-Direction): $U_{E1.loc.z} := \frac{\left[U_{A.E1} \cdot \left(W_B - Z_{U.A}\right) + U_{B.E1} \cdot \left(W_B - Z_{U.B}\right)\right]}{\left(U_{A.E1} + U_{B.E1}\right)} = 8.23 m$

$\Sigma V_{water.E1} := H_{1.E1} + H_{2.E1} + U_{E1} = -21410.27 \cdot kN$

$\Sigma M_{Vwater.E1.x} := H_{1.E1} \cdot H_{1.E1.loc.x} + H_{2.E1} \cdot H_{2.E1.loc.x} + U_{E1} \cdot U_{E1.loc.x} = -190115.66 \cdot kN \cdot m$

$\Sigma M_{Vwater.E1.z} := H_{1.E1} \cdot H_{1.E1.loc.z} + H_{2.E1} \cdot H_{2.E1.loc.z} + U_{E1} \cdot U_{E1.loc.z} = -207121.37 \cdot kN \cdot m$

Equivalent Fluid Pressure (EFP):

At rest lateral pressure coefficient: $K_{o.E1} := 1 - \sin(\phi_{backfill}) = 0.658$ (Section 5.3, Design Criteria)

Headwater Top of Soil Elevation: $TOS_{HW} = 1210\,m$

Top of Backfill Soil Elevation: $TOS_{BF} = 1216.5\,m$

Driving Soil Load Unit Width Projected Surface Area of Abutment: $W_{ds.hwa.E1} := 6.0m$

Driving Soil Load Unit Width on Projected Approach Slab + Key: $W_{hwas.E1} = 16.00\,m$

Resisting Soil Load Unit Width Projected Surface Area of Abutment: $W_{rsa.E1} := \frac{10.5m + 9.381m}{2} = 9.94\,m$ (From Section Cut)

Driving Soil Load Depth on Abutment: $d_{DS.a} = 0\,m$

Driving Soil Load Depth on Footing: $d_{DS.as} = 4\,m$

Resisting Soil Load Depth on Abutment: $d_{RS.a} = 8.5\,m$

Thickness of Stilling Basin: $T_{sb} = 2\,m$

Lateral X-Direction Driving Force (Headwater Side - at rest condition)

At-Rest Soil Load on Half of Abutment: $E_{act.a.E1.x} := \frac{\left(K_{o.E1} \cdot d_{DS.a}{}^2\right)}{2} \cdot \left(\gamma_r - \gamma_w\right) \cdot W_{ds.hwa.E1} \cdot -1 = 0 \cdot kN$

Acting at: $E_{act.a.E1.x.loc.y} := \frac{d_{DS.a}}{3} + T_{as} - d_{key} = 2.00\,m$

Acting at (from Toe Line): $E_{act.a.E1.x.loc.z} := W_{hwgg.E1} + r_{wall} = 10.00\,m$

At-Rest Soil Load on Top of Approach Slab: $\sigma_{DS.as.E1} := \left(K_{o.E1} \cdot d_{DS.a}\right) \cdot \left(\gamma_r - \gamma_w\right) = 0 \cdot kPa$

At-Rest Soil Load on Bottom of Approach Slab: $\sigma_{DS.key.E1} := \left(K_{o.E1} \cdot d_{DS.as}\right) \cdot \left(\gamma_r - \gamma_w\right) = 32.08 \cdot kPa$

At-Rest Soil Load on Approach Slab (Rect): $E_{act.as.rect.E1.x} := \sigma_{DS.as.E1} \cdot \left(T_{as}\right) \cdot W_{hwas.E1} \cdot -1 = 0 \cdot kN$

At-Rest Soil Load on Approach Slab (Tri): $E_{act.as.tri.E1.x} := \frac{\left(\sigma_{DS.key.E1} - \sigma_{DS.as.E1}\right) \cdot \left(T_{as}\right)}{2} \cdot W_{hwas.E1} \cdot -1 = -1026.66 \cdot kN$

At-Rest Soil Load on Approach Slab: $E_{act.as.E1.x} := E_{act.as.rect.E1.x} + E_{act.as.tri.E1.x} = -1026.66 \cdot kN$

Acting at:

$$E_{act.as.E1.x.loc.y} := \frac{\left(E_{act.as.rect.E1.x} \cdot \frac{T_{as}}{2} \cdots + E_{act.as.tri.E1.x} \cdot \frac{T_{as}}{3}\right)}{E_{act.as.E1.x}} = 1.33\,m$$

Acting at (from Toe Line): $E_{act.as.E1.x.loc.z} := \frac{W_B}{2} = 8.00\,m$

Lateral X-Direction Resisting Force (Tailwater Side - at rest condition)

E1 CASE

At-rest Soil Load: $E_{pass.E1.x} := \frac{\left(K_{o.E1} \cdot d_{RS.a}^{2}\right)}{2} \cdot \left(\gamma_r - \gamma_w\right) \cdot W_{rsa.E1} = 2880.26 \cdot kN$

Acting at: $E_{pass.E1.x.loc.y} := \frac{d_{RS.a}}{3} + T_{sb} - d_{key} = 2.83\ m$ $\quad W_{rsa.UN4} = 9.94\ m$

Acting at (from Toe Line): $E_{pass.E1.x.loc.z} := W_{hwgg.E1} + r_{wall} = 10\ m$

$\Sigma H_{soil.E1.x} := \left(E_{act.a.E1.x} + E_{act.as.E1.x} + E_{pass.E1.x}\right) = 1853.61 \cdot kN$

$\Sigma M_{soil.E1.x} := E_{act.a.E1.x} \cdot E_{act.a.E1.x.loc.y} + E_{act.as.E1.x} \cdot E_{act.as.E1.x.loc.y} + E_{pass.E1.x} \cdot E_{pass.E1.x.loc.y} = 6791.87 \cdot kN \cdot m$

Lateral Z-Direction Driving Force (Headwater Side - Before Gates & Aux. Spillway RCC - at rest condition)

Max./Min. Top of R.C.C. Soil Elevation: $TOS_{RCC.max} = 1216.5\ m$ $\quad TOS_{RCC.min} = 1212.8\ m$

Average Top of R.C.C. Soil Elevation: $TOS_{RCC} = 1214.65\ m$

Depth of R.C.C. Soil Acting on Abutment Walls: $d_{act.RCC.w} = 4.65\ m$

Depth of R.C.C. Soil Acting on Abutment Footings: $d_{act.RCC.f} = 8.65\ m$

Projected Width of soil acting on Abutment Walls: $w_{abut.RCC} = 9.45\ m$

Projected Width of soil acting on Abutment Footing: $w_{FTG.RCC} = 12.2\ m$

At-Rest Soil Load on Top of Footing Slab: $\sigma_{act.RCC.w.E1} := \left(K_{o.E1} \cdot d_{act.RCC.w}\right) \cdot \left(\gamma_r - \gamma_w\right) = 37.3 \cdot kPa$

At-Rest Soil Load on Bottom of Approach Slab: $\sigma_{act.RCC.f.E1} := \left(K_{o.E1} \cdot d_{act.RCC.f}\right) \cdot \left(\gamma_r - \gamma_w\right) = 69.38 \cdot kPa$

At-Rest Soil Load on Abutment Walls: $E_{act.a.E1.z} := \frac{\left(K_{o.E1} \cdot d_{act.RCC.w}^{2}\right)}{2} \cdot \left(\gamma_r - \gamma_w\right) \cdot w_{abut.RCC} \cdot -1 = -819.45 \cdot kN$

Acting at: $E_{act.a.E1.z.loc.y} := \frac{d_{DS.a}}{3} + T_{as} = 4.00\ m$

Acting at (from Toe Line): $E_{act.a.E1.z.loc.x} := \frac{\left(L_{wall} + r_{wall} - 6.35m\right)}{2} + 6.35m = 11.18\ m$

At-Rest Soil Load on Abutment Footing (Rect): $E_{act.as.rect.E1.z} := \sigma_{act.RCC.w.E1} \cdot \left(T_{as}\right) \cdot w_{abut.RCC} \cdot -1 = -1409.81 \cdot kN$

At-Rest Soil Load on Abutment Footing (Tri): $E_{act.as.tri.E1.z} := \frac{-\left(\sigma_{act.RCC.f.E1} - \sigma_{act.RCC.w.E1}\right) \cdot \left(T_{as}\right)}{2} \cdot w_{FTG.RCC} = -782.83 \cdot kN$

At-Rest Soil Load on Approach Slab: $E_{act.as.E1.z} := E_{act.as.rect.E1.z} + E_{act.as.tri.E1.z} = -2192.64 \cdot kN$

Acting at: $E_{act.as.E1.z.loc.y} := \frac{\left(E_{act.as.rect.E1.z} \cdot \frac{T_{as}}{2} \ldots + E_{act.as.tri.E1.z} \cdot \frac{T_{as}}{3}\right)}{E_{act.as.E1.z}} = 1.76\ m$

Acting at (from toe line): $E_{act.as.E1.z.loc.x} := \frac{\left(L_{wall} + r_{wall} - 6.35m\right)}{2} + 6.35m = 11.18\ m$

Lateral Z-Direction Driving Force (Headwater Side - After Gates & Aux. Spillway RCC - at rest condition) **E1 CASE**

Max. Top of R.C.C. Wall: $TORCC_{max} = 1215.8\ m$

Min. Top of R.C.C. Wall: $TORCC_{min} = 1214\ m$

Average Top of R.C.C. Wall Elevation: $TORCC = 1214.9\ m$

Width of Soil acting at Max. top of RCC: $w_{RCC.max} = 4.7\ m$

Width of Soil acting with average Top of RCC (Steps): $w_{RCC.avg} = 1.65\ m$

Depth of Top of Soil to Top of R.C.C. Wall: $d_{act.RCC} = 0.7\ m$

Depth of Top of Soil to Average Top of R.C.C. Wall (Steps): $d_{act.RCC.avg} = 1.6\ m$

At-Rest Soil Load on Abutment Walls after RCC:

$$E_{act.RCC.E1.z} := \frac{\left(K_{o.E1} \cdot d_{act.RCC}{}^{2}\right)}{2} \cdot \left(\gamma_r - \gamma_w\right) \cdot w_{RCC.max} \cdot -1 = -9.24 \cdot kN$$

Acting at:

$$E_{act.RCC.E1.z.loc.y} := \frac{d_{act.RCC}}{3} + \left(TORCC_{max} - BOF_{elev}\right) = 10.03\ m$$

Acting at (from Toe Line): $E_{act.RCC.E1.z.loc.x} := 4m$ (at SS-Axis Center Line)

At-Rest Soil Load on Abutment Walls at RCC Steps:

$$E_{act.RCC.s.E1.z} := \frac{\left(K_{o.E1} \cdot d_{act.RCC.avg}{}^{2}\right)}{2} \cdot \left(\gamma_r - \gamma_w\right) \cdot w_{RCC.avg} \cdot -1 = -16.94 \cdot kN$$

Acting at:

$$E_{act.RCC.s.E1.z.loc.y} := \frac{d_{act.RCC.avg}}{3} + \left(TORCC - BOF_{elev}\right) = 9.43\ m$$

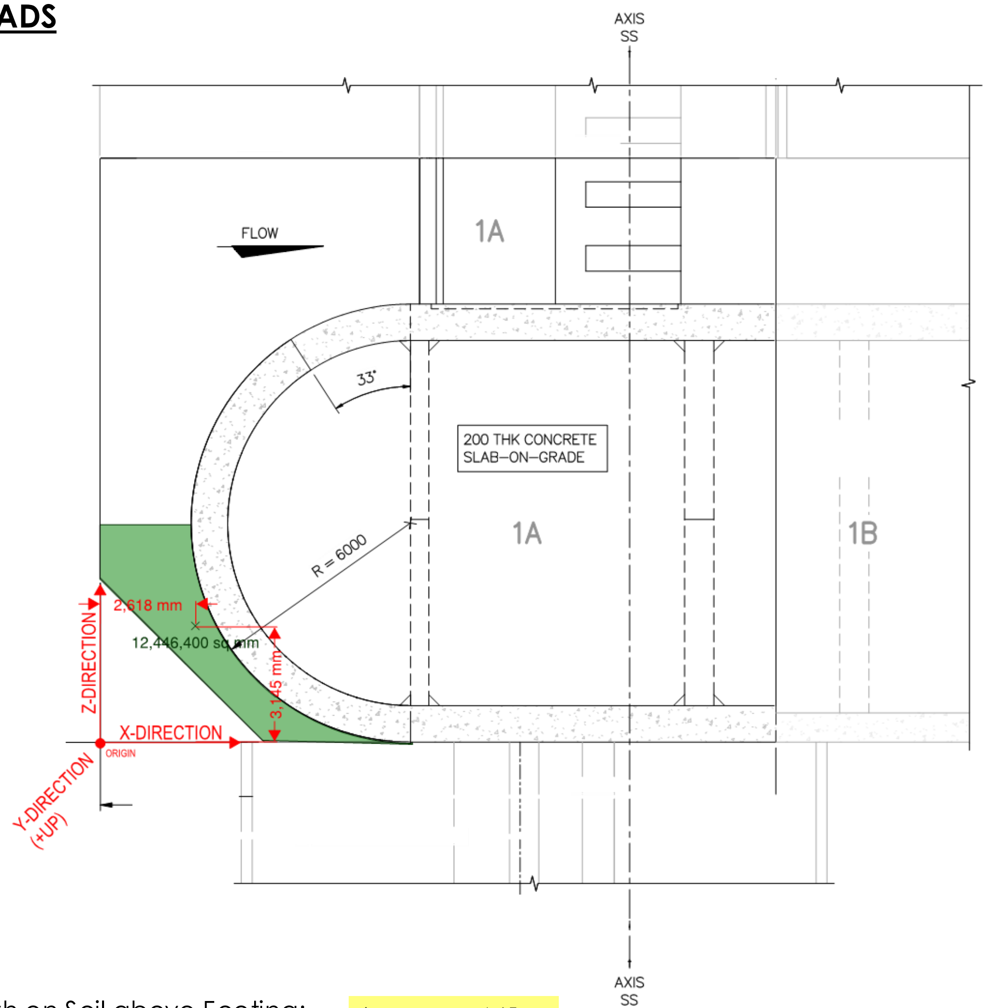
Acting at (from Toe Line): $E_{act.RCC.s.E1.z.loc.x} := \frac{4m - 2.35m}{2} = 0.83\ m$ (at Halfway point of RCC Steps)

$$\Sigma H_{soil.E1.z} := \left(E_{act.a.E1.z} + E_{act.as.E1.z} + E_{act.RCC.E1.z} + E_{act.RCC.s.E1.z}\right) = -3038.27 \cdot kN$$

$$\Sigma M_{soil.E1.z} := E_{act.a.E1.z} \cdot E_{act.a.E1.z.loc.y} + E_{act.as.E1.z} \cdot E_{act.as.E1.z.loc.y} \cdots + E_{act.RCC.E1.z} \cdot E_{act.RCC.E1.z.loc.y} + E_{act.RCC.s.E1.z} \cdot E_{act.RCC.s.E1.z.loc.y} = -7393.67 \cdot kN \cdot m$$

VERTICAL SOIL LOADS

E1 CASE



Average Depth on Soil above Footing: $d_{RCC.FTG} = 4.65\,m$

Area of Footing with Soil above: $A_{ftg.soil} = 0$ (From Bluebeam REVU)

Vertical Water Weight (H1) on Approach Slab: $E_{1.E1} := \left(A_{ftg.soil} \cdot d_{RCC.FTG}\right) \cdot \left(\gamma_r - \gamma_w\right) = 0.0 \cdot kN$

Moment Arm for Applicaiton of Water Weight (H1) from toe (X-Direction): $E_{1.E1.loc.x} := L_B - 5.607m = 12.89\,m$ (From Geom. Scaled on REVU)

Moment Arm for Applicaiton of Water Weight (H1) from toe (Z-Direction): $E_{1.E1.loc.z} := W_B - 3.145m = 12.86\,m$ (From Geom. Scaled on REVU)

$\Sigma E_{E1} := E_{1.E1} = 0 \cdot kN$ $\Sigma M_{E.E1.x} := E_{1.E1} \cdot E_{1.E1.loc.x} = 0 \cdot kN \cdot m$ $\Sigma M_{E.E1.z} := E_{1.E1} \cdot E_{1.E1.loc.z} = 0 \cdot kN \cdot m$

IMPACT LOADS (DEBRIS LOADING FROM MEMO)

Total Impact Load on Structure: $I_{E1} := 5704kN$ (SS Abutment) - PMF

Apply Ice load at: $I_{E1.loc.y} := \left(HW_{E1} - BOF_{elev} - 0.30m\right) = 11.00\,m$

$\Sigma H_{I.E1} := I_{E1} = 5704 \cdot kN$

$\Sigma M_{I.E1} := I_{E1} \cdot I_{E1.loc.y} = 62744 \cdot kN \cdot m$

SEISMIC LOAD (NOT APPLICABLE FOR THIS LOAD CASE)

E1 CASE

SUMMARY OF LOADS

	Loads	Moment Arm	
Dead load of Concrete Structure:	$D_{conc} = 35947.6 \cdot kN$	$X_{conc.loc} = 8.81\ m$	$Z_{conc.loc} = 8.46\ m$
Obermyer Gate Weight:	$D_{Gate} = 56.0 \cdot kN$	$X_{gate} = 9.50\ m$	$Z_{gate} = 2.00\ m$
Dead load of Fill:	$D_{fill} = 18056.6 \cdot kN$	$X_{fill.loc} = 7.31\ m$	$Z_{fill.loc} = 10.00\ m$
HW Lateral Load on Abutment:	$H_{hwa.E1} = -3136.6 \cdot kN$	$H_{hwa.E1.loc} = 6.43\ m$	
HW Lateral Load on Approach Slab:	$H_{hwas.E1} = -5838.9 \cdot kN$	$H_{hwas.E1.loc} = 1.86\ m$	
HW Lateral Load on Guard Gate:	$H_{hwgg.E1} = 0.0 \cdot kN$	$H_{hwgg.E1.loc} = 4.00\ m$	
TW Lateral Load on Abutment:	$H_{twa.E1} = 1413.2 \cdot kN$	$H_{twa.E1.loc} = 5.63\ m$	
TW Lateral Load on Pier Footing:	$H_{twgf.E1} = 2166.05 \cdot kN$	$H_{twgf.E1.loc} = 1.81\ m$	
TW Lateral Load on Guard Gate:	$H_{twgg.E1} = 0.0 \cdot kN$	$H_{twgg.E1.loc} = 4.00\ m$	
Vertical HW Load on Approach Slab:	$H_{1.E1} = 5703.6 \cdot kN$	$H_{1.E1.loc.x} = 14.42\ m$	$H_{1.E1.loc.z} = 4.73\ m$
Vertical TW Load on Pier Footing (crest):	$H_{2.E1} = 1743.7 \cdot kN$	$H_{2.E1.loc.x} = 5.68\ m$	$H_{2.E1.loc.z} = 2.00\ m$
Uplift:	$U_{E1} = -28857.6 \cdot kN$	$U_{E1.loc.x} = 9.78\ m$	$U_{E1.loc.z} = 8.23\ m$
X-Direction Lateral Soil Load on Abutment (driving):	$E_{act.a.E1.x} = 0.0 \cdot kN$	$E_{act.a.E1.x.loc.y} = 2.00\ m$	
X-Direction Lateral Lateral Soil Load on Approach Slab (driving):	$E_{act.as.E1.x} = -1026.7 \cdot kN$	$E_{act.as.E1.x.loc.y} = 1.33\ m$	
Lateral Soil Load (resisting):	$E_{pass.E1.x} = 2880.26 \cdot kN$	$E_{pass.E1.x.loc.y} = 2.83\ m$	
Z-Direction Lateral Soil Load on Abutment Before RCC (driving):	$E_{act.a.E1.z} = -819.5 \cdot kN$	$E_{act.a.E1.z.loc.y} = 4.00\ m$	
Z-Direction Lateral Lateral Soil Load on Approach Slab Before RCC (driving):	$E_{act.as.E1.z} = -2192.6 \cdot kN$	$E_{act.as.E1.z.loc.y} = 1.76\ m$	
Z-Direction Lateral Soil Load on Abutment After RCC (driving):	$E_{act.RCC.E1.z} = -9.24 \cdot kN$	$E_{act.RCC.E1.z.loc.y} = 10.03\ m$	
Z-Direction Lateral Soil Load on Abutment at RCC Steps (driving):	$E_{act.RCC.s.E1.z} = -16.94 \cdot kN$	$E_{act.RCC.s.E1.z.loc.y} = 9.43 \cdot m$	
Vertical Soil Load on Footing:	$E_{1.E1} = 0 \cdot kN$	$E_{1.E1.loc.x} = 12.89\ m$	$E_{1.E1.loc.z} = 12.86\ m$
Ice / Impact Load:	$I_{E1} = 5704.0 \cdot kN$	$I_{E1.loc.y} = 11.00\ m$	

STABILITY ASSESSMENT (SLIDNG, BEARING, FLOTATION AND OVERTURNING): E1 CASE

CHECK SLIDING (X-Direction & Z-Direction) ALONG HORIZONTAL PLANE THRU TOE, IGNORING BEDROCK MOBILIZED BY STRUCTURAL HEEL KEY, OR VOID BEHIND KEY

Sum of Vertical Forces:

$$\Sigma V_{E1} := \Sigma V_{DL} + \Sigma V_{water.E1} + \Sigma E_{E1} = 32649.9 \cdot kN$$

Sum of Horizontal Forces (X-Direction):

$$\Sigma H_{E1.x} := \Sigma H_{Water.E1.x} + \Sigma H_{soil.E1.x} + \Sigma H_{I.E1} = 2161.32 \cdot kN$$

Sum of Horizontal Forces (Z-Direction):

$$\Sigma H_{E1.z} := \Sigma H_{Water.E1.z} + \Sigma H_{soil.E1.z} = -3038.27 \cdot kN$$

Sum of Horizontal Forces (resultant):

$$\Sigma H_{E1} := \sqrt{\Sigma H_{E1.x}{}^2 + \Sigma H_{E1.z}{}^2} = 3728.59 \cdot kN$$

Sliding Factor of Safety:

$$FS_{HorizSliding.E1.x} := \frac{\tan_{\phi} \cdot \Sigma V_{E1}}{\left|\Sigma H_{E1.x}\right|} = 7.37 \qquad FS_{HorizSliding.E1.z} := \frac{\tan_{\phi} \cdot \Sigma V_{E1}}{\left|\Sigma H_{E1.z}\right|} = 5.24$$

Sliding Factor of Safety:

$$FS_{HorizSliding.E1} := \frac{\tan_{\phi} \cdot \Sigma V_{E1}}{\sqrt{\Sigma H_{E1.x}{}^2 + \Sigma H_{E1.z}{}^2}} = 4.27$$

$$FS_{HorizSliding.E1.Check.x} := \begin{cases} \text{"OKAY"} & \text{if } FS_{HorizSliding.E1.x} \geq FS_{req.E1.sl} \\ \text{"Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

$$FS_{HorizSliding.E1.Check.z} := \begin{cases} \text{"OKAY"} & \text{if } FS_{HorizSliding.E1.z} \geq FS_{req.E1.sl} \\ \text{"Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

$$FS_{HorizSliding.E1.Check} := \begin{cases} \text{"OKAY"} & \text{if } FS_{HorizSliding.E1} \geq FS_{req.E1.sl} \\ \text{"Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

CHECK FOUNDATION BEARING CAPACITY

Sum of the Moments (X-Direction):

$$\Sigma M_{E1.x} := \Sigma M_{DL.x} + \Sigma M_{HWater.E1.x} + \Sigma M_{Vwater.E1.x} + \Sigma M_{I.E1} + \Sigma M_{soil.E1.x} = 309606 \cdot kN \cdot m$$

Eccentricity:

$$e_{E1.x} := X_{BCG} - \frac{\Sigma M_{E1.x}}{\Sigma V_{E1}} = -0.51\ m$$

Eccentricity Check:

$$e_{check.E1.x} := \begin{cases} \text{"Okay"} & \text{if } e_{E1.x} \leq Kern_x \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$$e_{check.E1.x} = \text{"Okay"}$$

Foundation Bearing Pressures (X-Direction):

E1 CASE

Bearing Pressure at Heel:

$$\sigma_{heel.E1.x} := \frac{\Sigma V_{E1}}{A_b} - \frac{\Sigma V_{E1} \cdot e_{E1.x}}{S_{bx.L}} = 134.43 \cdot \frac{kN}{m^2}$$

$$\sigma_{heel.E1.check.x} := \left(\begin{array}{l} \text{"Okay"} \quad \text{if} \quad 0 \le \sigma_{heel.E1.x} \le \sigma_{allow.E1} \\ \text{"Revise Structure"} \quad \text{otherwise} \end{array} \right)$$

$\sigma_{heel.E1.check.x}$ = "Okay"

Bearing Pressure at Toe:

$$\sigma_{toe.E1.x} := \frac{\Sigma V_{E1}}{A_b} + \frac{\Sigma V_{E1} \cdot e_{E1.x}}{S_{bx.R}} = 95.16 \cdot \frac{kN}{m^2}$$

$$\sigma_{toe.E1.check.x} := \begin{array}{|l} \text{"Okay"} \quad \text{if} \quad 0 \le \sigma_{toe.E1.x} \le \sigma_{allow.E1} \\ \text{"Revise Structure"} \quad \text{otherwise} \end{array}$$

$\sigma_{toe.E1.check.x}$ = "Okay"

Sum of the Moments (Z-Direction):

$$\Sigma M_{E1.z} := \Sigma M_{DL.z} + \Sigma M_{HWater.E1.z} + \Sigma M_{Vwater.E1.z} + \Sigma M_{soil.E1.z} = 270301 \cdot kN \cdot m$$

Eccentricity:

$$e_{E1.z} := Z_{BCG} - \frac{\Sigma M_{E1.z}}{\Sigma V_{E1}} = -0.51\ m$$

Eccentricity Check:

$$e_{check.E1.z} := \begin{array}{|l} \text{"Okay"} \quad \text{if} \quad e_{E1.z} \le Kern_z \\ \text{"Revise Structure"} \quad \text{otherwise} \end{array}$$

$e_{check.E1.z}$ = "Okay"

Foundation Bearing Pressures (Z-Direction):

Bearing Pressure at Heel:

$$\sigma_{heel.E1.z} := \frac{\Sigma V_{E1}}{A_b} - \frac{\Sigma V_{E1} \cdot e_{E1.z}}{S_{bz.b}} = 137.54 \cdot \frac{kN}{m^2}$$

$$\sigma_{heel.E1.check.z} := \left(\begin{array}{l} \text{"Okay"} \quad \text{if} \quad 0 \le \sigma_{heel.E1.z} \le \sigma_{allow.E1} \\ \text{"Revise Structure"} \quad \text{otherwise} \end{array} \right)$$

$\sigma_{heel.E1.check.z}$ = "Okay"

Bearing Pressure at Toe:

$$\sigma_{toe.E1.z} := \frac{\Sigma V_{E1}}{A_b} + \frac{\Sigma V_{E1} \cdot e_{E1.z}}{S_{bz.t}} = 92.19 \cdot \frac{kN}{m^2}$$

$$\sigma_{toe.E1.check.z} := \begin{array}{|l} \text{"Okay"} \quad \text{if} \quad 0 \le \sigma_{heel.E1.z} \le \sigma_{allow.E1} \\ \text{"Revise Structure"} \quad \text{otherwise} \end{array}$$

$\sigma_{toe.E1.check.z}$ = "Okay"

E1 CASE

Foundation Bearing Pressure (Combined):

Linear pressure superimposed at Corners by both Moment_X and Moment_Z

Bearing Pressure at Heel(x)-Heel(z):

$$\sigma_{heel.E1} := \frac{\Sigma V_{E1}}{A_b} - \frac{\Sigma V_{E1}\cdot e_{E1.x}}{S_{bx.L}} - \frac{\Sigma V_{E1}\cdot e_{E1.z}}{S_{bz.b}} = 157.75\cdot kPa$$

$$\sigma_{heel.E1.check} := \begin{cases} \text{"Okay"} & \text{if } 0 \le \sigma_{heel.E1} \le \sigma_{allow.E1} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$\sigma_{heel.E1.check} = \text{"Okay"}$

Bearing Pressure at Toe(x)-Toe(z):

$$\sigma_{toe.E1} := \frac{\Sigma V_{E1}}{A_b} + \frac{\Sigma V_{E1}\cdot e_{E1.x}}{S_{bx.R}} + \frac{\Sigma V_{E1}\cdot e_{E1.z}}{S_{bz.t}} = 73.14\cdot kPa$$

$$\sigma_{toe.E1.check} := \begin{cases} \text{"Okay"} & \text{if } 0 \le \sigma_{toe.E1} \le \sigma_{allow.E1} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$\sigma_{toe.E1.check} = \text{"Okay"}$

Bearing Pressure at Heel(x)-Toe(z):

$$\sigma_{heeltoe.E1} := \frac{\Sigma V_{E1}}{A_b} - \frac{\Sigma V_{E1}\cdot e_{E1.x}}{S_{bx.L}} + \frac{\Sigma V_{E1}\cdot e_{E1.z}}{S_{bz.t}} = 112.4\cdot kPa$$

$$\sigma_{heeltoe.E1.check} := \begin{cases} \text{"Okay"} & \text{if } 0 \le \sigma_{heeltoe.E1} \le \sigma_{allow.E1} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$\sigma_{heeltoe.E1.check} = \text{"Okay"}$

Bearing Pressure at Toe(x)-Heel(z):

$$\sigma_{toeheel.E1} := \frac{\Sigma V_{E1}}{A_b} + \frac{\Sigma V_{E1}\cdot e_{E1.x}}{S_{bx.R}} - \frac{\Sigma V_{E1}\cdot e_{E1.z}}{S_{bz.b}} = 118.49\cdot kPa$$

$$\sigma_{toeheel.E1.check} := \begin{cases} \text{"Okay"} & \text{if } 0 \le \sigma_{toeheel.E1} \le \sigma_{allow.E1} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$\sigma_{toeheel.E1.check} = \text{"Okay"}$

FLOATATION ANALYSIS:

ACCEPTANCE PARAMETERS

Required Factor of Safety: $FS_{req.FE1} := 1.1$

VERTICAL LOADS RESISTING:

Dead Load: $\Sigma V_{DL} = 54060.17\cdot kN$

Water Weight H1+H2: $\Sigma V_{H.FE1} := H_{1.E1} + H_{2.E1} = 7447.34\cdot kN$

Summation Vertical Resisting: $\Sigma V_{FE1} := \Sigma V_{DL} + \Sigma V_{H.FE1} = 61507.5\cdot kN$

VERTICAL LOADS UPLIFT:

Uplift: $U_{E1} = -28857.62\cdot kN$

Factor of Safety Floatation:

$$FS_{act.FE1} := \frac{\Sigma V_{FE1}}{|U_{E1}|} = 2.13$$

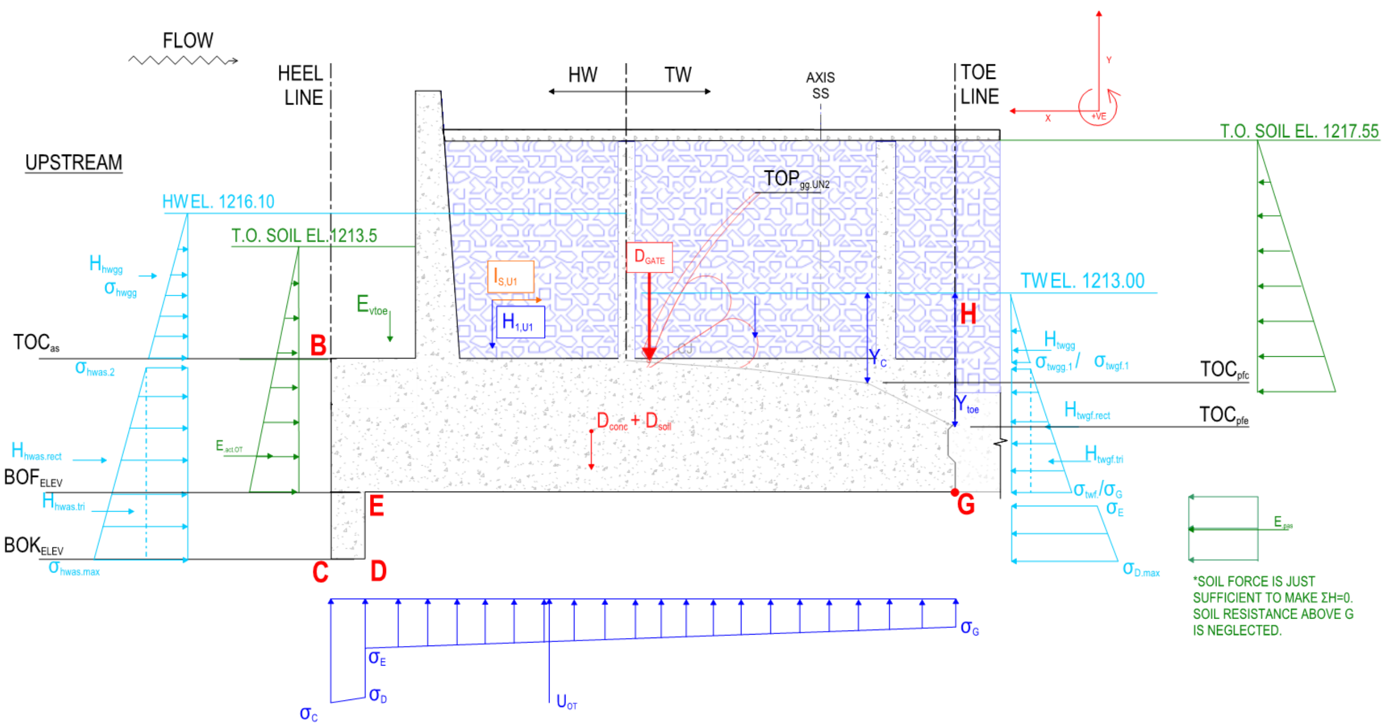
$$FS_{check.FE1} := \begin{cases} \text{"OKAY"} & \text{if } FS_{act.FE1} \ge FS_{req.FE1} \\ \text{"ANCHORS REQUIRED"} & \text{if } FS_{act.FE1} < FS_{req.FE1} \end{cases} = \text{"OKAY"}$$

MONOLITH OVERTURNING STABILITY ANALYSIS

E1 CASE

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.
Assumptions are made in order to compute overturning stablity of indetermine forces on monolith with key;
(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.
(b) The horizontal resisting force acting on the key, P.key, is that required for staticequilibrium
(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1 $Ratio_{OT.E1.min} := 0.25$ at Rock Foundation



Uplift Loads for Overturning Stability Analysis (X-Direction)

Line of Creep:

Change in Water Head: $\Delta_{h.E1} := HW_{E1} - TW_{E1} = 2.4\,m$

Length from Point C to Point G: $L_{CG} = 18.61\,m$

Length from Various Points to Points: $L_{CD} = 1\,m$ $L_{DE} = 2\,m$ $L_{EG} = 17.5\,m$

$L_{GH.E1} := TW_{E1} - TOC_{afe} = 6.9\,m$

Length from Point C, D, E to G: $L_{CDEG} = 20.5\,m$ $L_{CDE} = 3\,m$

Water Pressure at Point C & G: $\sigma_{C.E1} := \sigma_{hwas.E1.2} = -110.85 \cdot kPa$ $\sigma_{G.E1} := \sigma_{twtoe.E1} \cdot -1 = -87.31 \cdot kPa$

Water Pressure at Point D:

$$\sigma_{D.E1} := -\gamma_w \cdot \left[\left(HW_{E1} - BOK_{elev} \right) - \frac{\Delta_{h.E1} \cdot L_{CD}}{L_{CDEG}} \right] = -129.32 \cdot kPa$$

Water Pressure at Point E:

$$\sigma_{E.E1} := -\gamma_w \cdot \left[\left(HW_{E1} - BOF_{elev} \right) - \frac{\Delta_{h.E1} \cdot L_{CDE}}{L_{CDEG}} \right] = -107.41 \cdot kPa$$

Uplift for Overturning Analysis on Bottom of Key:

$$U_{OT.E1.key} := \frac{\sigma_{C.E1} + \sigma_{D.E1}}{2} \cdot L_{CD} \cdot W_B = -1921.42 \cdot kN$$

Acting at:

$$U_{OT.E1.key.loc} := \frac{L_{CD} \cdot \left(2 \cdot \sigma_{C.E1} + \sigma_{D.E1} \right)}{3 \left(\sigma_{C.E1} + \sigma_{D.E1} \right)} + L_{EG} = 17.99\,m$$

E1 CASE

Uplift for Overturning Analysis on Bottom of Footing: $U_{OT.E1.ftg} := \frac{\sigma_{E.E1} + \sigma_{G.E1}}{2} \cdot L_{EG} \cdot W_B = -27260.32 \cdot kN$

Acting at: $U_{OT.E1.ftg.loc} := \frac{L_{EG} \cdot (\sigma_{G.E1} + 2 \cdot \sigma_{E.E1})}{3(\sigma_{G.E1} + \sigma_{E.E1})} = 9.05\ m$

Uplift Load for Overturning Analysis: $U_{OT.E1} := U_{OT.E1.key} + U_{OT.E1.ftg} = -29181.74 \cdot kN$

Uplift Load Acting from Toe: $U_{OT.E1.loc} := \frac{U_{OT.E1.key} \cdot U_{OT.E1.key.loc} + U_{OT.E1.ftg} \cdot U_{OT.E1.ftg.loc}}{U_{OT.E1}} = 9.64\ m$

All Vertical Loads Appliable to Overturning Stability Analysis

Total Concrete Dead Loads:	$D_{conc} = 35947.58 \cdot kN$	at:	$X_{conc.loc} = 8.81\ m$
Dead Load of Gate:	$D_{Gate} = 56.0 \cdot kN$		$X_{gate} = 9.50\ m$
Total Fill Loads:	$D_{fill} = 18056.6 \cdot kN$		$X_{fill.loc} = 7.31\ m$
Water Weight (HW) on Apron Slab:	$H_{1.E1} = 5703.6 \cdot kN$		$H_{1.E1.loc.x} = 14.42\ m$
Water Weight (TW) on Guard Gate Footing:	$H_{2.E1} = 1743.7 \cdot kN$		$H_{2.E1.loc.x} = 5.68\ m$
Uplift Load for Overturning Analysis:	$U_{OT.E1} = -29181.74 \cdot kN$		$U_{OT.E1.loc} = 9.64 \cdot m$

Sum of All Overturning Analysis Vertical Load:

$$\Sigma V_{E1.OT} := D_{conc} + D_{Gate} + D_{fill} + H_{1.E1} + H_{2.E1} + U_{OT.E1} = 32325.78 \cdot kN$$

Sum of All Overturning Analysis Vertical Load Moments:

$$\Sigma M_{V.E1.OT} := \left(\begin{array}{l} D_{conc} \cdot X_{conc.loc} + D_{Gate} \cdot X_{gate} + D_{fill} \cdot X_{fill.loc} + H_{1.E1} \cdot H_{1.E1.loc.x} \ldots \\ + H_{2.E1} \cdot H_{2.E1.loc.x} + U_{OT.E1} \cdot U_{OT.E1.loc} \end{array}\right) = 260199.77 \cdot kN \cdot m$$

Lateral Tailwater Loads for Overturning Stability Analysis

TW Lateral Load on Gate Footing (No Key - Overturning Values Adjusted): $H_{twgf.E1} = 2166.05 \cdot kN$

Acting at: $H_{twgf.E1.loc} = 1.81\ m$

Horizontal Tailwater Pressure Top of Key (Overturning Analysis): $\sigma_{twtk.OT.E1} := \sigma_{E.E1} \cdot -1 = 107.41 \cdot kPa$

Horizontal Tailwater Pressure Bottom of Key (Overturning Analysis): $\sigma_{twbk.OT.E1} := \sigma_{D.E1} \cdot -1 = 129.32 \cdot kPa$

Triangular Distribution Unit Load Acting at Key: $H_{twbk.OT.E1.tri} := \frac{(\sigma_{twbk.OT.E1} - \sigma_{twtk.OT.E1})}{2} \cdot d_{key} \cdot W_{tw.E1} = 350.67 \cdot kN$

Triangular Distribution Unit Load Acting at Key: $H_{twbk.OT.E1.rect} := \sigma_{twtk.OT.E1} \cdot d_{key} \cdot W_{tw.E1} = 3437.04 \cdot kN$

Total Horizontal Tailwater Load on Key (Overturning Values Adjusted): $H_{twkey.OT.E1} := H_{twbk.OT.E1.tri} + H_{twbk.OT.E1.rect} = 3787.71 \cdot kN$

Acting at:

$$H_{twkey.OT.E1.loc} := \frac{H_{twbk.OT.E1.tri} \cdot \frac{-2 \cdot d_{key}}{3} + H_{twbk.OT.E1.rect} \cdot \frac{-d_{key}}{2}}{H_{twkey.OT.E1}} = -1.03 \cdot m$$

Lateral Driving Earth Loads for Overturning Stability Analysis (at rest condition)

E1 CASE

Depth of Driving Soil Loads (to top of key): $h_{E.OT.E1} := TOC_{as} - BOF_{elev} = 4\ m$

At-Rest Soil Load: $E_{act.OT.E1} := \frac{\left(K_{o.E1} \cdot h_{E.OT.E1}^{2}\right)}{2} \cdot \left(\gamma_r - \gamma_w\right) \cdot W_{hwas.E1} \cdot -1 = -1026.66 \cdot kN$

At Rest- Soil Load Acting from Toe: $E_{act.OT.E1.loc} := \frac{h_{E.OT.E1}}{3} = 1.33\ m$

All Lateral Loads Appliable to Overturning Stability Analysis (X-direction)

HW Lateral Load on Approach Slab:	$H_{hwas.E1} = -5838.9 \cdot kN$	$H_{hwas.E1.loc} = 1.86\ m$
HW Lateral Load on Guard Gate:	$H_{hwgg.E1} = 0.0 \cdot kN$	$H_{hwgg.E1.loc} = 4.00\ m$
HW Lateral Load on Abutment:	$H_{hwa.E1} = -3136.6 \cdot kN$	$H_{hwa.E1.loc} = 6.43\ m$
TW Lateral Load on Abutment:	$H_{twa.E1} = 1413.2 \cdot kN$	$H_{twa.E1.loc} = 5.63\ m$
TW Lateral Load on Guard Gate:	$H_{twgg.E1} = 0.0 \cdot kN$	$H_{twgg.E1.loc} = 4.00\ m$
TW Lateral Load on Gate Footing (No Key - Overturning Values Adjusted):	$H_{twgf.E1} = 2166.05 \cdot kN$	$H_{twgf.E1.loc} = 1.81\ m$
TW Lateral Load on Key:	$H_{twkey.OT.E1} = 3787.71 \cdot kN$	$H_{twkey.OT.E1.loc} = -1.03\ m$
Ice / Impact Load:	$I_{E1} = 5704.0 \cdot kN$	$I_{E1.loc.y} = 11.00\ m$
Lateral Soil Load (driving):	$E_{act.OT.E1} = -1026.7 \cdot kN$	$E_{act.OT.E1.loc} = 1.33\ m$

Resisting Lateral Soil Load as required to produce horizontal equilibrium:

$$E_{pas.OT.x.E1} := -\left(H_{hwas.E1} + H_{hwgg.E1} + H_{hwgg.E1} + H_{twgg.E1} \cdots + H_{twgf.E1} + H_{twkey.OT.E1} + I_{E1} + E_{act.OT.E1}\right) = -4792.19 \cdot kN$$

Acting at:

$$E_{pas.OT.E1.loc} := -1 \cdot \frac{d_{key}}{2} = -1\ m$$

Sum of All Overturning Analysis Horizontal Load (ΣH=0):

$$\Sigma H_{E1.OT.x} := H_{hwas.E1} + H_{hwgg.E1} + H_{twgg.E1} + H_{twgf.E1} + H_{twkey.OT.E1} + I_{E1} + E_{act.OT.E1} + E_{pas.OT.x.E1} = 0 \cdot kN$$

Sum of All Overturning Analysis Horizontal Load Moments:

$$\begin{aligned}\Sigma M_{H.E1.OT.x} := {} & H_{hwas.E1} \cdot H_{hwas.E1.loc} + H_{hwgg.E1} \cdot H_{hwgg.E1.loc} \cdots \\ & + H_{twgg.E1} \cdot H_{twgg.E1.loc} + H_{twgf.E1} \cdot H_{twgf.E1.loc} \cdots \\ & + H_{twkey.OT.E1} \cdot H_{twkey.OT.E1.loc} + I_{E1} \cdot I_{E1.loc.y} \cdots \\ & + E_{act.OT.E1} \cdot E_{act.OT.E1.loc} + E_{pas.OT.x.E1} \cdot E_{pas.OT.E1.loc}\end{aligned} = 55335.54 \cdot kN \cdot m$$

Overturning Stability Analysis (X-Direction)

$$\Sigma M_{E1.OT.x} := \Sigma M_{V.E1.OT} + \Sigma M_{H.E1.OT.x} = 315535.31 \cdot kN \cdot m$$

$$X_{R.E1} := \frac{\Sigma M_{E1.OT.x}}{\Sigma V_{E1.OT}} = 9.76\ m \qquad x_{OT.E1} := X_{R.E1} - \frac{L_B}{2} = 0.51\ m$$

Overturning Resultant Ratio

$$Ratio_{OT.x.E1} := \frac{X_{R.E1}}{L_B} = 0.53$$

$$Ratio_{OT.x.E1.check} := \begin{vmatrix} \text{"OKAY"} & \text{if } Ratio_{OT.x.E1} \geq Ratio_{OT.E1.min} \\ \text{"Revise Structure"} & \text{otherwise} \end{vmatrix} = \text{"OKAY"}$$

$$x_{OT.check.E1} := \begin{vmatrix} \text{"OKAY"} & \text{if } \left|x_{OT.E1}\right| \leq Kern_x \\ \text{"Revise Structure"} & \text{otherwise} \end{vmatrix} = \text{"OKAY"}$$

All Lateral Loads Appliable to Overturning Stability Analysis (Z-direction)

E1 CASE

Z-Direction Lateral Soil Load on Abutment Before RCC (driving): $E_{act.a.E1.z} = -819.5 \cdot kN$ $E_{act.a.E1.z.loc.y} = 4.00\ m$

Z-Direction Lateral Lateral Soil Load on Approach Slab Before RCC (driving): $E_{act.as.E1.z} = -2192.6 \cdot kN$ $E_{act.as.E1.z.loc.y} = 1.76\ m$

Z-Direction Lateral Soil Load on Abutment After RCC (driving): $E_{act.RCC.E1.z} = -9.24 \cdot kN$ $E_{act.RCC.E1.z.loc.y} = 10.03\ m$

Z-Direction Lateral Soil Load on Abutment at RCC Steps (driving): $E_{act.RCC.s.E1.z} = -16.94 \cdot kN$ $E_{act.RCC.s.E1.z.loc.y} = 9.43 \cdot m$

Resisting Lateral Soil Load as required to produce horizontal equilibrium:

$$E_{pas.OT.z.E1} := -\left(E_{act.a.E1.z} + E_{act.as.E1.z} + E_{act.RCC.E1.z} + E_{act.RCC.s.E1.z}\right) = 3038.27 \cdot kN$$

Acting at:

$$E_{pas.OT.E1.loc} = -1\ m$$

Sum of All Overturning Analysis Horizontal Load (ΣH=0):

$$\Sigma H_{E1.OT.z} := E_{act.a.E1.z} + E_{act.as.E1.z} + E_{act.RCC.E1.z} + E_{act.RCC.s.E1.z} + E_{pas.OT.z.E1} = 0 \cdot kN$$

Sum of All Overturning Analysis Horizontal Load Moments:

$$\Sigma M_{H.E1.OT.z} := E_{act.a.E1.z} \cdot E_{act.a.E1.z.loc.y} + E_{act.as.E1.z} \cdot E_{act.as.E1.z.loc.y} \cdots + E_{act.RCC.E1.z} \cdot E_{act.RCC.E1.z.loc.y} + E_{act.RCC.s.E1.z} \cdot E_{act.RCC.s.E1.z.loc.y} \cdots + E_{pas.OT.x.E1} \cdot E_{pas.OT.E1.loc} = -2601.48 \cdot kN \cdot m$$

Overturning Stability Analysis (Z-Direction)

$$\Sigma M_{E1.OT.z} := \Sigma M_{V.E1.OT} + \Sigma M_{H.E1.OT.z} = 257598.29 \cdot kN \cdot m$$

$$z_{R.E1} := \frac{\Sigma M_{E1.OT.z}}{\Sigma V_{E1.OT}} = 7.97\ m \qquad z_{OT.E1} := z_{R.E1} - \frac{W_B}{2} = -0.03\ m$$

Overturning Resultant Ratio

$$Ratio_{OT.z.E1} := \frac{z_{R.E1}}{L_B} = 0.43$$

$$Ratio_{OT.z.E1.check} := \begin{cases} \text{"OKAY"} & \text{if } Ratio_{OT.z.E1} \geq Ratio_{OT.E1.min} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

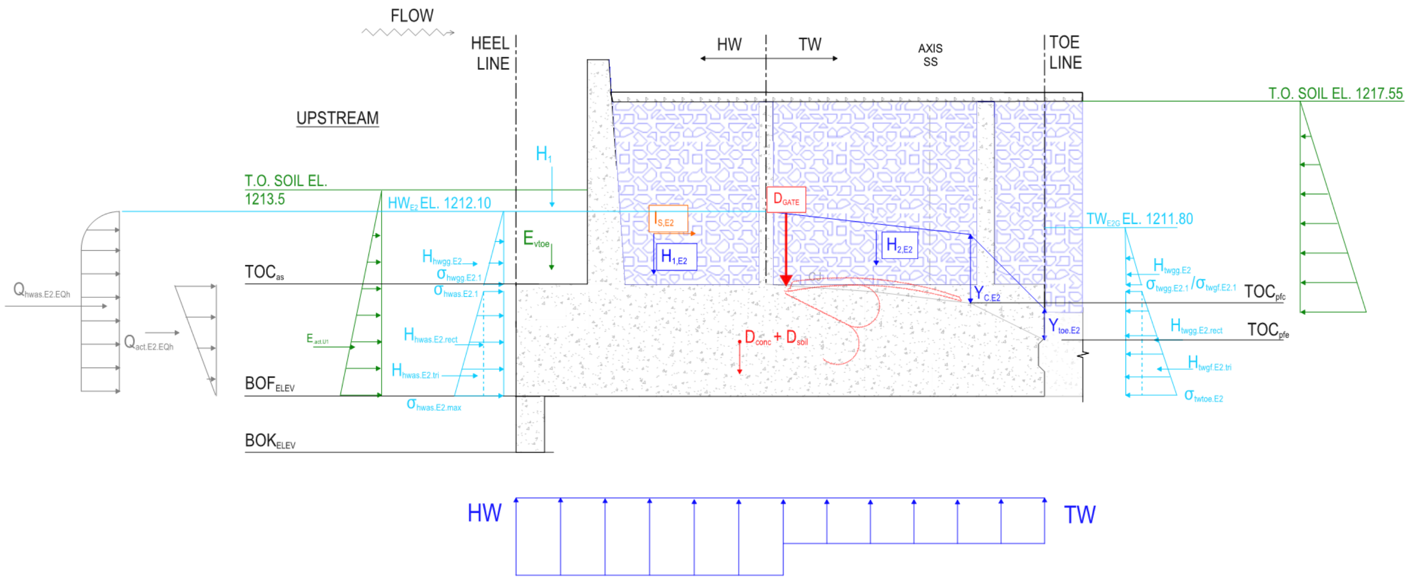
$$z_{OT.check.E1} := \begin{cases} \text{"OKAY"} & \text{if } \left|z_{OT.E1}\right| \leq Kern_z \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

SUMMARY OF STABILITY ASSESSMENT:

E1 CASE

Sliding Factor of Safety: (Horizontal Plane)	$FS_{HorizSliding.E1} = 4.27$	$FS_{HorizSliding.E1.Check} =$ "OKAY"
Flotation Factor of Safety (horizontal plane)	$FS_{act.FE1} = 2.13$	$FS_{check.FE1} =$ "OKAY"
Overturning Resultant Ratio: (X-direction)	$Ratio_{OT.x.E1} = 0.53$	$Ratio_{OT.x.E1.check} =$ "OKAY"
Overturning Resultant Ratio: (Z-direction)	$Ratio_{OT.z.E1} = 0.43$	$Ratio_{OT.z.E1.check} =$ "OKAY"
Eccentricity: (horizontal plane)	$x_{OT.E1} = 0.51\ m$	$x_{OT.check.E1} =$ "OKAY"
Eccentricity: (horizontal plane)	$z_{OT.E1} = -0.03\ m$	$z_{OT.check.E1} =$ "OKAY"
Bearing Pressure At Heel(x)- Heel(z): (horizontal plane)	$\sigma_{heel.E1} = 158 \cdot kPa$	$\sigma_{heel.E1.check} =$ "Okay"
Bearing Pressure At Toe(x)-Toe(z): (horizontal plane)	$\sigma_{toe.E1} = 73 \cdot kPa$	$\sigma_{toe.E1.check} =$ "Okay"
Bearing Pressure at Heel(x)-Toe(z): (horizontal plane)	$\sigma_{heeltoe.E1} = 112 \cdot kPa$	$\sigma_{heeltoe.E1.check} =$ "Okay"
Bearing Pressure at Toe(x)-Heel(z): (horizontal plane)	$\sigma_{toeheel.E1} = 118 \cdot kPa$	$\sigma_{toe.E1.check} =$ "Okay"

E2 DESIGN CASE



U1 CASE PLUS SEISMIC

ACCEPTANCE PARAMETERS

Required Factor of Safety for Sliding: $FS_{req.E2.sl} := 1.0$ (Without Cohesion) (Section 8.1, Design Criteria)

Resultant Within Middle Half of Base: $e \le \frac{L_b}{4} \wedge e \ge \frac{-L_b}{4}$

Allowable Rock Bearing Pressure: $\sigma_{allow.E2} := 1740 \cdot \frac{kN}{m^2}$ (Section 5.2, Design Criteria)

Required Factor of Safety for Flotation: $FS_{req.E2.flt} := 1.1$

INPUT PARAMETERS

Headwater Elevation: $HW_{E2} := 1212.10m$ (Section 8.3, Design Criteria)

Tailwater Elevation: $TW_{E2} := 1211.80m$ (Section 8.3, Design Criteria)

Bottom of Footing Elevation: $BOF_{elev} = 1206.00\ m$

Approach Slab Top of Concrete Elevation at Upstream Face: $TOC_{as} = 1210.00\ m$

Abutment Footing Top of Concrete Elevation at Stilling Basin: $TOC_{afe} = 1208\ m$

Abutment Footing Top of Concrete Elevation at Footing: $TOC_{afc} = 1209.73\ m$

Abutment Footing Top of Concrete Elevation at Footing Notch: $TOC_{afc.n} = 1209.3\ m$

Top of Guard Gate Elevation: $TOP_{gg.E2} := 1210.0m$

Bottom of Key Elevation: $BOK_{elev} = 1204\ m$

Gates are open when top of gate elevation is at 1210.0m

Gates are closed/up when top of gate elevation is at 1215.0m

SEISMIC LOAD (Three combinations of E_h and E_v considered) — E2.1 CASE

Seismic Case $Q_{E2.1}$ - 100% Horizontal Seismic Force, No Vertical

Include Seismic Load in Analysis? $Eq_{E2.1} := 1$ 0 = No, 1 = Yes

Horizontal Seismic Coefficient: $K_{h.E2.1} := -0.17$

Vertical Seismic Coefficient: $K_{v.E2.1} := -0.00$

Vertical Tailwater on Approach Slab: $H_{1.U1} = 1640.77 \cdot kN$

Acting At: $H_{1.U1.loc.x} = 14.42\ m$ $H_{1.U1.loc.z} = 4.73\ m$

Width of HW acting on Approach Slab (Z-dir.): $W_{hwas.U1.z} := 7.9m$

Width of TW acting on 1A Foundation (Z-dir.): $W_{twf.U1.z} := L_B - W_{hwas.U1.z} = 10.6\ m$

HORIZONTAL SEISMIC LOADS — **Loads** — **Moment Arm**

Horiz Seismic Component of Concrete: $Q_{conc.E2.EQh.1} := D_{conc} \cdot K_{h.E2.1} \cdot Eq_{E2.1} = -6111.1 \cdot kN$ $Y_{conc.loc} = 3.62\ m$

Horiz Seismic Component of Gates: $Q_{Gate.E2.EQh.1} := D_{Gate} \cdot K_{h.E2.1} \cdot Eq_{E2.1} = -9.5 \cdot kN$ $Y_{gate} = 4.00\ m$

Horiz Seismic Component of Fill: $Q_{fill.E2.EQh.1} := D_{fill} \cdot K_{h.E2.1} \cdot Eq_{E2.1} = -3069.6 \cdot kN$ $Y_{fill.loc} = 7.25\ m$

Horizontal Seismic Component of Headwater - Sliding (X-dir.):

$$Q_{hwas.E2.EQh.1.x} := \left(\frac{7}{12}\right) \cdot K_{h.E2.1} \cdot \gamma_w \cdot \left(HW_{U1} - BOF_{elev}\right)^2 \cdot W_{hwas.U1} \cdot Eq_{E2.1} = -579.2 \cdot kN$$

$$Y_{HWg.E2.x} := 0.4 \cdot \left(HW_{U1} - BOF_{elev}\right) = 2.44\ m$$

Horizontal Seismic Component of Headwater - Sliding (Z-dir.):

$$Q_{hwas.E2.EQh.1.z} := \left(\frac{7}{12}\right) \cdot K_{h.E2.1} \cdot \gamma_w \cdot \left(HW_{U1} - BOF_{elev}\right)^2 \cdot W_{hwas.U1.z} \cdot Eq_{E2.1} = -286.0 \cdot kN$$

$$Y_{HWg.E2.z} := Y_{HWg.E2.x} = 2.44\ m$$

Horizontal Seismic Component of Tailwater - Sliding (Z-dir.):

$$Q_{twf.E2.EQh.1.z} := \left(\frac{7}{12}\right) \cdot K_{h.E2.1} \cdot \gamma_w \cdot \left(TW_{U1} - BOF_{elev}\right)^2 \cdot W_{twf.U1.z} \cdot Eq_{E2.1} = -346.9 \cdot kN$$

$$Y_{TWg.E2.z} := 0.4 \cdot \left(TW_{U1} - BOF_{elev}\right) = 2.32\ m$$

Horizontal Seismic Component of Soil (Woods Method) - Overturning (X-Dir.):

$$Q_{act.E2.EQh.1.OT.x} := \left(\gamma_r - \gamma_w\right) \cdot \left(TOC_{as} - BOF_{elev}\right)^2 \cdot K_{h.E2.1} \cdot W_{hwas.U1} \cdot Eq_{E2.1} = -530.5 \cdot kN$$

$$Y_{E.act.E2.OT.x} := 0.63 \cdot \left(TOC_{as} - BOF_{elev}\right) = 2.52\ m$$

Horizontal Seismic Component of Soil (Woods Method X-Dir.)

$$Q_{act.E2.EQh.1.x} := \left(\gamma_r - \gamma_w\right) \cdot \left(TOC_{as} - BOF_{elev}\right)^2 \cdot K_{h.E2.1} \cdot W_{hwas.U1} \cdot Eq_{E2.1} = -530.5 \cdot kN$$

$$Y_{E.act.E2.x} := 0.63 \cdot \left(TOC_{as} - BOF_{elev}\right) = 2.52\ m$$

Horizontal Seismic Component of Soil (Woods Method Z-Dir.)

$$Q_{act.E2.EQh.1.z} := -K_{h.E2.1} \cdot \left(E_{act.a.U1.z} + E_{act.as.U1.z} + E_{act.RCC.U1.z} + E_{act.RCC.s.U1.z}\right) Eq_{E2.1} = -516.51 \cdot kN$$

$$Y_{E.act.E2.y} := \frac{\left(E_{act.a.U1.z} \cdot E_{act.a.U1.z.loc.y} + E_{act.as.U1.z} \cdot E_{act.as.U1.z.loc.y} + E_{act.RCC.U1.z} \cdot E_{act.RCC.U1.z.loc.y} + E_{act.RCC.s.U1.z} \cdot E_{act.RCC.s.U1.z.loc.y}\right) \cdot 1.909}{\left(E_{act.a.U1.z} + E_{act.as.U1.z} + E_{act.RCC.U1.z} + E_{act.RCC.s.U1.z}\right)} = 4.65\ m$$

$$\Sigma H_{Q.E2.EQh.1} := Q_{conc.E2.EQh.1} + Q_{Gate.E2.EQh.1} + Q_{fill.E2.EQh.1} = -9190.23 \cdot kN$$

$$\Sigma H_{Q.E2.EQh.1.x} := Q_{hwas.E2.EQh.1.x} + Q_{act.E2.EQh.1.x} = -1109.69 \cdot kN$$

$$\Sigma H_{Q.E2.EQh.1.OT.x} := Q_{hwas.E2.EQh.1.x} + Q_{act.E2.EQh.1.OT.x} = -1109.69 \cdot kN$$

$$\Sigma H_{Q.E2.EQh.1.z} := Q_{hwas.E2.EQh.1.z} + Q_{twf.E2.EQh.1.z} + Q_{hwas.E2.EQh.1.z} + Q_{act.E2.EQh.1.z} = -1435.34 \cdot kN$$

E2.1 CASE

VERTICAL SEISMIC LOADS	Loads	Moment Arm
Vertical Component of Concrete:	$Q_{conc.E2.EQv.1} := D_{conc} \cdot K_{v.E2.1} \cdot Eq_{E2.1} = 0.0 \cdot kN$	$X_{conc.loc} = 8.81\ m$
		$Z_{conc.loc} = 8.46\ m$
Vertical Component of Gate:	$Q_{Gate.E2.EQv.1} := D_{Gate} \cdot K_{v.E2.1} \cdot Eq_{E2.1} = 0.0 \cdot kN$	$X_{gate} = 9.50\ m$
		$Z_{gate} = 2\ m$
Vertical Component of Fill:	$Q_{fill.E2.EQv.1} := D_{fill} \cdot K_{v.E2.1} \cdot Eq_{E2.1} = 0 \cdot kN$	$X_{fill.loc} = 7.31\ m$
		$Z_{fill.loc} = 10\ m$
Vertical Seismic Component of Headwater over Apron Slab:	$Q_{H1.E2.EQv.1} := K_{v.E2.1} \cdot H_{1.U1} \cdot Eq_{E2.1} = 0.0 \cdot kN$	$H_{1.U1.loc.x} = 14.42\ m$
		$H_{1.U1.loc.z} = 4.73\ m$
Vertical Seismic Component of Tailwater over Pier Footing:	$Q_{H2.E2.EQv.1} := K_{v.E2.1} \cdot H_{2.U1} \cdot Eq_{E2.1} = 0.0 \cdot kN$	$H_{2.U1.loc.x} = 5.28\ m$
		$H_{2.U1.loc.z} = 2\ m$
Vertical Seismic Component of Soil over Approach Slab:	$Q_{E1.E2.EQv.1} := K_{v.E2.1} \cdot E_{1.U1} \cdot Eq_{E2.1} = 0 \cdot kN$	$E_{1.U1.loc.x} = 12.89\ m$

$$\Sigma V_{Q.E2.EQv.1} := Q_{conc.E2.EQv.1} + Q_{Gate.E2.EQv.1} + Q_{fill.E2.EQv.1} + Q_{H1.E2.EQv.1} + Q_{H2.E2.EQv.1} + Q_{E1.E2.EQv.1} = 0.0 \cdot kN$$

$$\Sigma M_{Q.E2.1} := Q_{conc.E2.EQh.1} \cdot Y_{conc.loc} + Q_{Gate.E2.EQh.1} \cdot Y_{gate} + Q_{fill.E2.EQh.1} \cdot Y_{fill.loc} = -44442.66 \cdot kN \cdot m$$

$$\begin{aligned}\Sigma M_{Q.E2.1.x} := {} & Q_{conc.E2.EQh.1} \cdot Y_{conc.loc} + Q_{Gate.E2.EQh.1} \cdot Y_{gate} + Q_{fill.E2.EQh.1} \cdot Y_{fill.loc} + Q_{hwas.E2.EQh.1.x} \cdot Y_{HWg.E2.x} \cdots = -47192.74 \cdot kN \cdot m \\ & + Q_{act.E2.EQh.1.x} \cdot Y_{E.act.E2.x} + Q_{conc.E2.EQv.1} \cdot X_{conc.loc} + Q_{Gate.E2.EQv.1} \cdot X_{gate} + Q_{fill.E2.EQv.1} \cdot X_{fill.loc} \cdots \\ & + Q_{H1.E2.EQv.1} \cdot H_{1.U1.loc.x} + Q_{H2.E2.EQv.1} \cdot H_{2.U1.loc.x} + Q_{E1.E2.EQv.1} \cdot E_{1.U1.loc.x}\end{aligned}$$

$$\begin{aligned}\Sigma M_{Q.E2.1.x.OT} := {} & Q_{conc.E2.EQh.1} \cdot Y_{conc.loc} + Q_{Gate.E2.EQh.1} \cdot Y_{gate} + Q_{fill.E2.EQh.1} \cdot Y_{fill.loc} \cdots = -47192.74 \cdot kN \cdot m \\ & + Q_{hwas.E2.EQh.1.x} \cdot Y_{HWg.E2.x} + Q_{act.E2.EQh.1.OT.x} \cdot Y_{E.act.E2.OT.x} \cdots \\ & + Q_{conc.E2.EQv.1} \cdot X_{conc.loc} + Q_{Gate.E2.EQv.1} \cdot X_{gate} + Q_{fill.E2.EQv.1} \cdot X_{fill.loc} \cdots \\ & + Q_{H1.E2.EQv.1} \cdot H_{1.U1.loc.x} + Q_{H2.E2.EQv.1} \cdot H_{2.U1.loc.x} + Q_{E1.E2.EQv.1} \cdot E_{1.U1.loc.x}\end{aligned}$$

$$\begin{aligned}\Sigma M_{Q.E2.1.z} := {} & Q_{conc.E2.EQh.1} \cdot Y_{conc.loc} + Q_{Gate.E2.EQh.1} \cdot Y_{gate} + Q_{fill.E2.EQh.1} \cdot Y_{fill.loc} + Q_{hwas.E2.EQh.1.z} \cdot Y_{HWg.E2.z} \cdots = -45945.22 \cdot kN \cdot m \\ & + Q_{twf.E2.EQh.1.z} \cdot Y_{TWg.E2.z} + Q_{conc.E2.EQv.1} \cdot Z_{conc.loc} + Q_{Gate.E2.EQv.1} \cdot Z_{gate} + Q_{fill.E2.EQv.1} \cdot Z_{fill.loc} \cdots \\ & + Q_{H1.E2.EQv.1} \cdot H_{1.U1.loc.z} + Q_{H2.E2.EQv.1} \cdot H_{2.U1.loc.z} + Q_{E1.E2.EQv.1} \cdot E_{1.U1.loc.z}\end{aligned}$$

STABILITY ASSESSMENT (SLIDNG, BEARING, FLOTATION AND OVERTURNING): E2.1 CASE

CHECK SLIDING ALONG HORIZONTAL PLANE THRU TOE,
IGNORING BEDROCK MOBILIZED BY STRUCTURAL HEEL KEY, OR VOID BEHIND KEY

Sum of Vertical Forces:

$\Sigma V_{E2.1} := \Sigma V_{U1} + \Sigma V_{Q.E2.EQv.1} = 39682.0 \cdot kN$

Sum of Horizontal Forces (X-Direction):

$\Sigma H_{E2.1.x} := \Sigma H_{Water.U1.x} + \Sigma H_{soil.U1.x} + \Sigma H_{Q.E2.EQh.1.x} = 486.7 \cdot kN$

Sum of Horizontal Forces (Z-Direction):

$\Sigma H_{E2.1.z} := \Sigma H_{Water.U1.z} + \Sigma H_{soil.U1.z} + \Sigma H_{Q.E2.EQh.1.z} = -4473.61 \cdot kN$

Sum of Horizontal Forces (Resultant):

$$\Sigma H_{E2.1} := \sqrt{\Sigma H_{E2.1.z}^{2} + \Sigma H_{E2.1.x}^{2}} = 4500.01 \cdot kN$$

Sliding Factor of Safety:

$$FS_{HorizSliding.E2.1.x} := \frac{\tan_{\phi} \cdot \Sigma V_{E2.1}}{\left|\Sigma H_{E2.1.x} + \Sigma H_{Q.E2.EQh.1}\right|} = 2.22$$

Sliding Factor of Safety:

$$FS_{HorizSliding.E2.1.z} := \frac{\tan_{\phi} \cdot \Sigma V_{E2.1}}{\left|\Sigma H_{E2.1.z} + \Sigma H_{Q.E2.EQh.1}\right|} = 1.42$$

Sliding Factor of Safety (Resultant):

$$FS_{HorizSliding.E2.1} := \frac{\tan_{\phi} \cdot \Sigma V_{E2.1}}{\Sigma H_{E2.1} + \left|\Sigma H_{Q.E2.EQh.1}\right|} = 1.41$$

$$FS_{HorizSliding.E2.1.Check} := \begin{array}{|l} \text{"OKAY" if } FS_{HorizSliding.E2.1} \geq FS_{req.E2.sl} \\ \text{"Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !" otherwise} \end{array} = \text{"OKAY"}$$

FLOATATION ANALYSIS:

ACCEPTANCE PARAMETERS

Required Factor of Safety: $FS_{req.FE2} := 1.0$

VERTICAL LOADS RESISTING:

Dead Load: $\Sigma V_{DL} = 54060.17 \cdot kN$

Water Weight H1+H2: $\Sigma V_{H.FE2.1} := H_{1.E1} + H_{2.E1} = 7447.34 \cdot kN$

Summation Vertical Resisting: $\Sigma V_{FE2.1} := \Sigma V_{U1} + \Sigma V_{Q.E2.EQv.1} = 39682.0 \cdot kN$

VERTICAL LOADS UPLIFT:

Uplift: $U_{U1} = -16750 \cdot kN$

Factor of Safety Floatation:

$$FS_{act.FE2.1} := \frac{\Sigma V_{FE2.1}}{\left|U_{U1}\right|} = 2.37$$

$$FS_{check.FE2.1} := \begin{array}{|l} \text{"OKAY" if } FS_{act.FE2.1} \geq FS_{req.FE2} \\ \text{"ANCHORS REQUIRED" if } FS_{act.FE2.1} < FS_{req.FE2} \end{array} = \text{"OKAY"}$$

CHECK FOUNDATION BEARING CAPACITY

E2.1 CASE

Sum of the Moments (X-Direction):

$$\Sigma M_{E2.1.x} := \Sigma M_{U1.x} - \Sigma M_{I.U1} + \Sigma M_{Q.E2.1.x} = 284721 \cdot kN \cdot m$$

Eccentricity:

$$e_{E2.1.x} := X_{BCG} - \frac{\Sigma M_{E2.1.x}}{\Sigma V_{E2.1}} = 1.80\ m$$

Eccentricity Check:

$$e_{check.E2.1.x} := \begin{cases} \text{"Okay"} & \text{if } e_{E2.1.x} \le \frac{L_B}{4} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$e_{check.E2.1.x} = \text{"Okay"}$

Foundation Bearing Pressures (X-Direction):

Bearing Pressure at Heel:

$$\sigma_{heel.E2.1.x} := \frac{\Sigma V_{E2.1}}{A_b} - \frac{\Sigma V_{E2.1} \cdot e_{E2.1.x}}{S_{bx.L}} = 51.58 \cdot \frac{kN}{m^2}$$

$$\sigma_{heel.E2.1.check.x} := \left(\begin{cases} \text{"Okay"} & \text{if } 0 \le \sigma_{heel.E2.1.x} \le \sigma_{allow.E2} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} \right)$$

$\sigma_{heel.E2.1.check.x} = \text{"Okay"}$

Bearing Pressure at Toe:

$$\sigma_{toe.E2.1.x} := \frac{\Sigma V_{E2.1}}{A_b} + \frac{\Sigma V_{E2.1} \cdot e_{E2.1.x}}{S_{bx.R}} = 221.01 \cdot \frac{kN}{m^2}$$

$$\sigma_{toe.E2.1.check.x} := \begin{cases} \text{"Okay"} & \text{if } 0 \le \sigma_{toe.E2.1.x} \le \sigma_{allow.E2} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$\sigma_{toe.E2.1.check.x} = \text{"Okay"}$

Sum of the Moments (Z-Direction):

$$\Sigma M_{E2.1.z} := \Sigma M_{U1.z} - \Sigma M_{Q.E2.1.z} = 394964 \cdot kN \cdot m$$

Eccentricity:

$$e_{E2.1.z} := Z_{BCG} - \frac{\Sigma M_{E2.1.z}}{\Sigma V_{E2.1}} = -2.18\ m$$

Eccentricity Check:

$$e_{check.E2.1.z} := \begin{cases} \text{"Okay"} & \text{if } e_{E2.1.z} \le \frac{W_B}{4} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$e_{check.E2.1.z} = \text{"Okay"}$

Foundation Bearing Pressures (Z-Direction):

Bearing Pressure at Heel:

$$\sigma_{heel.E2.1.z} := \frac{\Sigma V_{E2.1}}{A_b} - \frac{\Sigma V_{E2.1} \cdot e_{E2.1.z}}{S_{bz.b}} = 260.48 \cdot \frac{kN}{m^2}$$

$$\sigma_{heel.E2.1.check.z} := \left(\begin{cases} \text{"Okay"} & \text{if } 0 \le \sigma_{heel.E2.1.z} \le \sigma_{allow.E2} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} \right)$$

$\sigma_{heel.E2.1.check.z} = \text{"Okay"}$

Bearing Pressure at Toe:

$$\sigma_{toe.E2.1.z} := \frac{\Sigma V_{E2.1}}{A_b} + \frac{\Sigma V_{E2.1} \cdot e_{E2.1.z}}{S_{bz.t}} = 23.95 \cdot \frac{kN}{m^2}$$

$$\sigma_{toe.E2.1.check.z} := \begin{cases} \text{"Okay"} & \text{if } 0 \le \sigma_{heel.E3.1.z} \le \sigma_{allow.E3} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$\sigma_{toe.E3.1.check.z} = \text{"Okay"}$

Foundation Bearing Pressure (Combined):

Linear pressure superimposed at Corners by both Moment_X and Moment_Z not considered in seismic case.

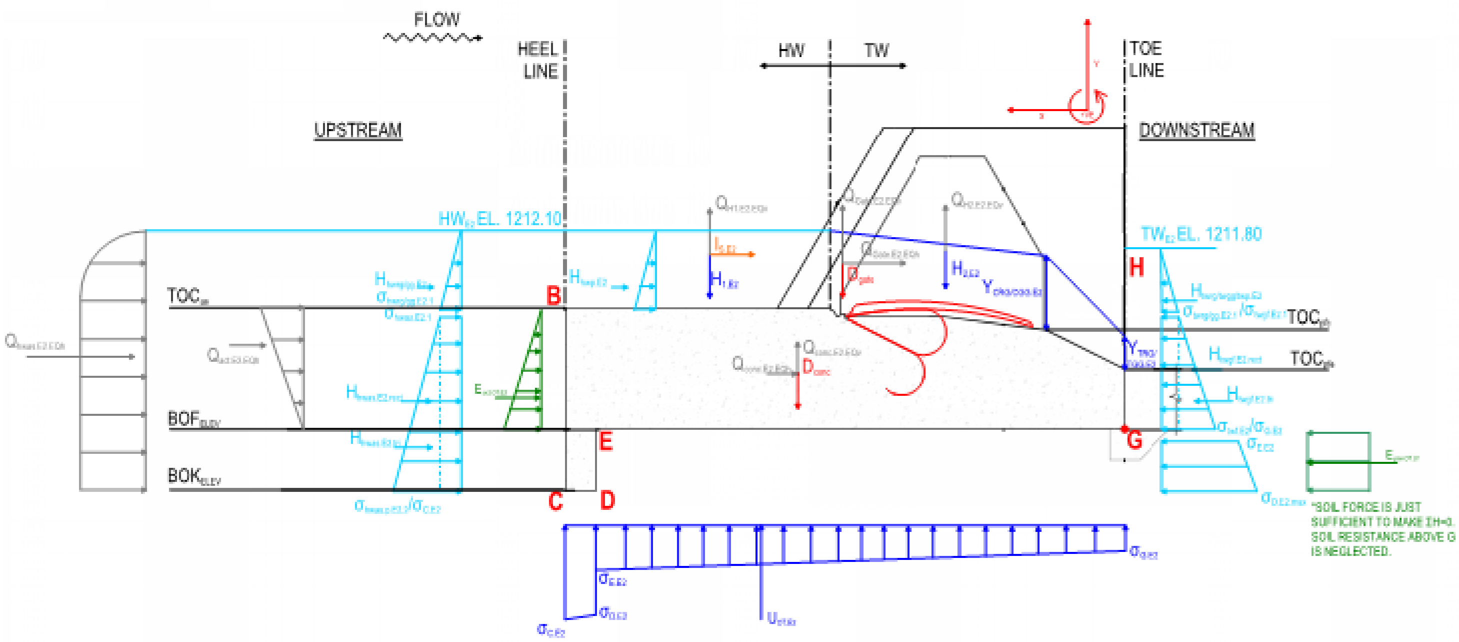
MONOLITH OVERTURNING STABILITY ANALYSIS

E2.1 CASE

Seismic Case $Q_{E2.1}$: 100% Horizontal Seismic Force, No Vertical

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.
Assumptions are made in order to compute overturning stability of indetermine forces on monolith with key;
(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.
(b) The horizontal resisting force acting on the key, P.key, is that required for static equilibrium
(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1 $Ratio_{overturning.allow.Extreme} := 0.25$ Resultant within Base



All Vertical Loads Applicable to Overturning Stability Analysis

Total Concrete Dead Loads:	$D_{conc} = 35947.58 \cdot kN$	at:	$X_{conc.loc} = 8.81\ m$
Dead Load of Gate:	$D_{Gate} = 56.0 \cdot kN$		$X_{gate} = 9.50\ m$
Water Weight (HW) on Apron Slab:	$H_{1.U1} = 1640.8 \cdot kN$		$H_{1.U1.loc.x} = 14.42\ m$
Water Weight (TW) on Gate Footing:	$H_{2.U1} = 731.0 \cdot kN$		$H_{2.U1.loc.x} = 5.28\ m$
Uplift Load for Overtuming Analysis:	$U_{OT.U1} = -17396.43 \cdot kN$		$U_{OT.U1.loc} = 9.4 \cdot m$
Vertical Seismic Component of Concrete Structure:	$Q_{conc.E2.EQv.1} = 0$		$X_{conc.loc} = 8.81\ m$
Vertical Seismic Component of Crest Gate:	$Q_{Gate.E2.EQv.1} = 0$		$X_{gate} = 9.50\ m$
Vertical Seismic Component of Headwater over Apron Slab:	$Q_{H1.E2.EQv.1} = 0$		$H_{1.U1.loc.x} = 14.42\ m$
Vertical Seismic Component of Headwater over Fixed Crest Slab:	$Q_{H2.E2.EQv.1} = 0$		$H_{2.U1.loc.x} = 5.28\ m$

Sum of All Overturning Analysis Vertical Load:

$$\Sigma V_{E2.OT.1} := D_{conc} + D_{Gate} + H_{1.U1} + H_{2.U1} + U_{OT.U1} + \Sigma V_{Q.E2.EQv.1} = 20978.95 \cdot kN$$

Sum of All Overturning Analysis Vertical Load Moments:

$$\Sigma M_{V.E2.OT.1} := D_{conc} \cdot X_{conc.loc} + D_{Gate} \cdot X_{gate} + H_{1.U1} \cdot H_{1.U1.loc.x} + H_{2.U1} \cdot H_{2.U1.loc.x} + U_{OT.U1} \cdot U_{OT.U1.loc} = 181354.01 \cdot kN \cdot m$$

Lateral Driving Earth Loads for Overturning Stability Analysis (at rest condition) **E2.1 CASE**

Depth of Driving Soil Loads (to top of key): $h_{E.OT.E2.1} := TOC_{as} - BOF_{elev} = 4\ m$

Applicable Soil Load: $E_{act.OT.E2.1} := \frac{\left(K_{o.U1} \cdot h_{E.OT.U1}{}^{2}\right)}{2} \cdot \left(\gamma_r - \gamma_w\right) \cdot W_{hwas.U1} \cdot -1 = -1026.66 \cdot kN$

At Rest- Soil Load Acting from Toe: $E_{act.OT.E2.1.loc} := \frac{h_{E.OT.U1}}{3} = 1.33\ m$

All Lateral Loads Applicable to Overturning Stability Analysis

HW Lateral Load on Approach Slab:	$H_{hwas.U1} = -2574.1 \cdot kN$	$H_{hwas.U1.loc} = 1.67\ m$
HW Lateral Load on Guard Gate:	$H_{hwgg.U1} = 0.0 \cdot kN$	$H_{hwgg.U1.loc} = 4.00\ m$
TW Lateral Load on Guard Gate:	$H_{twgg.U1} = 0.0 \cdot kN$	$H_{twgg.U1.loc} = 4.00\ m$
TW Lateral Load on Gate Footing (No Key - Overturning Values Adjusted):	$H_{twgf.U1} = 2385.79 \cdot kN$	$H_{twgf.U1.loc} = 1.65\ m$
TW Lateral Load on Key:	$H_{twkey.OT.U1} = 2219.64 \cdot kN$	$H_{twkey.OT.U1.loc} = -1.05\ m$
Ice / Impact Load:	$I_{U1} = 0.0 \cdot kN$	$I_{U1.loc.y} = 5.80\ m$
Lateral Soil Load (driving):	$E_{act.OT.U1} = -1026.7 \cdot kN$	$E_{act.OT.U1.loc} = 1.33\ m$
Horizontal Seismic Component of Concrete Structure:	$Q_{conc.E2.EQh.1} = -6111.09 \cdot kN$	$Y_{conc.loc} = 3.62\ m$
Horizontal Seismic Component of Vertical Lift Gate:	$Q_{Gate.E2.EQh.1} = -9.52 \cdot kN$	$Y_{gate} = 4.00\ m$
Horizontal Seismic Component of Headwater on Slab Footing:	$Q_{hwas.E2.EQh.1.x} = -579.18 \cdot kN$	$Y_{HWg.E2.x} = 2.44\ m$
Horizontal Seismic Component of Active Soil: (Section 5-5, USACE EM_1110-2-2100)	$Q_{act.E2.EQh.1.x} = -530.51 \cdot kN$	$Y_{E.act.E2.x} = 2.52\ m$

Resisting Lateral Soil Load as required to produce horizontal equilibrium:

$E_{pas.OT.E2.1} := -\left(H_{hwas.U1} + H_{hwgg.U1} + H_{twgg.U1} + H_{twgf.U1} + H_{twkey.OT.U1} + I_{U1} + E_{act.OT.U1} + \Sigma H_{Q.E2.EQh.1.OT.x}\right) = 105.06 \cdot kN$

Acting at: $E_{pas.OT.E2.1.loc} := -1 \cdot \frac{d_{key}}{2} = -1\ m$

Sum of All Overturning Analysis Horizontal Load (ΣH=0):

$\Sigma H_{E2.OT.1} := H_{hwas.U1} + H_{hwgg.U1} + H_{twgg.U1} + H_{twgf.U1} + H_{twkey.OT.U1} + I_{U1} + E_{act.OT.U1} + E_{pas.OT.E2.1} + \Sigma H_{Q.E2.EQh.1.OT.x} = 0 \cdot kN$

Sum of All Overturning Analysis Horizontal Load Moments:

$$\Sigma M_{H.E2.OT.1} := H_{hwas.U1} \cdot H_{hwas.U1.loc} + H_{hwgg.U1} \cdot H_{hwgg.U1.loc} + H_{twgg.U1} \cdot H_{twgg.U1.loc} \cdots + H_{twgf.U1} \cdot H_{twgf.U1.loc} + H_{twkey.OT.U1} \cdot H_{twkey.OT.U1.loc} + I_{U1} \cdot I_{U1.loc.y} \cdots + E_{act.OT.U1} \cdot E_{act.OT.U1.loc} + E_{pas.OT.x.U1} \cdot E_{pas.OT.U1.loc} + \Sigma M_{Q.E2.1} = -47509.42 \cdot kN \cdot m$$

Overturning Stability Analysis

$\Sigma M_{E2.OT.1} := \Sigma M_{V.E2.OT.1} + \Sigma M_{H.E2.OT.1} = 133844.58 \cdot kN \cdot m$

$X_{R.E2.1} := \frac{\Sigma M_{E2.OT.1}}{\Sigma V_{E2.OT.1}} = 6.38\ m$ $\qquad x_{OT.E2.1} := X_{R.E2.1} - \frac{L_B}{2} = -2.87\ m$

Overturning Resultant Ratio

$Ratio_{OT.E2.1} := \frac{X_{R.E2.1}}{L_B} = 0.34$

$Ratio_{OT.E2.1.check} := \begin{cases} \text{"OKAY"} & \text{if } Ratio_{OT.E2.1} \geq Ratio_{overturning.allow.Extreme} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"OKAY"}$

SEISMIC LOAD (Three combinations of E_h and E_v considered)

E2.2 CASE

Seismic Case $Q_{E2.2}$ - 100% Horizontal Seismic Force, 30% Vertical

Include Seismic Load in Analysis? $Eq_{E2.2} := 1$ 0 = No, 1 = Yes

Horizontal Seismic Coefficient: $K_{h.E2.2} := -0.17$

Vertical Seismic Coefficient: $K_{v.E2.2} := -0.03$

Vertical Tailwater on Approach Slab: $H_{1.U1} = 1640.77 \cdot kN$

Acting At: $H_{1.U1.loc.x} = 14.42\ m$ $H_{1.U1.loc.z} = 4.73\ m$

Width of HW acting on Approach Slab (Z-dir.): $W_{hwas.U1.z} = 7.9\ m$

Width of TW acting on 1A Foundation (Z-dir.): $W_{twf.U1.z} = 10.6\ m$

HORIZONTAL SEISMIC LOADS **Loads** **Moment Arm**

Horiz Seismic Component of Concrete: $Q_{conc.E2.EQh.2} := D_{conc} \cdot K_{h.E2.2} \cdot Eq_{E2.2} = -6111.1 \cdot kN$ $Y_{conc.loc} = 3.62\ m$

Horiz Seismic Component of Gates: $Q_{Gate.E2.EQh.2} := D_{Gate} \cdot K_{h.E2.2} \cdot Eq_{E2.2} = -9.5 \cdot kN$ $Y_{gate} = 4.00\ m$

Horiz Seismic Component of Fill: $Q_{fill.E2.EQh.2} := D_{fill} \cdot K_{h.E2.2} \cdot Eq_{E2.2} = -3069.6 \cdot kN$ $Y_{fill.loc} = 7.25\ m$

Horizontal Seismic Component of Headwater - Sliding (X-dir.):

$$Q_{hwas.E2.EQh.2.x} := \left(\frac{7}{12}\right) \cdot K_{h.E2.2} \cdot \gamma_w \cdot \left(HW_{U1} - BOK_{elev}\right)^2 \cdot W_{hwas.U1} \cdot Eq_{E2.2} = -1021.2 \cdot kN$$

$Y_{HWg.E2.x} = 2.44\ m$

Horizontal Seismic Component of Headwater - Sliding (Z-dir.):

$$Q_{hwas.E2.EQh.2.z} := \left(\frac{7}{12}\right) \cdot K_{h.E2.2} \cdot \gamma_w \cdot \left(HW_{U1} - BOK_{elev}\right)^2 \cdot W_{hwas.U1.z} \cdot Eq_{E2.2} = -504.2 \cdot kN$$

$Y_{HWg.E2.z} = 2.44\ m$

Horizontal Seismic Component of Tailwater - Sliding (Z-dir.):

$$Q_{twf.E2.EQh.2.z} := \left(\frac{7}{12}\right) \cdot K_{h.E2.2} \cdot \gamma_w \cdot \left(TW_{U1} - BOK_{elev}\right)^2 \cdot W_{twf.U1.z} \cdot Eq_{E2.2} = -627.4 \cdot kN$$

$Y_{TWg.E2.z} = 2.32\ m$

Horizontal Seismic Component of Soil (Woods Method) - Overturning (X-Dir.):

$$Q_{act.E2.EQh.2.OT.x} := \left(\gamma_r - \gamma_w\right) \cdot \left(TOC_{as} - BOF_{elev}\right)^2 \cdot K_{h.E2.2} \cdot W_{hwas.U1} \cdot Eq_{E2.2} = -530.5 \cdot kN$$

$Y_{E.act.E2.OT.x} = 2.52\ m$

Horizontal Seismic Component of Soil (Woods Method X-Dir.)

$$Q_{act.E2.EQh.2.x} := \left(\gamma_r - \gamma_w\right) \cdot \left(TOC_{as} - BOK_{elev}\right)^2 \cdot K_{h.E2.2} \cdot W_{hwas.U1} \cdot Eq_{E2.2} = -1193.6 \cdot kN$$

$Y_{E.act.E2.x} = 2.52\ m$

Horizontal Seismic Component of Soil (Woods Method Z-Dir.)

$$Q_{act.E2.EQh.2.z} := -K_{h.E2.2} \cdot \left(E_{act.a.U1.z} + E_{act.as.U1.z} \cdots + E_{act.RCC.U1.z} + E_{act.RCC.s.U1.z}\right) Eq_{E2.2} = -516.51 \cdot kN$$

$Y_{E.act.E2.y} = 4.65\ m$

$$\Sigma H_{Q.E2.EQh.2} := Q_{conc.E2.EQh.2} + Q_{Gate.E2.EQh.2} + Q_{fill.E2.EQh.2} = -9190.23 \cdot kN$$

$$\Sigma H_{Q.E2.EQh.2.x} := Q_{hwas.E2.EQh.2.x} + Q_{act.E2.EQh.2.x} = -2214.88 \cdot kN$$

$$\Sigma H_{Q.E2.EQh.2.OT.x} := Q_{hwas.E2.EQh.2.x} + Q_{act.E2.EQh.2.OT.x} = -1551.74 \cdot kN$$

$$\Sigma H_{Q.E2.EQh.2.z} := Q_{hwas.E2.EQh.2.z} + Q_{twf.E2.EQh.2.z} + Q_{hwas.E2.EQh.2.z} + Q_{act.E2.EQh.2.z} = -2152.35 \cdot kN$$

E2.2 CASE

VERTICAL SEISMIC LOADS	**Loads**	**Moment Arm**
Vertical Component of Concrete:	$Q_{conc.E2.EQv.2} := D_{conc} \cdot K_{v.E2.2} \cdot Eq_{E2.2} = -1078.4 \cdot kN$	$X_{conc.loc} = 8.81\ m$
		$Z_{conc.loc} = 8.46\ m$
Vertical Component of Gate:	$Q_{Gate.E2.EQv.2} := D_{Gate} \cdot K_{v.E2.2} \cdot Eq_{E2.2} = -1.7 \cdot kN$	$X_{gate} = 9.50\ m$
		$Z_{gate} = 2\ m$
Vertical Component of Fill:	$Q_{fill.E2.EQv.2} := D_{fill} \cdot K_{v.E2.2} \cdot Eq_{E2.2} = -541.7 \cdot kN$	$X_{fill.loc} = 7.31\ m$
		$Z_{fill.loc} = 10\ m$
Vertical Seismic Component of Headwater over Apron Slab:	$Q_{H1.E2.EQv.2} := K_{v.E2.2} \cdot H_{1.U1} \cdot Eq_{E2.2} = -49.2 \cdot kN$	$H_{1.U1.loc.x} = 14.42\ m$
		$H_{1.U1.loc.z} = 4.73\ m$
Vertical Seismic Component of Tailwater over Pier Footing:	$Q_{H2.E2.EQv.2} := K_{v.E2.2} \cdot H_{2.U1} \cdot Eq_{E2.2} = -21.9 \cdot kN$	$H_{2.U1.loc.x} = 5.28\ m$
		$H_{2.U1.loc.z} = 2\ m$
Vertical Seismic Component of Soil over Approach Slab:	$Q_{E1.E2.EQv.2} := K_{v.E2.2} \cdot E_{1.U1} \cdot Eq_{E2.2} = 0 \cdot kN$	$E_{1.U1.loc.x} = 12.89\ m$

$$\Sigma V_{Q.E2.EQv.2} := Q_{conc.E2.EQv.2} + Q_{Gate.E2.EQv.2} + Q_{fill.E2.EQv.2} + Q_{H1.E2.EQv.2} + Q_{H2.E2.EQv.2} + Q_{E1.E2.EQv.2} = -1693.0 \cdot kN$$

$$\Sigma M_{Q.E2.2} := Q_{conc.E2.EQh.2} \cdot Y_{conc.loc} + Q_{Gate.E2.EQh.2} \cdot Y_{gate} + Q_{fill.E2.EQh.2} \cdot Y_{fill.loc} = -44442.66 \cdot kN \cdot m$$

$$\begin{aligned}\Sigma M_{Q.E2.2.x} := {} & Q_{conc.E2.EQh.2} \cdot Y_{conc.loc} + Q_{Gate.E2.EQh.2} \cdot Y_{gate} + Q_{fill.E2.EQh.2} \cdot Y_{fill.loc} + Q_{hwas.E2.EQh.2.x} \cdot Y_{HWg.E2.x} \cdots = -64248.16 \cdot kN \cdot m \\ & + Q_{act.E2.EQh.2.x} \cdot Y_{E.act.E2.x} + Q_{conc.E2.EQv.2} \cdot X_{conc.loc} + Q_{Gate.E2.EQv.2} \cdot X_{gate} + Q_{fill.E2.EQv.2} \cdot X_{fill.loc} \cdots \\ & + Q_{H1.E2.EQv.2} \cdot H_{1.U1.loc.x} + Q_{H2.E2.EQv.2} \cdot H_{2.U1.loc.x} + Q_{E1.E2.EQv.2} \cdot E_{1.U1.loc.x}\end{aligned}$$

$$\begin{aligned}\Sigma M_{Q.E2.2.x.OT} := {} & Q_{conc.E2.EQh.2} \cdot Y_{conc.loc} + Q_{Gate.E2.EQh.2} \cdot Y_{gate} + Q_{fill.E2.EQh.2} \cdot Y_{fill.loc} \cdots = -62577.06 \cdot kN \cdot m \\ & + Q_{hwas.E2.EQh.2.x} \cdot Y_{HWg.E2.x} + Q_{act.E2.EQh.2.OT.x} \cdot Y_{E.act.E2.OT.x} \cdots \\ & + Q_{conc.E2.EQv.2} \cdot X_{conc.loc} + Q_{Gate.E2.EQv.2} \cdot X_{gate} + Q_{fill.E2.EQv.2} \cdot X_{fill.loc} \cdots \\ & + Q_{H1.E2.EQv.2} \cdot H_{1.U1.loc.x} + Q_{H2.E2.EQv.2} \cdot H_{2.U1.loc.x} + Q_{E1.E2.EQv.2} \cdot E_{1.U1.loc.x}\end{aligned}$$

$$\begin{aligned}\Sigma M_{Q.E2.2.z} := {} & Q_{conc.E2.EQh.2} \cdot Y_{conc.loc} + Q_{Gate.E2.EQh.2} \cdot Y_{gate} + Q_{fill.E2.EQh.2} \cdot Y_{fill.loc} + Q_{hwas.E2.EQh.2.z} \cdot Y_{HWg.E2.z} \cdots = -61949.52 \cdot kN \cdot m \\ & + Q_{twf.E2.EQh.2.z} \cdot Y_{TWg.E2.z} + Q_{conc.E2.EQv.2} \cdot Z_{conc.loc} + Q_{Gate.E2.EQv.2} \cdot Z_{gate} + Q_{fill.E2.EQv.2} \cdot Z_{fill.loc} \cdots \\ & + Q_{H1.E2.EQv.2} \cdot H_{1.U1.loc.z} + Q_{H2.E2.EQv.2} \cdot H_{2.U1.loc.z} + Q_{E1.E2.EQv.2} \cdot E_{1.U1.loc.z}\end{aligned}$$

STABILITY ASSESSMENT (SLIDNG, BEARING, FLOTATION AND OVERTURNING): E2.2 CASE

CHECK SLIDING ALONG HORIZONTAL PLANE THRU TOE, IGNORING BEDROCK MOBILIZED BY STRUCTURAL HEEL KEY, OR VOID BEHIND KEY

Sum of Vertical Forces:

$\Sigma V_{E2.2} := \Sigma V_{U1} + \Sigma V_{Q.E2.EQv.2} = 37989.0 \cdot kN$

Sum of Horizontal Forces (X-Direction):

$\Sigma H_{E2.2.x} := \Sigma H_{Water.U1.x} + \Sigma H_{soil.U1.x} + \Sigma H_{Q.E2.EQh.2.x} = -618.49 \cdot kN$

Sum of Horizontal Forces (Z-Direction):

$\Sigma H_{E2.2.z} := \Sigma H_{Water.U1.z} + \Sigma H_{soil.U1.z} + \Sigma H_{Q.E2.EQh.2.z} = -5190.62 \cdot kN$

Sum of Horizontal Forces (Resultant):

$$\Sigma H_{E2.2} := \sqrt{\Sigma H_{E2.2.z}^{\,2} + \Sigma H_{E2.2.x}^{\,2}} = 5227.34 \cdot kN$$

Sliding Factor of Safety (Single Axis):

$$FS_{HorizSliding.E2.2.x} := \frac{\tan_{\phi} \cdot \Sigma V_{E2.2}}{\left|\Sigma H_{E2.2.x} + \Sigma H_{Q.E2.EQh.2}\right|} = 1.89$$

$$FS_{HorizSliding.E2.2.z} := \frac{\tan_{\phi} \cdot \Sigma V_{E2.2}}{\left|\Sigma H_{E2.2.z} + \Sigma H_{Q.E2.EQh.2}\right|} = 1.29$$

Sliding Factor of Safety (Resultant):

$$FS_{HorizSliding.E2.2} := \frac{\tan_{\phi} \cdot \Sigma V_{E2.2}}{\Sigma H_{E2.2} + \left|\Sigma H_{Q.E2.EQh.2}\right|} = 1.29$$

$FS_{HorizSliding.E2.2.Check} :=$ | "OKAY" if $FS_{HorizSliding.E2.2} \geq FS_{req.E2.sl}$ = "OKAY"
"Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !" otherwise

FLOATATION ANALYSIS:

ACCEPTANCE PARAMETERS

Required Factor of Safety: $FS_{req.FE2} = 1$

VERTICAL LOADS RESISTING:

Dead Load: $\Sigma V_{DL} = 54060.17 \cdot kN$

Water Weight H1+H2: $\Sigma V_{H.FE2.2} := H_{1.U1} + H_{2.U1} = 2371.81 \cdot kN$

Summation Vertical Resisting: $\Sigma V_{FE2.2} := \Sigma V_{U1} + \Sigma V_{Q.E2.EQv.2} = 37989.0 \cdot kN$

VERTICAL LOADS UPLIFT:

Uplift: $U_{U1} = -16750 \cdot kN$

Factor of Safety Floatation:

$$FS_{act.FE2.2} := \frac{\Sigma V_{FE2.2}}{\left|U_{U1}\right|} = 2.27$$

$FS_{check.FE2.2} :=$ | "OKAY" if $FS_{act.FE2.2} \geq FS_{req.FE2}$ = "OKAY"
"ANCHORS REQUIRED" if $FS_{act.FE2.2} < FS_{req.FE2}$

CHECK FOUNDATION BEARING CAPACITY

E2.2 CASE

Sum of the Moments (X-Direction):

$$\Sigma M_{E2.2.x} := \Sigma M_{U1.x} - \Sigma M_{I.U1} + \Sigma M_{Q.E2.2.x} = 267666 \cdot kN \cdot m$$

Eccentricity:

$$e_{E2.2.x} := X_{BCG} - \frac{\Sigma M_{E2.2.x}}{\Sigma V_{E2.2}} = 1.93\ m$$

Eccentricity Check:

$$e_{check.E2.2.x} := \begin{vmatrix} \text{"Okay"} & \text{if } e_{E2.2.x} \le \frac{L_B}{4} \\ \text{"Revise Structure"} & \text{otherwise} \end{vmatrix}$$

$$e_{check.E2.2.x} = \text{"Okay"}$$

Foundation Bearing Pressures (X-Direction):

Bearing Pressure at Heel:

$$\sigma_{heel.E2.2.x} := \frac{\Sigma V_{E2.2}}{A_b} - \frac{\Sigma V_{E2.2} \cdot e_{E2.2.x}}{S_{bx.L}} = 43.39 \cdot \frac{kN}{m^2}$$

$$\sigma_{heel.E2.2.check.x} := \left(\begin{vmatrix} \text{"Okay"} & \text{if } 0 \le \sigma_{heel.E2.2.x} \le \sigma_{allow.E2} \\ \text{"Revise Structure"} & \text{otherwise} \end{vmatrix} \right)$$

$$\sigma_{heel.E2.2.check.x} = \text{"Okay"}$$

Bearing Pressure at Toe:

$$\sigma_{toe.E2.2.x} := \frac{\Sigma V_{E2.2}}{A_b} + \frac{\Sigma V_{E2.2} \cdot e_{E2.2.x}}{S_{bx.R}} = 217.23 \cdot \frac{kN}{m^2}$$

$$\sigma_{toe.E2.2.check.x} := \begin{vmatrix} \text{"Okay"} & \text{if } 0 \le \sigma_{toe.E2.2.x} \le \sigma_{allow.E2} \\ \text{"Revise Structure"} & \text{otherwise} \end{vmatrix}$$

$$\sigma_{toe.E2.2.check.x} = \text{"Okay"}$$

Sum of the Moments (Z-Direction):

$$\Sigma M_{E2.2.z} := \Sigma M_{U1.z} + \Sigma M_{Q.E2.2.z} = 287069 \cdot kN \cdot m$$

Eccentricity:

$$e_{E2.2.z} := Z_{mass} - \frac{\Sigma M_{E2.2.z}}{\Sigma V_{E2.2}} = 1.41\ m$$

Eccentricity Check:

$$e_{check.E2.2.z} := \begin{vmatrix} \text{"Okay"} & \text{if } e_{E2.2.z} \le \frac{W_B}{4} \\ \text{"Revise Structure"} & \text{otherwise} \end{vmatrix}$$

$$e_{check.E2.2.z} = \text{"Okay"}$$

Foundation Bearing Pressures (Z-Direction):

Bearing Pressure at Heel:

$$\sigma_{heel.E2.2.z} := \frac{\Sigma V_{E2.2}}{A_b} - \frac{\Sigma V_{E2.2} \cdot e_{E2.2.z}}{S_{bz.b}} = 57.58 \cdot \frac{kN}{m^2}$$

$$\sigma_{heel.E2.2.check.z} := \left(\begin{vmatrix} \text{"Okay"} & \text{if } 0 \le \sigma_{heel.E2.2.z} \le \sigma_{allow.E2} \\ \text{"Revise Structure"} & \text{otherwise} \end{vmatrix} \right)$$

$$\sigma_{heel.E2.2.check.z} = \text{"Okay"}$$

Bearing Pressure at Toe:

$$\sigma_{toe.E2.2.z} := \frac{\Sigma V_{E2.2}}{A_b} + \frac{\Sigma V_{E2.2} \cdot e_{E2.2.z}}{S_{bz.t}} = 203.98 \cdot \frac{kN}{m^2}$$

$$\sigma_{toe.E2.2.check.z} := \begin{vmatrix} \text{"Okay"} & \text{if } 0 \le \sigma_{heel.E3.2.z} \le \sigma_{allow.E2} \\ \text{"Revise Structure"} & \text{otherwise} \end{vmatrix}$$

$$\sigma_{toe.E2.2.check.z} = \text{"Okay"}$$

Foundation Bearing Pressure (Combined):

Linear pressure superimposed at Corners by both Moment_X and Moment_Z

E2.2 CASE

Bearing Pressure at Heel(x)-Heel(z):

$$\sigma_{heel.E2.2} := \min\left(\frac{\Sigma V_{E2.2}}{A_b} - \frac{\Sigma V_{U2} \cdot e_{U1.x}}{S_{bx.L}} - \frac{\Sigma V_{E2.2} \cdot e_{E2.2.z}}{S_{bz.b}}, \frac{\Sigma V_{E2.2}}{A_b} - \frac{\Sigma V_{E2.2} \cdot e_{E2.2.x}}{S_{bx.L}} - \frac{\Sigma V_{U1} \cdot e_{U1.z}}{S_{bz.b}}\right) = 29.11 \cdot kPa$$

$$\sigma_{heel.E2.2.check} := \left(\begin{array}{l} \text{"Okay"} \quad \text{if} \quad 0 \le \sigma_{heel.E2.2} \le \sigma_{allow.E2} \\ \text{"Revise Structure"} \quad \text{otherwise} \end{array} \right)$$

$\sigma_{heel.E2.2.check} = \text{"Okay"}$

Bearing Pressure at Toe(x)-Toe(z):

$$\sigma_{toe.E2.2} := \min\left(\frac{\Sigma V_{E2.2}}{A_b} + \frac{\Sigma V_{U2} \cdot e_{U1.x}}{S_{bx.R}} + \frac{\Sigma V_{E2.2} \cdot e_{E2.2.z}}{S_{bz.t}}, \frac{\Sigma V_{E2.2}}{A_b} + \frac{\Sigma V_{E2.2} \cdot e_{E2.2.x}}{S_{bx.R}} + \frac{\Sigma V_{U1} \cdot e_{U1.z}}{S_{bz.t}}\right) = 163.28 \cdot kPa$$

$$\sigma_{toe.E2.2.check} := \left| \begin{array}{l} \text{"Okay"} \quad \text{if} \quad 0 \le \sigma_{toe.E2.2} \le \sigma_{allow.E2} \\ \text{"Revise Structure"} \quad \text{otherwise} \end{array} \right.$$

$\sigma_{toe.E2.2.check} = \text{"Okay"}$

Bearing Pressure at Heel(x)-Toe(z):

$$\sigma_{heeltoe.E2.2} := \min\left(\frac{\Sigma V_{E2.2}}{A_b} - \frac{\Sigma V_{U2} \cdot e_{U1.x}}{S_{bx.L}} + \frac{\Sigma V_{E2.2} \cdot e_{E2.2.z}}{S_{bz.t}}, \frac{\Sigma V_{E2.2}}{A_b} - \frac{\Sigma V_{E2.2} \cdot e_{E2.2.x}}{S_{bx.L}} + \frac{\Sigma V_{U1} \cdot e_{U1.z}}{S_{bz.t}}\right) = -10.56 \cdot kPa$$

$$\sigma_{heeltoe.E2.2.check} := \left(\begin{array}{l} \text{"Okay"} \quad \text{if} \quad 0 \le \sigma_{heeltoe.E2.2} \le \sigma_{allow.E2} \\ \text{"Revise Structure"} \quad \text{otherwise} \end{array} \right)$$

$\sigma_{heeltoe.E2.2.check} = \text{"Revise Structure"}$

Bearing Pressure at Toe(x)-Heel(z):

$$\sigma_{toeheel.E2.2} := \min\left(\frac{\Sigma V_{E2.2}}{A_b} + \frac{\Sigma V_{U2} \cdot e_{U1.x}}{S_{bx.R}} - \frac{\Sigma V_{E2.2} \cdot e_{E2.2.z}}{S_{bz.b}}, \frac{\Sigma V_{E2.2}}{A_b} + \frac{\Sigma V_{E2.2} \cdot e_{E2.2.x}}{S_{bx.R}} - \frac{\Sigma V_{U1} \cdot e_{U1.z}}{S_{bz.b}}\right) = 84.42 \cdot kPa$$

$$\sigma_{toeheel.E2.2.check} := \left| \begin{array}{l} \text{"Okay"} \quad \text{if} \quad 0 \le \sigma_{toeheel.E2.2} \le \sigma_{allow.E2} \\ \text{"Revise Structure"} \quad \text{otherwise} \end{array} \right.$$

$\sigma_{toeheel.E2.2.check} = \text{"Okay"}$

Small Tension in corner is calculated under E2.2 Load Case, - to be reviewed in detail using 3D analysis during final design and cracked base to be reviewed as applicable, however due to the average compression along each exterior foundation line the tension appears to be minimal.

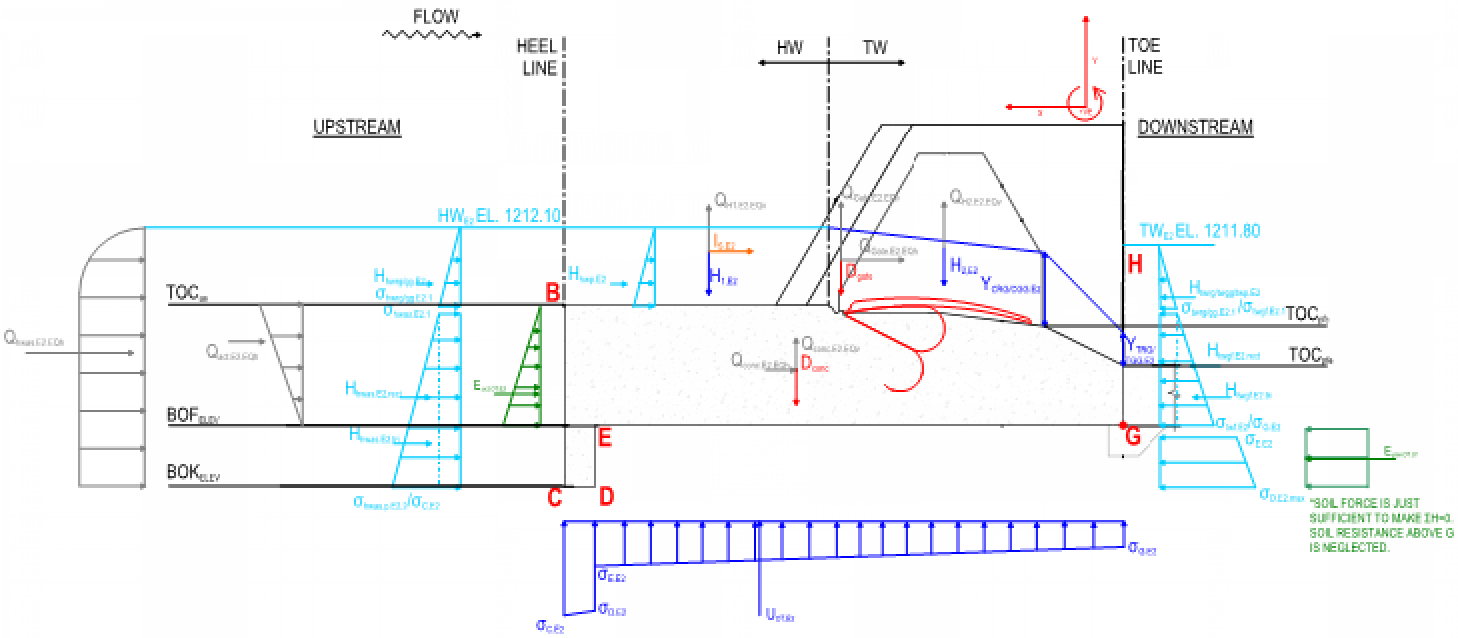
E2.2 CASE

MONOLITH OVERTURNING STABILITY ANALYSIS

Seismic Case $Q_{E2.2}$: 100% Horizontal Seismic Force, 30% Vertical

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.
Assumptions are made in order to compute overturning stability of indetermine forces on monolith with key;
(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.
(b) The horizontal resisting force acting on the key, P.key, is that required for static equilibrium
(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1 $Ratio_{overturning.allow.Extreme} = 0.25$ Resultant within Base



<u>All Vertical Loads Applicable to Overturning Stability Analysis</u>

Total Concrete Dead Loads:	$D_{conc} = 35947.58 \cdot kN$	at:	$X_{conc.loc} = 8.81\ m$
Dead Load of Gate:	$D_{Gate} = 56.0 \cdot kN$		$X_{gate} = 9.50\ m$
Water Weight (HW) on Apron Slab:	$H_{1.U1} = 1640.8 \cdot kN$		$H_{1.U1.loc.x} = 14.42\ m$
Water Weight (TW) on Gate Footing:	$H_{2.U1} = 731.0 \cdot kN$		$H_{2.U1.loc.x} = 5.28\ m$
Uplift Load for Overturning Analysis:	$U_{OT.U1} = -17396.43 \cdot kN$		$U_{OT.U1.loc} = 9.4 \cdot m$
Vertical Seismic Component of Concrete Structure:	$Q_{conc.E2.EQv.2} = -1078.43 \cdot kN$		$X_{conc.loc} = 8.81\ m$
Vertical Seismic Component of Crest Gate:	$Q_{Gate.E2.EQv.2} = -1.68 \cdot kN$		$X_{gate} = 9.50\ m$
Vertical Seismic Component of Headwater over Apron Slab:	$Q_{H1.E2.EQv.2} = -49.22 \cdot kN$		$H_{1.U1.loc.x} = 14.42\ m$
Vertical Seismic Component of Headwater over Fixed Crest Slab:	$Q_{H2.E2.EQv.2} = -21.93 \cdot kN$		$H_{2.U1.loc.x} = 5.28\ m$

Sum of All Overturning Analysis Vertical Load:

$$\Sigma V_{E2.OT.2} := D_{conc} + D_{Gate} + H_{1.U1} + H_{2.U1} + U_{OT.U1} + \Sigma V_{Q.E2.EQv.2} = 19285.99 \cdot kN$$

Sum of All Overturning Analysis Vertical Load Moments:

$$\Sigma M_{V.E2.OT.2} := D_{conc} \cdot X_{conc.loc} + D_{Gate} \cdot X_{gate} + H_{1.U1} \cdot H_{1.U1.loc.x} + H_{2.U1} \cdot H_{2.U1.loc.x} + U_{OT.U1} \cdot U_{OT.U1.loc} = 181354.01 \cdot kN \cdot m$$

Lateral Driving Earth Loads for Overturning Stability Analysis (at rest condition)

E2.2 CASE

Depth of Driving Soil Loads (to top of key): $h_{E.OT.E2.2} := TOC_{as} - BOF_{elev} = 4\ m$

Applicable Soil Load: $E_{act.OT.E2.2} := \frac{\left(K_{o.U1} \cdot h_{E.OT.U1}{}^{2}\right)}{2} \cdot \left(\gamma_r - \gamma_w\right) \cdot W_{hwas.U1} \cdot -1 = -1026.66 \cdot kN$

At Rest- Soil Load Acting from Toe: $E_{act.OT.E2.2.loc} := \frac{h_{E.OT.U1}}{3} = 1.33\ m$

All Lateral Loads Applicable to Overturning Stability Analysis

HW Lateral Load on Approach Slab:	$H_{hwas.U1} = -2574.1 \cdot kN$	$H_{hwas.U1.loc} = 1.67\ m$
HW Lateral Load on Guard Gate:	$H_{hwgg.U1} = 0.0 \cdot kN$	$H_{hwgg.U1.loc} = 4.00\ m$
TW Lateral Load on Guard Gate:	$H_{twgg.U1} = 0.0 \cdot kN$	$H_{twgg.U1.loc} = 4.00\ m$
TW Lateral Load on Gate Footing (No Key - Overturning Values Adjusted):	$H_{twgf.U1} = 2385.79 \cdot kN$	$H_{twgf.U1.loc} = 1.65\ m$
TW Lateral Load on Key:	$H_{twkey.OT.U1} = 2219.64 \cdot kN$	$H_{twkey.OT.U1.loc} = -1.05\ m$
Ice / Impact Load:	$I_{U1} = 0.0 \cdot kN$	$I_{U1.loc.y} = 5.80\ m$
Lateral Soil Load (driving):	$E_{act.OT.U1} = -1026.7 \cdot kN$	$E_{act.OT.U1.loc} = 1.33\ m$
Horizontal Seismic Component of Concrete Structure:	$Q_{conc.E2.EQh.2} = -6111.09 \cdot kN$	$Y_{conc.loc} = 3.62\ m$
Horizontal Seismic Component of Vertical Lift Gate:	$Q_{Gate.E2.EQh.2} = -9.52 \cdot kN$	$Y_{gate} = 4.00\ m$
Horizontal Seismic Component of Headwater on Slab Footing:	$Q_{hwas.E2.EQh.2.x} = -1021.23 \cdot kN$	$Y_{HWg.E2.x} = 2.44\ m$
Horizontal Seismic Component of Active Soil: (Section 5-5, USACE EM_1110-2-2100)	$Q_{act.E2.EQh.2.x} = -1193.64 \cdot kN$	$Y_{E.act.E2.x} = 2.52\ m$

Resisting Lateral Soil Load as required to produce horizontal equilibrium:

$$E_{pas.OT.E2.2} := -\left(H_{hwas.U1} + H_{hwgg.U1} + H_{twgg.U1} + H_{twgf.U1} + H_{twkey.OT.U1} + I_{U1} + E_{act.OT.U1} + \Sigma H_{Q.E2.EQh.2.OT.x}\right) = 547.11 \cdot kN$$

Acting at: $E_{pas.OT.E2.2.loc} := -1 \cdot \frac{d_{key}}{2} = -1\ m$

Sum of All Overturning Analysis Horizontal Load (ΣH=0):

$$\Sigma H_{E2.OT.2} := H_{hwas.U1} + H_{hwgg.U1} + H_{twgg.U1} + H_{twgf.U1} + H_{twkey.OT.U1} + I_{U1} + E_{act.OT.U1} + E_{pas.OT.E2.2} + \Sigma H_{Q.E2.EQh.2.OT.x} = 0 \cdot kN$$

Sum of All Overturning Analysis Horizontal Load Moments:

$$\Sigma M_{H.E2.OT.2} := H_{hwas.U1} \cdot H_{hwas.U1.loc} + H_{hwgg.U1} \cdot H_{hwgg.U1.loc} + H_{twgg.U1} \cdot H_{twgg.U1.loc} \cdots = -47509.42 \cdot kN \cdot m$$
$$+ H_{twgf.U1} \cdot H_{twgf.U1.loc} + H_{twkey.OT.U1} \cdot H_{twkey.OT.U1.loc} + I_{U1} \cdot I_{U1.loc.y} \cdots$$
$$+ E_{act.OT.U1} \cdot E_{act.OT.U1.loc} + E_{pas.OT.x.U1} \cdot E_{pas.OT.U1.loc} + \Sigma M_{Q.E2.2}$$

Overturning Stability Analysis

$\Sigma M_{E2.OT.2} := \Sigma M_{V.E2.OT.2} + \Sigma M_{H.E2.OT.2} = 133844.58 \cdot kN \cdot m$

$X_{R.E2.2} := \frac{\Sigma M_{E2.OT.2}}{\Sigma V_{E2.OT.2}} = 6.94\ m$ $x_{OT.E2.2} := X_{R.E2.2} - \frac{L_B}{2} = -2.31\ m$

Overturning Resultant Ratio

$Ratio_{OT.E2.2} := \frac{X_{R.E2.2}}{L_B} = 0.38$

$Ratio_{OT.E2.2.check} :=$ | "OKAY" if $Ratio_{OT.E2.2} \geq Ratio_{overturning.allow.Extreme}$ = "OKAY"
"Revise Structure" otherwise

SEISMIC LOAD (Three combinations of E_h and E_v considered)

Seismic Case $Q_{E2.3}$ - 30% Horizontal Seismic Force, 100% Vertical

Include Seismic Load in Analysis? $Eq_{E2.3} := 1$ 0 = No, 1 = Yes

Horizontal Seismic Coefficient: $K_{h.E2.3} := -0.05$

Vertical Seismic Coefficient: $K_{v.E2.3} := -0.10$

Vertical Tailwater on Approach Slab: $H_{1.U1} = 1640.77 \cdot kN$

Acting At: $H_{1.U1.loc.x} = 14.42\,m$ $H_{1.U1.loc.z} = 4.73\,m$

Width of HW acting on Approach Slab (Z-dir.): $W_{hwas.U1.z} = 7.9\,m$

Width of TW acting on 1A Foundation (Z-dir.): $W_{twf.U1.z} = 10.6\,m$

HORIZONTAL SEISMIC LOADS	Loads	Moment Arm
Horiz Seismic Component of Concrete:	$Q_{conc.E2.EQh.3} := D_{conc} \cdot K_{h.E2.3} \cdot Eq_{E2.3} = -1797.4 \cdot kN$	$Y_{conc.loc} = 3.62\,m$
Horiz Seismic Component of Gates:	$Q_{Gate.E2.EQh.3} := D_{Gate} \cdot K_{h.E2.3} \cdot Eq_{E2.3} = -2.8 \cdot kN$	$Y_{gate} = 4.00\,m$
Horiz Seismic Component of Fill:	$Q_{fill.E2.EQh.3} := D_{fill} \cdot K_{h.E2.3} \cdot Eq_{E2.3} = -902.8 \cdot kN$	$Y_{fill.loc} = 7.25\,m$

Horizontal Seismic Component of Headwater - Sliding (X-dir.):

$$Q_{hwas.E2.EQh.3.x} := \left(\frac{7}{12}\right) \cdot K_{h.E2.3} \cdot \gamma_w \cdot \left(HW_{U1} - BOK_{elev}\right)^2 \cdot W_{hwas.U1} \cdot Eq_{E2.3} = -300.4 \cdot kN$$

$$Y_{HWg.E2.x} = 2.44\,m$$

Horizontal Seismic Component of Headwater - Sliding (Z-dir.):

$$Q_{hwas.E2.EQh.3.z} := \left(\frac{7}{12}\right) \cdot K_{h.E2.3} \cdot \gamma_w \cdot \left(HW_{U1} - BOK_{elev}\right)^2 \cdot W_{hwas.U1.z} \cdot Eq_{E2.3} = -148.3 \cdot kN$$

$$Y_{HWg.E2.z} = 2.44\,m$$

Horizontal Seismic Component of Tailwater - Sliding (Z-dir.):

$$Q_{twf.E2.EQh.3.z} := \left(\frac{7}{12}\right) \cdot K_{h.E2.3} \cdot \gamma_w \cdot \left(TW_{U1} - BOK_{elev}\right)^2 \cdot W_{twf.U1.z} \cdot Eq_{E2.3} = -184.5 \cdot kN$$

$$Y_{TWg.E2.z} = 2.32\,m$$

Horizontal Seismic Component of Soil (Woods Method) - Overturning (X-Dir.):

$$Q_{act.E2.EQh.3.OT.x} := \left(\gamma_r - \gamma_w\right) \cdot \left(TOC_{as} - BOF_{elev}\right)^2 \cdot K_{h.E2.3} \cdot W_{hwas.U1} \cdot Eq_{E2.3} = -156.0 \cdot kN$$

$$Y_{E.act.E2.OT.x} = 2.52\,m$$

Horizontal Seismic Component of Soil (Woods Method X-Dir.)

$$Q_{act.E2.EQh.3.x} := \left(\gamma_r - \gamma_w\right) \cdot \left(TOC_{as} - BOK_{elev}\right)^2 \cdot K_{h.E2.3} \cdot W_{hwas.U1} \cdot Eq_{E2.3} = -351.1 \cdot kN$$

$$Y_{E.act.E2.x} = 2.52\,m$$

Horizontal Seismic Component of Soil (Woods Method Z-Dir.)

$$Q_{act.E2.EQh.3.z} := -K_{h.E2.3} \cdot \left(E_{act.a.U1.z} + E_{act.as.U1.z} \cdots + E_{act.RCC.U1.z} + E_{act.RCC.s.U1.z}\right) Eq_{E2.3} = -151.91 \cdot kN$$

$$Y_{E.act.E2.y} = 4.65\,m$$

$$\Sigma H_{Q.E2.EQh.3} := Q_{conc.E2.EQh.3} + Q_{Gate.E2.EQh.3} + Q_{fill.E2.EQh.3} = -2703.01 \cdot kN$$

$$\Sigma H_{Q.E2.EQh.3.x} := Q_{hwas.E2.EQh.2.x} + Q_{act.E2.EQh.2.x} = -2214.88 \cdot kN$$

$$\Sigma H_{Q.E2.EQh.3.OT.x} := Q_{hwas.E2.EQh.3.x} + Q_{act.E2.EQh.3.OT.x} = -456.39 \cdot kN$$

$$\Sigma H_{Q.E2.EQh.3.z} := Q_{hwas.E2.EQh.3.z} + Q_{twf.E2.EQh.3.z} + Q_{hwas.E2.EQh.3.z} + Q_{act.E2.EQh.3.z} = -633.04 \cdot kN$$

E2.3 CASE

VERTICAL SEISMIC LOADS	Loads	Moment Arm
Vertical Component of Concrete:	$Q_{conc.E2.EQv.3} := D_{conc} \cdot K_{v.E2.3} \cdot Eq_{E2.3} = -3594.8 \cdot kN$	$X_{conc.loc} = 8.81\ m$
		$Z_{conc.loc} = 8.46\ m$
Vertical Component of Gate:	$Q_{Gate.E2.EQv.3} := D_{Gate} \cdot K_{v.E2.3} \cdot Eq_{E2.3} = -5.6 \cdot kN$	$X_{gate} = 9.50\ m$
		$Z_{gate} = 2\ m$
Vertical Component of Fill:	$Q_{fill.E2.EQv.3} := D_{fill} \cdot K_{v.E2.3} \cdot Eq_{E2.3} = -1805.66 \cdot kN$	$X_{fill.loc} = 7.31\ m$
		$Z_{fill.loc} = 10\ m$
Vertical Seismic Component of Headwater over Apron Slab:	$Q_{H1.E2.EQv.3} := K_{v.E2.3} \cdot H_{1.U1} \cdot Eq_{E2.3} = -164.1 \cdot kN$	$H_{1.U1.loc.x} = 14.42\ m$
		$H_{1.U1.loc.z} = 4.73\ m$
Vertical Seismic Component of Tailwater over Pier Footing:	$Q_{H2.E2.EQv.3} := K_{v.E2.3} \cdot H_{2.U1} \cdot Eq_{E2.3} = -73.1 \cdot kN$	$H_{2.U1.loc.x} = 5.28\ m$
		$H_{2.U1.loc.z} = 2\ m$
Vertical Seismic Component of Soil over Approach Slab:	$Q_{E1.E2.EQv.3} := K_{v.E2.3} \cdot E_{1.U1} \cdot Eq_{E2.3} = 0 \cdot kN$	$E_{1.U1.loc.x} = 12.89\ m$

$$\Sigma V_{Q.E2.EQv.3} := Q_{conc.E2.EQv.3} + Q_{Gate.E2.EQv.3} + Q_{fill.E2.EQv.3} + Q_{H1.E2.EQv.3} + Q_{H2.E2.EQv.3} + Q_{E1.E2.EQv.3} = -5643.2 \cdot kN$$

$$\Sigma M_{Q.E2.3} := Q_{conc.E2.EQh.3} \cdot Y_{conc.loc} + Q_{Gate.E2.EQh.3} \cdot Y_{gate} + Q_{fill.E2.EQh.3} \cdot Y_{fill.loc} = -13071.37 \cdot kN \cdot m$$

$$\begin{aligned}\Sigma M_{Q.E2.3.x} := {} & Q_{conc.E2.EQh.3} \cdot Y_{conc.loc} + Q_{Gate.E2.EQh.3} \cdot Y_{gate} + Q_{fill.E2.EQh.3} \cdot Y_{fill.loc} + Q_{hwas.E2.EQh.3.x} \cdot Y_{HWg.E2.x} \cdots = -62337.41 \cdot kN \cdot m \\ & + Q_{act.E2.EQh.3.x} \cdot Y_{E.act.E2.x} + Q_{conc.E2.EQv.3} \cdot X_{conc.loc} + Q_{Gate.E3.EQv.2} \cdot X_{gate} + Q_{fill.E2.EQv.3} \cdot X_{fill.loc} \cdots \\ & + Q_{H1.E2.EQv.3} \cdot H_{1.U1.loc.x} + Q_{H2.E2.EQv.3} \cdot H_{2.U1.loc.x} + Q_{E1.E2.EQv.3} \cdot E_{1.U1.loc.x}\end{aligned}$$

$$\begin{aligned}\Sigma M_{Q.E2.3.x.OT} := {} & Q_{conc.E2.EQh.3} \cdot Y_{conc.loc} + Q_{Gate.E2.EQh.3} \cdot Y_{gate} + Q_{fill.E2.EQh.3} \cdot Y_{fill.loc} \cdots = -61883.14 \cdot kN \cdot m \\ & + Q_{hwas.E2.EQh.3.x} \cdot Y_{HWg.E2.x} + Q_{act.E2.EQh.3.OT.x} \cdot Y_{E.act.E2.OT.x} \cdots \\ & + Q_{conc.E2.EQv.3} \cdot X_{conc.loc} + Q_{Gate.E2.EQv.3} \cdot X_{gate} + Q_{fill.E2.EQv.3} \cdot X_{fill.loc} \cdots \\ & + Q_{H1.E2.EQv.3} \cdot H_{1.U1.loc.x} + Q_{H2.E2.EQv.3} \cdot H_{2.U1.loc.x} + Q_{E1.E2.EQv.3} \cdot E_{1.U1.loc.x}\end{aligned}$$

$$\begin{aligned}\Sigma M_{Q.E2.3.z} := {} & Q_{conc.E2.EQh.3} \cdot Y_{conc.loc} + Q_{Gate.E2.EQh.3} \cdot Y_{gate} + Q_{fill.E2.EQh.3} \cdot Y_{fill.loc} + Q_{hwas.E3.EQh.2.z} \cdot Y_{HWg.E2.z} \cdots = -65009.84 \cdot kN \cdot m \\ & + Q_{twf.E2.EQh.3.z} \cdot Y_{TWg.E2.z} + Q_{conc.E2.EQv.3} \cdot Z_{conc.loc} + Q_{Gate.E2.EQv.3} \cdot Z_{gate} + Q_{fill.E2.EQv.3} \cdot Z_{fill.loc} \cdots \\ & + Q_{H1.E2.EQv.3} \cdot H_{1.U1.loc.z} + Q_{H2.E2.EQv.3} \cdot H_{2.U1.loc.z} + Q_{E1.E2.EQv.3} \cdot E_{1.U1.loc.z}\end{aligned}$$

STABILITY ASSESSMENT (SLIDNG, BEARING, FLOTATION AND OVERTURNING): E2.3 CASE

CHECK SLIDING ALONG HORIZONTAL PLANE THRU TOE, IGNORING BEDROCK MOBILIZED BY STRUCTURAL HEEL KEY, OR VOID BEHIND KEY

Sum of Vertical Forces:

$$\Sigma V_{E2.3} := \Sigma V_{U1} + \Sigma V_{Q.E2.EQv.3} = 34038.8 \cdot kN$$

Sum of Horizontal Forces (X-Direction):

$$\Sigma H_{E2.3.x} := \Sigma H_{Water.U1.x} + \Sigma H_{soil.U1.x} + \Sigma H_{Q.E2.EQh.3.x} = -618.49 \cdot kN$$

Sum of Horizontal using 30% Seismic Horizontal (X-Direction):

$$\Sigma H_{E2.3.x.30\%} := \Sigma H_{Water.U1.x} + \Sigma H_{soil.U1.x} + 0.3 \cdot \Sigma H_{Q.E2.EQh.3.x} = 931.92 \cdot kN$$

Sum of Horizontal Forces (Z-Direction):

$$\Sigma H_{E2.3.z} := \Sigma H_{Water.U1.z} + \Sigma H_{soil.U1.z} + \Sigma H_{Q.E2.EQh.3.z} = -3671.31 \cdot kN$$

Sum of Horizontal using 30% Seismic Horizontal (Z-Direction):

$$\Sigma H_{E2.3.z.30\%} := \Sigma H_{Water.U1.z} + \Sigma H_{soil.U1.z} + 0.3 \cdot \Sigma H_{Q.E2.EQh.3.z} = -3228.18 \cdot kN$$

Sum of Horizontal Forces (Resultant):

$$\Sigma H_{2.3} := \sqrt{\Sigma H_{E2.3.x}^{\,2} + \Sigma H_{E2.3.z}^{\,2}} = 3723.05 \cdot kN$$

Sum of Horizontal Forces using 30% Seismic Horizontal (Resultant):

$$\Sigma H_{2.3.30\%} := \sqrt{\Sigma H_{E2.3.x.30\%}^{\,2} + \Sigma H_{E2.3.z.30\%}^{\,2}} = 3360.01 \cdot kN$$

Sliding Factor of Safety (Single Axis):

$$FS_{HorizSliding.E2.3.x} := \frac{\tan_{\phi} \cdot \Sigma V_{E2.3}}{\left|\Sigma H_{E2.3.x} + \Sigma H_{Q.E2.EQh.3}\right|} = 5.00$$

$$FS_{HorizSliding.E2.3.z} := \frac{\tan_{\phi} \cdot \Sigma V_{E2.3}}{\left|\Sigma H_{E2.3.z} + \Sigma H_{Q.E2.EQh.3}\right|} = 2.60$$

Sliding Factor of Safety (Resultant):

$$FS_{HorizSliding.E2.3} := \min\left[\frac{\tan_{\phi} \cdot \Sigma V_{E2.3}}{\Sigma H_{2.3} + \left|\Sigma H_{Q.E2.EQh.3}\right|}, \frac{\tan_{\phi} \cdot \Sigma V_{E2.3}}{\Sigma H_{2.3.30\%} + \left|\left(\Sigma H_{Q.E2.EQh.3}\right)\right|}\right] = 2.58$$

$$FS_{HorizSliding.E2.3.Check} := \begin{cases} \text{"OKAY"} & \text{if } FS_{HorizSliding.E2.3} \ge FS_{req.E2.sl} \\ \text{"Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

FLOATATION ANALYSIS:

ACCEPTANCE PARAMETERS

Required Factor of Safety: $FS_{req.FE2} = 1$

VERTICAL LOADS RESISTING:

Dead Load: $\Sigma V_{DL} = 54060.17 \cdot kN$

Water Weight H1+H2: $\Sigma V_{H.FE2.3} := H_{1.U1} + H_{2.U1} = 2371.81 \cdot kN$

Summation Vertical Resisting: $\Sigma V_{FE2.3} := \Sigma V_{U1} + \Sigma V_{Q.E2.EQv.3} = 34038.8 \cdot kN$

VERTICAL LOADS UPLIFT:

Uplift: $U_{U1} = -16750 \cdot kN$

Factor of Safety Floatation:

$$FS_{act.FE2.3} := \frac{\Sigma V_{FE2.3}}{\left|U_{U1}\right|} = 2.03$$

$$FS_{check.FE2.3} := \begin{cases} \text{"OKAY"} & \text{if } FS_{act.FE2.3} \ge FS_{req.FE2} \\ \text{"ANCHORS REQUIRED"} & \text{if } FS_{act.FE2.3} < FS_{req.FE2} \end{cases} = \text{"OKAY"}$$

CHECK FOUNDATION BEARING CAPACITY

Sum of the Moments (X-Direction):

$$\Sigma M_{E2.3.x} := \Sigma M_{U1.x} - \Sigma M_{I.U1} + \Sigma M_{Q.E2.3.x} = 269576 \cdot kN \cdot m$$

Eccentricity:

$$e_{E2.3.x} := X_{BCG} - \frac{\Sigma M_{E2.3.x}}{\Sigma V_{E2.3}} = 1.06\ m$$

Eccentricity Check:

$$e_{check.E2.3.x} := \begin{cases} \text{"Okay"} & \text{if } e_{E2.3.x} \le \frac{L_B}{4} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$e_{check.E2.3.x} = \text{"Okay"}$

Foundation Bearing Pressures (X-Direction):

Bearing Pressure at Heel:

$$\sigma_{heel.E2.3.x} := \frac{\Sigma V_{E2.3}}{A_b} - \frac{\Sigma V_{E2.3} \cdot e_{E2.3.x}}{S_{bx.L}} = 75.19 \cdot \frac{kN}{m^2}$$

$$\sigma_{heel.E2.3.check.x} := \left(\begin{cases} \text{"Okay"} & \text{if } \sigma_{heel.E2.3.x} \le \sigma_{allow.E2} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} \right)$$

$\sigma_{heel.E2.3.check.x} = \text{"Okay"}$

Bearing Pressure at Toe:

$$\sigma_{toe.E2.3.x} := \frac{\Sigma V_{E2.3}}{A_b} + \frac{\Sigma V_{E2.3} \cdot e_{E2.3.x}}{S_{bx.R}} = 160.42 \cdot \frac{kN}{m^2}$$

$$\sigma_{toe.E2.3.check.x} := \begin{cases} \text{"Okay"} & \text{if } \sigma_{toe.E2.3.x} \le \sigma_{allow.E2} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$\sigma_{toe.E2.3.check.x} = \text{"Okay"}$

Sum of the Moments (Z-Direction):

$$\Sigma M_{E2.3.z} := \Sigma M_{U1.z} + \Sigma M_{Q.E2.3.z} = 284009 \cdot kN \cdot m$$

Eccentricity:

$$e_{E2.3.z} := Z_{BCG} - \frac{\Sigma M_{E2.3.z}}{\Sigma V_{E2.3}} = -0.57\ m$$

Eccentricity Check:

$$e_{check.E2.3.z} := \begin{cases} \text{"Okay"} & \text{if } e_{E2.3.z} \le \frac{W_B}{4} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$e_{check.E2.3.z} = \text{"Okay"}$

Foundation Bearing Pressures (Z-Direction):

Bearing Pressure at Heel:

$$\sigma_{heel.E2.3.z} := \frac{\Sigma V_{E2.3}}{A_b} - \frac{\Sigma V_{E2.3} \cdot e_{E2.3.z}}{S_{bz.b}} = 146.49 \cdot \frac{kN}{m^2}$$

$$\sigma_{heel.E2.3.check.z} := \left(\begin{cases} \text{"Okay"} & \text{if } \sigma_{heel.E2.3.z} \le \sigma_{allow.E2} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} \right)$$

$\sigma_{heel.E2.3.check.z} = \text{"Okay"}$

Bearing Pressure at Toe:

$$\sigma_{toe.E2.3.z} := \frac{\Sigma V_{E2.3}}{A_b} + \frac{\Sigma V_{E2.3} \cdot e_{E2.3.z}}{S_{bz.t}} = 93.18 \cdot \frac{kN}{m^2}$$

$$\sigma_{toe.E2.3.check.z} := \begin{cases} \text{"Okay"} & \text{if } \sigma_{heel.E3.3.z} \le \sigma_{allow.E3} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$\sigma_{toe.E3.3.check.z} = \text{"Okay"}$

X-dir. Eccentricity without lateral seismic dead loads:

$$e_{E2.3.x.\sigma} := X_{mass} - \frac{\Sigma M_{E2.3.x} - \Sigma M_{Q.E2.3}}{\Sigma V_{E2.3}} = 0.01\ m$$

Z-dir. Eccentricity without lateral seismic dead loads:

$$e_{E2.3.z.\sigma} := Z_{mass} - \frac{\Sigma M_{E2.3.z} - \Sigma M_{Q.E2.3}}{\Sigma V_{E2.3}} = 0.24\ m$$

Foundation Bearing Pressure (Combined):

Linear pressure superimposed at Corners by both Moment_X and Moment_Z

Bearing Pressure at Heel(x)-Heel(z):

$$\sigma_{heel.E2.3} := \min\left(\frac{\Sigma V_{E2.3}}{A_b} - \frac{\Sigma V_{E2.3} \cdot e_{E2.3.x.\sigma}}{S_{bx.L}} - \frac{\Sigma V_{E2.3} \cdot e_{E2.3.z}}{S_{bz.b}}, \frac{\Sigma V_{E2.3}}{A_b} - \frac{\Sigma V_{E2.3} \cdot e_{E2.3.x}}{S_{bx.L}} - \frac{\Sigma V_{E2.3} \cdot e_{E2.3.z.\sigma}}{S_{bz.b}}\right) = 63.7 \cdot kPa$$

$$\sigma_{heel.E2.3.check} := \left(\begin{array}{l} \text{"Okay" if } \sigma_{heel.E2.3} \le \sigma_{allow.E2} \\ \text{"Revise Structure" otherwise} \end{array} \right)$$

$$\sigma_{heel.E2.3.check} = \text{"Okay"}$$

Bearing Pressure at Toe(x)-Toe(z):

$$\sigma_{toe.E2.3} := \min\left(\frac{\Sigma V_{E2.3}}{A_b} + \frac{\Sigma V_{E2.3} \cdot e_{E2.3.x.\sigma}}{S_{bx.R}} + \frac{\Sigma V_{E2.3} \cdot e_{E2.3.z}}{S_{bz.t}}, \frac{\Sigma V_{E2.3}}{A_b} + \frac{\Sigma V_{E2.3} \cdot e_{E2.3.x}}{S_{bx.R}} + \frac{\Sigma V_{E2.3} \cdot e_{E2.3.z.\sigma}}{S_{bz.t}}\right) = 93.49 \cdot kPa$$

$$\sigma_{toe.E2.3.check} := \begin{array}{l} \text{"Okay" if } \sigma_{toe.E2.3} \le \sigma_{allow.E2} \\ \text{"Revise Structure" otherwise} \end{array}$$

$$\sigma_{toe.E2.3.check} = \text{"Okay"}$$

Bearing Pressure at Heel(x)-Toe(z):

$$\sigma_{heeltoe.E2.3} := \min\left(\frac{\Sigma V_{E2.3}}{A_b} - \frac{\Sigma V_{E2.3} \cdot e_{E2.3.x.\sigma}}{S_{bx.L}} + \frac{\Sigma V_{E2.3} \cdot e_{E2.3.z}}{S_{bz.t}}, \frac{\Sigma V_{E2.3}}{A_b} - \frac{\Sigma V_{E2.3} \cdot e_{E2.3.x}}{S_{bx.L}} + \frac{\Sigma V_{E2.3} \cdot e_{E2.3.z.\sigma}}{S_{bz.t}}\right) = 86.04 \cdot kPa$$

$$\sigma_{heeltoe.E2.3.check} := \left(\begin{array}{l} \text{"Okay" if } \sigma_{heeltoe.E2.3} \le \sigma_{allow.E2} \\ \text{"Revise Structure" otherwise} \end{array} \right)$$

$$\sigma_{heeltoe.E2.3.check} = \text{"Okay"}$$

Bearing Pressure at Toe(x)-Heel(z):

$$\sigma_{toeheel.E2.3} := \min\left(\frac{\Sigma V_{E2.3}}{A_b} + \frac{\Sigma V_{E2.3} \cdot e_{E2.3.x.\sigma}}{S_{bx.R}} - \frac{\Sigma V_{E2.3} \cdot e_{E2.3.z}}{S_{bz.b}}, \frac{\Sigma V_{E2.3}}{A_b} + \frac{\Sigma V_{E2.3} \cdot e_{E2.3.x}}{S_{bx.R}} - \frac{\Sigma V_{E2.3} \cdot e_{E2.3.z.\sigma}}{S_{bz.b}}\right) = 146.81 \cdot kPa$$

$$\sigma_{toeheel.E2.3.check} := \begin{array}{l} \text{"Okay" if } \sigma_{toeheel.E2.3} \le \sigma_{allow.E2} \\ \text{"Revise Structure" otherwise} \end{array}$$

$$\sigma_{toeheel.E2.3.check} = \text{"Okay"}$$

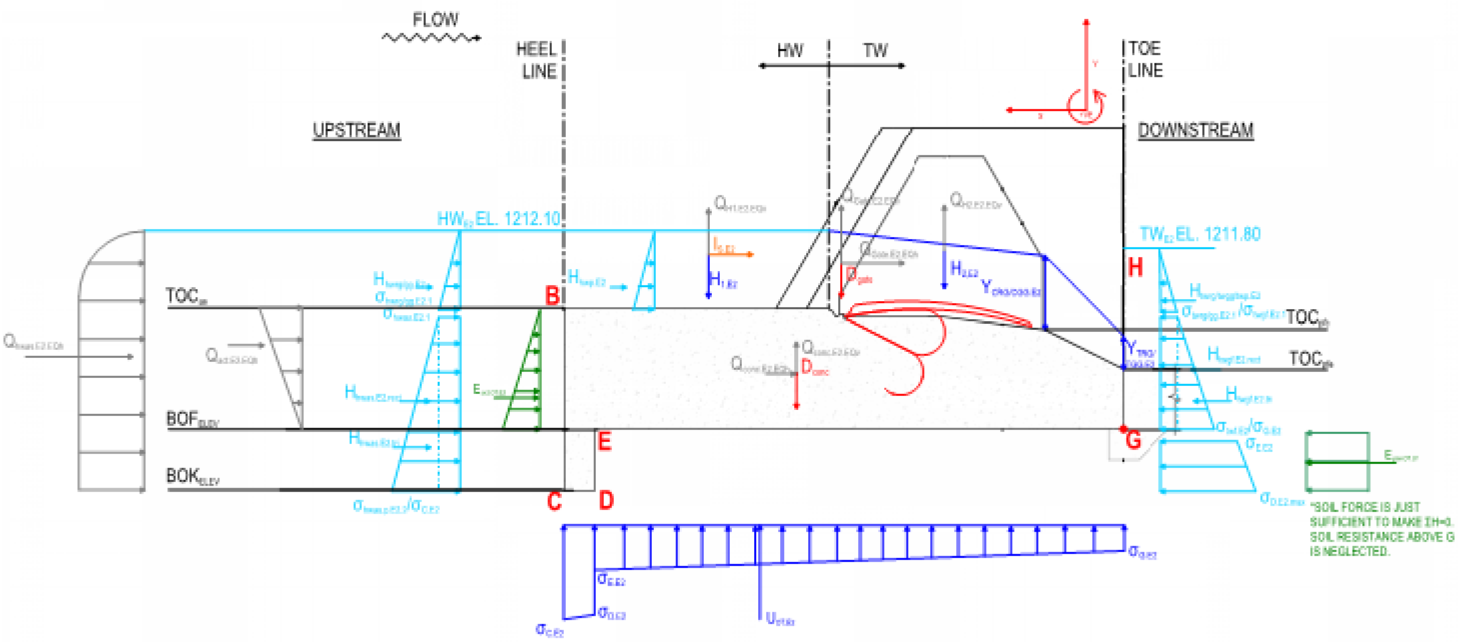
E2.3 CASE

MONOLITH OVERTURNING STABILITY ANALYSIS

Seismic Case $Q_{E2.3}$: 30% Horizontal Seismic Force, 100% Vertical

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.
Assumptions are made in order to compute overturning stability of indetermine forces on monolith with key;
(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.
(b) The horizontal resisting force acting on the key, P.key, is that required for static equilibrium
(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1 $Ratio_{overturning.allow.Extreme} = 0.25$ Resultant within Base



All Vertical Loads Applicable to Overturning Stability Analysis

Total Concrete Dead Loads: $D_{conc} = 35947.58 \cdot kN$ at: $X_{conc.loc} = 8.81\ m$

Dead Load of Gate: $D_{Gate} = 56.0 \cdot kN$ $X_{gate} = 9.50\ m$

Water Weight (HW) on Apron Slab: $H_{1.U1} = 1640.8 \cdot kN$ $H_{1.U1.loc.x} = 14.42\ m$

Water Weight (TW) on Gate Footing: $H_{2.U1} = 731.0 \cdot kN$ $H_{2.U1.loc.x} = 5.28\ m$

Uplift Load for Overtuming Analysis: $U_{OT.U1} = -17396.43 \cdot kN$ $U_{OT.U1.loc} = 9.4 \cdot m$

Vertical Seismic Component of Concrete Structure: $Q_{conc.E2.EQv.3} = -3594.76 \cdot kN$ $X_{conc.loc} = 8.81\ m$

Vertical Seismic Component of Crest Gate: $Q_{Gate.E2.EQv.3} = -5.6 \cdot kN$ $X_{gate} = 9.50\ m$

Vertical Seismic Component of Headwater over Apron Slab: $Q_{H1.E2.EQv.3} = -164.08 \cdot kN$ $H_{1.U1.loc.x} = 14.42\ m$

Vertical Seismic Component of Headwater over Fixed Crest Slab: $Q_{H2.E2.EQv.3} = -73.1 \cdot kN$ $H_{2.U1.loc.x} = 5.28\ m$

Sum of All Overturning Analysis Vertical Load:

$$\Sigma V_{E2.OT.3} := D_{conc} + D_{Gate} + H_{1.U1} + H_{2.U1} + U_{OT.U1} + \Sigma V_{Q.E2.EQv.3} = 15335.75 \cdot kN$$

Sum of All Overturning Analysis Vertical Load Moments:

$$\Sigma M_{V.E2.OT.3} := D_{conc} \cdot X_{conc.loc} + D_{Gate} \cdot X_{gate} + H_{1.U1} \cdot H_{1.U1.loc.x} + H_{2.U1} \cdot H_{2.U1.loc.x} + U_{OT.U1} \cdot U_{OT.U1.loc} = 181354.01 \cdot kN \cdot m$$

Lateral Driving Earth Loads for Overturning Stability Analysis (at rest condition)

E2.3 CASE

Depth of Driving Soil Loads (to top of key): $h_{E.OT.E2.3} := TOC_{as} - BOF_{elev} = 4\ m$

Applicable Soil Load: $E_{act.OT.E2.3} := \frac{\left(K_{o.U1} \cdot h_{E.OT.U1}\right)^2}{2} \cdot \left(\gamma_r - \gamma_w\right) \cdot W_{hwas.U1} \cdot -1 = -1026.66 \cdot kN$

At Rest- Soil Load Acting from Toe: $E_{act.OT.E2.3.loc} := \frac{h_{E.OT.U1}}{3} = 1.33\ m$

All Lateral Loads Applicable to Overturning Stability Analysis

HW Lateral Load on Approach Slab:	$H_{hwas.U1} = -2574.1 \cdot kN$	$H_{hwas.U1.loc} = 1.67\ m$
HW Lateral Load on Guard Gate:	$H_{hwgg.U1} = 0.0 \cdot kN$	$H_{hwgg.U1.loc} = 4.00\ m$
TW Lateral Load on Guard Gate:	$H_{twgg.U1} = 0.0 \cdot kN$	$H_{twgg.U1.loc} = 4.00\ m$
TW Lateral Load on Gate Footing (No Key - Overturning Values Adjusted):	$H_{twgf.U1} = 2385.79 \cdot kN$	$H_{twgf.U1.loc} = 1.65\ m$
TW Lateral Load on Key:	$H_{twkey.OT.U1} = 2219.64 \cdot kN$	$H_{twkey.OT.U1.loc} = -1.05\ m$
Ice / Impact Load:	$I_{U1} = 0.0 \cdot kN$	$I_{U1.loc.y} = 5.80\ m$
Lateral Soil Load (driving):	$E_{act.OT.U1} = -1026.7 \cdot kN$	$E_{act.OT.U1.loc} = 1.33\ m$
Horizontal Seismic Component of Concrete Structure:	$Q_{conc.E2.EQh.3} = -1797.38 \cdot kN$	$Y_{conc.loc} = 3.62\ m$
Horizontal Seismic Component of Vertical Lift Gate:	$Q_{Gate.E2.EQh.3} = -2.8 \cdot kN$	$Y_{gate} = 4.00\ m$
Horizontal Seismic Component of Headwater on Slab Footing:	$Q_{hwas.E2.EQh.3.x} = -300.36 \cdot kN$	$Y_{HWg.E2.x} = 2.44\ m$
Horizontal Seismic Component of Active Soil: (Section 5-5, USACE EM_1110-2-2100)	$Q_{act.E2.EQh.3.x} = -351.07 \cdot kN$	$Y_{E.act.E2.x} = 2.52\ m$

Resisting Lateral Soil Load as required to produce horizontal equilibrium:

$$E_{pas.OT.E2.3} := -\left(H_{hwas.U1} + H_{hwgg.U1} + H_{twgg.U1} + H_{twgf.U1} + H_{twkey.OT.U1} + I_{U1} + E_{act.OT.U1} + \Sigma H_{Q.E2.EQh.3.OT.x}\right) = -548.24 \cdot kN$$

Acting at: $E_{pas.OT.E2.3.loc} := -1 \cdot \frac{d_{key}}{2} = -1\ m$

Sum of All Overturning Analysis Horizontal Load (ΣH=0):

$$\Sigma H_{E2.OT.3} := H_{hwas.U1} + H_{hwgg.U1} + H_{twgg.U1} + H_{twgf.U1} + H_{twkey.OT.U1} + I_{U1} + E_{act.OT.U1} + E_{pas.OT.E2.3} + \Sigma H_{Q.E2.EQh.3.OT.x} = -0 \cdot kN$$

Sum of All Overturning Analysis Horizontal Load Moments:

$$\begin{aligned}\Sigma M_{H.E2.OT.3} := & H_{hwas.U1} \cdot H_{hwas.U1.loc} + H_{hwgg.U1} \cdot H_{hwgg.U1.loc} + H_{twgg.U1} \cdot H_{twgg.U1.loc} \cdots = -16138.14 \cdot kN \cdot m \\ & + H_{twgf.U1} \cdot H_{twgf.U1.loc} + H_{twkey.OT.U1} \cdot H_{twkey.OT.U1.loc} + I_{U1} \cdot I_{U1.loc.y} \cdots \\ & + E_{act.OT.U1} \cdot E_{act.OT.U1.loc} + E_{pas.OT.x.U1} \cdot E_{pas.OT.U1.loc} + \Sigma M_{Q.E2.3}\end{aligned}$$

Overturning Stability Analysis

$\Sigma M_{E2.OT.3} := \Sigma M_{V.E2.OT.3} + \Sigma M_{H.E2.OT.3} = 165215.87 \cdot kN \cdot m$

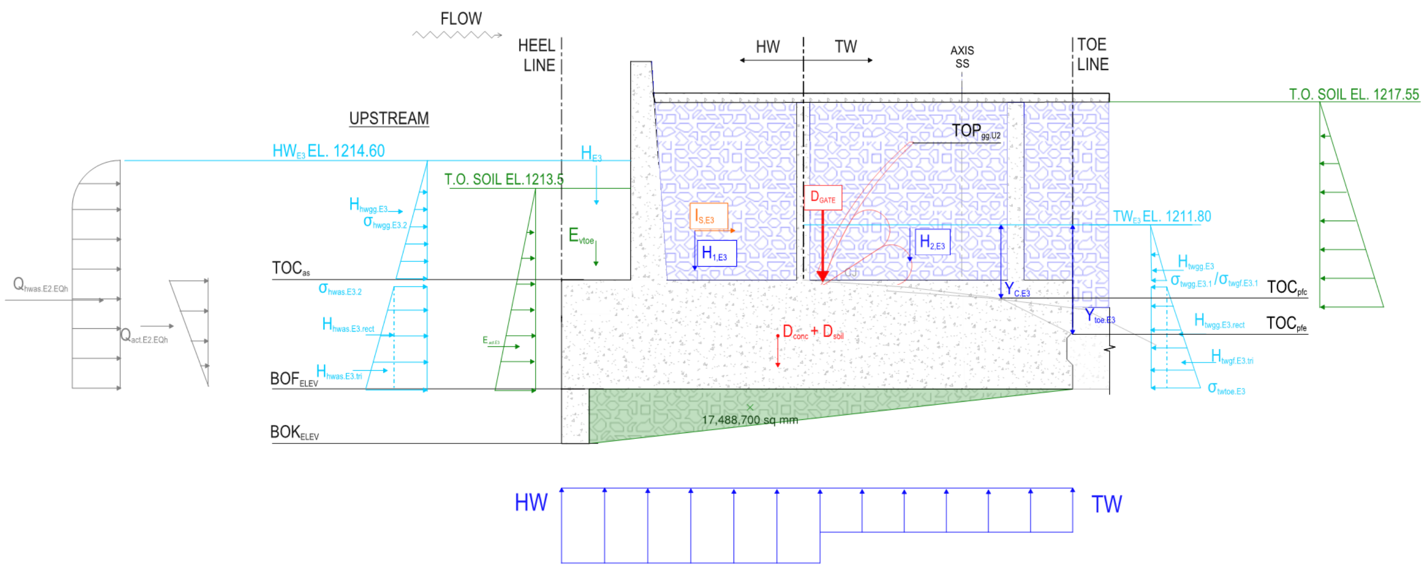
$X_{R.E2.3} := \frac{\Sigma M_{E2.OT.3}}{\Sigma V_{E2.OT.3}} = 10.77\ m$ $\quad X_{OT.E2.3} := X_{R.E2.3} - \frac{L_B}{2} = 1.52\ m$

Overturning Resultant Ratio

$Ratio_{OT.E2.3} := \frac{X_{R.E2.3}}{L_B} = 0.58$

$Ratio_{OT.E2.3.check} := \begin{cases} \text{"OKAY"} & \text{if } Ratio_{OT.E2.3} \geq Ratio_{overturning.allow.Extreme} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"OKAY"}$

E3 DESIGN CASE



U2 CASE PLUS SEISMIC

ACCEPTANCE PARAMETERS

Required Factor of Safety for Sliding: $FS_{req.E3.sl} := 1.0$ (Without Cohesion) (Section 8.1, Design Criteria)

Resultant Within Middle Half of Base: $e \le \frac{L_b}{4} \wedge e \ge \frac{-L_b}{4}$

Allowable Rock Bearing Pressure: $\sigma_{allow.E3} := 1740 \cdot \frac{kN}{m^2}$ (Section 5.2, Design Criteria)

Required Factor of Safety for Flotation: $FS_{req.E3.flt} := 1.1$

INPUT PARAMETERS

Headwater Elevation: $HW_{E3} := 1214.60m$ (Section 8.3, Design Criteria)

Tailwater Elevation: $TW_{E3} := 1211.80m$ (Section 8.3, Design Criteria)

Bottom of Footing Elevation: $BOF_{elev} = 1206.00\,m$

Approach Slab Top of Concrete Elevation at Upstream Face: $TOC_{as} = 1210.00\,m$

Abutment Footing Top of Concrete Elevation at Stilling Basin: $TOC_{afe} = 1208\,m$

Abutment Footing Top of Concrete Elevation at Footing: $TOC_{afc} = 1209.73\,m$

Abutment Footing Top of Concrete Elevation at Footing Notch: $TOC_{afc.n} = 1209.3\,m$

Gates are open when top of gate elevation is at 1210.00m

Top of Guard Gate Elevation: $TOP_{gg.E3} := 1215.0m$

Bottom of Key Elevation: $BOK_{elev} = 1204\,m$

Gates are closed/up when top of gate elevation is at 1215.0m

SEISMIC LOAD (Three combinations of E_h and E_v considered) — E3.1 CASE

Seismic Case $Q_{E3.1}$ - 100% Horizontal Seismic Force, No Vertical

Include Seismic Load in Analysis? $Eq_{E3.1} := 1$ — 0 = No, 1 = Yes

Horizontal Seismic Coefficient: $K_{h.E3.1} := -0.17$

Vertical Seismic Coefficient: $K_{v.E3.1} := -0.00$

Vertical Tailwater on Approach Slab: $H_{1.U2} = 3594.06 \cdot kN$

Acting At: $H_{1.U2.loc.x} = 14.42\ m$ $H_{1.U2.loc.z} = 4.73\ m$

Width of HW acting on Approach Slab (Z-dir.): $W_{hwas.U2.z} := 7.9m$

Width of TW acting on 1A Foundation (Z-dir.): $W_{twf.U2.z} := L_B - W_{hwas.U2.z} = 10.6\ m$

HORIZONTAL SEISMIC LOADS — **Loads** — **Moment Arm**

Horiz Seismic Component of Concrete: $Q_{conc.E3.EQh.1} := D_{conc} \cdot K_{h.E3.1} \cdot Eq_{E3.1} = -6111.1 \cdot kN$ $Y_{conc.loc} = 3.62\ m$

Horiz Seismic Component of Gates: $Q_{Gate.E3.EQh.1} := D_{Gate} \cdot K_{h.E3.1} \cdot Eq_{E3.1} = -9.5 \cdot kN$ $Y_{gate} = 4.00\ m$

Horiz Seismic Component of Fill: $Q_{fill.E3.EQh.1} := D_{fill} \cdot K_{h.E3.1} \cdot Eq_{E3.1} = -3069.6 \cdot kN$ $Y_{fill.loc} = 7.25\ m$

Horizontal Seismic Component of Headwater - Sliding (X-dir.):

$$Q_{hwas.E3.EQh.1.x} := \left(\frac{7}{12}\right) \cdot K_{h.E3.1} \cdot \gamma_w \cdot \left(HW_{U2} - BOF_{elev}\right)^2 \cdot W_{hwas.U2} \cdot Eq_{E3.1} = -1151.2 \cdot kN$$

$$Y_{HWg.E3.x} := 0.4 \cdot \left(HW_{U2} - TOC_{as}\right) + T_{as} - d_{key} = 3.84\ m$$

Horizontal Seismic Component of Headwater - Sliding (Z-dir.):

$$Q_{hwas.E3.EQh.1.z} := \left(\frac{7}{12}\right) \cdot K_{h.E3.1} \cdot \gamma_w \cdot \left(HW_{U2} - BOF_{elev}\right)^2 \cdot W_{hwas.U2.z} \cdot Eq_{E3.1} = -568.4 \cdot kN$$

$$Y_{HWg.E3.z} := Y_{HWg.E3.x} = 3.84\ m$$

Horizontal Seismic Component of Tailwater - Sliding (Z-dir.):

$$Q_{twf.E3.EQh.1.z} := \left(\frac{7}{12}\right) \cdot K_{h.E3.1} \cdot \gamma_w \cdot \left(TW_{U2} - BOF_{elev}\right)^2 \cdot W_{twf.U2.z} \cdot Eq_{E3.1} = -346.9 \cdot kN$$

$$Y_{TWg.E3.z} := 0.4 \cdot \left(TW_{U2} - BOF_{elev}\right) - d_{key} = 0.32\ m$$

Horizontal Seismic Component of Soil (Woods Method) - Overturning (X-Dir.):

$$Q_{act.E3.EQh.1.OT.x} := \left(\gamma_r - \gamma_w\right) \cdot \left(TOC_{as} - BOF_{elev}\right)^2 \cdot K_{h.E3.1} \cdot W_{hwas.U2} \cdot Eq_{E3.1} = -530.5 \cdot kN$$

$$Y_{E.act.E3.OT.x} := 0.63 \cdot \left(TOC_{as} - BOF_{elev}\right) - d_{key} = 0.52\ m$$

Horizontal Seismic Component of Soil (Woods Method X-Dir.)

$$Q_{act.E3.EQh.1.x} := \left(\gamma_r - \gamma_w\right) \cdot \left(TOC_{as} - BOF_{elev}\right)^2 \cdot K_{h.E3.1} \cdot W_{hwas.U2} \cdot Eq_{E3.1} = -530.5 \cdot kN$$

$$Y_{E.act.E3.x} := 0.63 \cdot \left(TOC_{as} - BOF_{elev}\right) = 2.52\ m$$

Horizontal Seismic Component of Soil (Woods Method Z-Dir.)

$$Q_{act.E3.EQh.1.z} := -K_{h.E3.1} \cdot \left(E_{act.a.U2.z} + E_{act.as.U2.z} \cdots + E_{act.RCC.U2.z} + E_{act.RCC.s.U2.z}\right) Eq_{E3.1} = -516.51 \cdot kN$$

$$Y_{E.act.E3.y} := \frac{\left(E_{act.a.U2.z} \cdot E_{act.a.U2.z.loc.y} + E_{act.as.U2.z} \cdot E_{act.as.U2.z.loc.y} \cdots + E_{act.RCC.U2.z} \cdot E_{act.RCC.U2.z.loc.y} \cdots + E_{act.RCC.s.U2.z} \cdot E_{act.RCC.s.U2.z.loc.y}\right) \cdot 1.909}{\left(E_{act.a.U2.z} + E_{act.as.U2.z} + E_{act.RCC.U2.z} + E_{act.RCC.s.U2.z}\right)} = 4.65\ m$$

$$\Sigma H_{Q.E3.EQh.1} := Q_{conc.E3.EQh.1} + Q_{Gate.E3.EQh.1} + Q_{fill.E3.EQh.1} = -9190.23 \cdot kN$$

$$\Sigma H_{Q.E3.EQh.1.x} := Q_{hwas.E3.EQh.1.x} + Q_{act.E3.EQh.1.x} = -1681.71 \cdot kN$$

$$\Sigma H_{Q.E3.EQh.1.OT.x} := Q_{hwas.E3.EQh.1.x} + Q_{act.E3.EQh.1.OT.x} = -1681.71 \cdot kN$$

$$\Sigma H_{Q.E3.EQh.1.z} := Q_{hwas.E3.EQh.1.z} + Q_{twf.E3.EQh.1.z} + Q_{hwas.E3.EQh.1.z} + Q_{act.E3.EQh.1.z} = -2000.21 \cdot kN$$

E3.1 CASE

VERTICAL SEISMIC LOADS	Loads	Moment Arm
Vertical Component of Concrete:	$Q_{conc.E3.EQv.1} := D_{conc} \cdot K_{v.E3.1} \cdot Eq_{E3.1} = 0.0 \cdot kN$	$X_{conc.loc} = 8.81\ m$
		$Z_{conc.loc} = 8.46\ m$
Vertical Component of Gate:	$Q_{Gate.E3.EQv.1} := D_{Gate} \cdot K_{v.E3.1} \cdot Eq_{E3.1} = 0.0 \cdot kN$	$X_{gate} = 9.50\ m$
		$Z_{gate} = 2\ m$
Vertical Component of Fill:	$Q_{fill.E3.EQv.1} := D_{fill} \cdot K_{v.E3.1} \cdot Eq_{E3.1} = 0 \cdot kN$	$X_{fill.loc} = 7.31\ m$
		$Z_{fill.loc} = 10\ m$
Vertical Seismic Component of Headwater over Apron Slab:	$Q_{H1.E3.EQv.1} := K_{v.E3.1} \cdot H_{1.U2} \cdot Eq_{E3.1} = 0.0 \cdot kN$	$H_{1.U2.loc.x} = 14.42\ m$
		$H_{1.U2.loc.z} = 4.73\ m$
Vertical Seismic Component of Tailwater over Pier Footing:	$Q_{H2.E3.EQv.1} := K_{v.E3.1} \cdot H_{2.U2} \cdot Eq_{E3.1} = 0.0 \cdot kN$	$H_{2.U2.loc.x} = 5.25\ m$
		$H_{2.U2.loc.z} = 2\ m$
Vertical Seismic Component of Soil over Approach Slab:	$Q_{E1.E3.EQv.1} := K_{v.E3.1} \cdot E_{1.U2} \cdot Eq_{E3.1} = 0 \cdot kN$	$E_{1.U2.loc.x} = 12.89\ m$

$$\Sigma V_{Q.E3.EQv.1} := Q_{conc.E3.EQv.1} + Q_{Gate.E3.EQv.1} + Q_{fill.E3.EQv.1} + Q_{H1.E3.EQv.1} + Q_{H2.E3.EQv.1} + Q_{E1.E3.EQv.1} = 0.0 \cdot kN$$

$$\Sigma M_{Q.E3.1} := Q_{conc.E3.EQh.1} \cdot Y_{conc.loc} + Q_{Gate.E3.EQh.1} \cdot Y_{gate} + Q_{fill.E3.EQh.1} \cdot Y_{fill.loc} = -44442.66 \cdot kN \cdot m$$

$$\begin{aligned}\Sigma M_{Q.E3.1.x} := {} & Q_{conc.E3.EQh.1} \cdot Y_{conc.loc} + Q_{Gate.E3.EQh.1} \cdot Y_{gate} + Q_{fill.E3.EQh.1} \cdot Y_{fill.loc} + Q_{hwas.E3.EQh.1.x} \cdot Y_{HWg.E3.x} \cdots \\ & + Q_{act.E3.EQh.1.x} \cdot Y_{E.act.E3.x} + Q_{conc.E3.EQv.1} \cdot X_{conc.loc} + Q_{Gate.E3.EQv.1} \cdot X_{gate} + Q_{fill.E3.EQv.1} \cdot X_{fill.loc} \cdots \\ & + Q_{H1.E3.EQv.1} \cdot H_{1.U2.loc.x} + Q_{H2.E3.EQv.1} \cdot H_{2.U2.loc.x} + Q_{E1.E3.EQv.1} \cdot E_{1.U2.loc.x} = -50200.16 \cdot kN \cdot m\end{aligned}$$

$$\begin{aligned}\Sigma M_{Q.E3.1.x.OT} := {} & Q_{conc.E3.EQh.1} \cdot Y_{conc.loc} + Q_{Gate.E3.EQh.1} \cdot Y_{gate} + Q_{fill.E3.EQh.1} \cdot Y_{fill.loc} \cdots \\ & + Q_{hwas.E3.EQh.1.x} \cdot Y_{HWg.E3.x} + Q_{act.E3.EQh.1.OT.x} \cdot Y_{E.act.E3.OT.x} \cdots \\ & + Q_{conc.E3.EQv.1} \cdot X_{conc.loc} + Q_{Gate.E3.EQv.1} \cdot X_{gate} + Q_{fill.E3.EQv.1} \cdot X_{fill.loc} \cdots \\ & + Q_{H1.E3.EQv.1} \cdot H_{1.U2.loc.x} + Q_{H2.E3.EQv.1} \cdot H_{2.U2.loc.x} + Q_{E1.E3.EQv.1} \cdot E_{1.U2.loc.x} = -49139.14 \cdot kN \cdot m\end{aligned}$$

$$\begin{aligned}\Sigma M_{Q.E3.1.z} := {} & Q_{conc.E3.EQh.1} \cdot Y_{conc.loc} + Q_{Gate.E3.EQh.1} \cdot Y_{gate} + Q_{fill.E3.EQh.1} \cdot Y_{fill.loc} + Q_{hwas.E3.EQh.1.z} \cdot Y_{HWg.E3.z} \cdots \\ & + Q_{twf.E3.EQh.1.z} \cdot Y_{TWg.E3.z} + Q_{conc.E3.EQv.1} \cdot Z_{conc.loc} + Q_{Gate.E3.EQv.1} \cdot Z_{gate} + Q_{fill.E3.EQv.1} \cdot Z_{fill.loc} \cdots \\ & + Q_{H1.E3.EQv.1} \cdot H_{1.U2.loc.z} + Q_{H2.E3.EQv.1} \cdot H_{2.U2.loc.z} + Q_{E1.E3.EQv.1} \cdot E_{1.U2.loc.z} = -46736.34 \cdot kN \cdot m\end{aligned}$$

STABILITY ASSESSMENT (SLIDNG, BEARING, FLOTATION AND OVERTURNING): E3.1 CASE

CHECK SLIDING ALONG HORIZONTAL PLANE THRU TOE, IGNORING BEDROCK MOBILIZED BY STRUCTURAL HEEL KEY, OR VOID BEHIND KEY

Sum of Vertical Forces:

$\Sigma V_{E3.1} := \Sigma V_{U2} + \Sigma V_{Q.E3.EQv.1} = 38160.6 \cdot kN$

Sum of Horizontal Forces (X-Direction):

$\Sigma H_{E3.1.x} := \Sigma H_{Water.U2.x} + \Sigma H_{soil.U2.x} + \Sigma H_{Q.E3.EQh.1.x} = -2992.42 \cdot kN$

Sum of Horizontal Forces (Z-Direction):

$\Sigma H_{E3.1.z} := \Sigma H_{Water.U2.z} + \Sigma H_{soil.U2.z} + \Sigma H_{Q.E3.EQh.1.z} = -5038.48 \cdot kN$

Sum of Horizontal Forces (Resultant):

$$\Sigma H_{E3.1} := \sqrt{\Sigma H_{E3.1.z}^{\ 2} + \Sigma H_{E3.1.x}^{\ 2}} = 5860.11 \cdot kN$$

Sliding Factor of Safety:

$$FS_{HorizSliding.E3.1.x} := \frac{\tan_\phi \cdot \Sigma V_{E3.1}}{\left|\Sigma H_{E3.1.x} + \Sigma H_{Q.E3.EQh.1}\right|} = 1.53$$

Sliding Factor of Safety:

$$FS_{HorizSliding.E3.1.z} := \frac{\tan_\phi \cdot \Sigma V_{E3.1}}{\left|\Sigma H_{E3.1.z} + \Sigma H_{Q.E3.EQh.1}\right|} = 1.31$$

Sliding Factor of Safety (Resultant):

$$FS_{HorizSliding.E3.1} := \frac{\tan_\phi \cdot \Sigma V_{E3.1}}{\Sigma H_{E3.1} + \left|\Sigma H_{Q.E3.EQh.1}\right|} = 1.24$$

$FS_{HorizSliding.E3.1.Check} :=$ "OKAY" if $FS_{HorizSliding.E3.1} \geq FS_{req.E3.sl}$ = "OKAY"
"Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !" otherwise

FLOATATION ANALYSIS:

ACCEPTANCE PARAMETERS

Required Factor of Safety: $FS_{req.FE3} := 1.0$

VERTICAL LOADS RESISTING:

Dead Load: $\Sigma V_{DL} = 54060.17 \cdot kN$

Water Weight H1+H2: $\Sigma V_{H.FE3.1} := H_{1.E1} + H_{2.E1} = 7447.34 \cdot kN$

Summation Vertical Resisting: $\Sigma V_{FE3.1} := \Sigma V_{U2} + \Sigma V_{Q.E3.EQv.1} = 38160.6 \cdot kN$

VERTICAL LOADS UPLIFT:

Uplift: $U_{U2} = -20816.49 \cdot kN$

Factor of Safety Floatation:

$$FS_{act.FE3.1} := \frac{\Sigma V_{FE3.1}}{\left|U_{U2}\right|} = 1.83$$

$FS_{check.FE3.1} :=$ "OKAY" if $FS_{act.FE3.1} \geq FS_{req.FE3}$ = "OKAY"
"ANCHORS REQUIRED" if $FS_{act.FE3.1} < FS_{req.FE3}$

CHECK FOUNDATION BEARING CAPACITY

E3.1 CASE

Sum of the Moments (X-Direction):

$$\Sigma M_{E3.1.x} := \Sigma M_{U2.x} - \Sigma M_{I.U2} + \Sigma M_{Q.E3.1.x} = 248393 \cdot kN \cdot m$$

Eccentricity:

$$e_{E3.1.x} := X_{BCG} - \frac{\Sigma M_{E3.1.x}}{\Sigma V_{E3.1}} = 2.47\ m$$

Eccentricity Check:

$$e_{check.E3.1.x} := \begin{cases} \text{"Okay"} & \text{if } e_{E3.1.x} \le \frac{L_B}{4} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$e_{check.E3.1.x} = \text{"Okay"}$

Foundation Bearing Pressures (X-Direction):

Bearing Pressure at Heel:

$$\sigma_{heel.E3.1.x} := \frac{\Sigma V_{E3.1}}{A_b} - \frac{\Sigma V_{E3.1} \cdot e_{E3.1.x}}{S_{bx.L}} = 18.58 \cdot \frac{kN}{m^2}$$

$$\sigma_{heel.E3.1.check.x} := \left(\begin{cases} \text{"Okay"} & \text{if } 0 \le \sigma_{heel.E3.1.x} \le \sigma_{allow.E3} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} \right)$$

$\sigma_{heel.E3.1.check.x} = \text{"Okay"}$

Bearing Pressure at Toe:

$$\sigma_{toe.E3.1.x} := \frac{\Sigma V_{E3.1}}{A_b} + \frac{\Sigma V_{E3.1} \cdot e_{E3.1.x}}{S_{bx.R}} = 241.77 \cdot \frac{kN}{m^2}$$

$$\sigma_{toe.E3.1.check.x} := \begin{cases} \text{"Okay"} & \text{if } 0 \le \sigma_{toe.E3.1.x} \le \sigma_{allow.E3} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$\sigma_{toe.E3.1.check.x} = \text{"Okay"}$

Sum of the Moments (Z-Direction):

$$\Sigma M_{E3.1.z} := \Sigma M_{U2.z} - \Sigma M_{Q.E3.1.z} = 372156 \cdot kN \cdot m$$

Eccentricity:

$$e_{E3.1.z} := Z_{BCG} - \frac{\Sigma M_{E3.1.z}}{\Sigma V_{E3.1}} = -1.98\ m$$

Eccentricity Check:

$$e_{check.E3.1.z} := \begin{cases} \text{"Okay"} & \text{if } e_{E3.1.z} \le \frac{W_B}{4} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$e_{check.E3.1.z} = \text{"Okay"}$

Foundation Bearing Pressures (Z-Direction):

Bearing Pressure at Heel:

$$\sigma_{heel.E3.1.z} := \frac{\Sigma V_{E3.1}}{A_b} - \frac{\Sigma V_{E3.1} \cdot e_{E3.1.z}}{S_{bz.b}} = 239.73 \cdot \frac{kN}{m^2}$$

$$\sigma_{heel.E3.1.check.z} := \left(\begin{cases} \text{"Okay"} & \text{if } 0 \le \sigma_{heel.E3.1.z} \le \sigma_{allow.E3} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} \right)$$

$\sigma_{heel.E3.1.check.z} = \text{"Okay"}$

Bearing Pressure at Toe:

$$\sigma_{toe.E3.1.z} := \frac{\Sigma V_{E3.1}}{A_b} + \frac{\Sigma V_{E3.1} \cdot e_{E3.1.z}}{S_{bz.t}} = 33.19 \cdot \frac{kN}{m^2}$$

$$\sigma_{toe.E3.1.check.z} := \begin{cases} \text{"Okay"} & \text{if } 0 \le \sigma_{heel.E3.1.z} \le \sigma_{allow.E3} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$\sigma_{toe.E3.1.check.z} = \text{"Okay"}$

Foundation Bearing Pressure (Combined):

Linear pressure superimposed at Corners by both Moment_X and Moment_Z not considered in seismic case

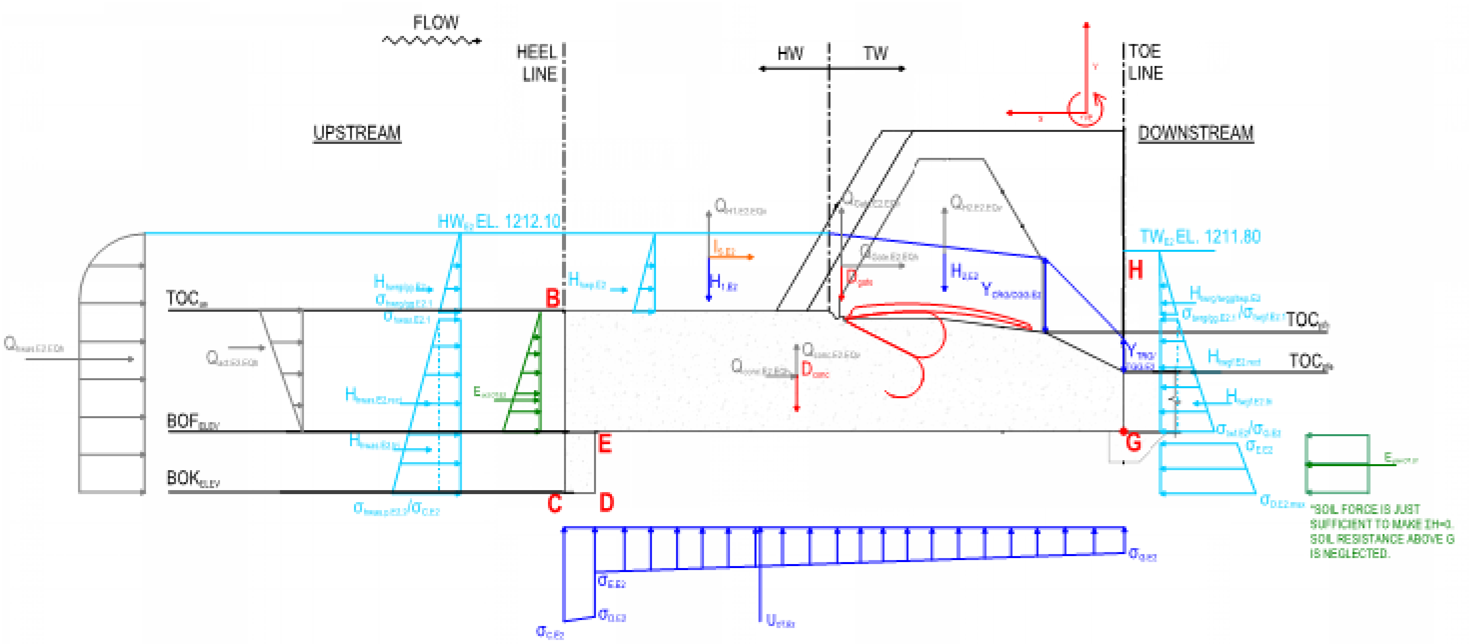
E3.1 CASE

MONOLITH OVERTURNING STABILITY ANALYSIS

Seismic Case $Q_{E3.1}$: 100% Horizontal Seismic Force, No Vertical

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.
Assumptions are made in order to compute overturning stability of indetermine forces on monolith with key;
(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.
(b) The horizontal resisting force acting on the key, P.key, is that required for static equilibrium
(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1 $Ratio_{overturning.allow.Extreme} = 0.25$ Resultant within Base



All Vertical Loads Applicable to Overturning Stability Analysis

Total Concrete Dead Loads:	$D_{conc} = 35947.58 \cdot kN$	at:	$X_{conc.loc} = 8.81\ m$
Dead Load of Gate:	$D_{Gate} = 56.0 \cdot kN$		$X_{gate} = 9.50\ m$
Water Weight (HW) on Apron Slab:	$H_{1.U2} = 3594.1 \cdot kN$		$H_{1.U2.loc.x} = 14.42\ m$
Water Weight (TW) on Gate Footing:	$H_{2.U2} = 1322.9 \cdot kN$		$H_{2.U2.loc.x} = 5.25\ m$
Uplift Load for Overtuming Analysis:	$U_{OT.U2} = -20710.3 \cdot kN$		$U_{OT.U2.loc} = 9.88 \cdot m$
Vertical Seismic Component of Concrete Structure:	$Q_{conc.E3.EQv.1} = 0 \cdot kN$		$X_{conc.loc} = 8.81\ m$
Vertical Seismic Component of Crest Gate:	$Q_{Gate.E3.EQv.1} = 0 \cdot kN$		$X_{gate} = 9.50\ m$
Vertical Seismic Component of Headwater over Apron Slab:	$Q_{H1.E3.EQv.1} = 0 \cdot kN$		$H_{1.U2.loc.x} = 14.42\ m$
Vertical Seismic Component of Headwater over Fixed Crest Slab:	$Q_{H2.E3.EQv.1} = 0 \cdot kN$		$H_{2.U2.loc.x} = 5.25\ m$

Sum of All Overturning Analysis Vertical Load:

$$\Sigma V_{E3.OT.1} := D_{conc} + D_{Gate} + H_{1.U2} + H_{2.U2} + U_{OT.U2} + \Sigma V_{Q.E3.EQv.1} = 20210.22 \cdot kN$$

Sum of All Overturning Analysis Vertical Load Moments:

$$\Sigma M_{V.E3.OT.1} := D_{conc} \cdot X_{conc.loc} + D_{Gate} \cdot X_{gate} + H_{1.U2} \cdot H_{1.U2.loc.x} + H_{2.U2} \cdot H_{2.U2.loc.x} + U_{OT.U2} \cdot U_{OT.U2.loc} = 171520.21 \cdot kN \cdot m$$

Lateral Driving Earth Loads for Overturning Stability Analysis (at rest condition)

E3.1 CASE

Depth of Driving Soil Loads (to top of key): $h_{E.OT.E3.1} := TOC_{as} - BOF_{elev} = 4\ m$

Applicable Soil Load: $E_{act.OT.E3.1} := \frac{\left(K_{o.U2} \cdot h_{E.OT.U2}\right)^2}{2} \cdot \left(\gamma_r - \gamma_w\right) \cdot W_{hwas.U2} \cdot -1 = -1026.66 \cdot kN$

At Rest- Soil Load Acting from Toe: $E_{act.OT.E3.1.loc} := \frac{h_{E.OT.U2}}{3} = 1.33\ m$

All Lateral Loads Applicable to Overturning Stability Analysis

HW Lateral Load on Approach Slab:	$H_{hwas.U2} = -4143.7 \cdot kN$	$H_{hwas.U2.loc} = 1.80\ m$
HW Lateral Load on Guard Gate:	$H_{hwgg.U2} = -415.2 \cdot kN$	$H_{hwgg.U2.loc} = 5.53\ m$
TW Lateral Load on Guard Gate:	$H_{twgg.U2} = 63.6 \cdot kN$	$H_{twgg.U2.loc} = 4.60\ m$
TW Lateral Load on Gate Footing (No Key - Overturning Values Adjusted):	$H_{twgf.U2} = 2385.79 \cdot kN$	$H_{twgf.U2.loc} = 1.65\ m$
TW Lateral Load on Key:	$H_{twkey.OT.U2} = 2927.88 \cdot kN$	$H_{twkey.OT.U2.loc} = -1.04\ m$
Ice / Impact Load:	$I_{U2} = 0.0 \cdot kN$	$I_{U2.loc.y} = 8.30\ m$
Lateral Soil Load (driving):	$E_{act.OT.U2} = -1026.7 \cdot kN$	$E_{act.OT.U2.loc} = 1.33\ m$
Horizontal Seismic Component of Concrete Structure:	$Q_{conc.E3.EQh.1} = -6111.09 \cdot kN$	$Y_{conc.loc} = 3.62\ m$
Horizontal Seismic Component of Vertical Lift Gate:	$Q_{Gate.E3.EQh.1} = -9.52 \cdot kN$	$Y_{gate} = 4.00\ m$
Horizontal Seismic Component of Headwater on Slab Footing:	$Q_{hwas.E3.EQh.1.x} = -1151.2 \cdot kN$	$Y_{HWg.E3.x} = 3.84\ m$
Horizontal Seismic Component of Active Soil: (Section 5-5, USACE EM_1110-2-2100)	$Q_{act.E3.EQh.1.x} = -530.51 \cdot kN$	$Y_{E.act.E3.x} = 2.52\ m$

Resisting Lateral Soil Load as required to produce horizontal equilibrium:

$$E_{pas.OT.E3.1} := -\left(H_{hwas.U2} + H_{hwgg.U2} + H_{twgg.U2} + H_{twgf.U2} + H_{twkey.OT.U2} + I_{U2} + E_{act.OT.U2} + \Sigma H_{Q.E3.EQh.1.OT.x}\right) = 1890.03 \cdot kN$$

Acting a $E_{pas.OT.E3.1.loc} := -1 \cdot \frac{d_{key}}{2} = -1\ m$

Sum of All Overturning Analysis Horizontal Load (ΣH=0):

$$\Sigma H_{E3.OT.1} := H_{hwas.U2} + H_{hwgg.U2} + H_{twgg.U2} + H_{twgf.U2} + H_{twkey.OT.U2} + I_{U2} + E_{act.OT.U2} + E_{pas.OT.E3.1} + \Sigma H_{Q.E3.EQh.1.OT.x} = 0 \cdot kN$$

Sum of All Overturning Analysis Horizontal Load Moments:

$$\Sigma M_{H.E3.OT.1} := H_{hwas.U2} \cdot H_{hwas.U2.loc} + H_{hwgg.U2} \cdot H_{hwgg.U2.loc} + H_{twgg.U2} \cdot H_{twgg.U2.loc} \cdots + H_{twgf.U2} \cdot H_{twgf.U2.loc} + H_{twkey.OT.U2} \cdot H_{twkey.OT.U2.loc} + I_{U2} \cdot I_{U2.loc.y} \cdots + E_{act.OT.U2} \cdot E_{act.OT.U2.loc} + E_{pas.OT.x.U2} \cdot E_{pas.OT.U2.loc} + \Sigma M_{Q.E3.1} = -55002.53 \cdot kN \cdot m$$

Overturning Stability Analysis

$$\Sigma M_{E3.OT.1} := \Sigma M_{V.E3.OT.1} + \Sigma M_{H.E3.OT.1} = 116517.68 \cdot kN \cdot m$$

$$X_{R.E3.1} := \frac{\Sigma M_{E3.OT.1}}{\Sigma V_{E3.OT.1}} = 5.77\ m \qquad x_{OT.E3.1} := X_{R.E3.1} - \frac{L_B}{2} = -3.48\ m$$

Overturning Resultant Ratio

$$Ratio_{OT.E3.1} := \frac{X_{R.E3.1}}{L_B} = 0.31$$

$$Ratio_{OT.E3.1.check} := \begin{cases} \text{"OKAY"} & \text{if } Ratio_{OT.E3.1} \geq Ratio_{overturning.allow.Extreme} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

SEISMIC LOAD (Three combinations of E_h and E_v considered)

E3.2 CASE

Seismic Case $Q_{E3.2}$ - 100% Horizontal Seismic Force, 30% Vertical

Include Seismic Load in Analysis? $Eq_{E3.2} := 1$ 0 = No, 1 = Yes

Horizontal Seismic Coefficient: $K_{h.E3.2} := -0.17$

Vertical Seismic Coefficient: $K_{v.E3.2} := -0.03$

Vertical Tailwater on Approach Slab: $H_{1.U2} = 3594.06 \cdot kN$

Acting At: $H_{1.U2.loc.x} = 14.42\ m$ $H_{1.U2.loc.z} = 4.73\ m$

Width of HW acting on Approach Slab (Z-dir.): $W_{hwas.U2.z} = 7.9\ m$

Width of TW acting on 1A Foundation (Z-dir.): $W_{twf.U2.z} = 10.6\ m$

HORIZONTAL SEISMIC LOADS — **Loads** — **Moment Arm**

Horiz Seismic Component of Concrete: $Q_{conc.E3.EQh.2} := D_{conc} \cdot K_{h.E3.2} \cdot Eq_{E3.2} = -6111.1 \cdot kN$ $Y_{conc.loc} = 3.62\ m$

Horiz Seismic Component of Gates: $Q_{Gate.E3.EQh.2} := D_{Gate} \cdot K_{h.E3.2} \cdot Eq_{E3.2} = -9.5 \cdot kN$ $Y_{gate} = 4.00\ m$

Horiz Seismic Component of Fill: $Q_{fill.E3.EQh.2} := D_{fill} \cdot K_{h.E3.2} \cdot Eq_{E3.2} = -3069.6 \cdot kN$ $Y_{fill.loc} = 7.25\ m$

Horizontal Seismic Component of Headwater - Sliding (X-dir.):

$$Q_{hwas.E3.EQh.2.x} := \left(\frac{7}{12}\right) \cdot K_{h.E3.2} \cdot \gamma_w \cdot \left(HW_{U2} - BOK_{elev}\right)^2 \cdot W_{hwas.U2} \cdot Eq_{E3.2} = -1748.9 \cdot kN$$

$Y_{HWg.E3.x} = 3.84\ m$

Horizontal Seismic Component of Headwater - Sliding (Z-dir.):

$$Q_{hwas.E3.EQh.2.z} := \left(\frac{7}{12}\right) \cdot K_{h.E3.2} \cdot \gamma_w \cdot \left(HW_{U2} - BOK_{elev}\right)^2 \cdot W_{hwas.U2.z} \cdot Eq_{E3.2} = -863.5 \cdot kN$$

$Y_{HWg.E3.z} = 3.84\ m$

Horizontal Seismic Component of Tailwater - Sliding (Z-dir.):

$$Q_{twf.E3.EQh.2.z} := \left(\frac{7}{12}\right) \cdot K_{h.E3.2} \cdot \gamma_w \cdot \left(TW_{U2} - BOK_{elev}\right)^2 \cdot W_{twf.U2.z} \cdot Eq_{E3.2} = -627.4 \cdot kN$$

$Y_{TWg.E3.z} = 0.32\ m$

Horizontal Seismic Component of Soil (Woods Method) - Overturning (X-Dir.):

$$Q_{act.E3.EQh.2.OT.x} := \left(\gamma_r - \gamma_w\right) \cdot \left(TOC_{as} - BOF_{elev}\right)^2 \cdot K_{h.E3.2} \cdot W_{hwas.U2} \cdot Eq_{E3.2} = -530.5 \cdot kN$$

$Y_{E.act.E3.OT.x} = 0.52\ m$

Horizontal Seismic Component of Soil (Woods Method X-Dir.)

$$Q_{act.E3.EQh.2.x} := \left(\gamma_r - \gamma_w\right) \cdot \left(TOC_{as} - BOK_{elev}\right)^2 \cdot K_{h.E3.2} \cdot W_{hwas.U2} \cdot Eq_{E3.2} = -1193.6 \cdot kN$$

$Y_{E.act.E3.x} = 2.52\ m$

Horizontal Seismic Component of Soil (Woods Method Z-Dir.)

$$Q_{act.E3.EQh.2.z} := -K_{h.E3.2} \cdot \left(E_{act.a.U2.z} + E_{act.as.U2.z} \cdots + E_{act.RCC.U2.z} + E_{act.RCC.s.U2.z}\right) Eq_{E3.2} = -516.51 \cdot kN$$

$Y_{E.act.E3.y} = 4.65\ m$

$$\Sigma H_{Q.E3.EQh.2} := Q_{conc.E3.EQh.2} + Q_{Gate.E3.EQh.2} + Q_{fill.E3.EQh.2} = -9190.23 \cdot kN$$

$$\Sigma H_{Q.E3.EQh.2.x} := Q_{hwas.E3.EQh.2.x} + Q_{act.E3.EQh.2.x} = -2942.55 \cdot kN$$

$$\Sigma H_{Q.E3.EQh.2.OT.x} := Q_{hwas.E3.EQh.2.x} + Q_{act.E3.EQh.2.OT.x} = -2279.41 \cdot kN$$

$$\Sigma H_{Q.E3.EQh.2.z} := Q_{hwas.E3.EQh.2.z} + Q_{twf.E3.EQh.2.z} + Q_{hwas.E3.EQh.2.z} + Q_{act.E3.EQh.2.z} = -2870.93 \cdot kN$$

E3.2 CASE

VERTICAL SEISMIC LOADS	Loads	Moment Arm
Vertical Component of Concrete:	$Q_{conc.E3.EQv.2} := D_{conc} \cdot K_{v.E3.2} \cdot Eq_{E3.2} = -1078.4 \cdot kN$	$X_{conc.loc} = 8.81\ m$
		$Z_{conc.loc} = 8.46\ m$
Vertical Component of Gate:	$Q_{Gate.E3.EQv.2} := D_{Gate} \cdot K_{v.E3.2} \cdot Eq_{E3.2} = -1.7 \cdot kN$	$X_{gate} = 9.50\ m$
		$Z_{gate} = 2\ m$
Vertical Component of Fill:	$Q_{fill.E3.EQv.2} := D_{fill} \cdot K_{v.E3.2} \cdot Eq_{E3.2} = -541.7 \cdot kN$	$X_{fill.loc} = 7.31\ m$
		$Z_{fill.loc} = 10\ m$
Vertical Seismic Component of Headwater over Apron Slab:	$Q_{H1.E3.EQv.2} := K_{v.E3.2} \cdot H_{1.U2} \cdot Eq_{E3.2} = -107.8 \cdot kN$	$H_{1.U2.loc.x} = 14.42\ m$
		$H_{1.U2.loc.z} = 4.73\ m$
Vertical Seismic Component of Tailwater over Pier Footing:	$Q_{H2.E3.EQv.2} := K_{v.E3.2} \cdot H_{2.U2} \cdot Eq_{E3.2} = -39.7 \cdot kN$	$H_{2.U2.loc.x} = 5.25\ m$
		$H_{2.U2.loc.z} = 2\ m$
Vertical Seismic Component of Soil over Approach Slab:	$Q_{E1.E3.EQv.2} := K_{v.E3.2} \cdot E_{1.U2} \cdot Eq_{E3.2} = 0 \cdot kN$	$E_{1.U2.loc.x} = 12.89\ m$

$$\Sigma V_{Q.E3.EQv.2} := Q_{conc.E3.EQv.2} + Q_{Gate.E3.EQv.2} + Q_{fill.E3.EQv.2} + Q_{H1.E3.EQv.2} + Q_{H2.E3.EQv.2} + Q_{E1.E3.EQv.2} = -1769.3 \cdot kN$$

$$\Sigma M_{Q.E3.2} := Q_{conc.E3.EQh.2} \cdot Y_{conc.loc} + Q_{Gate.E3.EQh.2} \cdot Y_{gate} + Q_{fill.E3.EQh.2} \cdot Y_{fill.loc} = -44442.66 \cdot kN \cdot m$$

$$\begin{aligned}\Sigma M_{Q.E3.2.x} := {} & Q_{conc.E3.EQh.2} \cdot Y_{conc.loc} + Q_{Gate.E3.EQh.2} \cdot Y_{gate} + Q_{fill.E3.EQh.2} \cdot Y_{fill.loc} + Q_{hwas.E3.EQh.2.x} \cdot Y_{HWg.E3.x} \cdots = -69409.77 \cdot kN \cdot m \\ & + Q_{act.E3.EQh.2.x} \cdot Y_{E.act.E3.x} + Q_{conc.E3.EQv.2} \cdot X_{conc.loc} + Q_{Gate.E3.EQv.2} \cdot X_{gate} + Q_{fill.E3.EQv.2} \cdot X_{fill.loc} \cdots \\ & + Q_{H1.E3.EQv.2} \cdot H_{1.U2.loc.x} + Q_{H2.E3.EQv.2} \cdot H_{2.U2.loc.x} + Q_{E1.E3.EQv.2} \cdot E_{1.U2.loc.x}\end{aligned}$$

$$\begin{aligned}\Sigma M_{Q.E3.2.x.OT} := {} & Q_{conc.E3.EQh.2} \cdot Y_{conc.loc} + Q_{Gate.E3.EQh.2} \cdot Y_{gate} + Q_{fill.E3.EQh.2} \cdot Y_{fill.loc} \cdots = -66677.65 \cdot kN \cdot m \\ & + Q_{hwas.E3.EQh.2.x} \cdot Y_{HWg.E3.x} + Q_{act.E3.EQh.2.OT.x} \cdot Y_{E.act.E3.OT.x} \cdots \\ & + Q_{conc.E3.EQv.2} \cdot X_{conc.loc} + Q_{Gate.E3.EQv.2} \cdot X_{gate} + Q_{fill.E3.EQv.2} \cdot X_{fill.loc} \cdots \\ & + Q_{H1.E3.EQv.2} \cdot H_{1.U2.loc.x} + Q_{H2.E3.EQv.2} \cdot H_{2.U2.loc.x} + Q_{E1.E3.EQv.2} \cdot E_{1.U2.loc.x}\end{aligned}$$

$$\begin{aligned}\Sigma M_{Q.E3.2.z} := {} & Q_{conc.E3.EQh.2} \cdot Y_{conc.loc} + Q_{Gate.E3.EQh.2} \cdot Y_{gate} + Q_{fill.E3.EQh.2} \cdot Y_{fill.loc} + Q_{hwas.E3.EQh.2.z} \cdot Y_{HWg.E3.z} \cdots = -63092.87 \cdot kN \cdot m \\ & + Q_{twf.E3.EQh.2.z} \cdot Y_{TWg.E3.z} + Q_{conc.E3.EQv.2} \cdot Z_{conc.loc} + Q_{Gate.E3.EQv.2} \cdot Z_{gate} + Q_{fill.E3.EQv.2} \cdot Z_{fill.loc} \cdots \\ & + Q_{H1.E3.EQv.2} \cdot H_{1.U2.loc.z} + Q_{H2.E3.EQv.2} \cdot H_{2.U2.loc.z} + Q_{E1.E3.EQv.2} \cdot E_{1.U2.loc.z}\end{aligned}$$

STABILITY ASSESSMENT (SLIDNG, BEARING, FLOTATION AND OVERTURNING): E3.2 CASE

CHECK SLIDING ALONG HORIZONTAL PLANE THRU TOE, IGNORING BEDROCK MOBILIZED BY STRUCTURAL HEEL KEY, OR VOID BEHIND KEY

Sum of Vertical Forces:

$$\Sigma V_{E3.2} := \Sigma V_{U2} + \Sigma V_{Q.E3.EQv.2} = 36391.3 \cdot kN$$

Sum of Horizontal Forces (X-Direction):

$$\Sigma H_{E3.2.x} := \Sigma H_{Water.U2.x} + \Sigma H_{soil.U2.x} + \Sigma H_{Q.E3.EQh.2.x} = -4253.26 \cdot kN$$

Sum of Horizontal Forces (Z-Direction):

$$\Sigma H_{E3.2.z} := \Sigma H_{Water.U2.z} + \Sigma H_{soil.U2.z} + \Sigma H_{Q.E3.EQh.2.z} = -5909.2 \cdot kN$$

Sum of Horizontal Forces (Resultant):

$$\Sigma H_{E3.2} := \sqrt{\Sigma H_{E3.2.z}^{\ 2} + \Sigma H_{E3.2.x}^{\ 2}} = 7280.72 \cdot kN$$

Sliding Factor of Safety (Single Axis):

$$FS_{HorizSliding.E3.2.x} := \frac{\tan_{\phi} \cdot \Sigma V_{E3.2}}{\left|\Sigma H_{E3.2.x} + \Sigma H_{Q.E3.EQh.2}\right|} = 1.32$$

$$FS_{HorizSliding.E3.2.z} := \frac{\tan_{\phi} \cdot \Sigma V_{E3.2}}{\left|\Sigma H_{E3.2.z} + \Sigma H_{Q.E3.EQh.2}\right|} = 1.18$$

Sliding Factor of Safety (Resultant):

$$FS_{HorizSliding.E3.2} := \frac{\tan_{\phi} \cdot \Sigma V_{E3.2}}{\Sigma H_{E3.2} + \left|\Sigma H_{Q.E3.EQh.2}\right|} = 1.08$$

$$FS_{HorizSliding.E3.2.Check} := \begin{cases} \text{"OKAY"} & \text{if } FS_{HorizSliding.E3.2} \ge FS_{req.E3.sl} \\ \text{"Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

FLOATATION ANALYSIS:

ACCEPTANCE PARAMETERS

Required Factor of Safety: $FS_{req.FE3} = 1$

VERTICAL LOADS RESISTING:

Dead Load: $\Sigma V_{DL} = 54060.17 \cdot kN$

Water Weight H1+H2: $\Sigma V_{H.FE3.2} := H_{1.U2} + H_{2.U2} = 4916.94 \cdot kN$

Summation Vertical Resisting: $\Sigma V_{FE3.2} := \Sigma V_{U2} + \Sigma V_{Q.E3.EQv.2} = 36391.3 \cdot kN$

VERTICAL LOADS UPLIFT:

Uplift: $U_{U2} = -20816.49 \cdot kN$

Factor of Safety Floatation:

$$FS_{act.FE3.2} := \frac{\Sigma V_{FE3.2}}{\left|U_{U2}\right|} = 1.75$$

$$FS_{check.FE3.2} := \begin{cases} \text{"OKAY"} & \text{if } FS_{act.FE3.2} \ge FS_{req.FE3} \\ \text{"ANCHORS REQUIRED"} & \text{if } FS_{act.FE3.2} < FS_{req.FE3} \end{cases} = \text{"OKAY"}$$

CHECK FOUNDATION BEARING CAPACITY

E3.2 CASE

Sum of the Moments (X-Direction):

$$\Sigma M_{E3.2.x} := \Sigma M_{U2.x} - \Sigma M_{I.U2} + \Sigma M_{Q.E3.2.x} = 229184 \cdot kN \cdot m$$

Eccentricity:

$$e_{E3.2.x} := X_{BCG} - \frac{\Sigma M_{E3.2.x}}{\Sigma V_{E3.2}} = 2.68\ m$$

Eccentricity Check:

$$e_{check.E3.2.x} := \begin{cases} \text{"Okay"} & \text{if } e_{E3.2.x} \le \frac{L_B}{4} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$e_{check.E3.2.x} = \text{"Okay"}$

Foundation Bearing Pressures (X-Direction):

Bearing Pressure at Heel:

$$\sigma_{heel.E3.2.x} := \frac{\Sigma V_{E3.2}}{A_b} - \frac{\Sigma V_{E3.2} \cdot e_{E3.2.x}}{S_{bx.L}} = 8.32 \cdot \frac{kN}{m^2}$$

$$\sigma_{heel.E3.2.check.x} := \left(\begin{cases} \text{"Okay"} & \text{if } 0 \le \sigma_{heel.E3.2.x} \le \sigma_{allow.E3} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} \right)$$

$\sigma_{heel.E3.2.check.x} = \text{"Okay"}$

Bearing Pressure at Toe:

$$\sigma_{toe.E3.2.x} := \frac{\Sigma V_{E3.2}}{A_b} + \frac{\Sigma V_{E3.2} \cdot e_{E3.2.x}}{S_{bx.R}} = 239.41 \cdot \frac{kN}{m^2}$$

$$\sigma_{toe.E3.2.check.x} := \begin{cases} \text{"Okay"} & \text{if } 0 \le \sigma_{toe.E3.2.x} \le \sigma_{allow.E3} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$\sigma_{toe.E3.2.check.x} = \text{"Okay"}$

Sum of the Moments (Z-Direction):

$$\Sigma M_{E3.2.z} := \Sigma M_{U2.z} + \Sigma M_{Q.E3.2.z} = 262326 \cdot kN \cdot m$$

Eccentricity:

$$e_{E3.2.z} := Z_{BCG} - \frac{\Sigma M_{E3.2.z}}{\Sigma V_{E3.2}} = 0.56\ m$$

Eccentricity Check:

$$e_{check.E3.2.z} := \begin{cases} \text{"Okay"} & \text{if } e_{E3.2.z} \le \frac{W_B}{4} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$e_{check.E3.2.z} = \text{"Okay"}$

Foundation Bearing Pressures (Z-Direction):

Bearing Pressure at Heel:

$$\sigma_{heel.E3.2.z} := \frac{\Sigma V_{E3.2}}{A_b} - \frac{\Sigma V_{E3.2} \cdot e_{E3.2.z}}{S_{bz.b}} = 98.6 \cdot \frac{kN}{m^2}$$

$$\sigma_{heel.E3.2.check.z} := \left(\begin{cases} \text{"Okay"} & \text{if } 0 \le \sigma_{heel.E3.2.z} \le \sigma_{allow.E3} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} \right)$$

$\sigma_{heel.E3.2.check.z} = \text{"Okay"}$

Bearing Pressure at Toe:

$$\sigma_{toe.E3.2.z} := \frac{\Sigma V_{E3.2}}{A_b} + \frac{\Sigma V_{E3.2} \cdot e_{E3.2.z}}{S_{bz.t}} = 154.39 \cdot \frac{kN}{m^2}$$

$$\sigma_{toe.E3.2.check.z} := \begin{cases} \text{"Okay"} & \text{if } 0 \le \sigma_{heel.E3.2.z} \le \sigma_{allow.E3} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$\sigma_{toe.E3.2.check.z} = \text{"Okay"}$

Foundation Bearing Pressure (Combined):

Linear pressure superimposed at Corners by both Moment_X and Moment_Z

E3.2 CASE

Bearing Pressure at Heel(x)-Heel(z):

$$\sigma_{heel.E3.2} := \min\left(\frac{\Sigma V_{E3.2}}{A_b} - \frac{\Sigma V_{U2} \cdot e_{U2.x}}{S_{bx.L}} - \frac{\Sigma V_{E3.2} \cdot e_{E3.2.z}}{S_{bz.b}}, \frac{\Sigma V_{E3.2}}{A_b} - \frac{\Sigma V_{E3.2} \cdot e_{E3.2.x}}{S_{bx.L}} - \frac{\Sigma V_{U2} \cdot e_{U2.z}}{S_{bz.b}}\right) = 44.98 \cdot kPa$$

$$\sigma_{heel.E3.2.check} := \left(\begin{array}{ll} \text{"Okay"} & \text{if } 0 \le \sigma_{heel.E3.2} \le \sigma_{allow.E3} \\ \text{"Revise Structure"} & \text{if } \sigma_{heel.E3.2} \le 0 \end{array} \right)$$

$\sigma_{heel.E3.2.check}$ = "Okay"

Bearing Pressure at Toe(x)-Toe(z):

$$\sigma_{toe.E3.2} := \min\left(\frac{\Sigma V_{E3.2}}{A_b} + \frac{\Sigma V_{U2} \cdot e_{U2.x}}{S_{bx.R}} + \frac{\Sigma V_{E3.2} \cdot e_{E3.2.z}}{S_{bz.t}}, \frac{\Sigma V_{E3.2}}{A_b} + \frac{\Sigma V_{E3.2} \cdot e_{E3.2.x}}{S_{bx.R}} + \frac{\Sigma V_{U2} \cdot e_{U2.z}}{S_{bz.t}}\right) = 201.08 \cdot kPa$$

$$\sigma_{toe.E3.2.check} := \begin{array}{ll} \text{"Okay"} & \text{if } 0 \le \sigma_{toe.E3.2} \le \sigma_{allow.E3} \\ \text{"Revise Structure"} & \text{otherwise} \end{array}$$

$\sigma_{toe.E3.2.check}$ = "Okay"

Bearing Pressure at Heel(x)-Toe(z):

$$\sigma_{heeltoe.E3.2} := \min\left(\frac{\Sigma V_{E3.2}}{A_b} - \frac{\Sigma V_{U2} \cdot e_{U2.x}}{S_{bx.L}} + \frac{\Sigma V_{E3.2} \cdot e_{E3.2.z}}{S_{bz.t}}, \frac{\Sigma V_{E3.2}}{A_b} - \frac{\Sigma V_{E3.2} \cdot e_{E3.2.x}}{S_{bx.L}} + \frac{\Sigma V_{U2} \cdot e_{U2.z}}{S_{bz.t}}\right) = -30.01 \cdot kPa$$

$$\sigma_{heeltoe.E3.2.check} := \left(\begin{array}{ll} \text{"Okay"} & \text{if } 0 \le \sigma_{heeltoe.E3.2} \le \sigma_{allow.E3} \\ \text{"Revise Structure"} & \text{otherwise} \end{array} \right)$$

$\sigma_{heeltoe.E3.2.check}$ = "Revise Structure"

Bearing Pressure at Toe(x)-Heel(z):

$$\sigma_{toeheel.E3.2} := \min\left(\frac{\Sigma V_{E3.2}}{A_b} + \frac{\Sigma V_{U2} \cdot e_{U2.x}}{S_{bx.R}} - \frac{\Sigma V_{E3.2} \cdot e_{E3.2.z}}{S_{bz.b}}, \frac{\Sigma V_{E3.2}}{A_b} + \frac{\Sigma V_{E3.2} \cdot e_{E3.2.x}}{S_{bx.R}} - \frac{\Sigma V_{U2} \cdot e_{U2.z}}{S_{bz.b}}\right) = 149.13 \cdot kPa$$

$$\sigma_{toeheel.E3.2.check} := \begin{array}{ll} \text{"Okay"} & \text{if } 0 \le \sigma_{toeheel.E3.2} \le \sigma_{allow.E3} \\ \text{"Revise Structure"} & \text{otherwise} \end{array}$$

$\sigma_{toeheel.E3.2.check}$ = "Okay"

Small Tension in corner is calculated under E2.2 Load Case, - to be reviewed in detail using 3D analysis during final design and cracked base to be reviewed as applicable, however due to the average compression along each exterior foundation line the tension appears to be minimal.

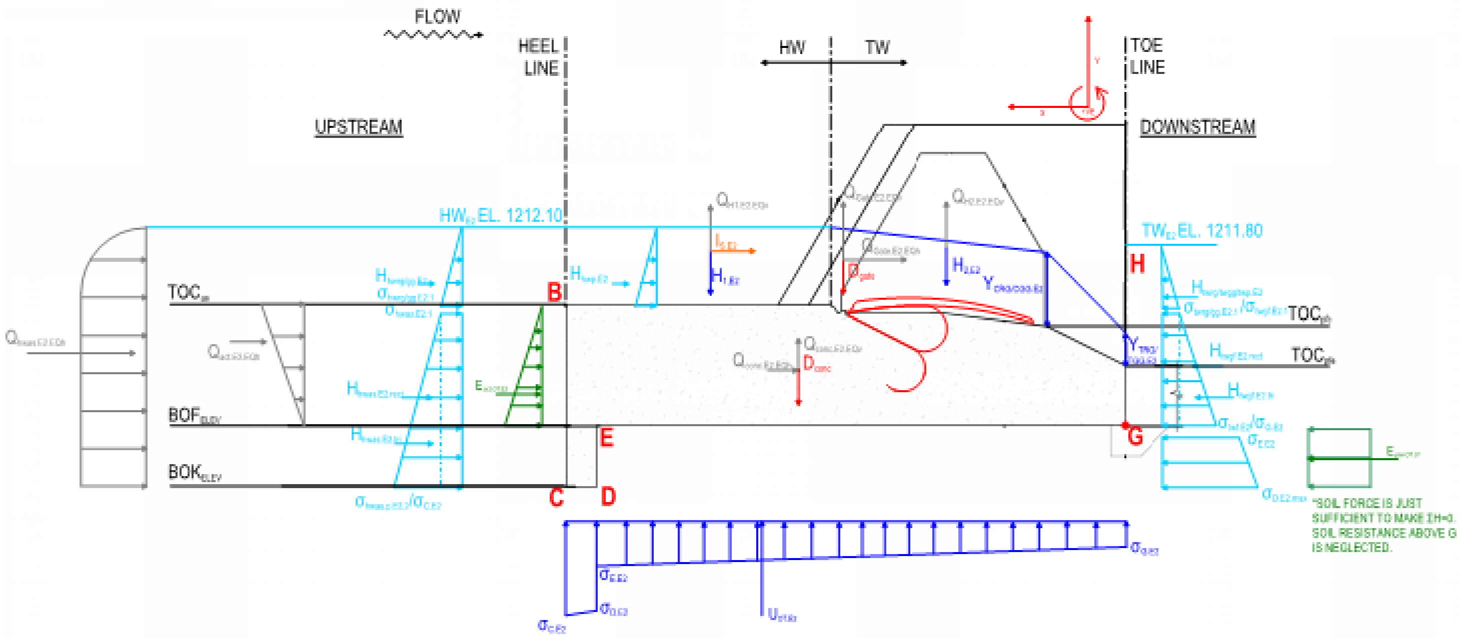
E3.2 CASE

MONOLITH OVERTURNING STABILITY ANALYSIS

Seismic Case $Q_{E3.2}$: 100% Horizontal Seismic Force, 30%ertical

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.
Assumptions are made in order to compute overturning stability of indetermine forces on monolith with key;
(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.
(b) The horizontal resisting force acting on the key, P.key, is that required for static equilibrium
(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1 $Ratio_{overturning.allow.Extreme} = 0.25$ Resultant within Base



All Vertical Loads Applicable to Overturning Stability Analysis

Total Concrete Dead Loads:	$D_{conc} = 35947.58 \cdot kN$	at:	$X_{conc.loc} = 8.81\ m$
Dead Load of Gate:	$D_{Gate} = 56.0 \cdot kN$		$X_{gate} = 9.50\ m$
Water Weight (HW) on Apron Slab:	$H_{1.U2} = 3594.1 \cdot kN$		$H_{1.U2.loc.x} = 14.42\ m$
Water Weight (TW) on Gate Footing:	$H_{2.U2} = 1322.9 \cdot kN$		$H_{2.U2.loc.x} = 5.25\ m$
Uplift Load for Overtuming Analysis:	$U_{OT.U2} = -20710.3 \cdot kN$		$U_{OT.U2.loc} = 9.88 \cdot m$
Vertical Seismic Component of Concrete Structure:	$Q_{conc.E3.EQv.2} = -1078.43 \cdot kN$		$X_{conc.loc} = 8.81\ m$
Vertical Seismic Component of Crest Gate:	$Q_{Gate.E3.EQv.2} = -1.68 \cdot kN$		$X_{gate} = 9.50\ m$
Vertical Seismic Component of Headwater over Apron Slab:	$Q_{H1.E3.EQv.2} = -107.82 \cdot kN$		$H_{1.U2.loc.x} = 14.42\ m$
Vertical Seismic Component of Headwater over Fixed Crest Slab:	$Q_{H2.E3.EQv.2} = -39.69 \cdot kN$		$H_{2.U2.loc.x} = 5.25\ m$

Sum of All Overturning Analysis Vertical Load:

$$\Sigma V_{E3.OT.2} := D_{conc} + D_{Gate} + H_{1.U2} + H_{2.U2} + U_{OT.U2} + \Sigma V_{Q.E3.EQv.2} = 18440.9 \cdot kN$$

Sum of All Overturning Analysis Vertical Load Moments:

$$\Sigma M_{V.E3.OT.2} := D_{conc} \cdot X_{conc.loc} + D_{Gate} \cdot X_{gate} + H_{1.U2} \cdot H_{1.U2.loc.x} + H_{2.U2} \cdot H_{2.U2.loc.x} + U_{OT.U2} \cdot U_{OT.U2.loc} = 171520.21 \cdot kN \cdot m$$

Lateral Driving Earth Loads for Overturning Stability Analysis (at rest condition)

E3.2 CASE

Depth of Driving Soil Loads (to top of key): $h_{E.OT.E3.2} := TOC_{as} - BOF_{elev} = 4\ m$

Applicable Soil Load: $E_{act.OT.E3.2} := \frac{\left(K_{o.U2} \cdot h_{E.OT.U2}\right)^2}{2} \cdot \left(\gamma_r - \gamma_w\right) \cdot W_{hwas.U2} \cdot -1 = -1026.66 \cdot kN$

At Rest- Soil Load Acting from Toe: $E_{act.OT.E3.2.loc} := \frac{h_{E.OT.U2}}{3} = 1.33\ m$

All Lateral Loads Applicable to Overturning Stability Analysis

HW Lateral Load on Approach Slab:	$H_{hwas.U2} = -4143.7 \cdot kN$	$H_{hwas.U2.loc} = 1.80\ m$
HW Lateral Load on Guard Gate:	$H_{hwgg.U2} = -415.2 \cdot kN$	$H_{hwgg.U2.loc} = 5.53\ m$
TW Lateral Load on Guard Gate:	$H_{twgg.U2} = 63.6 \cdot kN$	$H_{twgg.U2.loc} = 4.60\ m$
TW Lateral Load on Gate Footing (No Key - Overturning Values Adjusted):	$H_{twgf.U2} = 2385.79 \cdot kN$	$H_{twgf.U2.loc} = 1.65\ m$
TW Lateral Load on Key:	$H_{twkey.OT.U2} = 2927.88 \cdot kN$	$H_{twkey.OT.U2.loc} = -1.04\ m$
Ice / Impact Load:	$I_{U2} = 0.0 \cdot kN$	$I_{U2.loc.y} = 8.30\ m$
Lateral Soil Load (driving):	$E_{act.OT.U2} = -1026.7 \cdot kN$	$E_{act.OT.U2.loc} = 1.33\ m$
Horizontal Seismic Component of Concrete Structure:	$Q_{conc.E3.EQh.2} = -6111.09 \cdot kN$	$Y_{conc.loc} = 3.62\ m$
Horizontal Seismic Component of Vertical Lift Gate:	$Q_{Gate.E3.EQh.2} = -9.52 \cdot kN$	$Y_{gate} = 4.00\ m$
Horizontal Seismic Component of Headwater on Slab Footing:	$Q_{hwas.E3.EQh.2.x} = -1748.91 \cdot kN$	$Y_{HWg.E3.x} = 3.84\ m$
Horizontal Seismic Component of Active Soil: (Section 5-5, USACE EM_1110-2-2100)	$Q_{act.E3.EQh.2.x} = -1193.64 \cdot kN$	$Y_{E.act.E3.x} = 2.52\ m$

Resisting Lateral Soil Load as required to produce horizontal equilibrium:

$$E_{pas.OT.E3.2} := -\left(H_{hwas.U2} + H_{hwgg.U2} + H_{twgg.U2} + H_{twgf.U2} + H_{twkey.OT.U2} + I_{U2} + E_{act.OT.U2} + \Sigma H_{Q.E3.EQh.2.OT.x}\right) = 2487.74 \cdot kN$$

Acting at: $E_{pas.OT.E3.2.loc} := -1 \cdot \frac{d_{key}}{2} = -1\ m$

Sum of All Overturning Analysis Horizontal Load (ΣH=0):

$$\Sigma H_{E3.OT.2} := H_{hwas.U2} + H_{hwgg.U2} + H_{twgg.U2} + H_{twgf.U2} + H_{twkey.OT.U2} + I_{U2} + E_{act.OT.U2} + E_{pas.OT.E3.2} + \Sigma H_{Q.E3.EQh.2.OT.x} = 0 \cdot kN$$

Sum of All Overturning Analysis Horizontal Load Moments:

$$\begin{aligned}\Sigma M_{H.E3.OT.2} := {} & H_{hwas.U2} \cdot H_{hwas.U2.loc} + H_{hwgg.U2} \cdot H_{hwgg.U2.loc} + H_{twgg.U2} \cdot H_{twgg.U2.loc} \cdots = -55002.53 \cdot kN \cdot m \\ & + H_{twgf.U2} \cdot H_{twgf.U2.loc} + H_{twkey.OT.U2} \cdot H_{twkey.OT.U2.loc} + I_{U2} \cdot I_{U2.loc.y} \cdots \\ & + E_{act.OT.U2} \cdot E_{act.OT.U2.loc} + E_{pas.OT.x.U2} \cdot E_{pas.OT.U2.loc} + \Sigma M_{Q.E3.2}\end{aligned}$$

Overturning Stability Analysis

$$\Sigma M_{E3.OT.2} := \Sigma M_{V.E3.OT.2} + \Sigma M_{H.E3.OT.2} = 116517.68 \cdot kN \cdot m$$

$$X_{R.E3.2} := \frac{\Sigma M_{E3.OT.2}}{\Sigma V_{E3.OT.2}} = 6.32\ m \qquad x_{OT.E3.2} := X_{R.E3.2} - \frac{L_B}{2} = -2.93\ m$$

Overturning Resultant Ratio

$$Ratio_{OT.E3.2} := \frac{X_{R.E3.2}}{L_B} = 0.34$$

$$Ratio_{OT.E3.2.check} := \left| \begin{array}{l} \text{"OKAY"} \quad \text{if} \quad Ratio_{OT.E3.2} \geq Ratio_{overturning.allow.Extreme} \\ \text{"Revise Structure"} \quad \text{otherwise} \end{array} \right. = \text{"OKAY"}$$

SEISMIC LOAD (Three combinations of E_h and E_v considered) E3.3 CASE

Seismic Case $Q_{E3.3}$ - 30% Horizontal Seismic Force, 100% Vertical

Include Seismic Load in Analysis? $Eq_{E3.3} := 1$ 0 = No, 1 = Yes

Horizontal Seismic Coefficient: $K_{h.E3.3} := -0.05$

Vertical Seismic Coefficient: $K_{v.E3.3} := -0.10$

Vertical Tailwater on Approach Slab: $H_{1.U2} = 3594.06 \cdot kN$

Acting At: $H_{1.U2.loc.x} = 14.42\ m$ $H_{1.U2.loc.z} = 4.73\ m$

Width of HW acting on Approach Slab (Z-dir.): $W_{hwas.U2.z} = 7.9\ m$

Width of TW acting on 1A Foundation (Z-dir.): $W_{twf.U2.z} = 10.6\ m$

HORIZONTAL SEISMIC LOADS	**Loads**	**Moment Arm**
Horiz Seismic Component of Concrete:	$Q_{conc.E3.EQh.3} := D_{conc} \cdot K_{h.E3.3} \cdot Eq_{E3.3} = -1797.4 \cdot kN$	$Y_{conc.loc} = 3.62\ m$
Horiz Seismic Component of Gates:	$Q_{Gate.E3.EQh.3} := D_{Gate} \cdot K_{h.E3.3} \cdot Eq_{E3.3} = -2.8 \cdot kN$	$Y_{gate} = 4.00\ m$
Horiz Seismic Component of Fill:	$Q_{fill.E3.EQh.3} := D_{fill} \cdot K_{h.E3.3} \cdot Eq_{E3.3} = -902.8 \cdot kN$	$Y_{fill.loc} = 7.25\ m$

Horizontal Seismic Component of Headwater - Sliding (X-dir.):

$$Q_{hwas.E3.EQh.3.x} := \left(\frac{7}{12}\right) \cdot K_{h.E3.3} \cdot \gamma_w \cdot \left(HW_{U2} - BOK_{elev}\right)^2 \cdot W_{hwas.U2} \cdot Eq_{E3.3} = -514.4 \cdot kN$$

$$Y_{HWg.E3.x} = 3.84\ m$$

Horizontal Seismic Component of Headwater - Sliding (Z-dir.):

$$Q_{hwas.E3.EQh.3.z} := \left(\frac{7}{12}\right) \cdot K_{h.E3.3} \cdot \gamma_w \cdot \left(HW_{U2} - BOK_{elev}\right)^2 \cdot W_{hwas.U2.z} \cdot Eq_{E3.3} = -254.0 \cdot kN$$

$$Y_{HWg.E3.z} = 3.84\ m$$

Horizontal Seismic Component of Tailwater - Sliding (Z-dir.):

$$Q_{twf.E3.EQh.3.z} := \left(\frac{7}{12}\right) \cdot K_{h.E3.3} \cdot \gamma_w \cdot \left(TW_{U2} - BOK_{elev}\right)^2 \cdot W_{twf.U2.z} \cdot Eq_{E3.3} = -184.5 \cdot kN$$

$$Y_{TWg.E3.z} = 0.32\ m$$

Horizontal Seismic Component of Soil (Woods Method) - Overturning (X-Dir.):

$$Q_{act.E3.EQh.3.OT.x} := \left(\gamma_r - \gamma_w\right) \cdot \left(TOC_{as} - BOF_{elev}\right)^2 \cdot K_{h.E3.3} \cdot W_{hwas.U2} \cdot Eq_{E3.3} = -156.0 \cdot kN$$

$$Y_{E.act.E3.OT.x} = 0.52\ m$$

Horizontal Seismic Component of Soil (Woods Method X-Dir.)

$$Q_{act.E3.EQh.3.x} := \left(\gamma_r - \gamma_w\right) \cdot \left(TOC_{as} - BOK_{elev}\right)^2 \cdot K_{h.E3.3} \cdot W_{hwas.U2} \cdot Eq_{E3.3} = -351.1 \cdot kN$$

$$Y_{E.act.E3.x} = 2.52\ m$$

Horizontal Seismic Component of Soil (Woods Method Z-Dir.)

$$Q_{act.E3.EQh.3.z} := -K_{h.E3.3} \cdot \left(E_{act.a.U2.z} + E_{act.as.U2.z} \cdots + E_{act.RCC.U2.z} + E_{act.RCC.s.U2.z}\right) Eq_{E3.3} = -151.91 \cdot kN$$

$$Y_{E.act.E3.y} = 4.65\ m$$

$$\Sigma H_{Q.E3.EQh.3} := Q_{conc.E3.EQh.3} + Q_{Gate.E3.EQh.3} + Q_{fill.E3.EQh.3} = -2703.01 \cdot kN$$

$$\Sigma H_{Q.E3.EQh.3.x} := Q_{hwas.E3.EQh.3.x} + Q_{act.E3.EQh.3.x} = -865.46 \cdot kN$$

$$\Sigma H_{Q.E3.EQh.3.OT.x} := Q_{hwas.E3.EQh.3.x} + Q_{act.E3.EQh.3.OT.x} = -670.42 \cdot kN$$

$$\Sigma H_{Q.E3.EQh.3.z} := Q_{hwas.E3.EQh.3.z} + Q_{twf.E3.EQh.3.z} + Q_{hwas.E3.EQh.3.z} + Q_{act.E3.EQh.3.z} = -844.39 \cdot kN$$

E3.3 CASE

VERTICAL SEISMIC LOADS	**Loads**	**Moment Arm**
Vertical Component of Concrete:	$Q_{conc.E3.EQv.3} := D_{conc} \cdot K_{v.E3.3} \cdot Eq_{E3.3} = -3594.8 \cdot kN$	$X_{conc.loc} = 8.81\ m$
		$Z_{conc.loc} = 8.46\ m$
Vertical Component of Gate:	$Q_{Gate.E3.EQv.3} := D_{Gate} \cdot K_{v.E3.3} \cdot Eq_{E3.3} = -5.6 \cdot kN$	$X_{gate} = 9.50\ m$
		$Z_{gate} = 2\ m$
Vertical Component of Fill:	$Q_{fill.E3.EQv.3} := D_{fill} \cdot K_{v.E3.3} \cdot Eq_{E3.3} = -1805.66 \cdot kN$	$X_{fill.loc} = 7.31\ m$
		$Z_{fill.loc} = 10\ m$
Vertical Seismic Component of Headwater over Apron Slab:	$Q_{H1.E3.EQv.3} := K_{v.E3.3} \cdot H_{1.U2} \cdot Eq_{E3.3} = -359.4 \cdot kN$	$H_{1.U2.loc.x} = 14.42\ m$
		$H_{1.U2.loc.z} = 4.73\ m$
Vertical Seismic Component of Tailwater over Pier Footing:	$Q_{H2.E3.EQv.3} := K_{v.E3.3} \cdot H_{2.U2} \cdot Eq_{E3.3} = -132.3 \cdot kN$	$H_{2.U2.loc.x} = 5.25\ m$
		$H_{2.U2.loc.z} = 2\ m$
Vertical Seismic Component of Soil over Approach Slab:	$Q_{E1.E3.EQv.3} := K_{v.E3.3} \cdot E_{1.U2} \cdot Eq_{E3.3} = 0 \cdot kN$	$E_{1.U2.loc.x} = 12.89\ m$

$$\Sigma V_{Q.E3.EQv.3} := Q_{conc.E3.EQv.3} + Q_{Gate.E3.EQv.3} + Q_{fill.E3.EQv.3} + Q_{H1.E3.EQv.3} + Q_{H2.E3.EQv.3} + Q_{E1.E3.EQv.3} = -5897.7 \cdot kN$$

$$\Sigma M_{Q.E3.3} := Q_{conc.E3.EQh.3} \cdot Y_{conc.loc} + Q_{Gate.E3.EQh.3} \cdot Y_{gate} + Q_{fill.E3.EQh.3} \cdot Y_{fill.loc} = -13071.37 \cdot kN \cdot m$$

$$\begin{aligned}\Sigma M_{Q.E3.3.x} := {} & Q_{conc.E3.EQh.3} \cdot Y_{conc.loc} + Q_{Gate.E3.EQh.3} \cdot Y_{gate} + Q_{fill.E3.EQh.3} \cdot Y_{fill.loc} + Q_{hwas.E3.EQh.3.x} \cdot Y_{HWg.E3.x} \cdots = -66742.41 \cdot kN \cdot m \\ & + Q_{act.E3.EQh.3.x} \cdot Y_{E.act.E3.x} + Q_{conc.E3.EQv.3} \cdot X_{conc.loc} + Q_{Gate.E3.EQv.3} \cdot X_{gate} + Q_{fill.E3.EQv.3} \cdot X_{fill.loc} \cdots \\ & + Q_{H1.E3.EQv.3} \cdot H_{1.U2.loc.x} + Q_{H2.E3.EQv.3} \cdot H_{2.U2.loc.x} + Q_{E1.E3.EQv.3} \cdot E_{1.U2.loc.x}\end{aligned}$$

$$\begin{aligned}\Sigma M_{Q.E3.3.x.OT} := {} & Q_{conc.E3.EQh.3} \cdot Y_{conc.loc} + Q_{Gate.E3.EQh.3} \cdot Y_{gate} + Q_{fill.E3.EQh.3} \cdot Y_{fill.loc} \cdots = -65938.85 \cdot kN \cdot m \\ & + Q_{hwas.E3.EQh.3.x} \cdot Y_{HWg.E3.x} + Q_{act.E3.EQh.3.OT.x} \cdot Y_{E.act.E3.OT.x} \cdots \\ & + Q_{conc.E3.EQv.3} \cdot X_{conc.loc} + Q_{Gate.E3.EQv.3} \cdot X_{gate} + Q_{fill.E3.EQv.3} \cdot X_{fill.loc} \cdots \\ & + Q_{H1.E3.EQv.3} \cdot H_{1.U2.loc.x} + Q_{H2.E3.EQv.3} \cdot H_{2.U2.loc.x} + Q_{E1.E3.EQv.3} \cdot E_{1.U2.loc.x}\end{aligned}$$

$$\begin{aligned}\Sigma M_{Q.E3.3.z} := {} & Q_{conc.E3.EQh.3} \cdot Y_{conc.loc} + Q_{Gate.E3.EQh.3} \cdot Y_{gate} + Q_{fill.E3.EQh.3} \cdot Y_{fill.loc} + Q_{hwas.E3.EQh.3.z} \cdot Y_{HWg.E3.z} \cdots = -64550.76 \cdot kN \cdot m \\ & + Q_{twf.E3.EQh.3.z} \cdot Y_{TWg.E3.z} + Q_{conc.E3.EQv.3} \cdot Z_{conc.loc} + Q_{Gate.E3.EQv.3} \cdot Z_{gate} + Q_{fill.E3.EQv.3} \cdot Z_{fill.loc} \cdots \\ & + Q_{H1.E3.EQv.3} \cdot H_{1.U2.loc.z} + Q_{H2.E3.EQv.3} \cdot H_{2.U2.loc.z} + Q_{E1.E3.EQv.3} \cdot E_{1.U2.loc.z}\end{aligned}$$

STABILITY ASSESSMENT (SLIDNG, BEARING, FLOTATION AND OVERTURNING): E3.3 CASE

CHECK SLIDING ALONG HORIZONTAL PLANE THRU TOE, IGNORING BEDROCK MOBILIZED BY STRUCTURAL HEEL KEY, OR VOID BEHIND KEY

Sum of Vertical Forces:

$$\Sigma V_{E3.3} := \Sigma V_{U2} + \Sigma V_{Q.E3.EQv.3} = 32262.9 \cdot kN$$

Sum of Horizontal Forces (X-Direction):

$$\Sigma H_{E3.3.x} := \Sigma H_{Water.U2.x} + \Sigma H_{soil.U2.x} + \Sigma H_{Q.E3.EQh.3.x} = -2176.16 \cdot kN$$

Sum of Horizontal using 30% Seismic Horizontal (X-Direction):

$$\Sigma H_{E3.3.x.30\%} := \Sigma H_{Water.U2.x} + \Sigma H_{soil.U2.x} + 0.3 \cdot \Sigma H_{Q.E3.EQh.3.x} = -1570.34 \cdot kN$$

Sum of Horizontal Forces (Z-Direction):

$$\Sigma H_{E3.3.z} := \Sigma H_{Water.U2.z} + \Sigma H_{soil.U2.z} + \Sigma H_{Q.E3.EQh.3.z} = -3882.66 \cdot kN$$

Sum of Horizontal using 30% Seismic Horizontal (Z-Direction):

$$\Sigma H_{E3.3.z.30\%} := \Sigma H_{Water.U2.z} + \Sigma H_{soil.U2.z} + 0.3 \cdot \Sigma H_{Q.E3.EQh.3.z} = -3291.59 \cdot kN$$

Sum of Horizontal Forces (Resultant):

$$\Sigma H_{3.3} := \sqrt{\Sigma H_{E3.3.x}^{\ 2} + \Sigma H_{E3.3.z}^{\ 2}} = 4450.92 \cdot kN$$

Sum of Horizontal Forces using 30% Seismic Horizontal (Resultant):

$$\Sigma H_{3.3.30\%} := \sqrt{\Sigma H_{E3.3.x.30\%}^{\ 2} + \Sigma H_{E3.3.z.30\%}^{\ 2}} = 3646.99 \cdot kN$$

Sliding Factor of Safety (Single Axis):

$$FS_{HorizSliding.E3.3.x} := \frac{\tan_{\phi} \cdot \Sigma V_{E3.3}}{\left|\Sigma H_{E3.3.x} + \Sigma H_{Q.E3.EQh.3}\right|} = 3.23$$

$$FS_{HorizSliding.E3.3.z} := \frac{\tan_{\phi} \cdot \Sigma V_{E3.3}}{\left|\Sigma H_{E3.3.z} + \Sigma H_{Q.E3.EQh.3}\right|} = 2.39$$

Sliding Factor of Safety:

$$FS_{HorizSliding.E3.3} := \min\left(\frac{\tan_{\phi} \cdot \Sigma V_{E3.3}}{\Sigma H_{3.3} + \left|\Sigma H_{Q.E3.EQh.3}\right|}, \frac{\tan_{\phi} \cdot \Sigma V_{E3.3}}{\Sigma H_{3.3.30\%} + \left|\Sigma H_{Q.E3.EQh.3}\right|}\right) = 2.20$$

$$FS_{HorizSliding.E3.3.Check} := \begin{cases} \text{"OKAY"} & \text{if } FS_{HorizSliding.E3.3} \geq FS_{req.E3.sl} \\ \text{"Horizontal Sliding (No Key or Void Behind Key) Fail ! Revise Structure !"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

FLOATATION ANALYSIS:

ACCEPTANCE PARAMETERS

Required Factor of Safety: $FS_{req.FE3} = 1$

VERTICAL LOADS RESISTING:

Dead Load: $\Sigma V_{DL} = 54060.17 \cdot kN$

Water Weight H1+H2: $\Sigma V_{H.FE3.3} := H_{1.U2} + H_{2.U2} = 4916.94 \cdot kN$

Summation Vertical Resisting: $\Sigma V_{FE3.3} := \Sigma V_{U2} + \Sigma V_{Q.E3.EQv.3} = 32262.9 \cdot kN$

VERTICAL LOADS UPLIFT:

Uplift: $U_{U2} = -20816.49 \cdot kN$

Factor of Safety Floatation:

$$FS_{act.FE3.3} := \frac{\Sigma V_{FE3.3}}{\left|U_{U2}\right|} = 1.55$$

$$FS_{check.FE3.3} := \begin{cases} \text{"OKAY"} & \text{if } FS_{act.FE3.3} \geq FS_{req.FE3} \\ \text{"ANCHORS REQUIRED"} & \text{if } FS_{act.FE3.3} < FS_{req.FE3} \end{cases} = \text{"OKAY"}$$

CHECK FOUNDATION BEARING CAPACITY

Sum of the Moments (X-Direction):

$$\Sigma M_{E3.3.x} := \Sigma M_{U2.x} - \Sigma M_{I.U2} + \Sigma M_{Q.E3.3.x} = 231851 \cdot kN \cdot m$$

Eccentricity:

$$e_{E3.3.x} := X_{BCG} - \frac{\Sigma M_{E3.3.x}}{\Sigma V_{E3.3}} = 1.79\ m$$

Eccentricity Check:

$$e_{check.E3.3.x} := \begin{cases} \text{"Okay"} & \text{if } e_{E3.3.x} \le \frac{L_B}{4} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$$e_{check.E3.3.x} = \text{"Okay"}$$

Foundation Bearing Pressures (X-Direction):

Bearing Pressure at Heel:

$$\sigma_{heel.E3.3.x} := \frac{\Sigma V_{E3.3}}{A_b} - \frac{\Sigma V_{E3.3} \cdot e_{E3.3.x}}{S_{bx.L}} = 42.38 \cdot \frac{kN}{m^2}$$

$$\sigma_{heel.E3.3.check.x} := \left(\begin{cases} \text{"Okay"} & \text{if } \sigma_{heel.E3.3.x} \le \sigma_{allow.E3} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} \right)$$

$$\sigma_{heel.E3.3.check.x} = \text{"Okay"}$$

Bearing Pressure at Toe:

$$\sigma_{toe.E3.3.x} := \frac{\Sigma V_{E3.3}}{A_b} + \frac{\Sigma V_{E3.3} \cdot e_{E3.3.x}}{S_{bx.R}} = 179.27 \cdot \frac{kN}{m^2}$$

$$\sigma_{toe.E3.3.check.x} := \begin{cases} \text{"Okay"} & \text{if } \sigma_{toe.E3.3.x} \le \sigma_{allow.E3} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$$\sigma_{toe.E3.3.check.x} = \text{"Okay"}$$

Sum of the Moments (Z-Direction):

$$\Sigma M_{E3.3.z} := \Sigma M_{U2.z} + \Sigma M_{Q.E3.3.z} = 260868 \cdot kN \cdot m$$

Eccentricity:

$$e_{E3.3.z} := Z_{BCG} - \frac{\Sigma M_{E3.3.z}}{\Sigma V_{E3.3}} = -0.32\ m$$

Eccentricity Check:

$$e_{check.E3.3.z} := \begin{cases} \text{"Okay"} & \text{if } e_{E3.3.z} \le \frac{W_B}{4} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$$e_{check.E3.3.z} = \text{"Okay"}$$

Foundation Bearing Pressures (Z-Direction):

Bearing Pressure at Heel:

$$\sigma_{heel.E3.3.z} := \frac{\Sigma V_{E3.3}}{A_b} - \frac{\Sigma V_{E3.3} \cdot e_{E3.3.z}}{S_{bz.b}} = 127.16 \cdot \frac{kN}{m^2}$$

$$\sigma_{heel.E3.3.check.z} := \left(\begin{cases} \text{"Okay"} & \text{if } \sigma_{heel.E3.3.z} \le \sigma_{allow.E3} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} \right)$$

$$\sigma_{heel.E3.3.check.z} = \text{"Okay"}$$

Bearing Pressure at Toe:

$$\sigma_{toe.E3.3.z} := \frac{\Sigma V_{E3.3}}{A_b} + \frac{\Sigma V_{E3.3} \cdot e_{E3.3.z}}{S_{bz.t}} = 99.35 \cdot \frac{kN}{m^2}$$

$$\sigma_{toe.E3.3.check.z} := \begin{cases} \text{"Okay"} & \text{if } \sigma_{heel.E3.3.z} \le \sigma_{allow.E3} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases}$$

$$\sigma_{toe.E3.3.check.z} = \text{"Okay"}$$

X-dir. Eccentricity without lateral seismic dead loads:

$$e_{E3.3.x.\sigma} := X_{mass} - \frac{\Sigma M_{E3.3.x} - \Sigma M_{Q.E3.3}}{\Sigma V_{E3.3}} = 0.72\ m$$

Z-dir. Eccentricity without lateral seismic dead loads:

$$e_{E3.3.z.\sigma} := Z_{mass} - \frac{\Sigma M_{E3.3.z} - \Sigma M_{Q.E3.3}}{\Sigma V_{E3.3}} = 0.48\ m$$

Foundation Bearing Pressure (Combined):

Linear pressure superimposed at Corners by both Moment_X and Moment_Z

Bearing Pressure at Heel(x)-Heel(z):

$$\sigma_{heel.E3.3} := \min\left(\frac{\Sigma V_{E3.3}}{A_b} - \frac{\Sigma V_{E3.3} \cdot e_{E3.3.x.\sigma}}{S_{bx.L}} - \frac{\Sigma V_{E3.3} \cdot e_{E3.3.z}}{S_{bz.b}}, \frac{\Sigma V_{E3.3}}{A_b} - \frac{\Sigma V_{E3.3} \cdot e_{E3.3.x}}{S_{bx.L}} - \frac{\Sigma V_{E3.3} \cdot e_{E3.3.z.\sigma}}{S_{bz.b}}\right) = 20.76 \cdot kPa$$

$$\sigma_{heel.E3.3.check} := \left(\begin{array}{|l} \text{"Okay"} \quad \text{if} \quad \sigma_{heel.E3.2} \le \sigma_{allow.E3} \\ \text{"Revise Structure"} \quad \text{otherwise} \end{array} \right)$$

$\sigma_{heel.E3.3.check} = \text{"Okay"}$

Bearing Pressure at Toe(x)-Toe(z):

$$\sigma_{toe.E3.3} := \min\left(\frac{\Sigma V_{E3.3}}{A_b} + \frac{\Sigma V_{E3.3} \cdot e_{E3.3.x.\sigma}}{S_{bx.R}} + \frac{\Sigma V_{E3.3} \cdot e_{E3.3.z}}{S_{bz.t}}, \frac{\Sigma V_{E3.3}}{A_b} + \frac{\Sigma V_{E3.3} \cdot e_{E3.3.x}}{S_{bx.R}} + \frac{\Sigma V_{E3.3} \cdot e_{E3.3.z.\sigma}}{S_{bz.t}}\right) = 126.09 \cdot kPa$$

$$\sigma_{toe.E3.3.check} := \begin{array}{|l} \text{"Okay"} \quad \text{if} \quad \sigma_{toe.E3.3} \le \sigma_{allow.E3} \\ \text{"Revise Structure"} \quad \text{otherwise} \end{array}$$

$\sigma_{toe.E3.3.check} = \text{"Okay"}$

Bearing Pressure at Heel(x)-Toe(z):

$$\sigma_{heeltoe.E3.3} := \min\left(\frac{\Sigma V_{E3.3}}{A_b} - \frac{\Sigma V_{E3.3} \cdot e_{E3.3.x.\sigma}}{S_{bx.L}} + \frac{\Sigma V_{E3.3} \cdot e_{E3.3.z}}{S_{bz.t}}, \frac{\Sigma V_{E3.3}}{A_b} - \frac{\Sigma V_{E3.3} \cdot e_{E3.3.x}}{S_{bx.L}} + \frac{\Sigma V_{E3.3} \cdot e_{E3.3.z.\sigma}}{S_{bz.t}}\right) = 62.79 \cdot kPa$$

$$\sigma_{heeltoe.E3.3.check} := \left(\begin{array}{|l} \text{"Okay"} \quad \text{if} \quad \sigma_{heeltoe.E3.3} \le \sigma_{allow.E3} \\ \text{"Revise Structure"} \quad \text{otherwise} \end{array} \right)$$

$\sigma_{heeltoe.E3.3.check} = \text{"Okay"}$

Bearing Pressure at Toe(x)-Heel(z):

$$\sigma_{toeheel.E3.3} := \min\left(\frac{\Sigma V_{E3.3}}{A_b} + \frac{\Sigma V_{E3.3} \cdot e_{E3.3.x.\sigma}}{S_{bx.R}} - \frac{\Sigma V_{E3.3} \cdot e_{E3.3.z}}{S_{bz.b}}, \frac{\Sigma V_{E3.3}}{A_b} + \frac{\Sigma V_{E3.3} \cdot e_{E3.3.x}}{S_{bx.R}} - \frac{\Sigma V_{E3.3} \cdot e_{E3.3.z.\sigma}}{S_{bz.b}}\right) = 153.9 \cdot kPa$$

$$\sigma_{toeheel.E3.3.check} := \begin{array}{|l} \text{"Okay"} \quad \text{if} \quad \sigma_{toeheel.E3.3} \le \sigma_{allow.E3} \\ \text{"Revise Structure"} \quad \text{otherwise} \end{array}$$

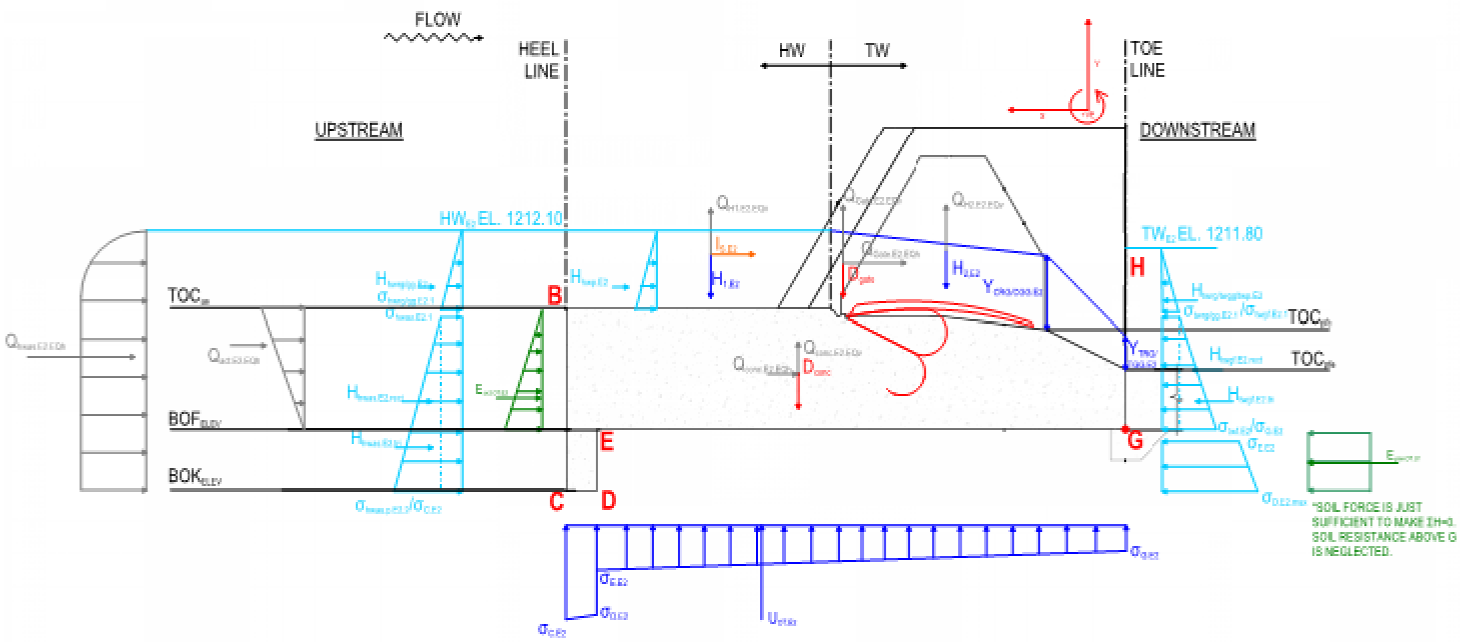
$\sigma_{toeheel.E3.3.check} = \text{"Okay"}$

MONOLITH OVERTURNING STABILITY ANALYSIS

Seismic Case $Q_{E3.3}$: 30% Horizontal Seismic Force, 100% Vertical

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.
Assumptions are made in order to compute overturning stability of indetermine forces on monolith with key;
(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.
(b) The horizontal resisting force acting on the key, P.key, is that required for static equilibrium
(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1 $Ratio_{overturning.allow.Extreme} = 0.25$ Resultant within Base



All Vertical Loads Applicable to Overturning Stability Analysis

Total Concrete Dead Loads:	$D_{conc} = 35947.58 \cdot kN$	at:	$X_{conc.loc} = 8.81\ m$
Dead Load of Gate:	$D_{Gate} = 56.0 \cdot kN$		$X_{gate} = 9.50\ m$
Water Weight (HW) on Apron Slab:	$H_{1.U2} = 3594.1 \cdot kN$		$H_{1.U2.loc.x} = 14.42\ m$
Water Weight (TW) on Gate Footing:	$H_{2.U2} = 1322.9 \cdot kN$		$H_{2.U2.loc.x} = 5.25\ m$
Uplift Load for Overturning Analysis:	$U_{OT.U2} = -20710.3 \cdot kN$		$U_{OT.U2.loc} = 9.88 \cdot m$
Vertical Seismic Component of Concrete Structure:	$Q_{conc.E3.EQv.3} = -3594.76 \cdot kN$		$X_{conc.loc} = 8.81\ m$
Vertical Seismic Component of Crest Gate:	$Q_{Gate.E3.EQv.3} = -5.6 \cdot kN$		$X_{gate} = 9.50\ m$
Vertical Seismic Component of Headwater over Apron Slab:	$Q_{H1.E3.EQv.3} = -359.41 \cdot kN$		$H_{1.U2.loc.x} = 14.42\ m$
Vertical Seismic Component of Headwater over Fixed Crest Slab:	$Q_{H2.E3.EQv.3} = -132.29 \cdot kN$		$H_{2.U2.loc.x} = 5.25\ m$

Sum of All Overturning Analysis Vertical Load:

$$\Sigma V_{E3.OT.3} := D_{conc} + D_{Gate} + H_{1.U2} + H_{2.U2} + U_{OT.U2} + \Sigma V_{Q.E3.EQv.3} = 14312.51 \cdot kN$$

Sum of All Overturning Analysis Vertical Load Moments:

$$\Sigma M_{V.E3.OT.3} := D_{conc} \cdot X_{conc.loc} + D_{Gate} \cdot X_{gate} + H_{1.U2} \cdot H_{1.U2.loc.x} + H_{2.U2} \cdot H_{2.U2.loc.x} + U_{OT.U2} \cdot U_{OT.U2.loc} = 171520.21 \cdot kN \cdot m$$

Lateral Driving Earth Loads for Overturning Stability Analysis (at rest condition)

E3.3 CASE

Depth of Driving Soil Loads (to top of key): $h_{E.OT.E3.3} := TOC_{as} - BOF_{elev} = 4\ m$

Applicable Soil Load: $E_{act.OT.E3.3} := \frac{\left(K_{o.U2} \cdot h_{E.OT.U2}\right)^2}{2} \cdot \left(\gamma_r - \gamma_w\right) \cdot W_{hwas.U2} \cdot -1 = -1026.66 \cdot kN$

At Rest- Soil Load Acting from Toe: $E_{act.OT.E3.3.loc} := \frac{h_{E.OT.U2}}{3} = 1.33\ m$

All Lateral Loads Applicable to Overturning Stability Analysis

HW Lateral Load on Approach Slab:	$H_{hwas.U2} = -4143.7 \cdot kN$	$H_{hwas.U2.loc} = 1.80\ m$
HW Lateral Load on Guard Gate:	$H_{hwgg.U2} = -415.2 \cdot kN$	$H_{hwgg.U2.loc} = 5.53\ m$
TW Lateral Load on Guard Gate:	$H_{twgg.U2} = 63.6 \cdot kN$	$H_{twgg.U2.loc} = 4.60\ m$
TW Lateral Load on Gate Footing (No Key - Overturning Values Adjusted):	$H_{twgf.U2} = 2385.79 \cdot kN$	$H_{twgf.U2.loc} = 1.65\ m$
TW Lateral Load on Key:	$H_{twkey.OT.U2} = 2927.88 \cdot kN$	$H_{twkey.OT.U2.loc} = -1.04\ m$
Ice / Impact Load:	$I_{U2} = 0.0 \cdot kN$	$I_{U2.loc.y} = 8.30\ m$
Lateral Soil Load (driving):	$E_{act.OT.U2} = -1026.7 \cdot kN$	$E_{act.OT.U2.loc} = 1.33\ m$
Horizontal Seismic Component of Concrete Structure:	$Q_{conc.E3.EQh.3} = -1797.38 \cdot kN$	$Y_{conc.loc} = 3.62\ m$
Horizontal Seismic Component of Vertical Lift Gate:	$Q_{Gate.E3.EQh.3} = -2.8 \cdot kN$	$Y_{gate} = 4.00\ m$
Horizontal Seismic Component of Headwater on Slab Footing:	$Q_{hwas.E3.EQh.3.x} = -514.38 \cdot kN$	$Y_{HWg.E3.x} = 3.84\ m$
Horizontal Seismic Component of Active Soil: (Section 5-5, USACE EM_1110-2-2100)	$Q_{act.E3.EQh.3.x} = -351.07 \cdot kN$	$Y_{E.act.E3.x} = 2.52\ m$

Resisting Lateral Soil Load as required to produce horizontal equilibrium:

$$E_{pas.OT.E3.3} := -\left(H_{hwas.U2} + H_{hwgg.U2} + H_{twgg.U2} + H_{twgf.U2} + H_{twkey.OT.U2} + I_{U2} + E_{act.OT.U2} + \Sigma H_{Q.E3.EQh.3.OT.x}\right) = 878.74 \cdot kN$$

Acting at: $E_{pas.OT.E3.3.loc} := -1 \cdot \frac{d_{key}}{2} = -1\ m$

Sum of All Overturning Analysis Horizontal Load (ΣH=0):

$$\Sigma H_{E3.OT.3} := H_{hwas.U2} + H_{hwgg.U2} + H_{twgg.U2} + H_{twgf.U2} + H_{twkey.OT.U2} + I_{U2} + E_{act.OT.U2} + E_{pas.OT.E3.3} + \Sigma H_{Q.E3.EQh.3.OT.x} = 0 \cdot kN$$

Sum of All Overturning Analysis Horizontal Load Moments:

$$\begin{aligned}\Sigma M_{H.E3.OT.3} := {} & H_{hwas.U2} \cdot H_{hwas.U2.loc} + H_{hwgg.U2} \cdot H_{hwgg.U2.loc} + H_{twgg.U2} \cdot H_{twgg.U2.loc} \cdots = -23631.24 \cdot kN \cdot m \\ & + H_{twgf.U2} \cdot H_{twgf.U2.loc} + H_{twkey.OT.U2} \cdot H_{twkey.OT.U2.loc} + I_{U2} \cdot I_{U2.loc.y} \cdots \\ & + E_{act.OT.U2} \cdot E_{act.OT.U2.loc} + E_{pas.OT.x.U2} \cdot E_{pas.OT.U2.loc} + \Sigma M_{Q.E3.3}\end{aligned}$$

Overturning Stability Analysis

$$\Sigma M_{E3.OT.3} := \Sigma M_{V.E3.OT.3} + \Sigma M_{H.E3.OT.3} = 147888.96 \cdot kN \cdot m$$

$$X_{R.E3.3} := \frac{\Sigma M_{E3.OT.3}}{\Sigma V_{E3.OT.3}} = 10.33\ m \qquad x_{OT.E3.3} := X_{R.E3.3} - \frac{L_B}{2} = 1.08\ m$$

Overturning Resultant Ratio

$$Ratio_{OT.E3.3} := \frac{X_{R.E3.3}}{L_B} = 0.56$$

$$Ratio_{OT.E3.3.check} := \begin{cases} \text{"OKAY"} & \text{if } Ratio_{OT.E3.3} \geq Ratio_{overturning.allow.Extreme} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

Appendix E.2-4 LEFT ABUTMENT RETAINING WALLS

Calculation Section I

Results Summary Table (overview)

Table E.2-4.1 – Service Spillway – Retaining Walls – Stability Analysis Summary

Load Case	Headwater (Heel) Elevation (m)	Tailwater (Toe) Elevation For Uplift (m)	Uplift Force (kN)	Floatation Safety Factor (FSF)		Sliding Safety Factor (SSF)		Foundation Bearing Stress		% Base in Compression
				Req	Calc	Req	Calc	Upstream (Heel) (kPa)	Downstream (Toe) (kPa)	
WALL BLOCK 5B										
U1 Normal Operation	1213.1	1210.0	802	1.5	3.36	1.5	1.67	149	213	100
UN1 Equip. Surcharge	1213.1	1210.0	802	1.3	3.49	1.3	2.01	140	242	100
UN2 Ineffective Drain	1216.2	1216.2	1372	1.3	2.00	1.3	1.30	99	184	100
E1 Seismic	1213.1	1210.0	802	1.1	3.03	1.0	1.79	119	203	100
WALL BLOCK 5C										
U1 Normal Operation	1213.0	1210.0	1041	1.5	3.23	1.5	1.64	73	404	100
UN1 Equip. Surcharge	1213.0	1210.0	1041	1.3	3.35	1.3	1.52	56	444	100
UN2 Ineffective Drain	1214.4	1214.4	1397	1.3	2.43	1.3	1.32	49	379	100
E1 Seismic	1213.0	1210.0	1041	1.1	2.92	1.0	1.30	43	386	100
WALL BLOCK 5D (Mid-section)										
U1 Normal Operation	1212.5	1210.0	862	1.5	2.78	1.5	1.92	85	272	100
UN1 Equip. Surcharge	1212.5	1210.0	862	1.3	2.90	1.3	1.73	76	304	100
UN2 Ineffective Drain	1214.4	1214.4	1202	1.3	2.02	1.3	1.31	49	258	100
E1 Seismic	1212.5	1210.0	862	1.1	2.51	1.0	1.35	55	266	100
WALL BLOCK 5D (Downstream)										
U1 Normal Operation	1212.5	1210.0	722	1.5	2.21	1.5	2.38	71	169	100
UN1 Equip. Surcharge	1212.5	1210.0	722	1.3	2.33	1.3	2.04	70	192	100
UN2 Ineffective Drain	1212.6	1212.6	847	1.3	1.88	1.3	1.31	69	145	100
E1 Seismic	1212.5	1210.0	722	1.1	1.99	1.0	1.28	42	172	100

Notes:
1. See Appendix E.2 for definition of wall section description, analysis methodology, and stability calculations.
2. Analysis assumes inclined sliding plane, interface friction angle Φ = 26 degrees, and no cohesion.
3. Seismic results utilize active soil pressure coefficients for stability values reported.

Calculation Section II

Results Summary Table (detailed)

RETAINING WALL SS-BLOCK 5C STABILITY SUMMARY

Load Combination	Σ Vertical (kN)	Σ Horizontal (kN)	Σ Vertical Inclined Plane (kN)	Σ Horizontal Inclined Plane (kN)	Σ Moments (kN*m)	e Inclined Plane (m)	σ @ Toe (kN/m2)	σ @ Heel (kN/m2)	Base in Compression %	SSF Stability Required	SSF Horiz	SSF Inclined	Σ Vertical Without Uplift (kN)	Σ Uplift (kN)	FSF Floatation Required	FSF Floatation Calculated
U1	2327.0	1587.1	3079.6	836.9	15288.4	1.49	403.9	72.9	100.0	1.5	0.72	1.64	3368.3	1041	1.5	3.23
UN1	2447.9	1730.5	3232.7	945.1	15488.1	1.67	444.1	56.4	100.0	1.3	0.69	1.52	3489.2	1041	1.3	3.35
UN2	1995.8	1596.5	2761.5	929.6	13248.3	1.66	378.7	48.8	100.0	1.3	0.61	1.32	3392.3	1397	1.3	2.43
E1	2000.1	1619.9	2771.5	951.1	16128.3	1.72	386.1	43.0	100.0	1.0	0.60	1.30	3041.4	1041	1.1	2.92

RETAINING WALL SS-BLOCK 5B STABILITY SUMMARY

Load Combination	Σ Vertical (kN)	Σ Horizontal (kN)	Σ Vertical Inclined Plane (kN)	Σ Horizontal Inclined Plane (kN)	Σ Moments (kN*m)	e Inclined Plane (m)	σ @ Toe (kN/m2)	σ @ Heel (kN/m2)	Base in Compression %	SSF Stability Required	SSF Horiz	SSF Inclined	Σ Vertical Without Uplift (kN)	Σ Uplift (kN)	FSF Floatation Required	FSF Floatation Calculated
U1	1891.2	821.2	2294.0	434.5	13700.7	0.37	212.6	149.0	100.0	1.5	2.35	1.67	2693.6	802	1.5	3.36
UN1	1998.3	944.0	2420.5	537.2	13981.1	0.57	242.0	139.6	100.0	1.3	1.03	2.01	2800.7	802	1.3	3.49
UN2	1369.1	913.0	1795.3	614.4	10251.7	0.63	183.9	99.1	100.0	1.3	0.73	1.30	2741.1	1372	1.3	2.00
E1	1629.8	848.8	2041.2	506.5	14791.7	0.56	203.3	118.5	100.0	1.0	0.94	1.79	2432.2	802	1.1	3.03

RETAINING WALL SS-BLOCK 5D (DOWNSTREAM) STABILITY SUMMARY

Load Combination	Σ Vertical (kN)	Σ Horizontal (kN)	Σ Vertical Inclined Plane (kN)	Σ Horizontal Inclined Plane (kN)	Σ Moments (kN*m)	e Inclined Plane (m)	σ @ Toe (kN/m2)	σ @ Heel (kN/m2)	Base in Compression %	SSF Stability Required	SSF Horiz	SSF Inclined	Σ Vertical Without Uplift (kN)	Σ Uplift (kN)	FSF Floatation Required	FSF Floatation Calculated
U1	870.0	480.6	1168.8	218.7	4926.5	0.66	168.7	70.8	100.0	1.5	0.88	2.38	1591.5	722	1.5	2.21
UN1	960.9	563.3	1276.2	278.4	5262.4	0.76	191.6	70.0	100.0	1.3	0.83	2.04	1682.4	722	1.3	2.33
UN2	745.6	459.7	1042.9	226.9	4486.8	0.58	144.8	68.9	100.0	1.3	0.67	1.31	1592.8	847	1.3	1.88
E1	715.5	592.7	1044.1	363.2	5231.9	0.99	172.0	41.9	100.0	1.0	0.59	1.28	1437.0	722	1.1	1.99

RETAINING WALL SS-BLOCK 5D (MIDSTREAM) STABILITY SUMMARY

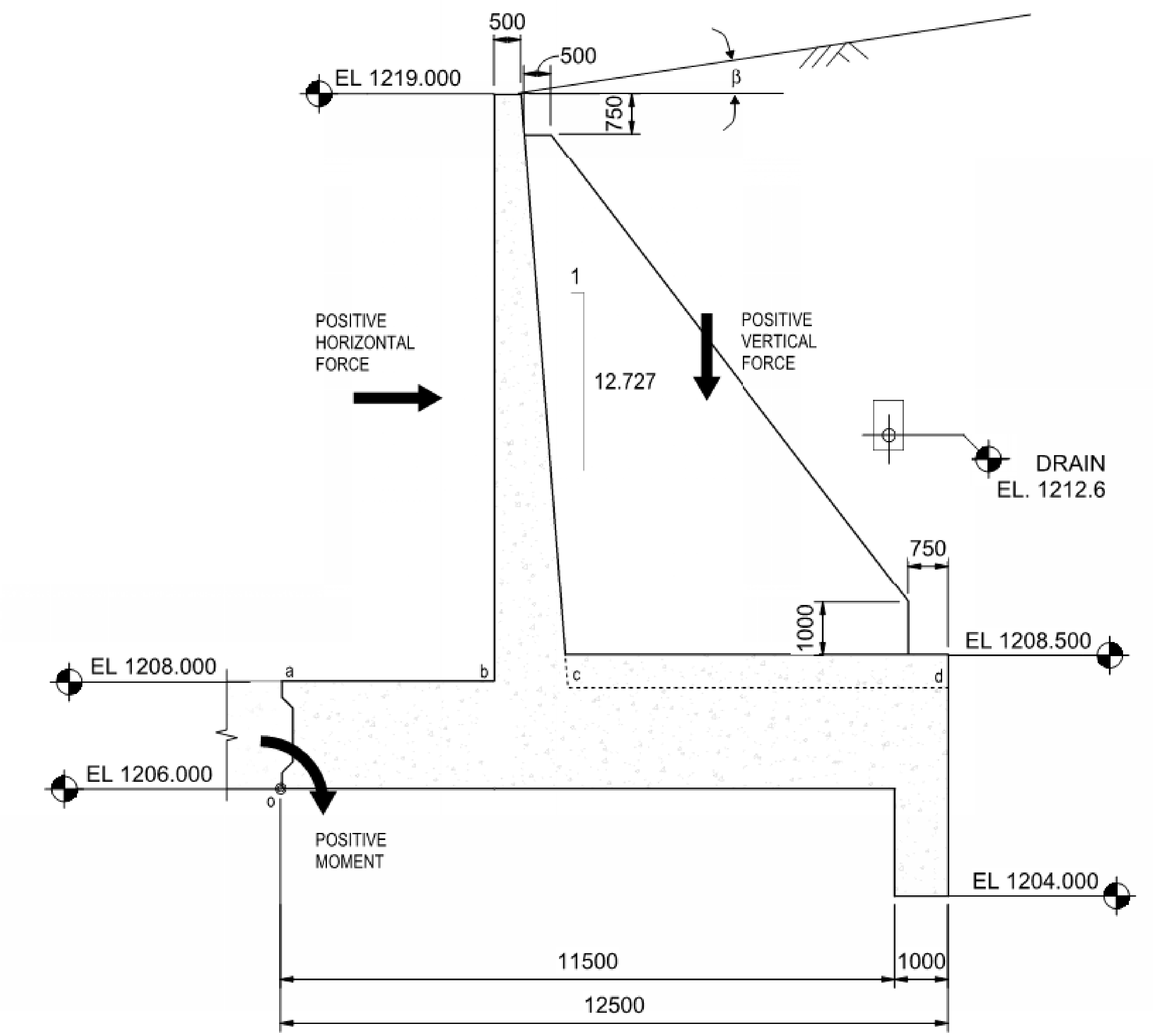
Load Combination	Σ Vertical (kN)	Σ Horizontal (kN)	Σ Vertical Inclined Plane (kN)	Σ Horizontal Inclined Plane (kN)	Σ Moments (kN*m)	e Inclined Plane (m)	σ @ Toe (kN/m2)	σ @ Heel (kN/m2)	Base in Compression %	SSF Stability Required	SSF Horiz	SSF Inclined	Σ Vertical Without Uplift (kN)	Σ Uplift (kN)	FSF Floatation Required	FSF Floatation Calculated
U1	1531.8	947.8	2026.4	470.3	9485.7	0.99	272.2	85.3	100.0	1.5	0.79	1.92	2394.2	862	1.5	2.78
UN1	1637.7	1060.8	2156.6	554.3	9779.4	1.13	304.4	76.0	100.0	1.3	0.75	1.73	2500.1	862	1.3	2.90
UN2	1221.0	991.1	1735.4	587.8	7598.5	0.69	257.6	48.5	100.0	1.3	0.60	1.31	2423.0	1202	1.3	2.02
E1	1299.4	1025.4	1819.8	602.0	10049.8	1.24	266.1	54.9	100.0	1.0	0.62	1.35	2161.8	862	1.1	2.51

Calculation Section III

SS-5B Retaining Wall Stability Calculations

Project Number:	110773396
Project Title:	SR1 - Diversion Structure
Client:	Alberta Transportation
Engineer:	Lawrence Choi — Date: 12/11/2018
Checker:	Sean Xiao — Date: 12/18/2018

Calculation for: Retaining Wall - Service Spillway Left - Block 5B



REGION COLOR CONVENTION

User Input

Calulation Highlights

Results

WALL GEOMETRY:

Top of Wall Elevation: $T_w := 1219.0 \cdot m$

Top of Footing Elevation: $Top_{ftg} := 1208.0 \cdot m$

Thickness of Footing: $t_{ftg} := 2.0m$

Bottom of Footing Elevation: $Bot_{ftg} := Top_{ftg} - t_{ftg} = 1206\,m$

Overall Height of wall: $h_w := T_w - Bot_{ftg} = 13.00\,m$

Thickness of Wall: Base: $t_{wb} := 1.364 \cdot m$ Top: $t_{wt} := 0.50m$

Length of toe: $L_{ab} := 4.0m$

Total Length of Footing: $b := 12.5m$

Length of heel: $L_{cd} := b - L_{ab} - t_{wb} = 7.136\,m$

Unit Width of Wall for analysis: $B := 1.00m$

SHEAR KEY GEOMETRY:

	Toe	Heel	
Key depth:	$Key_{t.d} := 0m$	$Key_{h.d} := 2m$	(Assumption: $Key_{h.d}$ >= $Key_{t.d}$)
Key width:	$Key_{t.w} := 0m$	$Key_{h.w} := 1m$	
Face of Key from Point O:	$Key_{t.loc} := 0 \cdot m$	$Key_{h.loc} := 11.5 \cdot m$	

Horizontal Distance between Keys: $Key_{hdist} := Key_{h.loc} - Key_{t.loc} - Key_{t.w} = 11.5\,m$

Key Depth Diff. (from point O): $Key_{vdist} := -Key_{h.d} + Key_{t.d} = -2\,m$

BASE PROPERTIES:

Base Area: $A_b := b \cdot B = 12.5\,m^2$

Centroidal Distance for Footing (from Toe): $Y_t := \frac{b}{2} = 6.25\,m$

RETAINED SOIL GEOMETRY:

Slope of retained ground surface: $\beta := 0 \cdot \frac{\pi}{180} = 0.00$

Height of retained earth at heel: $H_w := T_w - Bot_{ftg} + \left(t_{wb} + L_{cd} - t_{wt}\right) \cdot \tan(\beta) = 13.00\,m$

RETAINING WALL GEOMETRY CHECKS:

(Foundation Analysis & Design Bowles)

$$t_{bcheck} := \begin{cases} \text{"OKAY"} & \text{if } t_{ftg} \geq \frac{H_w}{12} \\ \text{"Warning"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

$$t_{wcheck} := \begin{cases} \text{"OKAY"} & \text{if } t_{wb} \geq \frac{H_w}{12} \\ \text{"Warning"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

$$b_{check} := \begin{cases} \text{"OKAY"} & \text{if } \frac{b}{H_w} \geq .4 \wedge \frac{b}{H_w} \leq 80 \\ \text{"Warning"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

$$L_{abcheck} := \begin{cases} \text{"OKAY"} & \text{if } \frac{L_{ab}}{b} \geq .25 \wedge \frac{L_{ab}}{b} \leq .4 \\ \text{"Warning"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

Material Properties:

Unit Weight of Water: $\gamma_w := 9.8 \frac{kN}{m^3}$ (Section 7.2, Design Criteria)

Unit Weight of Concrete: $\gamma_c := 23.5 \frac{kN}{m^3}$

Unit Weight of Soil (Moist): $\gamma_m := 20.0 \frac{kN}{m^3}$ (Section 5.3, Design Criteria) assumed moisture content (w) = 5%

Unit Weight Soil (Saturated): $\gamma_{sat} := 22.0 \frac{kN}{m^3}$ (Assuming Specific Gravity = 2.7

Unit Weight Soil (buoyant): $\gamma_b := \gamma_{sat} - \gamma_w = 12.2 \cdot \frac{kN}{m^3}$

Weight of Soil/Concrete above toe: $\gamma_{toe} := 22.0 \frac{kN}{m^3}$

Unit Weight of Rock: $\gamma_r := 25.6 \frac{kN}{m^3}$ (Section 7.2, Design Criteria)

Foundation Parameters:

Glacial Till Internal Friction: $\phi := 27 \cdot \frac{\pi}{180} = 0.471$

Bedrock Internal Friction Angle: $\phi_r := 24 \cdot \frac{\pi}{180} = 0.419$

Friction Angle at Base Concrete / Rock Interface: $\phi_{rock} := 26$

Base Friction Coefficient: $tan_{\phi rock} := \tan\left(\phi_{rock} \frac{\pi}{180}\right) = 0.488$ radians

Rip Rap Backfill, Refer Dwg. C-214 $\phi_{backfill} := \left(20 \frac{\pi}{180}\right) = 0.349$ radians

Shear strength along rock Failure plane $s_r := \frac{13100 \frac{kN}{m^2}}{2} = 6550 \cdot \frac{kN}{m^2}$ (Stantec Design Memo 8/8/16)

CONCRETE DEAD LOAD:

Area of Footing: $A_{ftg} := t_{ftg} \cdot b = 25\,m^2$

Weight of Footing: $D_{ftg} := A_{ftg} \cdot B \cdot \gamma_c = 587.5 \cdot kN$

Area of Stem (without batter): $A_{w1} := t_{wt} \cdot \left(h_w - t_{ftg}\right) = 5.5\,m^2$

Weight of Stem: $D_{w1} := A_{w1} \cdot B \cdot \gamma_c = 129.3 \cdot kN$

Area of stem Batter: $A_{w2} := \dfrac{\left(t_{wb} - t_{wt}\right)}{2} \left(h_w - t_{ftg}\right) = 4.75\,m^2$

Weight of Batter: $D_{w2} := A_{w2} \cdot B \cdot \gamma_c = 111.7 \cdot kN$

Slope of batter: $S_{batter} := \dfrac{t_{wb} - t_{wt}}{h_w - t_{ftg}} = 0.079$

Area of Key $A_{t.key} := Key_{t.d} \cdot Key_{t.w} = 0$ $A_{h.key} := Key_{h.d} \cdot Key_{h.w} = 2\,m^2$

Weight of Key $D_{t.key} := A_{t.key} \cdot B \cdot \gamma_c = 0 \cdot kN$ $D_{h.key} := A_{h.key} \cdot B \cdot \gamma_c = 47 \cdot kN$

Centroidal Horizontal Distance of Wall (From Toe):

$$H_{cent} := \frac{A_{w1} \cdot \left(L_{ab} + \frac{t_{wt}}{2}\right) + A_{w2} \cdot \left(L_{ab} + t_{wt} + \frac{t_{wb} - t_{wt}}{3}\right) + A_{ftg} \cdot \frac{b}{2} + A_{t.key} \cdot \left(Key_{t.loc} + \frac{Key_{t.w}}{2}\right) + A_{h.key} \cdot \left(Key_{h.loc} + \frac{Key_{h.w}}{2}\right)}{A_{w1} + A_{w2} + A_{ftg} + A_{t.key} + A_{h.key}} = 6.08\,m$$

Centroidal Vertical Distance of Wall (Above Base of Footing):

$$V_{Cent} := \frac{A_{ftg} \cdot \frac{t_{ftg}}{2} + A_{w1} \cdot \left[t_{ftg} + \frac{\left(h_w - t_{ftg}\right)}{2}\right] + A_{w2} \cdot \left[t_{ftg} + \frac{\left(h_w - t_{ftg}\right)}{3}\right] + A_{t.key} \cdot \left(\frac{-Key_{t.d}}{2}\right) + A_{h.key} \cdot \left(\frac{-Key_{h.d}}{2}\right)}{A_{ftg} + A_{w1} + A_{w2} + A_{t.key} + A_{h.key}} = 2.45\,m$$

$\Sigma V_{conc} := D_{ftg} + D_{w1} + D_{w2} + D_{t.key} + D_{h.key} = 875.4 \cdot kN$

$\Sigma M_{conc} := \Sigma V_{conc} \cdot H_{cent} = 5319.9\,m \cdot kN$

ROCK SECTION MOBILIZED FOR INCLINDED SLIDING FAILURE

Area of Rock Section Mobilized: $A_{rocksection} := \left(Key_{t.d} + Key_{h.d}\right) \cdot \dfrac{Key_{hdist}}{2} = 11.5\,m^2$

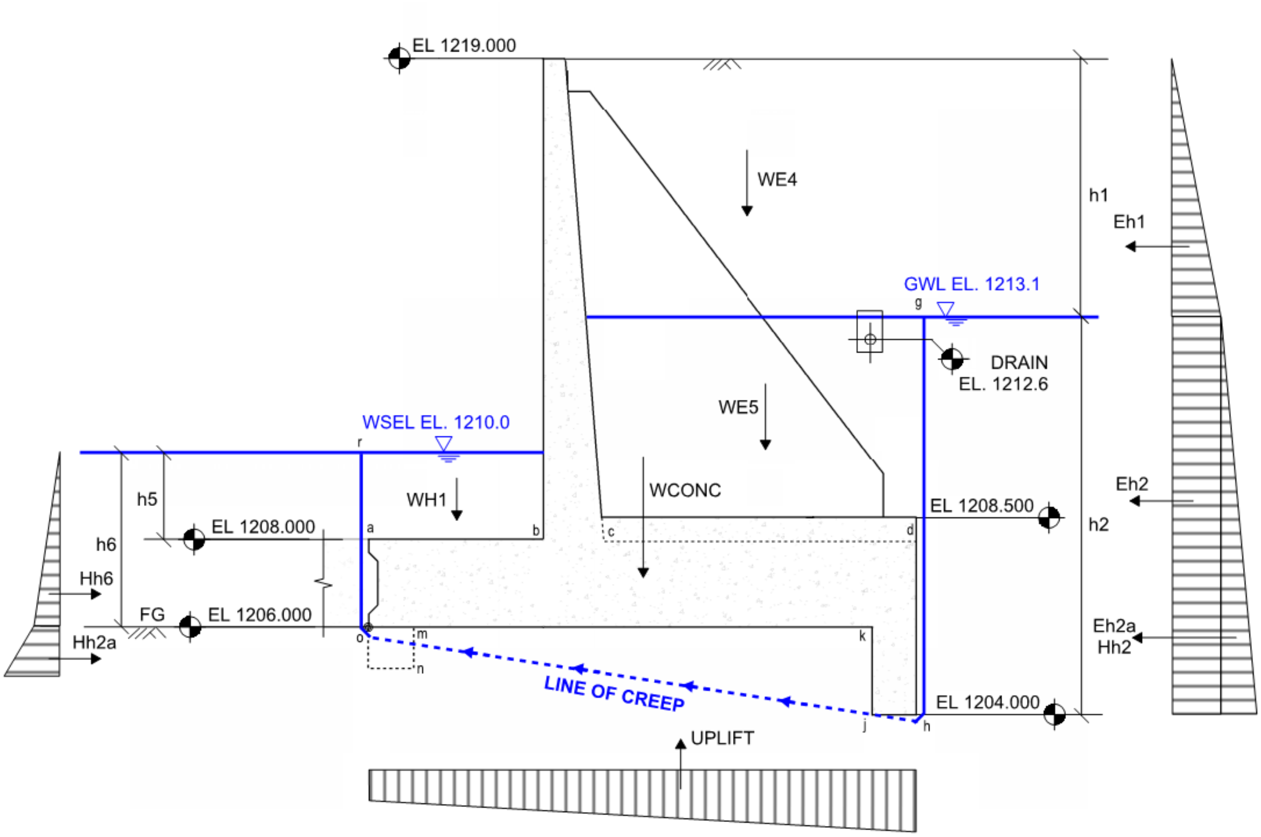
Rock Mass Mobilized: $V_{rocksection} := A_{rocksection} \cdot \gamma_r \cdot B = 294.4 \cdot kN$

(Pore pressure taken along assumed inclined sliding plane)

Distance from Toe to COG of Rock Section: $L_{rocksection} := \dfrac{Key_{hdist} \cdot \left(2 \cdot Key_{h.d} + Key_{t.d}\right)}{3\left(Key_{h.d} + Key_{t.d}\right)} + Key_{t.w} = 7.667\,m$

$\Sigma M_{rocksection} := V_{rocksection} \cdot L_{rocksection} = 2257.1\,m \cdot kN$

LOAD CASE U1 - NORMAL OPERATION



U1 DESIGN CASE

LOAD CASE U1 ACCEPTANCE PARAMETERS

FS sliding:

Usual (U) 1.5 (without cohesion) (Table 3-3, USACE EM 1110-2-2100)

Resultant Location:

Usual (U) Inside middle third ~100% base in compression

Required Factor of Safety for Sliding: $FS_{sliding.reqU1} := 1.5$ (Without Cohesion)

Allowable rock bearing pressure: $\sigma_{allowU1} := 1270kPa$ (Section 5.2, Design Criteria EM 1110-2-2100 Section 3-10)

Overturning Required Resultant Ratio: $X_{R.reqU1} := 0.333$ (EM 1110-2-2502, Figure 4-4)

Required Factor of Safety for Floatation $FS_{req.U1.flt} := 1.5$

SOIL HEIGHTS and Water Levels:

LOAD CASE U1

Heel Conditions:

Groundwater Elevation at Heel: $GWL_{U1} := 1213.1 m$

Distance from Finish Grade to Groundwater at Heel: $h_{1U1} := \left[T_w - GWL_{U1} + \left(L_{cd} + t_{wb} - t_{wt}\right)\cdot \tan(\beta)\right] = 5.90\ m$

Distance from Water Surface to Bottom of Footing at Heel: $h_{2U1} := GWL_{U1} - Bot_{ftg} + Key_{h.d} = 9.10\ m$

Toe Conditions:

Water Surface Elevation at Toe: $WSEL_{U1} := 1210.0m$

Water Surface Elevation at Toe for Uplift: $UWSEL_{U1} := 1210.0\cdot m$

Finish Grade at Toe providing lateral resistance: $FG_{toeU1} := 1206.0\cdot m$

Soil Depth Above top of footing: $h_{3aU1} := FG_{toeU1} - Top_{ftg} = -2\ m$

$$h_{3U1} := \begin{vmatrix} h_{3aU1} & \text{if } FG_{toeU1} - Top_{ftg} \geq 0 \\ 0 & \text{otherwise} \end{vmatrix} = 0$$

Resisting Fill at Toe: $h_{4U1} := FG_{toeU1} - Bot_{ftg} + Key_{t.d} = 0.00\ m$

Distance from Water Level to Top of Footing: $h_{5U1} := WSEL_{U1} - Top_{ftg} = 2.00\ m$

Distance from Water Surface to Bottom of Footing: $h_{6U1} := WSEL_{U1} - Bot_{ftg} + Key_{t.d} = 4.00\cdot m$

Soil Depth Above WSEL: $h_{7aU1} := FG_{toeU1} - WSEL_{U1} = -4\ m$

$$h_{7U1} := \begin{vmatrix} h_{7aU1} & \text{if } FG_{toeU1} - WSEL_{U1} \geq 0 \\ 0 & \text{otherwise} \end{vmatrix} = 0$$

Soil Depth Below WSEL:

$$h_{8U1} := \begin{vmatrix} WSEL_{U1} - Bot_{ftg} + Key_{t.d} & \text{if } FG_{toeU1} - WSEL_{U1} \geq 0 \\ h_{4U1} & \text{otherwise} \end{vmatrix} = 0$$

For Line of Creep Method: $L_{ho.U1} := \sqrt{b^2 + \left(Key_{h.d} - Key_{t.d}\right)^2} = 12.659\ m$

Head Loss from Point g:

$\Delta h_{g.hj.U1} := h_{2U1} = 9.1\ m$ (to point h & j)

$\Delta h_{g.km.U1} := GWL_{U1} - Bot_{ftg} = 7.1\ m$ (to point k & m)

$\Delta h_{g.no.U1} := GWL_{U1} - Bot_{ftg} + Key_{t.d} = 7.1\ m$ (to point n & o)

$\Delta h_{g.p.U1} := GWL_{U1} - FG_{toeU1} = 7.1\ m$ (to point p*)

$\Delta h_{g.r.U1} := GWL_{U1} - UWSEL_{U1} = 3.1\ m$ (to point r)

Surcharge

Surcharge on Heel: $S1_{U1} := 0.0 \frac{kN}{m^2}$

* same as point "o" in this case

Calculate Soil Lateral Pressure Coefficients:

LOAD CASE U1

For all load cases except seismic, soil loading to be based on At-Rest Condition.
Calculate at-rest pressure coefficient Ko based on Jaky's (1944) equation.

Soil At Rest Static Coefficient: $K_o := \frac{1 - \sin(\phi)}{1 + \sin(\beta)} = 0.546$ (Eq. 3-6, USACE EM 1110-2-2502)

Lateral - Driving Force (Headwater Side)

Lateral Soil Load:

Surcharge Load: $E_{s1U1} := S1_{U1} \cdot K_o \cdot \left(H_w + Key_{h.d}\right) \cdot B \cdot -1 = 0 \cdot kN$

Moment Arm (from bottom of footing): $E_{s1locU1} := \frac{H_w + Key_{h.d}}{2} + Key_{vdist} = 5.50\ m$

Moist Soil Load above GWL: $E_{h1U1} := \frac{\gamma_m \cdot K_o \cdot h_{1U1}^{\ 2}}{2} B \cdot -1 = -190.1 \cdot kN$

Moment Arm (from bottom of footing): $E_{h1locU1} := \frac{h_{1U1}}{3} + h_{2U1} + Key_{vdist} = 9.07\ m$

Saturated Soil Load below GWL:
(rectangular component) $E_{h2U1} := \left(\gamma_m \cdot K_o \cdot h_{1U1}\right) \cdot \left(h_{2U1}\right) \cdot B \cdot -1 = -586.3 \cdot kN$

Moment Arm (from bottom of footing): $E_{h2locU1} := \frac{h_{2U1}}{2} + Key_{vdist} = 2.55\ m$

Saturated Soil Load below GWL:
(triangular component) $E_{h2aU1} := \frac{\left(\gamma_{sat} - \gamma_w\right) \cdot K_o \cdot h_{2U1}^{\ 2}}{2} \cdot B \cdot -1 = -275.8 \cdot kN$

Moment Arm (from bottom of footing): $E_{h2alocU1} := \frac{h_{2U1}}{3} + Key_{vdist} = 1.03\ m$

Lateral Water Load:

Water Load GWL to Bottom of Key $H_{h2U1} := \frac{\gamma_w \cdot h_{2U1}^{\ 2}}{2} \cdot B \cdot -1 = -405.8 \cdot kN$

Moment Arm (from bottom of footing): $H_{h2locU1} := \frac{h_{2U1}}{3} + Key_{vdist} = 1.03\ m$

$\Sigma H_{SoildriveU1} := E_{s1U1} + E_{h1U1} + E_{h2U1} + E_{h2aU1} + H_{h2U1} = -1458.0 \cdot kN$

$\Sigma M_{LateralSoildriveU1} := E_{s1U1} \cdot E_{s1locU1} + E_{h1U1} \cdot E_{h1locU1} + E_{h2U1} \cdot E_{h2locU1} + E_{h2aU1} \cdot E_{h2alocU1} + H_{h2U1} \cdot H_{h2locU1} = -3922.6\ m \cdot kN$

Lateral - Resisting Force (Tailwater Side)

LOAD CASE U1

Lateral Water Load:

Water Load WSEL to Bot. of Footing: $H_{h6U1} := \frac{\gamma_w \cdot h_{6U1}^2}{2} \cdot B = 78.4 \cdot kN$

Moment Arm (from bot. of toe key): $H_{h6locU1} := \frac{h_{6U1}}{3} = 1.33\ m$

Water Load Bot. of Footing to Bot. of H. Key: $H_{h2aU1} := \left[\left(UWSEL_{U1} - Bot_{ftg} + Key_{t.d}\right) + h_{2U1}\right] \cdot \frac{Key_{h.d}}{2} \cdot \gamma_w \cdot B = 128.4 \cdot kN$

Moment Arm (from bot. of toe key): $H_{h2alocU1} := \frac{Key_{h.d} \cdot \left[2 \cdot \left(UWSEL_{U1} - Bot_{ftg} + Key_{t.d}\right) + h_{2U1}\right]}{3\left[h_{2U1} + \left(UWSEL_{U1} - Bot_{ftg} + Key_{t.d}\right)\right]} \ldots + Key_{vdist} = -1.13\ m$

Lateral Soil Load:

Moist Soil Load above WSEL: $E_{h7U1} := \frac{\gamma_m \cdot K_o \cdot h_{7U1}^2}{2} \cdot B = 0.0 \cdot kN$

Moment Arm (from bot. of toe key): $E_{h7locU1} := h_{6U1} + \frac{h_{7U1}}{3} + Key_{vdist} = 2.00\ m$

Saturated Soil Load below WSEL:
(rectangular component) $E_{h8U1} := \left(\gamma_m \cdot K_o \cdot h_{7U1}\right) \cdot h_{8U1} \cdot B = 0.0 \cdot kN$

Moment Arm (from bot. of toe key): $E_{h8locU1} := \frac{h_{8U1}}{2} = 0.00\ m$

Saturated Soil Load below WSEL:
(triangular component) $E_{h8aU1} := \frac{\left[\left(\gamma_{sat} - \gamma_w\right) \cdot K_o\right] \cdot h_{8U1}^2}{2} \cdot B = 0.0 \cdot kN$

Moment Arm (from bot. of footing): $E_{h8alocU1} := \frac{h_{8U1}}{3} = 0.00\ m$

Lateral Resistance from Stilling Basin:

Lateral Resistance from Stilling Basin: $P_{sbU1} := 430kN$ (Force needed to achieve the required sliding factor of safety in case UN2)

Moment Arm (from bot. of toe key): $P_{sblocU1} := \frac{t_{ftg}}{2} + Key_{t.d} = 1.00\ m$

$$\Sigma H_{SoilresistU1} := H_{h6U1} + H_{h2aU1} + E_{h7U1} + E_{h8U1} + E_{h8aU1} + P_{sbU1} = 636.8 \cdot kN$$

$$\Sigma M_{HorizSoilResistU1} := H_{h6U1} \cdot H_{h6locU1} + H_{h2aU1} \cdot H_{h2alocU1} + E_{h7U1} \cdot E_{h7locU1} \ldots + E_{h8U1} \cdot E_{h8locU1} + E_{h8aU1} \cdot E_{h8alocU1} + P_{sbU1} \cdot P_{sblocU1} = 389.5\ m \cdot kN$$

Vertical Force:

UPLIFT: Linear distribution from water at heel to water at toe:

$$\Sigma V_{UpliftU1} := \left[\left(UWSEL_{U1} - Bot_{ftg} + Key_{t.d}\right) + h_{2U1}\right] \cdot \frac{b}{2} \cdot \gamma_w \cdot B \cdot -1 = -802.375 \cdot kN$$

Moment Arm (from Point O): $V_{UpliftU1aloc} := \frac{b \cdot \left[2 \cdot h_{2U1} + \left(UWSEL_{U1} - Bot_{ftg} + Key_{t.d}\right)\right]}{3\left[h_{2U1} + \left(UWSEL_{U1} - Bot_{ftg} + Key_{t.d}\right)\right]} = 7.061\ m$

$$\Sigma M_{UpliftU1} := \Sigma V_{UpliftU1} \cdot V_{UpliftU1aloc} = -5665.625 \cdot kN \cdot m$$

Vertical Force (con't):

Weight of soil and water over toe:

Water Above the Top of Footing: $W_{H1U1} := \gamma_w \cdot h_{5U1} \cdot L_{ab} \cdot B = 78.4 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E1locU1} := \frac{L_{ab}}{2} = 2\,m$

Soil above top of footing: $W_{E6U1} := \gamma_b \cdot h_{3U1} \cdot L_{ab} \cdot B = 0.0 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E6locU1} := \frac{L_{ab}}{2} = 2\,m$

Vertical Load Due to Surcharge: $S_{U1} := S1_{U1} \cdot L_{cd} \cdot B = 0$ $\quad S_{U1loc} := b - \frac{L_{cd}}{2} = 8.93\,m$

Weight of soil and water over heel:

Moist Soil for sloped grade above top of wall:

Length of sloped portion of soil above top of wall: $L_{E3U1} := \left(L_{cd} + t_{wb} - t_{wt}\right) = 8.00\,m$

Height of sloped soil above top of wall over heel: $h_{E3locU1} := \left(L_{E3U1}\right) \cdot \tan(\beta) = 0.00\,m$

Weight of sloped soil above top of wall: $W_{E3U1} := \frac{\gamma_m}{2} \cdot h_{E3locU1} \cdot L_{E3U1} \cdot B = 0.0 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E3locU1} := L_{ab} + t_{wt} + \frac{2}{3} \cdot L_{E3U1} = 9.83\,m$

Moist soil from top of wall to groundwater level:

Height of soil from top of wall and top of GWL: $h_{1U1} = 5.90\,m$

Length from edge of wall at GWL to edge of heel: $L_{E4U1} := L_{E3U1} - \left(h_{1U1} \cdot S_{batter}\right) = 7.54\,m$

Weight of soil over heel from top of wall to GWL: $W_{E4U1} := \gamma_m \cdot h_{1U1} \cdot \frac{\left(L_{E3U1} + L_{E4U1}\right)}{2} \cdot B = 916.7 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E4locU1} := b - \frac{L_{E3U1}^{2} + L_{E3U1} \cdot L_{E4U1} + L_{E4U1}^{2}}{3\left(L_{E3U1} + L_{E4U1}\right)} = 8.61\,m$

Saturated soil from groundwater to top of footing:

Height of soil from GWL to top of heel: $h_{E4U1} := h_{2U1} - t_{ftg} - Key_{h.d} = 5.10\,m$

Weight of soil over heel from GWL to top of heel: $W_{E5U1} := \left(\gamma_{sat}\right) \cdot h_{E4U1} \cdot \frac{\left(L_{E4U1} + L_{cd}\right)}{2} \cdot B = 823.1 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E5locU1} := b - \frac{L_{E4U1}^{2} + L_{E4U1} \cdot L_{cd} + L_{cd}^{2}}{3\left(L_{E4U1} + L_{cd}\right)} = 8.83\,m$

$\Sigma V_{SoilWaterU1} := W_{H1U1} + W_{E6U1} + W_{E3U1} + W_{E4U1} + W_{E5U1} + S_{U1} = 1818.2 \cdot kN$

$$\Sigma M_{VertSoilWaterResistU1} := W_{H1U1} \cdot W_{E1locU1} + W_{E6U1} \cdot W_{E6locU1} \cdots + W_{E3U1} \cdot W_{E3locU1} + W_{E4U1} \cdot W_{E4locU1} + W_{E5U1} \cdot W_{E5locU1} + S_{U1} \cdot S_{U1loc} = 15322.6\,m \cdot kN$$

THIS PAGE INTENTIONALLY LEFT BLANK
PLEASE GO TO THE NEXT PAGE

STABILITY ASSESSMENT:

LOAD CASE U1

CHECK SLIDING ALONG HORIZONTAL SLIDING PLANE:

Summation of the vertical forces:

$$\Sigma V_{U1} := \Sigma V_{conc} + \Sigma V_{SoilWaterU1} + \Sigma V_{UpliftU1} = 1891.2 \cdot kN$$

Summation of the horizontal forces:

$$\Sigma H_{U1} := \Sigma H_{SoildriveU1} + \Sigma H_{SoilresistU1} = -821.2 \cdot kN$$

Safety Factor for Sliding Horizontal Failure Plane

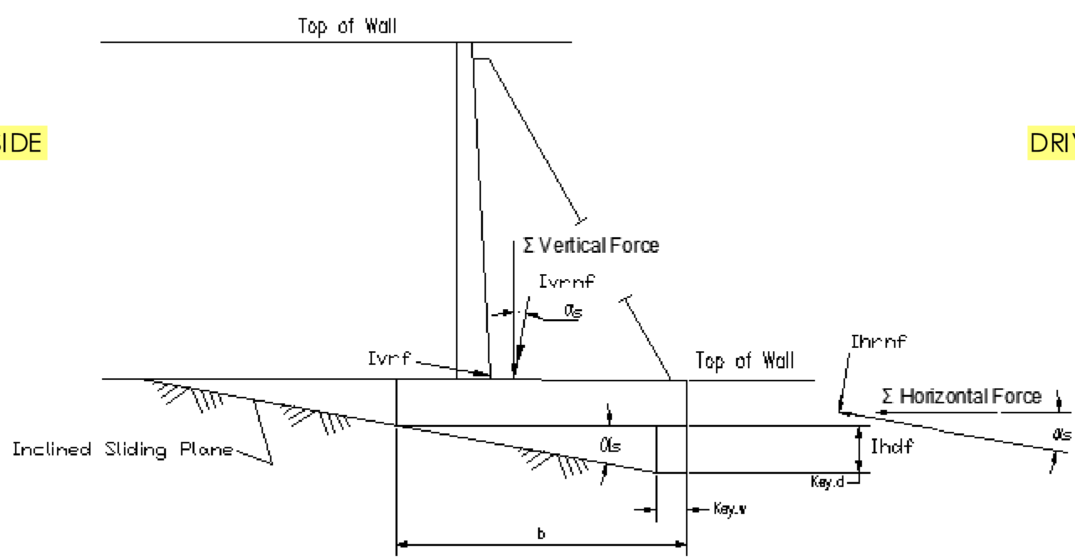
$$FS_{Horiz.SlidingU1} := \frac{\left|\Sigma V_{U1}\right| \cdot \tan\left(\phi_{rock} \cdot \frac{\pi}{180}\right)}{\left|\Sigma H_{U1}\right|} = 1.12$$

$$FS_{Sliding.check1.U1} := \begin{cases} \text{"OKAY "} & \text{if } FS_{Horiz.SlidingU1} > FS_{sliding.reqU1} \\ \text{"Key req""} & \text{otherwise} \end{cases} = \text{"Key req""}$$

CHECK FACTOR OF SAFETY SLIDING WITH KEY (INCLINED SLIDING PLANE):

RESISTING SIDE

DRIVING SIDE



TOE

HEEL

Ivrf=Inclined Resisting Force
Ivrnf=Inclined Resisting Normal Force
Ihrnf=Inclined Resisting Normal Force
Ihdf=Inclined Driving Force

$$\alpha s := \operatorname{atan}\left(\frac{-Key_{vdist}}{Key_{hdist}}\right) = 0.172 \qquad \text{as degrees=} \qquad \alpha s \cdot \left(\frac{180}{\pi}\right) = 9.87$$

(With properly engineered reinforced concrete Key, horizontal sliding plane thru Toe is protected, critical sliding plane is relocated to the INCLINED SLIDING PLANE FROM HEEL KEY To TOE, Bedrock Mass above this examing plane is mobilized by reinforced concrete key and combined into Structural Wedge.)

Resolve ΣV_{U1} & ΣH_{U1}

$$\Sigma V_{InclinedU1} := \cos(\alpha s) \cdot \left(\left|\Sigma V_{U1} + V_{rocksection}\right|\right) + \sin(\alpha s) \cdot \left|\Sigma H_{U1}\right| = 2294.0 \cdot kN$$

$$\Sigma H_{InclinedU1} := \cos(\alpha s) \cdot \left|\Sigma H_{U1}\right| - \sin(\alpha s) \cdot \left(\left|\Sigma V_{U1} + V_{rocksection}\right|\right) = 434.5 \cdot kN$$

LOAD CASE U1

Safety Factor for Sliding Inclined Failure Plane

$$FS_{InclinedlSlidingU1} := \frac{\Sigma V_{InclinedU1} \cdot \tan(\phi_r)}{\Sigma H_{InclinedU1}} = 2.35$$

$$FS_{Sliding.check2.U1} := \begin{cases} \text{"OKAY "} & \text{if } FS_{InclinedlSlidingU1} > FS_{sliding.reqU1} \\ \text{"NG - Revise Structure""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

CHECK FOUNDATION ECCENTRICITY:

Summation of the resisting moments about the toe:

$$\Sigma M_{resU1} := \Sigma M_{conc} + \Sigma M_{VertSoilWaterResistU1} + \Sigma M_{HorizSoilResistU1} + \Sigma M_{rocksection} = 23289 \cdot kN \cdot m$$

Summation of the overturning moments about the toe:

$$\Sigma M_{oU1} := \Sigma M_{LateralSoildriveU1} + \Sigma M_{UpliftU1} = -9588 \cdot kN \cdot m$$

Total moment: $\Sigma M_{U1} := \Sigma M_{resU1} + \Sigma M_{oU1} = 13700.7 \cdot kN \cdot m$

Normal force to base: $\Sigma V_{InclinedU1} = 2294.0 \cdot kN$

Inclined Sliding Plane Length: $L_{incline} := \frac{b}{\cos(\alpha s)} = 12.7\,m$

Eccentricity (inclined plane): $ex_{U1} := \frac{L_{incline}}{2} - \frac{\Sigma M_{U1}}{\Sigma V_{InclinedU1}} = 0.37\,m$ $\quad Kern := \frac{L_{incline}}{6} = 2.115\,m$

Eccentricity Check: $e_{check.U1} := \begin{cases} \text{"Okay"} & \text{if } ex_{U1} \le Kern \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"Okay"}$

CHECK FOUNDATION BEARING CAPACITY:

Base Section Modulus: $S_b := \frac{1}{6}\left(B \cdot L_{incline}^{\;2}\right) = 26.83\,m^3$

Bearing Pressure Under Toe:

$$\sigma_{ToeU1} := \begin{cases} \left(\frac{\Sigma V_{InclinedU1}}{L_{incline} \cdot B} + \frac{\Sigma V_{InclinedU1} \cdot ex_{U1}}{S_b}\right) & \text{if } \frac{\Sigma V_{InclinedU1} \cdot ex_{U1}}{S_b} \le \frac{\Sigma V_{InclinedU1}}{L_{incline} \cdot B} \\ \frac{2 \cdot \Sigma V_{InclinedU1}}{B \cdot 3\left(\frac{b}{2} - ex_{U1}\right)} & \text{otherwise} \end{cases} = 212.6 \cdot kPa$$

$$Bearing_{ChecktoeU1} := \begin{cases} \text{"OKAY "} & \text{if } \sigma_{ToeU1} < \sigma_{allowU1} \\ \text{"NG""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

Bearing Pressure Under Heel:

$$\sigma_{HeelU1} := \begin{cases} \left(\frac{\Sigma V_{InclinedU1}}{L_{incline} \cdot B} - \frac{\Sigma V_{InclinedU1} \cdot ex_{U1}}{S_b}\right) & \text{if } \frac{\Sigma V_{InclinedU1} \cdot ex_{U1}}{S_b} \le \frac{\Sigma V_{InclinedU1}}{L_{incline} \cdot B} \\ 0 & \text{otherwise} \end{cases} = 149.0 \cdot kPa$$

$$Bearing_{CheckheelU1} := \left(\begin{cases} \text{"OKAY "} & \text{if } \sigma_{HeelU1} < \sigma_{allowU1} \wedge \sigma_{HeelU1} > 0 \\ \text{"NG - perform cracked base analysis""} & \text{otherwise} \end{cases}\right) = \text{"OKAY "}$$

CHECK FLOATATION:

Safety Factor for Floatation:

$$FS_{FloatationU1} := \frac{\Sigma V_{conc} + \Sigma V_{SoilWaterU1}}{\left|\Sigma V_{UpliftU1}\right|} = 3.36$$

$$FS_{Floatation.U1.check} := \begin{cases} \text{"OKAY"} & \text{if } FS_{FloatationU1} > FS_{req.U1.flt} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

CHECK OVERTURNING

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.
Assumptions are made in order to compute overturning stablity of indetermine forces on monolith with key;
(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.
(b) The horizontal resisting force acting on the key, P.key, is that required for static equilibrium
(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1

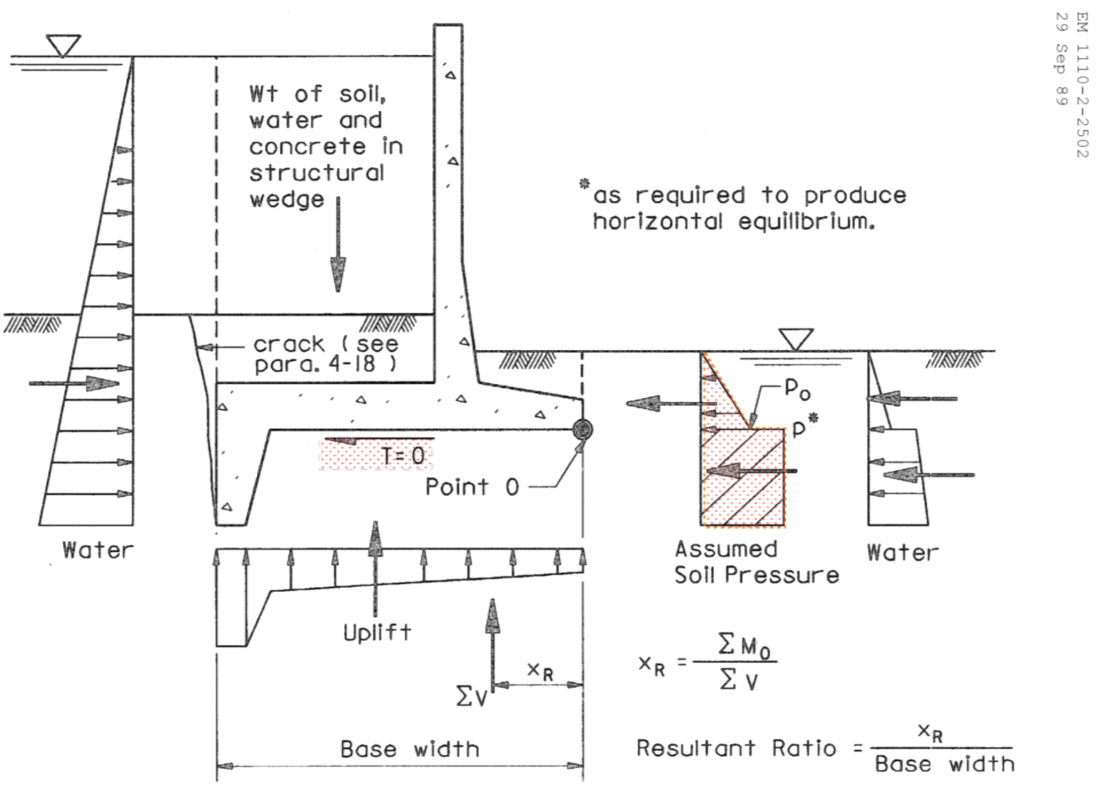


Figure 4-5. Forces for overturning analysis for wall with horizontal base and key

Modify Uplift for Overturning Analysis: **LOAD CASE U1**

(Uplift is calculated along the concrete/rock contact using the Line of Creep method)

Water Pressure at h: $u_{h.U1} := \Delta h_{g.hj.U1} \cdot \gamma_w = 89.18 \cdot kPa$

Water Pressure at o: $u_{o.U1} := \left(\Delta h_{g.no.U1} - \frac{\Delta h_{g.r.U1} \cdot L_{ho.U1}}{L_{ho.U1}}\right) \cdot \gamma_w = 39.2 \cdot kPa$

Head loss between point h and o: $\Delta h_{ho.U1} := \Delta h_{g.r.U1} \cdot \frac{L_{ho.U1}}{L_{ho.U1}} = 3.1\ m$

Length of concrete base (h -> o): $L_{baseho.U1} := Key_{h.w} + Key_{h.d} + Key_{hdist} + Key_{t.d} + Key_{t.w} = 14.5\ m$

Head loss along h -> j: $\Delta h_{hj.U1} := \Delta h_{ho.U1} \cdot \frac{Key_{h.w}}{L_{baseho.U1}} = 0.214\ m$

Water Pressure at j: $u_{j.U1} := \left(\Delta h_{g.hj.U1} - \Delta h_{hj.U1}\right) \cdot \gamma_w = 87.08 \cdot kPa$

Head loss along h -> k: $\Delta h_{hjk.U1} := \Delta h_{ho.U1} \cdot \left(\frac{Key_{h.w} + Key_{h.d}}{L_{baseho.U1}}\right) = 0.641\ m$

Water Pressure at k: $u_{k.U1} := \left(\Delta h_{g.km.U1} - \Delta h_{hjk.U1}\right) \cdot \gamma_w = 63.29 \cdot kPa$

Head loss along h -> m: $\Delta h_{hjkm.U1} := \Delta h_{ho.U1} \cdot \left(\frac{Key_{h.w} + Key_{h.d} + Key_{hdist}}{L_{baseho.U1}}\right) = 3.1\ m$

Water Pressure at m: $u_{m.U1} := \left(\Delta h_{g.km.U1} - \Delta h_{hjkm.U1}\right) \cdot \gamma_w = 39.20 \cdot kPa$

Head loss along h -> n: $\Delta h_{hjkmn.U1} := \Delta h_{ho.U1} \cdot \left(\frac{Key_{h.w} + Key_{h.d} + Key_{hdist} + Key_{t.d}}{L_{baseho.U1}}\right) = 3.1\ m$

Water Pressure at n: $u_{n.U1} := \left(\Delta h_{g.no.U1} - \Delta h_{hjkmn.U1}\right) \cdot \gamma_w = 39.20 \cdot kPa$

Uplift under key at heel: $V_{ulkeyhU1.OT} := \frac{\left(u_{h.U1} + u_{j.U1}\right) \cdot Key_{h.w}}{2} \cdot B \cdot -1 = -88.132 \cdot kN$

Moment Arm (from Point O): $V_{ulkeyhU1loc.OT} := b - \frac{Key_{h.w} \cdot \left(2 \cdot u_{j.U1} + u_{h.U1}\right)}{3 \cdot \left(u_{j.U1} + u_{h.U1}\right)} = 12.002\ m$

Uplift under base: $V_{ulbaseU1.OT} := \frac{\left(u_{k.U1} + u_{m.U1}\right) \cdot Key_{hdist}}{2} \cdot B \cdot -1 = -589.343 \cdot kN$

Moment Arm (from Point O): $V_{ulbaseU1loc.OT} := b - Key_{h.w} - \frac{Key_{hdist} \cdot \left(2 \cdot u_{m.U1} + u_{k.U1}\right)}{3 \cdot \left(u_{m.U1} + u_{k.U1}\right)} = 6.201\ m$

Uplift under key at toe: $V_{ulkeytU1.OT} := \frac{\left(u_{n.U1} + u_{o.U1}\right) \cdot Key_{t.w}}{2} \cdot B \cdot -1 = 0 \cdot kN$

Moment Arm (from Point O): $V_{ulkeytU1loc.OT} := \frac{Key_{t.w} \cdot \left(2 \cdot u_{n.U1} + u_{o.U1}\right)}{3 \cdot \left(u_{n.U1} + u_{o.U1}\right)} = 0$

$$\Sigma V_{UpliftU1.OT} := V_{ulkeyhU1.OT} + V_{ulbaseU1.OT} + V_{ulkeytU1.OT} = -677 \cdot kN$$

$$U_{U1.loc.OT} := \frac{V_{ulkeyhU1.OT} \cdot V_{ulkeyhU1loc.OT} + V_{ulbaseU1.OT} \cdot V_{ulbaseU1loc.OT} + V_{ulkeytU1.OT} \cdot V_{ulkeytU1loc.OT}}{\Sigma V_{UpliftU1.OT}} = 6.96\ m$$

$$\Sigma M_{UpliftU1.OT} := \Sigma V_{UpliftU1.OT} \cdot U_{U1.loc.OT} = -4712.0 \cdot kN \cdot m$$

Modify Lateral Water Pressure (Resisting) for Overturning Analysis:

(Resisting water pressure is calculated using the Line of Creep method)

Water Load at Key (heel): $H_{h2U1.OT} := \frac{u_{k.U1} + u_{j.U1}}{2} \cdot Key_{h.d} B = 150.4 \cdot kN$

Moment Arm (from Point O): $H_{h2locU1.OT} := \frac{Key_{h.d} \cdot (2 \cdot u_{k.U1} + u_{j.U1})}{3(u_{k.U1} + u_{j.U1})} + Key_{vdist} = -1.05\ m$

Water Load at Key (toe): $H_{h6U1.OT} := \frac{u_{o.U1} \cdot (UWSEL_{U1} - Bot_{ftg} + Key_{t.d})}{2} \cdot B = 78 \cdot kN$

Moment Arm (from Point O): $H_{h6locU1.OT} := \frac{UWSEL_{U1} - Bot_{ftg} + Key_{t.d}}{3} = 1.33\ m$

$$\Sigma H_{waterresistU1.OT} := H_{h2U1.OT} + H_{h6U1.OT} = 228.78 \cdot kN$$

$$H_{waterresistlocU1.OT} := \frac{H_{h2U1.OT} \cdot H_{h2locU1.OT} + H_{h6U1.OT} \cdot H_{h6locU1.OT}}{\Sigma H_{waterresistU1.OT}} = -0.235\ m$$

$$\Sigma M_{waterresistU1.OT} := \Sigma H_{waterresistU1.OT} \cdot H_{waterresistlocU1.OT} = -53.78 \cdot kN \cdot m$$

Modify Lateral Soil Loads for Overturning Analysis:

(Lateral soil loads are calculated down to Point O instead of bottom of shear key)

Driving Soil Load (Headwater Side):

Surcharge Load: $E_{s1U1.OT} := S1_{U1} \cdot K_o \cdot (H_w + Key_{h.d} + Key_{vdist}) \cdot B \cdot -1 = 0 \cdot kN$

Moment Arm (from Point O): $E_{s1locU1.OT} := \frac{H_w + Key_{h.d} + Key_{vdist}}{2} = 6.50\ m$

Moist Soil Load above GWL: $E_{h1U1.OT} := \frac{\gamma_m \cdot K_o \cdot h_{1U1}^2}{2} B \cdot -1 = -190.1 \cdot kN$

Moment Arm (from Point O): $E_{h1locU1.OT} := \frac{h_{1U1}}{3} + h_{2U1} + Key_{vdist} = 9.07\ m$

Saturated Soil Load below GWL:
(rectangular component)
$E_{h2U1.OT} := (\gamma_m \cdot K_o \cdot h_{1U1}) \cdot (h_{2U1} + Key_{vdist}) \cdot B \cdot -1 = -457.4 \cdot kN$

Moment Arm (from Point O): $E_{h2locU1.OT} := \frac{h_{2U1} + Key_{vdist}}{2} = 3.55\ m$

Saturated Soil Load below GWL:
(triangular component)
$E_{h2aU1.OT} := \frac{(\gamma_{sat} - \gamma_w) \cdot K_o \cdot (h_{2U1} + Key_{vdist})^2}{2} \cdot B \cdot -1 = -167.9 \cdot kN$

Moment Arm (from Point O): $E_{h2alocU1.OT} := \frac{h_{2U1} + Key_{vdist}}{3} = 2.37\ m$

Resisting Soil Load (Tailwater Side):

(Determine resisting soil load based on depth variation between the keys (ie. Key_{vdist}). In case where key at heel is deeper than key at toe (ie. $Key_{vdist} < 0$), resisting soil load (p*) is assumed to produce horizontal equilibrium as per Figure 4-5 above. Resisting soil load (p_o) is neglected.)

Total Driving Force: $\Sigma H_{SoildriveU1.OT} := E_{s1U1.OT} + E_{h1U1.OT} + E_{h2U1.OT} + E_{h2aU1.OT} + H_{h2U1} = -1221.2 \cdot kN$

Total Resisting Force: $\Sigma H_{waterresistU1.OT} = 228.8 \cdot kN$

Assumed Soil Load p*: $E_{h8U1a.OT} := \left(\Sigma H_{SoildriveU1.OT} + \Sigma H_{waterresistU1.OT}\right) \cdot -1 = 992.401 \cdot kN$

Moment Arm (from Point O): $E_{h8U1a.loc.OT} := \dfrac{Key_{vdist}}{2} = -1\,m$

$$E_{h8U1.OT} := \begin{cases} E_{h8U1a.OT} & \text{if } Key_{vdist} < 0 \\ \Sigma H_{SoilresistU1} - H_{h6U1} - H_{h2aU1} - P_{sbU1} & \text{otherwise} \end{cases} = 992.401 \cdot kN$$

$$\Sigma M_{SoilresistU1} := \begin{cases} E_{h8U1a.OT} \cdot E_{h8U1a.loc.OT} & \text{if } Key_{vdist} < 0 \\ \Sigma M_{HorizSoilResistU1} - H_{h6U1} \cdot H_{h6locU1} - H_{h2aU1} \cdot H_{h2alocU1} - P_{sbU1} \cdot P_{sblocU1} & \text{otherwise} \end{cases} = -992.401 \cdot kN \cdot m$$

Sum of Moment about Point O:

$$\Sigma M_{LateraldriveU1.OT} := E_{s1U1.OT} \cdot E_{s1locU1.OT} + E_{h1U1.OT} \cdot E_{h1locU1.OT} + E_{h2U1.OT} \cdot E_{h2locU1.OT} \cdots + E_{h2aU1.OT} \cdot E_{h2alocU1.OT} + H_{h2U1} \cdot H_{h2locU1} = -4163.9 \cdot kN \cdot m$$

$$\Sigma M_{LateralresistU1.OT} := \Sigma M_{waterresistU1.OT} + \Sigma M_{SoilresistU1} = -1046.2 \cdot kN \cdot m$$

Total moment:

$$\Sigma M_{U1.OT} := \Sigma M_{conc} + \Sigma M_{VertSoilWaterResistU1} + \Sigma M_{UpliftU1.OT} + \Sigma M_{LateraldriveU1.OT} + \Sigma M_{LateralresistU1.OT} = 10720.4 \cdot kN \cdot m$$

Total Vertical Force: $\Sigma V_{U1.OT} := \Sigma V_{conc} + \Sigma V_{SoilWaterU1} + \Sigma V_{UpliftU1.OT} = 2016.1 \cdot kN$

Distance X_R: EM 1110-2-2502 Eq.4-1 $X_{R.U1} := \dfrac{\Sigma M_{U1.OT}}{\Sigma V_{U1.OT}} = 5.317\,m$

Overturning Resultant Ratio $Ratio_{U1.OT} := \dfrac{X_{R.U1}}{b} = 0.43$

$$Ratio_{U1.OT.check} := \begin{cases} \text{"OKAY "} & \text{if } Ratio_{U1.OT} > X_{R.reqU1} \\ \text{"Revise Structure""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

CHECK FOUNDATION ECCENTRICITY (HORIZONTAL PLANE):

Eccentricity (horizontal plan): $ex_{U1.OT} := \dfrac{b}{2} - \dfrac{\Sigma M_{U1.OT}}{\Sigma V_{U1.OT}} = 0.93\,m$ $Kern_{OT} := \dfrac{b}{6} = 2.083\,m$

Eccentricity Check:

$$e_{check.U1.OT} := \begin{cases} \text{"Okay"} & \text{if } ex_{U1} \le Kern_{OT} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"Okay"}$$

CHECK FOUNDATION BEARING CAPACITY (HORIZONTAL PLANE):

Base Section Modulus:

$$S_{b.OT} := \frac{1}{6}\left(B \cdot b^2\right) = 26.04\,m^3$$

Bearing Pressure Under Toe:

$$\sigma_{ToeU1.OT} := \begin{cases} \left(\dfrac{\Sigma V_{U1.OT}}{b \cdot B} + \dfrac{\Sigma V_{U1.OT} \cdot ex_{U1.OT}}{S_{b.OT}}\right) & \text{if } \dfrac{\Sigma V_{U1.OT}}{b \cdot B} \geq \dfrac{\Sigma V_{U1.OT} \cdot ex_{U1.OT}}{S_{b.OT}} \\ \dfrac{2 \cdot \Sigma V_{U1.OT}}{B \cdot 3\left(\dfrac{b}{2} - ex_{U1.OT}\right)} & \text{otherwise} \end{cases} = 233.5 \cdot kPa$$

$$Bearing_{ChecktoeU1.OT} := \begin{cases} \text{"OKAY "} & \text{if } \sigma_{ToeU1.OT} < \sigma_{allowU1} \\ \text{"NG - for reference only""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

Bearing Pressure Under Heel:

$$\sigma_{HeelU1.OT} := \begin{cases} \left(\dfrac{\Sigma V_{U1.OT}}{b \cdot B} - \dfrac{\Sigma V_{U1.OT} \cdot ex_{U1.OT}}{S_{b.OT}}\right) & \text{if } \dfrac{\Sigma V_{U1.OT}}{b \cdot B} \geq \dfrac{\Sigma V_{U1.OT} \cdot ex_{U1.OT}}{S_{b.OT}} \\ 0 & \text{otherwise} \end{cases} = 89.1 \cdot kPa$$

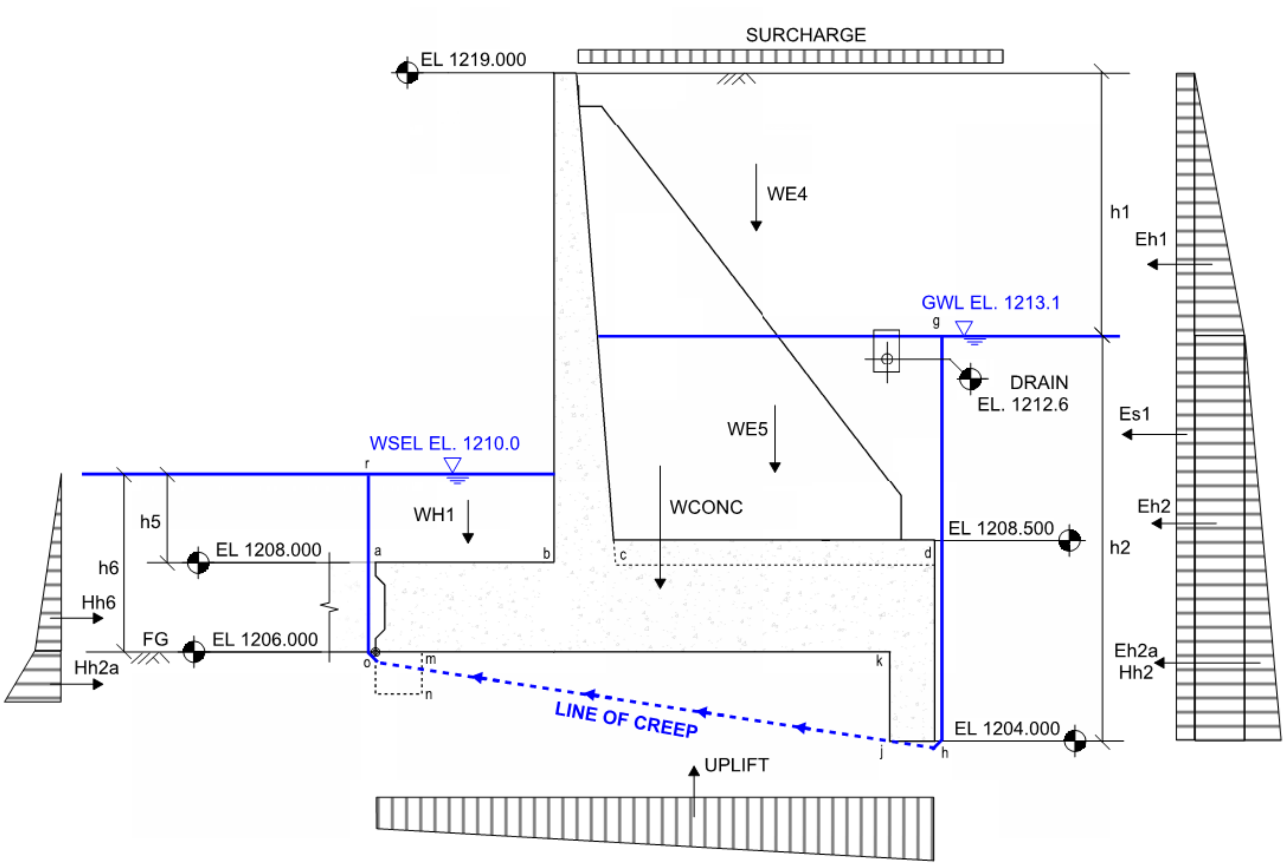
$$Bearing_{CheckheelU1.OT} := \left(\begin{cases} \text{"OKAY "} & \text{if } \sigma_{HeelU1.OT} < \sigma_{allowU1} \wedge \sigma_{HeelU1.OT} > 0 \\ \text{"NG - for reference only""} & \text{otherwise} \end{cases}\right) = \text{"OKAY "}$$

SUMMARY OF STABILITY ASSESSMENT:

LOAD CASE U1

Sliding Factor of Safety: (Horizontal Plane - Ref only)	$FS_{Horiz.SlidingU1} = 1.12$	$FS_{Sliding.check1.U1}$ = "Key req""
Sliding Factor of Safety: (Inclined Plane)	$FS_{InclinedISlidingU1} = 2.35$	$FS_{Sliding.check2.U1}$ = "OKAY "
Eccentricity: (Inclined Plane)	$ex_{U1} = 0.37\ m$	$e_{check.U1}$ = "Okay"
Bearing Pressure At Heel: (Inclined Plane)	$\sigma_{HeelU1} = 149 \cdot kPa$	$Bearing_{CheckheelU1}$ = "OKAY "
Bearing Pressure At Toe: (Inclined Plane)	$\sigma_{ToeU1} = 213 \cdot kPa$	$Bearing_{ChecktoeU1}$ = "OKAY "
Flotation Factor of Safety (horizontal plane)	$FS_{FloatationU1} = 3.36$	$FS_{Floatation.U1.check}$ = "OKAY "
Overturning Resultant Ratio: (horizontal plane)	$Ratio_{U1.OT} = 0.43$	$Ratio_{U1.OT.check}$ = "OKAY "
Eccentricity: (horizontal plane - Ref only)	$ex_{U1.OT} = 0.93\ m$	$e_{check.U1.OT}$ = "Okay"
Bearing Pressure At Heel: (horizontal plane - Ref only)	$\sigma_{HeelU1.OT} = 89 \cdot kPa$	$Bearing_{CheckheelU1.OT}$ = "OKAY "
Bearing Pressure At Toe: (horizontal plane - Ref only)	$\sigma_{ToeU1.OT} = 234 \cdot kPa$	$Bearing_{ChecktoeU1.OT}$ = "OKAY "

LOAD CASE UN1 - NORMAL OPERATION + SURCHARGE



UN1 DESIGN CASE

LOAD CASE UN1 ACCEPTANCE PARAMETERS

FS sliding:

Unusual (UN) 1.3 (without cohesion) (Table 3-3, USACE EM 1110-2-2100)

Resultant Location:

Unsual (UN) Inside middle third ~100% base in compression

Required Factor of Safety for Sliding: $FS_{sliding.reqUN1} := 1.3$ (Without Cohesion)

Allowable rock bearing pressure: $\sigma_{allowUN1} := 1470kPa$ (Section 5.2, Design Criteria EM 1110-2-2100 Section 3-10)

Overturning Required Resultant Ratio: $X_{R.reqUN1} := 0.333$ (EM 1110-2-2502, Figure 4-4)

Required Factor of Safety for Floatation $FS_{req.UN1.flt} := 1.3$

SOIL HEIGHTS and Water Levels:

LOAD CASE UN1

Heel Conditions:

Groundwater Elevation at Heel: $GWL_{UN1} := 1213.1m$

Distance from Finish Grade to Groundwater at Heel: $h_{1UN1} := \left[T_w - GWL_{UN1} + \left(L_{cd} + t_{wb} - t_{wt}\right)\cdot \tan(\beta)\right] = 5.90\ m$

Distance from Water Surface to Bottom of Footing at Heel: $h_{2UN1} := GWL_{UN1} - Bot_{ftg} + Key_{h.d} = 9.10\ m$

Toe Conditions:

Water Surface Elevation at Toe: $WSEL_{UN1} := 1210.0m$

Water Surface Elevation at Toe for Uplift: $UWSEL_{UN1} := 1210.0\cdot m$

Finish Grade at Toe providing lateral resistance: $FG_{toeUN1} := 1206.0\cdot m$

Soil Depth Above top of footing: $h_{3aUN1} := FG_{toeUN1} - Top_{ftg} = -2\ m$

$$h_{3UN1} := \begin{cases} h_{3aUN1} & \text{if } FG_{toeUN1} - Top_{ftg} \geq 0 \\ 0 & \text{otherwise} \end{cases} = 0$$

Resisting Fill at Toe: $h_{4UN1} := FG_{toeUN1} - Bot_{ftg} + Key_{t.d} = 0.00\ m$

Distance from Water Level to Top of Footing at Toe: $h_{5UN1} := WSEL_{UN1} - Top_{ftg} = 2.00\ m$

Distance from Water Surface to Bottom of Footing at Toe: $h_{6UN1} := WSEL_{UN1} - Bot_{ftg} + Key_{t.d} = 4.00\ m$

Soil Depth Above WSEL: $h_{7aUN1} := FG_{toeUN1} - WSEL_{UN1} = -4\ m$

$$h_{7UN1} := \begin{cases} h_{7aUN1} & \text{if } FG_{toeUN1} - WSEL_{UN1} \geq 0 \\ 0 & \text{otherwise} \end{cases} = 0$$

Soil Depth Below WSEL:

$$h_{8UN1} := \begin{cases} WSEL_{UN1} - Bot_{ftg} + Key_{t.d} & \text{if } FG_{toeUN1} - WSEL_{UN1} \geq 0 \\ h_{4UN1} & \text{otherwise} \end{cases} = 0$$

For Line of Creep Method: $L_{ho.UN1} := \sqrt{b^2 + \left(Key_{h.d} - Key_{t.d}\right)^2} = 12.659\ m$

Head Loss from Point g:

$\Delta h_{g.hj.UN1} := h_{2UN1} = 9.1\ m$ (to point h & j)

$\Delta h_{g.km.UN1} := GWL_{UN1} - Bot_{ftg} = 7.1\ m$ (to point k & m)

$\Delta h_{g.no.UN1} := GWL_{UN1} - Bot_{ftg} + Key_{t.d} = 7.1\ m$ (to point n & o)

$\Delta h_{g.p.UN1} := GWL_{UN1} - FG_{toeUN1} = 7.1\ m$ (to point p*)

$\Delta h_{g.r.UN1} := GWL_{UN1} - UWSEL_{UN1} = 3.1\ m$ (to point r)

Surcharge

Surcharge on Heel: $S1_{UN1} := 15.0\ \frac{kN}{m^2}$

* same as point "o" in this case

Calculate Soil Lateral Pressure Coefficients:

LOAD CASE UN1

For all load cases except seismic, soil loading to be based on At-Rest Condition.
Calculate at-rest pressure coefficient Ko based on Jaky's (1944) equation.

Soil At Rest Static Coefficient: $K_o := \dfrac{1 - \sin(\phi)}{1 + \sin(\beta)} = 0.546$ (Eq. 3-6, USACE EM 1110-2-2502)

Lateral - Driving Force

Static At-Rest:

Surcharge Load: $E_{s1UN1} := S1_{UN1} \cdot K_o \cdot \left(H_w + Key_{h.d}\right) \cdot B \cdot -1 = -122.852 \cdot kN$

Moment Arm (from bottom of footing): $E_{s1locUN1} := \dfrac{H_w + Key_{h.d}}{2} + Key_{vdist} = 5.50\ m$

Moist Soil Load above GWL: $E_{h1UN1} := \dfrac{\gamma_m \cdot K_o \cdot h_{1UN1}^{\ 2}}{2} B \cdot -1 = -190.1 \cdot kN$

Moment Arm (from bottom of footing): $E_{h1locUN1} := \dfrac{h_{1UN1}}{3} + h_{2UN1} + Key_{vdist} = 9.07\ m$

Saturated Soil Load below GWL:
(rectangular component)
$E_{h2UN1} := \left(\gamma_m \cdot K_o \cdot h_{1UN1}\right) \cdot \left(h_{2UN1}\right) \cdot B \cdot -1 = -586.3 \cdot kN$

Moment Arm (from bottom of footing): $E_{h2locUN1} := \dfrac{h_{2UN1}}{2} + Key_{vdist} = 2.55\ m$

Saturated Soil Load below GWT:
(triangular L
$E_{h2aUN1} := \dfrac{\left(\gamma_{sat} - \gamma_w\right) \cdot K_o \cdot h_{2UN1}^{\ 2}}{2} \cdot B \cdot -1 = -275.8 \cdot kN$

Moment Arm (from bottom of footing): $E_{h2alocUN1} := \dfrac{h_{2UN1}}{3} + Key_{vdist} = 1.03\ m$

Lateral Water Load:

Water Load GWL to Bottom of Key $H_{h2UN1} := \dfrac{\gamma_w \cdot h_{2UN1}^{\ 2}}{2} \cdot B \cdot -1 = -405.8 \cdot kN$

Moment Arm (from bottom of footing): $H_{h2locUN1} := \dfrac{h_{2UN1}}{3} + Key_{vdist} = 1.03\ m$

$\Sigma H_{SoildriveUN1} := E_{s1UN1} + E_{h1UN1} + E_{h2UN1} + E_{h2aUN1} + H_{h2UN1} = -1580.8 \cdot kN$

$$\Sigma M_{LateralSoildriveUN1} := E_{s1UN1} \cdot E_{s1locUN1} + E_{h1UN1} \cdot E_{h1locUN1} + E_{h2UN1} \cdot E_{h2locUN1} \ldots = -4598.3\ m \cdot kN$$
$$+ E_{h2aUN1} \cdot E_{h2alocUN1} + H_{h2UN1} \cdot H_{h2locUN1}$$

Lateral - Resisting Force

LOAD CASE UN1

Lateral Water Load:

Water Load WSEL to Bottom of Footing: $H_{h6UN1} := \frac{\gamma_w \cdot h_{6UN1}^2}{2} \cdot B = 78.4 \cdot kN$

Moment Arm (from bot. of toe key): $H_{h6locUN1} := \frac{h_{6UN1}}{3} = 1.33\ m$

Water Load Bot. of Footing to Bot. of H. Key: $H_{h2aUN1} := \left[\left(UWSEL_{UN1} - Bot_{ftg} + Key_{t.d}\right) + h_{2UN1}\right] \cdot \frac{Key_{h.d}}{2} \cdot \gamma_w \cdot B = 128.4 \cdot kN$

Moment Arm (from bot. of toe key): $H_{h2alocUN1} := \frac{Key_{h.d} \cdot \left[2 \cdot \left(UWSEL_{UN1} - Bot_{ftg} + Key_{t.d}\right) + h_{2UN1}\right]}{3\left[h_{2UN1} + \left(UWSEL_{UN1} - Bot_{ftg} + Key_{t.d}\right)\right]} \cdots + Key_{vdist} = -1.13\ m$

Lateral Soil Load:

Moist Soil Load above WSEL: $E_{h7UN1} := \frac{\gamma_m \cdot K_o \cdot h_{7UN1}^2}{2} \cdot B = 0.0 \cdot kN$

Moment Arm (from bot. of toe key): $E_{h7locUN1} := h_{6UN1} + \frac{h_{7UN1}}{3} + Key_{vdist} = 2.00\ m$

Saturated Soil Load below WSEL: (rectangular component) $E_{h8UN1} := \left(\gamma_m \cdot K_o \cdot h_{7UN1}\right) \cdot h_{8UN1} \cdot B = 0.0 \cdot kN$

Moment Arm (from bot. of toe key): $E_{h8locUN1} := \frac{h_{8UN1}}{2} = 0.00\ m$

Saturated Soil Load below WSEL: (triangular component) $E_{h8aUN1} := \frac{\left[\left(\gamma_{sat} - \gamma_w\right) \cdot K_o\right] \cdot h_{8UN1}^2}{2} \cdot B = 0.0 \cdot kN$

Moment Arm (from bot. of footing): $E_{h8alocUN1} := \frac{h_{8UN1}}{3} = 0.00\ m$

Lateral Resistance from Stilling Basin:

Lateral Resistance from Stilling Basin: $P_{sbUN1} := 430kN$ (Force needed to achieve the required sliding factor of safety in case UN2)

Moment Arm (from bot. of toe key): $P_{sblocUN1} := \frac{t_{ftg}}{2} + Key_{t.d} = 1.00\ m$

$$\Sigma H_{SoilresistUN1} := H_{h6UN1} + H_{h2aUN1} + E_{h7UN1} + E_{h8UN1} + E_{h8aUN1} + P_{sbUN1} = 636.8 \cdot kN$$

$$\Sigma M_{HorizSoilResistUN1} := H_{h6UN1} \cdot H_{h6locUN1} + H_{h2aUN1} \cdot H_{h2alocUN1} + E_{h7UN1} \cdot E_{h7locUN1} \cdots + E_{h8UN1} \cdot E_{h8locUN1} + E_{h8aUN1} \cdot E_{h8alocUN1} + P_{sbUN1} \cdot P_{sblocUN1} = 389.5\ m \cdot kN$$

Vertical Force:

UPLIFT: Linear distribution from water at heel to water at toe:

$$\Sigma V_{UpliftUN1} := \left[\left(UWSEL_{UN1} - Bot_{ftg} + Key_{t.d}\right) + h_{2UN1}\right] \cdot \frac{b}{2} \cdot \gamma_w \cdot B \cdot -1 = -802.375 \cdot kN$$

Moment Arm (from Point O): $V_{UpliftUN1aloc} := \frac{b \cdot \left[2 \cdot h_{2UN1} + \left(UWSEL_{UN1} - Bot_{ftg} + Key_{t.d}\right)\right]}{3\left[h_{2UN1} + \left(UWSEL_{UN1} - Bot_{ftg} + Key_{t.d}\right)\right]} = 7.061\ m$

$$\Sigma M_{UpliftUN1} := \Sigma V_{UpliftUN1} \cdot V_{UpliftUN1aloc} = -5665.625 \cdot kN \cdot m$$

Weight of soil and water over toe:

Water Above the Top of Footing: $W_{H1UN1} := \gamma_w \cdot h_{5UN1} \cdot L_{ab} \cdot B = 78.4 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E1locUN1} := \frac{L_{ab}}{2} = 2\,m$

Soil above top of footing: $W_{E6UN1} := \gamma_b \cdot h_{3UN1} \cdot L_{ab} \cdot B = 0.0 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E6locUN1} := \frac{L_{ab}}{2} = 2\,m$

Vertical Load Due to Surcharge: $S_{UN1} := S1_{UN1} \cdot L_{cd} \cdot B = 107.04 \cdot kN$ $S_{UN1loc} := b - \frac{L_{cd}}{2} = 8.93\,m$

Weight of soil and water over heel:

Moist Soil for sloped grade above top of wall:

Length of sloped portion of soil above top of wall: $L_{E3UN1} := \left(L_{cd} + t_{wb} - t_{wt}\right) = 8.00\,m$

Height of sloped soil above top of wall over heel: $h_{E3locUN1} := \left(L_{E3UN1}\right) \cdot \tan(\beta) = 0.00\,m$

Weight of sloped soil above top of wall: $W_{E3UN1} := \frac{\gamma_m}{2} \cdot h_{E3locUN1} \cdot L_{E3UN1} \cdot B = 0.0 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E3locUN1} := L_{ab} + t_{wt} + \frac{2}{3} \cdot L_{E3UN1} = 9.83\,m$

Moist soil from top of wall to groundwater level:

Height of soil from top of wall and top of GWL: $h_{1UN1} = 5.90\,m$

Length from edge of wall at GWL to edge of heel: $L_{E4UN1} := L_{E3UN1} - \left(h_{1UN1} \cdot S_{batter}\right) = 7.54\,m$

Weight of soil over heel from top of wall to GWL: $W_{E4UN1} := \gamma_m \cdot h_{1UN1} \cdot \frac{\left(L_{E3UN1} + L_{E4UN1}\right)}{2} \cdot B = 916.7 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E4locUN1} := b - \frac{L_{E3UN1}^{\;2} + L_{E3UN1} \cdot L_{E4UN1} + L_{E4UN1}^{\;2}}{3\left(L_{E3UN1} + L_{E4UN1}\right)} = 8.61\,m$

Saturated soil from groundwater to top of footing:

Height of soil from GWL to top of heel: $h_{E4UN1} := h_{2UN1} - t_{ftg} - Key_{h.d} = 5.10\,m$

Weight of soil over heel from GWL to top of heel: $W_{E5UN1} := \left(\gamma_{sat}\right) \cdot h_{E4UN1} \cdot \frac{\left(L_{E4UN1} + L_{cd}\right)}{2} \cdot B = 823.1 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E5locUN1} := b - \frac{L_{E4UN1}^{\;2} + L_{E4UN1} \cdot L_{cd} + L_{cd}^{\;2}}{3\left(L_{E4UN1} + L_{cd}\right)} = 8.83\,m$

$$\Sigma V_{SoilWaterUN1} := W_{H1UN1} + W_{E6UN1} + W_{E3UN1} + W_{E4UN1} + W_{E5UN1} + S_{UN1} = 1925.2 \cdot kN$$

$$\Sigma M_{VertSoilWaterResistUN1} := W_{H1UN1} \cdot W_{E1locUN1} + W_{E6UN1} \cdot W_{E6locUN1} \cdots + W_{E3UN1} \cdot W_{E3locUN1} + W_{E4UN1} \cdot W_{E4locUN1} + W_{E5UN1} \cdot W_{E5locUN1} + S_{UN1} \cdot S_{UN1loc} = 16278.7\,m \cdot kN$$

THIS PAGE INTENTIONALLY LEFT BLANK
PLEASE GO TO THE NEXT PAGE

STABILITY ASSESSMENT:

LOAD CASE UN1

CHECK SLIDING ALONG HORIZONTAL SLIDING PLANE:

Summation of the vertical forces:

$$\Sigma V_{UN1} := \Sigma V_{conc} + \Sigma V_{SoilWaterUN1} + \Sigma V_{UpliftUN1} = 1998.3 \cdot kN$$

Summation of the horizontal forces:

$$\Sigma H_{UN1} := \Sigma H_{SoildriveUN1} + \Sigma H_{SoilresistUN1} = -944.0 \cdot kN$$

Safety Factor for Sliding Horizontal Failure Plane

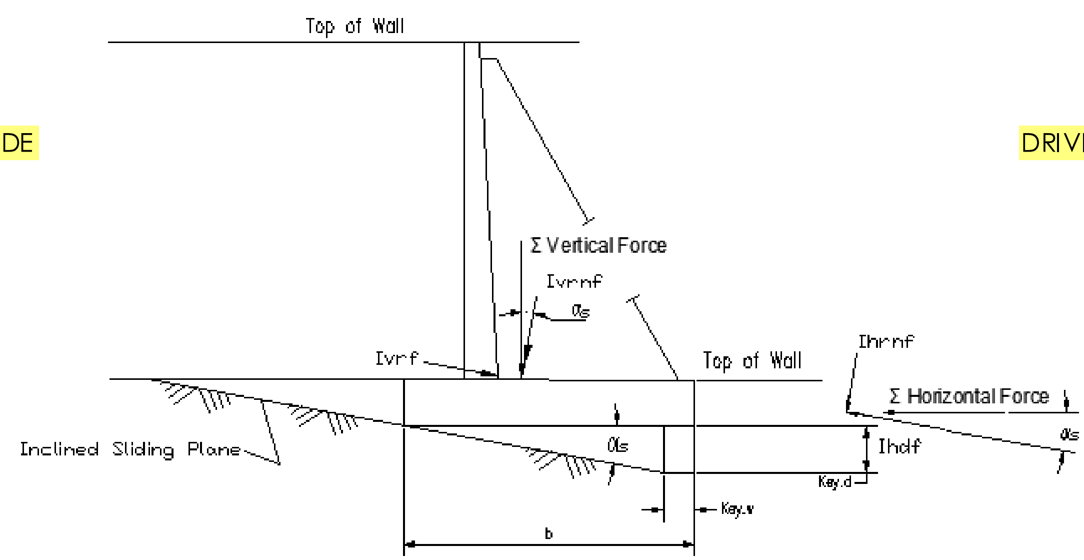
$$FS_{Horiz.SlidingUN1} := \frac{\left|\Sigma V_{UN1}\right| \cdot \tan\left(\phi_{rock} \cdot \frac{\pi}{180}\right)}{\left|\Sigma H_{UN1}\right|} = 1.03$$

$$FS_{Sliding.check1.UN1} := \begin{vmatrix} \text{"OKAY "} & \text{if} \quad FS_{Horiz.SlidingUN1} > FS_{sliding.reqUN1} \\ \text{"NG - key req'"} & \text{otherwise} \end{vmatrix} = \text{"NG - key req'"}$$

CHECK FACTOR OF SAFETY SLIDING WITH KEY (INCLINED SLIDING PLANE):

RESISTING SIDE

DRIVING SIDE



TOE

HEEL

Ivrf=Inclined Resisting Force
Ivrnf=Inclined Resisting Normal Force
Ihrnf=Inclined Resisting Normal Force
Ihdf=Inclined Driving Force

$\alpha s = 0.172$ as degrees= $\alpha s \cdot \left(\frac{180}{\pi}\right) = 9.87$

(With properly engineered reinforced concrete Key, horizontal sliding plane thru Toe is protected, critical sliding plane is relocated to the INCLINED SLIDING PLANE FROM HEEL KEY To TOE, Bedrock Mass above this examing plane is mobilized by reinforced concrete key and combined into Structural Wedge.)

Resolve ΣV_{UN1} & ΣH_{UN1}

$$\Sigma V_{InclinedUN1} := \cos(\alpha s) \cdot \left(\left|\Sigma V_{UN1} + V_{rocksection}\right|\right) + \sin(\alpha s) \cdot \left|\Sigma H_{UN1}\right| = 2420.5 \cdot kN$$

$$\Sigma H_{InclinedUN1} := \cos(\alpha s) \cdot \left|\Sigma H_{UN1}\right| - \sin(\alpha s) \cdot \left(\left|\Sigma V_{UN1} + V_{rocksection}\right|\right) = 537.2 \cdot kN$$

LOAD CASE UN1

Safety Factor for Sliding Inclined Failure Plane

$$FS_{InclinedlSlidingUN1} := \frac{\Sigma V_{InclinedUN1} \cdot \tan(\phi_r)}{\Sigma H_{InclinedUN1}} = 2.01$$

$$FS_{Sliding.check2.UN1} := \begin{cases} \text{"OKAY "} & \text{if } FS_{InclinedlSlidingUN1} > FS_{sliding.reqUN1} \\ \text{"NG - Revise Structure""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

CHECK FOUNDATION ECCENTRICITY:

Summation of the resisting moments about the toe:

$$\Sigma M_{resUN1} := \Sigma M_{conc} + \Sigma M_{VertSoilWaterResistUN1} + \Sigma M_{HorizSoilResistUN1} + \Sigma M_{rocksection} = 24245 \cdot kN \cdot m$$

Summation of the overturning moments about the toe:

$$\Sigma M_{oUN1} := \Sigma M_{LateralSoildriveUN1} + \Sigma M_{UpliftUN1} = -10264 \cdot kN \cdot m$$

Total moment: $\Sigma M_{UN1} := \Sigma M_{resUN1} + \Sigma M_{oUN1} = 13981.1 \cdot kN \cdot m$

Normal force to base: $\Sigma V_{InclinedUN1} = 2420.5 \cdot kN$

Inclined Sliding Plane Length: $L_{incline} = 12.7 \cdot m$

Eccentricity (inclined plane): $ex_{UN1} := \frac{L_{incline}}{2} - \frac{\Sigma M_{UN1}}{\Sigma V_{InclinedUN1}} = 0.57\ m$ $\qquad Kern = 2.115\ m$

Eccentricity Check:

$$e_{check.UN1} := \begin{cases} \text{"Okay"} & \text{if } ex_{UN1} \le Kern \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"Okay"}$$

CHECK FOUNDATION BEARING CAPACITY:

Base Section Modulus: $S_b = 26.83\ m^3$

Bearing Pressure Under Toe:

$$\sigma_{ToeUN1} := \begin{cases} \left(\frac{\Sigma V_{InclinedUN1}}{L_{incline} \cdot B} + \frac{\Sigma V_{InclinedUN1} \cdot ex_{UN1}}{S_b}\right) & \text{if } \frac{\Sigma V_{InclinedUN1} \cdot ex_{UN1}}{S_b} \le \frac{\Sigma V_{InclinedUN1}}{L_{incline} \cdot B} \\ \frac{2 \cdot \Sigma V_{InclinedUN1}}{B \cdot 3\left(\frac{b}{2} - ex_{UN1}\right)} & \text{otherwise} \end{cases} = 242.0 \cdot kPa$$

$$Bearing_{ChecktoeUN1} := \begin{cases} \text{"OKAY "} & \text{if } \sigma_{ToeUN1} < \sigma_{allowUN1} \\ \text{"NG""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

Bearing Pressure Under Heel:

$$\sigma_{HeelUN1} := \begin{cases} \left(\frac{\Sigma V_{InclinedUN1}}{L_{incline} \cdot B} - \frac{\Sigma V_{InclinedUN1} \cdot ex_{UN1}}{S_b}\right) & \text{if } \frac{\Sigma V_{InclinedUN1} \cdot ex_{UN1}}{S_b} \le \frac{\Sigma V_{InclinedUN1}}{L_{incline} \cdot B} \\ 0 & \text{otherwise} \end{cases} = 139.6 \cdot kPa$$

$$Bearing_{CheckheelUN1} := \left(\begin{cases} \text{"OKAY "} & \text{if } \sigma_{HeelUN1} < \sigma_{allowUN1} \wedge \sigma_{HeelUN1} > 0 \\ \text{"NG - perform cracked base analysis""} & \text{otherwise} \end{cases}\right) = \text{"OKAY "}$$

CHECK FLOATATION:

Safety Factor for Floatation:

$$FS_{FloatationUN1} := \frac{\Sigma V_{conc} + \Sigma V_{SoilWaterUN1}}{\left|\Sigma V_{UpliftUN1}\right|} = 3.49$$

$$FS_{Floatation.UN1.check} := \begin{cases} \text{"OKAY "} & \text{if } FS_{FloatationUN1} > FS_{req.UN1.flt} \\ \text{"Revise Structure""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

CHECK OVERTURNING

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.
Assumptions are made in order to compute overturning stablity of indetermine forces on monolith with key;
(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.
(b) The horizontal resisting force acting on the key, P.key, is that required for static equilibrium
(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1

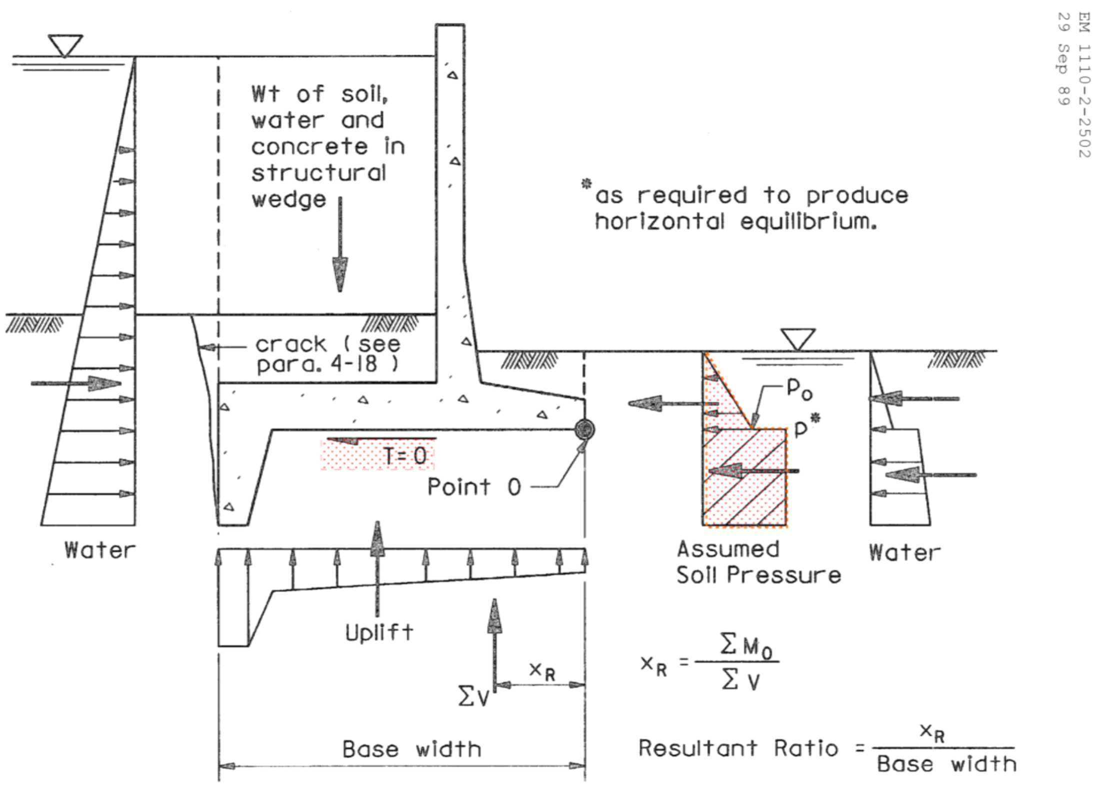


Figure 4-5. Forces for overturning analysis for wall with horizontal base and key

Modify Uplift for Overturning Analysis: **LOAD CASE UN1**

(Uplift is calculated along the concrete/rock contact using the Line of Creep method)

Water Pressure at h: $u_{h.UN1} := \Delta h_{g.hj.UN1} \cdot \gamma_w = 89.18 \cdot kPa$

Water Pressure at o: $u_{o.UN1} := \left(\Delta h_{g.no.UN1} - \frac{\Delta h_{g.r.UN1} \cdot L_{ho.UN1}}{L_{ho.UN1}}\right) \cdot \gamma_w = 39.2 \cdot kPa$

Head loss between point h and o: $\Delta h_{ho.UN1} := \Delta h_{g.r.UN1} \cdot \frac{L_{ho.UN1}}{L_{ho.UN1}} = 3.1\ m$

Length of concrete base (h -> o): $L_{baseho.UN1} := Key_{h.w} + Key_{h.d} + Key_{hdist} + Key_{t.d} + Key_{t.w} = 14.5\ m$

Head loss along h -> j: $\Delta h_{hj.UN1} := \Delta h_{ho.UN1} \cdot \frac{Key_{h.w}}{L_{baseho.UN1}} = 0.214\ m$

Water Pressure at j: $u_{j.UN1} := \left(\Delta h_{g.hj.UN1} - \Delta h_{hj.UN1}\right) \cdot \gamma_w = 87.08 \cdot kPa$

Head loss along h -> k: $\Delta h_{hjk.UN1} := \Delta h_{ho.UN1} \cdot \left(\frac{Key_{h.w} + Key_{h.d}}{L_{baseho.UN1}}\right) = 0.641\ m$

Water Pressure at k: $u_{k.UN1} := \left(\Delta h_{g.km.UN1} - \Delta h_{hjk.UN1}\right) \cdot \gamma_w = 63.29 \cdot kPa$

Head loss along h -> m: $\Delta h_{hjkm.UN1} := \Delta h_{ho.UN1} \cdot \left(\frac{Key_{h.w} + Key_{h.d} + Key_{hdist}}{L_{baseho.UN1}}\right) = 3.1\ m$

Water Pressure at m: $u_{m.UN1} := \left(\Delta h_{g.km.UN1} - \Delta h_{hjkm.UN1}\right) \cdot \gamma_w = 39.20 \cdot kPa$

Head loss along h -> n: $\Delta h_{hjkmn.UN1} := \Delta h_{ho.UN1} \cdot \left(\frac{Key_{h.w} + Key_{h.d} + Key_{hdist} + Key_{t.d}}{L_{baseho.UN1}}\right) = 3.1\ m$

Water Pressure at n: $u_{n.UN1} := \left(\Delta h_{g.no.UN1} - \Delta h_{hjkmn.UN1}\right) \cdot \gamma_w = 39.20 \cdot kPa$

Uplift under key at heel: $V_{ulkeyhUN1.OT} := \frac{\left(u_{h.UN1} + u_{j.UN1}\right) \cdot Key_{h.w}}{2} \cdot B \cdot -1 = -88.132 \cdot kN$

Moment Arm (from Point O): $V_{ulkeyhUN1loc.OT} := b - \frac{Key_{h.w} \cdot \left(2 \cdot u_{j.UN1} + u_{h.UN1}\right)}{3 \cdot \left(u_{j.UN1} + u_{h.UN1}\right)} = 12.002\ m$

Uplift under base: $V_{ulbaseUN1.OT} := \frac{\left(u_{k.UN1} + u_{m.UN1}\right) \cdot Key_{hdist}}{2} \cdot B \cdot -1 = -589.343 \cdot kN$

Moment Arm (from Point O): $V_{ulbaseUN1loc.OT} := b - Key_{h.w} - \frac{Key_{hdist} \cdot \left(2 \cdot u_{m.UN1} + u_{k.UN1}\right)}{3 \cdot \left(u_{m.UN1} + u_{k.UN1}\right)} = 6.201\ m$

Uplift under key at toe: $V_{ulkeytUN1.OT} := \frac{\left(u_{n.UN1} + u_{o.UN1}\right) \cdot Key_{t.w}}{2} \cdot B \cdot -1 = 0 \cdot kN$

Moment Arm (from Point O): $V_{ulkeytUN1loc.OT} := \frac{Key_{t.w} \cdot \left(2 \cdot u_{n.UN1} + u_{o.UN1}\right)}{3 \cdot \left(u_{n.UN1} + u_{o.UN1}\right)} = 0$

$$\Sigma V_{UpliftUN1.OT} := V_{ulkeyhUN1.OT} + V_{ulbaseUN1.OT} + V_{ulkeytUN1.OT} = -677 \cdot kN$$

$$U_{UN1.loc.OT} := \frac{V_{ulkeyhUN1.OT} \cdot V_{ulkeyhUN1loc.OT} + V_{ulbaseUN1.OT} \cdot V_{ulbaseUN1loc.OT} + V_{ulkeytUN1.OT} \cdot V_{ulkeytUN1loc.OT}}{\Sigma V_{UpliftUN1.OT}} = 6.96\ m$$

$$\Sigma M_{UpliftUN1.OT} := \Sigma V_{UpliftUN1.OT} \cdot U_{UN1.loc.OT} = -4712.0 \cdot kN \cdot m$$

Modify Lateral Water Pressure (Resisting) for Overturning Analysis:

(Resisting water pressure is calculated using the Line of Creep method)

Water Load at Key (heel): $H_{h2UN1.OT} := \dfrac{u_{k.UN1} + u_{j.UN1}}{2} \cdot Key_{h.d} B = 150.4 \cdot kN$

Moment Arm (from Point O): $H_{h2locUN1.OT} := \dfrac{Key_{h.d} \cdot (2 \cdot u_{k.UN1} + u_{j.UN1})}{3(u_{k.UN1} + u_{j.UN1})} + Key_{vdist} = -1.05\ m$

Water Load at Key (toe): $H_{h6UN1.OT} := \dfrac{u_{o.UN1} \cdot (UWSEL_{UN1} - Bot_{ftg} + Key_{t.d})}{2} \cdot B = 78 \cdot kN$

Moment Arm (from Point O): $H_{h6locUN1.OT} := \dfrac{UWSEL_{UN1} - Bot_{ftg} + Key_{t.d}}{3} = 1.33\ m$

$$\Sigma H_{waterresistUN1.OT} := H_{h2UN1.OT} + H_{h6UN1.OT} = 228.78 \cdot kN$$

$$H_{waterresistlocUN1.OT} := \frac{H_{h2UN1.OT} \cdot H_{h2locUN1.OT} + H_{h6UN1.OT} \cdot H_{h6locUN1.OT}}{\Sigma H_{waterresistUN1.OT}} = -0.235\ m$$

$$\Sigma M_{waterresistUN1.OT} := \Sigma H_{waterresistUN1.OT} \cdot H_{waterresistlocUN1.OT} = -53.78 \cdot kN \cdot m$$

Modify Lateral Soil Loads for Overturning Analysis:

(Lateral soil loads are calculated down to Point O instead of bottom of shear key)

Driving Soil Load (Headwater Side):

Surcharge Load: $E_{s1UN1.OT} := S1_{UN1} \cdot K_o \cdot (H_w + Key_{h.d} + Key_{vdist}) \cdot B \cdot -1 = -106.472 \cdot kN$

Moment Arm (from Point O): $E_{s1locUN1.OT} := \dfrac{H_w + Key_{h.d} + Key_{vdist}}{2} = 6.50\ m$

Moist Soil Load above GWL: $E_{h1UN1.OT} := \dfrac{\gamma_m \cdot K_o \cdot h_{1UN1}^{\ 2}}{2} B \cdot -1 = -190.1 \cdot kN$

Moment Arm (from Point O): $E_{h1locUN1.OT} := \dfrac{h_{1UN1}}{3} + h_{2UN1} + Key_{vdist} = 9.07\ m$

Saturated Soil Load below GWL:
(rectangular component) $E_{h2UN1.OT} := (\gamma_m \cdot K_o \cdot h_{1UN1}) \cdot (h_{2UN1} + Key_{vdist}) \cdot B \cdot -1 = -457.4 \cdot kN$

Moment Arm (from Point O): $E_{h2locUN1.OT} := \dfrac{h_{2UN1} + Key_{vdist}}{2} = 3.55\ m$

Saturated Soil Load below GWL:
(triangular component) $E_{h2aUN1.OT} := \dfrac{(\gamma_{sat} - \gamma_w) \cdot K_o \cdot (h_{2UN1} + Key_{vdist})^2}{2} \cdot B \cdot -1 = -167.9 \cdot kN$

Moment Arm (from Point O): $E_{h2alocUN1.OT} := \dfrac{h_{2UN1} + Key_{vdist}}{3} = 2.37\ m$

Resisting Soil Load (Tailwater Side):

(Determine resisting soil load based on depth variation between the keys (ie. Key_{vdist}). In case where key at heel is deeper than key at toe (ie. $Key_{vdist} < 0$), resisting soil load (p*) is assumed to produce horizontal equilibrium as per Figure 4-5 above. Resisting soil load (p_o) is neglected.)

Total Driving Force: $\Sigma H_{SoildriveUN1.OT} := E_{s1UN1.OT} + E_{h1UN1.OT} + E_{h2UN1.OT} + E_{h2aUN1.OT} + H_{h2UN1} = -1327.7 \cdot kN$

Total Resisting Force: $\Sigma H_{waterresistUN1.OT} = 228.8 \cdot kN$

Assumed Soil Load p*: $E_{h8UN1a.OT} := \left(\Sigma H_{SoildriveUN1.OT} + \Sigma H_{waterresistU1.OT}\right) \cdot -1 = 1098.873 \cdot kN$

Moment Arm (from Point O): $E_{h8UN1a.loc.OT} := \dfrac{Key_{vdist}}{2} = -1\,m$

$$E_{h8UN1.OT} := \begin{cases} E_{h8UN1a.OT} & \text{if } Key_{vdist} < 0 \\ \Sigma H_{SoilresistUN1} - H_{h6UN1} - H_{h2aUN1} - P_{sbUN1} & \text{otherwise} \end{cases} = 1098.873 \cdot kN$$

$$\Sigma M_{SoilresistUN1} := \begin{cases} E_{h8UN1a.OT} \cdot E_{h8UN1a.loc.OT} & \text{if } Key_{vdist} < 0 \\ \Sigma M_{HorizSoilResistUN1} - H_{h6UN1} \cdot H_{h6locUN1} - H_{h2aUN1} \cdot H_{h2alocUN1} - P_{sbUN1} \cdot P_{sblocUN1} & \text{otherwise} \end{cases} = -1098.873 \cdot kN \cdot m$$

Sum of Moment about Point O:

$$\Sigma M_{LateraldriveUN1.OT} := E_{s1UN1.OT} \cdot E_{s1locUN1.OT} + E_{h1UN1.OT} \cdot E_{h1locUN1.OT} + E_{h2UN1.OT} \cdot E_{h2locUN1.OT} \dots + E_{h2aUN1.OT} \cdot E_{h2alocUN1.OT} + H_{h2UN1} \cdot H_{h2locUN1} = -4855.9 \cdot kN \cdot m$$

$$\Sigma M_{LateralresistUN1.OT} := \Sigma M_{waterresistUN1.OT} + \Sigma M_{SoilresistUN1} = -1152.6 \cdot kN \cdot m$$

Total moment:

$$\Sigma M_{UN1.OT} := \Sigma M_{conc} + \Sigma M_{VertSoilWaterResistUN1} + \Sigma M_{UpliftUN1.OT} + \Sigma M_{LateraldriveUN1.OT} + \Sigma M_{LateralresistUN1.OT} = 10877.9 \cdot kN \cdot m$$

Total Vertical Force: $\Sigma V_{UN1.OT} := \Sigma V_{conc} + \Sigma V_{SoilWaterUN1} + \Sigma V_{UpllftUN1.OT} = 2123.2 \cdot kN$

Distance X_R: EM 1110-2-2502 Eq.4-1 $X_{R.UN1} := \dfrac{\Sigma M_{UN1.OT}}{\Sigma V_{UN1.OT}} = 5.123\,m$

Overturning Resultant Ratio $Ratio_{UN1.OT} := \dfrac{X_{R.UN1}}{b} = 0.41$

$$Ratio_{UN1.OT.check} := \begin{cases} \text{"OKAY "} & \text{if } Ratio_{UN1.OT} > X_{R.reqUN1} \\ \text{"Revise Structure""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

CHECK FOUNDATION ECCENTRICITY (HORIZONTAL PLANE):

Eccentricity (horizontal plan): $ex_{UN1.OT} := \dfrac{b}{2} - \dfrac{\Sigma M_{UN1.OT}}{\Sigma V_{UN1.OT}} = 1.13\,m$ $Kern_{OT} = 2.083\,m$

Eccentricity Check:

$$e_{check.UN1.OT} := \begin{cases} \text{"Okay"} & \text{if } ex_{UN1} \le Kern_{OT} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"Okay"}$$

LOAD CASE UN1

CHECK FOUNDATION BEARING CAPACITY (HORIZONTAL PLANE):

Base Section Modulus: $S_{b.OT} = 26.04\,m^3$

Bearing Pressure Under Toe:

$$\sigma_{ToeUN1.OT} := \begin{cases} \left(\dfrac{\Sigma V_{UN1.OT}}{b \cdot B} + \dfrac{\Sigma V_{UN1.OT} \cdot ex_{UN1.OT}}{S_{b.OT}}\right) & \text{if } \dfrac{\Sigma V_{UN1.OT}}{b \cdot B} \geq \dfrac{\Sigma V_{UN1.OT} \cdot ex_{UN1.OT}}{S_{b.OT}} \\ \dfrac{2 \cdot \Sigma V_{UN1.OT}}{B \cdot 3\left(\dfrac{b}{2} - ex_{UN1.OT}\right)} & \text{otherwise} \end{cases} = 261.7 \cdot kPa$$

$$Bearing_{ChecktoeUN1.OT} := \begin{cases} \text{"OKAY "} & \text{if } \sigma_{ToeUN1.OT} < \sigma_{allowUN1} \\ \text{"NG - for reference only""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

Bearing Pressure Under Heel:

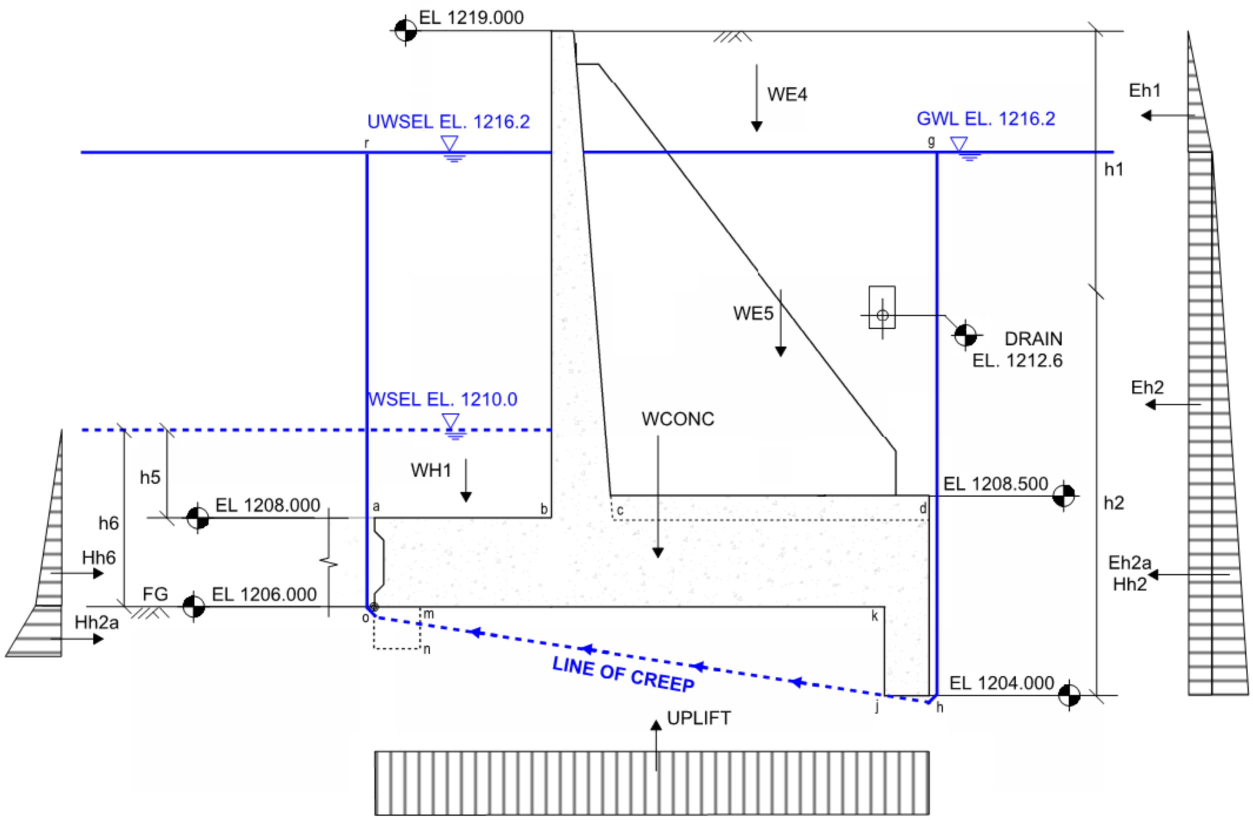
$$\sigma_{HeelUN1.OT} := \begin{cases} \left(\dfrac{\Sigma V_{UN1.OT}}{b \cdot B} - \dfrac{\Sigma V_{UN1.OT} \cdot ex_{UN1.OT}}{S_{b.OT}}\right) & \text{if } \dfrac{\Sigma V_{UN1.OT}}{b \cdot B} \geq \dfrac{\Sigma V_{UN1.OT} \cdot ex_{UN1.OT}}{S_{b.OT}} \\ 0 & \text{otherwise} \end{cases} = 78.0 \cdot kPa$$

$$Bearing_{CheckheelUN1.OT} := \left(\begin{cases} \text{"OKAY "} & \text{if } \sigma_{HeelUN1.OT} < \sigma_{allowUN1} \wedge \sigma_{HeelUN1.OT} > 0 \\ \text{"NG - for reference only""} & \text{otherwise} \end{cases} \right) = \text{"OKAY "}$$

SUMMARY OF STABILITY ASSESSMENT:

LOAD CASE UN1

Sliding Factor of Safety: (Horizontal Plane - Ref only)	$FS_{Horiz.SlidingUN1} = 1.03$	$FS_{Sliding.check1.UN1}$ = "NG - key req""
Sliding Factor of Safety: (Inclined Plane)	$FS_{InclinedlSlidingUN1} = 2.01$	$FS_{Sliding.check2.UN1}$ = "OKAY "
Eccentricity: (Inclined Plane)	$ex_{UN1} = 0.57\ m$	$e_{check.UN1}$ = "Okay"
Bearing Pressure At Heel: (Inclined Plane)	$\sigma_{HeelUN1} = 140 \cdot kPa$	$Bearing_{CheckheelUN1}$ = "OKAY "
Bearing Pressure At Toe: (Inclined Plane)	$\sigma_{ToeUN1} = 242 \cdot kPa$	$Bearing_{ChecktoeUN1}$ = "OKAY "
Flotation Factor of Safety (horizontal plane)	$FS_{FloatationUN1} = 3.49$	$FS_{Floatation.UN1.check}$ = "OKAY "
Overturning Resultant Ratio: (horizontal plane)	$Ratio_{UN1.OT} = 0.41$	$Ratio_{UN1.OT.check}$ = "OKAY "
Eccentricity: (horizontal plane - Ref only)	$ex_{UN1.OT} = 1.13\ m$	$e_{check.UN1.OT}$ = "Okay"
Bearing Pressure At Heel: (horizontal plane - Ref only)	$\sigma_{HeelUN1.OT} = 78 \cdot kPa$	$Bearing_{CheckheelUN1.OT}$ = "OKAY "
Bearing Pressure At Toe: (horizontal plane - Ref only)	$\sigma_{ToeUN1.OT} = 262 \cdot kPa$	$Bearing_{ChecktoeUN1.OT}$ = "OKAY "



UN2 DESIGN CASE

LOAD CASE UN2 ACCEPTANCE PARAMETERS

FS sliding:

Unusual (UN) 1.3 (without cohesion) (Table 3-3, USACE EM 1110-2-2100)

Resultant Location:

Unsual (UN) Inside middle third ~100% base in compression

Required Factor of Safety for Sliding: $FS_{sliding.reqUN2} := 1.3$ (Without Cohesion)

Allowable rock bearing pressure: $\sigma_{allowUN2} := 1470kPa$ (Section 5.2, Design Criteria EM 1110-2-2100 Section 3-10)

Overturning Required Resultant Ratio: $X_{R.reqUN2} := 0.333$ (EM 1110-2-2502, Figure 4-4)

Required Factor of Safety for Floatation $FS_{req.UN2.flt} := 1.3$

SOIL HEIGHTS and Water Levels:

LOAD CASE UN2

Heel Conditions:

Groundwater Elevation at Heel: $GWL_{UN2} := 1216.2m$

Distance from Finish Grade to Groundwater at Heel: $h_{1UN2} := \left[T_w - GWL_{UN2} + \left(L_{cd} + t_{wb} - t_{wt}\right)\cdot \tan(\beta)\right] = 2.80\ m$

Distance from Water Surface to Bottom of Footing at Heel: $h_{2UN2} := GWL_{UN2} - Bot_{ftg} + Key_{h.d} = 12.20\ m$

Toe Conditions:

Water Surface Elevation at Toe: $WSEL_{UN2} := 1210.0m$

Water Surface Elevation at Toe for Uplift: $UWSEL_{UN2} := 1216.2\cdot m$

Finish Grade at Toe providing lateral resistance: $FG_{toeUN2} := 1206.0\cdot m$

Soil Depth Above top of footing: $h_{3aUN2} := FG_{toeUN2} - Top_{ftg} = -2\ m$

$$h_{3UN2} := \begin{cases} h_{3aUN2} & \text{if } FG_{toeUN2} - Top_{ftg} \geq 0 \\ 0 & \text{otherwise} \end{cases} = 0$$

Resisting Fill at Toe: $h_{4UN2} := FG_{toeUN2} - Bot_{ftg} + Key_{t.d} = 0.00\ m$

Distance from Water Level to Top of Footing at Toe: $h_{5UN2} := WSEL_{UN2} - Top_{ftg} = 2.00\ m$

Distance from Water Surface to Bottom of Footing at Toe: $h_{6UN2} := WSEL_{UN2} - Bot_{ftg} + Key_{t.d} = 4.00\ m$

Soil Depth Above WSEL: $h_{7aUN2} := FG_{toeUN2} - WSEL_{UN2} = -4\ m$

$$h_{7UN2} := \begin{cases} h_{7aUN2} & \text{if } FG_{toeUN2} - WSEL_{UN2} \geq 0 \\ 0 & \text{otherwise} \end{cases} = 0$$

Soil Depth Below WSEL:

$$h_{8UN2} := \begin{cases} WSEL_{UN2} - Bot_{ftg} + Key_{t.d} & \text{if } FG_{toeUN2} - WSEL_{UN2} \geq 0 \\ h_{4UN2} & \text{otherwise} \end{cases} = 0$$

For Line of Creep Method: $L_{ho.UN2} := \sqrt{b^2 + \left(Key_{h.d} - Key_{t.d}\right)^2} = 12.659\ m$

Head Loss from Point g:

$\Delta h_{g.hj.UN2} := h_{2UN2} = 12.2\ m$ (to point h & j)

$\Delta h_{g.km.UN2} := GWL_{UN2} - Bot_{ftg} = 10.2\ m$ (to point k & m)

$\Delta h_{g.no.UN2} := GWL_{UN2} - Bot_{ftg} + Key_{t.d} = 10.2\ m$ (to point n & o)

$\Delta h_{g.p.UN2} := GWL_{UN2} - FG_{toeUN2} = 10.2\ m$ (to point p*)

$\Delta h_{g.r.UN2} := GWL_{UN2} - UWSEL_{UN2} = 0\ m$ (to point r)

Surcharge

Surcharge on Heel: $S1_{UN2} := 0.0 \frac{kN}{m^2}$

* same as point "o" in this case

Calculate Soil Lateral Pressure Coefficients:

LOAD CASE UN2

For all load cases except seismic, soil loading to be based on At-Rest Condition.
Calculate at-rest pressure coefficient Ko based on Jaky's (1944) equation.

Soil At Rest Static Coefficient: $K_o := \frac{1 - \sin(\phi)}{1 + \sin(\beta)} = 0.546$ (Eq. 3-6, USACE EM 1110-2-2502)

Lateral - Driving Force

Static At-Rest:

Surcharge Load: $E_{s1UN2} := S1_{UN2} \cdot K_o \cdot \left(H_w + Key_{h.d}\right) \cdot B \cdot -1 = 0 \cdot kN$

Moment Arm (from bottom of footing): $E_{s1locUN2} := \frac{H_w + Key_{h.d}}{2} + Key_{vdist} = 5.50\ m$

Moist Soil Load above GWL: $E_{h1UN2} := \frac{\gamma_m \cdot K_o \cdot h_{1UN2}^{\ 2}}{2} B \cdot -1 = -42.8 \cdot kN$

Moment Arm (from bottom of footing): $E_{h1locUN2} := \frac{h_{1UN2}}{3} + h_{2UN2} + Key_{vdist} = 11.13\ m$

Saturated Soil Load below GWL:
(rectangular component) $E_{h2UN2} := \left(\gamma_m \cdot K_o \cdot h_{1UN2}\right) \cdot h_{2UN2} \cdot B \cdot -1 = -373.0 \cdot kN$

Moment Arm (from bottom of footing): $E_{h2locUN2} := \frac{h_{2UN2}}{2} + Key_{vdist} = 4.10\ m$

Saturated Soil Load below GWL:
(triangular component) $E_{h2aUN2} := \frac{\left(\gamma_{sat} - \gamma_w\right) \cdot K_o \cdot h_{2UN2}^{\ 2}}{2} \cdot B \cdot -1 = -495.7 \cdot kN$

Moment Arm (from bottom of footing): $E_{h2alocUN2} := \frac{h_{2UN2}}{3} + Key_{vdist} = 2.07\ m$

Lateral Water Load:

Water Load GWL to Bottom of Key: $H_{h2UN2} := \frac{\gamma_w \cdot h_{2UN2}^{\ 2}}{2} \cdot B \cdot -1 = -729.3 \cdot kN$

Moment Arm (from bottom of footing): $H_{h2locUN2} := \frac{h_{2UN2}}{3} + Key_{vdist} = 2.07\ m$

$$\Sigma H_{SoildriveUN2} := E_{s1UN2} + E_{h1UN2} + E_{h2UN2} + E_{h2aUN2} + H_{h2UN2} = -1640.9 \cdot kN$$

$$\Sigma M_{LateralSoildriveUN2} := E_{s1UN2} \cdot E_{s1locUN2} + E_{h1UN2} \cdot E_{h1locUN2} + E_{h2UN2} \cdot E_{h2locUN2} \ldots + E_{h2aUN2} \cdot E_{h2alocUN2} + H_{h2UN2} \cdot H_{h2locUN2} = -4537.8\ m \cdot kN$$

Lateral - Resisting Force

LOAD CASE UN2

Lateral Water Load:

Water Load WSEL to Bottom of Footing: $H_{h6UN2} := \frac{\gamma_w \cdot h_{6UN2}^2}{2} \cdot B = 78.4 \cdot kN$

Moment Arm (from bot. of toe key): $H_{h6locUN2} := \frac{h_{6UN2}}{3} = 1.33\ m$

Water Load Bot. of Footing to Bot. of H. Key: $H_{h2aUN2} := \left[\left(UWSEL_{UN2} - Bot_{ftg} + Key_{t.d}\right) + h_{2UN2}\right] \cdot \frac{Key_{h.d}}{2} \cdot \gamma_w \cdot B = 219.5 \cdot kN$

Moment Arm (from bot. of toe key): $H_{h2alocUN2} := \frac{Key_{h.d} \cdot \left[2 \cdot \left(UWSEL_{UN2} - Bot_{ftg} + Key_{t.d}\right) + h_{2UN2}\right]}{3\left[h_{2UN2} + \left(UWSEL_{UN2} - Bot_{ftg} + Key_{t.d}\right)\right]} \dots + Key_{vdist} = -1.03\ m$

Lateral Soil Load:

Moist Soil Load above WSEL: $E_{h7UN2} := \frac{\gamma_m \cdot K_o \cdot h_{7UN2}^2}{2} \cdot B = 0.0 \cdot kN$

Moment Arm (from bot. of toe key): $E_{h7locUN2} := h_{6UN2} + \frac{h_{7UN2}}{3} + Key_{vdist} = 2.00\ m$

Saturated Soil Load below WSEL: (rectangular component) $E_{h8UN2} := \left(\gamma_m \cdot K_o \cdot h_{7UN2}\right) \cdot h_{8UN2} \cdot B = 0.0 \cdot kN$

Moment Arm (from bot. of toe key): $E_{h8locUN2} := \frac{h_{8UN2}}{2} = 0.00\ m$

Saturated Soil Load below WSEL: (triangular component) $E_{h8aUN2} := \frac{\left[\left(\gamma_{sat} - \gamma_w\right) \cdot K_o\right] \cdot h_{8UN2}^2}{2} \cdot B = 0.0 \cdot kN$

Moment Arm (from bot. of footing): $E_{h8alocUN2} := \frac{h_{8UN2}}{3} = 0.00\ m$

Lateral Resistance from Stilling Basin:

Lateral Resistance from Stilling Basin: $P_{sbUN2} := 430kN$ (Force needed to achieve the required sliding factor of safety in case UN2)

Moment Arm (from bot. of toe key): $P_{sblocUN2} := \frac{t_{ftg}}{2} + Key_{t.d} = 1.00\ m$

$\Sigma H_{SoilresistUN2} := H_{h6UN2} + H_{h2aUN2} + E_{h7UN2} + E_{h8UN2} + E_{h8aUN2} + P_{sbUN2} = 727.9 \cdot kN$

$\Sigma M_{HorizSoilResistUN2} := H_{h6UN2} \cdot H_{h6locUN2} + H_{h2aUN2} \cdot H_{h2alocUN2} + E_{h7UN2} \cdot E_{h7locUN2} \dots + E_{h8UN2} \cdot E_{h8locUN2} + E_{h8aUN2} \cdot E_{h8alocUN2} + P_{sbUN2} \cdot P_{sblocUN2} = 308.5\ m \cdot kN$

Vertical Force:

UPLIFT: Linear distribution from water at heel to water at toe:

$\Sigma V_{UpliftUN2} := \left[\left(UWSEL_{UN2} - Bot_{ftg} + Key_{t.d}\right) + h_{2UN2}\right] \cdot \frac{b}{2} \cdot \gamma_w \cdot B \cdot -1 = -1372 \cdot kN$

Moment Arm (from Point O): $V_{UpliftUN2aloc} := \frac{b \cdot \left[2 \cdot h_{2UN2} + \left(UWSEL_{UN2} - Bot_{ftg} + Key_{t.d}\right)\right]}{3\left[h_{2UN2} + \left(UWSEL_{UN2} - Bot_{ftg} + Key_{t.d}\right)\right]} = 6.436\ m$

$\Sigma M_{UpliftUN2} := \Sigma V_{UpliftUN2} \cdot V_{UpliftUN2aloc} = -8830.208 \cdot kN \cdot m$

Weight of soil and water over toe:

Water Above the Top of Footing: $W_{H1UN2} := \gamma_w \cdot h_{5UN2} \cdot L_{ab} \cdot B = 78.4 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E1locUN2} := \frac{L_{ab}}{2} = 2\,m$

Soil above top of footing: $W_{E6UN2} := \gamma_b \cdot h_{3UN2} \cdot L_{ab} \cdot B = 0.0 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E6locUN2} := \frac{L_{ab}}{2} = 2\,m$

Vertical Load Due to Surcharge: $S_{UN2} := S1_{UN2} \cdot L_{cd} \cdot B = 0 \cdot kN$ $\quad S_{UN2loc} := b - \frac{L_{cd}}{2} = 8.93\,m$

Weight of soil and water over heel:

Moist Soil for sloped grade above top of wall:

Length of sloped portion of soil above top of wall: $L_{E3UN2} := \left(L_{cd} + t_{wb} - t_{wt}\right) = 8.00\,m$

Height of sloped soil above top of wall over heel: $h_{E3locUN2} := \left(L_{E3UN2}\right) \cdot \tan(\beta) = 0.00\,m$

Weight of sloped soil above top of wall: $W_{E3UN2} := \frac{\gamma_m}{2} \cdot h_{E3locUN2} \cdot L_{E3UN2} \cdot B = 0.0 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E3locUN2} := L_{ab} + t_{wt} + \frac{2}{3} \cdot L_{E3UN2} = 9.83\,m$

Moist soil from top of wall to groundwater level:

Height of soil from top of wall and top of GWL: $h_{1UN2} = 2.80\,m$

Length from edge of wall at GWL to edge of heel: $L_{E4UN2} := L_{E3UN2} - \left(h_{1UN2} \cdot S_{batter}\right) = 7.78\,m$

Weight of soil over heel from top of wall to GWL: $W_{E4UN2} := \gamma_m \cdot h_{1UN2} \cdot \frac{\left(L_{E3UN2} + L_{E4UN2}\right)}{2} \cdot B = 441.8 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E4locUN2} := b - \frac{L_{E3UN2}^{\,2} + L_{E3UN2} \cdot L_{E4UN2} + L_{E4UN2}^{\,2}}{3\left(L_{E3UN2} + L_{E4UN2}\right)} = 8.55\,m$

Saturated soil from groundwater to top of footing:

Height of soil from GWL to top of heel: $h_{E4UN2} := h_{2UN2} - t_{ftg} - Key_{h.d} = 8.20\,m$

Weight of soil over heel from GWL to top of heel: $W_{E5UN2} := \left(\gamma_{sat}\right) \cdot h_{E4UN2} \cdot \frac{\left(L_{E4UN2} + L_{cd}\right)}{2} \cdot B = 1345.4 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E5locUN2} := b - \frac{L_{E4UN2}^{\,2} + L_{E4UN2} \cdot L_{cd} + L_{cd}^{\,2}}{3\left(L_{E4UN2} + L_{cd}\right)} = 8.77\,m$

$$\Sigma V_{SoilWaterUN2} := W_{H1UN2} + W_{E6UN2} + W_{E3UN2} + W_{E4UN2} + W_{E5UN2} + S_{UN2} = 1865.7 \cdot kN$$

$$\Sigma M_{VertSoilWaterResistUN2} := W_{H1UN2} \cdot W_{E1locUN2} + W_{E6UN2} \cdot W_{E6locUN2} \cdots + W_{E3UN2} \cdot W_{E3locUN2} + W_{E4UN2} \cdot W_{E4locUN2} + W_{E5UN2} \cdot W_{E5locUN2} + S_{UN2} \cdot S_{UN2loc} = 15734.3\,m \cdot kN$$

THIS PAGE INTENTIONALLY LEFT BLANK
PLEASE GO TO THE NEXT PAGE

STABILITY ASSESSMENT:

LOAD CASE UN2

CHECK SLIDING ALONG HORIZONTAL SLIDING PLANE:

Summation of the vertical forces:

$$\Sigma V_{UN2} := \Sigma V_{conc} + \Sigma V_{SoilWaterUN2} + \Sigma V_{UpliftUN2} = 1369.1 \cdot kN$$

Summation of the horizontal forces:

$$\Sigma H_{UN2} := \Sigma H_{SoildriveUN2} + \Sigma H_{SoilresistUN2} = -913.0 \cdot kN$$

Safety Factor for Sliding Horizontal Failure Plane

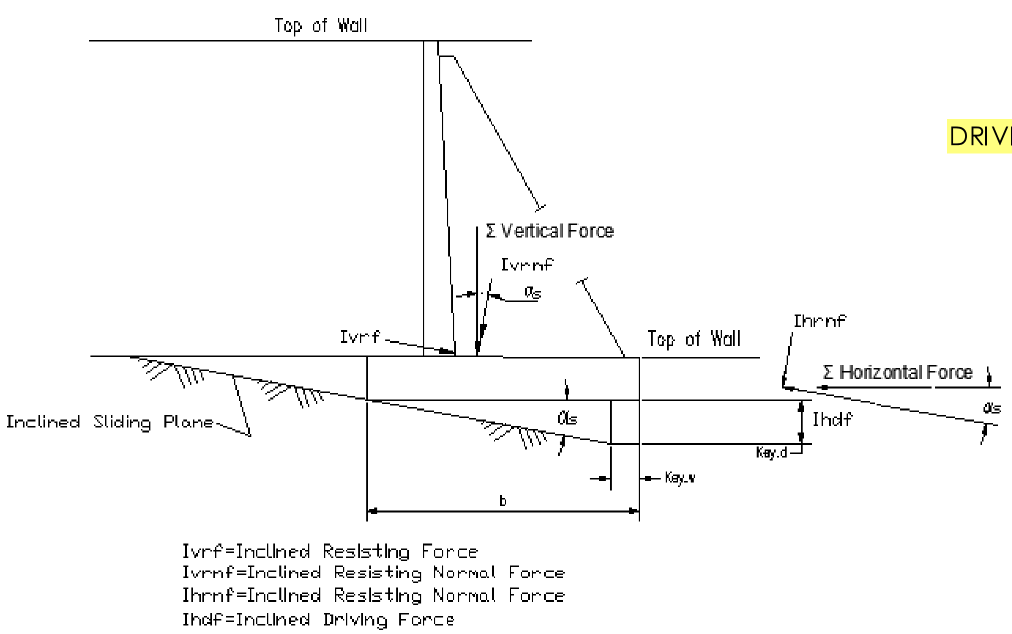
$$FS_{Horiz.SlidingUN2} := \frac{\left|\Sigma V_{UN2}\right| \cdot \tan\left(\phi_{rock} \cdot \frac{\pi}{180}\right)}{\left|\Sigma H_{UN2}\right|} = 0.73$$

$$FS_{Sliding.check1.UN2} := \begin{cases} \text{"OKAY "} & \text{if } FS_{Horiz.SlidingUN2} > FS_{sliding.reqUN2} \\ \text{"NG - key req""} & \text{otherwise} \end{cases} = \text{"NG - key req""}$$

CHECK FACTOR OF SAFETY SLIDING WITH KEY (INCLINED SLIDING PLANE):

RESISTING SIDE

DRIVING SIDE



TOE

HEEL

$\alpha s = 0.172$ as degrees= $\alpha s \cdot \left(\frac{180}{\pi}\right) = 9.87$

(With properly engineered reinforced concrete Key, horizontal sliding plane thru Toe is protected, critical sliding plane is relocated to the INCLINED SLIDING PLANE FROM HEEL KEY To TOE, Bedrock Mass above this examing plane is mobilized by reinforced concrete key and combined into Structural Wedge.)

Resolve ΣV_{UN2} & ΣH_{UN2}

$$\Sigma V_{InclinedUN2} := \cos(\alpha s) \cdot \left(\left|\Sigma V_{UN2} + V_{rocksection}\right|\right) + \sin(\alpha s) \cdot \left|\Sigma H_{UN2}\right| = 1795.3 \cdot kN$$

$$\Sigma H_{InclinedUN2} := \cos(\alpha s) \cdot \left|\Sigma H_{UN2}\right| - \sin(\alpha s) \cdot \left(\left|\Sigma V_{UN2} + V_{rocksection}\right|\right) = 614.4 \cdot kN$$

Safety Factor for Sliding Inclined Failure Plane

$$FS_{InclinedSlidingUN2} := \frac{\Sigma V_{InclinedUN2} \cdot \tan(\phi_r)}{\Sigma H_{InclinedUN2}} = 1.30$$

$$FS_{Sliding.check2.UN2} := \begin{cases} \text{"OKAY"} & \text{if } FS_{InclinedSlidingUN2} > FS_{sliding.reqUN2} \\ \text{"NG - Revise Structure"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

CHECK FOUNDATION ECCENTRICITY:

Summation of the resisting moments about the toe:

$$\Sigma M_{resUN2} := \Sigma M_{conc} + \Sigma M_{VertSoilWaterResistUN2} + \Sigma M_{HorizSoilResistUN2} + \Sigma M_{rocksection} = 23620 \cdot kN \cdot m$$

Summation of the overturning moments about the toe:

$$\Sigma M_{oUN2} := \Sigma M_{LateralSoildriveUN2} + \Sigma M_{UpliftUN2} = -13368 \cdot kN \cdot m$$

Total moment: $\Sigma M_{UN2} := \Sigma M_{resUN2} + \Sigma M_{oUN2} = 10251.7\ m \cdot kN$

Normal force to base: $\Sigma V_{InclinedUN2} = 1795.3 \cdot kN$

Inclined Sliding Plane Length: $L_{incline} = 12.7 \cdot m$

Eccentricity (inclined plane): $ex_{UN2} := \frac{L_{incline}}{2} - \frac{\Sigma M_{UN2}}{\Sigma V_{InclinedUN2}} = 0.63\ m$ $\quad Kern = 2.115\ m$

Eccentricity Check: $e_{check.UN2} := \begin{cases} \text{"Okay"} & \text{if } ex_{UN2} \le Kern \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"Okay"}$

CHECK FOUNDATION BEARING CAPACITY:

Base Section Modulus: $S_b = 26.83\ m^3$

Bearing Pressure Under Toe:

$$\sigma_{ToeUN2} := \begin{cases} \left(\frac{\Sigma V_{InclinedUN2}}{L_{incline} \cdot B} + \frac{\Sigma V_{InclinedUN2} \cdot ex_{UN2}}{S_b} \right) & \text{if } \frac{\Sigma V_{InclinedUN2} \cdot ex_{UN2}}{S_b} \le \frac{\Sigma V_{InclinedUN2}}{L_{incline} \cdot B} \\ \frac{2 \cdot \Sigma V_{InclinedUN2}}{B \cdot 3 \left(\frac{b}{2} - ex_{UN2} \right)} & \text{otherwise} \end{cases} = 183.9 \cdot kPa$$

$$Bearing_{ChecktoeUN2} := \begin{cases} \text{"OKAY"} & \text{if } \sigma_{ToeUN2} < \sigma_{allowUN2} \\ \text{"NG"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

Bearing Pressure Under Heel:

$$\sigma_{HeelUN2} := \begin{cases} \left(\frac{\Sigma V_{InclinedUN2}}{L_{incline} \cdot B} - \frac{\Sigma V_{InclinedUN2} \cdot ex_{UN2}}{S_b} \right) & \text{if } \frac{\Sigma V_{InclinedUN2} \cdot ex_{UN2}}{S_b} \le \frac{\Sigma V_{InclinedUN2}}{L_{incline} \cdot B} \\ 0 & \text{otherwise} \end{cases} = 99.1 \cdot kPa$$

$$Bearing_{CheckheelUN2} := \left(\begin{cases} \text{"OKAY"} & \text{if } \sigma_{HeelUN2} < \sigma_{allowUN2} \wedge \sigma_{HeelUN2} > 0 \\ \text{"NG - perform cracked base analysis"} & \text{otherwise} \end{cases} \right) = \text{"OKAY"}$$

CHECK FLOATATION:

Safety Factor for Floatation:

$$FS_{FloatationUN2} := \frac{\Sigma V_{conc} + \Sigma V_{SoilWaterUN2}}{\left|\Sigma V_{UpliftUN2}\right|} = 2.00$$

$$FS_{Floatation.UN2.check} := \begin{cases} \text{"OKAY "} & \text{if } FS_{FloatationUN2} > FS_{req.UN2.flt} \\ \text{"Revise Structure""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

CHECK OVERTURNING

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.
Assumptions are made in order to compute overturning stablity of indetermine forces on monolith with key;
(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.
(b) The horizontal resisting force acting on the key, P.key, is that required for static equilibrium
(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1

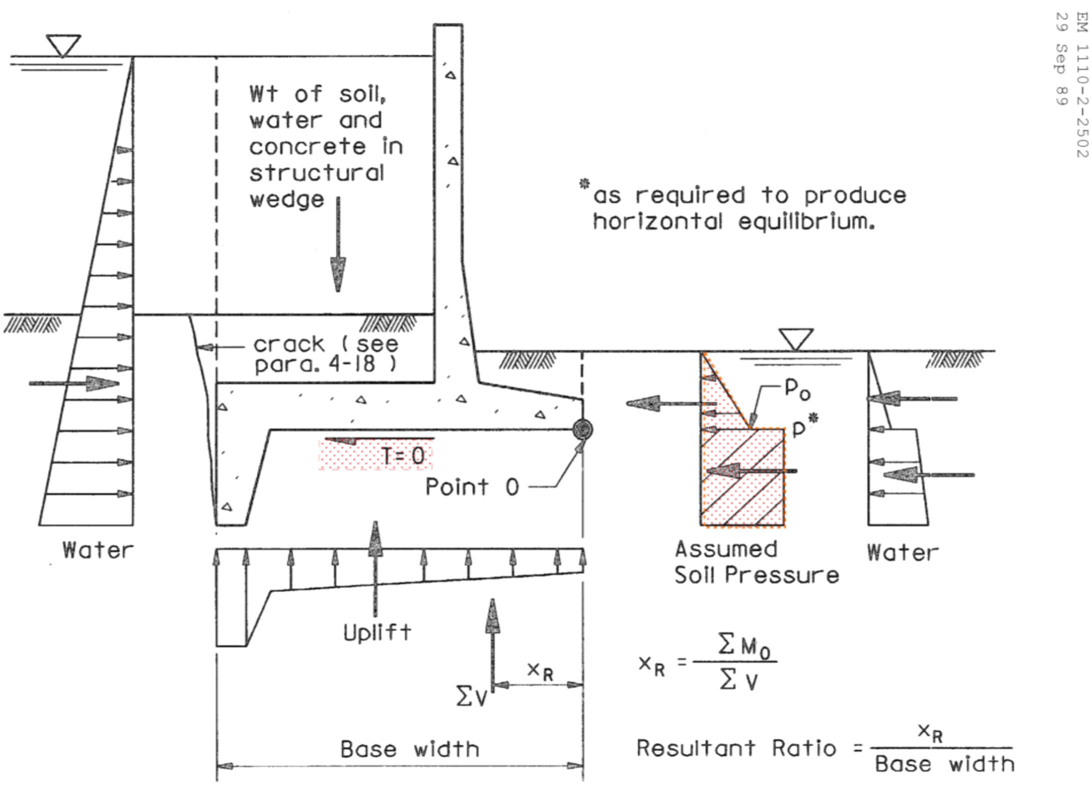


Figure 4-5. Forces for overturning analysis for wall with horizontal base and key

Modify Uplift for Overturning Analysis:

(Uplift is calculated along the concrete/rock contact using the Line of Creep method)

Water Pressure at h: $u_{h.UN2} := \Delta h_{g.hj.UN2} \cdot \gamma_w = 119.56 \cdot kPa$

Water Pressure at o: $u_{o.UN2} := \left(\Delta h_{g.no.UN2} - \frac{\Delta h_{g.r.UN2} \cdot L_{ho.UN2}}{L_{ho.UN2}}\right) \cdot \gamma_w = 99.96 \cdot kPa$

Head loss between point h and o: $\Delta h_{ho.UN2} := \Delta h_{g.r.UN2} \cdot \frac{L_{ho.UN2}}{L_{ho.UN2}} = 0\,m$

Length of concrete base (h -> o): $L_{baseho.UN2} := Key_{h.w} + Key_{h.d} + Key_{hdist} + Key_{t.d} + Key_{t.w} = 14.5\,m$

Head loss along h -> j: $\Delta h_{hj.UN2} := \Delta h_{ho.UN2} \cdot \frac{Key_{h.w}}{L_{baseho.UN2}} = 0\,m$

Water Pressure at j: $u_{j.UN2} := \left(\Delta h_{g.hj.UN2} - \Delta h_{hj.UN2}\right) \cdot \gamma_w = 119.56 \cdot kPa$

Head loss along h -> k: $\Delta h_{hjk.UN2} := \Delta h_{ho.UN2} \cdot \left(\frac{Key_{h.w} + Key_{h.d}}{L_{baseho.UN2}}\right) = 0\,m$

Water Pressure at k: $u_{k.UN2} := \left(\Delta h_{g.km.UN2} - \Delta h_{hjk.UN2}\right) \cdot \gamma_w = 99.96 \cdot kPa$

Head loss along h -> m: $\Delta h_{hjkm.UN2} := \Delta h_{ho.UN2} \cdot \left(\frac{Key_{h.w} + Key_{h.d} + Key_{hdist}}{L_{baseho.UN2}}\right) = 0\,m$

Water Pressure at m: $u_{m.UN2} := \left(\Delta h_{g.km.UN2} - \Delta h_{hjkm.UN2}\right) \cdot \gamma_w = 99.96 \cdot kPa$

Head loss along h -> n: $\Delta h_{hjkmn.UN2} := \Delta h_{ho.UN2} \cdot \left(\frac{Key_{h.w} + Key_{h.d} + Key_{hdist} + Key_{t.d}}{L_{baseho.UN2}}\right) = 0\,m$

Water Pressure at n: $u_{n.UN2} := \left(\Delta h_{g.no.UN2} - \Delta h_{hjkmn.UN2}\right) \cdot \gamma_w = 99.96 \cdot kPa$

Uplift under key at heel: $V_{ulkeyhUN2.OT} := \frac{\left(u_{h.UN2} + u_{j.UN2}\right) \cdot Key_{h.w}}{2} \cdot B \cdot -1 = -119.56 \cdot kN$

Moment Arm (from Point O): $V_{ulkeyhUN2loc.OT} := b - \frac{Key_{h.w} \cdot \left(2 \cdot u_{j.UN2} + u_{h.UN2}\right)}{3 \cdot \left(u_{j.UN2} + u_{h.UN2}\right)} = 12\,m$

Uplift under base: $V_{ulbaseUN2.OT} := \frac{\left(u_{k.UN2} + u_{m.UN2}\right) \cdot Key_{hdist}}{2} \cdot B \cdot -1 = -1149.54 \cdot kN$

Moment Arm (from Point O): $V_{ulbaseUN2loc.OT} := b - Key_{h.w} - \frac{Key_{hdist} \cdot \left(2 \cdot u_{m.UN2} + u_{k.UN2}\right)}{3 \cdot \left(u_{m.UN2} + u_{k.UN2}\right)} = 5.75\,m$

Uplift under key at toe: $V_{ulkeytUN2.OT} := \frac{\left(u_{n.UN2} + u_{o.UN2}\right) \cdot Key_{t.w}}{2} \cdot B \cdot -1 = 0 \cdot kN$

Moment Arm (from Point O): $V_{ulkeytUN2loc.OT} := \frac{Key_{t.w} \cdot \left(2 \cdot u_{n.UN2} + u_{o.UN2}\right)}{3 \cdot \left(u_{n.UN2} + u_{o.UN2}\right)} = 0$

$$\Sigma V_{UpliftUN2.OT} := V_{ulkeyhUN2.OT} + V_{ulbaseUN2.OT} + V_{ulkeytUN2.OT} = -1269 \cdot kN$$

$$U_{UN2.loc.OT} := \frac{V_{ulkeyhUN2.OT} \cdot V_{ulkeyhUN2loc.OT} + V_{ulbaseUN2.OT} \cdot V_{ulbaseUN2loc.OT} + V_{ulkeytUN2.OT} \cdot V_{ulkeytUN2loc.OT}}{\Sigma V_{UpliftUN2.OT}} = 6.34\,m$$

$$\Sigma M_{UpliftUN2.OT} := \Sigma V_{UpliftUN2.OT} \cdot U_{UN2.loc.OT} = -8044.6 \cdot kN \cdot m$$

Modify Lateral Water Pressure (Resisting) for Overturning Analysis:

(Resisting water pressure is calculated using the Line of Creep method)

Water Load at Key (heel): $H_{h2UN2.OT} := \frac{u_{k.UN2} + u_{j.UN2}}{2} \cdot Key_{h.d} B = 219.5 \cdot kN$

Moment Arm (from Point O): $H_{h2locUN2.OT} := \frac{Key_{h.d} \cdot (2 \cdot u_{k.UN2} + u_{j.UN2})}{3(u_{k.UN2} + u_{j.UN2})} + Key_{vdist} = -1.03\ m$

Water Load at Key (toe): $H_{h6UN2.OT} := \frac{u_{o.UN2} \cdot (UWSEL_{UN2} - Bot_{ftg} + Key_{t.d})}{2} \cdot B = 510 \cdot kN$

Moment Arm (from Point O): $H_{h6locUN2.OT} := \frac{UWSEL_{UN2} - Bot_{ftg} + Key_{t.d}}{3} = 3.40\ m$

$$\Sigma H_{waterresistUN2.OT} := H_{h2UN2.OT} + H_{h6UN2.OT} = 729.32 \cdot kN$$

$$H_{waterresistlocUN2.OT} := \frac{H_{h2UN2.OT} \cdot H_{h2locUN2.OT} + H_{h6UN2.OT} \cdot H_{h6locUN2.OT}}{\Sigma H_{waterresistUN2.OT}} = 2.067\ m$$

$$\Sigma M_{waterresistUN2.OT} := \Sigma H_{waterresistUN2.OT} \cdot H_{waterresistlocUN2.OT} = 1507.25 \cdot kN \cdot m$$

Modify Lateral Soil Loads for Overturning Analysis:

(Lateral soil loads are calculated down to Point O instead of bottom of shear key)

__**Driving Soil Load (Headwater Side):**__

Surcharge Load: $E_{s1UN2.OT} := S1_{UN2} \cdot K_o \cdot (H_w + Key_{h.d} + Key_{vdist}) \cdot B \cdot -1 = 0 \cdot kN$

Moment Arm (from Point O): $E_{s1locUN2.OT} := \frac{H_w + Key_{h.d} + Key_{vdist}}{2} = 6.50\ m$

Moist Soil Load above GWL: $E_{h1UN2.OT} := \frac{\gamma_m \cdot K_o \cdot h_{1UN2}^{\ 2}}{2} B \cdot -1 = -42.8 \cdot kN$

Moment Arm (from Point O): $E_{h1locUN2.OT} := \frac{h_{1UN2}}{3} + h_{2UN2} + Key_{vdist} = 11.13\ m$

Saturated Soil Load below GWL: (rectangular component) $E_{h2UN2.OT} := (\gamma_m \cdot K_o \cdot h_{1UN2}) \cdot (h_{2UN2} + Key_{vdist}) \cdot B \cdot -1 = -311.9 \cdot kN$

Moment Arm (from Point O): $E_{h2locUN2.OT} := \frac{h_{2UN2} + Key_{vdist}}{2} = 5.10\ m$

Saturated Soil Load below GWL: (triangular component) $E_{h2aUN2.OT} := \frac{(\gamma_{sat} - \gamma_w) \cdot K_o \cdot (h_{2UN2} + Key_{vdist})^2}{2} \cdot B \cdot -1 = -346.5 \cdot kN$

Moment Arm (from Point O): $E_{h2alocUN2.OT} := \frac{h_{2UN2} + Key_{vdist}}{3} = 3.40\ m$

Resisting Soil Load (Tailwater Side):

(Determine resisting soil load based on depth variation between the keys (ie. Key_{vdist}). In case where key at heel is deeper than key at toe (ie. Key_{vdist}< 0), resisting soil load (p*) is assumed to produce horizontal equilibrium as per Figure 4-5 above. Resisting soil load (p_o) is neglected.)

Total Driving Force: $\Sigma H_{SoildriveUN2.OT} := E_{s1UN2.OT} + E_{h1UN2.OT} + E_{h2UN2.OT} + E_{h2aUN2.OT} + H_{h2UN2} = -1430.5 \cdot kN$

Total Resisting Force: $\Sigma H_{waterresistUN2.OT} = 729.3 \cdot kN$

Assumed Soil Load p*: $E_{h8UN2a.OT} := \left(\Sigma H_{SoildriveUN2.OT} + \Sigma H_{waterresistUN2.OT}\right) \cdot -1 = 701.209 \cdot kN$

Moment Arm (from Point O): $E_{h8UN2a.loc.OT} := \frac{Key_{vdist}}{2} = -1\ m$

$$E_{h8UN2.OT} := \begin{cases} E_{h8UN2a.OT} & \text{if } Key_{vdist} < 0 \\ \Sigma H_{SoilresistUN2} - H_{h6UN2} - H_{h2aUN2} - P_{sbUN2} & \text{otherwise} \end{cases} = 701.209 \cdot kN$$

$$\Sigma M_{SoilresistUN2} := \begin{cases} E_{h8UN2a.OT} \cdot E_{h8UN2a.loc.OT} & \text{if } Key_{vdist} < 0 \\ \Sigma M_{HorizSoilResistUN2} - H_{h6UN2} \cdot H_{h6locUN2} - H_{h2aUN2} \cdot H_{h2alocUN2} - P_{sbUN2} \cdot P_{sblocUN2} & \text{otherwise} \end{cases} = -701.209 \cdot kN \cdot m$$

Sum of Moment about Point O:

$$\Sigma M_{LateraldriveUN2.OT} := E_{s1UN2.OT} \cdot E_{s1locUN2.OT} + E_{h1UN2.OT} \cdot E_{h1locUN2.OT} + E_{h2UN2.OT} \cdot E_{h2locUN2.OT} \ldots + E_{h2aUN2.OT} \cdot E_{h2alocUN2.OT} + H_{h2UN2} \cdot H_{h2locUN2} = -4752.6 \cdot kN \cdot m$$

$$\Sigma M_{LateralresistUN2.OT} := \Sigma M_{waterresistUN2.OT} + \Sigma M_{SoilresistUN2} = 806.0 \cdot kN \cdot m$$

Total moment:

$$\Sigma M_{UN2.OT} := \Sigma M_{conc} + \Sigma M_{VertSoilWaterResistUN2} + \Sigma M_{UpliftUN2.OT} + \Sigma M_{LateraldriveUN2.OT} + \Sigma M_{LateralresistUN2.OT} = 9063.0 \cdot kN \cdot m$$

Total Vertical Force: $\Sigma V_{UN2.OT} := \Sigma V_{conc} + \Sigma V_{SoilWaterUN2} + \Sigma V_{UplliftUN2.OT} = 1472.0 \cdot kN$

Distance X_R: EM 1110-2-2502 Eq.4-1 $X_{R.UN2} := \frac{\Sigma M_{UN2.OT}}{\Sigma V_{UN2.OT}} = 6.157\ m$

Overturning Resultant Ratio $Ratio_{UN2.OT} := \frac{X_{R.UN2}}{b} = 0.49$

$$Ratio_{UN2.OT.check} := \begin{cases} \text{"OKAY "} & \text{if } Ratio_{UN2.OT} > X_{R.reqUN2} \\ \text{"Revise Structure""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

CHECK FOUNDATION ECCENTRICITY (HORIZONTAL PLANE):

Eccentricity (horizontal plan): $ex_{UN2.OT} := \frac{b}{2} - \frac{\Sigma M_{UN2.OT}}{\Sigma V_{UN2.OT}} = 0.09\ m$ $Kern_{OT} = 2.083\ m$

Eccentricity Check:

$$e_{check.UN2.OT} := \begin{cases} \text{"Okay"} & \text{if } ex_{UN2} \le Kern_{OT} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"Okay"}$$

LOAD CASE UN2

CHECK FOUNDATION BEARING CAPACITY (HORIZONTAL PLANE):

Base Section Modulus: $S_{b.OT} = 26.04\,m^3$

Bearing Pressure Under Toe:

$$\sigma_{ToeUN2.OT} := \begin{cases} \left(\dfrac{\Sigma V_{UN2.OT}}{b\cdot B} + \dfrac{\Sigma V_{UN2.OT}\cdot ex_{UN2.OT}}{S_{b.OT}}\right) & \text{if } \dfrac{\Sigma V_{UN2.OT}}{b\cdot B} \geq \dfrac{\Sigma V_{UN2.OT}\cdot ex_{UN2.OT}}{S_{b.OT}} \\ \dfrac{2\cdot \Sigma V_{UN2.OT}}{B\cdot 3\left(\dfrac{b}{2} - ex_{UN2.OT}\right)} & \text{otherwise} \end{cases} = 123.0\cdot kPa$$

$$Bearing_{ChecktoeUN2.OT} := \begin{cases} \text{"OKAY "} & \text{if } \sigma_{ToeUN2.OT} < \sigma_{allowUN2} \\ \text{"NG - for reference only""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

Bearing Pressure Under Heel:

$$\sigma_{HeelUN2.OT} := \begin{cases} \left(\dfrac{\Sigma V_{UN2.OT}}{b\cdot B} - \dfrac{\Sigma V_{UN2.OT}\cdot ex_{UN2.OT}}{S_{b.OT}}\right) & \text{if } \dfrac{\Sigma V_{UN2.OT}}{b\cdot B} \geq \dfrac{\Sigma V_{UN2.OT}\cdot ex_{UN2.OT}}{S_{b.OT}} \\ 0 & \text{otherwise} \end{cases} = 112.5\cdot kPa$$

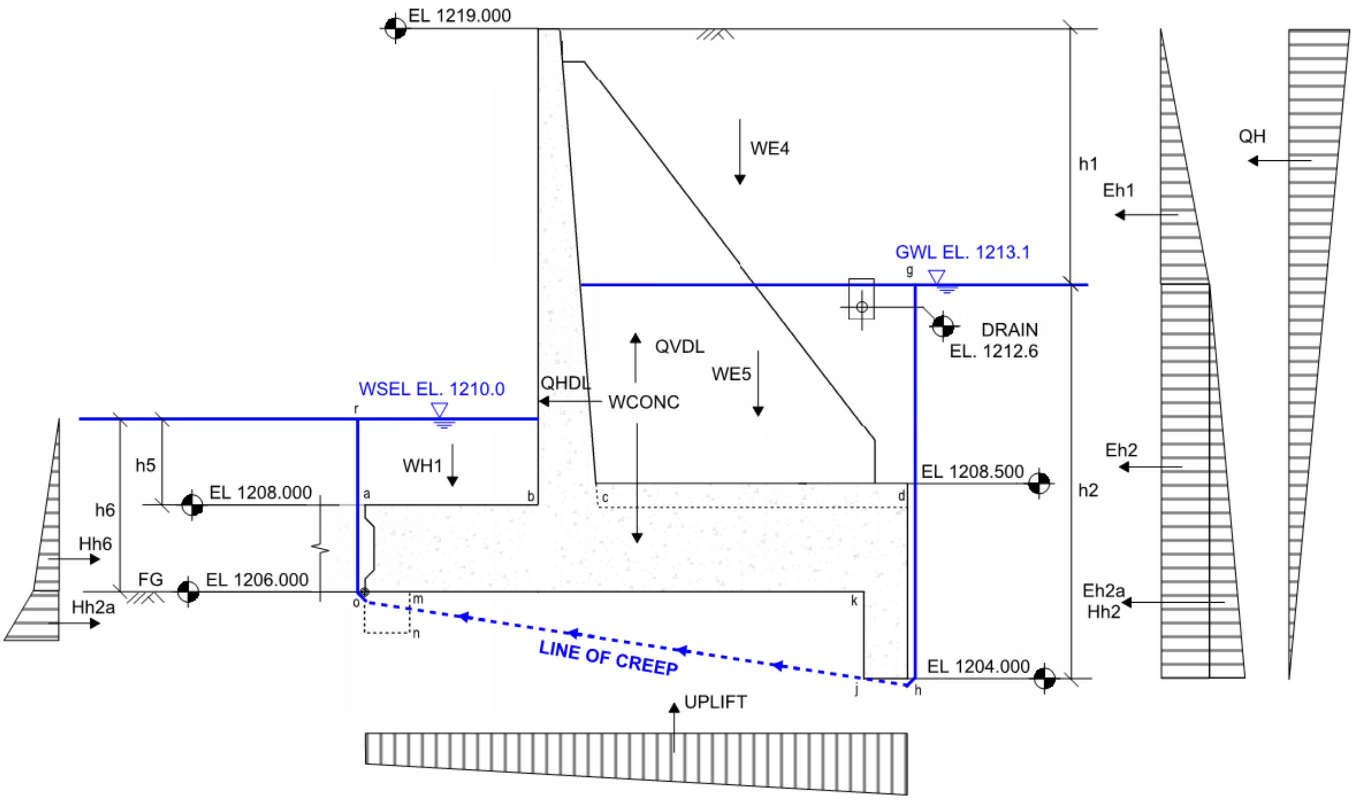
$$Bearing_{CheckheelUN2.OT} := \left(\begin{cases} \text{"OKAY "} & \text{if } \sigma_{ToeUN2.OT} < \sigma_{allowUN2} \wedge \sigma_{ToeUN2.OT} > 0 \\ \text{"NG - for reference only""} & \text{otherwise} \end{cases}\right) = \text{"OKAY "}$$

SUMMARY OF STABILITY ASSESSMENT:

LOAD CASE UN2

Sliding Factor of Safety: (Horizontal Plane - Ref only)	$FS_{Horiz.SlidingUN2} = 0.73$	$FS_{Sliding.check1.UN2}$ = "NG - key req""
Sliding Factor of Safety: (Inclined Plane)	$FS_{InclinedISlidingUN2} = 1.3$	$FS_{Sliding.check2.UN2}$ = "OKAY "
Eccentricity: (Inclined Plane)	$ex_{UN2} = 0.63\ m$	$e_{check.UN2}$ = "Okay"
Bearing Pressure At Heel: (Inclined Plane)	$\sigma_{HeelUN2} = 99 \cdot kPa$	$Bearing_{CheckheelUN2}$ = "OKAY "
Bearing Pressure At Toe: (Inclined Plane)	$\sigma_{ToeUN2} = 184 \cdot kPa$	$Bearing_{ChecktoeUN2}$ = "OKAY "
Flotation Factor of Safety (horizontal plane)	$FS_{FloatationUN2} = 2$	$FS_{Floatation.UN2.check}$ = "OKAY "
Overturning Resultant Ratio: (horizontal plane)	$Ratio_{UN2.OT} = 0.49$	$Ratio_{UN2.OT.check}$ = "OKAY "
Eccentricity: (horizontal plane - Ref only)	$ex_{UN2.OT} = 0.09\ m$	$e_{check.UN2.OT}$ = "Okay"
Bearing Pressure At Heel: (horizontal plane - Ref only)	$\sigma_{HeelUN2.OT} = 113 \cdot kPa$	$Bearing_{CheckheelUN2.OT}$ = "OKAY "
Bearing Pressure At Toe: (horizontal plane - Ref only)	$\sigma_{ToeUN2.OT} = 123 \cdot kPa$	$Bearing_{ChecktoeUN2.OT}$ = "OKAY "

LOAD CASE E1 - SEISMIC LOADING



E1 DESIGN CASE

LOAD CASE E1 ACCEPTANCE PARAMETERS

FS sliding:

Extreme (E) loading)	1.0 (without cohesion, seismic	(Table 3-3, USACE EM 1110-2-2100)

Resultant Location:

Extremem (E) Inside middle half ~75% base in compression

Required Factor of Safety for Sliding:	$FS_{sliding.reqE1} := 1.0$	(Without Cohesion)
Allowable rock bearing pressure:	$\sigma_{allowE1} := 1740kPa$	(Section 5.2, Design Criteria EM 1110-2-2100 Section 3-10)
Overturning Required Resultant Ratio:	$X_{R.reqE1} := 0.25$	(EM 1110-2-2502, Figure 4-4)
Required Factor of Safety for Floatation	$FS_{req.E1.flt} := 1.1$	

SOIL HEIGHTS and Water Levels:

LOAD CASE E1

Heel Conditions:

Groundwater Elevation at Heel: $GWL_{E1} := 1213.1m$

Distance from Finish Grade to Groundwater at Heel: $h_{1E1} := \left[T_w - GWL_{E1} + \left(L_{cd} + t_{wb} - t_{wt}\right) \cdot \tan(\beta)\right] = 5.90\ m$

Distance from Water Surface to Bottom of Footing at Heel: $h_{2E1} := GWL_{E1} - Bot_{ftg} + Key_{h.d} = 9.10\ m$

Toe Conditions:

Water Surface Elevation at Toe: $WSEL_{E1} := 1210.0m$

Water Surface Elevation at Toe for Uplift: $UWSEL_{E1} := 1210.0 \cdot m$

Finish Grade at Toe providing lateral resistance: $FG_{toeE1} := 1206.0 \cdot m$

Soil Depth Above top of footing: $h_{3aE1} := FG_{toeE1} - Top_{ftg} = -2\ m$

$$h_{3E1} := \begin{cases} h_{3aE1} & \text{if } FG_{toeE1} - Top_{ftg} \geq 0 \\ 0 & \text{otherwise} \end{cases} = 0$$

Resisting Fill at Toe: $h_{4E1} := FG_{toeE1} - Bot_{ftg} + Key_{t.d} = 0.00\ m$

Distance from Water Level to Top of Footing at Toe: $h_{5E1} := WSEL_{E1} - Top_{ftg} = 2.00\ m$

Distance from Water Surface to Bottom of Footing at Toe: $h_{6E1} := WSEL_{E1} - Bot_{ftg} + Key_{t.d} = 4.00\ m$

Soil Depth Above WSEL: $h_{7aE1} := FG_{toeE1} - WSEL_{E1} = -4\ m$

$$h_{7E1} := \begin{cases} h_{7aE1} & \text{if } FG_{toeE1} - WSEL_{E1} \geq 0 \\ 0 & \text{otherwise} \end{cases} = 0$$

Soil Depth Below WSEL:

$$h_{8E1} := \begin{cases} WSEL_{E1} - Bot_{ftg} + Key_{t.d} & \text{if } FG_{toeE1} - WSEL_{E1} \geq 0 \\ h_{4E1} & \text{otherwise} \end{cases} = 0$$

For Line of Creep Method: $L_{ho.E1} := \sqrt{b^2 + \left(Key_{h.d} - Key_{t.d}\right)^2} = 12.659\ m$

Head Loss from Point g:

$\Delta h_{g.hj.E1} := h_{2E1} = 9.1\ m$ (to point h & j)

$\Delta h_{g.km.E1} := GWL_{E1} - Bot_{ftg} = 7.1\ m$ (to point k & m)

$\Delta h_{g.no.E1} := GWL_{E1} - Bot_{ftg} + Key_{t.d} = 7.1\ m$ (to point n & o)

$\Delta h_{g.p.E1} := GWL_{E1} - FG_{toeE1} = 7.1\ m$ (to point p*)

$\Delta h_{g.r.E1} := GWL_{E1} - UWSEL_{E1} = 3.1\ m$ (to point r)

Surcharge

Surcharge on Heel: $S1_{E1} := 0.0 \dfrac{kN}{m^2}$

* same as point "o" in this case

Calculate Soil Lateral Pressure Coefficients:

LOAD CASE E1

Calculate at-rest pressure coefficient K_o based on Jaky's (1944) equation.

Soil At Rest Static Coefficient:
(apply to resisting soil loads)

$$K_o := \frac{1 - \sin(\phi)}{1 + \sin(\beta)} = 0.546$$

(Eq. 3-6, USACE EM 1110-2-2502)

Calculate active pressure coefficient K_A based on Coulumb equations.

Determine Slope of Active Wedge: (cohesionless backfill with water table)

$$c_1 := 2 \cdot \tan(\phi) = 1.019 \qquad c_2 := 1 - \tan(\phi) \cdot \tan(\beta) - \frac{\tan(\beta)}{\tan(\phi)} = 1$$

(Eq. G-14 / G-15, USACE EM 1110-2-2100)

$$\alpha := \operatorname{atan}\left(\frac{c_1 + \sqrt{c_1^{\,2} + 4 \cdot c_2}}{2}\right) = 1.021 \qquad \alpha_{deg} := \alpha \cdot \frac{180}{\pi} = 58.5 \text{ degrees}$$

(Eq. G-13, USACE EM 1110-2-2100)

Soil Active Coefficient above GWL:

$$K_{Aagwt} := \left(\frac{1 - \tan(\phi) \cdot \cot(\alpha)}{1 + \tan(\phi) \cdot \tan(\alpha)}\right) \cdot \left(\frac{\tan(\alpha)}{\tan(\alpha) - \tan(\beta)}\right) = 0.376$$

Soil Active Coefficient below GWL:

$$K_{Abgwt} := \frac{1 - \tan(\phi) \cdot \cot(\alpha)}{1 + \tan(\phi) \cdot \tan(\alpha)} \cdot \left[1 + \left(\frac{\tan(\alpha)}{\tan(\alpha) - \tan(\beta)} - 1\right) \cdot \left(\frac{\gamma_m}{\gamma_{sat} - \gamma_w}\right)\right] = 0.376$$

(Eq. G-29, USACE EM 1110-2-2100)

Lateral - Driving Force

Static Copmonent : Active Pressure:

Surcharge Load:

$$E_{s1E1} := S1_{E1} \cdot K_{Aagwt} \cdot \left(H_w + Key_{h.d}\right) \cdot B \cdot -1 = 0 \cdot kN$$

Moment Arm (from bottom of footing):

$$E_{s1locE1} := \frac{H_w + Key_{h.d}}{2} + Key_{vdist} = 5.50\ m$$

Moist Soil Load above GWL:

$$E_{h1E1} := \frac{\gamma_m \cdot K_{Aagwt} \cdot h_{1E1}^{\,2}}{2} \cdot B \cdot -1 = -130.7 \cdot kN$$

Moment Arm (from bottom of footing):

$$E_{h1locE1} := \frac{h_{1E1}}{3} + h_{2E1} + Key_{vdist} = 9.07\ m$$

Saturated Soil Load below GWL:
(rectangular component)

$$E_{h2E1} := \left(\gamma_m \cdot K_{Abgwt} \cdot h_{1E1}\right) \cdot h_{2E1} \cdot B \cdot -1 = -403.2 \cdot kN$$

Moment Arm (from bottom of footing):

$$E_{h2locE1} := \frac{h_{2E1}}{2} + Key_{vdist} = 2.55\ m$$

Saturated Soil Load below GWL:
(triangular component)

$$E_{h2aE1} := \frac{\left(\gamma_{sat} - \gamma_w\right) \cdot K_{Abgwt} \cdot h_{2E1}^{\,2}}{2} \cdot B \cdot -1 = -189.7 \cdot kN$$

Moment Arm (from bottom of footing):

$$E_{h2alocE1} := \frac{h_{2E1}}{3} + Key_{vdist} = 1.03\ m$$

Lateral Water Load:

Water Load GWL to Bottom of Key

$$H_{h2E1} := \frac{\gamma_w \cdot h_{2E1}^{\,2}}{2} \cdot B \cdot -1 = -405.8 \cdot kN$$

Moment Arm (from bottom of footing):

$$H_{h2locE1} := \frac{h_{2E1}}{3} + Key_{vdist} = 1.03\ m$$

$$\Sigma H_{SoildriveE1} := E_{s1E1} + E_{h1E1} + E_{h2E1} + E_{h2aE1} + H_{h2E1} = -1129.4 \cdot kN$$

$$\Sigma M_{LateralSoildriveE1} := E_{s1E1} \cdot E_{s1locE1} + E_{h1E1} \cdot E_{h1locE1} + E_{h2E1} \cdot E_{h2locE1} \ldots + E_{h2aE1} \cdot E_{h2alocE1} + H_{h2E1} \cdot H_{h2locE1} = -2828.8\ m \cdot kN$$

Lateral - Resisting Force

LOAD CASE E1

Note: **Due to the relatively shallow depth of resisting soil/rock, a conservative apporach using at-rest coefficient in lieu of a passive wedge is used to calculate resisting forces.**

Lateral Water Load:

Water Load WSEL to Bottom of Footing: $H_{h6E1} := H_{h6U1} = 78.4 \cdot kN$

Moment Arm (from bot. of toe key): $H_{h6locE1} := H_{h6locU1} = 1.33\ m$

Water Load Bot. of Footing to Bot. of H. Key: $H_{h2aE1} := \left[\left(UWSEL_{E1} - Bot_{ftg} + Key_{t.d}\right) + h_{2E1}\right] \cdot \frac{Key_{h.d}}{2} \cdot \gamma_w \cdot B = 128.4 \cdot kN$

Moment Arm (from bot. of toe key):

$$H_{h2alocE1} := \frac{Key_{h.d} \cdot \left[2 \cdot \left(UWSEL_{E1} - Bot_{ftg} + Key_{t.d}\right) + h_{2E1}\right]}{3\left[h_{2E1} + \left(UWSEL_{E1} - Bot_{ftg} + Key_{t.d}\right)\right]} \ldots = -1.13\ m$$
$$+ Key_{vdist}$$

Lateral Soil Load:

Moist Soil Load above WSEL: $E_{h7E1} := \frac{\gamma_m \cdot K_o \cdot h_{7E1}^{\ 2}}{2} B = 0.0 \cdot kN$

Moment Arm (from bot. of toe key): $E_{h7locE1} := h_{6E1} + \frac{h_{7E1}}{3} + Key_{vdist} = 2.00\ m$

Saturated Soil Load below WSEL: (rectangular component) $E_{h8E1} := \left(\gamma_m \cdot K_o \cdot h_{7E1}\right) \cdot h_{8E1} \cdot B = 0.0 \cdot kN$

Moment Arm (from bot. of toe key): $E_{h8locE1} := \frac{h_{8E1}}{2} = 0.00\ m$

Saturated Soil Load below WSEL: (triangular component) $E_{h8aE1} := \frac{\left[\left(\gamma_{sat} - \gamma_w\right) \cdot K_o\right] \cdot h_{8E1}^{\ 2}}{2} \cdot B = 0.0 \cdot kN$

Moment Arm (from bot. of footing): $E_{h8alocE1} := \frac{h_{8E1}}{3} = 0.00\ m$

Lateral Resistance from Stilling Basin:

Lateral Resistance from Stilling Basin: $P_{sbE1} := 430kN$ (Force needed to achieve the required sliding factor of safety in case UN2)

Moment Arm (from bot. of toe key): $P_{sblocE1} := \frac{t_{ftg}}{2} + Key_{t.d} = 1.00\ m$

$$\Sigma H_{SoilresistE1} := H_{h6E1} + H_{h2aE1} + E_{h7E1} + E_{h8E1} + E_{h8aE1} + P_{sbE1} = 636.8 \cdot kN$$

$$\Sigma M_{HorizSoilResistE1} := H_{h6E1} \cdot H_{h6locE1} + H_{h2aE1} \cdot H_{h2alocE1} + E_{h7E1} \cdot E_{h7locE1} \ldots = 389.5\ m \cdot kN$$
$$+ E_{h8E1} \cdot E_{h8locE1} + E_{h8aE1} \cdot E_{h8alocE1} + P_{sbE1} \cdot P_{sblocE1}$$

Vertical Force:

UPLIFT: Linear distribution from water at heel to water at toe:

$$\Sigma V_{UpliftE1} := \left[\left(UWSEL_{E1} - Bot_{ftg} + Key_{t.d}\right) + h_{2E1}\right] \cdot \frac{b}{2} \cdot \gamma_w \cdot B \cdot -1 = -802.375 \cdot kN$$

Moment Arm (from Point O):

$$V_{UpliftE1aloc} := \frac{b \cdot \left[2 \cdot h_{2E1} + \left(UWSEL_{E1} - Bot_{ftg} + Key_{t.d}\right)\right]}{3\left[h_{2E1} + \left(UWSEL_{E1} - Bot_{ftg} + Key_{t.d}\right)\right]} = 7.061\ m$$

$$\Sigma M_{UpliftE1} := \Sigma V_{UpliftE1} \cdot V_{UpliftE1aloc} = -5665.625 \cdot kN \cdot m$$

Weight of soil and water over toe:

Water Above the Top of Footing: $W_{H1E1} := \gamma_w \cdot h_{5E1} \cdot L_{ab} \cdot B = 78.4 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E1locE1} := \frac{L_{ab}}{2} = 2\,m$

Soil above top of footing: $W_{E6E1} := \gamma_b \cdot h_{3E1} \cdot L_{ab} \cdot B = 0.0 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E6locE1} := \frac{L_{ab}}{2} = 2\,m$

Vertical Load Due to Surcharge: $S_{E1} := S1_{E1} \cdot L_{cd} \cdot B = 0 \cdot kN$ $\quad S_{E1loc} := b - \frac{L_{cd}}{2} = 8.93\,m$

Weight of soil and water over heel:

Moist Soil for sloped grade above top of wall:

Length of sloped portion of soil above top of wall: $L_{E3E1} := \left(L_{cd} + t_{wb} - t_{wt}\right) = 8.00\,m$

Height of sloped soil above top of wall over heel: $h_{E3locE1} := \left(L_{E3E1}\right) \cdot \tan(\beta) = 0.00\,m$

Weight of sloped soil above top of wall: $W_{E3E1} := \frac{\gamma_m}{2} \cdot h_{E3locE1} \cdot L_{E3E1} \cdot B = 0.0 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E3locE1} := L_{ab} + t_{wt} + \frac{2}{3} \cdot L_{E3E1} = 9.83\,m$

Moist soil from top of wall to groundwater level:

Height of soil from top of wall and top of GWL: $h_{1E1} = 5.90\,m$

Length from edge of wall at GWL to edge of heel: $L_{E4E1} := L_{E3E1} - \left(h_{1E1} \cdot S_{batter}\right) = 7.54\,m$

Weight of soil over heel from top of wall to GWL: $W_{E4E1} := \gamma_m \cdot h_{1E1} \cdot \frac{\left(L_{E3E1} + L_{E4E1}\right)}{2} \cdot B = 916.7 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E4locE1} := b - \frac{L_{E3E1}^{\,2} + L_{E3E1} \cdot L_{E4U1} + L_{E4E1}^{\,2}}{3\left(L_{E3E1} + L_{E4E1}\right)} = 8.61\,m$

Saturated soil from groundwater to top of footing:

Height of soil from GWL to top of heel: $h_{E4E1} := h_{2E1} - t_{ftg} - Key_{h.d} = 5.10\,m$

Weight of soil over heel from GWL to top of heel: $W_{E5E1} := \left(\gamma_{sat}\right) \cdot h_{E4E1} \cdot \frac{\left(L_{E4E1} + L_{cd}\right)}{2} \cdot B = 823.1 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E5locE1} := b - \frac{L_{E4E1}^{\,2} + L_{E4E1} \cdot L_{cd} + L_{cd}^{\,2}}{3\left(L_{E4E1} + L_{cd}\right)} = 8.83\,m$

$$\Sigma V_{SoilWaterE1} := W_{H1E1} + W_{E6E1} + W_{E3E1} + W_{E4E1} + W_{E5E1} + S_{E1} = 1818.2 \cdot kN$$

$$\Sigma M_{VertSoilWaterResistE1} := W_{H1E1} \cdot W_{E1locE1} + W_{E6E1} \cdot W_{E6locE1} \cdots + W_{E3E1} \cdot W_{E3locE1} + W_{E4E1} \cdot W_{E4locE1} + W_{E5E1} \cdot W_{E5locE1} + S_{E1} \cdot S_{E1loc} = 15322.6\,m \cdot kN$$

SESIMIC ANALYSIS:

LOAD CASE E1

Seismic coefficient will be applied to dead loads to calculate seismic force and force is applied at center of gravity of the mass. Vertical and Horizontal loads are applied in the "destabilizing direction"

SEISMIC PARAMETERS:

(Section 7.9, Design Criteria)

Peak Ground Acceleration for Seismic Load $PGA_{Horiz} := 0.26$ $PGA_{Vert} := 0.56 \cdot PGA_{Horiz} = 0.146$

In accordance with USACE EM 1110-2-2100 Section 4-7.b, consider 2/3 PGA as seismic coefficient for stabilitiy.

Horizontal Seismic coefficient for stabilty: $K_{hE1} := \frac{2}{3} PGA_{Horiz} = 0.173$

Vertical Seismic coefficient for stabilty: $K_{vE1} := \frac{2}{3} PGA_{Vert} = 0.097$

SEISMIC ACCELERATION OF RIGID MASSES (Q_D):

Vertical Load Application:

$\Sigma V_{conc} = 875.4 \cdot kN$

$Q_{v.conc} := \Sigma V_{conc} \cdot K_{vE1} \cdot -1 = -85 \cdot kN$ (assume acting upwards for adverse sliding effect)

Moment arm for siesmic load application (From Toe): $H_{cent} = 6.077\,m$

$M_{Qv.conc} := Q_{v.conc} \cdot H_{cent} = -516.4 \cdot kN \cdot m$

Lateral Load Application:

$Q_{h.conc} := \Sigma V_{conc} \cdot K_{hE1} \cdot -1 = -151.7 \cdot kN$

Moment arm for siesmic load application (Above Base of Footing): $V_{Cent} = 2.448\,m$

$M_{Q.conc} := Q_{h.conc} \cdot V_{Cent} = -371.4 \cdot kN \cdot m$

SEISMIC ACCELERATION OF SOIL WEDGE + WATER (Q_{EH}):

Vertical Load Application:

$\Sigma V_{SoilWaterE1} = 1818.2 \cdot kN$

$Q_{v.SoilWaterE1} := \Sigma V_{SoilWaterE1} \cdot K_{vE1} \cdot -1 = -176.5 \cdot kN$ (assume acting upwards for adverse sliding effect)

Moment arm for siesmic load application (From Toe): $e_{QE1} := \frac{\Sigma M_{VertSoilWaterResistE1}}{\Sigma V_{SoilWaterE1}} = 8.427\,m$

$M_{Qv.SoilWaterE1} := Q_{v.SoilWaterE1} \cdot e_{QE1} = -1487.3 \cdot kN \cdot m$

Lateral Load Application:

Seismic soil load is calculated based on Mononobe-Okabe method to determine combined static and dynamic coefficient (K_{AE}). Coulomb's active component (K_A) is subtracted from K_{AE} to obtain the seismic coefficient (ΔK_{AE}) for dynamic component of soil force.

Glacial Till Internal Friction (radians): $\phi = 0.471$

Seismic Inertia Angle (radians): $\psi := \operatorname{atan}\left(\frac{K_{hE1}}{1 - K_{vE1}}\right) = 0.190$

Inclination of batter (radians): $\theta := 0.00$ assuming zero is conservative

Slope of retained ground surface: $\beta = 0.00$

$$K_{AE} := \frac{\cos(\phi - \psi - \theta) \cdot \cos(\phi - \psi - \theta)}{\cos(\psi) \cdot \cos(\theta) \cdot \cos(\theta)\ \cos(\psi + \theta) \cdot \left(1 + \sqrt{\frac{\sin(\phi)\ \sin(\phi - \psi - \beta)}{\cos(\beta - \theta) \cdot \cos(\psi + \theta)}}\right)^2} = 0.519$$

$\Delta K_{AE} := K_{AE} - K_{Abgwt} = 0.143$

Dynamic component of active seismic wedge:

$$Q_{h.SoilWaterE1} := \Delta K_{AE} \cdot \left[\frac{\gamma_m \cdot \left(H_w + Key_{h.d}\right)^2}{2 \cdot (\tan(\alpha) - \tan(\beta))} + \frac{\left(\gamma_{sat} - \gamma_m\right) \cdot h_{2E1}{}^2}{2 \cdot \tan(\alpha)}\right] \cdot B \cdot -1 = -204.4 \cdot kN$$

(Eq. G-64, USACE EM 1110-2-2100)

Moment arm for siesmic load application (About Point O): $Q_{h.SoilWaterlocE1} := \frac{2}{3} \cdot \left(H_w + Key_{h.d}\right) + Key_{vdist} = 8.00\,m$

$M_{Q.h.SoilWaterE1} := Q_{h.SoilWaterE1} \cdot Q_{h.SoilWaterlocE1} = -1635.2 \cdot kN \cdot m$

STABILITY ASSESSMENT:

LOAD CASE E1

CHECK SLIDING ALONG HORIZONTAL SLIDING PLANE:

Summation of the vertical forces: $\Sigma V_{E1} := \Sigma V_{conc} + \Sigma V_{SoilWaterE1} + \Sigma V_{UpliftE1} + Q_{v.conc} + Q_{v.SoilWaterE1} = 1629.8 \cdot kN$

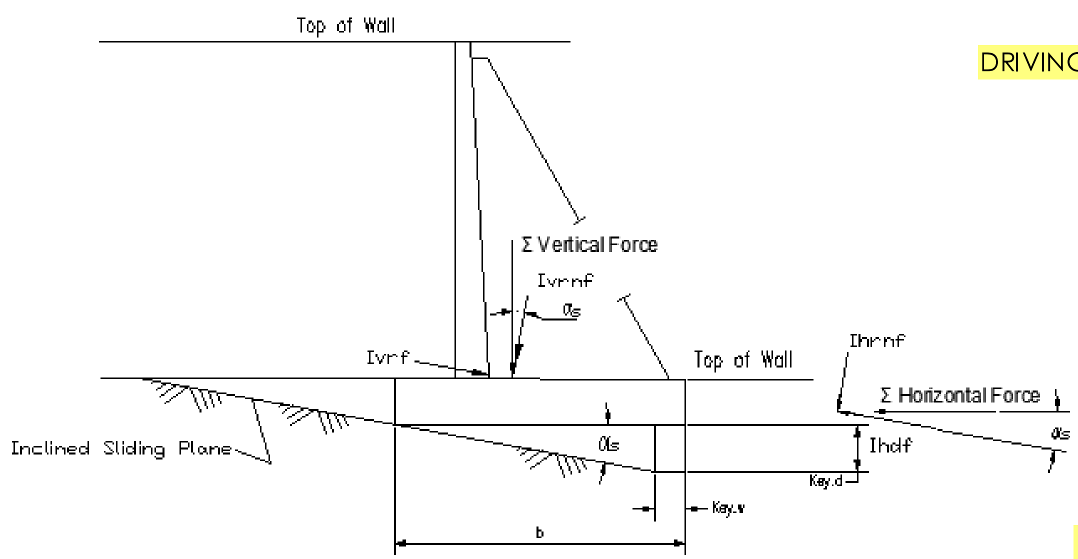
Summation of the horizontal forces: $\Sigma H_{E1} := \Sigma H_{SoildriveE1} + Q_{h.conc} + Q_{h.SoilWaterE1} + \Sigma H_{SoilresistE1} = -848.8 \cdot kN$

Safety Factor for Sliding Horizontal Failure Plane

$$FS_{Horiz.SlidingE1} := \frac{\left|\Sigma V_{E1}\right| \cdot \tan\left(\phi_{rock} \cdot \frac{\pi}{180}\right)}{\left|\Sigma H_{E1}\right|} = 0.94$$

$$FS_{Sliding.check1.E1} := \begin{cases} \text{"OKAY"} & \text{if } FS_{Horiz.SlidingE1} > FS_{sliding.reqE1} \\ \text{"NG - key req'"} & \text{otherwise} \end{cases} = \text{"NG - key req'"}$$

CHECK FACTOR OF SAFETY SLIDING WITH KEY (INCLINED SLIDING PLANE):



(With properly engineered reinforced concrete Key, horizontal sliding plane thru Toe is protected, critical sliding plane is relocated to the INCLINED SLIDING PLANE FROM HEEL KEY To TOE, Bedrock Mass above this examing plane is mobilized by reinforced concrete key and combined into Structural Wedge.)

Resolve ΣV_{E1} & ΣH_{E1}

$$\Sigma V_{InclinedE1} := \cos(\alpha s) \cdot \left(\left|\Sigma V_{E1} + V_{rocksection}\right|\right) + \sin(\alpha s) \cdot \left|\Sigma H_{E1}\right| = 2041.2 \cdot kN$$

$$\Sigma H_{InclinedE1} := \cos(\alpha s) \cdot \left|\Sigma H_{E1}\right| - \sin(\alpha s) \cdot \left(\left|\Sigma V_{E1} + V_{rocksection}\right|\right) = 506.5 \cdot kN$$

Safety Factor for Sliding Inclined Failure Plane

$$FS_{InclinedISlidingE1} := \frac{\Sigma V_{InclinedE1} \cdot \tan(\phi_r)}{\Sigma H_{InclinedE1}} = 1.79$$

$$FS_{Sliding.check2.E1} := \begin{cases} \text{"OKAY"} & \text{if } FS_{InclinedISlidingE1} > FS_{sliding.reqE1} \\ \text{"NG'"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

CHECK FOUNDATION ECCENTRICITY:

LOAD CASE E1

(Vertical seismic loads from concrete, soil and water are assumed acting downwards for adverse bearing effect)

Summation of the vertical forces: $\Sigma V_{seisE1} := \Sigma V_{conc} + \Sigma V_{SoilWaterE1} + \Sigma V_{UpliftE1} - Q_{v.conc} - Q_{v.SoilWaterE1} = 2152.7 \cdot kN$

Summation of the horizontal forces: $\Sigma H_{seisE1} := \Sigma H_{E1} = -848.8 \cdot kN$

Resolve ΣV_{seisE1} & ΣH_{seisE1}

$$\Sigma V_{InclinedseisE1} := \cos(\alpha s) \cdot \left(\left|\Sigma V_{seisE1} + V_{rocksection}\right|\right) + \sin(\alpha s) \cdot \left|\Sigma H_{seisE1}\right| = 2556.3 \cdot kN$$

$$\Sigma H_{InclinedseisE1} := \cos(\alpha s) \cdot \left|\Sigma H_{seisE1}\right| - \sin(\alpha s) \cdot \left(\left|\Sigma V_{seisE1} + V_{rocksection}\right|\right) = 416.9 \cdot kN$$

Summation of the resisting moments about the toe:

$$\Sigma M_{resE1} := \Sigma M_{conc} + \Sigma M_{VertSoilWaterResistE1} + \Sigma M_{HorizSoilResistE1} + \Sigma M_{rocksection} = 23289 \cdot kN \cdot m$$

Summation of seismic moments about the toe:

$$\Sigma M_{seisE1} := -M_{Qv.conc} + M_{Q.conc} - M_{Qv.SoilWaterE1} + M_{Q.h.SoilWaterE1} = -3 \cdot kN \cdot m$$

Summation of the overturning moments about the toe:

$$\Sigma M_{oE1} := \Sigma M_{LateralSoildriveE1} + \Sigma M_{UpliftE1} = -8494 \cdot kN \cdot m$$

Total moment: $\Sigma M_{E1} := \Sigma M_{resE1} + \Sigma M_{seisE1} + \Sigma M_{oE1} = 14791.7 \cdot kN \cdot m$

Normal force to base: $\Sigma V_{InclinedseisE1} = 2556.3 \cdot kN$

Inclined Sliding Plane Length: $L_{incline} = 12.7 \cdot m$

Eccentricity (inclined plane): $ex_{E1} := \dfrac{L_{incline}}{2} - \dfrac{\Sigma M_{E1}}{\Sigma V_{InclinedseisE1}} = 0.56\,m$ $\qquad Kern_{E1} := \dfrac{L_{incline}}{4} = 3.172\,m$

Eccentricity Check:

$$e_{check.E1} := \begin{cases} \text{"Okay"} & \text{if } ex_{E1} \le Kern \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"Okay"}$$

CHECK FOUNDATION BEARING CAPACITY:

Base Section Modulus: $S_b = 26.83\,m^3$

Bearing Pressure Under Toe:

$$\sigma_{ToeE1} := \begin{cases} \left(\dfrac{\Sigma V_{InclinedE1}}{L_{incline} \cdot B} + \dfrac{\Sigma V_{InclinedE1} \cdot ex_{E1}}{S_b}\right) & \text{if } \dfrac{\Sigma V_{InclinedE1} \cdot ex_{E1}}{S_b} \le \dfrac{\Sigma V_{InclinedE1}}{L_{incline} \cdot B} \\ \dfrac{2 \cdot \Sigma V_{InclinedE1}}{B \cdot 3\left(\dfrac{b}{2} - ex_{E1}\right)} & \text{otherwise} \end{cases} = 203.3 \cdot kPa$$

$$Bearing_{ChecktoeE1} := \begin{cases} \text{"OKAY "} & \text{if } \sigma_{ToeE1} < \sigma_{allowE1} \\ \text{"NG""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

Bearing Pressure Under Heel:

$$\sigma_{HeelE1} := \begin{cases} \left(\dfrac{\Sigma V_{InclinedE1}}{L_{incline} \cdot B} - \dfrac{\Sigma V_{InclinedE1} \cdot ex_{E1}}{S_b}\right) & \text{if } \dfrac{\Sigma V_{InclinedE1} \cdot ex_{E1}}{S_b} \le \dfrac{\Sigma V_{InclinedE1}}{L_{incline} \cdot B} \\ 0 & \text{otherwise} \end{cases} = 118.5 \cdot kPa$$

$$Bearing_{CheckheelE1} := \left(\begin{cases} \text{"OKAY "} & \text{if } \sigma_{HeelE1} < \sigma_{allowE1} \wedge \sigma_{HeelE1} > 0 \\ \text{"NG - perform cracked base analysis""} & \text{otherwise} \end{cases}\right) = \text{"OKAY "}$$

CHECK FLOATATION:

Safety Factor for Floatation:

$$FS_{FloatationE1} := \frac{\Sigma V_{conc} + \Sigma V_{SoilWaterE1} + Q_{v.conc} + Q_{v.SoilWaterE1}}{\left|\Sigma V_{UpliftE1}\right|} = 3.03$$

$$FS_{Floatation.E1.check} := \begin{cases} \text{"OKAY"} & \text{if } FS_{FloatationE1} > FS_{req.E1.flt} \\ \text{"Revise Structure""} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

CHECK OVERTURNING

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.
Assumptions are made in order to compute overturning stablity of indetermine forces on monolith with key;
(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.
(b) The horizontal resisting force acting on the key, P.key, is that required for static equilibrium
(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1

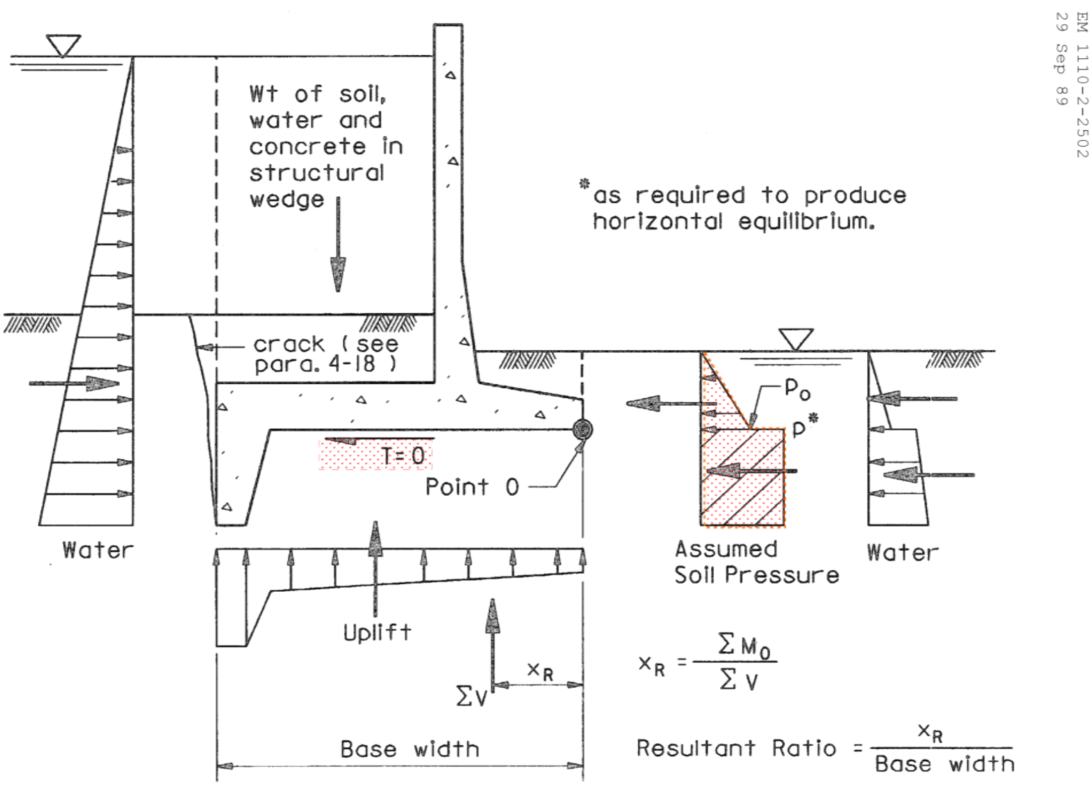


Figure 4-5. Forces for overturning analysis for wall with horizontal base and key

Modify Uplift for Overturning Analysis: **LOAD CASE E1**

(Uplift is calculated along the concrete/rock contact using the Line of Creep method)

Water Pressure at h: $u_{h.E1} := \Delta h_{g.hj.E1} \cdot \gamma_w = 89.18 \cdot kPa$

Water Pressure at o: $u_{o.E1} := \left(\Delta h_{g.no.E1} - \frac{\Delta h_{g.r.E1} \cdot L_{ho.E1}}{L_{ho.E1}}\right) \cdot \gamma_w = 39.2 \cdot kPa$

Head loss between point h and o: $\Delta h_{ho.E1} := \Delta h_{g.r.E1} \cdot \frac{L_{ho.E1}}{L_{ho.E1}} = 3.1\ m$

Length of concrete base (h -> o): $L_{baseho.E1} := Key_{h.w} + Key_{h.d} + Key_{hdist} + Key_{t.d} + Key_{t.w} = 14.5\ m$

Head loss along h -> j: $\Delta h_{hj.E1} := \Delta h_{ho.E1} \cdot \frac{Key_{h.w}}{L_{baseho.E1}} = 0.214\ m$

Water Pressure at j: $u_{j.E1} := \left(\Delta h_{g.hj.E1} - \Delta h_{hj.E1}\right) \cdot \gamma_w = 87.08 \cdot kPa$

Head loss along h -> k: $\Delta h_{hjk.E1} := \Delta h_{ho.E1} \cdot \left(\frac{Key_{h.w} + Key_{h.d}}{L_{baseho.E1}}\right) = 0.641\ m$

Water Pressure at k: $u_{k.E1} := \left(\Delta h_{g.km.E1} - \Delta h_{hjk.E1}\right) \cdot \gamma_w = 63.29 \cdot kPa$

Head loss along h -> m: $\Delta h_{hjkm.E1} := \Delta h_{ho.E1} \cdot \left(\frac{Key_{h.w} + Key_{h.d} + Key_{hdist}}{L_{baseho.E1}}\right) = 3.1\ m$

Water Pressure at m: $u_{m.E1} := \left(\Delta h_{g.km.E1} - \Delta h_{hjkm.E1}\right) \cdot \gamma_w = 39.20 \cdot kPa$

Head loss along h -> n: $\Delta h_{hjkmn.E1} := \Delta h_{ho.E1} \cdot \left(\frac{Key_{h.w} + Key_{h.d} + Key_{hdist} + Key_{t.d}}{L_{baseho.E1}}\right) = 3.1\ m$

Water Pressure at n: $u_{n.E1} := \left(\Delta h_{g.no.E1} - \Delta h_{hjkmn.E1}\right) \cdot \gamma_w = 39.20 \cdot kPa$

Uplift under key at heel: $V_{ulkeyhE1.OT} := \frac{\left(u_{h.E1} + u_{j.E1}\right) \cdot Key_{h.w}}{2} \cdot B \cdot -1 = -88.132 \cdot kN$

Moment Arm (from Point O): $V_{ulkeyhE1loc.OT} := b - \frac{Key_{h.w} \cdot \left(2 \cdot u_{j.E1} + u_{h.E1}\right)}{3 \cdot \left(u_{j.E1} + u_{h.E1}\right)} = 12.002\ m$

Uplift under base: $V_{ulbaseE1.OT} := \frac{\left(u_{k.E1} + u_{m.E1}\right) \cdot Key_{hdist}}{2} \cdot B \cdot -1 = -589.343 \cdot kN$

Moment Arm (from Point O): $V_{ulbaseE1loc.OT} := b - Key_{h.w} - \frac{Key_{hdist} \cdot \left(2 \cdot u_{m.E1} + u_{k.E1}\right)}{3 \cdot \left(u_{m.E1} + u_{k.E1}\right)} = 6.201\ m$

Uplift under key at toe: $V_{ulkeytE1.OT} := \frac{\left(u_{n.E1} + u_{o.E1}\right) \cdot Key_{t.w}}{2} \cdot B \cdot -1 = 0 \cdot kN$

Moment Arm (from Point O): $V_{ulkeytE1loc.OT} := \frac{Key_{t.w} \cdot \left(2 \cdot u_{n.E1} + u_{o.E1}\right)}{3 \cdot \left(u_{n.E1} + u_{o.E1}\right)} = 0$

$$\Sigma V_{UpliftE1.OT} := V_{ulkeyhE1.OT} + V_{ulbaseE1.OT} + V_{ulkeytE1.OT} = -677 \cdot kN$$

$$U_{E1.loc.OT} := \frac{V_{ulkeyhE1.OT} \cdot V_{ulkeyhE1loc.OT} + V_{ulbaseE1.OT} \cdot V_{ulbaseE1loc.OT} + V_{ulkeytE1.OT} \cdot V_{ulkeytE1loc.OT}}{\Sigma V_{UpliftE1.OT}} = 6.96\ m$$

$$\Sigma M_{UpliftE1.OT} := \Sigma V_{UpliftE1.OT} \cdot U_{E1.loc.OT} = -4712.0 \cdot kN \cdot m$$

LOAD CASE E1

Modify Lateral Water Pressure (Resisting) for Overturning Analysis:

(Resisting water pressure is calculated using the Line of Creep method)

Water Load at Key (heel): $H_{h2E1.OT} := \frac{u_{k.E1} + u_{j.E1}}{2} \cdot Key_{h.d} B = 150.4 \cdot kN$

Moment Arm (from Point O): $H_{h2locE1.OT} := \frac{Key_{h.d} \cdot \left(2 \cdot u_{k.E1} + u_{j.E1}\right)}{3\left(u_{k.E1} + u_{j.E1}\right)} + Key_{vdist} = -1.05\ m$

Water Load at Key (toe): $H_{h6E1.OT} := \frac{u_{o.E1} \cdot \left(UWSEL_{E1} - Bot_{ftg} + Key_{t.d}\right)}{2} \cdot B = 78 \cdot kN$

Moment Arm (from Point O): $H_{h6locE1.OT} := \frac{UWSEL_{E1} - Bot_{ftg} + Key_{t.d}}{3} = 1.33\ m$

$$\Sigma H_{waterresistE1.OT} := H_{h2E1.OT} + H_{h6E1.OT} = 228.78 \cdot kN$$

$$H_{waterresistlocE1.OT} := \frac{H_{h2E1.OT} \cdot H_{h2locE1.OT} + H_{h6E1.OT} \cdot H_{h6locE1.OT}}{\Sigma H_{waterresistE1.OT}} = -0.235\ m$$

$$\Sigma M_{waterresistE1.OT} := \Sigma H_{waterresistE1.OT} \cdot H_{waterresistlocE1.OT} = -53.78 \cdot kN \cdot m$$

Modify Lateral Soil Loads for Overturning Analysis:

(Lateral soil loads are calculated down to Point O instead of bottom of shear key)

Driving Soil Load (Headwater Side):

Surcharge Load: $E_{s1E1.OT} := S1_{E1} \cdot K_{Aagwt} \cdot \left(H_w + Key_{h.d} + Key_{vdist}\right) \cdot B \cdot -1 = 0 \cdot kN$

Moment Arm (from Point O): $E_{s1locE1.OT} := \frac{H_w + Key_{h.d} + Key_{vdist}}{2} = 6.50\ m$

Moist Soil Load above GWL: $E_{h1E1.OT} := \frac{\gamma_m \cdot K_{Aagwt} \cdot h_{1E1}^{\ 2}}{2} B \cdot -1 = -130.7 \cdot kN$

Moment Arm (from Point O): $E_{h1locE1.OT} := \frac{h_{1E1}}{3} + h_{2E1} + Key_{vdist} = 9.07\ m$

Saturated Soil Load below GWL: (rectangular component) $E_{h2E1.OT} := \left(\gamma_m \cdot K_{Aagwt} \cdot h_{1E1}\right) \cdot \left(h_{2E1} + Key_{vdist}\right) \cdot B \cdot -1 = -314.6 \cdot kN$

Moment Arm (from Point O): $E_{h2locE1.OT} := \frac{h_{2E1} + Key_{vdist}}{2} = 3.55\ m$

Saturated Soil Load below GWL: (triangular component) $E_{h2aE1.OT} := \frac{\left(\gamma_{sat} - \gamma_w\right) \cdot K_{Aagwt} \cdot \left(h_{2E1} + Key_{vdist}\right)^2}{2} \cdot B \cdot -1 = -115.5 \cdot kN$

Moment Arm (from Point O): $E_{h2alocE1.OT} := \frac{h_{2E1} + Key_{vdist}}{3} = 2.37\ m$

LOAD CASE E1

Resisting Soil Load (Tailwater Side):

(Determine resisting soil load based on depth variation between the keys (ie. Key_{vdist}). In case where key at heel is deeper than key at toe (ie. $Key_{vdist} < 0$), resisting soil load (p*) is assumed to produce horizontal equilibrium as per Figure 4-5 above. Resisting soil load (p_o) is neglected.)

Total Driving Force:
$$\Sigma H_{SoildriveE1.OT} := E_{s1E1.OT} + E_{h1E1.OT} + E_{h2E1.OT} + E_{h2aE1.OT} + H_{h2E1} \cdots + Q_{h.conc} + Q_{h.SoilWaterE1} = -1322.7 \cdot kN$$

Total Resisting Force:
$$\Sigma H_{waterresistE1.OT} = 228.779 \cdot kN$$

Assumed Soil Load p*:
$$E_{h8E1a.OT} := \left(\Sigma H_{SoildriveE1.OT} + \Sigma H_{waterresistE1.OT}\right) \cdot -1 = 1093.945 \cdot kN$$

Moment Arm (from Point O):
$$E_{h8E1a.loc.OT} := \frac{Key_{vdist}}{2} = -1\ m$$

$$E_{h8E1.OT} := \begin{cases} E_{h8E1a.OT} & \text{if } Key_{vdist} < 0 \\ \Sigma H_{SoilresistE1} - H_{h6E1} - H_{h2aE1} - P_{sbE1} & \text{otherwise} \end{cases} = 1093.945 \cdot kN$$

$$\Sigma M_{SoilresistE1} := \begin{cases} E_{h8E1a.OT} \cdot E_{h8E1a.loc.OT} & \text{if } Key_{vdist} < 0 \\ \Sigma M_{HorizSoilResistE1} - H_{h6E1} \cdot H_{h6locE1} - H_{h2aE1} \cdot H_{h2alocE1} - P_{sbE1} \cdot P_{sblocE1} & \text{otherwise} \end{cases} = -1093.945 \cdot kN \cdot m$$

Sum of Moment about Point O:

$$\Sigma M_{LateraldriveE1.OT} := E_{s1E1.OT} \cdot E_{s1locE1.OT} + E_{h1E1.OT} \cdot E_{h1locE1.OT} + E_{h2E1.OT} \cdot E_{h2locE1.OT} \cdots + E_{h2aE1.OT} \cdot E_{h2alocE1.OT} + H_{h2E1} \cdot H_{h2locE1} = -2994.7 \cdot kN \cdot m$$

$$\Sigma M_{LateralresistE1.OT} := \Sigma M_{waterresistE1.OT} + \Sigma M_{SoilresistE1} = -1147.7 \cdot kN \cdot m$$

$$\Sigma M_{seisE1.OT} := M_{Qv.conc} + M_{Q.conc} + M_{Qv.SoilWaterE1} + M_{Q.h.SoilWaterE1} = -4010 \cdot kN \cdot m$$

(seismic moment modified for the most adverse overturning effect)

Total moment:

$$\Sigma M_{E1.OT} := \Sigma M_{conc} + \Sigma M_{VertSoilWaterResistE1} + \Sigma M_{UpliftE1.OT} + \Sigma M_{LateraldriveE1.OT} + \Sigma M_{LateralresistE1.OT} + \Sigma M_{seisE1.OT} = 7777.7 \cdot kN \cdot m$$

Total Vertical Force:
$$\Sigma V_{E1.OT} := \Sigma V_{conc} + \Sigma V_{SoilWaterE1} + \Sigma V_{UpliftE1.OT} + Q_{v.conc} + Q_{v.SoilWaterE1} = 1754.7 \cdot kN$$

Distance X_R: EM 1110-2-2502 Eq.4-1
$$X_{R.E1} := \frac{\Sigma M_{E1.OT}}{\Sigma V_{E1.OT}} = 4.433\ m$$

Overturning Resultant Ratio
$$Ratio_{E1.OT} := \frac{X_{R.E1}}{b} = 0.35$$

$$Ratio_{E1.OT.check} := \begin{cases} \text{"OKAY "} & \text{if } Ratio_{E1.OT} > X_{R.reqE1} \\ \text{"Revise Structure""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

CHECK FOUNDATION ECCENTRICITY (HORIZONTAL PLANE):

Eccentricity (horizontal plan):
$$ex_{E1.OT} := \frac{b}{2} - \frac{\Sigma M_{E1.OT}}{\Sigma V_{E1.OT}} = 1.82\ m \qquad Kern_{E1.OT} := \frac{b}{4} = 3.125\ m$$

Eccentricity Check:
$$e_{check.E1.OT} := \begin{cases} \text{"Okay"} & \text{if } ex_{E1.OT} \le Kern_{E1.OT} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"Okay"}$$

LOAD CASE E1

CHECK FOUNDATION BEARING CAPACITY (HORIZONTAL PLANE):

Base Section Modulus: $S_{b.OT} = 26.04\,m^3$

Bearing Pressure Under Toe:

$$\sigma_{ToeE1.OT} := \begin{cases} \left(\frac{\Sigma V_{E1.OT}}{b \cdot B} + \frac{\Sigma V_{E1.OT} \cdot ex_{E1.OT}}{S_{b.OT}}\right) & \text{if } \frac{\Sigma V_{E1.OT}}{b \cdot B} \geq \frac{\Sigma V_{E1.OT} \cdot ex_{E1.OT}}{S_{b.OT}} \\ \frac{2 \cdot \Sigma V_{E1.OT}}{B \cdot 3\left(\frac{b}{2} - ex_{E1.OT}\right)} & \text{otherwise} \end{cases} = 262.8 \cdot kPa$$

$$Bearing_{ChecktoeE1.OT} := \begin{cases} \text{"OKAY "} & \text{if } \sigma_{ToeE1.OT} < \sigma_{allowE1} \\ \text{"NG - for reference only""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

Bearing Pressure Under Heel:

$$\sigma_{HeelE1.OT} := \begin{cases} \left(\frac{\Sigma V_{E1.OT}}{b \cdot B} - \frac{\Sigma V_{E1.OT} \cdot ex_{E1.OT}}{S_{b.OT}}\right) & \text{if } \frac{\Sigma V_{E1.OT}}{b \cdot B} \geq \frac{\Sigma V_{E1.OT} \cdot ex_{E1.OT}}{S_{b.OT}} \\ 0 & \text{otherwise} \end{cases} = 17.9 \cdot kPa$$

$$Bearing_{CheckheelE1.OT} := \left(\begin{cases} \text{"OKAY "} & \text{if } \sigma_{HeelE1.OT} < \sigma_{allowE1} \wedge \sigma_{HeelE1.OT} > 0 \\ \text{"NG - for reference only""} & \text{otherwise} \end{cases}\right) = \text{"OKAY "}$$

SUMMARY OF STABILITY ASSESSMENT:

LOAD CASE E1

Sliding Factor of Safety: (Horizontal Plane - Ref only)	$FS_{Horiz.SlidingE1} = 0.94$	$FS_{Sliding.check1.E1}$ = "NG - key req""
Sliding Factor of Safety: (Inclined Plane)	$FS_{InclinedlSlidingE1} = 1.79$	$FS_{Sliding.check2.E1}$ = "OKAY "
Eccentricity: (Inclined Plane)	$ex_{E1} = 0.56\ m$	$e_{check.E1}$ = "Okay"
Bearing Pressure At Heel: (Inclined Plane)	$\sigma_{HeelE1} = 118\cdot kPa$	$Bearing_{CheckheelE1}$ = "OKAY "
Bearing Pressure At Toe: (Inclined Plane)	$\sigma_{ToeE1} = 203\cdot kPa$	$Bearing_{ChecktoeE1}$ = "OKAY "
Flotation Factor of Safety (horizontal plane)	$FS_{FloatationE1} = 3.03$	$FS_{Floatation.E1.check}$ = "OKAY "
Overturning Resultant Ratio: (horizontal plane)	$Ratio_{E1.OT} = 0.35$	$Ratio_{E1.OT.check}$ = "OKAY "
Eccentricity: (horizontal plane - Ref only)	$ex_{E1.OT} = 1.82\ m$	$e_{check.E1.OT}$ = "Okay"
Bearing Pressure At Heel: (horizontal plane - Ref only)	$\sigma_{HeelE1.OT} = 18\cdot kPa$	$Bearing_{CheckheelE1.OT}$ = "OKAY "
Bearing Pressure At Toe: (horizontal plane - Ref only)	$\sigma_{ToeE1.OT} = 263\cdot kPa$	$Bearing_{ChecktoeE1.OT}$ = "OKAY "

Calculation Section IV

SS-5C Retaining Wall Stability Calculations

Project Number: 110773396

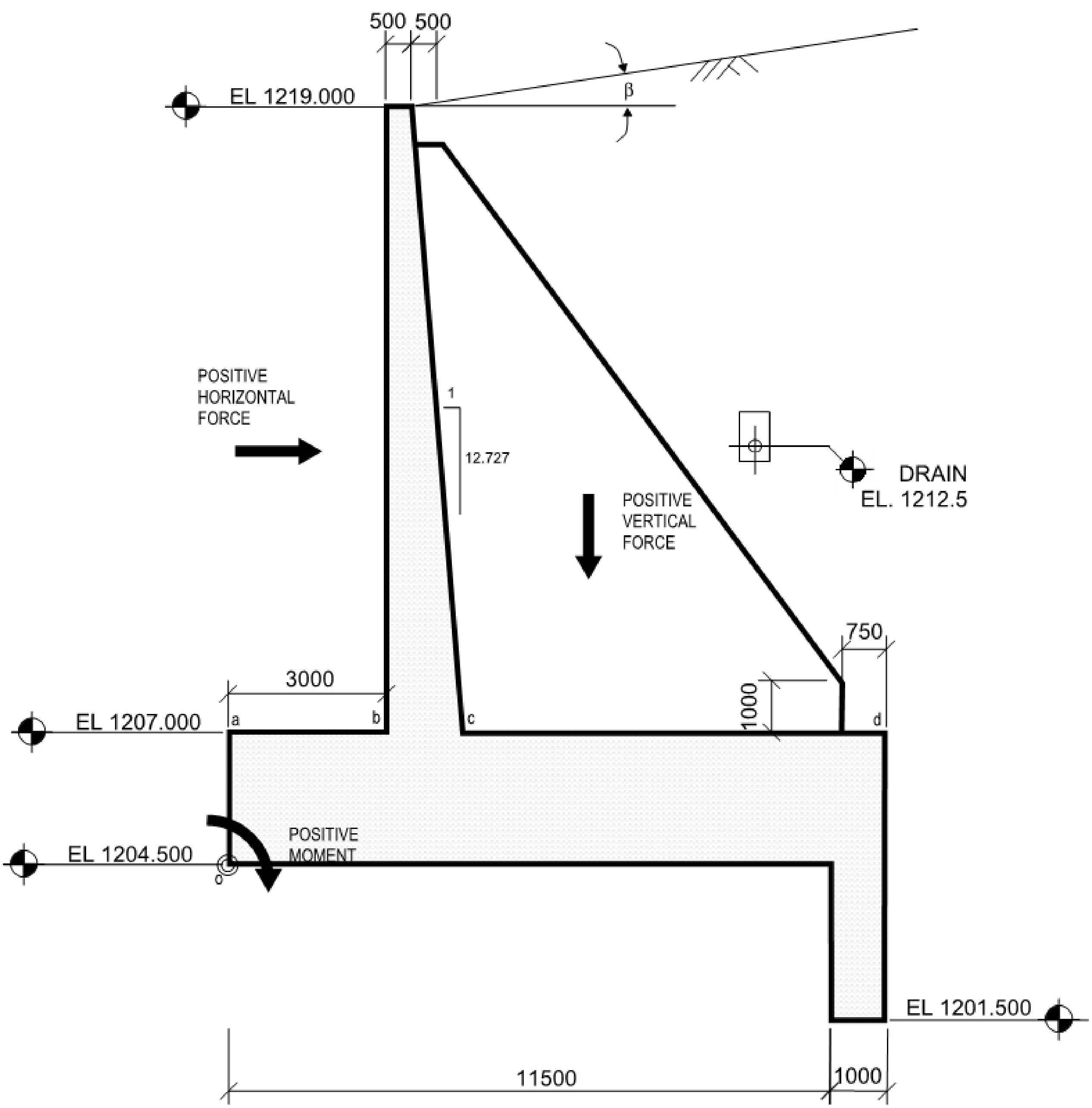
Project Title: SR1 - Diversion Structure

Client: Alberta Transportation

Engineer: Lawrence Choi Date: 12/11/2018

Checker: Sean Xiao Date: 12/18/2018

Calculation for: Retaining Wall - Service Spillway Left - Block 5C



REGION COLOR CONVENTION

User Input

Calulation Highlights

Results

WALL GEOMETRY:

Top of Wall Elevation: $T_w := 1219.0 \cdot m$

Top of Footing Elevation: $Top_{ftg} := 1207.0 \cdot m$

Thickness of Footing: $t_{ftg} := 2.5m$

Bottom of Footing Elevation: $Bot_{ftg} := Top_{ftg} - t_{ftg} = 1204.5\ m$

Overall Height of wall: $h_w := T_w - Bot_{ftg} = 14.50\ m$

Thickness of Wall: Base: $t_{wb} := 1.443 \cdot m$ Top: $t_{wt} := 0.50m$

Length of toe: $L_{ab} := 3.0m$

Total Length of Footing: $b := 12.5m$

Length of heel: $L_{cd} := b - L_{ab} - t_{wb} = 8.057\ m$

Unit Width of Wall for analysis: $B := 1.00m$

SHEAR KEY GEOMETRY:

	Toe	Heel	
Key depth:	$Key_{t.d} := 0m$	$Key_{h.d} := 3.0m$	(Assumption: $Key_{h.d}$ >= $Key_{t.d}$)
Key width:	$Key_{t.w} := 0m$	$Key_{h.w} := 1m$	
Face of Key from Point O:	$Key_{t.loc} := 0 \cdot m$	$Key_{h.loc} := b - Key_{h.w} = 11.5\ m$	

Horizontal Distance between Keys: $Key_{hdist} := Key_{h.loc} - Key_{t.loc} - Key_{t.w} = 11.5\ m$

Key Depth Diff. (from point O): $Key_{vdist} := -Key_{h.d} + Key_{t.d} = -3\ m$

BASE PROPERTIES:

Base Area: $A_b := b \cdot B = 12.5\ m^2$

Centroidal Distance for Footing (from Toe): $Y_f := \frac{b}{2} = 6.25\ m$

RETAINED SOIL GEOMETRY:

Slope of retained ground surface: $\beta := 0 \cdot \frac{\pi}{180} = 0.00$

Height of retained earth at heel: $H_w := T_w - Bot_{ftg} + \left(t_{wb} + L_{cd} - t_{wt}\right) \cdot \tan(\beta) = 14.50\ m$

RETAINING WALL GEOMETRY CHECKS:

(Foundation Analysis & Design Bowles)

$$t_{bcheck} := \begin{cases} \text{"OKAY"} & \text{if } t_{ftg} \geq \frac{H_w}{12} \\ \text{"Warning"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

$$t_{wcheck} := \begin{cases} \text{"OKAY"} & \text{if } t_{wb} \geq \frac{H_w}{12} \\ \text{"Warning"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

$$b_{check} := \begin{cases} \text{"OKAY"} & \text{if } \frac{b}{H_w} \geq .4 \wedge \frac{b}{H_w} \leq 80 \\ \text{"Warning"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

$$L_{abcheck} := \begin{cases} \text{"OKAY"} & \text{if } \frac{L_{ab}}{b} \geq .25 \wedge \frac{L_{ab}}{b} \leq .4 \\ \text{"Warning"} & \text{otherwise} \end{cases} = \text{"Warning"}$$

Material Properties:

Unit Weight of Water:	$\gamma_w := 9.8 \frac{kN}{m^3}$	(Section 7.2, Design Criteria)
Unit Weight of Concrete:	$\gamma_c := 23.5 \frac{kN}{m^3}$	
Unit Weight of Soil (Moist):	$\gamma_m := 20.0 \frac{kN}{m^3}$	(Section 5.3, Design Criteria) assumed moisture content (w) = 5%
Unit Weight Soil (Saturated):	$\gamma_{sat} := 22.0 \frac{kN}{m^3}$	(Assuming Specific Gravity = 2.7
Unit Weight Soil (buoyant):	$\gamma_b := \gamma_{sat} - \gamma_w = 12.2 \cdot \frac{kN}{m^3}$	
Weight of Soil/Concrete above toe:	$\gamma_{toe} := 22.0 \frac{kN}{m^3}$	
Unit Weight of Rock:	$\gamma_r := 25.6 \frac{kN}{m^3}$	(Section 7.2, Design Criteria)

Foundation Parameters:

Glacial Till Internal Friction:	$\phi := 27 \cdot \frac{\pi}{180} = 0.471$	
Bedrock Internal Friction Angle:	$\phi_r := 24 \cdot \frac{\pi}{180} = 0.419$	
Friction Angle at Base Concrete / Rock Interface:	$\phi_{rock} := 26$	
Base Friction Coefficient:	$tan_{\phi rock} := \tan\left(\phi_{rock} \frac{\pi}{180}\right) = 0.488$	radians
Rip Rap Backfill, Refer Dwg. C-214	$\phi_{backfill} := \left(20 \frac{\pi}{180}\right) = 0.349$	radians
Shear strength along rock Failure plane	$s_r := \frac{13100 \frac{kN}{m^2}}{2} = 6550 \cdot \frac{kN}{m^2}$	(Stantec Design Memo 8/8/16)

CONCRETE DEAD LOAD:

Area of Footing: $A_{ftg} := t_{ftg} \cdot b = 31.25\,m^2$

Weight of Footing: $D_{ftg} := A_{ftg} \cdot B \cdot \gamma_c = 734.4 \cdot kN$

Area of Stem (without batter): $A_{w1} := t_{wt} \cdot (h_w - t_{ftg}) = 6\,m^2$

Weight of Stem: $D_{w1} := A_{w1} \cdot B \cdot \gamma_c = 141 \cdot kN$

Area of stem Batter: $A_{w2} := \frac{(t_{wb} - t_{wt})}{2} (h_w - t_{ftg}) = 5.66\,m^2$

Weight of Batter: $D_{w2} := A_{w2} \cdot B \cdot \gamma_c = 133 \cdot kN$

Slope of batter: $S_{batter} := \frac{t_{wb} - t_{wt}}{h_w - t_{ftg}} = 0.079$

Area of Key $A_{t.key} := Key_{t.d} \cdot Key_{t.w} = 0$ $A_{h.key} := Key_{h.d} \cdot Key_{h.w} = 3\,m^2$

Weight of Key $D_{t.key} := A_{t.key} \cdot B \cdot \gamma_c = 0 \cdot kN$ $D_{h.key} := A_{h.key} \cdot B \cdot \gamma_c = 70.5 \cdot kN$

Centroidal Horizontal Distance of Wall (From Toe):

$$H_{cent} := \frac{A_{w1} \cdot \left(L_{ab} + \frac{t_{wt}}{2}\right) + A_{w2} \cdot \left(L_{ab} + t_{wt} + \frac{t_{wb} - t_{wt}}{3}\right) + A_{ftg} \cdot \frac{b}{2} + A_{t.key} \cdot \left(Key_{t.loc} + \frac{Key_{t.w}}{2}\right) + A_{h.key} \cdot \left(Key_{h.loc} + \frac{Key_{h.w}}{2}\right)}{A_{w1} + A_{w2} + A_{ftg} + A_{t.key} + A_{h.key}} = 5.93\,m$$

Centroidal Vertical Distance of Wall (Above Base of Footing):

$$V_{Cent} := \frac{A_{ftg} \cdot \frac{t_{ftg}}{2} + A_{w1} \cdot \left[t_{ftg} + \frac{(h_w - t_{ftg})}{2}\right] + A_{w2} \cdot \left[t_{ftg} + \frac{(h_w - t_{ftg})}{3}\right] + A_{t.key} \cdot \left(\frac{-Key_{t.d}}{2}\right) + A_{h.key} \cdot \left(\frac{-Key_{h.d}}{2}\right)}{A_{ftg} + A_{w1} + A_{w2} + A_{t.key} + A_{h.key}} = 2.66\,m$$

$\Sigma V_{conc} := D_{ftg} + D_{w1} + D_{w2} + D_{t.key} + D_{h.key} = 1078.8 \cdot kN$

$\Sigma M_{conc} := \Sigma V_{conc} \cdot H_{cent} = 6401.3\,m \cdot kN$

ROCK SECTION MOBILIZED FOR INCLINDED SLIDING FAILURE

Area of Rock Section Mobilized: $A_{rocksection} := (Key_{t.d} + Key_{h.d}) \cdot \frac{Key_{hdist}}{2} = 17.25\,m^2$

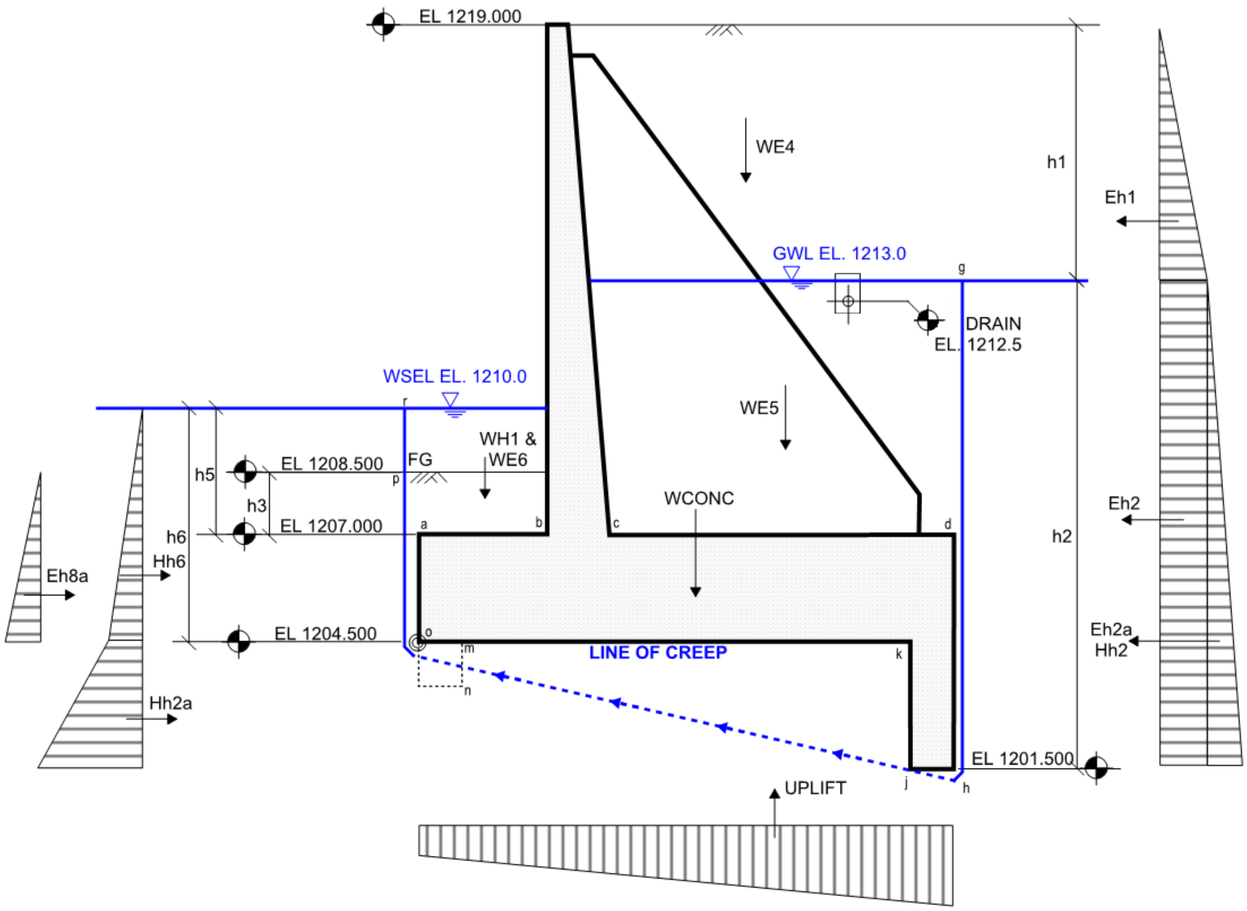
Rock Mass Mobilized: $V_{rocksection} := A_{rocksection} \cdot \gamma_r \cdot B = 441.6 \cdot kN$

(Pore pressure taken along assumed inclined sliding plane)

Distance from Toe to COG of Rock Section: $L_{rocksection} := \frac{Key_{hdist} \cdot (2 \cdot Key_{h.d} + Key_{t.d})}{3(Key_{h.d} + Key_{t.d})} + Key_{t.w} = 7.667\,m$

$\Sigma M_{rocksection} := V_{rocksection} \cdot L_{rocksection} = 3385.6\,m \cdot kN$

LOAD CASE U1 - NORMAL OPERATION



U1 DESIGN CASE

LOAD CASE U1 ACCEPTANCE PARAMETERS

FS sliding:

Usual (U) 1.5 (without cohesion) (Table 3-3, USACE EM 1110-2-2100)

Resultant Location:

Usual (U) Inside middle third ~100% base in compression

Required Factor of Safety for Sliding: $FS_{sliding.reqU1} := 1.5$ (Without Cohesion)

Allowable rock bearing pressure: $\sigma_{allowU1} := 1270kPa$ (Section 5.2, Design Criteria EM 1110-2-2100 Section 3-10)

Overturning Required Resultant Ratio: $X_{R.reqU1} := 0.333$ (EM 1110-2-2502, Figure 4-4)

Required Factor of Safety for Floatation $FS_{req.U1.flt} := 1.5$

SOIL HEIGHTS and Water Levels:

LOAD CASE U1

Heel Conditions:

Groundwater Elevation at Heel: $GWL_{U1} := 1213.0m$

Distance from Finish Grade to Groundwater at Heel: $h_{1U1} := \left[T_w - GWL_{U1} + \left(L_{cd} + t_{wb} - t_{wt}\right)\cdot\tan(\beta)\right] = 6.00\ m$

Distance from Water Surface to Bottom of Footing at Heel: $h_{2U1} := GWL_{U1} - Bot_{ftg} + Key_{h.d} = 11.50\ m$

Toe Conditions:

Water Surface Elevation at Toe: $WSEL_{U1} := 1210.0m$

Water Surface Elevation at Toe for Uplift: $UWSEL_{U1} := 1210.0\cdot m$

Finish Grade at Toe providing lateral resistance: $FG_{toeU1} := 1208.5\cdot m$

Soil Depth Above top of footing: $h_{3aU1} := FG_{toeU1} - Top_{ftg} = 1.5\ m$

$$h_{3U1} := \begin{vmatrix} h_{3aU1} & \text{if } FG_{toeU1} - Top_{ftg} \ge 0 \\ 0 & \text{otherwise} \end{vmatrix} = 1.5$$

Resisting Fill at Toe: $h_{4U1} := FG_{toeU1} - Bot_{ftg} + Key_{t.d} = 4.00\ m$

Distance from Water Level to Top of Footing: $h_{5U1} := WSEL_{U1} - Top_{ftg} = 3.00\ m$

Distance from Water Surface to Bottom of Footing: $h_{6U1} := WSEL_{U1} - Bot_{ftg} + Key_{t.d} = 5.50\cdot m$

Soil Depth Above WSEL: $h_{7aU1} := FG_{toeU1} - WSEL_{U1} = -1.5\ m$

$$h_{7U1} := \begin{vmatrix} h_{7aU1} & \text{if } FG_{toeU1} - WSEL_{U1} \ge 0 \\ 0 & \text{otherwise} \end{vmatrix} = 0$$

Soil Depth Below WSEL:

$$h_{8U1} := \begin{vmatrix} WSEL_{U1} - Bot_{ftg} + Key_{t.d} & \text{if } FG_{toeU1} - WSEL_{U1} \ge 0 \\ h_{4U1} & \text{otherwise} \end{vmatrix} = 4$$

For Line of Creep Method: $L_{ho.U1} := \sqrt{b^2 + \left(Key_{h.d} - Key_{t.d}\right)^2} = 12.855\ m$

Head Loss from Point g:

$\Delta h_{g.hj.U1} := h_{2U1} = 11.5\ m$ (to point h & j)

$\Delta h_{g.km.U1} := GWL_{U1} - Bot_{ftg} = 8.5\ m$ (to point k & m)

$\Delta h_{g.no.U1} := GWL_{U1} - Bot_{ftg} + Key_{t.d} = 8.5\ m$ (to point n & o)

$\Delta h_{g.p.U1} := GWL_{U1} - FG_{toeU1} = 4.5\ m$ (to point p)

$\Delta h_{g.r.U1} := GWL_{U1} - UWSEL_{U1} = 3\ m$ (to point r)

Surcharge

Surcharge on Heel: $S1_{U1} := 0.0\ \frac{kN}{m^2}$

Calculate Soil Lateral Pressure Coefficients:

For all load cases except seismic, soil loading to be based on At-Rest Condition.
Calculate at-rest pressure coefficient Ko based on Jaky's (1944) equation.

Soil At Rest Static Coefficient: $K_o := \dfrac{1 - \sin(\phi)}{1 + \sin(\beta)} = 0.546$ (Eq. 3-6, USACE EM 1110-2-2502)

Lateral - Driving Force (Headwater Side)

Lateral Soil Load:

Surcharge Load: $E_{s1U1} := S1_{U1} \cdot K_o \cdot \left(H_w + Key_{h.d}\right) \cdot B \cdot -1 = 0 \cdot kN$

Moment Arm (from bottom of footing): $E_{s1locU1} := \dfrac{H_w + Key_{h.d}}{2} + Key_{vdist} = 5.75\ m$

Moist Soil Load above GWL: $E_{h1U1} := \dfrac{\gamma_m \cdot K_o \cdot h_{1U1}^{\ 2}}{2} B \cdot -1 = -196.6 \cdot kN$

Moment Arm (from bottom of footing): $E_{h1locU1} := \dfrac{h_{1U1}}{3} + h_{2U1} + Key_{vdist} = 10.50\ m$

Saturated Soil Load below GWL:
(rectangular component) $E_{h2U1} := \left(\gamma_m \cdot K_o \cdot h_{1U1}\right) \cdot \left(h_{2U1}\right) \cdot B \cdot -1 = -753.5 \cdot kN$

Moment Arm (from bottom of footing): $E_{h2locU1} := \dfrac{h_{2U1}}{2} + Key_{vdist} = 2.75\ m$

Saturated Soil Load below GWL:
(triangular component) $E_{h2aU1} := \dfrac{\left(\gamma_{sat} - \gamma_w\right) \cdot K_o \cdot h_{2U1}^{\ 2}}{2} \cdot B \cdot -1 = -440.5 \cdot kN$

Moment Arm (from bottom of footing): $E_{h2alocU1} := \dfrac{h_{2U1}}{3} + Key_{vdist} = 0.83\ m$

Lateral Water Load:

Water Load GWL to Bottom of Key $H_{h2U1} := \dfrac{\gamma_w \cdot h_{2U1}^{\ 2}}{2} \cdot B \cdot -1 = -648.0 \cdot kN$

Moment Arm (from bottom of footing): $H_{h2locU1} := \dfrac{h_{2U1}}{3} + Key_{vdist} = 0.83\ m$

$\Sigma H_{SoildriveU1} := E_{s1U1} + E_{h1U1} + E_{h2U1} + E_{h2aU1} + H_{h2U1} = -2038.6 \cdot kN$

$\Sigma M_{LateralSoildriveU1} := E_{s1U1} \cdot E_{s1locU1} + E_{h1U1} \cdot E_{h1locU1} + E_{h2U1} \cdot E_{h2locU1} \ldots + E_{h2aU1} \cdot E_{h2alocU1} + H_{h2U1} \cdot H_{h2locU1} = -5043.1\ m \cdot kN$

Lateral - Resisting Force (Tailwater Side)

LOAD CASE U1

Lateral Water Load:

Water Load WSEL to Bot. of Footing:

$$H_{h6U1} := \frac{\gamma_w \cdot h_{6U1}^2}{2} \cdot B = 148.2 \cdot kN$$

Moment Arm (from bot. of toe key):

$$H_{h6locU1} := \frac{h_{6U1}}{3} = 1.83\ m$$

Water Load Bot. of Footing to Bot. of H. Key:

$$H_{h2aU1} := \left[\left(UWSEL_{U1} - Bot_{ftg} + Key_{t.d}\right) + h_{2U1}\right] \cdot \frac{Key_{h.d}}{2} \cdot \gamma_w \cdot B = 249.9 \cdot kN$$

Moment Arm (from bot. of toe key):

$$H_{h2alocU1} := \frac{Key_{h.d} \cdot \left[2 \cdot \left(UWSEL_{U1} - Bot_{ftg} + Key_{t.d}\right) + h_{2U1}\right]}{3\left[h_{2U1} + \left(UWSEL_{U1} - Bot_{ftg} + Key_{t.d}\right)\right]} \ldots = -1.68\ m$$
$$+ Key_{vdist}$$

Lateral Soil Load:

Moist Soil Load above WSEL:

$$E_{h7U1} := \frac{\gamma_m \cdot K_o \cdot h_{7U1}^2}{2} \cdot B = 0.0 \cdot kN$$

Moment Arm (from bot. of toe key):

$$E_{h7locU1} := h_{6U1} + \frac{h_{7U1}}{3} + Key_{vdist} = 2.50\ m$$

Saturated Soil Load below WSEL:
(rectangular component)

$$E_{h8U1} := \left(\gamma_m \cdot K_o \cdot h_{7U1}\right) \cdot h_{8U1} \cdot B = 0.0 \cdot kN$$

Moment Arm (from bot. of toe key):

$$E_{h8locU1} := \frac{h_{8U1}}{2} = 2.00\ m$$

Saturated Soil Load below WSEL:
(triangular component)

$$E_{h8aU1} := \frac{\left[\left(\gamma_{sat} - \gamma_w\right) \cdot K_o\right] \cdot h_{8U1}^2}{2} \cdot B = 53.3 \cdot kN$$

Moment Arm (from bot. of footing):

$$E_{h8alocU1} := \frac{h_{8U1}}{3} = 1.33\ m$$

$$\Sigma H_{SoilresistU1} := H_{h6U1} + H_{h2aU1} + E_{h7U1} + E_{h8U1} + E_{h8aU1} = 451.4 \cdot kN$$

$$\Sigma M_{HorizSoilResistU1} := H_{h6U1} \cdot H_{h6locU1} + H_{h2aU1} \cdot H_{h2alocU1} + E_{h7U1} \cdot E_{h7locU1} \ldots = -76.2\ m \cdot kN$$
$$+ E_{h8U1} \cdot E_{h8locU1} + E_{h8aU1} \cdot E_{h8alocU1}$$

Vertical Force:

UPLIFT: Linear distribution from water at heel to water at toe:

$$\Sigma V_{UpliftU1} := \left[\left(UWSEL_{U1} - Bot_{ftg} + Key_{t.d}\right) + h_{2U1}\right] \cdot \frac{b}{2} \cdot \gamma_w \cdot B \cdot -1 = -1041.25 \cdot kN$$

Moment Arm (from Point O):

$$V_{UpliftU1aloc} := \frac{b \cdot \left[2 \cdot h_{2U1} + \left(UWSEL_{U1} - Bot_{ftg} + Key_{t.d}\right)\right]}{3\left[h_{2U1} + \left(UWSEL_{U1} - Bot_{ftg} + Key_{t.d}\right)\right]} = 6.985\ m$$

$$\Sigma M_{UpliftU1} := \Sigma V_{UpliftU1} \cdot V_{UpliftU1aloc} = -7273.438 \cdot kN \cdot m$$

Vertical Force (con't):

Weight of soil and water over toe:

Water Above the Top of Footing: $W_{H1U1} := \gamma_w \cdot h_{5U1} \cdot L_{ab} \cdot B = 88.2 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E1locU1} := \frac{L_{ab}}{2} = 1.5\, m$

Soil above top of footing: $W_{E6U1} := \gamma_b \cdot h_{3U1} \cdot L_{ab} \cdot B = 54.9 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E6locU1} := \frac{L_{ab}}{2} = 1.5\, m$

Vertical Load Due to Surcharge: $S_{U1} := S1_{U1} \cdot L_{cd} \cdot B = 0$ $\quad S_{U1loc} := b - \frac{L_{cd}}{2} = 8.47\, m$

Weight of soil and water over heel:

Moist Soil for sloped grade above top of wall:

Length of sloped portion of soil above top of wall: $L_{E3U1} := \left(L_{cd} + t_{wb} - t_{wt}\right) = 9.00\, m$

Height of sloped soil above top of wall over heel: $h_{E3locU1} := \left(L_{E3U1}\right) \cdot \tan(\beta) = 0.00\, m$

Weight of sloped soil above top of wall: $W_{E3U1} := \frac{\gamma_m}{2} \cdot h_{E3locU1} \cdot L_{E3U1} \cdot B = 0.0 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E3locU1} := L_{ab} + t_{wt} + \frac{2}{3} \cdot L_{E3U1} = 9.50\, m$

Moist soil from top of wall to groundwater level:

Height of soil from top of wall and top of GWL: $h_{1U1} = 6.00\, m$

Length from edge of wall at GWL to edge of heel: $L_{E4U1} := L_{E3U1} - \left(h_{1U1} \cdot S_{batter}\right) = 8.53\, m$

Weight of soil over heel from top of wall to GWL: $W_{E4U1} := \gamma_m \cdot h_{1U1} \cdot \frac{\left(L_{E3U1} + L_{E4U1}\right)}{2} \cdot B = 1051.7 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E4locU1} := b - \frac{L_{E3U1}^2 + L_{E3U1} \cdot L_{E4U1} + L_{E4U1}^2}{3\left(L_{E3U1} + L_{E4U1}\right)} = 8.12\, m$

Saturated soil from groundwater to top of footing:

Height of soil from GWL to top of heel: $h_{E4U1} := h_{2U1} - t_{ftg} - Key_{h.d} = 6.00\, m$

Weight of soil over heel from GWL to top of heel: $W_{E5U1} := \left(\gamma_{sat}\right) \cdot h_{E4U1} \cdot \frac{\left(L_{E4U1} + L_{cd}\right)}{2} \cdot B = 1094.6 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E5locU1} := b - \frac{L_{E4U1}^2 + L_{E4U1} \cdot L_{cd} + L_{cd}^2}{3\left(L_{E4U1} + L_{cd}\right)} = 8.35\, m$

$$\Sigma V_{SoilWaterU1} := W_{H1U1} + W_{E6U1} + W_{E3U1} + W_{E4U1} + W_{E5U1} + S_{U1} = 2289.5 \cdot kN$$

$$\Sigma M_{VertSoilWaterResistU1} := W_{H1U1} \cdot W_{E1locU1} + W_{E6U1} \cdot W_{E6locU1} \cdots + W_{E3U1} \cdot W_{E3locU1} + W_{E4U1} \cdot W_{E4locU1} + W_{E5U1} \cdot W_{E5locU1} + S_{U1} \cdot S_{U1loc} = 17894.2\, m \cdot kN$$

THIS PAGE INTENTIONALLY LEFT BLANK
PLEASE GO TO THE NEXT PAGE

STABILITY ASSESSMENT:

LOAD CASE U1

CHECK SLIDING ALONG HORIZONTAL SLIDING PLANE:

Summation of the vertical forces:

$$\Sigma V_{U1} := \Sigma V_{conc} + \Sigma V_{SoilWaterU1} + \Sigma V_{UpliftU1} = 2327.0 \cdot kN$$

Summation of the horizontal forces:

$$\Sigma H_{U1} := \Sigma H_{SoildriveU1} + \Sigma H_{SoilresistU1} = -1587.1 \cdot kN$$

Safety Factor for Sliding Horizontal Failure Plane

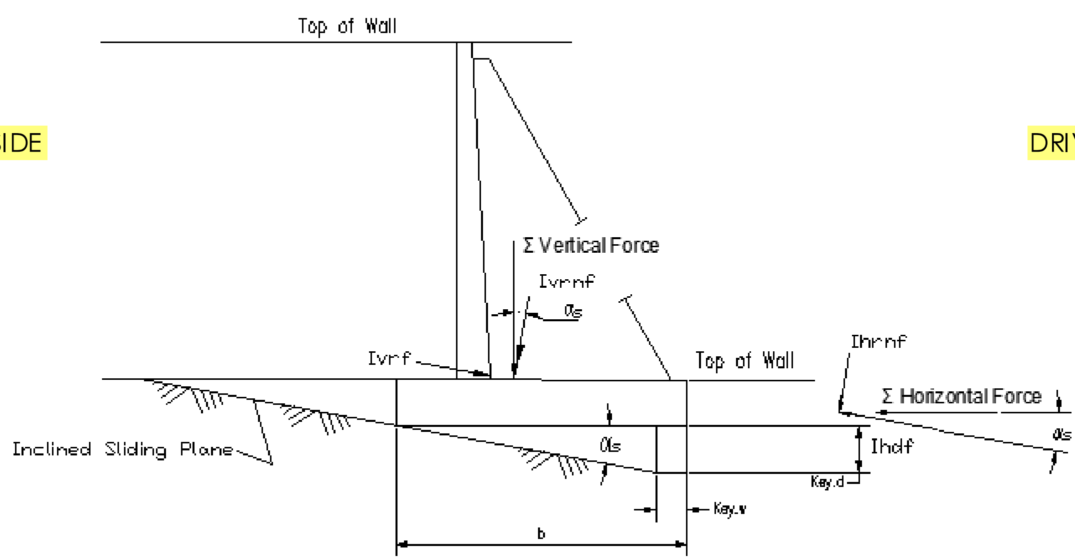
$$FS_{Horiz.SlidingU1} := \frac{\left|\Sigma V_{U1}\right| \cdot \tan\left(\phi_{rock} \cdot \frac{\pi}{180}\right)}{\left|\Sigma H_{U1}\right|} = 0.72$$

$$FS_{Sliding.check1.U1} := \begin{array}{|ll} \text{"OKAY"} & \text{if } FS_{Horiz.SlidingU1} > FS_{sliding.reqU1} \\ \text{"Key req'"} & \text{otherwise} \end{array} = \text{"Key req'"}$$

CHECK FACTOR OF SAFETY SLIDING WITH KEY (INCLINED SLIDING PLANE):

RESISTING SIDE

DRIVING SIDE



TOE

HEEL

Ivrf=Inclined Resisting Force
Ivrnf=Inclined Resisting Normal Force
Ihrnf=Inclined Resisting Normal Force
Ihdf=Inclined Driving Force

$$\alpha s := \operatorname{atan}\left(\frac{-Key_{vdist}}{Key_{hdist}}\right) = 0.255 \qquad \text{as degrees=} \qquad \alpha s \cdot \left(\frac{180}{\pi}\right) = 14.62$$

(With properly engineered reinforced concrete Key, horizontal sliding plane thru Toe is protected, critical sliding plane is relocated to the INCLINED SLIDING PLANE FROM HEEL KEY To TOE, Bedrock Mass above this examing plane is mobilized by reinforced concrete key and combined into Structural Wedge.)

Resolve ΣV_{U1} & ΣH_{U1}

$$\Sigma V_{InclinedU1} := \cos(\alpha s) \cdot \left(\left|\Sigma V_{U1} + V_{rocksection}\right|\right) + \sin(\alpha s) \cdot \left|\Sigma H_{U1}\right| = 3079.6 \cdot kN$$

$$\Sigma H_{InclinedU1} := \cos(\alpha s) \cdot \left|\Sigma H_{U1}\right| - \sin(\alpha s) \cdot \left(\left|\Sigma V_{U1} + V_{rocksection}\right|\right) = 836.9 \cdot kN$$

Safety Factor for Sliding Inclined Failure Plane

LOAD CASE U1

$$FS_{InclinedISlidingU1} := \frac{\Sigma V_{InclinedU1} \cdot \tan(\phi_r)}{\Sigma H_{InclinedU1}} = 1.64$$

$$FS_{Sliding.check2.U1} := \begin{cases} \text{"OKAY "} & \text{if } FS_{InclinedISlidingU1} > FS_{sliding.reqU1} \\ \text{"NG - Revise Structure""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

CHECK FOUNDATION ECCENTRICITY:

Summation of the resisting moments about the toe:

$$\Sigma M_{resU1} := \Sigma M_{conc} + \Sigma M_{VertSoilWaterResistU1} + \Sigma M_{HorizSoilResistU1} + \Sigma M_{rocksection} = 27605 \cdot kN \cdot m$$

Summation of the overturning moments about the toe:

$$\Sigma M_{oU1} := \Sigma M_{LateralSoildriveU1} + \Sigma M_{UpliftU1} = -12317 \cdot kN \cdot m$$

Total moment: $\Sigma M_{U1} := \Sigma M_{resU1} + \Sigma M_{oU1} = 15288.4 \cdot kN \cdot m$

Normal force to base: $\Sigma V_{InclinedU1} = 3079.6 \cdot kN$

Inclined Sliding Plane Length: $L_{incline} := \dfrac{b}{\cos(\alpha s)} = 12.9\ m$

Eccentricity (inclined plane): $ex_{U1} := \dfrac{L_{incline}}{2} - \dfrac{\Sigma M_{U1}}{\Sigma V_{InclinedU1}} = 1.49\ m$ $Kern := \dfrac{L_{incline}}{6} = 2.153\ m$

Eccentricity Check: $e_{check.U1} := \begin{cases} \text{"Okay"} & \text{if } ex_{U1} \le Kern \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"Okay"}$

CHECK FOUNDATION BEARING CAPACITY:

Base Section Modulus: $S_b := \dfrac{1}{6}\left(B \cdot L_{incline}{}^2\right) = 27.81\ m^3$

Bearing Pressure Under Toe:

$$\sigma_{ToeU1} := \begin{cases} \left(\dfrac{\Sigma V_{InclinedU1}}{L_{incline} \cdot B} + \dfrac{\Sigma V_{InclinedU1} \cdot ex_{U1}}{S_b}\right) & \text{if } \dfrac{\Sigma V_{InclinedU1} \cdot ex_{U1}}{S_b} \le \dfrac{\Sigma V_{InclinedU1}}{L_{incline} \cdot B} \\ \dfrac{2 \cdot \Sigma V_{InclinedU1}}{B \cdot 3\left(\dfrac{b}{2} - ex_{U1}\right)} & \text{otherwise} \end{cases} = 403.9 \cdot kPa$$

$$Bearing_{ChecktoeU1} := \begin{cases} \text{"OKAY "} & \text{if } \sigma_{ToeU1} < \sigma_{allowU1} \\ \text{"NG""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

Bearing Pressure Under Heel:

$$\sigma_{HeelU1} := \begin{cases} \left(\dfrac{\Sigma V_{InclinedU1}}{L_{incline} \cdot B} - \dfrac{\Sigma V_{InclinedU1} \cdot ex_{U1}}{S_b}\right) & \text{if } \dfrac{\Sigma V_{InclinedU1} \cdot ex_{U1}}{S_b} \le \dfrac{\Sigma V_{InclinedU1}}{L_{incline} \cdot B} \\ 0 & \text{otherwise} \end{cases} = 72.9 \cdot kPa$$

$$Bearing_{CheckheelU1} := \left(\begin{cases} \text{"OKAY "} & \text{if } \sigma_{HeelU1} < \sigma_{allowU1} \wedge \sigma_{HeelU1} > 0 \\ \text{"NG - perform cracked base analysis""} & \text{otherwise} \end{cases}\right) = \text{"OKAY "}$$

CHECK FLOATATION:

Safety Factor for Floatation:

$$FS_{FloatationU1} := \frac{\Sigma V_{conc} + \Sigma V_{SoilWaterU1}}{\left|\Sigma V_{UpliftU1}\right|} = 3.23$$

$$FS_{Floatation.U1.check} := \begin{cases} \text{"OKAY"} & \text{if } FS_{FloatationU1} > FS_{req.U1.flt} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

CHECK OVERTURNING

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.
Assumptions are made in order to compute overturning stablity of indetermine forces on monolith with key;
(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.
(b) The horizontal resisting force acting on the key, P.key, is that required for static equilibrium
(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1

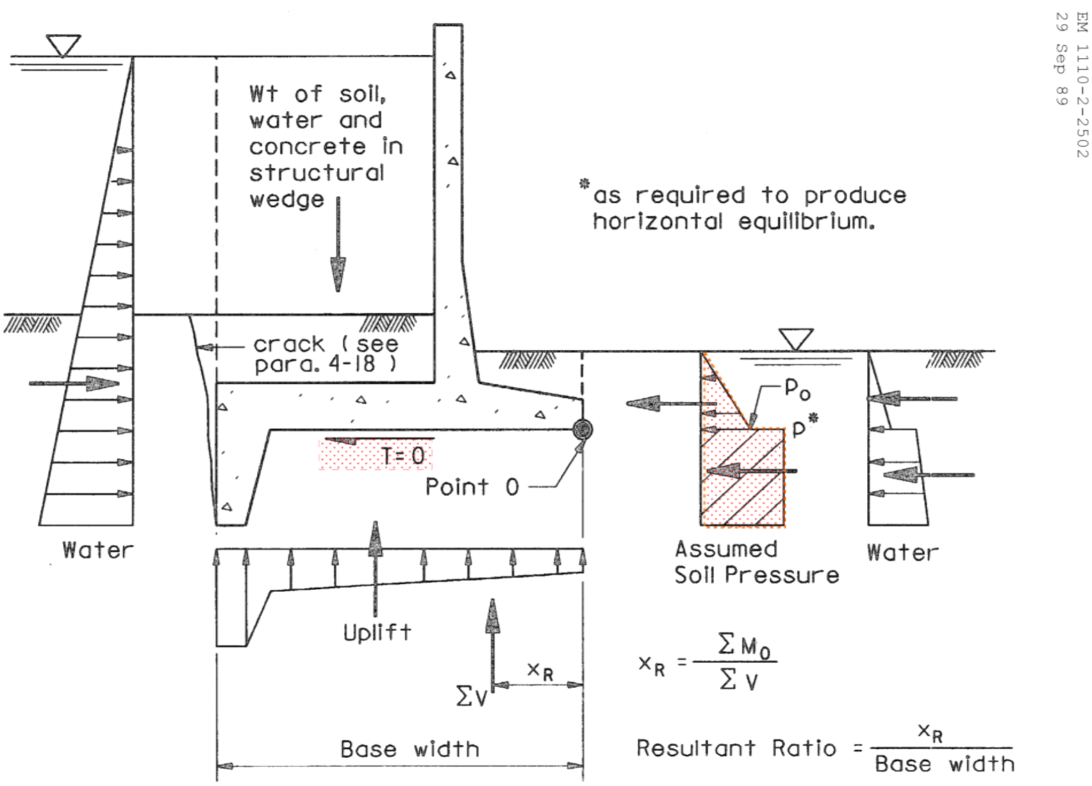


Figure 4-5. Forces for overturning analysis for wall with horizontal base and key

Modify Uplift for Overturning Analysis: **LOAD CASE U1**

(Uplift is calculated along the concrete/rock contact using the Line of Creep method)

Water Pressure at h: $u_{h.U1} := \Delta h_{g.hj.U1} \cdot \gamma_w = 112.70 \cdot kPa$

Water Pressure at o: $u_{o.U1} := \left(\Delta h_{g.no.U1} - \frac{\Delta h_{g.r.U1} \cdot L_{ho.U1}}{L_{ho.U1}}\right) \cdot \gamma_w = 53.9 \cdot kPa$

Head loss between point h and o: $\Delta h_{ho.U1} := \Delta h_{g.r.U1} \cdot \frac{L_{ho.U1}}{L_{ho.U1}} = 3\,m$

Length of concrete base (h -> o): $L_{baseho.U1} := Key_{h.w} + Key_{h.d} + Key_{hdist} + Key_{t.d} + Key_{t.w} = 15.5\,m$

Head loss along h -> j: $\Delta h_{hj.U1} := \Delta h_{ho.U1} \cdot \frac{Key_{h.w}}{L_{baseho.U1}} = 0.194\,m$

Water Pressure at j: $u_{j.U1} := \left(\Delta h_{g.hj.U1} - \Delta h_{hj.U1}\right) \cdot \gamma_w = 110.80 \cdot kPa$

Head loss along h -> k: $\Delta h_{hjk.U1} := \Delta h_{ho.U1} \cdot \left(\frac{Key_{h.w} + Key_{h.d}}{L_{baseho.U1}}\right) = 0.774\,m$

Water Pressure at k: $u_{k.U1} := \left(\Delta h_{g.km.U1} - \Delta h_{hjk.U1}\right) \cdot \gamma_w = 75.71 \cdot kPa$

Head loss along h -> m: $\Delta h_{hjkm.U1} := \Delta h_{ho.U1} \cdot \left(\frac{Key_{h.w} + Key_{h.d} + Key_{hdist}}{L_{baseho.U1}}\right) = 3\,m$

Water Pressure at m: $u_{m.U1} := \left(\Delta h_{g.km.U1} - \Delta h_{hjkm.U1}\right) \cdot \gamma_w = 53.90 \cdot kPa$

Head loss along h -> n: $\Delta h_{hjkmn.U1} := \Delta h_{ho.U1} \cdot \left(\frac{Key_{h.w} + Key_{h.d} + Key_{hdist} + Key_{t.d}}{L_{baseho.U1}}\right) = 3\,m$

Water Pressure at n: $u_{n.U1} := \left(\Delta h_{g.no.U1} - \Delta h_{hjkmn.U1}\right) \cdot \gamma_w = 53.90 \cdot kPa$

Uplift under key at heel: $V_{ulkeyhU1.OT} := \frac{\left(u_{h.U1} + u_{j.U1}\right) \cdot Key_{h.w}}{2} \cdot B \cdot -1 = -111.752 \cdot kN$

Moment Arm (from Point O): $V_{ulkeyhU1loc.OT} := b - \frac{Key_{h.w} \cdot \left(2 \cdot u_{j.U1} + u_{h.U1}\right)}{3 \cdot \left(u_{j.U1} + u_{h.U1}\right)} = 12.001\,m$

Uplift under base: $V_{ulbaseU1.OT} := \frac{\left(u_{k.U1} + u_{m.U1}\right) \cdot Key_{hdist}}{2} \cdot B \cdot -1 = -745.274 \cdot kN$

Moment Arm (from Point O): $V_{ulbaseU1loc.OT} := b - Key_{h.w} - \frac{Key_{hdist} \cdot \left(2 \cdot u_{m.U1} + u_{k.U1}\right)}{3 \cdot \left(u_{m.U1} + u_{k.U1}\right)} = 6.073\,m$

Uplift under key at toe: $V_{ulkeytU1.OT} := \frac{\left(u_{n.U1} + u_{o.U1}\right) \cdot Key_{t.w}}{2} \cdot B \cdot -1 = 0 \cdot kN$

Moment Arm (from Point O): $V_{ulkeytU1loc.OT} := \frac{Key_{t.w} \cdot \left(2 \cdot u_{n.U1} + u_{o.U1}\right)}{3 \cdot \left(u_{n.U1} + u_{o.U1}\right)} = 0$

$$\Sigma V_{UpliftU1.OT} := V_{ulkeyhU1.OT} + V_{ulbaseU1.OT} + V_{ulkeytU1.OT} = -857 \cdot kN$$

$$U_{U1.loc.OT} := \frac{V_{ulkeyhU1.OT} \cdot V_{ulkeyhU1loc.OT} + V_{ulbaseU1.OT} \cdot V_{ulbaseU1loc.OT} + V_{ulkeytU1.OT} \cdot V_{ulkeytU1loc.OT}}{\Sigma V_{UpliftU1.OT}} = 6.85\,m$$

$$\Sigma M_{UpliftU1.OT} := \Sigma V_{UpliftU1.OT} \cdot U_{U1.loc.OT} = -5866.9 \cdot kN \cdot m$$

Modify Lateral Water Pressure (Resisting) for Overturning Analysis:

(Resisting water pressure is calculated using the Line of Creep method)

Water Load at Key (heel): $H_{h2U1.OT} := \frac{u_{k.U1} + u_{j.U1}}{2} \cdot Key_{h.d} B = 279.8 \cdot kN$

Moment Arm (from Point O): $H_{h2locU1.OT} := \frac{Key_{h.d} \cdot (2 \cdot u_{k.U1} + u_{j.U1})}{3(u_{k.U1} + u_{j.U1})} + Key_{vdist} = -1.59\ m$

Water Load at Key (toe): $H_{h6U1.OT} := \frac{u_{o.U1} \cdot (UWSEL_{U1} - Bot_{ftg} + Key_{t.d})}{2} \cdot B = 148 \cdot kN$

Moment Arm (from Point O): $H_{h6locU1.OT} := \frac{UWSEL_{U1} - Bot_{ftg} + Key_{t.d}}{3} = 1.83\ m$

$$\Sigma H_{waterresistU1.OT} := H_{h2U1.OT} + H_{h6U1.OT} = 428 \cdot kN$$

$$H_{waterresistlocU1.OT} := \frac{H_{h2U1.OT} \cdot H_{h2locU1.OT} + H_{h6U1.OT} \cdot H_{h6locU1.OT}}{\Sigma H_{waterresistU1.OT}} = -0.407\ m$$

$$\Sigma M_{waterresistU1.OT} := \Sigma H_{waterresistU1.OT} \cdot H_{waterresistlocU1.OT} = -174.23 \cdot kN \cdot m$$

Modify Lateral Soil Loads for Overturning Analysis:

(Lateral soil loads are calculated down to Point O instead of bottom of shear key)

Driving Soil Load (Headwater Side):

Surcharge Load: $E_{s1U1.OT} := S1_{U1} \cdot K_o \cdot (H_w + Key_{h.d} + Key_{vdist}) \cdot B \cdot -1 = 0 \cdot kN$

Moment Arm (from Point O): $E_{s1locU1.OT} := \frac{H_w + Key_{h.d} + Key_{vdist}}{2} = 7.25\ m$

Moist Soil Load above GWL: $E_{h1U1.OT} := \frac{\gamma_m \cdot K_o \cdot h_{1U1}^2}{2} B \cdot -1 = -196.6 \cdot kN$

Moment Arm (from Point O): $E_{h1locU1.OT} := \frac{h_{1U1}}{3} + h_{2U1} + Key_{vdist} = 10.50\ m$

Saturated Soil Load below GWL: (rectangular component) $E_{h2U1.OT} := (\gamma_m \cdot K_o \cdot h_{1U1}) \cdot (h_{2U1} + Key_{vdist}) \cdot B \cdot -1 = -556.9 \cdot kN$

Moment Arm (from Point O): $E_{h2locU1.OT} := \frac{h_{2U1} + Key_{vdist}}{2} = 4.25\ m$

Saturated Soil Load below GWL: (triangular component) $E_{h2aU1.OT} := \frac{(\gamma_{sat} - \gamma_w) \cdot K_o \cdot (h_{2U1} + Key_{vdist})^2}{2} \cdot B \cdot -1 = -240.6 \cdot kN$

Moment Arm (from Point O): $E_{h2alocU1.OT} := \frac{h_{2U1} + Key_{vdist}}{3} = 2.83\ m$

Resisting Soil Load (Tailwater Side):

(Determine resisting soil load based on depth variation between the keys (ie. Key_{vdist}). In case where key at heel is deeper than key at toe (ie. $Key_{vdist} < 0$), resisting soil load (p*) is assumed to produce horizontal equilibrium as per Figure 4-5 above. Resisting soil load (p_o) is neglected.)

Total Driving Force: $\Sigma H_{SoildriveU1.OT} := E_{s1U1.OT} + E_{h1U1.OT} + E_{h2U1.OT} + E_{h2aU1.OT} + H_{h2U1} = -1642.2 \cdot kN$

Total Resisting Force: $\Sigma H_{waterresistU1.OT} = 428.0 \cdot kN$

Assumed Soil Load p*: $E_{h8U1a.OT} := \left(\Sigma H_{SoildriveU1.OT} + \Sigma H_{waterresistU1.OT}\right) \cdot -1 = 1214.159 \cdot kN$

Moment Arm (from Point O): $E_{h8U1a.loc.OT} := \frac{Key_{vdist}}{2} = -1.5\,m$

$$E_{h8U1.OT} := \begin{cases} E_{h8U1a.OT} & \text{if } Key_{vdist} < 0 \\ \Sigma H_{SoilresistU1} - H_{h6U1} - H_{h2aU1} & \text{otherwise} \end{cases} = 1214.159 \cdot kN$$

$$\Sigma M_{SoilresistU1} := \begin{cases} E_{h8U1a.OT} \cdot E_{h8U1a.loc.OT} & \text{if } Key_{vdist} < 0 \\ \Sigma M_{HorizSoilResistU1} - H_{h6U1} \cdot H_{h6locU1} - H_{h2aU1} \cdot H_{h2alocU1} & \text{otherwise} \end{cases} = -1821.238 \cdot kN \cdot m$$

Sum of Moment about Point O:

$$\Sigma M_{LateraldriveU1.OT} := E_{s1U1.OT} \cdot E_{s1locU1.OT} + E_{h1U1.OT} \cdot E_{h1locU1.OT} + E_{h2U1.OT} \cdot E_{h2locU1.OT} \ldots + E_{h2aU1.OT} \cdot E_{h2alocU1.OT} + H_{h2U1} \cdot H_{h2locU1} = -5652.7 \cdot kN \cdot m$$

$$\Sigma M_{LateralresistU1.OT} := \Sigma M_{waterresistU1.OT} + \Sigma M_{SoilresistU1} = -1995.5 \cdot kN \cdot m$$

Total moment:

$$\Sigma M_{U1.OT} := \Sigma M_{conc} + \Sigma M_{VertSoilWaterResistU1} + \Sigma M_{UpliftU1.OT} + \Sigma M_{LateraldriveU1.OT} + \Sigma M_{LateralresistU1.OT} = 10780.4 \cdot kN \cdot m$$

Total Vertical Force: $\Sigma V_{U1.OT} := \Sigma V_{conc} + \Sigma V_{SoilWaterU1} + \Sigma V_{UpliftU1.OT} = 2511.3 \cdot kN$

Distance X_R: EM 1110-2-2502 Eq.4-1 $X_{R.U1} := \frac{\Sigma M_{U1.OT}}{\Sigma V_{U1.OT}} = 4.293\,m$

Overturning Resultant Ratio $Ratio_{U1.OT} := \frac{X_{R.U1}}{b} = 0.34$

$$Ratio_{U1.OT.check} := \begin{cases} \text{"OKAY "} & \text{if } Ratio_{U1.OT} > X_{R.reqU1} \\ \text{"Revise Structure""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

CHECK FOUNDATION ECCENTRICITY (HORIZONTAL PLANE):

Eccentricity (horizontal plan): $ex_{U1.OT} := \frac{b}{2} - \frac{\Sigma M_{U1.OT}}{\Sigma V_{U1.OT}} = 1.96\,m$ $Kern_{OT} := \frac{b}{6} = 2.083\,m$

Eccentricity Check:

$$e_{check.U1.OT} := \begin{cases} \text{"Okay"} & \text{if } ex_{U1} \le Kern_{OT} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"Okay"}$$

CHECK FOUNDATION BEARING CAPACITY (HORIZONTAL PLANE):

Base Section Modulus: $S_{b.OT} := \frac{1}{6}\left(B \cdot b^2\right) = 26.04\,m^3$

Bearing Pressure Under Toe:

$$\sigma_{ToeU1.OT} := \begin{cases} \left(\dfrac{\Sigma V_{U1.OT}}{b \cdot B} + \dfrac{\Sigma V_{U1.OT} \cdot ex_{U1.OT}}{S_{b.OT}}\right) & \text{if } \dfrac{\Sigma V_{U1.OT}}{b \cdot B} \ge \dfrac{\Sigma V_{U1.OT} \cdot ex_{U1.OT}}{S_{b.OT}} \\ \dfrac{2 \cdot \Sigma V_{U1.OT}}{B \cdot 3\left(\dfrac{b}{2} - ex_{U1.OT}\right)} & \text{otherwise} \end{cases} = 389.6 \cdot kPa$$

$$Bearing_{CheckToeU1.OT} := \begin{cases} \text{"OKAY "} & \text{if } \sigma_{ToeU1.OT} < \sigma_{allowU1} \\ \text{"NG - for reference only""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

Bearing Pressure Under Heel:

$$\sigma_{HeelU1.OT} := \begin{cases} \left(\dfrac{\Sigma V_{U1.OT}}{b \cdot B} - \dfrac{\Sigma V_{U1.OT} \cdot ex_{U1.OT}}{S_{b.OT}}\right) & \text{if } \dfrac{\Sigma V_{U1.OT}}{b \cdot B} \ge \dfrac{\Sigma V_{U1.OT} \cdot ex_{U1.OT}}{S_{b.OT}} \\ 0 & \text{otherwise} \end{cases} = 12.2 \cdot kPa$$

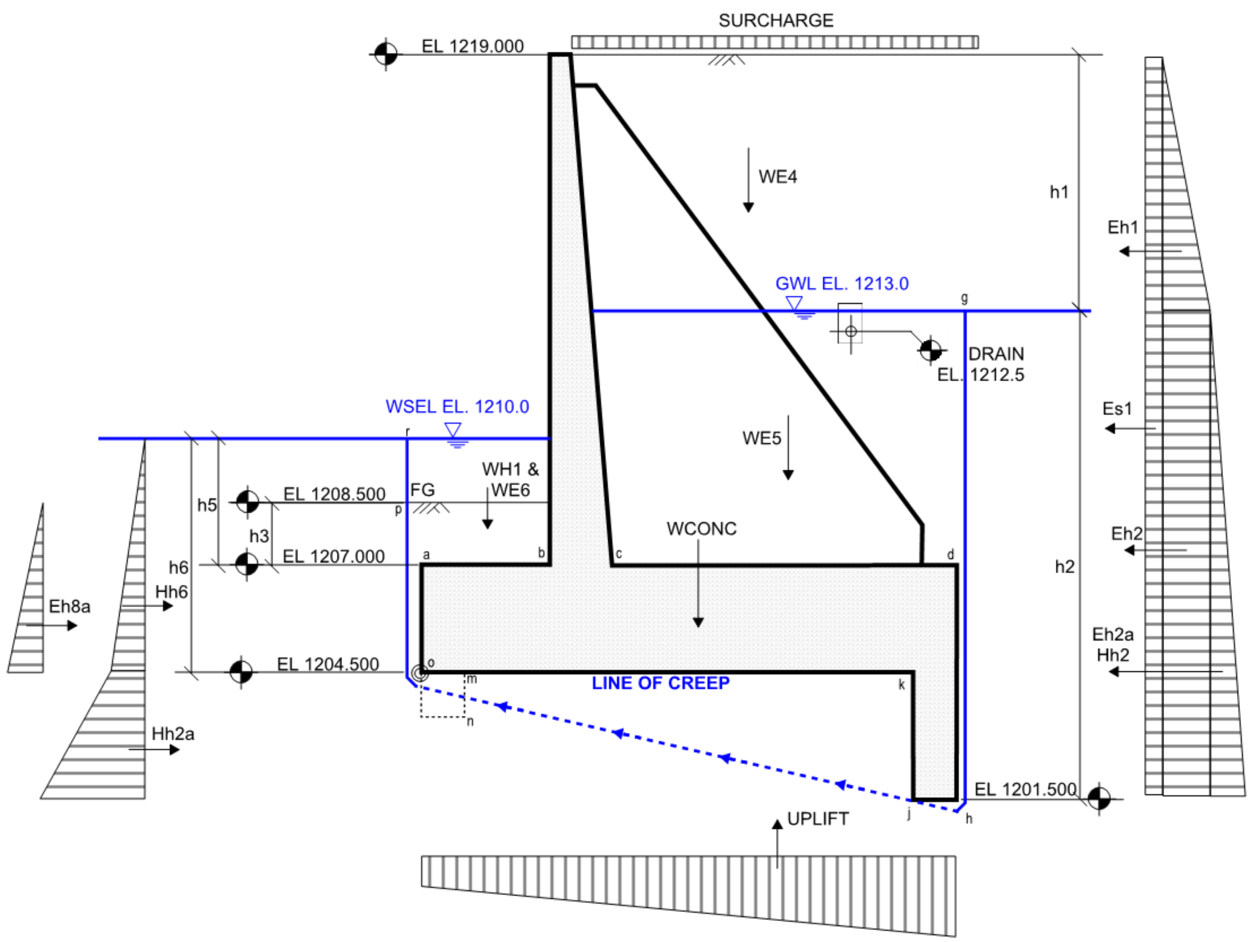
$$Bearing_{CheckheelU1.OT} := \left(\begin{cases} \text{"OKAY "} & \text{if } \sigma_{HeelU1.OT} < \sigma_{allowU1} \wedge \sigma_{HeelU1.OT} > 0 \\ \text{"NG - for reference only""} & \text{otherwise} \end{cases}\right) = \text{"OKAY "}$$

SUMMARY OF STABILITY ASSESSMENT:

LOAD CASE U1

Sliding Factor of Safety: (Horizontal Plane - Ref only)	$FS_{Horiz.SlidingU1} = 0.72$	$FS_{Sliding.check1.U1}$ = "Key req""
Sliding Factor of Safety: (Inclined Plane)	$FS_{InclinedlSlidingU1} = 1.64$	$FS_{Sliding.check2.U1}$ = "OKAY "
Eccentricity: (Inclined Plane)	$ex_{U1} = 1.49\ m$	$e_{check.U1}$ = "Okay"
Bearing Pressure At Heel: (Inclined Plane)	$\sigma_{HeelU1} = 73 \cdot kPa$	$Bearing_{CheckheelU1}$ = "OKAY "
Bearing Pressure At Toe: (Inclined Plane)	$\sigma_{ToeU1} = 404 \cdot kPa$	$Bearing_{ChecktoeU1}$ = "OKAY "
Flotation Factor of Safety (horizontal plane)	$FS_{FloatationU1} = 3.23$	$FS_{Floatation.U1.check}$ = "OKAY "
Overturning Resultant Ratio: (horizontal plane)	$Ratio_{U1.OT} = 0.34$	$Ratio_{U1.OT.check}$ = "OKAY "
Eccentricity: (horizontal plane - Ref only)	$ex_{U1.OT} = 1.96\ m$	$e_{check.U1.OT}$ = "Okay"
Bearing Pressure At Heel: (horizontal plane - Ref only)	$\sigma_{HeelU1.OT} = 12 \cdot kPa$	$Bearing_{CheckheelU1.OT}$ = "OKAY "
Bearing Pressure At Toe: (horizontal plane - Ref only)	$\sigma_{ToeU1.OT} = 390 \cdot kPa$	$Bearing_{ChecktoeU1.OT}$ = "OKAY "

LOAD CASE UN1 - NORMAL OPERATION + SURCHARGE



UN1 DESIGN CASE

LOAD CASE UN1 ACCEPTANCE PARAMETERS

FS sliding:

Unusual (UN) 1.3 (without cohesion) (Table 3-3, USACE EM 1110-2-2100)

Resultant Location:

Unsual (UN) Inside middle third ~100% base in compression

Required Factor of Safety for Sliding: $FS_{sliding.reqUN1} := 1.3$ (Without Cohesion)

Allowable rock bearing pressure: $\sigma_{allowUN1} := 1470kPa$ (Section 5.2, Design Criteria EM 1110-2-2100 Section 3-10)

Overturning Required Resultant Ratio: $X_{R.reqUN1} := 0.333$ (EM 1110-2-2502, Figure 4-4)

Required Factor of Safety for Floatation $FS_{req.UN1.flt} := 1.3$

SOIL HEIGHTS and Water Levels:

LOAD CASE UN1

Heel Conditions:

Groundwater Elevation at Heel: $GWL_{UN1} := 1213.0m$

Distance from Finish Grade to Groundwater at Heel: $h_{1UN1} := \left[T_w - GWL_{UN1} + \left(L_{cd} + t_{wb} - t_{wt}\right) \cdot \tan(\beta)\right] = 6.00\ m$

Distance from Water Surface to Bottom of Footing at Heel: $h_{2UN1} := GWL_{UN1} - Bot_{ftg} + Key_{h.d} = 11.50\ m$

Toe Conditions:

Water Surface Elevation at Toe: $WSEL_{UN1} := 1210.0m$

Water Surface Elevation at Toe for Uplift: $UWSEL_{UN1} := 1210.0 \cdot m$

Finish Grade at Toe providing lateral resistance: $FG_{toeUN1} := 1208.5 \cdot m$

Soil Depth Above top of footing: $h_{3aUN1} := FG_{toeUN1} - Top_{ftg} = 1.5\ m$

$$h_{3UN1} := \begin{cases} h_{3aUN1} & \text{if } FG_{toeUN1} - Top_{ftg} \geq 0 \\ 0 & \text{otherwise} \end{cases} = 1.5$$

Resisting Fill at Toe: $h_{4UN1} := FG_{toeUN1} - Bot_{ftg} + Key_{t.d} = 4.00\ m$

Distance from Water Level to Top of Footing at Toe: $h_{5UN1} := WSEL_{UN1} - Top_{ftg} = 3.00\ m$

Distance from Water Surface to Bottom of Footing at Toe: $h_{6UN1} := WSEL_{UN1} - Bot_{ftg} + Key_{t.d} = 5.50\ m$

Soil Depth Above WSEL: $h_{7aUN1} := FG_{toeUN1} - WSEL_{UN1} = -1.5\ m$

$$h_{7UN1} := \begin{cases} h_{7aUN1} & \text{if } FG_{toeUN1} - WSEL_{UN1} \geq 0 \\ 0 & \text{otherwise} \end{cases} = 0$$

Soil Depth Below WSEL:

$$h_{8UN1} := \begin{cases} WSEL_{UN1} - Bot_{ftg} + Key_{t.d} & \text{if } FG_{toeUN1} - WSEL_{UN1} \geq 0 \\ h_{4UN1} & \text{otherwise} \end{cases} = 4$$

For Line of Creep Method: $L_{ho.UN1} := \sqrt{b^2 + \left(Key_{h.d} - Key_{t.d}\right)^2} = 12.855\ m$

Head Loss from Point g:

$\Delta h_{g.hj.UN1} := h_{2UN1} = 11.5\ m$ (to point h & j)

$\Delta h_{g.km.UN1} := GWL_{UN1} - Bot_{ftg} = 8.5\ m$ (to point k & m)

$\Delta h_{g.no.UN1} := GWL_{UN1} - Bot_{ftg} + Key_{t.d} = 8.5\ m$ (to point n & o)

$\Delta h_{g.p.UN1} := GWL_{UN1} - FG_{toeUN1} = 4.5\ m$ (to point p)

$\Delta h_{g.r.UN1} := GWL_{UN1} - UWSEL_{UN1} = 3\ m$ (to point r)

Surcharge

Surcharge on Heel: $S1_{UN1} := 15.0 \dfrac{kN}{m^2}$

Calculate Soil Lateral Pressure Coefficients:

LOAD CASE UN1

For all load cases except seismic, soil loading to be based on At-Rest Condition.
Calculate at-rest pressure coefficient Ko based on Jaky's (1944) equation.

Soil At Rest Static Coefficient: $K_o := \dfrac{1 - \sin(\phi)}{1 + \sin(\beta)} = 0.546$ (Eq. 3-6, USACE EM 1110-2-2502)

Lateral - Driving Force

Static At-Rest:

Surcharge Load: $E_{s1UN1} := S1_{UN1} \cdot K_o \cdot \left(H_w + Key_{h.d}\right) \cdot B \cdot -1 = -143.327 \cdot kN$

Moment Arm (from bottom of footing): $E_{s1locUN1} := \dfrac{H_w + Key_{h.d}}{2} + Key_{vdist} = 5.75\ m$

Moist Soil Load above GWL: $E_{h1UN1} := \dfrac{\gamma_m \cdot K_o \cdot h_{1UN1}^{\ 2}}{2} B \cdot -1 = -196.6 \cdot kN$

Moment Arm (from bottom of footing): $E_{h1locUN1} := \dfrac{h_{1UN1}}{3} + h_{2UN1} + Key_{vdist} = 10.50\ m$

Saturated Soil Load below GWL:
(rectangular component) $E_{h2UN1} := \left(\gamma_m \cdot K_o \cdot h_{1UN1}\right) \cdot \left(h_{2UN1}\right) \cdot B \cdot -1 = -753.5 \cdot kN$

Moment Arm (from bottom of footing): $E_{h2locUN1} := \dfrac{h_{2UN1}}{2} + Key_{vdist} = 2.75\ m$

Saturated Soil Load below GWT:
(triangular L $E_{h2aUN1} := \dfrac{\left(\gamma_{sat} - \gamma_w\right) \cdot K_o \cdot h_{2UN1}^{\ 2}}{2} \cdot B \cdot -1 = -440.5 \cdot kN$

Moment Arm (from bottom of footing): $E_{h2alocUN1} := \dfrac{h_{2UN1}}{3} + Key_{vdist} = 0.83\ m$

Lateral Water Load:

Water Load GWL to Bottom of Key $H_{h2UN1} := \dfrac{\gamma_w \cdot h_{2UN1}^{\ 2}}{2} \cdot B \cdot -1 = -648.0 \cdot kN$

Moment Arm (from bottom of footing): $H_{h2locUN1} := \dfrac{h_{2UN1}}{3} + Key_{vdist} = 0.83\ m$

$\Sigma H_{SoildriveUN1} := E_{s1UN1} + E_{h1UN1} + E_{h2UN1} + E_{h2aUN1} + H_{h2UN1} = -2181.9 \cdot kN$

$$\Sigma M_{LateralSoildriveUN1} := E_{s1UN1} \cdot E_{s1locUN1} + E_{h1UN1} \cdot E_{h1locUN1} + E_{h2UN1} \cdot E_{h2locUN1} \ldots = -5867.2\ m \cdot kN$$
$$+ E_{h2aUN1} \cdot E_{h2alocUN1} + H_{h2UN1} \cdot H_{h2locUN1}$$

Lateral - Resisting Force

LOAD CASE UN1

Lateral Water Load:

Water Load WSEL to Bottom of Footing:

$$H_{h6UN1} := \frac{\gamma_w \cdot h_{6UN1}^{\ 2}}{2} \cdot B = 148.2 \cdot kN$$

Moment Arm (from bottom of footing):

$$H_{h6locUN1} := \frac{h_{6UN1}}{3} = 1.83\ m$$

Water Load Bot. of Footing to Bot. of H. Key:

$$H_{h2aUN1} := \left[\left(UWSEL_{UN1} - Bot_{ftg} + Key_{t.d}\right) + h_{2UN1}\right] \cdot \frac{Key_{h.d}}{2} \cdot \gamma_w \cdot B = 249.9 \cdot kN$$

Moment Arm (from bot. of toe key):

$$H_{h2alocUN1} := \frac{Key_{h.d} \cdot \left[2 \cdot \left(UWSEL_{UN1} - Bot_{ftg} + Key_{t.d}\right) + h_{2UN1}\right]}{3\left[h_{2UN1} + \left(UWSEL_{UN1} - Bot_{ftg} + Key_{t.d}\right)\right]} \ldots = -1.68\ m$$
$$+ Key_{vdist}$$

Lateral Soil Load:

Moist Soil Load above WSEL:

$$E_{h7UN1} := \frac{\gamma_m \cdot K_o \cdot h_{7UN1}^{\ 2}}{2} B = 0.0 \cdot kN$$

Moment Arm (from bot. of toe key):

$$E_{h7locUN1} := h_{6UN1} + \frac{h_{7UN1}}{3} + Key_{vdist} = 2.50\ m$$

Saturated Soil Load below WSEL: (rectangular component)

$$E_{h8UN1} := \left(\gamma_m \cdot K_o \cdot h_{7UN1}\right) \cdot h_{8UN1} \cdot B = 0.0 \cdot kN$$

Moment Arm (from bot. of toe key):

$$E_{h8locUN1} := \frac{h_{8UN1}}{2} = 2.00\ m$$

Saturated Soil Load below WSEL: (triangular component)

$$E_{h8aUN1} := \frac{\left[\left(\gamma_{sat} - \gamma_w\right) \cdot K_o\right] \cdot h_{8UN1}^{\ 2}}{2} \cdot B = 53.3 \cdot kN$$

Moment Arm (from bot. of footing):

$$E_{h8alocUN1} := \frac{h_{8UN1}}{3} = 1.33\ m$$

$$\Sigma H_{SoilresistUN1} := H_{h6UN1} + H_{h2aUN1} + E_{h7UN1} + E_{h8UN1} + E_{h8aUN1} = 451.4 \cdot kN$$

$$\Sigma M_{HorizSoilResistUN1} := H_{h6UN1} \cdot H_{h6locUN1} + H_{h2aUN1} \cdot H_{h2alocUN1} + E_{h7UN1} \cdot E_{h7locUN1} + E_{h8UN1} \cdot E_{h8locUN1} \ldots = -76.2\ m \cdot kN$$
$$+ E_{h8aUN1} \cdot E_{h8alocUN1}$$

Vertical Force:

UPLIFT: Linear distribution from water at heel to water at toe:

$$\Sigma V_{UpliftUN1} := \left[\left(UWSEL_{UN1} - Bot_{ftg} + Key_{t.d}\right) + h_{2UN1}\right] \cdot \frac{b}{2} \cdot \gamma_w \cdot B \cdot -1 = -1041.25 \cdot kN$$

Moment Arm (from Point O):

$$V_{UpliftUN1aloc} := \frac{b \cdot \left[2 \cdot h_{2UN1} + \left(UWSEL_{UN1} - Bot_{ftg} + Key_{t.d}\right)\right]}{3\left[h_{2UN1} + \left(UWSEL_{UN1} - Bot_{ftg} + Key_{t.d}\right)\right]} = 6.985\ m$$

$$\Sigma M_{UpliftUN1} := \Sigma V_{UpliftUN1} \cdot V_{UpliftUN1aloc} = -7273.438 \cdot kN \cdot m$$

Weight of soil and water over toe:

Water Above the Top of Footing: $W_{H1UN1} := \gamma_w \cdot h_{5UN1} \cdot L_{ab} \cdot B = 88.2 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E1locUN1} := \frac{L_{ab}}{2} = 1.5\,m$

Soil above top of footing: $W_{E6UN1} := \gamma_b \cdot h_{3UN1} \cdot L_{ab} \cdot B = 54.9 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E6locUN1} := \frac{L_{ab}}{2} = 1.5\,m$

Vertical Load Due to Surcharge: $S_{UN1} := S1_{UN1} \cdot L_{cd} \cdot B = 120.855 \cdot kN$ $\quad S_{UN1loc} := b - \frac{L_{cd}}{2} = 8.47\,m$

Weight of soil and water over heel:

Moist Soil for sloped grade above top of wall:

Length of sloped portion of soil above top of wall: $L_{E3UN1} := \left(L_{cd} + t_{wb} - t_{wt}\right) = 9.00\,m$

Height of sloped soil above top of wall over heel: $h_{E3locUN1} := \left(L_{E3UN1}\right) \cdot \tan(\beta) = 0.00\,m$

Weight of sloped soil above top of wall: $W_{E3UN1} := \frac{\gamma_m}{2} \cdot h_{E3locUN1} \cdot L_{E3UN1} \cdot B = 0.0 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E3locUN1} := L_{ab} + t_{wt} + \frac{2}{3} \cdot L_{E3UN1} = 9.50\,m$

Moist soil from top of wall to groundwater level:

Height of soil from top of wall and top of GWL: $h_{1UN1} = 6.00\,m$

Length from edge of wall at GWL to edge of heel: $L_{E4UN1} := L_{E3UN1} - \left(h_{1UN1} \cdot S_{batter}\right) = 8.53\,m$

Weight of soil over heel from top of wall to GWL: $W_{E4UN1} := \gamma_m \cdot h_{1UN1} \cdot \frac{\left(L_{E3UN1} + L_{E4UN1}\right)}{2} \cdot B = 1051.7 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E4locUN1} := b - \frac{L_{E3UN1}^{\,2} + L_{E3UN1} \cdot L_{E4UN1} + L_{E4UN1}^{\,2}}{3\left(L_{E3UN1} + L_{E4UN1}\right)} = 8.12\,m$

Saturated soil from groundwater to top of footing:

Height of soil from GWL to top of heel: $h_{E4UN1} := h_{2UN1} - t_{ftg} - Key_{h.d} = 6.00\,m$

Weight of soil over heel from GWL to top of heel: $W_{E5UN1} := \left(\gamma_{sat}\right) \cdot h_{E4UN1} \cdot \frac{\left(L_{E4UN1} + L_{cd}\right)}{2} \cdot B = 1094.6 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E5locUN1} := b - \frac{L_{E4UN1}^{\,2} + L_{E4UN1} \cdot L_{cd} + L_{cd}^{\,2}}{3\left(L_{E4UN1} + L_{cd}\right)} = 8.35\,m$

$$\Sigma V_{SoilWaterUN1} := W_{H1UN1} + W_{E6UN1} + W_{E3UN1} + W_{E4UN1} + W_{E5UN1} + S_{UN1} = 2410.3 \cdot kN$$

$$\Sigma M_{VertSoilWaterResistUN1} := W_{H1UN1} \cdot W_{E1locUN1} + W_{E6UN1} \cdot W_{E6locUN1} \cdots + W_{E3UN1} \cdot W_{E3locUN1} + W_{E4UN1} \cdot W_{E4locUN1} + W_{E5UN1} \cdot W_{E5locUN1} + S_{UN1} \cdot S_{UN1loc} = 18918.0\,m \cdot kN$$

THIS PAGE INTENTIONALLY LEFT BLANK
PLEASE GO TO THE NEXT PAGE

STABILITY ASSESSMENT:

LOAD CASE UN1

CHECK SLIDING ALONG HORIZONTAL SLIDING PLANE:

Summation of the vertical forces:

$$\Sigma V_{UN1} := \Sigma V_{conc} + \Sigma V_{SoilWaterUN1} + \Sigma V_{UpliftUN1} = 2447.9 \cdot kN$$

Summation of the horizontal forces:

$$\Sigma H_{UN1} := \Sigma H_{SoildriveUN1} + \Sigma H_{SoilresistUN1} = -1730.5 \cdot kN$$

Safety Factor for Sliding Horizontal Failure Plane

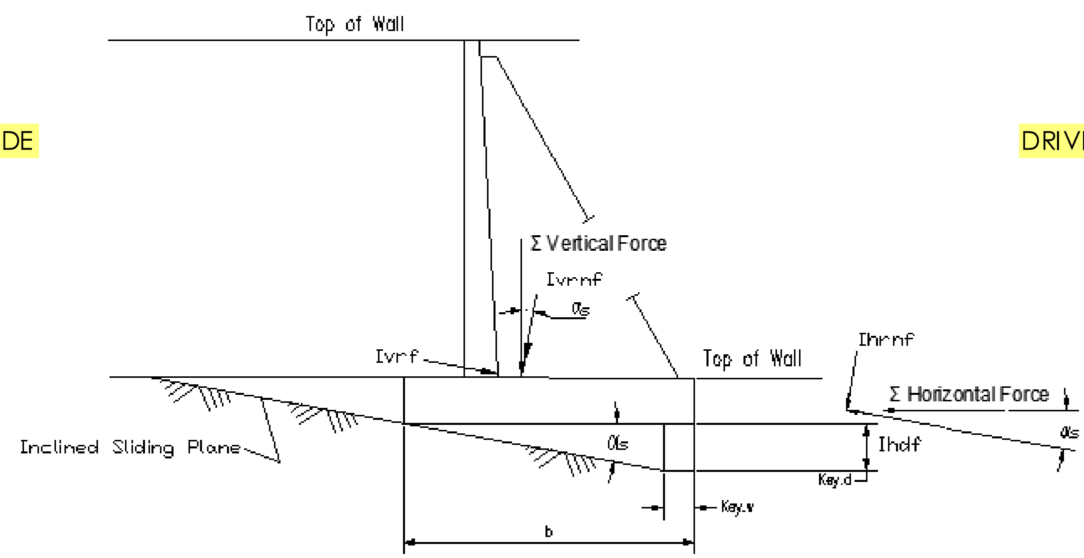
$$FS_{Horiz.SlidingUN1} := \frac{\left|\Sigma V_{UN1}\right| \cdot \tan\left(\phi_{rock} \cdot \frac{\pi}{180}\right)}{\left|\Sigma H_{UN1}\right|} = 0.69$$

$$FS_{Sliding.check1.UN1} := \begin{vmatrix} \text{"OKAY "} \quad \text{if} \quad FS_{Horiz.SlidingUN1} > FS_{sliding.reqUN1} \\ \text{"NG - key req""} \quad \text{otherwise} \end{vmatrix} = \text{"NG - key req""}$$

CHECK FACTOR OF SAFETY SLIDING WITH KEY (INCLINED SLIDING PLANE):

RESISTING SIDE

DRIVING SIDE



TOE

HEEL

Ivrf=Inclined Resisting Force
Ivrnf=Inclined Resisting Normal Force
Ihrnf=Inclined Resisting Normal Force
Ihdf=Inclined Driving Force

$\alpha s = 0.255$ as degrees= $\alpha s \cdot \left(\frac{180}{\pi}\right) = 14.62$

(With properly engineered reinforced concrete Key, horizontal sliding plane thru Toe is protected, critical sliding plane is relocated to the INCLINED SLIDING PLANE FROM HEEL KEY To TOE, Bedrock Mass above this examing plane is mobilized by reinforced concrete key and combined into Structural Wedge.)

Resolve ΣV_{UN1} & ΣH_{UN1}

$$\Sigma V_{InclinedUN1} := \cos(\alpha s) \cdot \left(\left|\Sigma V_{UN1} + V_{rocksection}\right|\right) + \sin(\alpha s) \cdot \left|\Sigma H_{UN1}\right| = 3232.7 \cdot kN$$

$$\Sigma H_{InclinedUN1} := \cos(\alpha s) \cdot \left|\Sigma H_{UN1}\right| - \sin(\alpha s) \cdot \left(\left|\Sigma V_{UN1} + V_{rocksection}\right|\right) = 945.1 \cdot kN$$

Safety Factor for Sliding Inclined Failure Plane

$$FS_{InclinedISlidingUN1} := \frac{\Sigma V_{InclinedUN1} \cdot \tan(\phi_r)}{\Sigma H_{InclinedUN1}} = 1.52$$

$$FS_{Sliding.check2.UN1} := \begin{cases} \text{"OKAY "} & \text{if } FS_{InclinedISlidingUN1} > FS_{sliding.reqUN1} \\ \text{"NG - Revise Structure""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

CHECK FOUNDATION ECCENTRICITY:

Summation of the resisting moments about the toe:

$$\Sigma M_{resUN1} := \Sigma M_{conc} + \Sigma M_{VertSoilWaterResistUN1} + \Sigma M_{HorizSoilResistUN1} + \Sigma M_{rocksection} = 28629 \cdot kN \cdot m$$

Summation of the overturning moments about the toe:

$$\Sigma M_{oUN1} := \Sigma M_{LateralSoildriveUN1} + \Sigma M_{UpliftUN1} = -13141 \cdot kN \cdot m$$

Total moment: $\Sigma M_{UN1} := \Sigma M_{resUN1} + \Sigma M_{oUN1} = 15488.1 \cdot kN \cdot m$

Normal force to base: $\Sigma V_{InclinedUN1} = 3232.7 \cdot kN$

Inclined Sliding Plane Length: $L_{incline} = 12.9 \cdot m$

Eccentricity (inclined plane): $ex_{UN1} := \frac{L_{incline}}{2} - \frac{\Sigma M_{UN1}}{\Sigma V_{InclinedUN1}} = 1.67\ m$ $\quad Kern = 2.153\ m$

Eccentricity Check:

$$e_{check.UN1} := \begin{cases} \text{"Okay"} & \text{if } ex_{UN1} \le Kern \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"Okay"}$$

CHECK FOUNDATION BEARING CAPACITY:

Base Section Modulus: $S_b = 27.81\ m^3$

Bearing Pressure Under Toe:

$$\sigma_{ToeUN1} := \begin{cases} \left(\frac{\Sigma V_{InclinedUN1}}{L_{incline} \cdot B} + \frac{\Sigma V_{InclinedUN1} \cdot ex_{UN1}}{S_b}\right) & \text{if } \frac{\Sigma V_{InclinedUN1} \cdot ex_{UN1}}{S_b} \le \frac{\Sigma V_{InclinedUN1}}{L_{incline} \cdot B} \\ \frac{2 \cdot \Sigma V_{InclinedUN1}}{B \cdot 3\left(\frac{b}{2} - ex_{UN1}\right)} & \text{otherwise} \end{cases} = 444.1 \cdot kPa$$

$$Bearing_{ChecktoeUN1} := \begin{cases} \text{"OKAY "} & \text{if } \sigma_{ToeUN1} < \sigma_{allowUN1} \\ \text{"NG""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

Bearing Pressure Under Heel:

$$\sigma_{HeelUN1} := \begin{cases} \left(\frac{\Sigma V_{InclinedUN1}}{L_{incline} \cdot B} - \frac{\Sigma V_{InclinedUN1} \cdot ex_{UN1}}{S_b}\right) & \text{if } \frac{\Sigma V_{InclinedUN1} \cdot ex_{UN1}}{S_b} \le \frac{\Sigma V_{InclinedUN1}}{L_{incline} \cdot B} \\ 0 & \text{otherwise} \end{cases} = 56.4 \cdot kPa$$

$$Bearing_{CheckheelUN1} := \left(\begin{cases} \text{"OKAY "} & \text{if } \sigma_{HeelUN1} < \sigma_{allowUN1} \wedge \sigma_{HeelUN1} > 0 \\ \text{"NG - perform cracked base analysis""} & \text{otherwise} \end{cases}\right) = \text{"OKAY "}$$

CHECK FLOATATION:

Safety Factor for Floatation:

$$FS_{FloatationUN1} := \frac{\Sigma V_{conc} + \Sigma V_{SoilWaterUN1}}{\left|\Sigma V_{UplliftUN1}\right|} = 3.35$$

$$FS_{Floatation.UN1.check} := \begin{cases} \text{"OKAY "} & \text{if } FS_{FloatationUN1} > FS_{req.UN1.flt} \\ \text{"Revise Structure""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

CHECK OVERTURNING

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.
Assumptions are made in order to compute overturning stablity of indetermine forces on monolith with key;
(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.
(b) The horizontal resisting force acting on the key, P.key, is that required for static equilibrium
(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1

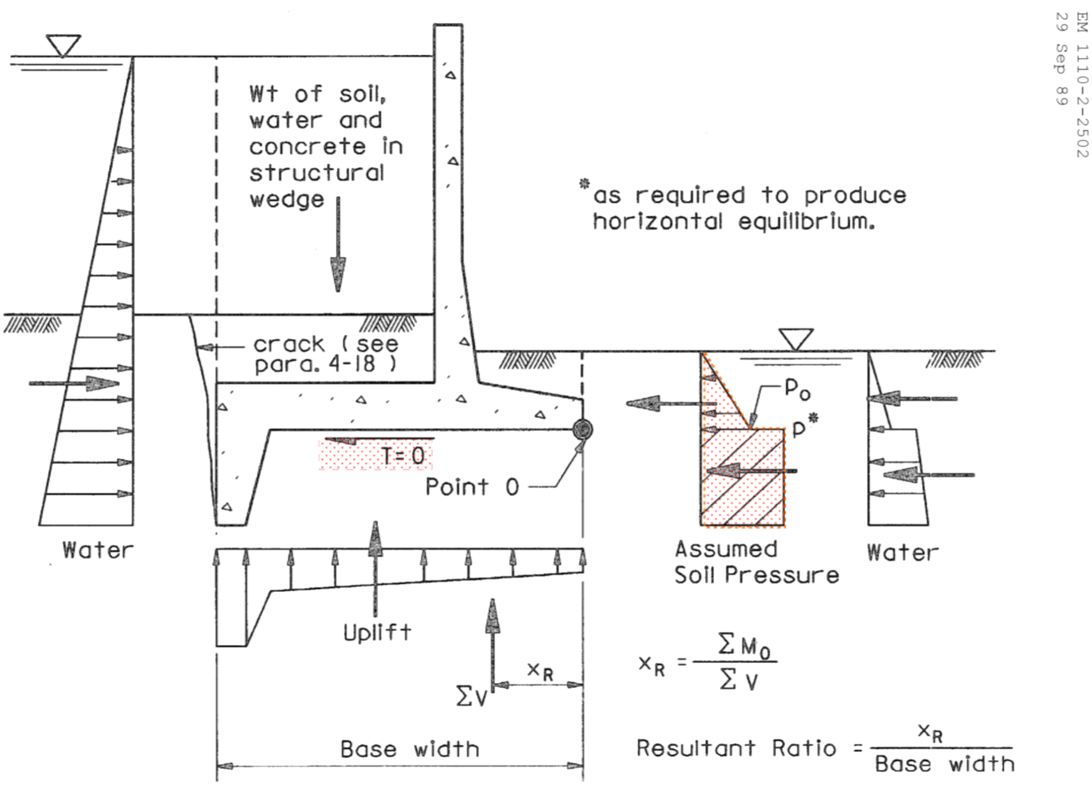


Figure 4-5. Forces for overturning analysis for wall with horizontal base and key

Modify Uplift for Overturning Analysis: **LOAD CASE UN1**

(Uplift is calculated along the concrete/rock contact using the Line of Creep method)

Water Pressure at h: $u_{h.UN1} := \Delta h_{g.hj.UN1} \cdot \gamma_w = 112.70 \cdot kPa$

Water Pressure at o: $u_{o.UN1} := \left(\Delta h_{g.no.UN1} - \frac{\Delta h_{g.r.UN1} \cdot L_{ho.UN1}}{L_{ho.UN1}}\right) \cdot \gamma_w = 53.9 \cdot kPa$

Head loss between point h and o: $\Delta h_{ho.UN1} := \Delta h_{g.r.UN1} \cdot \frac{L_{ho.UN1}}{L_{ho.UN1}} = 3\,m$

Length of concrete base (h -> o): $L_{baseho.UN1} := Key_{h.w} + Key_{h.d} + Key_{hdist} + Key_{t.d} + Key_{t.w} = 15.5\,m$

Head loss along h -> j: $\Delta h_{hj.UN1} := \Delta h_{ho.UN1} \cdot \frac{Key_{h.w}}{L_{baseho.UN1}} = 0.194\,m$

Water Pressure at j: $u_{j.UN1} := \left(\Delta h_{g.hj.UN1} - \Delta h_{hj.UN1}\right) \cdot \gamma_w = 110.80 \cdot kPa$

Head loss along h -> k: $\Delta h_{hjk.UN1} := \Delta h_{ho.UN1} \cdot \left(\frac{Key_{h.w} + Key_{h.d}}{L_{baseho.UN1}}\right) = 0.774\,m$

Water Pressure at k: $u_{k.UN1} := \left(\Delta h_{g.km.UN1} - \Delta h_{hjk.UN1}\right) \cdot \gamma_w = 75.71 \cdot kPa$

Head loss along h -> m: $\Delta h_{hjkm.UN1} := \Delta h_{ho.UN1} \cdot \left(\frac{Key_{h.w} + Key_{h.d} + Key_{hdist}}{L_{baseho.UN1}}\right) = 3\,m$

Water Pressure at m: $u_{m.UN1} := \left(\Delta h_{g.km.UN1} - \Delta h_{hjkm.UN1}\right) \cdot \gamma_w = 53.90 \cdot kPa$

Head loss along h -> n: $\Delta h_{hjkmn.UN1} := \Delta h_{ho.UN1} \cdot \left(\frac{Key_{h.w} + Key_{h.d} + Key_{hdist} + Key_{t.d}}{L_{baseho.UN1}}\right) = 3\,m$

Water Pressure at n: $u_{n.UN1} := \left(\Delta h_{g.no.UN1} - \Delta h_{hjkmn.UN1}\right) \cdot \gamma_w = 53.90 \cdot kPa$

Uplift under key at heel: $V_{ulkeyhUN1.OT} := \frac{\left(u_{h.UN1} + u_{j.UN1}\right) \cdot Key_{h.w}}{2} \cdot B \cdot -1 = -111.752 \cdot kN$

Moment Arm (from Point O): $V_{ulkeyhUN1loc.OT} := b - \frac{Key_{h.w} \cdot \left(2 \cdot u_{j.UN1} + u_{h.UN1}\right)}{3 \cdot \left(u_{j.UN1} + u_{h.UN1}\right)} = 12.001\,m$

Uplift under base: $V_{ulbaseUN1.OT} := \frac{\left(u_{k.UN1} + u_{m.UN1}\right) \cdot Key_{hdist}}{2} \cdot B \cdot -1 = -745.274 \cdot kN$

Moment Arm (from Point O): $V_{ulbaseUN1loc.OT} := b - Key_{h.w} - \frac{Key_{hdist} \cdot \left(2 \cdot u_{m.UN1} + u_{k.UN1}\right)}{3 \cdot \left(u_{m.UN1} + u_{k.UN1}\right)} = 6.073\,m$

Uplift under key at toe: $V_{ulkeytUN1.OT} := \frac{\left(u_{n.UN1} + u_{o.UN1}\right) \cdot Key_{t.w}}{2} \cdot B \cdot -1 = 0 \cdot kN$

Moment Arm (from Point O): $V_{ulkeytUN1loc.OT} := \frac{Key_{t.w} \cdot \left(2 \cdot u_{n.UN1} + u_{o.UN1}\right)}{3 \cdot \left(u_{n.UN1} + u_{o.UN1}\right)} = 0$

$$\Sigma V_{UpliftUN1.OT} := V_{ulkeyhUN1.OT} + V_{ulbaseUN1.OT} + V_{ulkeytUN1.OT} = -857 \cdot kN$$

$$U_{UN1.loc.OT} := \frac{V_{ulkeyhUN1.OT} \cdot V_{ulkeyhUN1loc.OT} + V_{ulbaseUN1.OT} \cdot V_{ulbaseUN1loc.OT} + V_{ulkeytUN1.OT} \cdot V_{ulkeytUN1loc.OT}}{\Sigma V_{UpliftUN1.OT}} = 6.85\,m$$

$$\Sigma M_{UpliftUN1.OT} := \Sigma V_{UpliftUN1.OT} \cdot U_{UN1.loc.OT} = -5866.9 \cdot kN \cdot m$$

Modify Lateral Water Pressure (Resisting) for Overturning Analysis:

(Resisting water pressure is calculated using the Line of Creep method)

Water Load at Key (heel):
$$H_{h2UN1.OT} := \frac{u_{k.UN1} + u_{j.UN1}}{2} \cdot Key_{h.d} B = 279.8 \cdot kN$$

Moment Arm (from Point O):
$$H_{h2locUN1.OT} := \frac{Key_{h.d} \cdot (2 \cdot u_{k.UN1} + u_{j.UN1})}{3(u_{k.UN1} + u_{j.UN1})} + Key_{vdist} = -1.59\ m$$

Water Load at Key (toe):
$$H_{h6UN1.OT} := \frac{u_{o.UN1} \cdot (UWSEL_{UN1} - Bot_{ftg} + Key_{t.d})}{2} \cdot B = 148 \cdot kN$$

Moment Arm (from Point O):
$$H_{h6locUN1.OT} := \frac{UWSEL_{UN1} - Bot_{ftg} + Key_{t.d}}{3} = 1.83\ m$$

$$\Sigma H_{waterresistUN1.OT} := H_{h2UN1.OT} + H_{h6UN1.OT} = 428 \cdot kN$$

$$H_{waterresistlocUN1.OT} := \frac{H_{h2UN1.OT} \cdot H_{h2locUN1.OT} + H_{h6UN1.OT} \cdot H_{h6locUN1.OT}}{\Sigma H_{waterresistUN1.OT}} = -0.407\ m$$

$$\Sigma M_{waterresistUN1.OT} := \Sigma H_{waterresistUN1.OT} \cdot H_{waterresistlocUN1.OT} = -174.23 \cdot kN \cdot m$$

Modify Lateral Soil Loads for Overturning Analysis:

(Lateral soil loads are calculated down to Point O instead of bottom of shear key)

Driving Soil Load (Headwater Side):

Surcharge Load:
$$E_{s1UN1.OT} := S1_{UN1} \cdot K_o \cdot (H_w + Key_{h.d} + Key_{vdist}) \cdot B \cdot -1 = -118.757 \cdot kN$$

Moment Arm (from Point O):
$$E_{s1locUN1.OT} := \frac{H_w + Key_{h.d} + Key_{vdist}}{2} = 7.25\ m$$

Moist Soil Load above GWL:
$$E_{h1UN1.OT} := \frac{\gamma_m \cdot K_o \cdot h_{1UN1}^{\ 2}}{2} B \cdot -1 = -196.6 \cdot kN$$

Moment Arm (from Point O):
$$E_{h1locUN1.OT} := \frac{h_{1UN1}}{3} + h_{2UN1} + Key_{vdist} = 10.50\ m$$

Saturated Soil Load below GWL:
(rectangular component)
$$E_{h2UN1.OT} := (\gamma_m \cdot K_o \cdot h_{1UN1}) \cdot (h_{2UN1} + Key_{vdist}) \cdot B \cdot -1 = -556.9 \cdot kN$$

Moment Arm (from Point O):
$$E_{h2locUN1.OT} := \frac{h_{2UN1} + Key_{vdist}}{2} = 4.25\ m$$

Saturated Soil Load below GWL:
(triangular component)
$$E_{h2aUN1.OT} := \frac{(\gamma_{sat} - \gamma_w) \cdot K_o \cdot (h_{2UN1} + Key_{vdist})^2}{2} \cdot B \cdot -1 = -240.6 \cdot kN$$

Moment Arm (from Point O):
$$E_{h2alocUN1.OT} := \frac{h_{2UN1} + Key_{vdist}}{3} = 2.83\ m$$

Resisting Soil Load (Tailwater Side):

(Determine resisting soil load based on depth variation between the keys (ie. Key_{vdist}). In case where key at heel is deeper than key at toe (ie. $Key_{vdist} < 0$), resisting soil load (p*) is assumed to produce horizontal equilibrium as per Figure 4-5 above. Resisting soil load (p_o) is neglected.)

Total Driving Force: $\Sigma H_{SoildriveUN1.OT} := E_{s1UN1.OT} + E_{h1UN1.OT} + E_{h2UN1.OT} + E_{h2aUN1.OT} + H_{h2UN1} = -1760.9 \cdot kN$

Total Resisting Force: $\Sigma H_{waterresistUN1.OT} = 428.0 \cdot kN$

Assumed Soil Load p*: $E_{h8UN1a.OT} := \left(\Sigma H_{SoildriveUN1.OT} + \Sigma H_{waterresistU1.OT}\right) \cdot -1 = 1332.916 \cdot kN$

Moment Arm (from Point O): $E_{h8UN1a.loc.OT} := \dfrac{Key_{vdist}}{2} = -1.5\,m$

$$E_{h8UN1.OT} := \begin{cases} E_{h8UN1a.OT} & \text{if } Key_{vdist} < 0 \\ \Sigma H_{SoilresistUN1} - H_{h6UN1} - H_{h2aUN1} & \text{otherwise} \end{cases} = 1332.916 \cdot kN$$

$$\Sigma M_{SoilresistUN1} := \begin{cases} E_{h8UN1a.OT} \cdot E_{h8UN1a.loc.OT} & \text{if } Key_{vdist} < 0 \\ \Sigma M_{HorizSoilResistUN1} - H_{h6UN1} \cdot H_{h6locUN1} - H_{h2aUN1} \cdot H_{h2alocUN1} & \text{otherwise} \end{cases} = -1999.374 \cdot kN \cdot m$$

Sum of Moment about Point O:

$$\Sigma M_{LateraldriveUN1.OT} := E_{s1UN1.OT} \cdot E_{s1locUN1.OT} + E_{h1UN1.OT} \cdot E_{h1locUN1.OT} + E_{h2UN1.OT} \cdot E_{h2locUN1.OT} \ldots + E_{h2aUN1.OT} \cdot E_{h2alocUN1.OT} + H_{h2UN1} \cdot H_{h2locUN1} = -6513.7 \cdot kN \cdot m$$

$$\Sigma M_{LateralresistUN1.OT} := \Sigma M_{waterresistUN1.OT} + \Sigma M_{SoilresistUN1} = -2173.6 \cdot kN \cdot m$$

Total moment:

$$\Sigma M_{UN1.OT} := \Sigma M_{conc} + \Sigma M_{VertSoilWaterResistUN1} + \Sigma M_{UpliftUN1.OT} + \Sigma M_{LateraldriveUN1.OT} + \Sigma M_{LateralresistUN1.OT} = 10765.1 \cdot kN \cdot m$$

Total Vertical Force: $\Sigma V_{UN1.OT} := \Sigma V_{conc} + \Sigma V_{SoilWaterUN1} + \Sigma V_{UplliftUN1.OT} = 2632.1 \cdot kN$

Distance X_R: EM 1110-2-2502 Eq.4-1 $X_{R.UN1} := \dfrac{\Sigma M_{UN1.OT}}{\Sigma V_{UN1.OT}} = 4.09\,m$

Overturning Resultant Ratio $Ratio_{UN1.OT} := \dfrac{X_{R.UN1}}{b} = 0.33$

$$Ratio_{UN1.OT.check} := \begin{cases} \text{"OKAY "} & \text{if } Ratio_{UN1.OT} > X_{R.reqUN1} \\ \text{"Revise Structure""} & \text{otherwise} \end{cases} = \text{"Revise Structure""}$$

CHECK FOUNDATION ECCENTRICITY (HORIZONTAL PLANE):

Eccentricity (horizontal plan): $ex_{UN1.OT} := \dfrac{b}{2} - \dfrac{\Sigma M_{UN1.OT}}{\Sigma V_{UN1.OT}} = 2.16\,m$ $Kern_{OT} = 2.083\,m$

Eccentricity Check:

$$e_{check.UN1.OT} := \begin{cases} \text{"Okay"} & \text{if } ex_{UN1} \le Kern_{OT} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"Okay"}$$

LOAD CASE UN1

CHECK FOUNDATION BEARING CAPACITY (HORIZONTAL PLANE):

Base Section Modulus: $S_{b.OT} = 26.04\,m^3$

Bearing Pressure Under Toe:

$$\sigma_{ToeUN1.OT} := \begin{cases} \left(\dfrac{\Sigma V_{UN1.OT}}{b \cdot B} + \dfrac{\Sigma V_{UN1.OT} \cdot ex_{UN1.OT}}{S_{b.OT}}\right) & \text{if } \dfrac{\Sigma V_{UN1.OT}}{b \cdot B} \geq \dfrac{\Sigma V_{UN1.OT} \cdot ex_{UN1.OT}}{S_{b.OT}} \\ \dfrac{2 \cdot \Sigma V_{UN1.OT}}{B \cdot 3 \left(\dfrac{b}{2} - ex_{UN1.OT}\right)} & \text{otherwise} \end{cases} = 429.0 \cdot kPa$$

$$Bearing_{ChecktoeUN1.OT} := \begin{cases} \text{"OKAY "} & \text{if } \sigma_{ToeUN1.OT} < \sigma_{allowUN1} \\ \text{"NG - for reference only""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

Bearing Pressure Under Heel:

$$\sigma_{HeelUN1.OT} := \begin{cases} \left(\dfrac{\Sigma V_{UN1.OT}}{b \cdot B} - \dfrac{\Sigma V_{UN1.OT} \cdot ex_{UN1.OT}}{S_{b.OT}}\right) & \text{if } \dfrac{\Sigma V_{UN1.OT}}{b \cdot B} \geq \dfrac{\Sigma V_{UN1.OT} \cdot ex_{UN1.OT}}{S_{b.OT}} \\ 0 & \text{otherwise} \end{cases} = 0.0 \cdot kPa$$

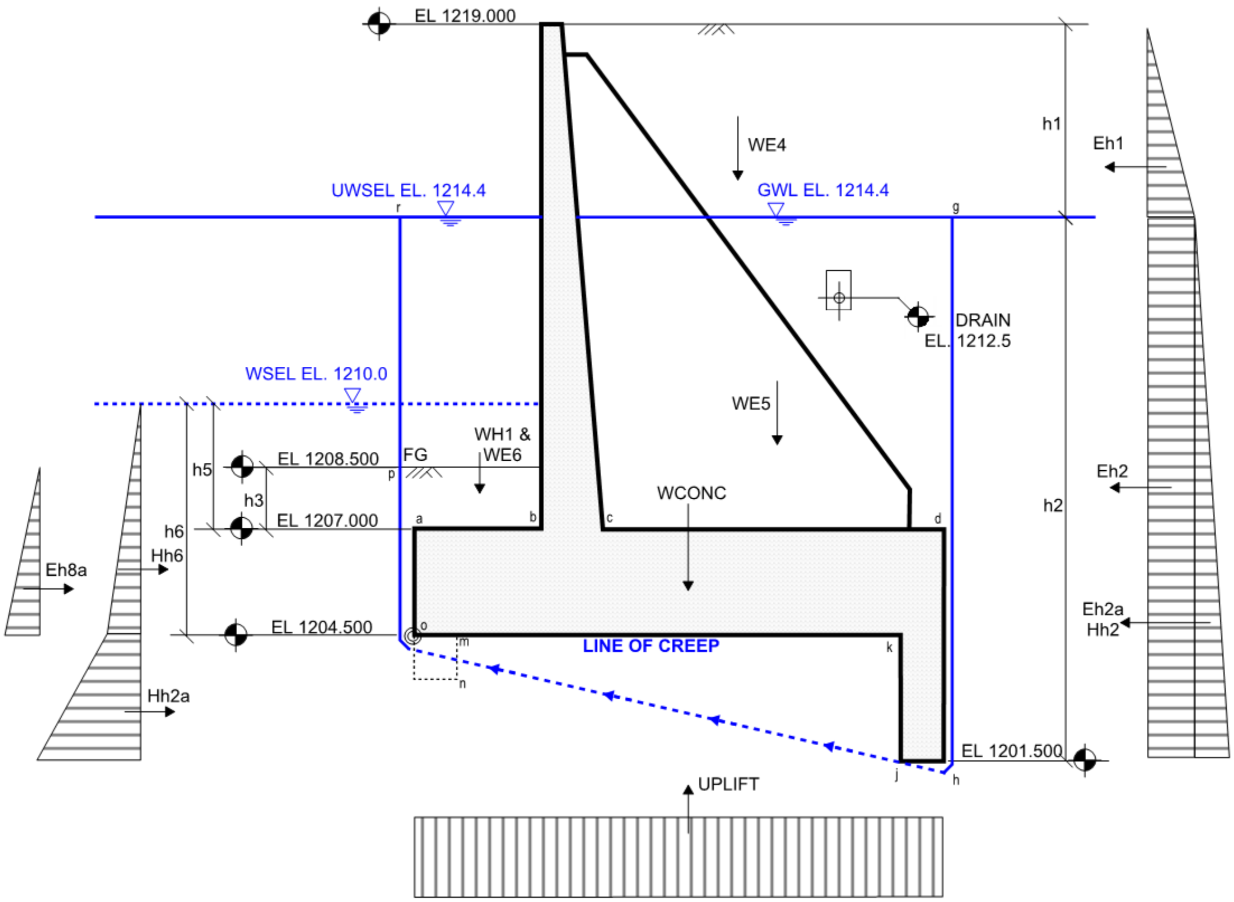
$$Bearing_{CheckheelUN1.OT} := \left(\begin{cases} \text{"OKAY "} & \text{if } \sigma_{HeelUN1.OT} < \sigma_{allowUN1} \wedge \sigma_{HeelUN1.OT} > 0 \\ \text{"NG - for reference only""} & \text{otherwise} \end{cases}\right) = \text{"NG - for reference only""}$$

SUMMARY OF STABILITY ASSESSMENT:

LOAD CASE UN1

Sliding Factor of Safety: (Horizontal Plane - Ref only)	$FS_{Horiz.SlidingUN1} = 0.69$	$FS_{Sliding.check1.UN1}$ = "NG - key req""
Sliding Factor of Safety: (Inclined Plane)	$FS_{InclinedlSlidingUN1} = 1.52$	$FS_{Sliding.check2.UN1}$ = "OKAY "
Eccentricity: (Inclined Plane)	$ex_{UN1} = 1.67\ m$	$e_{check.UN1}$ = "Okay"
Bearing Pressure At Heel: (Inclined Plane)	$\sigma_{HeelUN1} = 56 \cdot kPa$	$Bearing_{CheckheelUN1}$ = "OKAY "
Bearing Pressure At Toe: (Inclined Plane)	$\sigma_{ToeUN1} = 444 \cdot kPa$	$Bearing_{ChecktoeUN1}$ = "OKAY "
Flotation Factor of Safety (horizontal plane)	$FS_{FloatationUN1} = 3.35$	$FS_{Floatation.UN1.check}$ = "OKAY "
Overturning Resultant Ratio: (horizontal plane)	$Ratio_{UN1.OT} = 0.327$	$Ratio_{UN1.OT.check}$ = "Revise Structure""
Eccentricity: (horizontal plane - Ref only)	$ex_{UN1.OT} = 2.16\ m$	$e_{check.UN1.OT}$ = "Okay"
Bearing Pressure At Heel: (horizontal plane - Ref only)	$\sigma_{HeelUN1.OT} = 0 \cdot kPa$	$Bearing_{CheckheelUN1.OT}$ = "NG - for reference only""
Bearing Pressure At Toe: (horizontal plane - Ref only)	$\sigma_{ToeUN1.OT} = 429 \cdot kPa$	$Bearing_{ChecktoeUN1.OT}$ = "OKAY "

LOAD CASE UN2 - INEFFECTIVE DRAIN



UN2 DESIGN CASE

LOAD CASE UN2 ACCEPTANCE PARAMETERS

FS sliding:

Unusual (UN) 1.3 (without cohesion) (Table 3-3, USACE EM 1110-2-2100)

Resultant Location:

Unsual (UN) Inside middle third ~100% base in compression

Required Factor of Safety for Sliding: $FS_{sliding.reqUN2} := 1.3$ (Without Cohesion)

Allowable rock bearing pressure: $\sigma_{allowUN2} := 1470kPa$ (Section 5.2, Design Criteria EM 1110-2-2100 Section 3-10)

Overturning Required Resultant Ratio: $X_{R.reqUN2} := 0.333$ (EM 1110-2-2502, Figure 4-4)

Required Factor of Safety for Floatation $FS_{req.UN2.flt} := 1.3$

SOIL HEIGHTS and Water Levels:

LOAD CASE UN2

Heel Conditions:

Groundwater Elevation at Heel: $GWL_{UN2} := 1214.4m$

Distance from Finish Grade to Groundwater at Heel: $h_{1UN2} := \left[T_w - GWL_{UN2} + \left(L_{cd} + t_{wb} - t_{wt}\right) \cdot \tan(\beta)\right] = 4.60\ m$

Distance from Water Surface to Bottom of Footing at Heel: $h_{2UN2} := GWL_{UN2} - Bot_{ftg} + Key_{h.d} = 12.90\ m$

Toe Conditions:

Water Surface Elevation at Toe: $WSEL_{UN2} := 1210.0m$

Water Surface Elevation at Toe for Uplift: $UWSEL_{UN2} := 1214.4 \cdot m$

Finish Grade at Toe providing lateral resistance: $FG_{toeUN2} := 1208.5 \cdot m$

Soil Depth Above top of footing: $h_{3aUN2} := FG_{toeUN2} - Top_{ftg} = 1.5\ m$

$$h_{3UN2} := \begin{cases} h_{3aUN2} & \text{if } FG_{toeUN2} - Top_{ftg} \ge 0 \\ 0 & \text{otherwise} \end{cases} = 1.5$$

Resisting Fill at Toe: $h_{4UN2} := FG_{toeUN2} - Bot_{ftg} + Key_{t.d} = 4.00\ m$

Distance from Water Level to Top of Footing at Toe: $h_{5UN2} := WSEL_{UN2} - Top_{ftg} = 3.00\ m$

Distance from Water Surface to Bottom of Footing at Toe: $h_{6UN2} := WSEL_{UN2} - Bot_{ftg} + Key_{t.d} = 5.50\ m$

Soil Depth Above WSEL: $h_{7aUN2} := FG_{toeUN2} - WSEL_{UN2} = -1.5\ m$

$$h_{7UN2} := \begin{cases} h_{7aUN2} & \text{if } FG_{toeUN2} - WSEL_{UN2} \ge 0 \\ 0 & \text{otherwise} \end{cases} = 0$$

Soil Depth Below WSEL:

$$h_{8UN2} := \begin{cases} WSEL_{UN2} - Bot_{ftg} + Key_{t.d} & \text{if } FG_{toeUN2} - WSEL_{UN2} \ge 0 \\ h_{4UN2} & \text{otherwise} \end{cases} = 4$$

For Line of Creep Method: $L_{ho.UN2} := \sqrt{b^2 + \left(Key_{h.d} - Key_{t.d}\right)^2} = 12.855\ m$

Head Loss from Point g:

$\Delta h_{g.hj.UN2} := h_{2UN2} = 12.9\ m$ (to point h & j)

$\Delta h_{g.km.UN2} := GWL_{UN2} - Bot_{ftg} = 9.9\ m$ (to point k & m)

$\Delta h_{g.no.UN2} := GWL_{UN2} - Bot_{ftg} + Key_{t.d} = 9.9\ m$ (to point n & o)

$\Delta h_{g.p.UN2} := GWL_{UN2} - FG_{toeUN2} = 5.9\ m$ (to point p)

$\Delta h_{g.r.UN2} := GWL_{UN2} - UWSEL_{UN2} = 0\ m$ (to point r)

Surcharge

Surcharge on Heel: $S1_{UN2} := 0.0 \dfrac{kN}{m^2}$

Calculate Soil Lateral Pressure Coefficients:

LOAD CASE UN2

For all load cases except seismic, soil loading to be based on At-Rest Condition.
Calculate at-rest pressure coefficient Ko based on Jaky's (1944) equation.

Soil At Rest Static Coefficient: $K_o := \dfrac{1 - \sin(\phi)}{1 + \sin(\beta)} = 0.546$ (Eq. 3-6, USACE EM 1110-2-2502)

Lateral - Driving Force

Static At-Rest:

Surcharge Load: $E_{s1UN2} := S1_{UN2} \cdot K_o \cdot \left(H_w + Key_{h.d}\right) \cdot B \cdot -1 = 0 \cdot kN$

Moment Arm (from bottom of footing): $E_{s1locUN2} := \dfrac{H_w + Key_{h.d}}{2} + Key_{vdist} = 5.75\ m$

Moist Soil Load above GWL: $E_{h1UN2} := \dfrac{\gamma_m \cdot K_o \cdot h_{1UN2}^{\ 2}}{2} \cdot B \cdot -1 = -115.5 \cdot kN$

Moment Arm (from bottom of footing): $E_{h1locUN2} := \dfrac{h_{1UN2}}{3} + h_{2UN2} + Key_{vdist} = 11.43\ m$

Saturated Soil Load below GWL:
(rectangular component) $E_{h2UN2} := \left(\gamma_m \cdot K_o \cdot h_{1UN2}\right) \cdot h_{2UN2} \cdot B \cdot -1 = -648.0 \cdot kN$

Moment Arm (from bottom of footing): $E_{h2locUN2} := \dfrac{h_{2UN2}}{2} + Key_{vdist} = 3.45\ m$

Saturated Soil Load below GWL:
(triangular component) $E_{h2aUN2} := \dfrac{\left(\gamma_{sat} - \gamma_w\right) \cdot K_o \cdot h_{2UN2}^{\ 2}}{2} \cdot B \cdot -1 = -554.3 \cdot kN$

Moment Arm (from bottom of footing): $E_{h2alocUN2} := \dfrac{h_{2UN2}}{3} + Key_{vdist} = 1.30\ m$

Lateral Water Load:

Water Load GWL to Bottom of Key $H_{h2UN2} := \dfrac{\gamma_w \cdot h_{2UN2}^{\ 2}}{2} \cdot B \cdot -1 = -815.4 \cdot kN$

Moment Arm (from bottom of footing): $H_{h2locUN2} := \dfrac{h_{2UN2}}{3} + Key_{vdist} = 1.30\ m$

$$\Sigma H_{SoildriveUN2} := E_{s1UN2} + E_{h1UN2} + E_{h2UN2} + E_{h2aUN2} + H_{h2UN2} = -2133.2 \cdot kN$$

$$\Sigma M_{LateralSoildriveUN2} := E_{s1UN2} \cdot E_{s1locUN2} + E_{h1UN2} \cdot E_{h1locUN2} + E_{h2UN2} \cdot E_{h2locUN2} \dots + E_{h2aUN2} \cdot E_{h2alocUN2} + H_{h2UN2} \cdot H_{h2locUN2} = -5337.1\ m \cdot kN$$

Lateral - Resisting Force

LOAD CASE UN2

Lateral Water Load:

Water Load WSEL to Bottom of Footing:

$$H_{h6UN2} := \frac{\gamma_w \cdot h_{6UN2}^{\,2}}{2} \cdot B = 148.2 \cdot kN$$

Moment Arm (from bottom of footing):

$$H_{h6locUN2} := \frac{h_{6UN2}}{3} = 1.83\ m$$

Water Load Bot. of Footing to Bot. of H. Key:

$$H_{h2aUN2} := \left[\left(UWSEL_{UN2} - Bot_{ftg} + Key_{t.d}\right) + h_{2UN2}\right] \cdot \frac{Key_{h.d}}{2} \cdot \gamma_w \cdot B = 335.2 \cdot kN$$

Moment Arm (from bot. of toe key):

$$H_{h2alocUN2} := \frac{Key_{h.d} \cdot \left[2 \cdot \left(UWSEL_{UN2} - Bot_{ftg} + Key_{t.d}\right) + h_{2UN2}\right]}{3\left[h_{2UN2} + \left(UWSEL_{UN2} - Bot_{ftg} + Key_{t.d}\right)\right]} \ldots = -1.57\ m$$
$$+ Key_{vdist}$$

Lateral Soil Load:

Moist Soil Load above WSEL:

$$E_{h7UN2} := \frac{\gamma_m \cdot K_o \cdot h_{7UN2}^{\,2}}{2} B = 0.0 \cdot kN$$

Moment Arm (from bot. of toe key):

$$E_{h7locUN2} := h_{6UN2} + \frac{h_{7UN2}}{3} + Key_{vdist} = 2.50\ m$$

Saturated Soil Load below WSEL: (rectangular component)

$$E_{h8UN2} := \left(\gamma_m \cdot K_o \cdot h_{7UN2}\right) \cdot h_{8UN2} \cdot B = 0.0 \cdot kN$$

Moment Arm (from bot. of toe key):

$$E_{h8locUN2} := \frac{h_{8UN2}}{2} = 2.00\ m$$

Saturated Soil Load below WSEL: (triangular component)

$$E_{h8aUN2} := \frac{\left[\left(\gamma_{sat} - \gamma_w\right) \cdot K_o\right] \cdot h_{8UN2}^{\,2}}{2} \cdot B = 53.3 \cdot kN$$

Moment Arm (from bot. of footing):

$$E_{h8alocUN2} := \frac{h_{8UN2}}{3} = 1.33\ m$$

$$\Sigma H_{SoilresistUN2} := H_{h6UN2} + H_{h2aUN2} + E_{h7UN2} + E_{h8UN2} + E_{h8aUN2} = 536.7 \cdot kN$$

$$\Sigma M_{HorizSoilResistUN2} := H_{h6UN2} \cdot H_{h6locUN2} + H_{h2aUN2} \cdot H_{h2alocUN2} + E_{h7UN2} \cdot E_{h7locUN2} \ldots = -182.0\ m \cdot kN$$
$$+ E_{h8UN2} \cdot E_{h8locUN2} + E_{h8aUN2} \cdot E_{h8alocUN2}$$

Vertical Force:

UPLIFT: Linear distribution from water at heel to water at toe:

$$\Sigma V_{UpliftUN2} := \left[\left(UWSEL_{UN2} - Bot_{ftg} + Key_{t.d}\right) + h_{2UN2}\right] \cdot \frac{b}{2} \cdot \gamma_w \cdot B \cdot -1 = -1396.5 \cdot kN$$

Moment Arm (from Point O):

$$V_{UpliftUN2aloc} := \frac{b \cdot \left[2 \cdot h_{2UN2} + \left(UWSEL_{UN2} - Bot_{ftg} + Key_{t.d}\right)\right]}{3\left[h_{2UN2} + \left(UWSEL_{UN2} - Bot_{ftg} + Key_{t.d}\right)\right]} = 6.524\ m$$

$$\Sigma M_{UpliftUN2} := \Sigma V_{UpliftUN2} \cdot V_{UpliftUN2aloc} = -9110.938 \cdot kN \cdot m$$

Weight of soil and water over toe:

Water Above the Top of Footing: $W_{H1UN2} := \gamma_w \cdot h_{5UN2} \cdot L_{ab} \cdot B = 88.2 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E1locUN2} := \frac{L_{ab}}{2} = 1.5\,m$

Soil above top of footing: $W_{E6UN2} := \gamma_b \cdot h_{3UN2} \cdot L_{ab} \cdot B = 54.9 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E6locUN2} := \frac{L_{ab}}{2} = 1.5\,m$

Vertical Load Due to Surcharge: $S_{UN2} := S1_{UN2} \cdot L_{cd} \cdot B = 0 \cdot kN \qquad S_{UN2loc} := b - \frac{L_{cd}}{2} = 8.47\,m$

Weight of soil and water over heel:

Moist Soil for sloped grade above top of wall:

Length of sloped portion of soil above top of wall: $L_{E3UN2} := \left(L_{cd} + t_{wb} - t_{wt}\right) = 9.00\,m$

Height of sloped soil above top of wall over heel: $h_{E3locUN2} := \left(L_{E3UN2}\right) \cdot \tan(\beta) = 0.00\,m$

Weight of sloped soil above top of wall: $W_{E3UN2} := \frac{\gamma_m}{2} \cdot h_{E3locUN2} \cdot L_{E3UN2} \cdot B = 0.0 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E3locUN2} := L_{ab} + t_{wt} + \frac{2}{3} \cdot L_{E3UN2} = 9.50\,m$

Moist soil from top of wall to groundwater level:

Height of soil from top of wall and top of GWL: $h_{1UN2} = 4.60\,m$

Length from edge of wall at GWL to edge of heel: $L_{E4UN2} := L_{E3UN2} - \left(h_{1UN2} \cdot S_{batter}\right) = 8.64\,m$

Weight of soil over heel from top of wall to GWL: $W_{E4UN2} := \gamma_m \cdot h_{1UN2} \cdot \frac{\left(L_{E3UN2} + L_{E4UN2}\right)}{2} \cdot B = 811.4 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E4locUN2} := b - \frac{L_{E3UN2}^2 + L_{E3UN2} \cdot L_{E4UN2} + L_{E4UN2}^2}{3\left(L_{E3UN2} + L_{E4UN2}\right)} = 8.09\,m$

Saturated soil from groundwater to top of footing:

Height of soil from GWL to top of heel: $h_{E4UN2} := h_{2UN2} - t_{ftg} - Key_{h.d} = 7.40\,m$

Weight of soil over heel from GWL to top of heel: $W_{E5UN2} := \left(\gamma_{sat}\right) \cdot h_{E4UN2} \cdot \frac{\left(L_{E4UN2} + L_{cd}\right)}{2} \cdot B = 1359.0 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E5locUN2} := b - \frac{L_{E4UN2}^2 + L_{E4UN2} \cdot L_{cd} + L_{cd}^2}{3\left(L_{E4UN2} + L_{cd}\right)} = 8.32\,m$

$$\Sigma V_{SoilWaterUN2} := W_{H1UN2} + W_{E6UN2} + W_{E3UN2} + W_{E4UN2} + W_{E5UN2} + S_{UN2} = 2313.5 \cdot kN$$

$$\Sigma M_{VertSoilWaterResistUN2} := W_{H1UN2} \cdot W_{E1locUN2} + W_{E6UN2} \cdot W_{E6locUN2} \cdots + W_{E3UN2} \cdot W_{E3locUN2} + W_{E4UN2} \cdot W_{E4locUN2} + W_{E5UN2} \cdot W_{E5locUN2} + S_{UN2} \cdot S_{UN2loc} = 18091.5\,m \cdot kN$$

THIS PAGE INTENTIONALLY LEFT BLANK
PLEASE GO TO THE NEXT PAGE

STABILITY ASSESSMENT:

LOAD CASE UN2

CHECK SLIDING ALONG HORIZONTAL SLIDING PLANE:

Summation of the vertical forces:

$$\Sigma V_{UN2} := \Sigma V_{conc} + \Sigma V_{SoilWaterUN2} + \Sigma V_{UpliftUN2} = 1995.8 \cdot kN$$

Summation of the horizontal forces:

$$\Sigma H_{UN2} := \Sigma H_{SoildriveUN2} + \Sigma H_{SoilresistUN2} = -1596.5 \cdot kN$$

Safety Factor for Sliding Horizontal Failure Plane

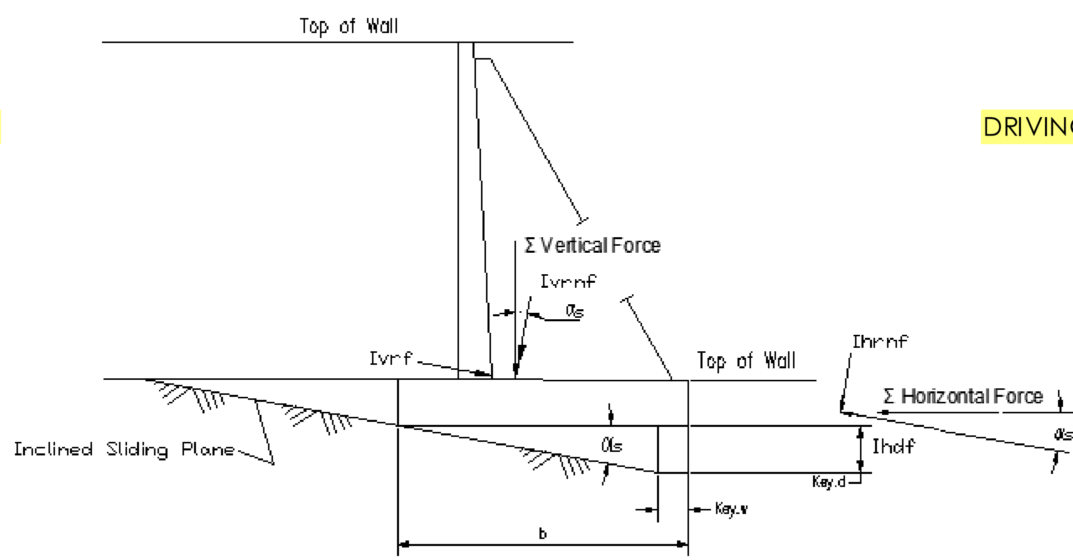
$$FS_{Horiz.SlidingUN2} := \frac{\left|\Sigma V_{UN2}\right| \cdot \tan\left(\phi_{rock} \cdot \frac{\pi}{180}\right)}{\left|\Sigma H_{UN2}\right|} = 0.61$$

$$FS_{Sliding.check1.UN2} := \begin{cases} \text{"OKAY"} & \text{if } FS_{Horiz.SlidingUN2} > FS_{sliding.reqUN2} \\ \text{"NG - key req'"} & \text{otherwise} \end{cases} = \text{"NG - key req'"}$$

CHECK FACTOR OF SAFETY SLIDING WITH KEY (INCLINED SLIDING PLANE):

RESISTING SIDE

DRIVING SIDE



TOE

HEEL

Ivrf=Inclined Resisting Force
Ivrnf=Inclined Resisting Normal Force
Ihrnf=Inclined Resisting Normal Force
Ihdf=Inclined Driving Force

$\alpha s = 0.255$ as degrees= $\alpha s \cdot \left(\frac{180}{\pi}\right) = 14.62$

(With properly engineered reinforced concrete Key, horizontal sliding plane thru Toe is protected, critical sliding plane is relocated to the INCLINED SLIDING PLANE FROM HEEL KEY To TOE, Bedrock Mass above this examing plane is mobilized by reinforced concrete key and combined into Structural Wedge.)

Resolve ΣV_{UN2} & ΣH_{UN2}

$$\Sigma V_{InclinedUN2} := \cos(\alpha s) \cdot \left(\left|\Sigma V_{UN2} + V_{rocksection}\right|\right) + \sin(\alpha s) \cdot \left|\Sigma H_{UN2}\right| = 2761.5 \cdot kN$$

$$\Sigma H_{InclinedUN2} := \cos(\alpha s) \cdot \left|\Sigma H_{UN2}\right| - \sin(\alpha s) \cdot \left(\left|\Sigma V_{UN2} + V_{rocksection}\right|\right) = 929.6 \cdot kN$$

LOAD CASE UN2

Safety Factor for Sliding Inclined Failure Plane

$$FS_{InclinedISlidingUN2} := \frac{\Sigma V_{InclinedUN2} \cdot \tan(\phi_r)}{\Sigma H_{InclinedUN2}} = 1.32$$

$$FS_{Sliding.check2.UN2} := \begin{cases} \text{"OKAY "} & \text{if } FS_{InclinedISlidingUN2} > FS_{sliding.reqUN2} \\ \text{"NG - Revise Structure""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

CHECK FOUNDATION ECCENTRICITY:

Summation of the resisting moments about the toe:

$$\Sigma M_{resUN2} := \Sigma M_{conc} + \Sigma M_{VertSoilWaterResistUN2} + \Sigma M_{HorizSoilResistUN2} + \Sigma M_{rocksection} = 27696 \cdot kN \cdot m$$

Summation of the overturning moments about the toe:

$$\Sigma M_{oUN2} := \Sigma M_{LateralSoildriveUN2} + \Sigma M_{UpliftUN2} = -14448 \cdot kN \cdot m$$

Total moment: $\Sigma M_{UN2} := \Sigma M_{resUN2} + \Sigma M_{oUN2} = 13248.3\, m \cdot kN$

Normal force to base: $\Sigma V_{InclinedUN2} = 2761.5 \cdot kN$

Inclined Sliding Plane Length: $L_{incline} = 12.9 \cdot m$

Eccentricity (inclined plane): $ex_{UN2} := \frac{L_{incline}}{2} - \frac{\Sigma M_{UN2}}{\Sigma V_{InclinedUN2}} = 1.66\, m$ $\quad Kern = 2.153\, m$

Eccentricity Check: $e_{check.UN2} := \begin{cases} \text{"Okay"} & \text{if } ex_{UN2} \le Kern \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"Okay"}$

CHECK FOUNDATION BEARING CAPACITY:

Base Section Modulus: $S_b = 27.81\, m^3$

Bearing Pressure Under Toe:

$$\sigma_{ToeUN2} := \begin{cases} \left(\frac{\Sigma V_{InclinedUN2}}{L_{incline} \cdot B} + \frac{\Sigma V_{InclinedUN2} \cdot ex_{UN2}}{S_b} \right) & \text{if } \frac{\Sigma V_{InclinedUN2} \cdot ex_{UN2}}{S_b} \le \frac{\Sigma V_{InclinedUN2}}{L_{incline} \cdot B} \\ \frac{2 \cdot \Sigma V_{InclinedUN2}}{B \cdot 3 \left(\frac{b}{2} - ex_{UN2} \right)} & \text{otherwise} \end{cases} = 378.7 \cdot kPa$$

$$Bearing_{ChecktoeUN2} := \begin{cases} \text{"OKAY "} & \text{if } \sigma_{ToeUN2} < \sigma_{allowUN2} \\ \text{"NG""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

Bearing Pressure Under Heel:

$$\sigma_{HeelUN2} := \begin{cases} \left(\frac{\Sigma V_{InclinedUN2}}{L_{incline} \cdot B} - \frac{\Sigma V_{InclinedUN2} \cdot ex_{UN2}}{S_b} \right) & \text{if } \frac{\Sigma V_{InclinedUN2} \cdot ex_{UN2}}{S_b} \le \frac{\Sigma V_{InclinedUN2}}{L_{incline} \cdot B} \\ 0 & \text{otherwise} \end{cases} = 48.8 \cdot kPa$$

$$Bearing_{CheckheelUN2} := \left(\begin{cases} \text{"OKAY "} & \text{if } \sigma_{HeelUN2} < \sigma_{allowUN2} \wedge \sigma_{HeelUN2} > 0 \\ \text{"NG - perform cracked base analysis""} & \text{otherwise} \end{cases} \right) = \text{"OKAY "}$$

CHECK FLOATATION:

Safety Factor for Floatation:

$$FS_{FloatationUN2} := \frac{\Sigma V_{conc} + \Sigma V_{SoilWaterUN2}}{\left|\Sigma V_{UpliftUN2}\right|} = 2.43$$

$$FS_{Floatation.UN2.check} := \begin{cases} \text{"OKAY "} & \text{if } FS_{FloatationUN2} > FS_{req.UN2.flt} \\ \text{"Revise Structure""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

CHECK OVERTURNING

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.
Assumptions are made in order to compute overturning stablity of indetermine forces on monolith with key;
(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.
(b) The horizontal resisting force acting on the key, P.key, is that required for static equilibrium
(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1

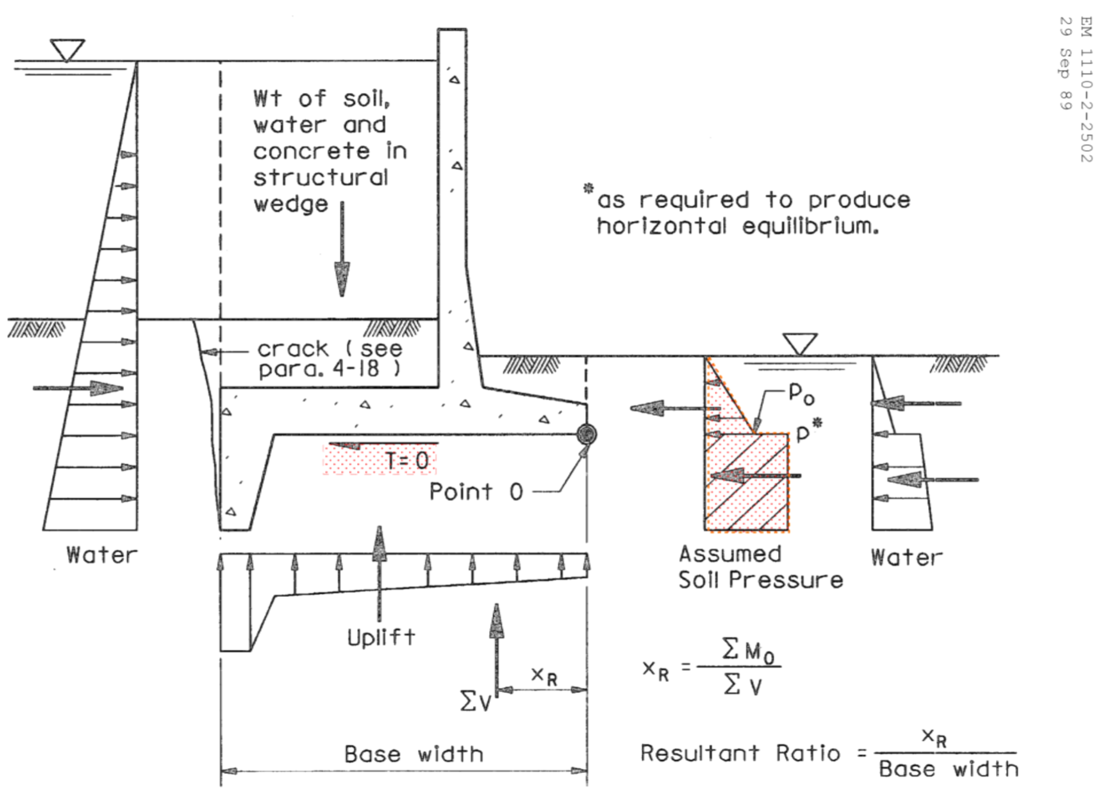


Figure 4-5. Forces for overturning analysis for wall with horizontal base and key

Modify Uplift for Overturning Analysis: **LOAD CASE UN2**

(Uplift is calculated along the concrete/rock contact using the Line of Creep method)

Water Pressure at h: $u_{h.UN2} := \Delta h_{g.hj.UN2} \cdot \gamma_w = 126.42 \cdot kPa$

Water Pressure at o: $u_{o.UN2} := \left(\Delta h_{g.no.UN2} - \frac{\Delta h_{g.r.UN2} \cdot L_{ho.UN2}}{L_{ho.UN2}}\right) \cdot \gamma_w = 97.02 \cdot kPa$

Head loss between point h and o: $\Delta h_{ho.UN2} := \Delta h_{g.r.UN2} \cdot \frac{L_{ho.UN2}}{L_{ho.UN2}} = 0\,m$

Length of concrete base (h -> o): $L_{baseho.UN2} := Key_{h.w} + Key_{h.d} + Key_{hdist} + Key_{t.d} + Key_{t.w} = 15.5\,m$

Head loss along h -> j: $\Delta h_{hj.UN2} := \Delta h_{ho.UN2} \cdot \frac{Key_{h.w}}{L_{baseho.UN2}} = 0\,m$

Water Pressure at j: $u_{j.UN2} := \left(\Delta h_{g.hj.UN2} - \Delta h_{hj.UN2}\right) \cdot \gamma_w = 126.42 \cdot kPa$

Head loss along h -> k: $\Delta h_{hjk.UN2} := \Delta h_{ho.UN2} \cdot \left(\frac{Key_{h.w} + Key_{h.d}}{L_{baseho.UN2}}\right) = 0\,m$

Water Pressure at k: $u_{k.UN2} := \left(\Delta h_{g.km.UN2} - \Delta h_{hjk.UN2}\right) \cdot \gamma_w = 97.02 \cdot kPa$

Head loss along h -> m: $\Delta h_{hjkm.UN2} := \Delta h_{ho.UN2} \cdot \left(\frac{Key_{h.w} + Key_{h.d} + Key_{hdist}}{L_{baseho.UN2}}\right) = 0\,m$

Water Pressure at m: $u_{m.UN2} := \left(\Delta h_{g.km.UN2} - \Delta h_{hjkm.UN2}\right) \cdot \gamma_w = 97.02 \cdot kPa$

Head loss along h -> n: $\Delta h_{hjkmn.UN2} := \Delta h_{ho.UN2} \cdot \left(\frac{Key_{h.w} + Key_{h.d} + Key_{hdist} + Key_{t.d}}{L_{baseho.UN2}}\right) = 0\,m$

Water Pressure at n: $u_{n.UN2} := \left(\Delta h_{g.no.UN2} - \Delta h_{hjkmn.UN2}\right) \cdot \gamma_w = 97.02 \cdot kPa$

Uplift under key at heel: $V_{ulkeyhUN2.OT} := \frac{\left(u_{h.UN2} + u_{j.UN2}\right) \cdot Key_{h.w}}{2} \cdot B \cdot -1 = -126.42 \cdot kN$

Moment Arm (from Point O): $V_{ulkeyhUN2loc.OT} := b - \frac{Key_{h.w} \cdot \left(2 \cdot u_{j.UN2} + u_{h.UN2}\right)}{3 \cdot \left(u_{j.UN2} + u_{h.UN2}\right)} = 12\,m$

Uplift under base: $V_{ulbaseUN2.OT} := \frac{\left(u_{k.UN2} + u_{m.UN2}\right) \cdot Key_{hdist}}{2} \cdot B \cdot -1 = -1115.73 \cdot kN$

Moment Arm (from Point O): $V_{ulbaseUN2loc.OT} := b - Key_{h.w} - \frac{Key_{hdist} \cdot \left(2 \cdot u_{m.UN2} + u_{k.UN2}\right)}{3 \cdot \left(u_{m.UN2} + u_{k.UN2}\right)} = 5.75\,m$

Uplift under key at toe: $V_{ulkeytUN2.OT} := \frac{\left(u_{n.UN2} + u_{o.UN2}\right) \cdot Key_{t.w}}{2} \cdot B \cdot -1 = 0 \cdot kN$

Moment Arm (from Point O): $V_{ulkeytUN2loc.OT} := \frac{Key_{t.w} \cdot \left(2 \cdot u_{n.UN2} + u_{o.UN2}\right)}{3 \cdot \left(u_{n.UN2} + u_{o.UN2}\right)} = 0$

$$\Sigma V_{UpliftUN2.OT} := V_{ulkeyhUN2.OT} + V_{ulbaseUN2.OT} + V_{ulkeytUN2.OT} = -1242 \cdot kN$$

$$U_{UN2.loc.OT} := \frac{V_{ulkeyhUN2.OT} \cdot V_{ulkeyhUN2loc.OT} + V_{ulbaseUN2.OT} \cdot V_{ulbaseUN2loc.OT} + V_{ulkeytUN2.OT} \cdot V_{ulkeytUN2loc.OT}}{\Sigma V_{UpliftUN2.OT}} = 6.39\,m$$

$$\Sigma M_{UpliftUN2.OT} := \Sigma V_{UpliftUN2.OT} \cdot U_{UN2.loc.OT} = -7932.5 \cdot kN \cdot m$$

Modify Lateral Water Pressure (Resisting) for Overturning Analysis:

(Resisting water pressure is calculated using the Line of Creep method)

Water Load at Key (heel):

$$H_{h2UN2.OT} := \frac{u_{k.UN2} + u_{j.UN2}}{2} \cdot Key_{h.d}\, B = 335.2 \cdot kN$$

Moment Arm (from Point O):

$$H_{h2locUN2.OT} := \frac{Key_{h.d} \cdot \left(2 \cdot u_{k.UN2} + u_{j.UN2}\right)}{3\left(u_{k.UN2} + u_{j.UN2}\right)} + Key_{vdist} = -1.57\ m$$

Water Load at Key (toe):

$$H_{h6UN2.OT} := \frac{u_{o.UN2} \cdot \left(UWSEL_{UN2} - Bot_{ftg} + Key_{t.d}\right)}{2} \cdot B = 480 \cdot kN$$

Moment Arm (from Point O):

$$H_{h6locUN2.OT} := \frac{UWSEL_{UN2} - Bot_{ftg} + Key_{t.d}}{3} = 3.30\ m$$

$$\Sigma H_{waterresistUN2.OT} := H_{h2UN2.OT} + H_{h6UN2.OT} = 815.41 \cdot kN$$

$$H_{waterresistlocUN2.OT} := \frac{H_{h2UN2.OT} \cdot H_{h2locUN2.OT} + H_{h6UN2.OT} \cdot H_{h6locUN2.OT}}{\Sigma H_{waterresistUN2.OT}} = 1.3\ m$$

$$\Sigma M_{waterresistUN2.OT} := \Sigma H_{waterresistUN2.OT} \cdot H_{waterresistlocUN2.OT} = 1060.03 \cdot kN \cdot m$$

Modify Lateral Soil Loads for Overturning Analysis:

(Lateral soil loads are calculated down to Point O instead of bottom of shear key)

<u>Driving Soil Load (Headwater Side):</u>

Surcharge Load:

$$E_{s1UN2.OT} := S1_{UN2} \cdot K_o \cdot \left(H_w + Key_{h.d} + Key_{vdist}\right) \cdot B \cdot -1 = 0 \cdot kN$$

Moment Arm (from Point O):

$$E_{s1locUN2.OT} := \frac{H_w + Key_{h.d} + Key_{vdist}}{2} = 7.25\ m$$

Moist Soil Load above GWL:

$$E_{h1UN2.OT} := \frac{\gamma_m \cdot K_o \cdot h_{1UN2}^{\,2}}{2} B \cdot -1 = -115.5 \cdot kN$$

Moment Arm (from Point O):

$$E_{h1locUN2.OT} := \frac{h_{1UN2}}{3} + h_{2UN2} + Key_{vdist} = 11.43\ m$$

Saturated Soil Load below GWL:
(rectangular component)

$$E_{h2UN2.OT} := \left(\gamma_m \cdot K_o \cdot h_{1UN2}\right) \cdot \left(h_{2UN2} + Key_{vdist}\right) \cdot B \cdot -1 = -497.3 \cdot kN$$

Moment Arm (from Point O):

$$E_{h2locUN2.OT} := \frac{h_{2UN2} + Key_{vdist}}{2} = 4.95\ m$$

Saturated Soil Load below GWL:
(triangular component)

$$E_{h2aUN2.OT} := \frac{\left(\gamma_{sat} - \gamma_w\right) \cdot K_o \cdot \left(h_{2UN2} + Key_{vdist}\right)^2}{2} \cdot B \cdot -1 = -326.4 \cdot kN$$

Moment Arm (from Point O):

$$E_{h2alocUN2.OT} := \frac{h_{2UN2} + Key_{vdist}}{3} = 3.30\ m$$

Resisting Soil Load (Tailwater Side):

(Determine resisting soil load based on depth variation between the keys (ie. Key_{vdist}). In case where key at heel is deeper than key at toe (ie. Key_{vdist}< 0), resisting soil load (p*) is assumed to produce horizontal equilibrium as per Figure 4-5 above. Resisting soil load (p_o) is neglected.)

Total Driving Force: $\Sigma H_{SoildriveUN2.OT} := E_{s1UN2.OT} + E_{h1UN2.OT} + E_{h2UN2.OT} + E_{h2aUN2.OT} + H_{h2UN2} = -1754.7 \cdot kN$

Total Resisting Force: $\Sigma H_{waterresistUN2.OT} = 815.4 \cdot kN$

Assumed Soil Load p*: $E_{h8UN2a.OT} := \left(\Sigma H_{SoildriveUN2.OT} + \Sigma H_{waterresistUN2.OT}\right) \cdot -1 = 939.279 \cdot kN$

Moment Arm (from Point O): $E_{h8UN2a.loc.OT} := \dfrac{Key_{vdist}}{2} = -1.5\, m$

$$E_{h8UN2.OT} := \begin{cases} E_{h8UN2a.OT} & \text{if } Key_{vdist} < 0 \\ \Sigma H_{SoilresistUN2} - H_{h6UN2} - H_{h2aUN2} & \text{otherwise} \end{cases} = 939.279 \cdot kN$$

$$\Sigma M_{SoilresistUN2} := \begin{cases} E_{h8UN2a.OT} \cdot E_{h8UN2a.loc.OT} & \text{if } Key_{vdist} < 0 \\ \Sigma M_{HorizSoilResistUN2} - H_{h6UN2} \cdot H_{h6locUN2} - H_{h2aUN2} \cdot H_{h2alocUN2} & \text{otherwise} \end{cases} = -1408.918 \cdot kN \cdot m$$

Sum of Moment about Point O:

$$\Sigma M_{LateraldriveUN2.OT} := E_{s1UN2.OT} \cdot E_{s1locUN2.OT} + E_{h1UN2.OT} \cdot E_{h1locUN2.OT} + E_{h2UN2.OT} \cdot E_{h2locUN2.OT} \cdots + E_{h2aUN2.OT} \cdot E_{h2alocUN2.OT} + H_{h2UN2} \cdot H_{h2locUN2} = -5919.9 \cdot kN \cdot m$$

$$\Sigma M_{LateralresistUN2.OT} := \Sigma M_{waterresistUN2.OT} + \Sigma M_{SoilresistUN2} = -348.9 \cdot kN \cdot m$$

Total moment:

$$\Sigma M_{UN2.OT} := \Sigma M_{conc} + \Sigma M_{VertSoilWaterResistUN2} + \Sigma M_{UpliftUN2.OT} + \Sigma M_{LateraldriveUN2.OT} + \Sigma M_{LateralresistUN2.OT} = 10291.5 \cdot kN \cdot m$$

Total Vertical Force: $\Sigma V_{UN2.OT} := \Sigma V_{conc} + \Sigma V_{SoilWaterUN2} + \Sigma V_{UpliftUN2.OT} = 2150.2 \cdot kN$

Distance X_R: EM 1110-2-2502 Eq.4-1 $X_{R.UN2} := \dfrac{\Sigma M_{UN2.OT}}{\Sigma V_{UN2.OT}} = 4.786\, m$

Overturning Resultant Ratio $Ratio_{UN2.OT} := \dfrac{X_{R.UN2}}{b} = 0.38$

$$Ratio_{UN2.OT.check} := \begin{cases} \text{"OKAY "} & \text{if } Ratio_{UN2.OT} > X_{R.reqUN2} \\ \text{"Revise Structure""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

CHECK FOUNDATION ECCENTRICITY (HORIZONTAL PLANE):

Eccentricity (horizontal plan): $ex_{UN2.OT} := \dfrac{b}{2} - \dfrac{\Sigma M_{UN2.OT}}{\Sigma V_{UN2.OT}} = 1.46\, m$ $Kern_{OT} = 2.083\, m$

Eccentricity Check:

$$e_{check.UN2.OT} := \begin{cases} \text{"Okay"} & \text{if } ex_{UN2} \le Kern_{OT} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"Okay"}$$

LOAD CASE UN2

CHECK FOUNDATION BEARING CAPACITY (HORIZONTAL PLANE):

Base Section Modulus: $S_{b.OT} = 26.04\,m^3$

Bearing Pressure Under Toe:

$$\sigma_{ToeUN2.OT} := \begin{cases} \left(\dfrac{\Sigma V_{UN2.OT}}{b \cdot B} + \dfrac{\Sigma V_{UN2.OT} \cdot ex_{UN2.OT}}{S_{b.OT}}\right) & \text{if } \dfrac{\Sigma V_{UN2.OT}}{b \cdot B} \geq \dfrac{\Sigma V_{UN2.OT} \cdot ex_{UN2.OT}}{S_{b.OT}} \\ \dfrac{2 \cdot \Sigma V_{UN2.OT}}{B \cdot 3\left(\dfrac{b}{2} - ex_{UN2.OT}\right)} & \text{otherwise} \end{cases} = 292.9 \cdot kPa$$

$$Bearing_{ChecktoeUN2.OT} := \begin{cases} \text{"OKAY "} & \text{if } \sigma_{ToeUN2.OT} < \sigma_{allowUN2} \\ \text{"NG - for reference only""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

Bearing Pressure Under Heel:

$$\sigma_{HeelUN2.OT} := \begin{cases} \left(\dfrac{\Sigma V_{UN2.OT}}{b \cdot B} - \dfrac{\Sigma V_{UN2.OT} \cdot ex_{UN2.OT}}{S_{b.OT}}\right) & \text{if } \dfrac{\Sigma V_{UN2.OT}}{b \cdot B} \geq \dfrac{\Sigma V_{UN2.OT} \cdot ex_{UN2.OT}}{S_{b.OT}} \\ 0 & \text{otherwise} \end{cases} = 51.2 \cdot kPa$$

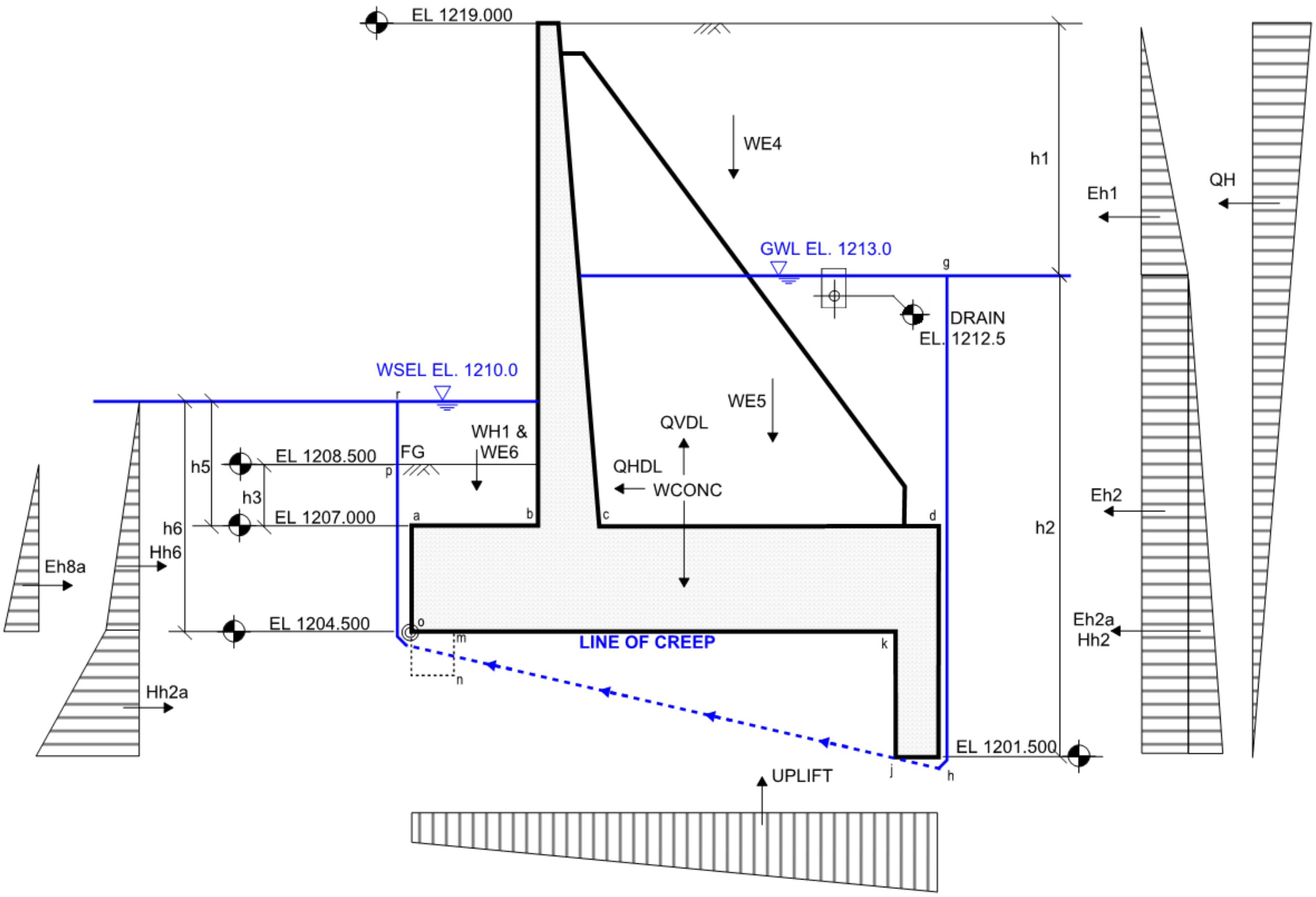
$$Bearing_{CheckheelUN2.OT} := \left(\begin{cases} \text{"OKAY "} & \text{if } \sigma_{ToeUN2.OT} < \sigma_{allowUN2} \wedge \sigma_{ToeUN2.OT} > 0 \\ \text{"NG - for reference only""} & \text{otherwise} \end{cases}\right) = \text{"OKAY "}$$

SUMMARY OF STABILITY ASSESSMENT:

LOAD CASE UN2

Sliding Factor of Safety: (Horizontal Plane - Ref only)	$FS_{Horiz.SlidingUN2} = 0.61$	$FS_{Sliding.check1.UN2}$ = "NG - key req'"
Sliding Factor of Safety: (Inclined Plane)	$FS_{InclinedlSlidingUN2} = 1.32$	$FS_{Sliding.check2.UN2}$ = "OKAY "
Eccentricity: (Inclined Plane)	$ex_{UN2} = 1.66\ m$	$e_{check.UN2}$ = "Okay"
Bearing Pressure At Heel: (Inclined Plane)	$\sigma_{HeelUN2} = 49 \cdot kPa$	$Bearing_{CheckheelUN2}$ = "OKAY "
Bearing Pressure At Toe: (Inclined Plane)	$\sigma_{ToeUN2} = 379 \cdot kPa$	$Bearing_{ChecktoeUN2}$ = "OKAY "
Flotation Factor of Safety (horizontal plane)	$FS_{FloatationUN2} = 2.43$	$FS_{Floatation.UN2.check}$ = "OKAY "
Overturning Resultant Ratio: (horizontal plane)	$Ratio_{UN2.OT} = 0.38$	$Ratio_{UN2.OT.check}$ = "OKAY "
Eccentricity: (horizontal plane - Ref only)	$ex_{UN2.OT} = 1.46\ m$	$e_{check.UN2.OT}$ = "Okay"
Bearing Pressure At Heel: (horizontal plane - Ref only)	$\sigma_{HeelUN2.OT} = 51 \cdot kPa$	$Bearing_{CheckheelUN2.OT}$ = "OKAY "
Bearing Pressure At Toe: (horizontal plane - Ref only)	$\sigma_{ToeUN2.OT} = 293 \cdot kPa$	$Bearing_{ChecktoeUN2.OT}$ = "OKAY "

LOAD CASE E1 - SEISMIC LOADING



E1 DESIGN CASE

LOAD CASE E1 ACCEPTANCE PARAMETERS

FS sliding:

Extreme (E) loading)	1.0 (without cohesion, seismic	(Table 3-3, USACE EM 1110-2-2100)

Resultant Location:

Extremem (E) Inside middle half ~75% base in compression

Required Factor of Safety for Sliding:	$FS_{sliding.reqE1} := 1.0$	(Without Cohesion)
Allowable rock bearing pressure:	$\sigma_{allowE1} := 1740kPa$	(Section 5.2, Design Criteria EM 1110-2-2100 Section 3-10)
Overturning Required Resultant Ratio:	$X_{R.reqE1} := 0.25$	(EM 1110-2-2502, Figure 4-4)
Required Factor of Safety for Floatation	$FS_{req.E1.flt} := 1.1$	

SOIL HEIGHTS and Water Levels:

LOAD CASE E1

Heel Conditions:

Groundwater Elevation at Heel: $GWL_{E1} := 1213.0m$

Distance from Finish Grade to Groundwater at Heel: $h_{1E1} := \left[T_w - GWL_{E1} + \left(L_{cd} + t_{wb} - t_{wt}\right)\cdot\tan(\beta)\right] = 6.00\ m$

Distance from Water Surface to Bottom of Footing at Heel: $h_{2E1} := GWL_{E1} - Bot_{ftg} + Key_{h.d} = 11.50\ m$

Toe Conditions:

Water Surface Elevation at Toe: $WSEL_{E1} := 1210.0m$

Water Surface Elevation at Toe for Uplift: $UWSEL_{E1} := 1210.0\cdot m$

Finish Grade at Toe providing lateral resistance: $FG_{toeE1} := 1208.5\cdot m$

Soil Depth Above top of footing: $h_{3aE1} := FG_{toeE1} - Top_{ftg} = 1.5\ m$

$$h_{3E1} := \begin{cases} h_{3aE1} & \text{if } FG_{toeE1} - Top_{ftg} \geq 0 \\ 0 & \text{otherwise} \end{cases} = 1.5$$

Resisting Fill at Toe: $h_{4E1} := FG_{toeE1} - Bot_{ftg} + Key_{t.d} = 4.00\ m$

Distance from Water Level to Top of Footing at Toe: $h_{5E1} := WSEL_{E1} - Top_{ftg} = 3.00\ m$

Distance from Water Surface to Bottom of Footing at Toe: $h_{6E1} := WSEL_{E1} - Bot_{ftg} + Key_{t.d} = 5.50\ m$

Soil Depth Above WSEL: $h_{7aE1} := FG_{toeE1} - WSEL_{E1} = -1.5\ m$

$$h_{7E1} := \begin{cases} h_{7aE1} & \text{if } FG_{toeE1} - WSEL_{E1} \geq 0 \\ 0 & \text{otherwise} \end{cases} = 0$$

Soil Depth Below WSEL:

$$h_{8E1} := \begin{cases} WSEL_{E1} - Bot_{ftg} + Key_{t.d} & \text{if } FG_{toeE1} - WSEL_{E1} \geq 0 \\ h_{4E1} & \text{otherwise} \end{cases} = 4$$

For Line of Creep Method: $L_{ho.E1} := \sqrt{b^2 + \left(Key_{h.d} - Key_{t.d}\right)^2} = 12.855\ m$

Head Loss from Point g:

$\Delta h_{g.hj.E1} := h_{2E1} = 11.5\ m$ (to point h & j)

$\Delta h_{g.km.E1} := GWL_{E1} - Bot_{ftg} = 8.5\ m$ (to point k & m)

$\Delta h_{g.no.E1} := GWL_{E1} - Bot_{ftg} + Key_{t.d} = 8.5\ m$ (to point n & o)

$\Delta h_{g.p.E1} := GWL_{E1} - FG_{toeE1} = 4.5\ m$ (to point p)

$\Delta h_{g.r.E1} := GWL_{E1} - UWSEL_{E1} = 3\ m$ (to point r)

Surcharge

Surcharge on Heel: $S1_{E1} := 0.0\ \frac{kN}{m^2}$

Calculate Soil Lateral Pressure Coefficients:

LOAD CASE E1

Calculate at-rest pressure coefficient K_o based on Jaky's (1944) equation.

Soil At Rest Static Coefficient: (apply to resisting soil loads)

$$K_o := \frac{1 - \sin(\phi)}{1 + \sin(\beta)} = 0.546$$

(Eq. 3-6, USACE EM 1110-2-2502)

Calculate active pressure coefficient K_A based on Coulumb equations.

Determine Slope of Active Wedge: (cohesionless backfill with water table)

$$c_1 := 2 \cdot \tan(\phi) = 1.019 \qquad c_2 := 1 - \tan(\phi) \cdot \tan(\beta) - \frac{\tan(\beta)}{\tan(\phi)} = 1$$

(Eq. G-14 / G-15, USACE EM 1110-2-2100)

$$\alpha := \operatorname{atan}\left(\frac{c_1 + \sqrt{{c_1}^2 + 4 \cdot c_2}}{2}\right) = 1.021 \qquad \alpha_{deg} := \alpha \cdot \frac{180}{\pi} = 58.5$$

degrees (Eq. G-13, USACE EM 1110-2-2100)

Soil Active Coefficient above GWL:

$$K_{Aagwt} := \left(\frac{1 - \tan(\phi) \cdot \cot(\alpha)}{1 + \tan(\phi) \cdot \tan(\alpha)}\right) \cdot \left(\frac{\tan(\alpha)}{\tan(\alpha) - \tan(\beta)}\right) = 0.376$$

Soil Active Coefficient below GWL:

$$K_{Abgwt} := \frac{1 - \tan(\phi) \cdot \cot(\alpha)}{1 + \tan(\phi) \cdot \tan(\alpha)} \cdot \left[1 + \left(\frac{\tan(\alpha)}{\tan(\alpha) - \tan(\beta)} - 1\right) \cdot \left(\frac{\gamma_m}{\gamma_{sat} - \gamma_w}\right)\right] = 0.376$$

(Eq. G-29, USACE EM 1110-2-2100)

Lateral - Driving Force

Static Copmonent : Active Pressure:

Surcharge Load:

$$E_{s1E1} := S1_{E1} \cdot K_{Aagwt} \cdot \left(H_w + Key_{h.d}\right) \cdot B \cdot -1 = 0 \cdot kN$$

Moment Arm (from bottom of footing):

$$E_{s1locE1} := \frac{H_w + Key_{h.d}}{2} + Key_{vdist} = 5.75\ m$$

Moist Soil Load above GWL:

$$E_{h1E1} := \frac{\gamma_m \cdot K_{Aagwt} \cdot {h_{1E1}}^2}{2} \cdot B \cdot -1 = -135.2 \cdot kN$$

Moment Arm (from bottom of footing):

$$E_{h1locE1} := \frac{h_{1E1}}{3} + h_{2E1} + Key_{vdist} = 10.50\ m$$

Saturated Soil Load below GWL: (rectangular component)

$$E_{h2E1} := \left(\gamma_m \cdot K_{Abgwt} \cdot h_{1E1}\right) \cdot h_{2E1} \cdot B \cdot -1 = -518.2 \cdot kN$$

Moment Arm (from bottom of footing):

$$E_{h2locE1} := \frac{h_{2E1}}{2} + Key_{vdist} = 2.75\ m$$

Saturated Soil Load below GWL: (triangular component)

$$E_{h2aE1} := \frac{\left(\gamma_{sat} - \gamma_w\right) \cdot K_{Abgwt} \cdot {h_{2E1}}^2}{2} \cdot B \cdot -1 = -302.9 \cdot kN$$

Moment Arm (from bottom of footing):

$$E_{h2alocE1} := \frac{h_{2E1}}{3} + Key_{vdist} = 0.83\ m$$

Lateral Water Load:

Water Load GWL to Bottom of Key

$$H_{h2E1} := \frac{\gamma_w \cdot {h_{2E1}}^2}{2} \cdot B \cdot -1 = -648.0 \cdot kN$$

Moment Arm (from bottom of footing):

$$H_{h2locE1} := \frac{h_{2E1}}{3} + Key_{vdist} = 0.83\ m$$

$$\Sigma H_{SoildriveE1} := E_{s1E1} + E_{h1E1} + E_{h2E1} + E_{h2aE1} + H_{h2E1} = -1604.4 \cdot kN$$

$$\Sigma M_{LateralSoildriveE1} := E_{s1E1} \cdot E_{s1locE1} + E_{h1E1} \cdot E_{h1locE1} + E_{h2E1} \cdot E_{h2locE1} \ldots + E_{h2aE1} \cdot E_{h2alocE1} + H_{h2E1} \cdot H_{h2locE1} = -3637.1\ m \cdot kN$$

Lateral - Resisting Force

LOAD CASE E1

Note: **Due to the relatively shallow depth of resisting soil/rock, a conservative apporach using at-rest coefficient in lieu of a passive wedge is used to calculate resisting forces.**

Lateral Water Load:

Water Load WSEL to Bottom of Footing: $H_{h6E1} := H_{h6U1} = 148.2 \cdot kN$

Moment Arm (from bottom of footing): $H_{h6locE1} := H_{h6locU1} = 1.83\ m$

Water Load Bot. of Footing to Bot. of H. Key: $H_{h2aE1} := \left[\left(UWSEL_{E1} - Bot_{ftg} + Key_{t.d}\right) + h_{2E1}\right] \cdot \frac{Key_{h.d}}{2} \cdot \gamma_w \cdot B = 249.9 \cdot kN$

Moment Arm (from bot. of toe key): $H_{h2alocE1} := \frac{Key_{h.d} \cdot \left[2 \cdot \left(UWSEL_{E1} - Bot_{ftg} + Key_{t.d}\right) + h_{2E1}\right]}{3\left[h_{2E1} + \left(UWSEL_{E1} - Bot_{ftg} + Key_{t.d}\right)\right]} \ldots = -1.68\ m$
$+ Key_{vdist}$

Lateral Soil Load:

Moist Soil Load above WSEL: $E_{h7E1} := \frac{\gamma_m \cdot K_o \cdot h_{7E1}^{\ 2}}{2} B = 0.0 \cdot kN$

Moment Arm (from bot. of toe key): $E_{h7locE1} := h_{6E1} + \frac{h_{7E1}}{3} + Key_{vdist} = 2.50\ m$

Saturated Soil Load below WSEL: (rectangular component) $E_{h8E1} := \left(\gamma_m \cdot K_o \cdot h_{7E1}\right) \cdot h_{8E1} \cdot B = 0.0 \cdot kN$

Moment Arm (from bot. of toe key): $E_{h8locE1} := \frac{h_{8E1}}{2} = 2.00\ m$

Saturated Soil Load below WSEL: (triangular component) $E_{h8aE1} := \frac{\left[\left(\gamma_{sat} - \gamma_w\right) \cdot K_o\right] \cdot h_{8E1}^{\ 2}}{2} \cdot B = 53.3 \cdot kN$

Moment Arm (from bot. of footing): $E_{h8alocE1} := \frac{h_{8E1}}{3} = 1.33\ m$

$\Sigma H_{SoilresistE1} := H_{h6E1} + H_{h2aE1} + E_{h7E1} + E_{h8E1} + E_{h8aE1} = 451.4 \cdot kN$

$\Sigma M_{HorizSoilResistE1} := H_{h6E1} \cdot H_{h6locE1} + H_{h2aE1} \cdot H_{h2alocE1} + E_{h7E1} \cdot E_{h7locE1} \ldots = -76.2\ m \cdot kN$
$+ E_{h8E1} \cdot E_{h8locE1} + E_{h8aE1} \cdot E_{h8alocE1}$

Vertical Force:

UPLIFT: Linear distribution from water at heel to water at toe:

$\Sigma V_{UpliftE1} := \left[\left(UWSEL_{E1} - Bot_{ftg} + Key_{t.d}\right) + h_{2E1}\right] \cdot \frac{b}{2} \cdot \gamma_w \cdot B \cdot -1 = -1041.25 \cdot kN$

Moment Arm (from Point O): $V_{UpliftE1aloc} := \frac{b \cdot \left[2 \cdot h_{2E1} + \left(UWSEL_{E1} - Bot_{ftg} + Key_{t.d}\right)\right]}{3\left[h_{2E1} + \left(UWSEL_{E1} - Bot_{ftg} + Key_{t.d}\right)\right]} = 6.985\ m$

$\Sigma M_{UpliftE1} := \Sigma V_{UpliftE1} \cdot V_{UpliftE1aloc} = -7273.438 \cdot kN \cdot m$

Weight of soil and water over toe:

Water Above the Top of Footing: $W_{H1E1} := \gamma_w \cdot h_{5E1} \cdot L_{ab} \cdot B = 88.2 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E1locE1} := \frac{L_{ab}}{2} = 1.5\,m$

Soil above top of footing: $W_{E6E1} := \gamma_b \cdot h_{3E1} \cdot L_{ab} \cdot B = 54.9 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E6locE1} := \frac{L_{ab}}{2} = 1.5\,m$

Vertical Load Due to Surcharge: $S_{E1} := S1_{E1} \cdot L_{cd} \cdot B = 0 \cdot kN$ $\quad S_{E1loc} := b - \frac{L_{cd}}{2} = 8.47\,m$

Weight of soil and water over heel:

Moist Soil for sloped grade above top of wall:

Length of sloped portion of soil above top of wall: $L_{E3E1} := \left(L_{cd} + t_{wb} - t_{wt}\right) = 9.00\,m$

Height of sloped soil above top of wall over heel: $h_{E3locE1} := \left(L_{E3E1}\right) \cdot \tan(\beta) = 0.00\,m$

Weight of sloped soil above top of wall: $W_{E3E1} := \frac{\gamma_m}{2} \cdot h_{E3locE1} \cdot L_{E3E1} \cdot B = 0.0 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E3locE1} := L_{ab} + t_{wt} + \frac{2}{3} \cdot L_{E3E1} = 9.50\,m$

Moist soil from top of wall to groundwater level:

Height of soil from top of wall and top of GWL: $h_{1E1} = 6.00\,m$

Length from edge of wall at GWL to edge of heel: $L_{E4E1} := L_{E3E1} - \left(h_{1E1} \cdot S_{batter}\right) = 8.53\,m$

Weight of soil over heel from top of wall to GWL: $W_{E4E1} := \gamma_m \cdot h_{1E1} \cdot \frac{\left(L_{E3E1} + L_{E4E1}\right)}{2} \cdot B = 1051.7 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E4locE1} := b - \frac{L_{E3E1}^{\ 2} + L_{E3E1} \cdot L_{E4U1} + L_{E4E1}^{\ 2}}{3\left(L_{E3E1} + L_{E4E1}\right)} = 8.12\,m$

Saturated soil from groundwater to top of footing:

Height of soil from GWL to top of heel: $h_{E4E1} := h_{2E1} - t_{ftg} - Key_{h.d} = 6.00\,m$

Weight of soil over heel from GWL to top of heel: $W_{E5E1} := \left(\gamma_{sat}\right) \cdot h_{E4E1} \cdot \frac{\left(L_{E4E1} + L_{cd}\right)}{2} \cdot B = 1094.6 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E5locE1} := b - \frac{L_{E4E1}^{\ 2} + L_{E4E1} \cdot L_{cd} + L_{cd}^{\ 2}}{3\left(L_{E4E1} + L_{cd}\right)} = 8.35\,m$

$\Sigma V_{SoilWaterE1} := W_{H1E1} + W_{E6E1} + W_{E3E1} + W_{E4E1} + W_{E5E1} + S_{E1} = 2289.5 \cdot kN$

$$\Sigma M_{VertSoilWaterResistE1} := W_{H1E1} \cdot W_{E1locE1} + W_{E6E1} \cdot W_{E6locE1} \cdots + W_{E3E1} \cdot W_{E3locE1} + W_{E4E1} \cdot W_{E4locE1} + W_{E5E1} \cdot W_{E5locE1} + S_{E1} \cdot S_{E1loc} = 17894.2\,m \cdot kN$$

SESIMIC ANALYSIS:

LOAD CASE E1

Seismic coefficient will be applied to dead loads to calculate seismic force and force is applied at center of gravity of the mass. Vertical and Horizontal loads are applied in the "destabilizing direction"

SEISMIC PARAMETERS:

Peak Ground Acceleration for Seismic Load $PGA_{Horiz} := 0.26$ $PGA_{Vert} := 0.56 \cdot PGA_{Horiz} = 0.146$ (Section 7.9, Design Criteria)

In accordance with USACE EM 1110-2-2100 Section 4-7.b, consider 2/3 PGA as seismic coefficient for stabilitiy.

Horizontal Seismic coefficient for stabilty: $K_{hE1} := \frac{2}{3} PGA_{Horiz} = 0.173$

Vertical Seismic coefficient for stabilty: $K_{vE1} := \frac{2}{3} PGA_{Vert} = 0.097$

SEISMIC ACCELERATION OF RIGID MASSES (Q_D):

Vertical Load Application:

$\Sigma V_{conc} = 1078.8 \cdot kN$

$Q_{v.conc} := \Sigma V_{conc} \cdot K_{vE1} \cdot -1 = -104.7 \cdot kN$ (assume acting upwards for adverse sliding effect)

Moment arm for siesmic load application (From Toe): $H_{cent} = 5.933\,m$

$M_{Qv.conc} := Q_{v.conc} \cdot H_{cent} = -621.3 \cdot kN \cdot m$

Lateral Load Application:

$Q_{h.conc} := \Sigma V_{conc} \cdot K_{hE1} \cdot -1 = -187 \cdot kN$

Moment arm for siesmic load application (Above Base of Footing): $V_{Cent} = 2.665\,m$

$M_{Q.conc} := Q_{h.conc} \cdot V_{Cent} = -498.3 \cdot kN \cdot m$

SEISMIC ACCELERATION OF SOIL WEDGE + WATER (Q_{EH}):

Vertical Load Application:

$\Sigma V_{SoilWaterE1} = 2289.5 \cdot kN$

$Q_{v.SoilWaterE1} := \Sigma V_{SoilWaterE1} \cdot K_{vE1} \cdot -1 = -222.2 \cdot kN$ (assume acting upwards for adverse sliding effect)

Moment arm for siesmic load application (From Toe): $e_{QE1} := \frac{\Sigma M_{VertSoilWaterResistE1}}{\Sigma V_{SoilWaterE1}} = 7.816\,m$

$M_{Qv.SoilWaterE1} := Q_{v.SoilWaterE1} \cdot e_{QE1} = -1736.9 \cdot kN \cdot m$

Lateral Load Application:

Seismic soil load is calculated based on Mononobe-Okabe method to determine combined static and dynamic coefficient (K_{AE}). Coulomb's active component (K_A) is subtracted from K_{AE} to obtain the seismic coefficient (ΔK_{AE}) for dynamic component of soil force.

Glacial Till Internal Friction (radians): $\phi = 0.471$

Seismic Inertia Angle (radians): $\psi := atan\left(\frac{K_{hE1}}{1 - K_{vE1}}\right) = 0.190$

Inclination of batter (radians): $\theta := 0.00$ assuming zero is conservative

Slope of retained ground surface: $\beta = 0.00$

$$K_{AE} := \frac{\cos(\phi - \psi - \theta) \cdot \cos(\phi - \psi - \theta)}{\cos(\psi) \cdot \cos(\theta) \cdot \cos(\theta)\ \cos(\psi + \theta) \cdot \left(1 + \sqrt{\frac{\sin(\phi)\ \sin(\phi - \psi - \beta)}{\cos(\beta - \theta) \cdot \cos(\psi + \theta)}}\right)^2} = 0.519$$

$\Delta K_{AE} := K_{AE} - K_{Abgwt} = 0.143$

Dynamic component of active seismic wedge:

$$Q_{h.SoilWaterE1} := \Delta K_{AE} \cdot \left[\frac{\gamma_m \cdot \left(H_w + Key_{h.d}\right)^2}{2 \cdot (\tan(\alpha) - \tan(\beta))} + \frac{\left(\gamma_{sat} - \gamma_m\right) \cdot h_{2E1}^{\ 2}}{2 \cdot \tan(\alpha)}\right] \cdot B \cdot -1 = -279.9 \cdot kN$$

(Eq. G-64, USACE EM 1110-2-2100)

Moment arm for siesmic load application (About Point O): $Q_{h.SoilWaterlocE1} := \frac{2}{3} \cdot \left(H_w + Key_{h.d}\right) + Key_{vdist} = 8.67\,m$

$M_{Q.h.SoilWaterE1} := Q_{h.SoilWaterE1} \cdot Q_{h.SoilWaterlocE1} = -2426.1 \cdot kN \cdot m$

STABILITY ASSESSMENT:

LOAD CASE E1

CHECK SLIDING ALONG HORIZONTAL SLIDING PLANE:

Summation of the vertical forces: $\Sigma V_{E1} := \Sigma V_{conc} + \Sigma V_{SoilWaterE1} + \Sigma V_{UpliftE1} + Q_{v.conc} + Q_{v.SoilWaterE1} = 2000.1 \cdot kN$

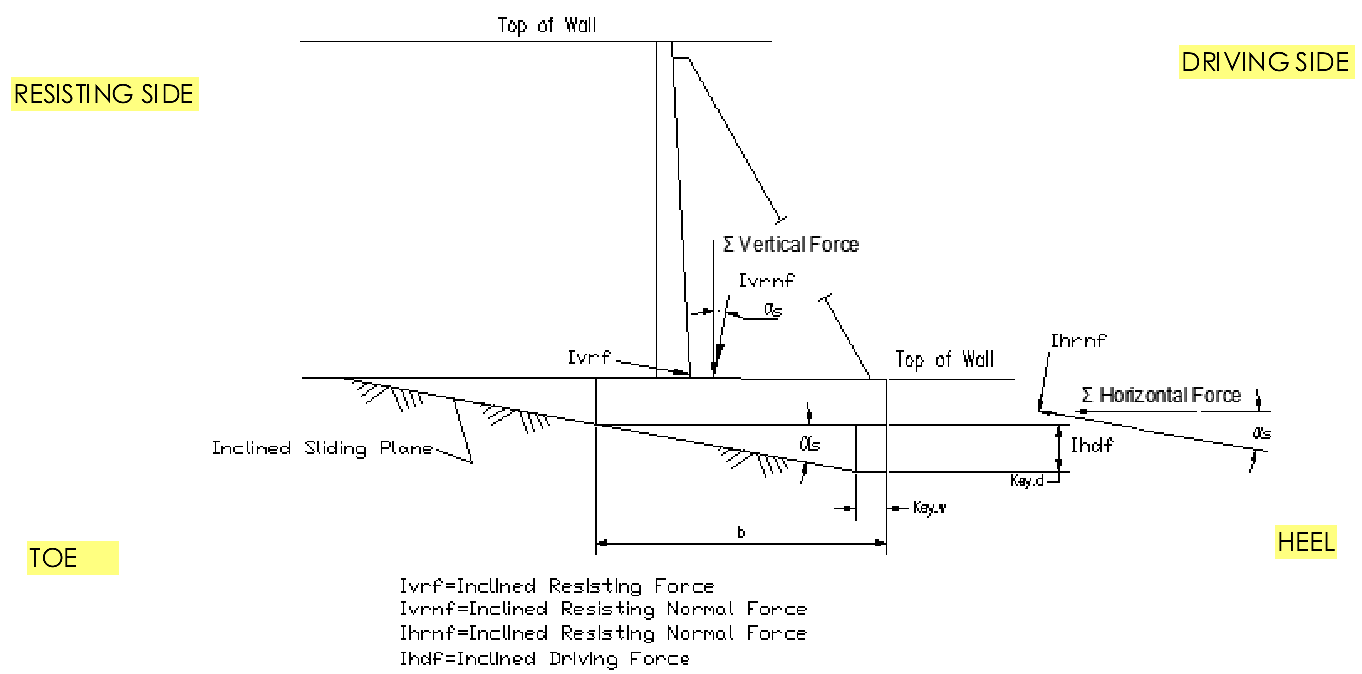
Summation of the horizontal forces: $\Sigma H_{E1} := \Sigma H_{SoildriveE1} + Q_{h.conc} + Q_{h.SoilWaterE1} + \Sigma H_{SoilresistE1} = -1619.9 \cdot kN$

Safety Factor for Sliding Horizontal Failure Plane

$$FS_{Horiz.SlidingE1} := \frac{\left|\Sigma V_{E1}\right| \cdot \tan\left(\phi_{rock} \cdot \frac{\pi}{180}\right)}{\left|\Sigma H_{E1}\right|} = 0.60$$

$$FS_{Sliding.check1.E1} := \begin{cases} \text{"OKAY"} & \text{if } FS_{Horiz.SlidingE1} > FS_{sliding.reqE1} \\ \text{"NG - key req'"} & \text{otherwise} \end{cases} = \text{"NG - key req'"}$$

CHECK FACTOR OF SAFETY SLIDING WITH KEY (INCLINED SLIDING PLANE):



(With properly engineered reinforced concrete Key, horizontal sliding plane thru Toe is protected, critical sliding plane is relocated to the INCLINED SLIDING PLANE FROM HEEL KEY To TOE, Bedrock Mass above this examing plane is mobilized by reinforced concrete key and combined into Structural Wedge.)

Resolve ΣV_{E1} & ΣH_{E1}

$$\Sigma V_{InclinedE1} := \cos(\alpha s) \cdot \left(\left|\Sigma V_{E1} + V_{rocksection}\right|\right) + \sin(\alpha s) \cdot \left|\Sigma H_{E1}\right| = 2771.5 \cdot kN$$

$$\Sigma H_{InclinedE1} := \cos(\alpha s) \cdot \left|\Sigma H_{E1}\right| - \sin(\alpha s) \cdot \left(\left|\Sigma V_{E1} + V_{rocksection}\right|\right) = 951.1 \cdot kN$$

Safety Factor for Sliding Inclined Failure Plane

$$FS_{InclinedISlidingE1} := \frac{\Sigma V_{InclinedE1} \cdot \tan\left(\phi_r\right)}{\Sigma H_{InclinedE1}} = 1.30$$

$$FS_{Sliding.check2.E1} := \begin{cases} \text{"OKAY"} & \text{if } FS_{InclinedISlidingE1} > FS_{sliding.reqE1} \\ \text{"NG'"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

CHECK FOUNDATION ECCENTRICITY:

LOAD CASE E1

(Vertical seismic loads from concrete, soil and water are assumed acting downwards for adverse bearing effect)

Summation of the vertical forces: $\Sigma V_{seisE1} := \Sigma V_{conc} + \Sigma V_{SoilWaterE1} + \Sigma V_{UpliftE1} - Q_{v.conc} - Q_{v.SoilWaterE1} = 2654.0 \cdot kN$

Summation of the horizontal forces: $\Sigma H_{seisE1} := \Sigma H_{E1} = -1619.9 \cdot kN$

Resolve ΣV_{seisE1} & ΣH_{seisE1}

$$\Sigma V_{InclinedseisE1} := \cos(\alpha s) \cdot \left(\left| \Sigma V_{seisE1} + V_{rocksection} \right| \right) + \sin(\alpha s) \cdot \left| \Sigma H_{seisE1} \right| = 3404.2 \cdot kN$$

$$\Sigma H_{InclinedseisE1} := \cos(\alpha s) \cdot \left| \Sigma H_{seisE1} \right| - \sin(\alpha s) \cdot \left(\left| \Sigma V_{seisE1} + V_{rocksection} \right| \right) = 786.0 \cdot kN$$

Summation of the resisting moments about the toe:

$$\Sigma M_{resE1} := \Sigma M_{conc} + \Sigma M_{VertSoilWaterResistE1} + \Sigma M_{HorizSoilResistE1} + \Sigma M_{rocksection} = 27605 \cdot kN \cdot m$$

Summation of seismic moments about the toe:

$$\Sigma M_{seisE1} := -M_{Qv.conc} + M_{Q.conc} - M_{Qv.SoilWaterE1} + M_{Q.h.SoilWaterE1} = -566 \cdot kN \cdot m$$

Summation of the overturning moments about the toe:

$$\Sigma M_{oE1} := \Sigma M_{LateralSoildriveE1} + \Sigma M_{UpliftE1} = -10911 \cdot kN \cdot m$$

Total moment: $\Sigma M_{E1} := \Sigma M_{resE1} + \Sigma M_{seisE1} + \Sigma M_{oE1} = 16128.3 \cdot kN \cdot m$

Normal force to base: $\Sigma V_{InclinedseisE1} = 3404.2 \cdot kN$

Inclined Sliding Plane Length: $L_{incline} = 12.9 \cdot m$

Eccentricity (inclined plane): $ex_{E1} := \frac{L_{incline}}{2} - \frac{\Sigma M_{E1}}{\Sigma V_{InclinedseisE1}} = 1.72\ m$ $\quad Kern_{E1} := \frac{L_{incline}}{4} = 3.23\ m$

Eccentricity Check:

$$e_{check.E1} := \begin{cases} \text{"Okay"} & \text{if } ex_{E1} \le Kern_{E1} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"Okay"}$$

CHECK FOUNDATION BEARING CAPACITY:

Base Section Modulus: $S_b = 27.81\ m^3$

Bearing Pressure Under Toe:

$$\sigma_{ToeE1} := \begin{cases} \left(\frac{\Sigma V_{InclinedE1}}{L_{incline} \cdot B} + \frac{\Sigma V_{InclinedE1} \cdot ex_{E1}}{S_b} \right) & \text{if } \frac{\Sigma V_{InclinedE1} \cdot ex_{E1}}{S_b} \le \frac{\Sigma V_{InclinedE1}}{L_{incline} \cdot B} \\ \frac{2 \cdot \Sigma V_{InclinedE1}}{B \cdot 3 \left(\frac{b}{2} - ex_{E1} \right)} & \text{otherwise} \end{cases} = 386.1 \cdot kPa$$

$$Bearing_{ChecktoeE1} := \begin{cases} \text{"OKAY "} & \text{if } \sigma_{ToeE1} < \sigma_{allowE1} \\ \text{"NG""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

Bearing Pressure Under Heel:

$$\sigma_{HeelE1} := \begin{cases} \left(\frac{\Sigma V_{InclinedE1}}{L_{incline} \cdot B} - \frac{\Sigma V_{InclinedE1} \cdot ex_{E1}}{S_b} \right) & \text{if } \frac{\Sigma V_{InclinedE1} \cdot ex_{E1}}{S_b} \le \frac{\Sigma V_{InclinedE1}}{L_{incline} \cdot B} \\ 0 & \text{otherwise} \end{cases} = 43.0 \cdot kPa$$

$$Bearing_{CheckheelE1} := \left(\begin{cases} \text{"OKAY "} & \text{if } \sigma_{HeelE1} < \sigma_{allowE1} \land \sigma_{HeelE1} > 0 \\ \text{"NG - perform cracked base analysis""} & \text{otherwise} \end{cases} \right) = \text{"OKAY "}$$

CHECK FLOATATION:

Safety Factor for Floatation:

$$FS_{FloatationE1} := \frac{\Sigma V_{conc} + \Sigma V_{SoilWaterE1} + Q_{v.conc} + Q_{v.SoilWaterE1}}{\left|\Sigma V_{UpliftE1}\right|} = 2.92$$

$$FS_{Floatation.E1.check} := \begin{array}{|l} \text{"OKAY" if } FS_{FloatationE1} > FS_{req.E1.flt} \\ \text{"Revise Structure"" otherwise} \end{array} = \text{"OKAY"}$$

CHECK OVERTURNING

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.
Assumptions are made in order to compute overturning stablity of indetermine forces on monolith with key;
(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.
(b) The horizontal resisting force acting on the key, P.key, is that required for static equilibrium
(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1

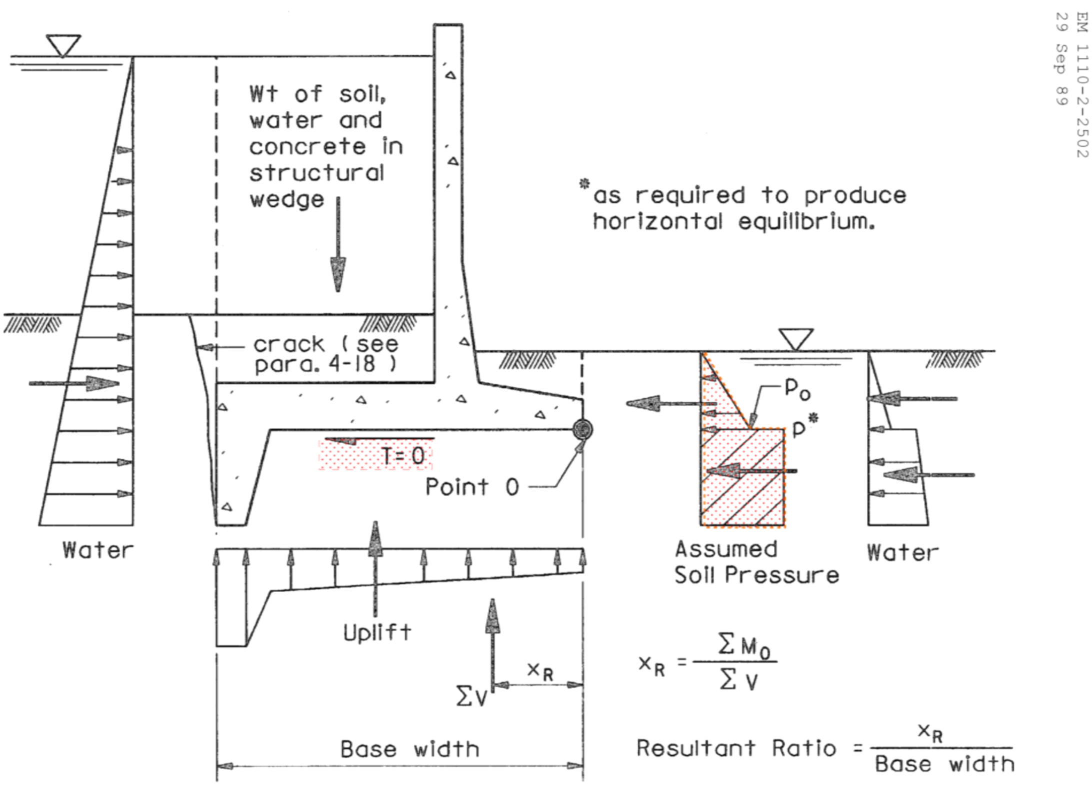


Figure 4-5. Forces for overturning analysis for wall with horizontal base and key

Modify Uplift for Overturning Analysis: **LOAD CASE E1**

(Uplift is calculated along the concrete/rock contact using the Line of Creep method)

Water Pressure at h: $u_{h.E1} := \Delta h_{g.hj.E1} \cdot \gamma_w = 112.70 \cdot kPa$

Water Pressure at o: $u_{o.E1} := \left(\Delta h_{g.no.E1} - \frac{\Delta h_{g.r.E1} \cdot L_{ho.E1}}{L_{ho.E1}} \right) \cdot \gamma_w = 53.9 \cdot kPa$

Head loss between point h and o: $\Delta h_{ho.E1} := \Delta h_{g.r.E1} \cdot \frac{L_{ho.E1}}{L_{ho.E1}} = 3\,m$

Length of concrete base (h -> o): $L_{baseho.E1} := Key_{h.w} + Key_{h.d} + Key_{hdist} + Key_{t.d} + Key_{t.w} = 15.5\,m$

Head loss along h -> j: $\Delta h_{hj.E1} := \Delta h_{ho.E1} \cdot \frac{Key_{h.w}}{L_{baseho.E1}} = 0.194\,m$

Water Pressure at j: $u_{j.E1} := \left(\Delta h_{g.hj.E1} - \Delta h_{hj.E1} \right) \cdot \gamma_w = 110.80 \cdot kPa$

Head loss along h -> k: $\Delta h_{hjk.E1} := \Delta h_{ho.E1} \cdot \left(\frac{Key_{h.w} + Key_{h.d}}{L_{baseho.E1}} \right) = 0.774\,m$

Water Pressure at k: $u_{k.E1} := \left(\Delta h_{g.km.E1} - \Delta h_{hjk.E1} \right) \cdot \gamma_w = 75.71 \cdot kPa$

Head loss along h -> m: $\Delta h_{hjkm.E1} := \Delta h_{ho.E1} \cdot \left(\frac{Key_{h.w} + Key_{h.d} + Key_{hdist}}{L_{baseho.E1}} \right) = 3\,m$

Water Pressure at m: $u_{m.E1} := \left(\Delta h_{g.km.E1} - \Delta h_{hjkm.E1} \right) \cdot \gamma_w = 53.90 \cdot kPa$

Head loss along h -> n: $\Delta h_{hjkmn.E1} := \Delta h_{ho.E1} \cdot \left(\frac{Key_{h.w} + Key_{h.d} + Key_{hdist} + Key_{t.d}}{L_{baseho.E1}} \right) = 3\,m$

Water Pressure at n: $u_{n.E1} := \left(\Delta h_{g.no.E1} - \Delta h_{hjkmn.E1} \right) \cdot \gamma_w = 53.90 \cdot kPa$

Uplift under key at heel: $V_{ulkeyhE1.OT} := \frac{\left(u_{h.E1} + u_{j.E1} \right) \cdot Key_{h.w}}{2} \cdot B \cdot -1 = -111.752 \cdot kN$

Moment Arm (from Point O): $V_{ulkeyhE1loc.OT} := b - \frac{Key_{h.w} \cdot \left(2 \cdot u_{j.E1} + u_{h.E1} \right)}{3 \cdot \left(u_{j.E1} + u_{h.E1} \right)} = 12.001\,m$

Uplift under base: $V_{ulbaseE1.OT} := \frac{\left(u_{k.E1} + u_{m.E1} \right) \cdot Key_{hdist}}{2} \cdot B \cdot -1 = -745.274 \cdot kN$

Moment Arm (from Point O): $V_{ulbaseE1loc.OT} := b - Key_{h.w} - \frac{Key_{hdist} \cdot \left(2 \cdot u_{m.E1} + u_{k.E1} \right)}{3 \cdot \left(u_{m.E1} + u_{k.E1} \right)} = 6.073\,m$

Uplift under key at toe $V_{ulkeytE1.OT} := \frac{\left(u_{n.E1} + u_{o.E1} \right) \cdot Key_{t.w}}{2} \cdot B \cdot -1 = 0 \cdot kN$

Moment Arm (from Point O): $V_{ulkeytE1loc.OT} := \frac{Key_{t.w} \cdot \left(2 \cdot u_{n.E1} + u_{o.E1} \right)}{3 \cdot \left(u_{n.E1} + u_{o.E1} \right)} = 0$

$$\Sigma V_{UpliftE1.OT} := V_{ulkeyhE1.OT} + V_{ulbaseE1.OT} + V_{ulkeytE1.OT} = -857 \cdot kN$$

$$U_{E1.loc.OT} := \frac{V_{ulkeyhE1.OT} \cdot V_{ulkeyhE1loc.OT} + V_{ulbaseE1.OT} \cdot V_{ulbaseE1loc.OT} + V_{ulkeytE1.OT} \cdot V_{ulkeytE1loc.OT}}{\Sigma V_{UpliftE1.OT}} = 6.85\,m$$

$$\Sigma M_{UpliftE1.OT} := \Sigma V_{UpliftE1.OT} \cdot U_{E1.loc.OT} = -5866.9 \cdot kN \cdot m$$

LOAD CASE E1

Modify Lateral Water Pressure (Resisting) for Overturning Analysis:

(Resisting water pressure is calculated using the Line of Creep method)

Water Load at Key (heel): $H_{h2E1.OT} := \frac{u_{k.E1} + u_{j.E1}}{2} \cdot Key_{h.d} B = 279.8 \cdot kN$

Moment Arm (from Point O): $H_{h2locE1.OT} := \frac{Key_{h.d} \cdot (2 \cdot u_{k.E1} + u_{j.E1})}{3(u_{k.E1} + u_{j.E1})} + Key_{vdist} = -1.59\ m$

Water Load at Key (toe): $H_{h6E1.OT} := \frac{u_{o.E1} \cdot (UWSEL_{E1} - Bot_{ftg} + Key_{t.d})}{2} \cdot B = 148 \cdot kN$

Moment Arm (from Point O): $H_{h6locE1.OT} := \frac{UWSEL_{E1} - Bot_{ftg} + Key_{t.d}}{3} = 1.83\ m$

$$\Sigma H_{waterresistE1.OT} := H_{h2E1.OT} + H_{h6E1.OT} = 428 \cdot kN$$

$$H_{waterresistlocE1.OT} := \frac{H_{h2E1.OT} \cdot H_{h2locE1.OT} + H_{h6E1.OT} \cdot H_{h6locE1.OT}}{\Sigma H_{waterresistE1.OT}} = -0.407\ m$$

$$\Sigma M_{waterresistE1.OT} := \Sigma H_{waterresistE1.OT} \cdot H_{waterresistlocE1.OT} = -174.23 \cdot kN \cdot m$$

Modify Lateral Soil Loads for Overturning Analysis:

(Lateral soil loads are calculated down to Point O instead of bottom of shear key)

Driving Soil Load (Headwater Side):

Surcharge Load: $E_{s1E1.OT} := S1_{E1} \cdot K_{Aagwt} \cdot (H_w + Key_{h.d} + Key_{vdist}) \cdot B \cdot -1 = 0 \cdot kN$

Moment Arm (from Point O): $E_{s1locE1.OT} := \frac{H_w + Key_{h.d} + Key_{vdist}}{2} = 7.25\ m$

Moist Soil Load above GWL: $E_{h1E1.OT} := \frac{\gamma_m \cdot K_{Aagwt} \cdot h_{1E1}^{\ 2}}{2} B \cdot -1 = -135.2 \cdot kN$

Moment Arm (from Point O): $E_{h1locE1.OT} := \frac{h_{1E1}}{3} + h_{2E1} + Key_{vdist} = 10.50\ m$

Saturated Soil Load below GWL:
(rectangular component) $E_{h2E1.OT} := (\gamma_m \cdot K_{Aagwt} \cdot h_{1E1}) \cdot (h_{2E1} + Key_{vdist}) \cdot B \cdot -1 = -383.0 \cdot kN$

Moment Arm (from Point O): $E_{h2locE1.OT} := \frac{h_{2E1} + Key_{vdist}}{2} = 4.25\ m$

Saturated Soil Load below GWL:
(triangular component) $E_{h2aE1.OT} := \frac{(\gamma_{sat} - \gamma_w) \cdot K_{Aagwt} \cdot (h_{2E1} + Key_{vdist})^2}{2} \cdot B \cdot -1 = -165.5 \cdot kN$

Moment Arm (from Point O): $E_{h2alocE1.OT} := \frac{h_{2E1} + Key_{vdist}}{3} = 2.83\ m$

Resisting Soil Load (Tailwater Side):

LOAD CASE E1

(Determine resisting soil load based on depth variation between the keys (ie. Key_{vdist}). In case where key at heel is deeper than key at toe (ie. Key_{vdist}< 0), resisting soil load (p*) is assumed to produce horizontal equilibrium as per Figure 4-5 above. Resisting soil load (p_o) is neglected.)

Total Driving Force:

$$\Sigma H_{SoildriveE1.OT} := E_{s1E1.OT} + E_{h1E1.OT} + E_{h2E1.OT} + E_{h2aE1.OT} + H_{h2E1} \cdots + Q_{h.conc} + Q_{h.SoilWaterE1} = -1798.7 \cdot kN$$

Total Resisting Force:

$$\Sigma H_{waterresistE1.OT} = 427.999 \cdot kN$$

Assumed Soil Load p*:

$$E_{h8E1a.OT} := \left(\Sigma H_{SoildriveE1.OT} + \Sigma H_{waterresistE1.OT}\right) \cdot -1 = 1370.683 \cdot kN$$

Moment Arm (from Point O):

$$E_{h8E1a.loc.OT} := \frac{Key_{vdist}}{2} = -1.5\,m$$

$$E_{h8E1.OT} := \begin{cases} E_{h8E1a.OT} & \text{if } Key_{vdist} < 0 \\ \Sigma H_{SoilresistE1} - H_{h6E1} - H_{h2aE1} & \text{otherwise} \end{cases} = 1370.683 \cdot kN$$

$$\Sigma M_{SoilresistE1} := \begin{cases} E_{h8E1a.OT} \cdot E_{h8E1a.loc.OT} & \text{if } Key_{vdist} < 0 \\ \Sigma M_{HorizSoilResistE1} - H_{h6E1} \cdot H_{h6locE1} - H_{h2aE1} \cdot H_{h2alocE1} & \text{otherwise} \end{cases} = -2056.025 \cdot kN \cdot m$$

Sum of Moment about Point O:

$$\Sigma M_{LateraldriveE1.OT} := E_{s1E1.OT} \cdot E_{s1locE1.OT} + E_{h1E1.OT} \cdot E_{h1locE1.OT} + E_{h2E1.OT} \cdot E_{h2locE1.OT} \cdots + E_{h2aE1.OT} \cdot E_{h2alocE1.OT} + H_{h2E1} \cdot H_{h2locE1} = -4056.3 \cdot kN \cdot m$$

$$\Sigma M_{LateralresistE1.OT} := \Sigma M_{waterresistE1.OT} + \Sigma M_{SoilresistE1} = -2230.3 \cdot kN \cdot m$$

$$\Sigma M_{seisE1.OT} := M_{Qv.conc} + M_{Q.conc} + M_{Qv.SoilWaterE1} + M_{Q.h.SoilWaterE1} = -5283 \cdot kN \cdot m$$

(seismic moment modified for the most adverse overturning effect)

Total moment:

$$\Sigma M_{E1.OT} := \Sigma M_{conc} + \Sigma M_{VertSoilWaterResistE1} + \Sigma M_{UpliftE1.OT} + \Sigma M_{LateraldriveE1.OT} + \Sigma M_{LateralresistE1.OT} + \Sigma M_{seisE1.OT} = 6859.3 \cdot kN \cdot m$$

Total Vertical Force:

$$\Sigma V_{E1.OT} := \Sigma V_{conc} + \Sigma V_{SoilWaterE1} + \Sigma V_{UpliftE1.OT} + Q_{v.conc} + Q_{v.SoilWaterE1} = 2184.3 \cdot kN$$

Distance X_R: EM 1110-2-2502 Eq.4-1

$$X_{R.E1} := \frac{\Sigma M_{E1.OT}}{\Sigma V_{E1.OT}} = 3.14\,m$$

Overturning Resultant Ratio

$$Ratio_{E1.OT} := \frac{X_{R.E1}}{b} = 0.25$$

$$Ratio_{E1.OT.check} := \begin{cases} \text{"OKAY "} & \text{if } Ratio_{E1.OT} > X_{R.reqE1} \\ \text{"Revise Structure""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

CHECK FOUNDATION ECCENTRICITY (HORIZONTAL PLANE):

Eccentricity (horizontal plan):

$$ex_{E1.OT} := \frac{b}{2} - \frac{\Sigma M_{E1.OT}}{\Sigma V_{E1.OT}} = 3.11\,m \qquad Kern_{E1.OT} := \frac{b}{4} = 3.125\,m$$

Eccentricity Check:

$$e_{check.E1.OT} := \begin{cases} \text{"Okay"} & \text{if } ex_{E1.OT} \le Kern_{E1.OT} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"Okay"}$$

CHECK FOUNDATION BEARING CAPACITY (HORIZONTAL PLANE):

Base Section Modulus: $S_{b.OT} = 26.04\,m^3$

Bearing Pressure Under Toe:

$$\sigma_{ToeE1.OT} := \begin{cases} \left(\dfrac{\Sigma V_{E1.OT}}{b \cdot B} + \dfrac{\Sigma V_{E1.OT} \cdot ex_{E1.OT}}{S_{b.OT}}\right) & \text{if } \dfrac{\Sigma V_{E1.OT}}{b \cdot B} \geq \dfrac{\Sigma V_{E1.OT} \cdot ex_{E1.OT}}{S_{b.OT}} \\ \dfrac{2 \cdot \Sigma V_{E1.OT}}{B \cdot 3\left(\dfrac{b}{2} - ex_{E1.OT}\right)} & \text{otherwise} \end{cases} = 463.7 \cdot kPa$$

$$Bearing_{ChecktoeE1.OT} := \begin{cases} \text{"OKAY "} & \text{if } \sigma_{ToeE1.OT} < \sigma_{allowE1} \\ \text{"NG - for reference only""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

Bearing Pressure Under Heel:

$$\sigma_{HeelE1.OT} := \begin{cases} \left(\dfrac{\Sigma V_{E1.OT}}{b \cdot B} - \dfrac{\Sigma V_{E1.OT} \cdot ex_{E1.OT}}{S_{b.OT}}\right) & \text{if } \dfrac{\Sigma V_{E1.OT}}{b \cdot B} \geq \dfrac{\Sigma V_{E1.OT} \cdot ex_{E1.OT}}{S_{b.OT}} \\ 0 & \text{otherwise} \end{cases} = 0.0 \cdot kPa$$

$$Bearing_{CheckheelE1.OT} := \left(\begin{cases} \text{"OKAY "} & \text{if } \sigma_{HeelE1.OT} < \sigma_{allowE1} \wedge \sigma_{HeelE1.OT} > 0 \\ \text{"NG - for reference only""} & \text{otherwise} \end{cases}\right) = \text{"NG - for reference only""}$$

SUMMARY OF STABILITY ASSESSMENT:

LOAD CASE E1

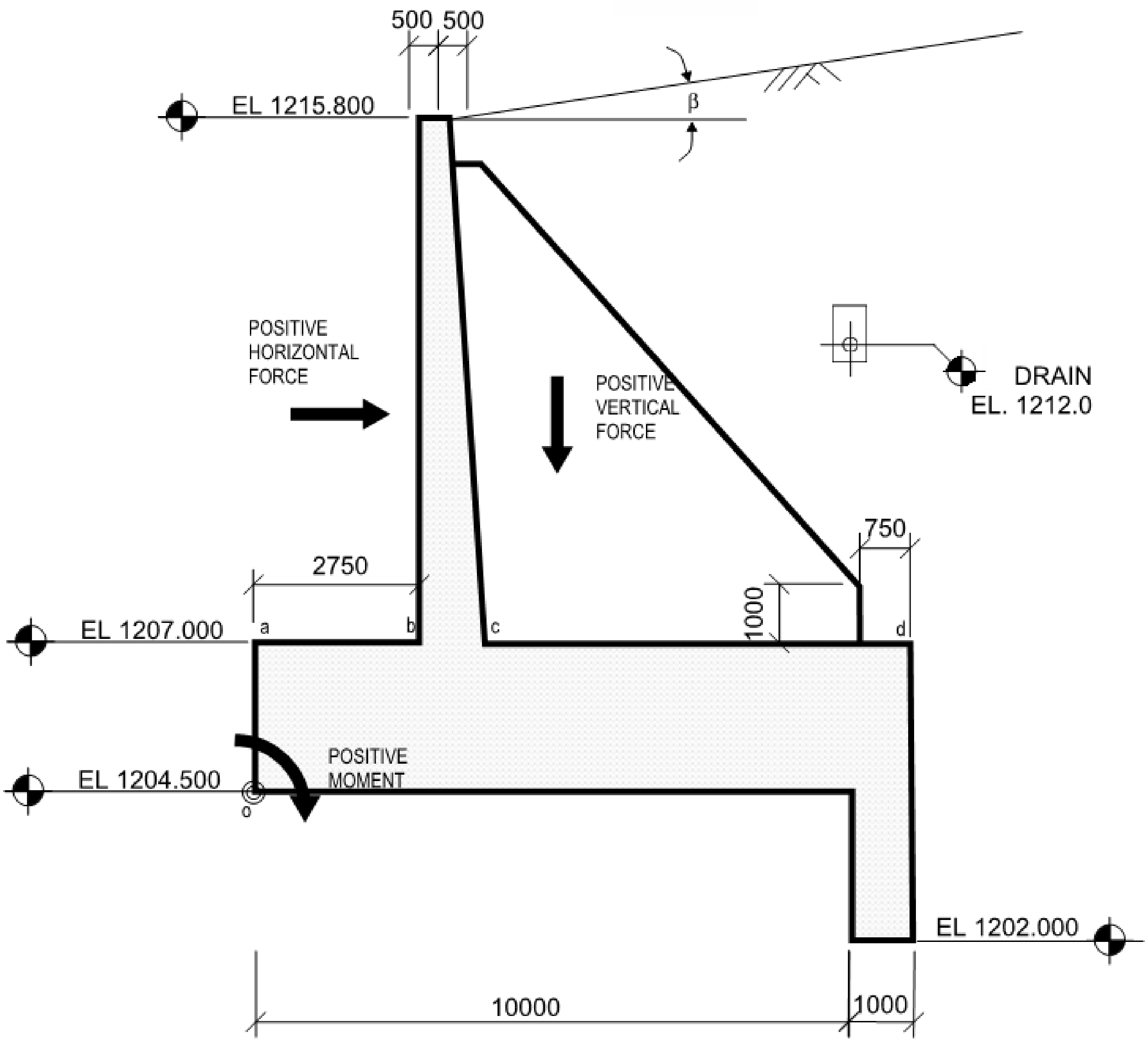
Sliding Factor of Safety: (Horizontal Plane - Ref only)	$FS_{Horiz.SlidingE1} = 0.60$	$FS_{Sliding.check1.E1}$ = "NG - key req""
Sliding Factor of Safety: (Inclined Plane)	$FS_{InclinedlSlidingE1} = 1.3$	$FS_{Sliding.check2.E1}$ = "OKAY "
Eccentricity: (Inclined Plane)	$ex_{E1} = 1.72\ m$	$e_{check.E1}$ = "Okay"
Bearing Pressure At Heel: (Inclined Plane)	$\sigma_{HeelE1} = 43 \cdot kPa$	$Bearing_{CheckheelE1}$ = "OKAY "
Bearing Pressure At Toe: (Inclined Plane)	$\sigma_{ToeE1} = 386 \cdot kPa$	$Bearing_{ChecktoeE1}$ = "OKAY "
Flotation Factor of Safety (horizontal plane)	$FS_{FloatationE1} = 2.92$	$FS_{Floatation.E1.check}$ = "OKAY "
Overturning Resultant Ratio: (horizontal plane)	$Ratio_{E1.OT} = 0.25$	$Ratio_{E1.OT.check}$ = "OKAY "
Eccentricity: (horizontal plane - Ref only)	$ex_{E1.OT} = 3.11\ m$	$e_{check.E1.OT}$ = "Okay"
Bearing Pressure At Heel: (horizontal plane - Ref only)	$\sigma_{HeelE1.OT} = 0 \cdot kPa$	$Bearing_{CheckheelE1.OT}$ = "NG - for reference only""
Bearing Pressure At Toe: (horizontal plane - Ref only)	$\sigma_{ToeE1.OT} = 464 \cdot kPa$	$Bearing_{ChecktoeE1.OT}$ = "OKAY "

Calculation Section V

SS-5D (Midsection) Retaining Wall Stability Calculations

Project Number:	110773396
Project Title:	SR1 - Diversion Structure
Client:	Alberta Transportation
Engineer:	Lawrence Choi — Date: 12/11/2018
Checker:	Sean Xiao — Date: 12/18/2018

Calculation for: Retaining Wall - Service Spillway Left - Block 5D (Mid-section)



(DIMENSIONS BASED ON MID SECTION)

REGION COLOR CONVENTION

User Input

Calulation Highlights

Results

WALL GEOMETRY:

Top of Wall Elevation: $T_w := 1215.8 \cdot m$

Top of Footing Elevation: $Top_{ftg} := 1207.0 \cdot m$

Thickness of Footing: $t_{ftg} := 2.5m$

Bottom of Footing Elevation: $Bot_{ftg} := Top_{ftg} - t_{ftg} = 1204.5\ m$

Overall Height of wall: $h_w := T_w - Bot_{ftg} = 11.30\ m$

Thickness of Wall: Base: $t_{wb} := 1.191 \cdot m$ Top: $t_{wt} := 0.50m$

Length of toe: $L_{ab} := 2.75m$

Total Length of Footing: $b := 11.0m$

Length of heel: $L_{cd} := b - L_{ab} - t_{wb} = 7.059\ m$

Unit Width of Wall for analysis: $B := 1.00m$

SHEAR KEY GEOMETRY:

	Toe	Heel	
Key depth:	$Key_{t.d} := 0m$	$Key_{h.d} := 2.5m$	(Assumption: $Key_{h.d}$ >= $Key_{t.d}$)
Key width:	$Key_{t.w} := 0m$	$Key_{h.w} := 1m$	
Face of Key from Point O:	$Key_{t.loc} := 0 \cdot m$	$Key_{h.loc} := b - Key_{h.w} = 10\ m$	

Horizontal Distance between Keys: $Key_{hdist} := Key_{h.loc} - Key_{t.loc} - Key_{t.w} = 10\ m$

Key Depth Diff. (from point O): $Key_{vdist} := -Key_{h.d} + Key_{t.d} = -2.5\ m$

BASE PROPERTIES:

Base Area: $A_b := b \cdot B = 11\ m^2$

Centroidal Distance for Footing (from Toe): $Y_f := \frac{b}{2} = 5.50\ m$

RETAINED SOIL GEOMETRY:

Slope of retained ground surface: $\beta := 0 \cdot \frac{\pi}{180} = 0.00$

Height of retained earth at heel: $H_w := T_w - Bot_{ftg} + \left(t_{wb} + L_{cd} - t_{wt}\right) \cdot \tan(\beta) = 11.30\ m$

RETAINING WALL GEOMETRY CHECKS:

(Foundation Analysis & Design Bowles)

$$t_{bcheck} := \begin{cases} \text{"OKAY"} & \text{if } t_{ftg} \ge \frac{H_w}{12} \\ \text{"Warning"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

$$t_{wcheck} := \begin{cases} \text{"OKAY"} & \text{if } t_{wb} \ge \frac{H_w}{12} \\ \text{"Warning"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

$$b_{check} := \begin{cases} \text{"OKAY"} & \text{if } \frac{b}{H_w} \ge .4 \wedge \frac{b}{H_w} \le 80 \\ \text{"Warning"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

$$L_{abcheck} := \begin{cases} \text{"OKAY"} & \text{if } \frac{L_{ab}}{b} \ge .25 \wedge \frac{L_{ab}}{b} \le .4 \\ \text{"Warning"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

Material Properties:

Unit Weight of Water: $\gamma_w := 9.8 \frac{kN}{m^3}$ (Section 7.2, Design Criteria)

Unit Weight of Concrete: $\gamma_c := 23.5 \frac{kN}{m^3}$

Unit Weight of Soil (Moist): $\gamma_m := 20.0 \frac{kN}{m^3}$ (Section 5.3, Design Criteria)
assumed moisture content (w) = 5%

Unit Weight Soil (Saturated): $\gamma_{sat} := 22.0 \frac{kN}{m^3}$ (Assuming Specific Gravity = 2.7

Unit Weight Soil (buoyant): $\gamma_b := \gamma_{sat} - \gamma_w = 12.2 \cdot \frac{kN}{m^3}$

Weight of Soil/Concrete above toe: $\gamma_{toe} := 22.0 \frac{kN}{m^3}$

Unit Weight of Rock: $\gamma_r := 25.6 \frac{kN}{m^3}$ (Section 7.2, Design Criteria)

Foundation Parameters:

Glacial Till Internal Friction: $\phi := 27 \cdot \frac{\pi}{180} = 0.471$

Bedrock Internal Friction Angle: $\phi_r := 24 \cdot \frac{\pi}{180} = 0.419$

Friction Angle at Base
Concrete / Rock Interface: $\phi_{rock} := 26$

Base Friction Coefficient: $\tan_{\phi rock} := \tan\left(\phi_{rock} \frac{\pi}{180}\right) = 0.488$ radians

Rip Rap Backfill, Refer Dwg. C-214 $\phi_{backfill} := \left(20 \frac{\pi}{180}\right) = 0.349$ radians

Shear strength along rock
Failure plane $s_r := \frac{13100 \frac{kN}{m^2}}{2} = 6550 \cdot \frac{kN}{m^2}$ (Stantec Design Memo 8/8/16)

CONCRETE DEAD LOAD:

Area of Footing: $A_{ftg} := t_{ftg} \cdot b = 27.5\,m^2$

Weight of Footing: $D_{ftg} := A_{ftg} \cdot B \cdot \gamma_c = 646.3 \cdot kN$

Area of Stem (without batter): $A_{w1} := t_{wt} \cdot (h_w - t_{ftg}) = 4.4\,m^2$

Weight of Stem: $D_{w1} := A_{w1} \cdot B \cdot \gamma_c = 103.4 \cdot kN$

Area of stem Batter: $A_{w2} := \frac{(t_{wb} - t_{wt})}{2} (h_w - t_{ftg}) = 3.04\,m^2$

Weight of Batter: $D_{w2} := A_{w2} \cdot B \cdot \gamma_c = 71.4 \cdot kN$

Slope of batter: $S_{batter} := \frac{t_{wb} - t_{wt}}{h_w - t_{ftg}} = 0.079$

Area of Key $A_{t.key} := Key_{t.d} \cdot Key_{t.w} = 0$ $A_{h.key} := Key_{h.d} \cdot Key_{h.w} = 2.5\,m^2$

Weight of Key $D_{t.key} := A_{t.key} \cdot B \cdot \gamma_c = 0 \cdot kN$ $D_{h.key} := A_{h.key} \cdot B \cdot \gamma_c = 58.8 \cdot kN$

Centroidal Horizontal Distance of Wall (From Toe):

$$H_{cent} := \frac{A_{w1} \cdot \left(L_{ab} + \frac{t_{wt}}{2}\right) + A_{w2} \cdot \left(L_{ab} + t_{wt} + \frac{t_{wb} - t_{wt}}{3}\right) + A_{ftg} \cdot \frac{b}{2} + A_{t.key} \cdot \left(Key_{t.loc} + \frac{Key_{t.w}}{2}\right) + A_{h.key} \cdot \left(Key_{h.loc} + \frac{Key_{h.w}}{2}\right)}{A_{w1} + A_{w2} + A_{ftg} + A_{t.key} + A_{h.key}} = 5.38\,m$$

Centroidal Vertical Distance of Wall (Above Base of Footing):

$$V_{Cent} := \frac{A_{ftg} \cdot \frac{t_{ftg}}{2} + A_{w1} \cdot \left[t_{ftg} + \frac{(h_w - t_{ftg})}{2}\right] + A_{w2} \cdot \left[t_{ftg} + \frac{(h_w - t_{ftg})}{3}\right] + A_{t.key} \cdot \left(\frac{-Key_{t.d}}{2}\right) + A_{h.key} \cdot \left(\frac{-Key_{h.d}}{2}\right)}{A_{ftg} + A_{w1} + A_{w2} + A_{t.key} + A_{h.key}} = 2.09\,m$$

$\Sigma V_{conc} := D_{ftg} + D_{w1} + D_{w2} + D_{t.key} + D_{h.key} = 879.8 \cdot kN$

$\Sigma M_{conc} := \Sigma V_{conc} \cdot H_{cent} = 4730.1\,m \cdot kN$

ROCK SECTION MOBILIZED FOR INCLINDED SLIDING FAILURE

Area of Rock Section Mobilized: $A_{rocksection} := (Key_{t.d} + Key_{h.d}) \cdot \frac{Key_{hdist}}{2} = 12.5\,m^2$

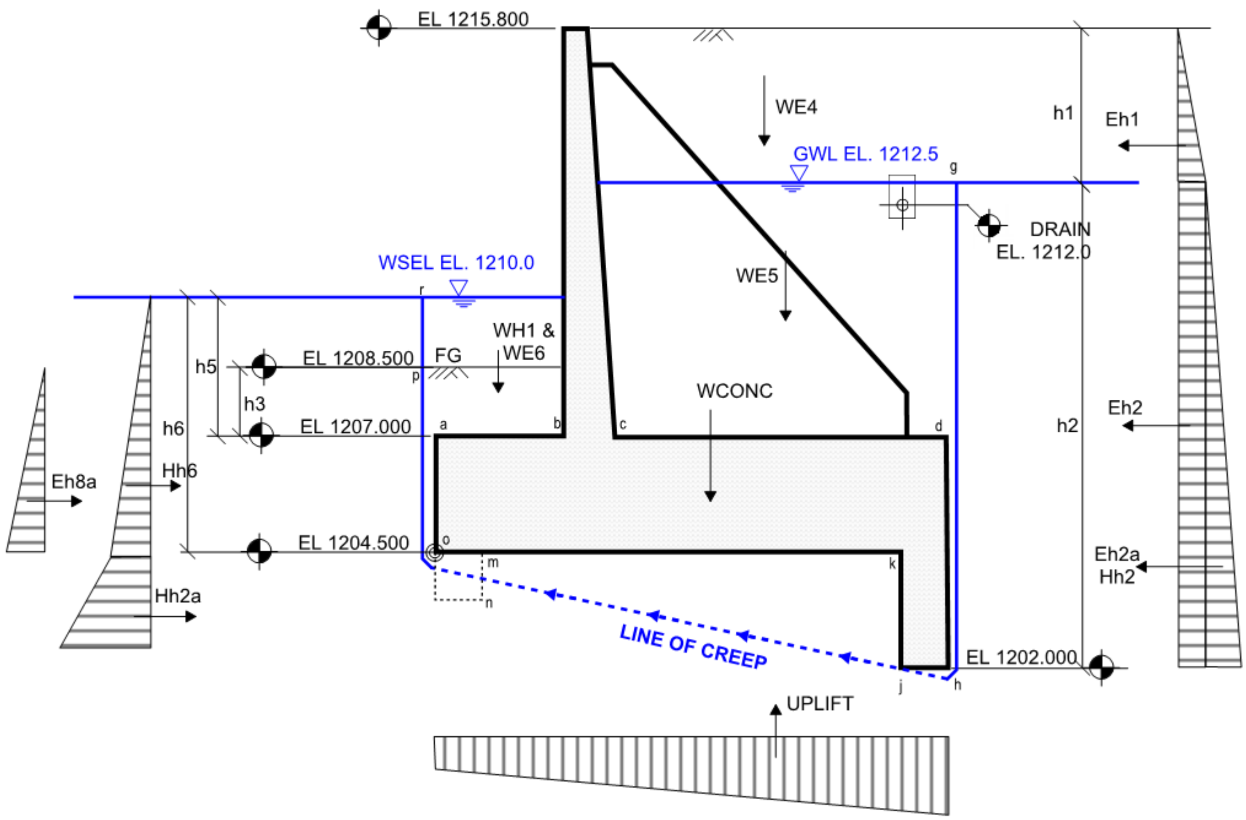
Rock Mass Mobilized: $V_{rocksection} := A_{rocksection} \cdot \gamma_r \cdot B = 320 \cdot kN$

(Pore pressure taken along assumed inclined sliding plane)

Distance from Toe to COG of Rock Section: $L_{rocksection} := \frac{Key_{hdist} \cdot (2 \cdot Key_{h.d} + Key_{t.d})}{3(Key_{h.d} + Key_{t.d})} + Key_{t.w} = 6.667\,m$

$\Sigma M_{rocksection} := V_{rocksection} \cdot L_{rocksection} = 2133.3\,m \cdot kN$

LOAD CASE U1 - NORMAL OPERATION



U1 DESIGN CASE

LOAD CASE U1 ACCEPTANCE PARAMETERS

FS sliding:

Usual (U) 1.5 (without cohesion) (Table 3-3, USACE EM 1110-2-2100)

Resultant Location:

Usual (U) Inside middle third ~100% base in compression

Required Factor of Safety for Sliding: $FS_{sliding.reqU1} := 1.5$ (Without Cohesion)

Allowable rock bearing pressure: $\sigma_{allowU1} := 1270kPa$ (Section 5.2, Design Criteria EM 1110-2-2100 Section 3-10)

Overturning Required Resultant Ratio: $X_{R.reqU1} := 0.333$ (EM 1110-2-2502, Figure 4-4)

Required Factor of Safety for Floatation $FS_{req.U1.flt} := 1.5$

SOIL HEIGHTS and Water Levels:

LOAD CASE U1

Heel Conditions:

Groundwater Elevation at Heel: $GWL_{U1} := 1212.5m$

Distance from Finish Grade to Groundwater at Heel: $h_{1U1} := \left[T_w - GWL_{U1} + \left(L_{cd} + t_{wb} - t_{wt}\right)\cdot \tan(\beta)\right] = 3.30\ m$

Distance from Water Surface to Bottom of Footing at Heel: $h_{2U1} := GWL_{U1} - Bot_{ftg} + Key_{h.d} = 10.50\ m$

Toe Conditions:

Water Surface Elevation at Toe: $WSEL_{U1} := 1210.0m$

Water Surface Elevation at Toe for Uplift: $UWSEL_{U1} := 1210.0\cdot m$

Finish Grade at Toe providing lateral resistance: $FG_{toeU1} := 1208.5\cdot m$

Soil Depth Above top of footing: $h_{3aU1} := FG_{toeU1} - Top_{ftg} = 1.5\ m$

$$h_{3U1} := \begin{cases} h_{3aU1} & \text{if } FG_{toeU1} - Top_{ftg} \ge 0 \\ 0 & \text{otherwise} \end{cases} = 1.5$$

Resisting Fill at Toe: $h_{4U1} := FG_{toeU1} - Bot_{ftg} + Key_{t.d} = 4.00\ m$

Distance from Water Level to Top of Footing: $h_{5U1} := WSEL_{U1} - Top_{ftg} = 3.00\ m$

Distance from Water Surface to Bottom of Footing: $h_{6U1} := WSEL_{U1} - Bot_{ftg} + Key_{t.d} = 5.50\cdot m$

Soil Depth Above WSEL: $h_{7aU1} := FG_{toeU1} - WSEL_{U1} = -1.5\ m$

$$h_{7U1} := \begin{cases} h_{7aU1} & \text{if } FG_{toeU1} - WSEL_{U1} \ge 0 \\ 0 & \text{otherwise} \end{cases} = 0$$

Soil Depth Below WSEL:

$$h_{8U1} := \begin{cases} WSEL_{U1} - Bot_{ftg} + Key_{t.d} & \text{if } FG_{toeU1} - WSEL_{U1} \ge 0 \\ h_{4U1} & \text{otherwise} \end{cases} = 4$$

For Line of Creep Method: $L_{ho.U1} := \sqrt{b^2 + \left(Key_{h.d} - Key_{t.d}\right)^2} = 11.281\ m$

Head Loss from Point g:

$\Delta h_{g.hj.U1} := h_{2U1} = 10.5\ m$ (to point h & j)

$\Delta h_{g.km.U1} := GWL_{U1} - Bot_{ftg} = 8\ m$ (to point k & m)

$\Delta h_{g.no.U1} := GWL_{U1} - Bot_{ftg} + Key_{t.d} = 8\ m$ (to point n & o)

$\Delta h_{g.p.U1} := GWL_{U1} - FG_{toeU1} = 4\ m$ (to point p)

$\Delta h_{g.r.U1} := GWL_{U1} - UWSEL_{U1} = 2.5\ m$ (to point r)

Surcharge

Surcharge on Heel: $S1_{U1} := 0.0\ \frac{kN}{m^2}$

LOAD CASE U1

Calculate Soil Lateral Pressure Coefficients:

For all load cases except seismic, soil loading to be based on At-Rest Condition.
Calculate at-rest pressure coefficient Ko based on Jaky's (1944) equation.

Soil At Rest Static Coefficient: $K_o := \dfrac{1 - \sin(\phi)}{1 + \sin(\beta)} = 0.546$ (Eq. 3-6, USACE EM 1110-2-2502)

Lateral - Driving Force (Headwater Side)

Lateral Soil Load:

Surcharge Load: $E_{s1U1} := S1_{U1} \cdot K_o \cdot \left(H_w + Key_{h.d}\right) \cdot B \cdot -1 = 0 \cdot kN$

Moment Arm (from bottom of footing): $E_{s1locU1} := \dfrac{H_w + Key_{h.d}}{2} + Key_{vdist} = 4.40\ m$

Moist Soil Load above GWL: $E_{h1U1} := \dfrac{\gamma_m \cdot K_o \cdot h_{1U1}^2}{2} B \cdot -1 = -59.5 \cdot kN$

Moment Arm (from bottom of footing): $E_{h1locU1} := \dfrac{h_{1U1}}{3} + h_{2U1} + Key_{vdist} = 9.10\ m$

Saturated Soil Load below GWL:
(rectangular component) $E_{h2U1} := \left(\gamma_m \cdot K_o \cdot h_{1U1}\right) \cdot \left(h_{2U1}\right) \cdot B \cdot -1 = -378.4 \cdot kN$

Moment Arm (from bottom of footing): $E_{h2locU1} := \dfrac{h_{2U1}}{2} + Key_{vdist} = 2.75\ m$

Saturated Soil Load below GWL:
(triangular component) $E_{h2aU1} := \dfrac{\left(\gamma_{sat} - \gamma_w\right) \cdot K_o \cdot h_{2U1}^2}{2} \cdot B \cdot -1 = -367.2 \cdot kN$

Moment Arm (from bottom of footing): $E_{h2alocU1} := \dfrac{h_{2U1}}{3} + Key_{vdist} = 1.00\ m$

Lateral Water Load:

Water Load GWL to Bottom of Key $H_{h2U1} := \dfrac{\gamma_w \cdot h_{2U1}^2}{2} \cdot B \cdot -1 = -540.2 \cdot kN$

Moment Arm (from bottom of footing): $H_{h2locU1} := \dfrac{h_{2U1}}{3} + Key_{vdist} = 1.00\ m$

$\Sigma H_{SoildriveU1} := E_{s1U1} + E_{h1U1} + E_{h2U1} + E_{h2aU1} + H_{h2U1} = -1345.3 \cdot kN$

$$\Sigma M_{LateralSoildriveU1} := E_{s1U1} \cdot E_{s1locU1} + E_{h1U1} \cdot E_{h1locU1} + E_{h2U1} \cdot E_{h2locU1} \ldots = -2489.1\ m \cdot kN$$
$$+ E_{h2aU1} \cdot E_{h2alocU1} + H_{h2U1} \cdot H_{h2locU1}$$

Lateral - Resisting Force (Tailwater Side)

LOAD CASE U1

Lateral Water Load:

Water Load WSEL to Bot. of Footing: $H_{h6U1} := \frac{\gamma_w \cdot h_{6U1}^2}{2} \cdot B = 148.2 \cdot kN$

Moment Arm (from bot. of toe key): $H_{h6locU1} := \frac{h_{6U1}}{3} = 1.83\ m$

Water Load Bot. of Footing to Bot. of H. Key: $H_{h2aU1} := \left[\left(UWSEL_{U1} - Bot_{ftg} + Key_{t.d}\right) + h_{2U1}\right] \cdot \frac{Key_{h.d}}{2} \cdot \gamma_w \cdot B = 196.0 \cdot kN$

Moment Arm (from bot. of toe key): $H_{h2alocU1} := \frac{Key_{h.d} \cdot \left[2 \cdot \left(UWSEL_{U1} - Bot_{ftg} + Key_{t.d}\right) + h_{2U1}\right]}{3\left[h_{2U1} + \left(UWSEL_{U1} - Bot_{ftg} + Key_{t.d}\right)\right]} \ldots = -1.38\ m$
$+ Key_{vdist}$

Lateral Soil Load:

Moist Soil Load above WSEL: $E_{h7U1} := \frac{\gamma_m \cdot K_o \cdot h_{7U1}^2}{2} \cdot B = 0.0 \cdot kN$

Moment Arm (from bot. of toe key): $E_{h7locU1} := h_{6U1} + \frac{h_{7U1}}{3} + Key_{vdist} = 3.00\ m$

Saturated Soil Load below WSEL:
(rectangular component) $E_{h8U1} := \left(\gamma_m \cdot K_o \cdot h_{7U1}\right) \cdot h_{8U1} \cdot B = 0.0 \cdot kN$

Moment Arm (from bot. of toe key): $E_{h8locU1} := \frac{h_{8U1}}{2} = 2.00\ m$

Saturated Soil Load below WSEL:
(triangular component) $E_{h8aU1} := \frac{\left[\left(\gamma_{sat} - \gamma_w\right) \cdot K_o\right] \cdot h_{8U1}^2}{2} \cdot B = 53.3 \cdot kN$

Moment Arm (from bot. of footing): $E_{h8alocU1} := \frac{h_{8U1}}{3} = 1.33\ m$

$\Sigma H_{SoilresistU1} := H_{h6U1} + H_{h2aU1} + E_{h7U1} + E_{h8U1} + E_{h8aU1} = 397.5 \cdot kN$

$\Sigma M_{HorizSoilResistU1} := H_{h6U1} \cdot H_{h6locU1} + H_{h2aU1} \cdot H_{h2alocU1} + E_{h7U1} \cdot E_{h7locU1} \ldots = 72.3\ m \cdot kN$
$+ E_{h8U1} \cdot E_{h8locU1} + E_{h8aU1} \cdot E_{h8alocU1}$

Vertical Force:

UPLIFT: Linear distribution from water at heel to water at toe:

$\Sigma V_{UpliftU1} := \left[\left(UWSEL_{U1} - Bot_{ftg} + Key_{t.d}\right) + h_{2U1}\right] \cdot \frac{b}{2} \cdot \gamma_w \cdot B \cdot -1 = -862.4 \cdot kN$

Moment Arm (from Point O): $V_{UpliftU1aloc} := \frac{b \cdot \left[2 \cdot h_{2U1} + \left(UWSEL_{U1} - Bot_{ftg} + Key_{t.d}\right)\right]}{3\left[h_{2U1} + \left(UWSEL_{U1} - Bot_{ftg} + Key_{t.d}\right)\right]} = 6.073\ m$

$\Sigma M_{UpliftU1} := \Sigma V_{UpliftU1} \cdot V_{UpliftU1aloc} = -5237.283 \cdot kN \cdot m$

Vertical Force (con't):

Weight of soil and water over toe:

Water Above the Top of Footing: $W_{H1U1} := \gamma_w \cdot h_{5U1} \cdot L_{ab} \cdot B = 80.85 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E1locU1} := \frac{L_{ab}}{2} = 1.375\,m$

Soil above top of footing: $W_{E6U1} := \gamma_b \cdot h_{3U1} \cdot L_{ab} \cdot B = 50.3 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E6locU1} := \frac{L_{ab}}{2} = 1.375\,m$

Vertical Load Due to Surcharge: $S_{U1} := S1_{U1} \cdot L_{cd} \cdot B = 0$ $\quad S_{U1loc} := b - \frac{L_{cd}}{2} = 7.47\,m$

Weight of soil and water over heel:

Moist Soil for sloped grade above top of wall:

Length of sloped portion of soil above top of wall: $L_{E3U1} := \left(L_{cd} + t_{wb} - t_{wt}\right) = 7.75\,m$

Height of sloped soil above top of wall over heel: $h_{E3locU1} := \left(L_{E3U1}\right) \cdot \tan(\beta) = 0.00\,m$

Weight of sloped soil above top of wall: $W_{E3U1} := \frac{\gamma_m}{2} \cdot h_{E3locU1} \cdot L_{E3U1} \cdot B = 0.0 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E3locU1} := L_{ab} + t_{wt} + \frac{2}{3} \cdot L_{E3U1} = 8.42\,m$

Moist soil from top of wall to groundwater level:

Height of soil from top of wall and top of GWL: $h_{1U1} = 3.30\,m$

Length from edge of wall at GWL to edge of heel: $L_{E4U1} := L_{E3U1} - \left(h_{1U1} \cdot S_{batter}\right) = 7.49\,m$

Weight of soil over heel from top of wall to GWL: $W_{E4U1} := \gamma_m \cdot h_{1U1} \cdot \frac{\left(L_{E3U1} + L_{E4U1}\right)}{2} \cdot B = 502.9 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E4locU1} := b - \frac{L_{E3U1}^2 + L_{E3U1} \cdot L_{E4U1} + L_{E4U1}^2}{3\left(L_{E3U1} + L_{E4U1}\right)} = 7.19\,m$

Saturated soil from groundwater to top of footing:

Height of soil from GWL to top of heel: $h_{E4U1} := h_{2U1} - t_{ftg} - Key_{h.d} = 5.50\,m$

Weight of soil over heel from GWL to top of heel: $W_{E5U1} := \left(\gamma_{sat}\right) \cdot h_{E4U1} \cdot \frac{\left(L_{E4U1} + L_{cd}\right)}{2} \cdot B = 880.3 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E5locU1} := b - \frac{L_{E4U1}^2 + L_{E4U1} \cdot L_{cd} + L_{cd}^2}{3\left(L_{E4U1} + L_{cd}\right)} = 7.36\,m$

$$\Sigma V_{SoilWaterU1} := W_{H1U1} + W_{E6U1} + W_{E3U1} + W_{E4U1} + W_{E5U1} + S_{U1} = 1514.4 \cdot kN$$

$$\Sigma M_{VertSoilWaterResistU1} := W_{H1U1} \cdot W_{E1locU1} + W_{E6U1} \cdot W_{E6locU1} \cdots + W_{E3U1} \cdot W_{E3locU1} + W_{E4U1} \cdot W_{E4locU1} + W_{E5U1} \cdot W_{E5locU1} + S_{U1} \cdot S_{U1loc} = 10276.3\,m \cdot kN$$

THIS PAGE INTENTIONALLY LEFT BLANK
PLEASE GO TO THE NEXT PAGE

CHECK SLIDING ALONG HORIZONTAL SLIDING PLANE:

Summation of the vertical forces:

$$\Sigma V_{U1} := \Sigma V_{conc} + \Sigma V_{SoilWaterU1} + \Sigma V_{UpliftU1} = 1531.8 \cdot kN$$

Summation of the horizontal forces:

$$\Sigma H_{U1} := \Sigma H_{SoildriveU1} + \Sigma H_{SoilresistU1} = -947.8 \cdot kN$$

Safety Factor for Sliding Horizontal Failure Plane

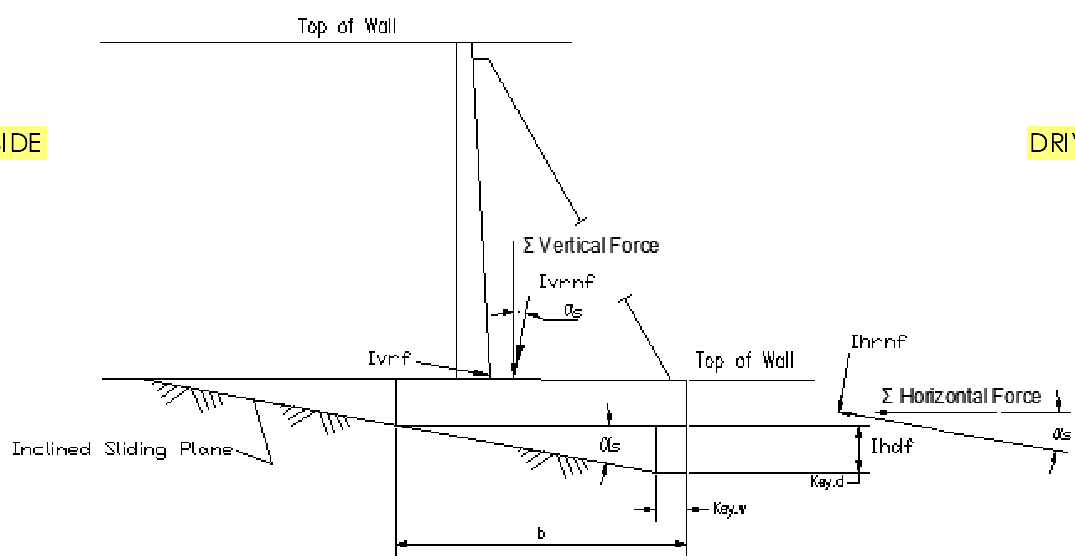
$$FS_{Horiz.SlidingU1} := \frac{\left|\Sigma V_{U1}\right| \cdot \tan\left(\phi_{rock} \cdot \frac{\pi}{180}\right)}{\left|\Sigma H_{U1}\right|} = 0.79$$

$$FS_{Sliding.check1.U1} := \begin{cases} \text{"OKAY "} & \text{if } FS_{Horiz.SlidingU1} > FS_{sliding.reqU1} \\ \text{"Key req'"} & \text{otherwise} \end{cases} = \text{"Key req'"}$$

CHECK FACTOR OF SAFETY SLIDING WITH KEY (INCLINED SLIDING PLANE):

RESISTING SIDE

DRIVING SIDE



TOE

HEEL

Ivrf=Inclined Resisting Force
Ivrnf=Inclined Resisting Normal Force
Ihrnf=Inclined Resisting Normal Force
Ihdf=Inclined Driving Force

$$\alpha s := \operatorname{atan}\left(\frac{-Key_{vdist}}{Key_{hdist}}\right) = 0.245 \qquad \text{as degrees=} \qquad \alpha s \cdot \left(\frac{180}{\pi}\right) = 14.04$$

(With properly engineered reinforced concrete Key, horizontal sliding plane thru Toe is protected, critical sliding plane is relocated to the INCLINED SLIDING PLANE FROM HEEL KEY To TOE, Bedrock Mass above this examing plane is mobilized by reinforced concrete key and combined into Structural Wedge.)

Resolve ΣV_{U1} & ΣH_{U1}

$$\Sigma V_{InclinedU1} := \cos(\alpha s) \cdot \left(\left|\Sigma V_{U1} + V_{rocksection}\right|\right) + \sin(\alpha s) \cdot \left|\Sigma H_{U1}\right| = 2026.4 \cdot kN$$

$$\Sigma H_{InclinedU1} := \cos(\alpha s) \cdot \left|\Sigma H_{U1}\right| - \sin(\alpha s) \cdot \left(\left|\Sigma V_{U1} + V_{rocksection}\right|\right) = 470.3 \cdot kN$$

LOAD CASE U1

Safety Factor for Sliding Inclined Failure Plane

$$FS_{InclinedlSlidingU1} := \frac{\Sigma V_{InclinedU1} \cdot \tan(\phi_r)}{\Sigma H_{InclinedU1}} = 1.92$$

$$FS_{Sliding.check2.U1} := \begin{cases} \text{"OKAY "} & \text{if } FS_{InclinedlSlidingU1} > FS_{sliding.reqU1} \\ \text{"NG - Revise Structure""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

CHECK FOUNDATION ECCENTRICITY:

Summation of the resisting moments about the toe:

$$\Sigma M_{resU1} := \Sigma M_{conc} + \Sigma M_{VertSoilWaterResistU1} + \Sigma M_{HorizSoilResistU1} + \Sigma M_{rocksection} = 17212 \cdot kN \cdot m$$

Summation of the overturning moments about the toe:

$$\Sigma M_{oU1} := \Sigma M_{LateralSoildriveU1} + \Sigma M_{UpliftU1} = -7726 \cdot kN \cdot m$$

Total moment: $\Sigma M_{U1} := \Sigma M_{resU1} + \Sigma M_{oU1} = 9485.7 \cdot kN \cdot m$

Normal force to base: $\Sigma V_{InclinedU1} = 2026.4 \cdot kN$

Inclined Sliding Plane Length: $L_{incline} := \frac{b}{\cos(\alpha s)} = 11.3\,m$

Eccentricity (inclined plane): $ex_{U1} := \frac{L_{incline}}{2} - \frac{\Sigma M_{U1}}{\Sigma V_{InclinedU1}} = 0.99\,m$ $\quad Kern := \frac{L_{incline}}{6} = 1.89\,m$

Eccentricity Check: $e_{check.U1} := \begin{cases} \text{"Okay"} & \text{if } ex_{U1} \le Kern \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"Okay"}$

CHECK FOUNDATION BEARING CAPACITY:

Base Section Modulus: $S_b := \frac{1}{6}\left(B \cdot L_{incline}^{\;2}\right) = 21.43\,m^3$

Bearing Pressure Under Toe:

$$\sigma_{ToeU1} := \begin{cases} \left(\frac{\Sigma V_{InclinedU1}}{L_{incline} \cdot B} + \frac{\Sigma V_{InclinedU1} \cdot ex_{U1}}{S_b}\right) & \text{if } \frac{\Sigma V_{InclinedU1} \cdot ex_{U1}}{S_b} \le \frac{\Sigma V_{InclinedU1}}{L_{incline} \cdot B} \\ \frac{2 \cdot \Sigma V_{InclinedU1}}{B \cdot 3\left(\frac{b}{2} - ex_{U1}\right)} & \text{otherwise} \end{cases} = 272.2 \cdot kPa$$

$$Bearing_{ChecktoeU1} := \begin{cases} \text{"OKAY "} & \text{if } \sigma_{ToeU1} < \sigma_{allowU1} \\ \text{"NG""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

Bearing Pressure Under Heel:

$$\sigma_{HeelU1} := \begin{cases} \left(\frac{\Sigma V_{InclinedU1}}{L_{incline} \cdot B} - \frac{\Sigma V_{InclinedU1} \cdot ex_{U1}}{S_b}\right) & \text{if } \frac{\Sigma V_{InclinedU1} \cdot ex_{U1}}{S_b} \le \frac{\Sigma V_{InclinedU1}}{L_{incline} \cdot B} \\ 0 & \text{otherwise} \end{cases} = 85.3 \cdot kPa$$

$$Bearing_{CheckheelU1} := \left(\begin{cases} \text{"OKAY "} & \text{if } \sigma_{HeelU1} < \sigma_{allowU1} \wedge \sigma_{HeelU1} > 0 \\ \text{"NG - perform cracked base analysis""} & \text{otherwise} \end{cases}\right) = \text{"OKAY "}$$

CHECK FLOATATION:

Safety Factor for Floatation:

$$FS_{FloatationU1} := \frac{\Sigma V_{conc} + \Sigma V_{SoilWaterU1}}{\left|\Sigma V_{UpliftU1}\right|} = 2.78$$

$$FS_{Floatation.U1.check} := \begin{cases} \text{"OKAY "} & \text{if } FS_{FloatationU1} > FS_{req.U1.flt} \\ \text{"Revise Structure""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

CHECK OVERTURNING

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.
Assumptions are made in order to compute overturning stablity of indetermine forces on monolith with key;
(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.
(b) The horizontal resisting force acting on the key, P.key, is that required for static equilibrium
(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1

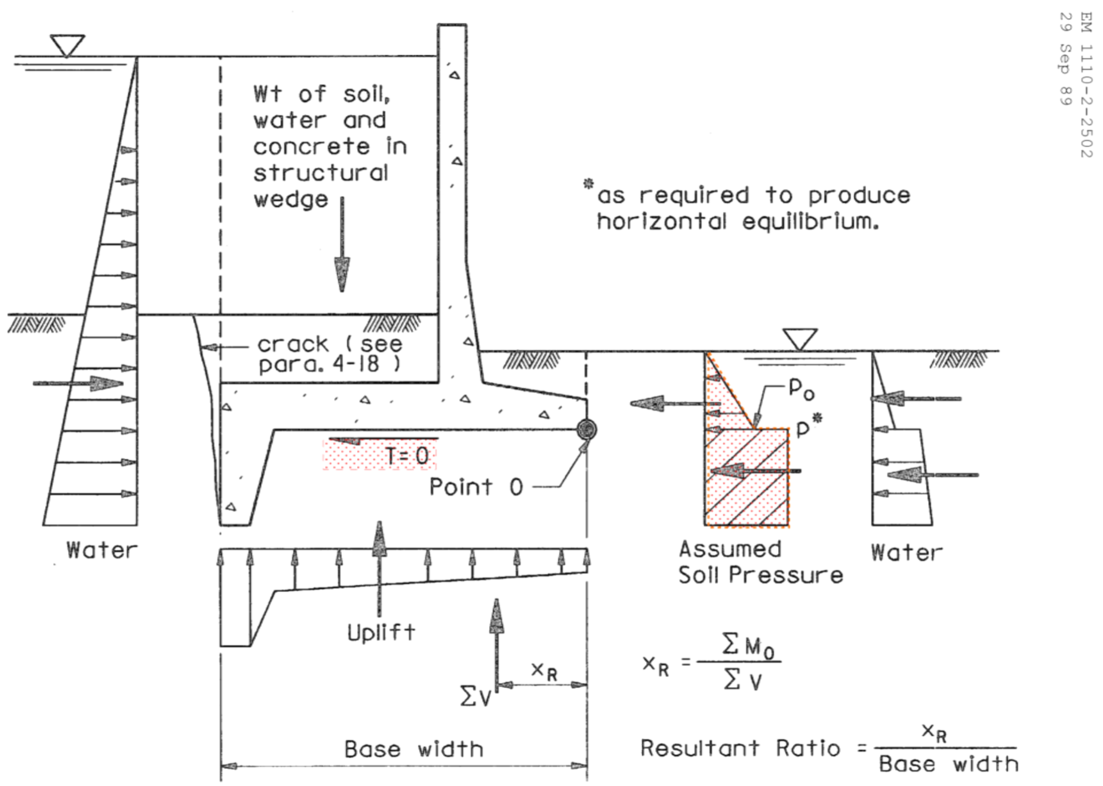


Figure 4-5. Forces for overturning analysis for wall with horizontal base and key

Modify Uplift for Overturning Analysis: **LOAD CASE U1**

(Uplift is calculated along the concrete/rock contact using the Line of Creep method)

Water Pressure at h: $u_{h.U1} := \Delta h_{g.hj.U1} \cdot \gamma_w = 102.90 \cdot kPa$

Water Pressure at o: $u_{o.U1} := \left(\Delta h_{g.no.U1} - \frac{\Delta h_{g.r.U1} \cdot L_{ho.U1}}{L_{ho.U1}}\right) \cdot \gamma_w = 53.9 \cdot kPa$

Head loss between point h and o: $\Delta h_{ho.U1} := \Delta h_{g.r.U1} \cdot \frac{L_{ho.U1}}{L_{ho.U1}} = 2.5\,m$

Length of concrete base (h -> o): $L_{baseho.U1} := Key_{h.w} + Key_{h.d} + Key_{hdist} + Key_{t.d} + Key_{t.w} = 13.5\,m$

Head loss along h -> j: $\Delta h_{hj.U1} := \Delta h_{ho.U1} \cdot \frac{Key_{h.w}}{L_{baseho.U1}} = 0.185\,m$

Water Pressure at j: $u_{j.U1} := \left(\Delta h_{g.hj.U1} - \Delta h_{hj.U1}\right) \cdot \gamma_w = 101.09 \cdot kPa$

Head loss along h -> k: $\Delta h_{hjk.U1} := \Delta h_{ho.U1} \cdot \left(\frac{Key_{h.w} + Key_{h.d}}{L_{baseho.U1}}\right) = 0.648\,m$

Water Pressure at k: $u_{k.U1} := \left(\Delta h_{g.km.U1} - \Delta h_{hjk.U1}\right) \cdot \gamma_w = 72.05 \cdot kPa$

Head loss along h -> m: $\Delta h_{hjkm.U1} := \Delta h_{ho.U1} \cdot \left(\frac{Key_{h.w} + Key_{h.d} + Key_{hdist}}{L_{baseho.U1}}\right) = 2.5\,m$

Water Pressure at m: $u_{m.U1} := \left(\Delta h_{g.km.U1} - \Delta h_{hjkm.U1}\right) \cdot \gamma_w = 53.90 \cdot kPa$

Head loss along h -> n: $\Delta h_{hjkmn.U1} := \Delta h_{ho.U1} \cdot \left(\frac{Key_{h.w} + Key_{h.d} + Key_{hdist} + Key_{t.d}}{L_{baseho.U1}}\right) = 2.5\,m$

Water Pressure at n: $u_{n.U1} := \left(\Delta h_{g.no.U1} - \Delta h_{hjkmn.U1}\right) \cdot \gamma_w = 53.90 \cdot kPa$

Uplift under key at heel: $V_{ulkeyhU1.OT} := \frac{\left(u_{h.U1} + u_{j.U1}\right) \cdot Key_{h.w}}{2} \cdot B \cdot -1 = -101.993 \cdot kN$

Moment Arm (from Point O): $V_{ulkeyhU1loc.OT} := b - \frac{Key_{h.w} \cdot \left(2 \cdot u_{j.U1} + u_{h.U1}\right)}{3 \cdot \left(u_{j.U1} + u_{h.U1}\right)} = 10.501\,m$

Uplift under base: $V_{ulbaseU1.OT} := \frac{\left(u_{k.U1} + u_{m.U1}\right) \cdot Key_{hdist}}{2} \cdot B \cdot -1 = -629.741 \cdot kN$

Moment Arm (from Point O): $V_{ulbaseU1loc.OT} := b - Key_{h.w} - \frac{Key_{hdist} \cdot \left(2 \cdot u_{m.U1} + u_{k.U1}\right)}{3 \cdot \left(u_{m.U1} + u_{k.U1}\right)} = 5.24\,m$

Uplift under key at toe $V_{ulkeytU1.OT} := \frac{\left(u_{n.U1} + u_{o.U1}\right) \cdot Key_{t.w}}{2} \cdot B \cdot -1 = 0 \cdot kN$

Moment Arm (from Point O): $V_{ulkeytU1loc.OT} := \frac{Key_{t.w} \cdot \left(2 \cdot u_{n.U1} + u_{o.U1}\right)}{3 \cdot \left(u_{n.U1} + u_{o.U1}\right)} = 0$

$$\Sigma V_{UpliftU1.OT} := V_{ulkeyhU1.OT} + V_{ulbaseU1.OT} + V_{ulkeytU1.OT} = -732 \cdot kN$$

$$U_{U1.loc.OT} := \frac{V_{ulkeyhU1.OT} \cdot V_{ulkeyhU1loc.OT} + V_{ulbaseU1.OT} \cdot V_{ulbaseU1loc.OT} + V_{ulkeytU1.OT} \cdot V_{ulkeytU1loc.OT}}{\Sigma V_{UpliftU1.OT}} = 5.97\,m$$

$$\Sigma M_{UpliftU1.OT} := \Sigma V_{UpliftU1.OT} \cdot U_{U1.loc.OT} = -4371.0 \cdot kN \cdot m$$

Modify Lateral Water Pressure (Resisting) for Overturning Analysis:

(Resisting water pressure is calculated using the Line of Creep method)

Water Load at Key (heel):
$$H_{h2U1.OT} := \frac{u_{k.U1} + u_{j.U1}}{2} \cdot Key_{h.d} B = 216.4 \cdot kN$$

Moment Arm (from Point O):
$$H_{h2locU1.OT} := \frac{Key_{h.d} \cdot \left(2 \cdot u_{k.U1} + u_{j.U1}\right)}{3\left(u_{k.U1} + u_{j.U1}\right)} + Key_{vdist} = -1.32\ m$$

Water Load at Key (toe):
$$H_{h6U1.OT} := \frac{u_{o.U1} \cdot \left(UWSEL_{U1} - Bot_{ftg} + Key_{t.d}\right)}{2} \cdot B = 148 \cdot kN$$

Moment Arm (from Point O):
$$H_{h6locU1.OT} := \frac{UWSEL_{U1} - Bot_{ftg} + Key_{t.d}}{3} = 1.83\ m$$

$$\Sigma H_{waterresistU1.OT} := H_{h2U1.OT} + H_{h6U1.OT} = 364.64 \cdot kN$$

$$H_{waterresistlocU1.OT} := \frac{H_{h2U1.OT} \cdot H_{h2locU1.OT} + H_{h6U1.OT} \cdot H_{h6locU1.OT}}{\Sigma H_{waterresistU1.OT}} = -0.038\ m$$

$$\Sigma M_{waterresistU1.OT} := \Sigma H_{waterresistU1.OT} \cdot H_{waterresistlocU1.OT} = -13.9 \cdot kN \cdot m$$

Modify Lateral Soil Loads for Overturning Analysis:

(Lateral soil loads are calculated down to Point O instead of bottom of shear key)

Driving Soil Load (Headwater Side):

Surcharge Load:
$$E_{s1U1.OT} := S1_{U1} \cdot K_o \cdot \left(H_w + Key_{h.d} + Key_{vdist}\right) \cdot B \cdot -1 = 0 \cdot kN$$

Moment Arm (from Point O):
$$E_{s1locU1.OT} := \frac{H_w + Key_{h.d} + Key_{vdist}}{2} = 5.65\ m$$

Moist Soil Load above GWL:
$$E_{h1U1.OT} := \frac{\gamma_m \cdot K_o \cdot h_{1U1}^{\ 2}}{2} \cdot B \cdot -1 = -59.5 \cdot kN$$

Moment Arm (from Point O):
$$E_{h1locU1.OT} := \frac{h_{1U1}}{3} + h_{2U1} + Key_{vdist} = 9.10\ m$$

Saturated Soil Load below GWL:
(rectangular component)
$$E_{h2U1.OT} := \left(\gamma_m \cdot K_o \cdot h_{1U1}\right) \cdot \left(h_{2U1} + Key_{vdist}\right) \cdot B \cdot -1 = -288.3 \cdot kN$$

Moment Arm (from Point O):
$$E_{h2locU1.OT} := \frac{h_{2U1} + Key_{vdist}}{2} = 4.00\ m$$

Saturated Soil Load below GWL:
(triangular component)
$$E_{h2aU1.OT} := \frac{\left(\gamma_{sat} - \gamma_w\right) \cdot K_o \cdot \left(h_{2U1} + Key_{vdist}\right)^2}{2} \cdot B \cdot -1 = -213.2 \cdot kN$$

Moment Arm (from Point O):
$$E_{h2alocU1.OT} := \frac{h_{2U1} + Key_{vdist}}{3} = 2.67\ m$$

Resisting Soil Load (Tailwater Side):

(Determine resisting soil load based on depth variation between the keys (ie. Key_{vdist}). In case where key at heel is deeper than key at toe (ie. $Key_{vdist}< 0$), resisting soil load (p*) is assumed to produce horizontal equilibrium as per Figure 4-5 above. Resisting soil load (p_o) is neglected.)

Total Driving Force: $\Sigma H_{SoildriveU1.OT} := E_{s1U1.OT} + E_{h1U1.OT} + E_{h2U1.OT} + E_{h2aU1.OT} + H_{h2U1} = -1101.1 \cdot kN$

Total Resisting Force: $\Sigma H_{waterresistU1.OT} = 364.6 \cdot kN$

Assumed Soil Load p*: $E_{h8U1a.OT} := \left(\Sigma H_{SoildriveU1.OT} + \Sigma H_{waterresistU1.OT}\right) \cdot -1 = 736.499 \cdot kN$

Moment Arm (from Point O): $E_{h8U1a.loc.OT} := \dfrac{Key_{vdist}}{2} = -1.25\, m$

$$E_{h8U1.OT} := \begin{cases} E_{h8U1a.OT} & \text{if } Key_{vdist} < 0 \\ \Sigma H_{SoilresistU1} - H_{h6U1} - H_{h2aU1} & \text{otherwise} \end{cases} = 736.499 \cdot kN$$

$$\Sigma M_{SoilresistU1} := \begin{cases} E_{h8U1a.OT} \cdot E_{h8U1a.loc.OT} & \text{if } Key_{vdist} < 0 \\ \Sigma M_{HorizSoilResistU1} - H_{h6U1} \cdot H_{h6locU1} - H_{h2aU1} \cdot H_{h2alocU1} & \text{otherwise} \end{cases} = -920.624 \cdot kN \cdot m$$

Sum of Moment about Point O:

$$\Sigma M_{LateraldriveU1.OT} := E_{s1U1.OT} \cdot E_{s1locU1.OT} + E_{h1U1.OT} \cdot E_{h1locU1.OT} + E_{h2U1.OT} \cdot E_{h2locU1.OT} \dots + E_{h2aU1.OT} \cdot E_{h2alocU1.OT} + H_{h2U1} \cdot H_{h2locU1} = -2802.9 \cdot kN \cdot m$$

$$\Sigma M_{LateralresistU1.OT} := \Sigma M_{waterresistU1.OT} + \Sigma M_{SoilresistU1} = -934.5 \cdot kN \cdot m$$

Total moment:

$$\Sigma M_{U1.OT} := \Sigma M_{conc} + \Sigma M_{VertSoilWaterResistU1} + \Sigma M_{UpliftU1.OT} + \Sigma M_{LateraldriveU1.OT} + \Sigma M_{LateralresistU1.OT} = 6898.0 \cdot kN \cdot m$$

Total Vertical Force: $\Sigma V_{U1.OT} := \Sigma V_{conc} + \Sigma V_{SoilWaterU1} + \Sigma V_{UpliftU1.OT} = 1662.5 \cdot kN$

Distance X_R: EM 1110-2-2502 Eq.4-1 $X_{R.U1} := \dfrac{\Sigma M_{U1.OT}}{\Sigma V_{U1.OT}} = 4.149\, m$

Overturning Resultant Ratio $Ratio_{U1.OT} := \dfrac{X_{R.U1}}{b} = 0.38$

$$Ratio_{U1.OT.check} := \begin{cases} \text{"OKAY "} & \text{if } Ratio_{U1.OT} > X_{R.reqU1} \\ \text{"Revise Structure""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

CHECK FOUNDATION ECCENTRICITY (HORIZONTAL PLANE):

Eccentricity (horizontal plan): $ex_{U1.OT} := \dfrac{b}{2} - \dfrac{\Sigma M_{U1.OT}}{\Sigma V_{U1.OT}} = 1.35\, m$ $Kern_{OT} := \dfrac{b}{6} = 1.833\, m$

Eccentricity Check: $$e_{check.U1.OT} := \begin{cases} \text{"Okay"} & \text{if } ex_{U1} \le Kern_{OT} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"Okay"}$$

CHECK FOUNDATION BEARING CAPACITY (HORIZONTAL PLANE):

Base Section Modulus: $S_{b.OT} := \frac{1}{6}\left(B\cdot b^2\right) = 20.17\,m^3$

Bearing Pressure Under Toe:

$$\sigma_{ToeU1.OT} := \begin{cases} \left(\frac{\Sigma V_{U1.OT}}{b\cdot B} + \frac{\Sigma V_{U1.OT}\cdot ex_{U1.OT}}{S_{b.OT}}\right) & \text{if } \frac{\Sigma V_{U1.OT}}{b\cdot B} \ge \frac{\Sigma V_{U1.OT}\cdot ex_{U1.OT}}{S_{b.OT}} \\ \frac{2\cdot \Sigma V_{U1.OT}}{B\cdot 3\left(\frac{b}{2} - ex_{U1.OT}\right)} & \text{otherwise} \end{cases} = 262.5\cdot kPa$$

$$Bearing_{ChecktoeU1.OT} := \begin{cases} \text{"OKAY "} & \text{if } \sigma_{ToeU1.OT} < \sigma_{allowU1} \\ \text{"NG - for reference only""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

Bearing Pressure Under Heel:

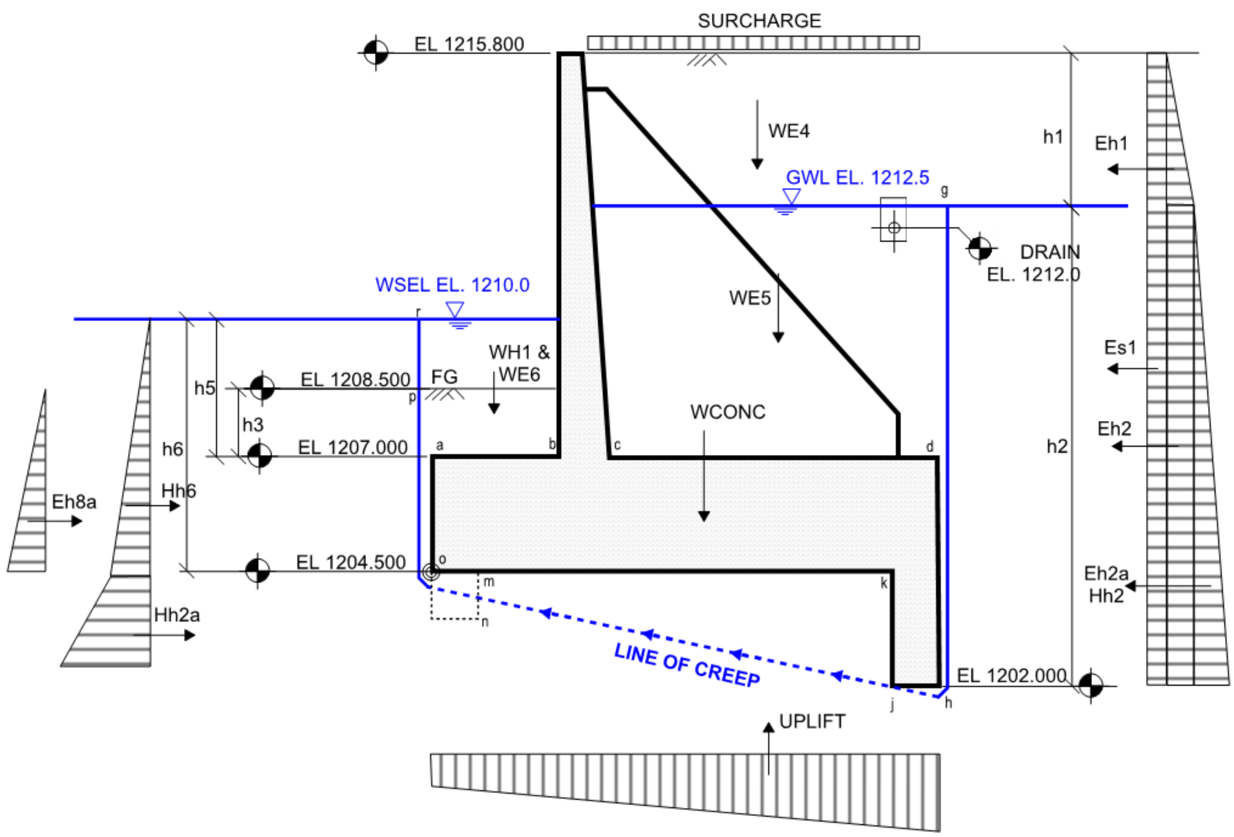
$$\sigma_{HeelU1.OT} := \begin{cases} \left(\frac{\Sigma V_{U1.OT}}{b\cdot B} - \frac{\Sigma V_{U1.OT}\cdot ex_{U1.OT}}{S_{b.OT}}\right) & \text{if } \frac{\Sigma V_{U1.OT}}{b\cdot B} \ge \frac{\Sigma V_{U1.OT}\cdot ex_{U1.OT}}{S_{b.OT}} \\ 0 & \text{otherwise} \end{cases} = 39.8\cdot kPa$$

$$Bearing_{CheckheelU1.OT} := \left(\begin{cases} \text{"OKAY "} & \text{if } \sigma_{HeelU1.OT} < \sigma_{allowU1} \wedge \sigma_{HeelU1.OT} > 0 \\ \text{"NG - for reference only""} & \text{otherwise} \end{cases}\right) = \text{"OKAY "}$$

SUMMARY OF STABILITY ASSESSMENT:

LOAD CASE U1

Sliding Factor of Safety: (Horizontal Plane - Ref only)	$FS_{Horiz.SlidingU1} = 0.79$	$FS_{Sliding.check1.U1}$ = "Key req""
Sliding Factor of Safety: (Inclined Plane)	$FS_{InclinedlSlidingU1} = 1.92$	$FS_{Sliding.check2.U1}$ = "OKAY "
Eccentricity: (Inclined Plane)	$ex_{U1} = 0.99\ m$	$e_{check.U1}$ = "Okay"
Bearing Pressure At Heel: (Inclined Plane)	$\sigma_{HeelU1} = 85 \cdot kPa$	$Bearing_{CheckheelU1}$ = "OKAY "
Bearing Pressure At Toe: (Inclined Plane)	$\sigma_{ToeU1} = 272 \cdot kPa$	$Bearing_{ChecktoeU1}$ = "OKAY "
Flotation Factor of Safety (horizontal plane)	$FS_{FloatationU1} = 2.78$	$FS_{Floatation.U1.check}$ = "OKAY "
Overturning Resultant Ratio: (horizontal plane)	$Ratio_{U1.OT} = 0.38$	$Ratio_{U1.OT.check}$ = "OKAY "
Eccentricity: (horizontal plane - Ref only)	$ex_{U1.OT} = 1.35\ m$	$e_{check.U1.OT}$ = "Okay"
Bearing Pressure At Heel: (horizontal plane - Ref only)	$\sigma_{HeelU1.OT} = 40 \cdot kPa$	$Bearing_{CheckheelU1.OT}$ = "OKAY "
Bearing Pressure At Toe: (horizontal plane - Ref only)	$\sigma_{ToeU1.OT} = 262 \cdot kPa$	$Bearing_{ChecktoeU1.OT}$ = "OKAY "



UN1 DESIGN CASE

LOAD CASE UN1 ACCEPTANCE PARAMETERS

FS sliding:

Unusual (UN) 1.3 (without cohesion) (Table 3-3, USACE EM 1110-2-2100)

Resultant Location:

Unsual (UN) Inside middle third ~100% base in compression

Required Factor of Safety for Sliding: $FS_{sliding.reqUN1} := 1.3$ (Without Cohesion)

Allowable rock bearing pressure: $\sigma_{allowUN1} := 1470kPa$ (Section 5.2, Design Criteria EM 1110-2-2100 Section 3-10)

Overturning Required Resultant Ratio: $X_{R.reqUN1} := 0.333$ (EM 1110-2-2502, Figure 4-4)

Required Factor of Safety for Floatation $FS_{req.UN1.flt} := 1.3$

SOIL HEIGHTS and Water Levels:

LOAD CASE UN1

Heel Conditions:

Groundwater Elevation at Heel: $GWL_{UN1} := 1212.5m$

Distance from Finish Grade to Groundwater at Heel: $h_{1UN1} := \left[T_w - GWL_{UN1} + \left(L_{cd} + t_{wb} - t_{wt}\right)\cdot\tan(\beta)\right] = 3.30\ m$

Distance from Water Surface to Bottom of Footing at Heel: $h_{2UN1} := GWL_{UN1} - Bot_{ftg} + Key_{h.d} = 10.50\ m$

Toe Conditions:

Water Surface Elevation at Toe: $WSEL_{UN1} := 1210.0m$

Water Surface Elevation at Toe for Uplift: $UWSEL_{UN1} := 1210.0\cdot m$

Finish Grade at Toe providing lateral resistance: $FG_{toeUN1} := 1208.5\cdot m$

Soil Depth Above top of footing: $h_{3aUN1} := FG_{toeUN1} - Top_{ftg} = 1.5\ m$

$$h_{3UN1} := \begin{cases} h_{3aUN1} & \text{if } FG_{toeUN1} - Top_{ftg} \geq 0 \\ 0 & \text{otherwise} \end{cases} = 1.5$$

Resisting Fill at Toe: $h_{4UN1} := FG_{toeUN1} - Bot_{ftg} + Key_{t.d} = 4.00\ m$

Distance from Water Level to Top of Footing at Toe: $h_{5UN1} := WSEL_{UN1} - Top_{ftg} = 3.00\ m$

Distance from Water Surface to Bottom of Footing at Toe: $h_{6UN1} := WSEL_{UN1} - Bot_{ftg} + Key_{t.d} = 5.50\ m$

Soil Depth Above WSEL: $h_{7aUN1} := FG_{toeUN1} - WSEL_{UN1} = -1.5\ m$

$$h_{7UN1} := \begin{cases} h_{7aUN1} & \text{if } FG_{toeUN1} - WSEL_{UN1} \geq 0 \\ 0 & \text{otherwise} \end{cases} = 0$$

Soil Depth Below WSEL:

$$h_{8UN1} := \begin{cases} WSEL_{UN1} - Bot_{ftg} + Key_{t.d} & \text{if } FG_{toeUN1} - WSEL_{UN1} \geq 0 \\ h_{4UN1} & \text{otherwise} \end{cases} = 4$$

For Line of Creep Method: $L_{ho.UN1} := \sqrt{b^2 + \left(Key_{h.d} - Key_{t.d}\right)^2} = 11.281\ m$

Head Loss from Point g:

$\Delta h_{g.hj.UN1} := h_{2UN1} = 10.5\ m$ (to point h & j)

$\Delta h_{g.km.UN1} := GWL_{UN1} - Bot_{ftg} = 8\ m$ (to point k & m)

$\Delta h_{g.no.UN1} := GWL_{UN1} - Bot_{ftg} + Key_{t.d} = 8\ m$ (to point n & o)

$\Delta h_{g.p.UN1} := GWL_{UN1} - FG_{toeUN1} = 4\ m$ (to point p)

$\Delta h_{g.r.UN1} := GWL_{UN1} - UWSEL_{UN1} = 2.5\ m$ (to point r)

Surcharge

Surcharge on Heel: $S1_{UN1} := 15.0\ \frac{kN}{m^2}$

LOAD CASE UN1

Calculate Soil Lateral Pressure Coefficients:

For all load cases except seismic, soil loading to be based on At-Rest Condition.
Calculate at-rest pressure coefficient Ko based on Jaky's (1944) equation.

Soil At Rest Static Coefficient: $K_o := \frac{1 - \sin(\phi)}{1 + \sin(\beta)} = 0.546$ (Eq. 3-6, USACE EM 1110-2-2502)

Lateral - Driving Force

Static At-Rest:

Surcharge Load: $E_{s1UN1} := S1_{UN1} \cdot K_o \cdot \left(H_w + Key_{h.d}\right) \cdot B \cdot -1 = -113.024 \cdot kN$

Moment Arm (from bottom of footing): $E_{s1locUN1} := \frac{H_w + Key_{h.d}}{2} + Key_{vdist} = 4.40\ m$

Moist Soil Load above GWL: $E_{h1UN1} := \frac{\gamma_m \cdot K_o \cdot h_{1UN1}^{\ 2}}{2} B \cdot -1 = -59.5 \cdot kN$

Moment Arm (from bottom of footing): $E_{h1locUN1} := \frac{h_{1UN1}}{3} + h_{2UN1} + Key_{vdist} = 9.10\ m$

Saturated Soil Load below GWL:
(rectangular component) $E_{h2UN1} := \left(\gamma_m \cdot K_o \cdot h_{1UN1}\right) \cdot \left(h_{2UN1}\right) \cdot B \cdot -1 = -378.4 \cdot kN$

Moment Arm (from bottom of footing): $E_{h2locUN1} := \frac{h_{2UN1}}{2} + Key_{vdist} = 2.75\ m$

Saturated Soil Load below GWT:
(triangular L $E_{h2aUN1} := \frac{\left(\gamma_{sat} - \gamma_w\right) \cdot K_o \cdot h_{2UN1}^{\ 2}}{2} \cdot B \cdot -1 = -367.2 \cdot kN$

Moment Arm (from bottom of footing): $E_{h2alocUN1} := \frac{h_{2UN1}}{3} + Key_{vdist} = 1.00\ m$

Lateral Water Load:

Water Load GWL to Bottom of Key $H_{h2UN1} := \frac{\gamma_w \cdot h_{2UN1}^{\ 2}}{2} \cdot B \cdot -1 = -540.2 \cdot kN$

Moment Arm (from bottom of footing): $H_{h2locUN1} := \frac{h_{2UN1}}{3} + Key_{vdist} = 1.00\ m$

$$\Sigma H_{SoildriveUN1} := E_{s1UN1} + E_{h1UN1} + E_{h2UN1} + E_{h2aUN1} + H_{h2UN1} = -1458.3 \cdot kN$$

$$\Sigma M_{LateralSoildriveUN1} := E_{s1UN1} \cdot E_{s1locUN1} + E_{h1UN1} \cdot E_{h1locUN1} + E_{h2UN1} \cdot E_{h2locUN1} \ldots = -2986.4\ m \cdot kN$$
$$+ E_{h2aUN1} \cdot E_{h2alocUN1} + H_{h2UN1} \cdot H_{h2locUN1}$$

Lateral - Resisting Force

LOAD CASE UN1

Lateral Water Load:

Water Load WSEL to Bottom of Footing:

$$H_{h6UN1} := \frac{\gamma_w \cdot h_{6UN1}^{\ 2}}{2} \cdot B = 148.2 \cdot kN$$

Moment Arm (from bot. of toe key):

$$H_{h6locUN1} := \frac{h_{6UN1}}{3} = 1.83\ m$$

Water Load Bot. of Footing to Bot. of H. Key:

$$H_{h2aUN1} := \left[\left(UWSEL_{UN1} - Bot_{ftg} + Key_{t.d}\right) + h_{2UN1}\right] \cdot \frac{Key_{h.d}}{2} \cdot \gamma_w \cdot B = 196.0 \cdot kN$$

Moment Arm (from bot. of toe key):

$$H_{h2alocUN1} := \frac{Key_{h.d} \cdot \left[2 \cdot \left(UWSEL_{UN1} - Bot_{ftg} + Key_{t.d}\right) + h_{2UN1}\right]}{3\left[h_{2UN1} + \left(UWSEL_{UN1} - Bot_{ftg} + Key_{t.d}\right)\right]} \ ... \ + Key_{vdist} = -1.38\ m$$

Lateral Soil Load:

Moist Soil Load above WSEL:

$$E_{h7UN1} := \frac{\gamma_m \cdot K_o \cdot h_{7UN1}^{\ 2}}{2} B = 0.0 \cdot kN$$

Moment Arm (from bot. of toe key):

$$E_{h7locUN1} := h_{6UN1} + \frac{h_{7UN1}}{3} + Key_{vdist} = 3.00\ m$$

Saturated Soil Load below WSEL:
(rectangular component)

$$E_{h8UN1} := \left(\gamma_m \cdot K_o \cdot h_{7UN1}\right) \cdot h_{8UN1} \cdot B = 0.0 \cdot kN$$

Moment Arm (from bot. of toe key):

$$E_{h8locUN1} := \frac{h_{8UN1}}{2} = 2.00\ m$$

Saturated Soil Load below WSEL:
(triangular component)

$$E_{h8aUN1} := \frac{\left[\left(\gamma_{sat} - \gamma_w\right) \cdot K_o\right] \cdot h_{8UN1}^{\ 2}}{2} \cdot B = 53.3 \cdot kN$$

Moment Arm (from bot. of footing):

$$E_{h8alocUN1} := \frac{h_{8UN1}}{3} = 1.33\ m$$

$$\Sigma H_{SoilresistUN1} := H_{h6UN1} + H_{h2aUN1} + E_{h7UN1} + E_{h8UN1} + E_{h8aUN1} = 397.5 \cdot kN$$

$$\Sigma M_{HorizSoilResistUN1} := H_{h6UN1} \cdot H_{h6locUN1} + H_{h2aUN1} \cdot H_{h2alocUN1} + E_{h7UN1} \cdot E_{h7locUN1} \ ... \ + E_{h8UN1} \cdot E_{h8locUN1} + E_{h8aUN1} \cdot E_{h8alocUN1} = 72.3\ m \cdot kN$$

Vertical Force:

UPLIFT: Linear distribution from water at heel to water at toe:

$$\Sigma V_{UpliftUN1} := \left[\left(UWSEL_{UN1} - Bot_{ftg} + Key_{t.d}\right) + h_{2UN1}\right] \cdot \frac{b}{2} \cdot \gamma_w \cdot B \cdot -1 = -862.4 \cdot kN$$

Moment Arm (from Point O):

$$V_{UpliftUN1aloc} := \frac{b \cdot \left[2 \cdot h_{2UN1} + \left(UWSEL_{UN1} - Bot_{ftg} + Key_{t.d}\right)\right]}{3\left[h_{2UN1} + \left(UWSEL_{UN1} - Bot_{ftg} + Key_{t.d}\right)\right]} = 6.073\ m$$

$$\Sigma M_{UpliftUN1} := \Sigma V_{UpliftUN1} \cdot V_{UpliftUN1aloc} = -5237.283 \cdot kN \cdot m$$

Weight of soil and water over toe:

Water Above the Top of Footing: $W_{H1UN1} := \gamma_w \cdot h_{5UN1} \cdot L_{ab} \cdot B = 80.85 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E1locUN1} := \frac{L_{ab}}{2} = 1.375\,m$

Soil above top of footing: $W_{E6UN1} := \gamma_b \cdot h_{3UN1} \cdot L_{ab} \cdot B = 50.3 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E6locUN1} := \frac{L_{ab}}{2} = 1.375\,m$

Vertical Load Due to Surcharge: $S_{UN1} := S1_{UN1} \cdot L_{cd} \cdot B = 105.885 \cdot kN$ $\quad S_{UN1loc} := b - \frac{L_{cd}}{2} = 7.47\,m$

Weight of soil and water over heel:

Moist Soil for sloped grade above top of wall:

Length of sloped portion of soil above top of wall: $L_{E3UN1} := \left(L_{cd} + t_{wb} - t_{wt}\right) = 7.75\,m$

Height of sloped soil above top of wall over heel: $h_{E3locUN1} := \left(L_{E3UN1}\right) \cdot \tan(\beta) = 0.00\,m$

Weight of sloped soil above top of wall: $W_{E3UN1} := \frac{\gamma_m}{2} \cdot h_{E3locUN1} \cdot L_{E3UN1} \cdot B = 0.0 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E3locUN1} := L_{ab} + t_{wt} + \frac{2}{3} \cdot L_{E3UN1} = 8.42\,m$

Moist soil from top of wall to groundwater level:

Height of soil from top of wall and top of GWL: $h_{1UN1} = 3.30\,m$

Length from edge of wall at GWL to edge of heel: $L_{E4UN1} := L_{E3UN1} - \left(h_{1UN1} \cdot S_{batter}\right) = 7.49\,m$

Weight of soil over heel from top of wall to GWL: $W_{E4UN1} := \gamma_m \cdot h_{1UN1} \cdot \frac{\left(L_{E3UN1} + L_{E4UN1}\right)}{2} \cdot B = 502.9 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E4locUN1} := b - \frac{L_{E3UN1}^2 + L_{E3UN1} \cdot L_{E4UN1} + L_{E4UN1}^2}{3\left(L_{E3UN1} + L_{E4UN1}\right)} = 7.19\,m$

Saturated soil from groundwater to top of footing:

Height of soil from GWL to top of heel: $h_{E4UN1} := h_{2UN1} - t_{ftg} - Key_{h.d} = 5.50\,m$

Weight of soil over heel from GWL to top of heel: $W_{E5UN1} := \left(\gamma_{sat}\right) \cdot h_{E4UN1} \cdot \frac{\left(L_{E4UN1} + L_{cd}\right)}{2} \cdot B = 880.3 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E5locUN1} := b - \frac{L_{E4UN1}^2 + L_{E4UN1} \cdot L_{cd} + L_{cd}^2}{3\left(L_{E4UN1} + L_{cd}\right)} = 7.36\,m$

$$\Sigma V_{SoilWaterUN1} := W_{H1UN1} + W_{E6UN1} + W_{E3UN1} + W_{E4UN1} + W_{E5UN1} + S_{UN1} = 1620.3 \cdot kN$$

$$\Sigma M_{VertSoilWaterResistUN1} := W_{H1UN1} \cdot W_{E1locUN1} + W_{E6UN1} \cdot W_{E6locUN1} \cdots + W_{E3UN1} \cdot W_{E3locUN1} + W_{E4UN1} \cdot W_{E4locUN1} + W_{E5UN1} \cdot W_{E5locUN1} + S_{UN1} \cdot S_{UN1loc} = 11067.3\,m \cdot kN$$

THIS PAGE INTENTIONALLY LEFT BLANK
PLEASE GO TO THE NEXT PAGE

STABILITY ASSESSMENT:

LOAD CASE UN1

CHECK SLIDING ALONG HORIZONTAL SLIDING PLANE:

Summation of the vertical forces:

$$\Sigma V_{UN1} := \Sigma V_{conc} + \Sigma V_{SoilWaterUN1} + \Sigma V_{UpliftUN1} = 1637.7 \cdot kN$$

Summation of the horizontal forces:

$$\Sigma H_{UN1} := \Sigma H_{SoildriveUN1} + \Sigma H_{SoilresistUN1} = -1060.8 \cdot kN$$

Safety Factor for Sliding Horizontal Failure Plane

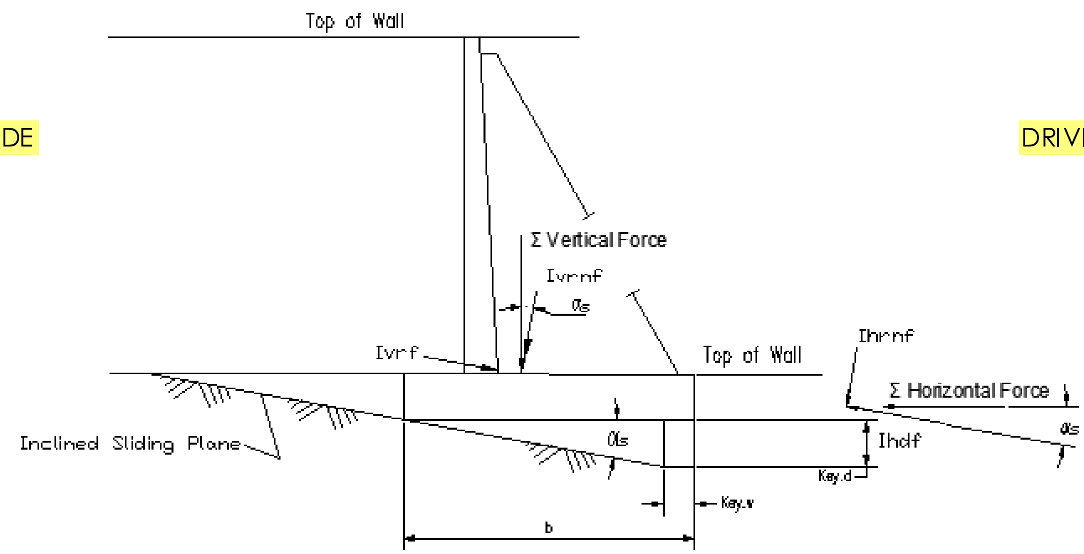
$$FS_{Horiz.SlidingUN1} := \frac{\left|\Sigma V_{UN1}\right| \cdot \tan\left(\phi_{rock} \cdot \frac{\pi}{180}\right)}{\left|\Sigma H_{UN1}\right|} = 0.75$$

$$FS_{Sliding.check1.UN1} := \begin{vmatrix} \text{"OKAY"} \quad \text{if} \quad FS_{Horiz.SlidingUN1} > FS_{sliding.reqUN1} \\ \text{"NG - key req'"} \quad \text{otherwise} \end{vmatrix} = \text{"NG - key req'"}$$

CHECK FACTOR OF SAFETY SLIDING WITH KEY (INCLINED SLIDING PLANE):

RESISTING SIDE

DRIVING SIDE



TOE

HEEL

Ivrf=Inclined Resisting Force
Ivrnf=Inclined Resisting Normal Force
Ihrnf=Inclined Resisting Normal Force
Ihdf=Inclined Driving Force

$\alpha s = 0.245$ as degrees= $\alpha s \cdot \left(\frac{180}{\pi}\right) = 14.04$

(With properly engineered reinforced concrete Key, horizontal sliding plane thru Toe is protected, critical sliding plane is relocated to the INCLINED SLIDING PLANE FROM HEEL KEY To TOE, Bedrock Mass above this examing plane is mobilized by reinforced concrete key and combined into Structural Wedge.)

Resolve ΣV_{UN1} & ΣH_{UN1}

$$\Sigma V_{InclinedUN1} := \cos(\alpha s) \cdot \left(\left|\Sigma V_{UN1} + V_{rocksection}\right|\right) + \sin(\alpha s) \cdot \left|\Sigma H_{UN1}\right| = 2156.6 \cdot kN$$

$$\Sigma H_{InclinedUN1} := \cos(\alpha s) \cdot \left|\Sigma H_{UN1}\right| - \sin(\alpha s) \cdot \left(\left|\Sigma V_{UN1} + V_{rocksection}\right|\right) = 554.3 \cdot kN$$

LOAD CASE UN1

Safety Factor for Sliding Inclined Failure Plane

$$FS_{InclinedlSlidingUN1} := \frac{\Sigma V_{InclinedUN1} \cdot \tan(\phi_r)}{\Sigma H_{InclinedUN1}} = 1.73$$

$$FS_{Sliding.check2.UN1} := \begin{cases} \text{"OKAY "} & \text{if } FS_{InclinedlSlidingUN1} > FS_{sliding.reqUN1} \\ \text{"NG - Revise Structure""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

CHECK FOUNDATION ECCENTRICITY:

Summation of the resisting moments about the toe:

$$\Sigma M_{resUN1} := \Sigma M_{conc} + \Sigma M_{VertSoilWaterResistUN1} + \Sigma M_{HorizSoilResistUN1} + \Sigma M_{rocksection} = 18003 \cdot kN \cdot m$$

Summation of the overturning moments about the toe:

$$\Sigma M_{oUN1} := \Sigma M_{LateralSoildriveUN1} + \Sigma M_{UpliftUN1} = -8224 \cdot kN \cdot m$$

Total moment: $\Sigma M_{UN1} := \Sigma M_{resUN1} + \Sigma M_{oUN1} = 9779.4 \cdot kN \cdot m$

Normal force to base: $\Sigma V_{InclinedUN1} = 2156.6 \cdot kN$

Inclined Sliding Plane Length: $L_{incline} = 11.3 \cdot m$

Eccentricity (inclined plane): $ex_{UN1} := \frac{L_{incline}}{2} - \frac{\Sigma M_{UN1}}{\Sigma V_{InclinedUN1}} = 1.13\, m$ $\quad Kern = 1.89\, m$

Eccentricity Check: $e_{check.UN1} := \begin{cases} \text{"Okay"} & \text{if } ex_{UN1} \le Kern \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"Okay"}$

CHECK FOUNDATION BEARING CAPACITY:

Base Section Modulus: $S_b = 21.43\, m^3$

Bearing Pressure Under Toe:

$$\sigma_{ToeUN1} := \begin{cases} \left(\frac{\Sigma V_{InclinedUN1}}{L_{incline} \cdot B} + \frac{\Sigma V_{InclinedUN1} \cdot ex_{UN1}}{S_b} \right) & \text{if } \frac{\Sigma V_{InclinedUN1} \cdot ex_{UN1}}{S_b} \le \frac{\Sigma V_{InclinedUN1}}{L_{incline} \cdot B} \\ \frac{2 \cdot \Sigma V_{InclinedUN1}}{B \cdot 3 \left(\frac{b}{2} - ex_{UN1} \right)} & \text{otherwise} \end{cases} = 304.4 \cdot kPa$$

$$Bearing_{ChecktoeUN1} := \begin{cases} \text{"OKAY "} & \text{if } \sigma_{ToeUN1} < \sigma_{allowUN1} \\ \text{"NG""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

Bearing Pressure Under Heel:

$$\sigma_{HeelUN1} := \begin{cases} \left(\frac{\Sigma V_{InclinedUN1}}{L_{incline} \cdot B} - \frac{\Sigma V_{InclinedUN1} \cdot ex_{UN1}}{S_b} \right) & \text{if } \frac{\Sigma V_{InclinedUN1} \cdot ex_{UN1}}{S_b} \le \frac{\Sigma V_{InclinedUN1}}{L_{incline} \cdot B} \\ 0 & \text{otherwise} \end{cases} = 76.0 \cdot kPa$$

$$Bearing_{CheckheelUN1} := \left(\begin{cases} \text{"OKAY "} & \text{if } \sigma_{HeelUN1} < \sigma_{allowUN1} \wedge \sigma_{HeelUN1} > 0 \\ \text{"NG - perform cracked base analysis""} & \text{otherwise} \end{cases} \right) = \text{"OKAY "}$$

CHECK FLOATATION:

Safety Factor for Floatation: $FS_{FloatationUN1} := \frac{\Sigma V_{conc} + \Sigma V_{SoilWaterUN1}}{\left|\Sigma V_{UpliftUN1}\right|} = 2.90$

$FS_{Floatation.UN1.check} := \begin{cases} \text{"OKAY "} & \text{if } FS_{FloatationUN1} > FS_{req.UN1.flt} \\ \text{"Revise Structure""} & \text{otherwise} \end{cases} = \text{"OKAY "}$

CHECK OVERTURNING

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.
Assumptions are made in order to compute overturning stablity of indetermine forces on monolith with key;
(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.
(b) The horizontal resisting force acting on the key, P.key, is that required for static equilibrium
(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1

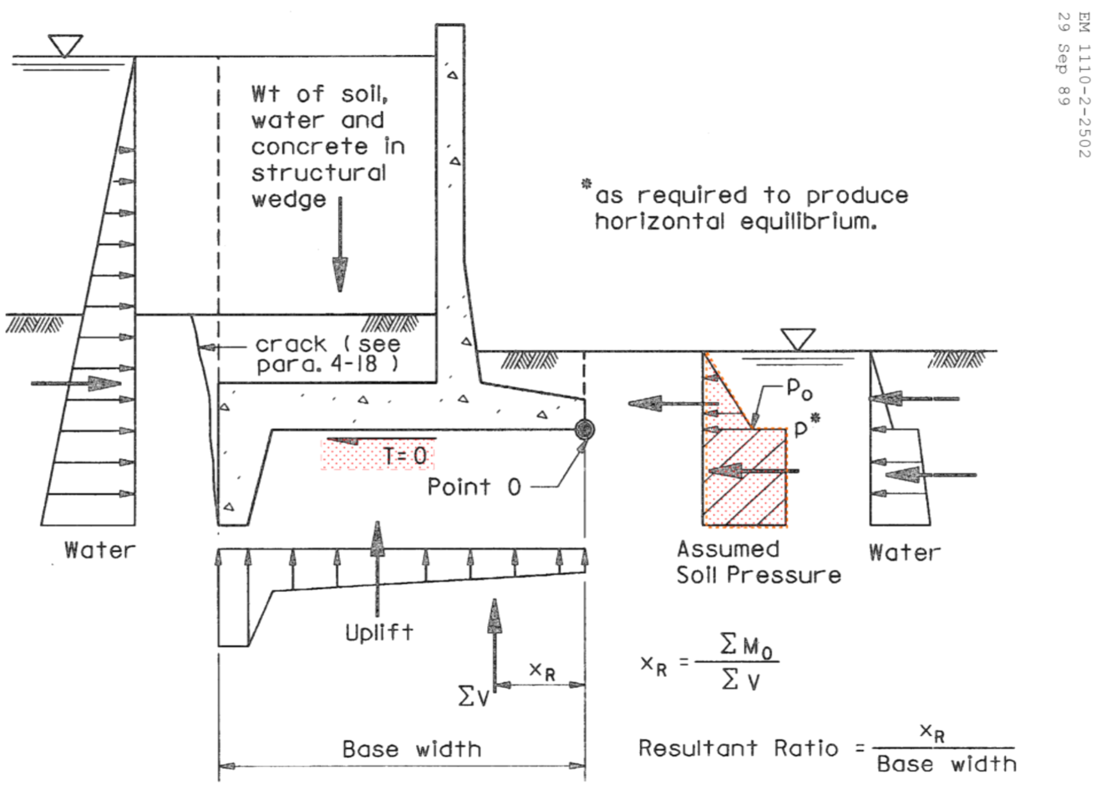


Figure 4-5. Forces for overturning analysis for wall with horizontal base and key

Modify Uplift for Overturning Analysis: **LOAD CASE UN1**

(Uplift is calculated along the concrete/rock contact using the Line of Creep method)

Water Pressure at h: $u_{h.UN1} := \Delta h_{g.hj.UN1} \cdot \gamma_w = 102.90 \cdot kPa$

Water Pressure at o: $u_{o.UN1} := \left(\Delta h_{g.no.UN1} - \dfrac{\Delta h_{g.r.UN1} \cdot L_{ho.UN1}}{L_{ho.UN1}} \right) \cdot \gamma_w = 53.9 \cdot kPa$

Head loss between point h and o: $\Delta h_{ho.UN1} := \Delta h_{g.r.UN1} \cdot \dfrac{L_{ho.UN1}}{L_{ho.UN1}} = 2.5\,m$

Length of concrete base (h -> o): $L_{baseho.UN1} := Key_{h.w} + Key_{h.d} + Key_{hdist} + Key_{t.d} + Key_{t.w} = 13.5\,m$

Head loss along h -> j: $\Delta h_{hj.UN1} := \Delta h_{ho.UN1} \cdot \dfrac{Key_{h.w}}{L_{baseho.UN1}} = 0.185\,m$

Water Pressure at j: $u_{j.UN1} := \left(\Delta h_{g.hj.UN1} - \Delta h_{hj.UN1} \right) \cdot \gamma_w = 101.09 \cdot kPa$

Head loss along h -> k: $\Delta h_{hjk.UN1} := \Delta h_{ho.UN1} \cdot \left(\dfrac{Key_{h.w} + Key_{h.d}}{L_{baseho.UN1}} \right) = 0.648\,m$

Water Pressure at k: $u_{k.UN1} := \left(\Delta h_{g.km.UN1} - \Delta h_{hjk.UN1} \right) \cdot \gamma_w = 72.05 \cdot kPa$

Head loss along h -> m: $\Delta h_{hjkm.UN1} := \Delta h_{ho.UN1} \cdot \left(\dfrac{Key_{h.w} + Key_{h.d} + Key_{hdist}}{L_{baseho.UN1}} \right) = 2.5\,m$

Water Pressure at m: $u_{m.UN1} := \left(\Delta h_{g.km.UN1} - \Delta h_{hjkm.UN1} \right) \cdot \gamma_w = 53.90 \cdot kPa$

Head loss along h -> n: $\Delta h_{hjkmn.UN1} := \Delta h_{ho.UN1} \cdot \left(\dfrac{Key_{h.w} + Key_{h.d} + Key_{hdist} + Key_{t.d}}{L_{baseho.UN1}} \right) = 2.5\,m$

Water Pressure at n: $u_{n.UN1} := \left(\Delta h_{g.no.UN1} - \Delta h_{hjkmn.UN1} \right) \cdot \gamma_w = 53.90 \cdot kPa$

Uplift under key at heel: $V_{ulkeyhUN1.OT} := \dfrac{\left(u_{h.UN1} + u_{j.UN1} \right) \cdot Key_{h.w}}{2} \cdot B \cdot -1 = -101.993 \cdot kN$

Moment Arm (from Point O): $V_{ulkeyhUN1loc.OT} := b - \dfrac{Key_{h.w} \cdot \left(2 \cdot u_{j.UN1} + u_{h.UN1} \right)}{3 \cdot \left(u_{j.UN1} + u_{h.UN1} \right)} = 10.501\,m$

Uplift under base: $V_{ulbaseUN1.OT} := \dfrac{\left(u_{k.UN1} + u_{m.UN1} \right) \cdot Key_{hdist}}{2} \cdot B \cdot -1 = -629.741 \cdot kN$

Moment Arm (from Point O): $V_{ulbaseUN1loc.OT} := b - Key_{h.w} - \dfrac{Key_{hdist} \cdot \left(2 \cdot u_{m.UN1} + u_{k.UN1} \right)}{3 \cdot \left(u_{m.UN1} + u_{k.UN1} \right)} = 5.24\,m$

Uplift under key at toe: $V_{ulkeytUN1.OT} := \dfrac{\left(u_{n.UN1} + u_{o.UN1} \right) \cdot Key_{t.w}}{2} \cdot B \cdot -1 = 0 \cdot kN$

Moment Arm (from Point O): $V_{ulkeytUN1loc.OT} := \dfrac{Key_{t.w} \cdot \left(2 \cdot u_{n.UN1} + u_{o.UN1} \right)}{3 \cdot \left(u_{n.UN1} + u_{o.UN1} \right)} = 0$

$$\Sigma V_{UpliftUN1.OT} := V_{ulkeyhUN1.OT} + V_{ulbaseUN1.OT} + V_{ulkeytUN1.OT} = -732 \cdot kN$$

$$U_{UN1.loc.OT} := \frac{V_{ulkeyhUN1.OT} \cdot V_{ulkeyhUN1loc.OT} + V_{ulbaseUN1.OT} \cdot V_{ulbaseUN1loc.OT} + V_{ulkeytUN1.OT} \cdot V_{ulkeytUN1loc.OT}}{\Sigma V_{UpliftUN1.OT}} = 5.97\,m$$

$$\Sigma M_{UpliftUN1.OT} := \Sigma V_{UpliftUN1.OT} \cdot U_{UN1.loc.OT} = -4371.0 \cdot kN \cdot m$$

Modify Lateral Water Pressure (Resisting) for Overturning Analysis:

(Resisting water pressure is calculated using the Line of Creep method)

Water Load at Key (heel):
$$H_{h2UN1.OT} := \frac{u_{k.UN1} + u_{j.UN1}}{2} \cdot Key_{h.d} \cdot B = 216.4 \cdot kN$$

Moment Arm (from Point O):
$$H_{h2locUN1.OT} := \frac{Key_{h.d} \cdot (2 \cdot u_{k.UN1} + u_{j.UN1})}{3(u_{k.UN1} + u_{j.UN1})} + Key_{vdist} = -1.32\ m$$

Water Load at Key (toe):
$$H_{h6UN1.OT} := \frac{u_{o.UN1} \cdot (UWSEL_{UN1} - Bot_{ftg} + Key_{t.d})}{2} \cdot B = 148 \cdot kN$$

Moment Arm (from Point O):
$$H_{h6locUN1.OT} := \frac{UWSEL_{UN1} - Bot_{ftg} + Key_{t.d}}{3} = 1.83\ m$$

$$\Sigma H_{waterresistUN1.OT} := H_{h2UN1.OT} + H_{h6UN1.OT} = 364.64 \cdot kN$$

$$H_{waterresistlocUN1.OT} := \frac{H_{h2UN1.OT} \cdot H_{h2locUN1.OT} + H_{h6UN1.OT} \cdot H_{h6locUN1.OT}}{\Sigma H_{waterresistUN1.OT}} = -0.038\ m$$

$$\Sigma M_{waterresistUN1.OT} := \Sigma H_{waterresistUN1.OT} \cdot H_{waterresistlocUN1.OT} = -13.9 \cdot kN \cdot m$$

Modify Lateral Soil Loads for Overturning Analysis:

(Lateral soil loads are calculated down to Point O instead of bottom of shear key)

Driving Soil Load (Headwater Side):

Surcharge Load:
$$E_{s1UN1.OT} := S1_{UN1} \cdot K_o \cdot (H_w + Key_{h.d} + Key_{vdist}) \cdot B \cdot -1 = -92.549 \cdot kN$$

Moment Arm (from Point O):
$$E_{s1locUN1.OT} := \frac{H_w + Key_{h.d} + Key_{vdist}}{2} = 5.65\ m$$

Moist Soil Load above GWL:
$$E_{h1UN1.OT} := \frac{\gamma_m \cdot K_o \cdot h_{1UN1}^{\ 2}}{2} B \cdot -1 = -59.5 \cdot kN$$

Moment Arm (from Point O):
$$E_{h1locUN1.OT} := \frac{h_{1UN1}}{3} + h_{2UN1} + Key_{vdist} = 9.10\ m$$

Saturated Soil Load below GWL:
(rectangular component)
$$E_{h2UN1.OT} := (\gamma_m \cdot K_o \cdot h_{1UN1}) \cdot (h_{2UN1} + Key_{vdist}) \cdot B \cdot -1 = -288.3 \cdot kN$$

Moment Arm (from Point O):
$$E_{h2locUN1.OT} := \frac{h_{2UN1} + Key_{vdist}}{2} = 4.00\ m$$

Saturated Soil Load below GWL:
(triangular component)
$$E_{h2aUN1.OT} := \frac{(\gamma_{sat} - \gamma_w) \cdot K_o \cdot (h_{2UN1} + Key_{vdist})^2}{2} \cdot B \cdot -1 = -213.2 \cdot kN$$

Moment Arm (from Point O):
$$E_{h2alocUN1.OT} := \frac{h_{2UN1} + Key_{vdist}}{3} = 2.67\ m$$

Resisting Soil Load (Tailwater Side):

(Determine resisting soil load based on depth variation between the keys (ie. Key_{vdist}). In case where key at heel is deeper than key at toe (ie. $Key_{vdist} < 0$), resisting soil load (p*) is assumed to produce horizontal equilibrium as per Figure 4-5 above. Resisting soil load (p_o) is neglected.)

Total Driving Force: $\Sigma H_{SoildriveUN1.OT} := E_{s1UN1.OT} + E_{h1UN1.OT} + E_{h2UN1.OT} + E_{h2aUN1.OT} + H_{h2UN1} = -1193.7 \cdot kN$

Total Resisting Force: $\Sigma H_{waterresistUN1.OT} = 364.6 \cdot kN$

Assumed Soil Load p*: $E_{h8UN1a.OT} := \left(\Sigma H_{SoildriveUN1.OT} + \Sigma H_{waterresistU1.OT}\right) \cdot -1 = 829.048 \cdot kN$

Moment Arm (from Point O): $E_{h8UN1a.loc.OT} := \dfrac{Key_{vdist}}{2} = -1.25\, m$

$$E_{h8UN1.OT} := \begin{cases} E_{h8UN1a.OT} & \text{if } Key_{vdist} < 0 \\ \Sigma H_{SoilresistUN1} - H_{h6UN1} - H_{h2aUN1} & \text{otherwise} \end{cases} = 829.048 \cdot kN$$

$$\Sigma M_{SoilresistUN1} := \begin{cases} E_{h8UN1a.OT} \cdot E_{h8UN1a.loc.OT} & \text{if } Key_{vdist} < 0 \\ \Sigma M_{HorizSoilResistUN1} - H_{h6UN1} \cdot H_{h6locUN1} - H_{h2aUN1} \cdot H_{h2alocUN1} & \text{otherwise} \end{cases} = -1036.309 \cdot kN \cdot m$$

Sum of Moment about Point O:

$$\Sigma M_{LateraldriveUN1.OT} := E_{s1UN1.OT} \cdot E_{s1locUN1.OT} + E_{h1UN1.OT} \cdot E_{h1locUN1.OT} + E_{h2UN1.OT} \cdot E_{h2locUN1.OT} \cdots + E_{h2aUN1.OT} \cdot E_{h2alocUN1.OT} + H_{h2UN1} \cdot H_{h2locUN1} = -3325.8 \cdot kN \cdot m$$

$$\Sigma M_{LateralresistUN1.OT} := \Sigma M_{waterresistUN1.OT} + \Sigma M_{SoilresistUN1} = -1050.2 \cdot kN \cdot m$$

Total moment:

$$\Sigma M_{UN1.OT} := \Sigma M_{conc} + \Sigma M_{VertSoilWaterResistUN1} + \Sigma M_{UpliftUN1.OT} + \Sigma M_{LateraldriveUN1.OT} + \Sigma M_{LateralresistUN1.OT} = 7050.4 \cdot kN \cdot m$$

Total Vertical Force: $\Sigma V_{UN1.OT} := \Sigma V_{conc} + \Sigma V_{SoilWaterUN1} + \Sigma V_{UplliftUN1.OT} = 1768.4 \cdot kN$

Distance X_R: EM 1110-2-2502 Eq.4-1 $X_{R.UN1} := \dfrac{\Sigma M_{UN1.OT}}{\Sigma V_{UN1.OT}} = 3.987\, m$

Overturning Resultant Ratio $Ratio_{UN1.OT} := \dfrac{X_{R.UN1}}{b} = 0.36$

$$Ratio_{UN1.OT.check} := \begin{cases} \text{"OKAY "} & \text{if } Ratio_{UN1.OT} > X_{R.reqUN1} \\ \text{"Revise Structure""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

CHECK FOUNDATION ECCENTRICITY (HORIZONTAL PLANE):

Eccentricity (horizontal plan): $ex_{UN1.OT} := \dfrac{b}{2} - \dfrac{\Sigma M_{UN1.OT}}{\Sigma V_{UN1.OT}} = 1.51\, m$ $\quad Kern_{OT} = 1.833\, m$

Eccentricity Check:

$$e_{check.UN1.OT} := \begin{cases} \text{"Okay"} & \text{if } ex_{UN1} \le Kern_{OT} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"Okay"}$$

CHECK FOUNDATION BEARING CAPACITY (HORIZONTAL PLANE):

Base Section Modulus: $S_{b.OT} = 20.17\,m^3$

Bearing Pressure Under Toe:

$$\sigma_{ToeUN1.OT} := \begin{cases} \left(\dfrac{\Sigma V_{UN1.OT}}{b \cdot B} + \dfrac{\Sigma V_{UN1.OT} \cdot ex_{UN1.OT}}{S_{b.OT}}\right) & \text{if } \dfrac{\Sigma V_{UN1.OT}}{b \cdot B} \ge \dfrac{\Sigma V_{UN1.OT} \cdot ex_{UN1.OT}}{S_{b.OT}} \\ \dfrac{2 \cdot \Sigma V_{UN1.OT}}{B \cdot 3\left(\dfrac{b}{2} - ex_{UN1.OT}\right)} & \text{otherwise} \end{cases} = 293.4 \cdot kPa$$

$$Bearing_{ChecktoeUN1.OT} := \begin{cases} \text{"OKAY "} & \text{if } \sigma_{ToeUN1.OT} < \sigma_{allowUN1} \\ \text{"NG - for reference only""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

Bearing Pressure Under Heel:

$$\sigma_{HeelUN1.OT} := \begin{cases} \left(\dfrac{\Sigma V_{UN1.OT}}{b \cdot B} - \dfrac{\Sigma V_{UN1.OT} \cdot ex_{UN1.OT}}{S_{b.OT}}\right) & \text{if } \dfrac{\Sigma V_{UN1.OT}}{b \cdot B} \ge \dfrac{\Sigma V_{UN1.OT} \cdot ex_{UN1.OT}}{S_{b.OT}} \\ 0 & \text{otherwise} \end{cases} = 28.1 \cdot kPa$$

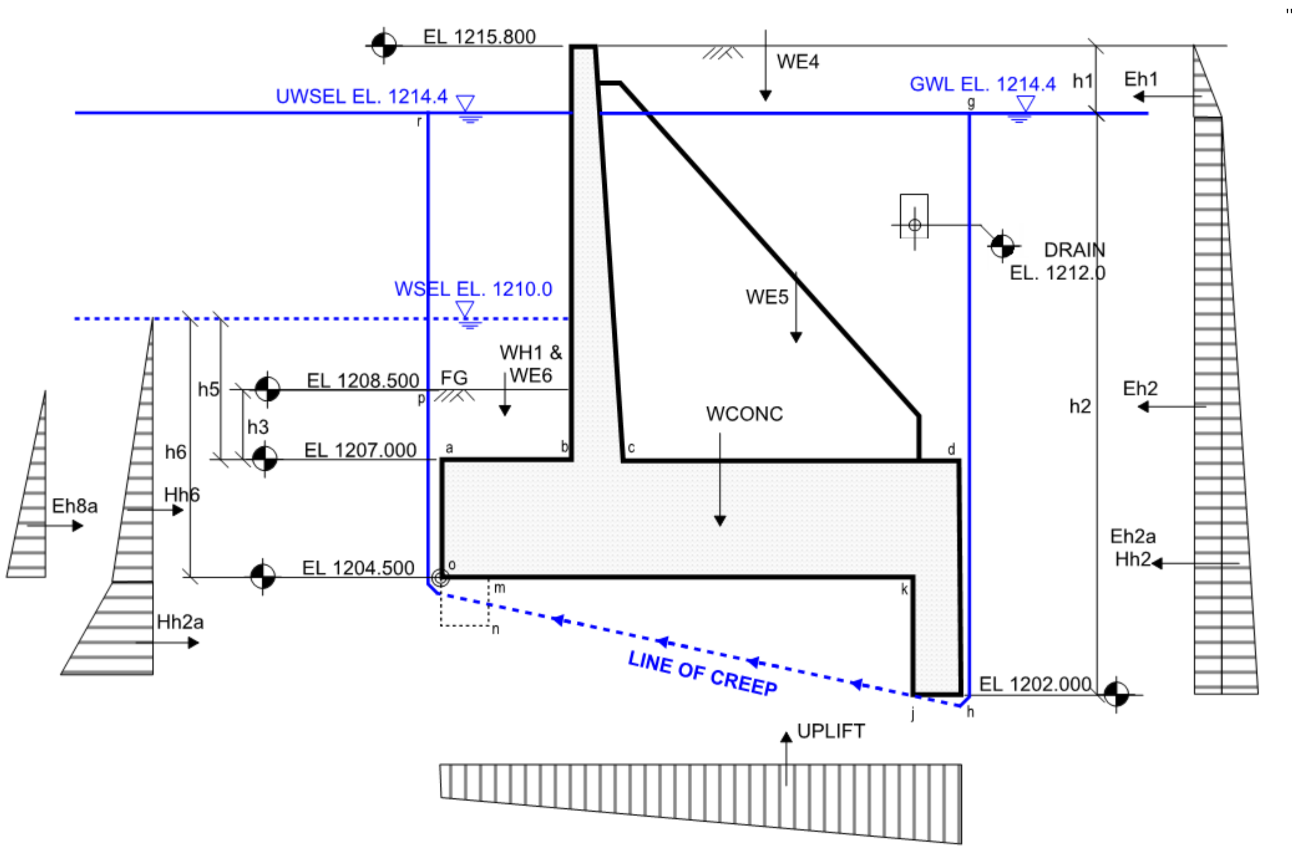
$$Bearing_{CheckheelUN1.OT} := \left(\begin{cases} \text{"OKAY "} & \text{if } \sigma_{HeelUN1.OT} < \sigma_{allowUN1} \wedge \sigma_{HeelUN1.OT} > 0 \\ \text{"NG - for reference only""} & \text{otherwise} \end{cases}\right) = \text{"OKAY "}$$

SUMMARY OF STABILITY ASSESSMENT:

LOAD CASE UN1

Sliding Factor of Safety: (Horizontal Plane - Ref only)	$FS_{Horiz.SlidingUN1} = 0.75$	$FS_{Sliding.check1.UN1}$ = "NG - key req'"
Sliding Factor of Safety: (Inclined Plane)	$FS_{InclinedlSlidingUN1} = 1.73$	$FS_{Sliding.check2.UN1}$ = "OKAY "
Eccentricity: (Inclined Plane)	$ex_{UN1} = 1.13\ m$	$e_{check.UN1}$ = "Okay"
Bearing Pressure At Heel: (Inclined Plane)	$\sigma_{HeelUN1} = 76 \cdot kPa$	$Bearing_{CheckheelUN1}$ = "OKAY "
Bearing Pressure At Toe: (Inclined Plane)	$\sigma_{ToeUN1} = 304 \cdot kPa$	$Bearing_{ChecktoeUN1}$ = "OKAY "
Flotation Factor of Safety (horizontal plane)	$FS_{FloatationUN1} = 2.9$	$FS_{Floatation.UN1.check}$ = "OKAY "
Overturning Resultant Ratio: (horizontal plane)	$Ratio_{UN1.OT} = 0.36$	$Ratio_{UN1.OT.check}$ = "OKAY "
Eccentricity: (horizontal plane - Ref only)	$ex_{UN1.OT} = 1.51\ m$	$e_{check.UN1.OT}$ = "Okay"
Bearing Pressure At Heel: (horizontal plane - Ref only)	$\sigma_{HeelUN1.OT} = 28 \cdot kPa$	$Bearing_{CheckheelUN1.OT}$ = "OKAY "
Bearing Pressure At Toe: (horizontal plane - Ref only)	$\sigma_{ToeUN1.OT} = 293 \cdot kPa$	$Bearing_{ChecktoeUN1.OT}$ = "OKAY "

LOAD CASE UN2 - INEFFECTIVE DRAIN



UN2 DESIGN CASE

LOAD CASE UN2 ACCEPTANCE PARAMETERS

FS sliding:

Unusual (UN) 1.3 (without cohesion) (Table 3-3, USACE EM 1110-2-2100)

Resultant Location:

Unsual (UN) Inside middle third ~100% base in compression

Required Factor of Safety for Sliding: $FS_{sliding.reqUN2} := 1.3$ (Without Cohesion)

Allowable rock bearing pressure: $\sigma_{allowUN2} := 1470kPa$ (Section 5.2, Design Criteria EM 1110-2-2100 Section 3-10)

Overturning Required Resultant Ratio: $X_{R.reqUN2} := 0.333$ (EM 1110-2-2502, Figure 4-4)

Required Factor of Safety for Floatation $FS_{req.UN2.flt} := 1.3$

SOIL HEIGHTS and Water Levels:

LOAD CASE UN2

Heel Conditions:

Groundwater Elevation at Heel: $GWL_{UN2} := 1214.4m$

Distance from Finish Grade to Groundwater at Heel: $h_{1UN2} := \left[T_w - GWL_{UN2} + \left(L_{cd} + t_{wb} - t_{wt}\right)\cdot\tan(\beta)\right] = 1.40\ m$

Distance from Water Surface to Bottom of Footing at Heel: $h_{2UN2} := GWL_{UN2} - Bot_{ftg} + Key_{h.d} = 12.40\ m$

Toe Conditions:

Water Surface Elevation at Toe: $WSEL_{UN2} := 1210.0m$

Water Surface Elevation at Toe for Uplift: $UWSEL_{UN2} := 1214.4\cdot m$

Finish Grade at Toe providing lateral resistance: $FG_{toeUN2} := 1208.5\cdot m$

Soil Depth Above top of footing: $h_{3aUN2} := FG_{toeUN2} - Top_{ftg} = 1.5\ m$

$$h_{3UN2} := \begin{cases} h_{3aUN2} & \text{if } FG_{toeUN2} - Top_{ftg} \ge 0 \\ 0 & \text{otherwise} \end{cases} = 1.5$$

Resisting Fill at Toe: $h_{4UN2} := FG_{toeUN2} - Bot_{ftg} + Key_{t.d} = 4.00\ m$

Distance from Water Level to Top of Footing at Toe: $h_{5UN2} := WSEL_{UN2} - Top_{ftg} = 3.00\ m$

Distance from Water Surface to Bottom of Footing at Toe: $h_{6UN2} := WSEL_{UN2} - Bot_{ftg} + Key_{t.d} = 5.50\ m$

Soil Depth Above WSEL: $h_{7aUN2} := FG_{toeUN2} - WSEL_{UN2} = -1.5\ m$

$$h_{7UN2} := \begin{cases} h_{7aUN2} & \text{if } FG_{toeUN2} - WSEL_{UN2} \ge 0 \\ 0 & \text{otherwise} \end{cases} = 0$$

Soil Depth Below WSEL:

$$h_{8UN2} := \begin{cases} WSEL_{UN2} - Bot_{ftg} + Key_{t.d} & \text{if } FG_{toeUN2} - WSEL_{UN2} \ge 0 \\ h_{4UN2} & \text{otherwise} \end{cases} = 4$$

For Line of Creep Method: $L_{ho.UN2} := \sqrt{b^2 + \left(Key_{h.d} - Key_{t.d}\right)^2} = 11.281\ m$

Head Loss from Point g:

$\Delta h_{g.hj.UN2} := h_{2UN2} = 12.4\ m$ (to point h & j)

$\Delta h_{g.km.UN2} := GWL_{UN2} - Bot_{ftg} = 9.9\ m$ (to point k & m)

$\Delta h_{g.no.UN2} := GWL_{UN2} - Bot_{ftg} + Key_{t.d} = 9.9\ m$ (to point n & o)

$\Delta h_{g.p.UN2} := GWL_{UN2} - FG_{toeUN2} = 5.9\ m$ (to point p)

$\Delta h_{g.r.UN2} := GWL_{UN2} - UWSEL_{UN2} = 0\ m$ (to point r)

Surcharge

Surcharge on Heel: $S1_{UN2} := 0.0\ \frac{kN}{m^2}$

LOAD CASE UN2

Calculate Soil Lateral Pressure Coefficients:

For all load cases except seismic, soil loading to be based on At-Rest Condition.
Calculate at-rest pressure coefficient Ko based on Jaky's (1944) equation.

Soil At Rest Static Coefficient: $K_o := \frac{1 - \sin(\phi)}{1 + \sin(\beta)} = 0.546$ (Eq. 3-6, USACE EM 1110-2-2502)

Lateral - Driving Force

Static At-Rest:

Surcharge Load: $E_{s1UN2} := S1_{UN2} \cdot K_o \cdot \left(H_w + Key_{h.d}\right) \cdot B \cdot -1 = 0 \cdot kN$

Moment Arm (from bottom of footing): $E_{s1locUN2} := \frac{H_w + Key_{h.d}}{2} + Key_{vdist} = 4.40\ m$

Moist Soil Load above GWL: $E_{h1UN2} := \frac{\gamma_m \cdot K_o \cdot h_{1UN2}^{\ 2}}{2} \cdot B \cdot -1 = -10.7 \cdot kN$

Moment Arm (from bottom of footing): $E_{h1locUN2} := \frac{h_{1UN2}}{3} + h_{2UN2} + Key_{vdist} = 10.37\ m$

Saturated Soil Load below GWL:
(rectangular component) $E_{h2UN2} := \left(\gamma_m \cdot K_o \cdot h_{1UN2}\right) \cdot h_{2UN2} \cdot B \cdot -1 = -189.6 \cdot kN$

Moment Arm (from bottom of footing): $E_{h2locUN2} := \frac{h_{2UN2}}{2} + Key_{vdist} = 3.70\ m$

Saturated Soil Load below GWL:
(triangular component) $E_{h2aUN2} := \frac{\left(\gamma_{sat} - \gamma_w\right) \cdot K_o \cdot h_{2UN2}^{\ 2}}{2} \cdot B \cdot -1 = -512.1 \cdot kN$

Moment Arm (from bottom of footing): $E_{h2alocUN2} := \frac{h_{2UN2}}{3} + Key_{vdist} = 1.63\ m$

Lateral Water Load:

Water Load GWL to Bottom of Key $H_{h2UN2} := \frac{\gamma_w \cdot h_{2UN2}^{\ 2}}{2} \cdot B \cdot -1 = -753.4 \cdot kN$

Moment Arm (from bottom of footing): $H_{h2locUN2} := \frac{h_{2UN2}}{3} + Key_{vdist} = 1.63\ m$

$$\Sigma H_{SoildriveUN2} := E_{s1UN2} + E_{h1UN2} + E_{h2UN2} + E_{h2aUN2} + H_{h2UN2} = -1465.8 \cdot kN$$

$$\Sigma M_{LateralSoildriveUN2} := E_{s1UN2} \cdot E_{s1locUN2} + E_{h1UN2} \cdot E_{h1locUN2} + E_{h2UN2} \cdot E_{h2locUN2} \cdots + E_{h2aUN2} \cdot E_{h2alocUN2} + H_{h2UN2} \cdot H_{h2locUN2} = -2879.4\ m \cdot kN$$

Lateral - Resisting Force

LOAD CASE UN2

Lateral Water Load:

Water Load WSEL to Bottom of Footing:
$$H_{h6UN2} := \frac{\gamma_w \cdot h_{6UN2}^2}{2} \cdot B = 148.2 \cdot kN$$

Moment Arm (from bot. of toe key):
$$H_{h6locUN2} := \frac{h_{6UN2}}{3} = 1.83\ m$$

Water Load Bot. of Footing to Bot. of H. Key:
$$H_{h2aUN2} := \left[\left(UWSEL_{UN2} - Bot_{ftg} + Key_{t.d}\right) + h_{2UN2}\right] \cdot \frac{Key_{h.d}}{2} \cdot \gamma_w \cdot B = 273.2 \cdot kN$$

Moment Arm (from bot. of toe key):
$$H_{h2alocUN2} := \frac{Key_{h.d} \cdot \left[2 \cdot \left(UWSEL_{UN2} - Bot_{ftg} + Key_{t.d}\right) + h_{2UN2}\right]}{3\left[h_{2UN2} + \left(UWSEL_{UN2} - Bot_{ftg} + Key_{t.d}\right)\right]} \ldots = -1.30\ m$$
$$+ Key_{vdist}$$

Lateral Soil Load:

Moist Soil Load above WSEL:
$$E_{h7UN2} := \frac{\gamma_m \cdot K_o \cdot h_{7UN2}^2}{2} B = 0.0 \cdot kN$$

Moment Arm (from bot. of toe key):
$$E_{h7locUN2} := h_{6UN2} + \frac{h_{7UN2}}{3} + Key_{vdist} = 3.00\ m$$

Saturated Soil Load below WSEL:
(rectangular component)
$$E_{h8UN2} := \left(\gamma_m \cdot K_o \cdot h_{7UN2}\right) \cdot h_{8UN2} \cdot B = 0.0 \cdot kN$$

Moment Arm (from bot. of toe key):
$$E_{h8locUN2} := \frac{h_{8UN2}}{2} = 2.00\ m$$

Saturated Soil Load below WSEL:
(triangular component)
$$E_{h8aUN2} := \frac{\left[\left(\gamma_{sat} - \gamma_w\right) \cdot K_o\right] \cdot h_{8UN2}^2}{2} \cdot B = 53.3 \cdot kN$$

Moment Arm (from bot. of footing):
$$E_{h8alocUN2} := \frac{h_{8UN2}}{3} = 1.33\ m$$

$$\Sigma H_{SoilresistUN2} := H_{h6UN2} + H_{h2aUN2} + E_{h7UN2} + E_{h8UN2} + E_{h8aUN2} = 474.7 \cdot kN$$

$$\Sigma M_{HorizSoilResistUN2} := H_{h6UN2} \cdot H_{h6locUN2} + H_{h2aUN2} \cdot H_{h2alocUN2} + E_{h7UN2} \cdot E_{h7locUN2} \ldots = -11.4\ m \cdot kN$$
$$+ E_{h8UN2} \cdot E_{h8locUN2} + E_{h8aUN2} \cdot E_{h8alocUN2}$$

Vertical Force:

UPLIFT: Linear distribution from water at heel to water at toe:

$$\Sigma V_{UpliftUN2} := \left[\left(UWSEL_{UN2} - Bot_{ftg} + Key_{t.d}\right) + h_{2UN2}\right] \cdot \frac{b}{2} \cdot \gamma_w \cdot B \cdot -1 = -1201.97 \cdot kN$$

Moment Arm (from Point O):
$$V_{UpliftUN2aloc} := \frac{b \cdot \left[2 \cdot h_{2UN2} + \left(UWSEL_{UN2} - Bot_{ftg} + Key_{t.d}\right)\right]}{3\left[h_{2UN2} + \left(UWSEL_{UN2} - Bot_{ftg} + Key_{t.d}\right)\right]} = 5.706\ m$$

$$\Sigma M_{UpliftUN2} := \Sigma V_{UpliftUN2} \cdot V_{UpliftUN2aloc} = -6857.877 \cdot kN \cdot m$$

Weight of soil and water over toe:

Water Above the Top of Footing: $W_{H1UN2} := \gamma_w \cdot h_{5UN2} \cdot L_{ab} \cdot B = 80.85 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E1locUN2} := \frac{L_{ab}}{2} = 1.375\,m$

Soil above top of footing: $W_{E6UN2} := \gamma_b \cdot h_{3UN2} \cdot L_{ab} \cdot B = 50.3 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E6locUN2} := \frac{L_{ab}}{2} = 1.375\,m$

Vertical Load Due to Surcharge: $S_{UN2} := S1_{UN2} \cdot L_{cd} \cdot B = 0 \cdot kN$ $\quad S_{UN2loc} := b - \frac{L_{cd}}{2} = 7.47\,m$

Weight of soil and water over heel:

Moist Soil for sloped grade above top of wall:

Length of sloped portion of soil above top of wall: $L_{E3UN2} := \left(L_{cd} + t_{wb} - t_{wt}\right) = 7.75\,m$

Height of sloped soil above top of wall over heel: $h_{E3locUN2} := \left(L_{E3UN2}\right) \cdot \tan(\beta) = 0.00\,m$

Weight of sloped soil above top of wall: $W_{E3UN2} := \frac{\gamma_m}{2} \cdot h_{E3locUN2} \cdot L_{E3UN2} \cdot B = 0.0 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E3locUN2} := L_{ab} + t_{wt} + \frac{2}{3} \cdot L_{E3UN2} = 8.42\,m$

Moist soil from top of wall to groundwater level:

Height of soil from top of wall and top of GWL: $h_{1UN2} = 1.40\,m$

Length from edge of wall at GWL to edge of heel: $L_{E4UN2} := L_{E3UN2} - \left(h_{1UN2} \cdot S_{batter}\right) = 7.64\,m$

Weight of soil over heel from top of wall to GWL: $W_{E4UN2} := \gamma_m \cdot h_{1UN2} \cdot \frac{\left(L_{E3UN2} + L_{E4UN2}\right)}{2} \cdot B = 215.5 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E4locUN2} := b - \frac{L_{E3UN2}^2 + L_{E3UN2} \cdot L_{E4UN2} + L_{E4UN2}^2}{3\left(L_{E3UN2} + L_{E4UN2}\right)} = 7.15\,m$

Saturated soil from groundwater to top of footing:

Height of soil from GWL to top of heel: $h_{E4UN2} := h_{2UN2} - t_{ftg} - Key_{h.d} = 7.40\,m$

Weight of soil over heel from GWL to top of heel: $W_{E5UN2} := \left(\gamma_{sat}\right) \cdot h_{E4UN2} \cdot \frac{\left(L_{E4UN2} + L_{cd}\right)}{2} \cdot B = 1196.5 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E5locUN2} := b - \frac{L_{E4UN2}^2 + L_{E4UN2} \cdot L_{cd} + L_{cd}^2}{3\left(L_{E4UN2} + L_{cd}\right)} = 7.32\,m$

$$\Sigma V_{SoilWaterUN2} := W_{H1UN2} + W_{E6UN2} + W_{E3UN2} + W_{E4UN2} + W_{E5UN2} + S_{UN2} = 1543.1 \cdot kN$$

$$\Sigma M_{VertSoilWaterResistUN2} := W_{H1UN2} \cdot W_{E1locUN2} + W_{E6UN2} \cdot W_{E6locUN2} \cdots + W_{E3UN2} \cdot W_{E3locUN2} + W_{E4UN2} \cdot W_{E4locUN2} + W_{E5UN2} \cdot W_{E5locUN2} + S_{UN2} \cdot S_{UN2loc} = 10483.8\,m \cdot kN$$

THIS PAGE INTENTIONALLY LEFT BLANK
PLEASE GO TO THE NEXT PAGE

STABILITY ASSESSMENT:

LOAD CASE UN2

CHECK SLIDING ALONG HORIZONTAL SLIDING PLANE:

Summation of the vertical forces:

$$\Sigma V_{UN2} := \Sigma V_{conc} + \Sigma V_{SoilWaterUN2} + \Sigma V_{UpliftUN2} = 1221.0 \cdot kN$$

Summation of the horizontal forces:

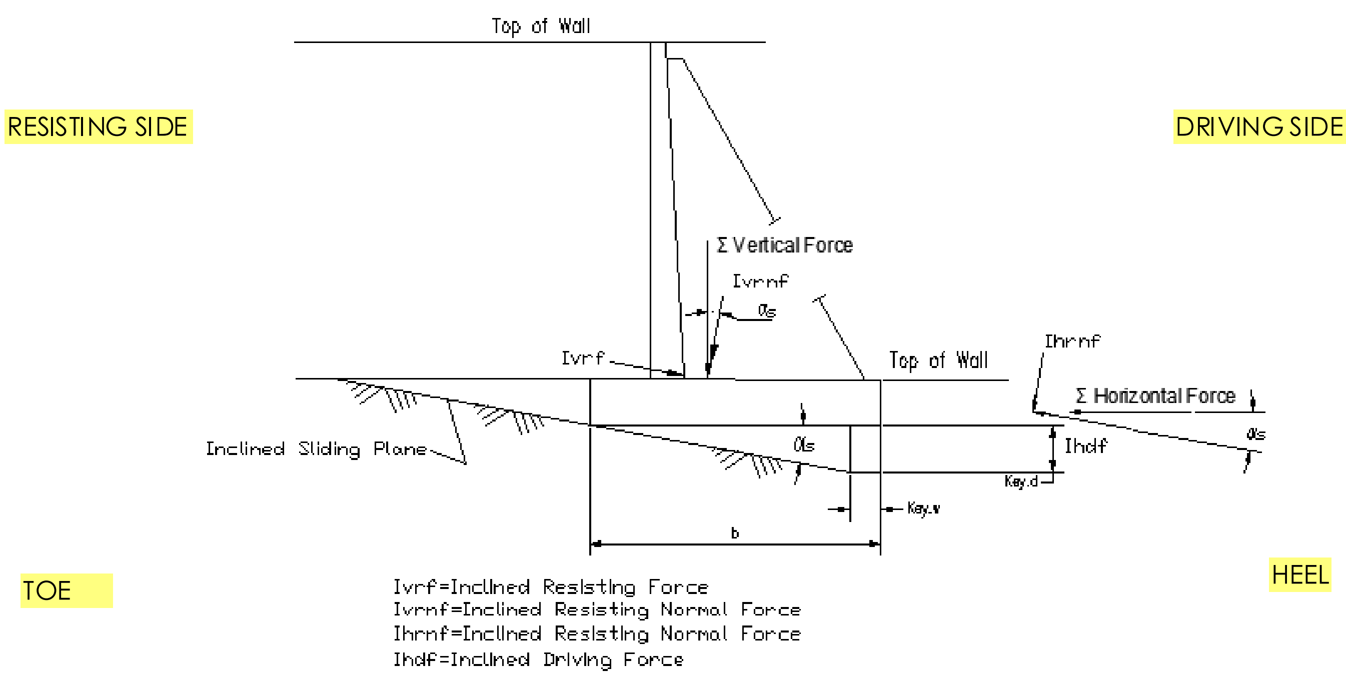
$$\Sigma H_{UN2} := \Sigma H_{SoildriveUN2} + \Sigma H_{SoilresistUN2} = -991.1 \cdot kN$$

Safety Factor for Sliding Horizontal Failure Plane

$$FS_{Horiz.SlidingUN2} := \frac{\left|\Sigma V_{UN2}\right| \cdot \tan\left(\phi_{rock} \cdot \frac{\pi}{180}\right)}{\left|\Sigma H_{UN2}\right|} = 0.60$$

$$FS_{Sliding.check1.UN2} := \begin{vmatrix} \text{"OKAY "} & \text{if } FS_{Horiz.SlidingUN2} > FS_{sliding.reqUN2} \\ \text{"NG - key req'"} & \text{otherwise} \end{vmatrix} = \text{"NG - key req'"}$$

CHECK FACTOR OF SAFETY SLIDING WITH KEY (INCLINED SLIDING PLANE):



$\alpha s = 0.245$ as degrees= $\alpha s \cdot \left(\frac{180}{\pi}\right) = 14.04$

(With properly engineered reinforced concrete Key, horizontal sliding plane thru Toe is protected, critical sliding plane is relocated to the INCLINED SLIDING PLANE FROM HEEL KEY To TOE, Bedrock Mass above this examing plane is mobilized by reinforced concrete key and combined into Structural Wedge.)

Resolve ΣV_{UN2} & ΣH_{UN2}

$$\Sigma V_{InclinedUN2} := \cos(\alpha s) \cdot \left(\left|\Sigma V_{UN2} + V_{rocksection}\right|\right) + \sin(\alpha s) \cdot \left|\Sigma H_{UN2}\right| = 1735.4 \cdot kN$$

$$\Sigma H_{InclinedUN2} := \cos(\alpha s) \cdot \left|\Sigma H_{UN2}\right| - \sin(\alpha s) \cdot \left(\left|\Sigma V_{UN2} + V_{rocksection}\right|\right) = 587.8 \cdot kN$$

Safety Factor for Sliding Inclined Failure Plane

$$FS_{InclinedISlidingUN2} := \frac{\Sigma V_{InclinedUN2} \cdot \tan(\phi_r)}{\Sigma H_{InclinedUN2}} = 1.31$$

$$FS_{Sliding.check2.UN2} := \begin{vmatrix} \text{"OKAY "} & \text{if } FS_{InclinedISlidingUN2} > FS_{sliding.reqUN2} \\ \text{"NG - Revise Structure""} & \text{otherwise} \end{vmatrix} = \text{"OKAY "}$$

CHECK FOUNDATION ECCENTRICITY:

Summation of the resisting moments about the toe:

$$\Sigma M_{resUN2} := \Sigma M_{conc} + \Sigma M_{VertSoilWaterResistUN2} + \Sigma M_{HorizSoilResistUN2} + \Sigma M_{rocksection} = 17336 \cdot kN \cdot m$$

Summation of the overturning moments about the toe:

$$\Sigma M_{oUN2} := \Sigma M_{LateralSoildriveUN2} + \Sigma M_{UpliftUN2} = -9737 \cdot kN \cdot m$$

Total moment: $\Sigma M_{UN2} := \Sigma M_{resUN2} + \Sigma M_{oUN2} = 7598.5\ m \cdot kN$

Normal force to base: $\Sigma V_{InclinedUN2} = 1735.4 \cdot kN$

Inclined Sliding Plane Length: $L_{incline} = 11.3 \cdot m$

Eccentricity (inclined plane): $ex_{UN2} := \frac{L_{incline}}{2} - \frac{\Sigma M_{UN2}}{\Sigma V_{InclinedUN2}} = 1.29\ m$ $\quad$ Kern = 1.89 m

Eccentricity Check: $e_{check.UN2} := \begin{vmatrix} \text{"Okay"} & \text{if } ex_{UN2} \le Kern \\ \text{"Revise Structure"} & \text{otherwise} \end{vmatrix} = \text{"Okay"}$

CHECK FOUNDATION BEARING CAPACITY:

Base Section Modulus: $S_b = 21.43\ m^3$

Bearing Pressure Under Toe:

$$\sigma_{ToeUN2} := \begin{vmatrix} \left(\frac{\Sigma V_{InclinedUN2}}{L_{incline} \cdot B} + \frac{\Sigma V_{InclinedUN2} \cdot ex_{UN2}}{S_b}\right) & \text{if } \frac{\Sigma V_{InclinedUN2} \cdot ex_{UN2}}{S_b} \le \frac{\Sigma V_{InclinedUN2}}{L_{incline} \cdot B} \\ \frac{2 \cdot \Sigma V_{InclinedUN2}}{B \cdot 3\left(\frac{b}{2} - ex_{UN2}\right)} & \text{otherwise} \end{vmatrix} = 257.6 \cdot kPa$$

$$Bearing_{ChecktoeUN2} := \begin{vmatrix} \text{"OKAY "} & \text{if } \sigma_{ToeUN2} < \sigma_{allowUN2} \\ \text{"NG""} & \text{otherwise} \end{vmatrix} = \text{"OKAY "}$$

Bearing Pressure Under Heel:

$$\sigma_{HeelUN2} := \begin{vmatrix} \left(\frac{\Sigma V_{InclinedUN2}}{L_{incline} \cdot B} - \frac{\Sigma V_{InclinedUN2} \cdot ex_{UN2}}{S_b}\right) & \text{if } \frac{\Sigma V_{InclinedUN2} \cdot ex_{UN2}}{S_b} \le \frac{\Sigma V_{InclinedUN2}}{L_{incline} \cdot B} \\ 0 & \text{otherwise} \end{vmatrix} = 48.5 \cdot kPa$$

$$Bearing_{CheckheelUN2} := \left(\begin{vmatrix} \text{"OKAY "} & \text{if } \sigma_{HeelUN2} < \sigma_{allowUN2} \wedge \sigma_{HeelUN2} > 0 \\ \text{"NG - perform cracked base analysis""} & \text{otherwise} \end{vmatrix}\right) = \text{"OKAY "}$$

CHECK FLOATATION:

Safety Factor for Floatation:

$$FS_{FloatationUN2} := \frac{\Sigma V_{conc} + \Sigma V_{SoilWaterUN2}}{\left|\Sigma V_{UpliftUN2}\right|} = 2.02$$

$$FS_{Floatation.UN2.check} := \begin{cases} \text{"OKAY "} & \text{if } FS_{FloatationUN2} > FS_{req.UN2.flt} \\ \text{"Revise Structure""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

CHECK OVERTURNING

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.
Assumptions are made in order to compute overturning stablity of indetermine forces on monolith with key;
(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.
(b) The horizontal resisting force acting on the key, P.key, is that required for static equilibrium
(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1

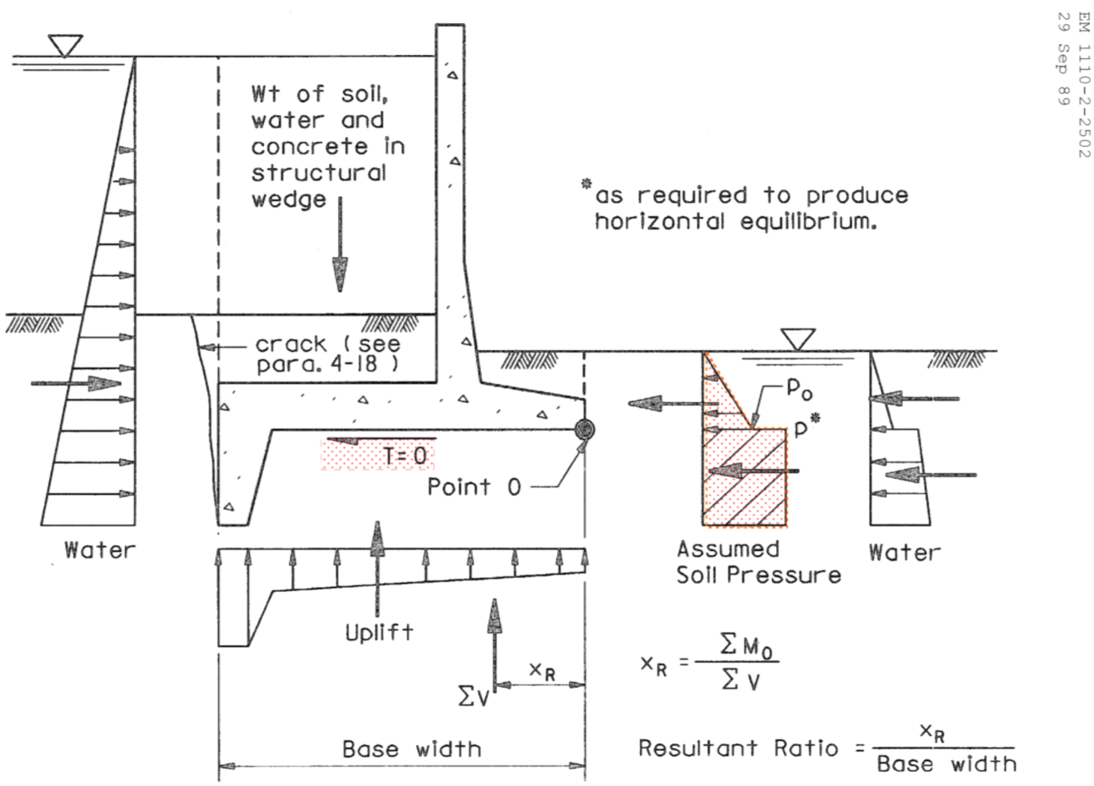


Figure 4-5. Forces for overturning analysis for wall with horizontal base and key

Modify Uplift for Overturning Analysis: **LOAD CASE UN2**

(Uplift is calculated along the concrete/rock contact using the Line of Creep method)

Water Pressure at h: $u_{h.UN2} := \Delta h_{g.hj.UN2} \cdot \gamma_w = 121.52 \cdot kPa$

Water Pressure at o: $u_{o.UN2} := \left(\Delta h_{g.no.UN2} - \frac{\Delta h_{g.r.UN2} \cdot L_{ho.UN2}}{L_{ho.UN2}}\right) \cdot \gamma_w = 97.02 \cdot kPa$

Head loss between point h and o: $\Delta h_{ho.UN2} := \Delta h_{g.r.UN2} \cdot \frac{L_{ho.UN2}}{L_{ho.UN2}} = 0\,m$

Length of concrete base (h -> o): $L_{baseho.UN2} := Key_{h.w} + Key_{h.d} + Key_{hdist} + Key_{t.d} + Key_{t.w} = 13.5\,m$

Head loss along h -> j: $\Delta h_{hj.UN2} := \Delta h_{ho.UN2} \cdot \frac{Key_{h.w}}{L_{baseho.UN2}} = 0\,m$

Water Pressure at j: $u_{j.UN2} := \left(\Delta h_{g.hj.UN2} - \Delta h_{hj.UN2}\right) \cdot \gamma_w = 121.52 \cdot kPa$

Head loss along h -> k: $\Delta h_{hjk.UN2} := \Delta h_{ho.UN2} \cdot \left(\frac{Key_{h.w} + Key_{h.d}}{L_{baseho.UN2}}\right) = 0\,m$

Water Pressure at k: $u_{k.UN2} := \left(\Delta h_{g.km.UN2} - \Delta h_{hjk.UN2}\right) \cdot \gamma_w = 97.02 \cdot kPa$

Head loss along h -> m: $\Delta h_{hjkm.UN2} := \Delta h_{ho.UN2} \cdot \left(\frac{Key_{h.w} + Key_{h.d} + Key_{hdist}}{L_{baseho.UN2}}\right) = 0\,m$

Water Pressure at m: $u_{m.UN2} := \left(\Delta h_{g.km.UN2} - \Delta h_{hjkm.UN2}\right) \cdot \gamma_w = 97.02 \cdot kPa$

Head loss along h -> n: $\Delta h_{hjkmn.UN2} := \Delta h_{ho.UN2} \cdot \left(\frac{Key_{h.w} + Key_{h.d} + Key_{hdist} + Key_{t.d}}{L_{baseho.UN2}}\right) = 0\,m$

Water Pressure at n: $u_{n.UN2} := \left(\Delta h_{g.no.UN2} - \Delta h_{hjkmn.UN2}\right) \cdot \gamma_w = 97.02 \cdot kPa$

Uplift under key at heel: $V_{ulkeyhUN2.OT} := \frac{\left(u_{h.UN2} + u_{j.UN2}\right) \cdot Key_{h.w}}{2} \cdot B \cdot -1 = -121.52 \cdot kN$

Moment Arm (from Point O): $V_{ulkeyhUN2loc.OT} := b - \frac{Key_{h.w} \cdot \left(2 \cdot u_{j.UN2} + u_{h.UN2}\right)}{3 \cdot \left(u_{j.UN2} + u_{h.UN2}\right)} = 10.5\,m$

Uplift under base: $V_{ulbaseUN2.OT} := \frac{\left(u_{k.UN2} + u_{m.UN2}\right) \cdot Key_{hdist}}{2} \cdot B \cdot -1 = -970.2 \cdot kN$

Moment Arm (from Point O): $V_{ulbaseUN2loc.OT} := b - Key_{h.w} - \frac{Key_{hdist} \cdot \left(2 \cdot u_{m.UN2} + u_{k.UN2}\right)}{3 \cdot \left(u_{m.UN2} + u_{k.UN2}\right)} = 5\,m$

Uplift under key at toe $V_{ulkeytUN2.OT} := \frac{\left(u_{n.UN2} + u_{o.UN2}\right) \cdot Key_{t.w}}{2} \cdot B \cdot -1 = 0 \cdot kN$

Moment Arm (from Point O): $V_{ulkeytUN2loc.OT} := \frac{Key_{t.w} \cdot \left(2 \cdot u_{n.UN2} + u_{o.UN2}\right)}{3 \cdot \left(u_{n.UN2} + u_{o.UN2}\right)} = 0$

$$\Sigma V_{UpliftUN2.OT} := V_{ulkeyhUN2.OT} + V_{ulbaseUN2.OT} + V_{ulkeytUN2.OT} = -1092 \cdot kN$$

$$U_{UN2.loc.OT} := \frac{V_{ulkeyhUN2.OT} \cdot V_{ulkeyhUN2loc.OT} + V_{ulbaseUN2.OT} \cdot V_{ulbaseUN2loc.OT} + V_{ulkeytUN2.OT} \cdot V_{ulkeytUN2loc.OT}}{\Sigma V_{UpliftUN2.OT}} = 5.61\,m$$

$$\Sigma M_{UpliftUN2.OT} := \Sigma V_{UpliftUN2.OT} \cdot U_{UN2.loc.OT} = -6127.0 \cdot kN \cdot m$$

Modify Lateral Water Pressure (Resisting) for Overturning Analysis:

(Resisting water pressure is calculated using the Line of Creep method)

Water Load at Key (heel): $H_{h2UN2.OT} := \frac{u_{k.UN2} + u_{j.UN2}}{2} \cdot Key_{h.d} \cdot B = 273.2 \cdot kN$

Moment Arm (from Point O): $H_{h2locUN2.OT} := \frac{Key_{h.d} \cdot (2 \cdot u_{k.UN2} + u_{j.UN2})}{3(u_{k.UN2} + u_{j.UN2})} + Key_{vdist} = -1.30\ m$

Water Load at Key (toe): $H_{h6UN2.OT} := \frac{u_{o.UN2} \cdot (UWSEL_{UN2} - Bot_{ftg} + Key_{t.d})}{2} \cdot B = 480 \cdot kN$

Moment Arm (from Point O): $H_{h6locUN2.OT} := \frac{UWSEL_{UN2} - Bot_{ftg} + Key_{t.d}}{3} = 3.30\ m$

$$\Sigma H_{waterresistUN2.OT} := H_{h2UN2.OT} + H_{h6UN2.OT} = 753.42 \cdot kN$$

$$H_{waterresistlocUN2.OT} := \frac{H_{h2UN2.OT} \cdot H_{h2locUN2.OT} + H_{h6UN2.OT} \cdot H_{h6locUN2.OT}}{\Sigma H_{waterresistUN2.OT}} = 1.633\ m$$

$$\Sigma M_{waterresistUN2.OT} := \Sigma H_{waterresistUN2.OT} \cdot H_{waterresistlocUN2.OT} = 1230.59 \cdot kN \cdot m$$

Modify Lateral Soil Loads for Overturning Analysis:

(Lateral soil loads are calculated down to Point O instead of bottom of shear key)

Driving Soil Load (Headwater Side):

Surcharge Load: $E_{s1UN2.OT} := S1_{UN2} \cdot K_o \cdot (H_w + Key_{h.d} + Key_{vdist}) \cdot B \cdot -1 = 0 \cdot kN$

Moment Arm (from Point O): $E_{s1locUN2.OT} := \frac{H_w + Key_{h.d} + Key_{vdist}}{2} = 5.65\ m$

Moist Soil Load above GWL: $E_{h1UN2.OT} := \frac{\gamma_m \cdot K_o \cdot h_{1UN2}^2}{2} B \cdot -1 = -10.7 \cdot kN$

Moment Arm (from Point O): $E_{h1locUN2.OT} := \frac{h_{1UN2}}{3} + h_{2UN2} + Key_{vdist} = 10.37\ m$

Saturated Soil Load below GWL: (rectangular component) $E_{h2UN2.OT} := (\gamma_m \cdot K_o \cdot h_{1UN2}) \cdot (h_{2UN2} + Key_{vdist}) \cdot B \cdot -1 = -151.4 \cdot kN$

Moment Arm (from Point O): $E_{h2locUN2.OT} := \frac{h_{2UN2} + Key_{vdist}}{2} = 4.95\ m$

Saturated Soil Load below GWL: (triangular component) $E_{h2aUN2.OT} := \frac{(\gamma_{sat} - \gamma_w) \cdot K_o \cdot (h_{2UN2} + Key_{vdist})^2}{2} \cdot B \cdot -1 = -326.4 \cdot kN$

Moment Arm (from Point O): $E_{h2alocUN2.OT} := \frac{h_{2UN2} + Key_{vdist}}{3} = 3.30\ m$

Resisting Soil Load (Tailwater Side):

(Determine resisting soil load based on depth variation between the keys (ie. Key_{vdist}). In case where key at heel is deeper than key at toe (ie. $Key_{vdist} < 0$), resisting soil load (p*) is assumed to produce horizontal equilibrium as per Figure 4-5 above. Resisting soil load (p_o) is neglected.)

Total Driving Force: $\Sigma H_{SoildriveUN2.OT} := E_{s1UN2.OT} + E_{h1UN2.OT} + E_{h2UN2.OT} + E_{h2aUN2.OT} + H_{h2UN2} = -1241.9 \cdot kN$

Total Resisting Force: $\Sigma H_{waterresistUN2.OT} = 753.4 \cdot kN$

Assumed Soil Load p*: $E_{h8UN2a.OT} := \left(\Sigma H_{SoildriveUN2.OT} + \Sigma H_{waterresistUN2.OT}\right) \cdot -1 = 488.493 \cdot kN$

Moment Arm (from Point O): $E_{h8UN2a.loc.OT} := \frac{Key_{vdist}}{2} = -1.25\ m$

$$E_{h8UN2.OT} := \begin{cases} E_{h8UN2a.OT} & \text{if } Key_{vdist} < 0 \\ \Sigma H_{SoilresistUN2} - H_{h6UN2} - H_{h2aUN2} & \text{otherwise} \end{cases} = 488.493 \cdot kN$$

$$\Sigma M_{SoilresistUN2} := \begin{cases} E_{h8UN2a.OT} \cdot E_{h8UN2a.loc.OT} & \text{if } Key_{vdist} < 0 \\ \Sigma M_{HorizSoilResistUN2} - H_{h6UN2} \cdot H_{h6locUN2} - H_{h2aUN2} \cdot H_{h2alocUN2} & \text{otherwise} \end{cases} = -610.617 \cdot kN \cdot m$$

Sum of Moment about Point O:

$$\Sigma M_{LateraldriveUN2.OT} := E_{s1UN2.OT} \cdot E_{s1locUN2.OT} + E_{h1UN2.OT} \cdot E_{h1locUN2.OT} + E_{h2UN2.OT} \cdot E_{h2locUN2.OT} \dots + E_{h2aUN2.OT} \cdot E_{h2alocUN2.OT} + H_{h2UN2} \cdot H_{h2locUN2} = -3168.0 \cdot kN \cdot m$$

$$\Sigma M_{LateralresistUN2.OT} := \Sigma M_{waterresistUN2.OT} + \Sigma M_{SoilresistUN2} = 620.0 \cdot kN \cdot m$$

Total moment:

$$\Sigma M_{UN2.OT} := \Sigma M_{conc} + \Sigma M_{VertSoilWaterResistUN2} + \Sigma M_{UpliftUN2.OT} + \Sigma M_{LateraldriveUN2.OT} + \Sigma M_{LateralresistUN2.OT} = 6539.0 \cdot kN \cdot m$$

Total Vertical Force: $\Sigma V_{UN2.OT} := \Sigma V_{conc} + \Sigma V_{SoilWaterUN2} + \Sigma V_{UplliftUN2.OT} = 1331.3 \cdot kN$

Distance X_R: EM 1110-2-2502 Eq.4-1 $X_{R.UN2} := \frac{\Sigma M_{UN2.OT}}{\Sigma V_{UN2.OT}} = 4.912\ m$

Overturning Resultant Ratio $Ratio_{UN2.OT} := \frac{X_{R.UN2}}{b} = 0.45$

$$Ratio_{UN2.OT.check} := \begin{cases} \text{"OKAY "} & \text{if } Ratio_{UN2.OT} > X_{R.reqUN2} \\ \text{"Revise Structure""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

CHECK FOUNDATION ECCENTRICITY (HORIZONTAL PLANE):

Eccentricity (horizontal plan): $ex_{UN2.OT} := \frac{b}{2} - \frac{\Sigma M_{UN2.OT}}{\Sigma V_{UN2.OT}} = 0.59\ m$ $Kern_{OT} = 1.833\ m$

Eccentricity Check:

$$e_{check.UN2.OT} := \begin{cases} \text{"Okay"} & \text{if } ex_{UN2} \le Kern_{OT} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"Okay"}$$

LOAD CASE UN2

CHECK FOUNDATION BEARING CAPACITY (HORIZONTAL PLANE):

Base Section Modulus: $S_{b.OT} = 20.17\,m^3$

Bearing Pressure Under Toe:

$$\sigma_{ToeUN2.OT} := \begin{cases} \left(\dfrac{\Sigma V_{UN2.OT}}{b \cdot B} + \dfrac{\Sigma V_{UN2.OT} \cdot ex_{UN2.OT}}{S_{b.OT}}\right) & \text{if } \dfrac{\Sigma V_{UN2.OT}}{b \cdot B} \geq \dfrac{\Sigma V_{UN2.OT} \cdot ex_{UN2.OT}}{S_{b.OT}} \\ \dfrac{2 \cdot \Sigma V_{UN2.OT}}{B \cdot 3\left(\dfrac{b}{2} - ex_{UN2.OT}\right)} & \text{otherwise} \end{cases} = 159.9 \cdot kPa$$

$$Bearing_{ChecktoeUN2.OT} := \begin{cases} \text{"OKAY "} & \text{if } \sigma_{ToeUN2.OT} < \sigma_{allowUN2} \\ \text{"NG - for reference only""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

Bearing Pressure Under Heel:

$$\sigma_{HeelUN2.OT} := \begin{cases} \left(\dfrac{\Sigma V_{UN2.OT}}{b \cdot B} - \dfrac{\Sigma V_{UN2.OT} \cdot ex_{UN2.OT}}{S_{b.OT}}\right) & \text{if } \dfrac{\Sigma V_{UN2.OT}}{b \cdot B} \geq \dfrac{\Sigma V_{UN2.OT} \cdot ex_{UN2.OT}}{S_{b.OT}} \\ 0 & \text{otherwise} \end{cases} = 82.2 \cdot kPa$$

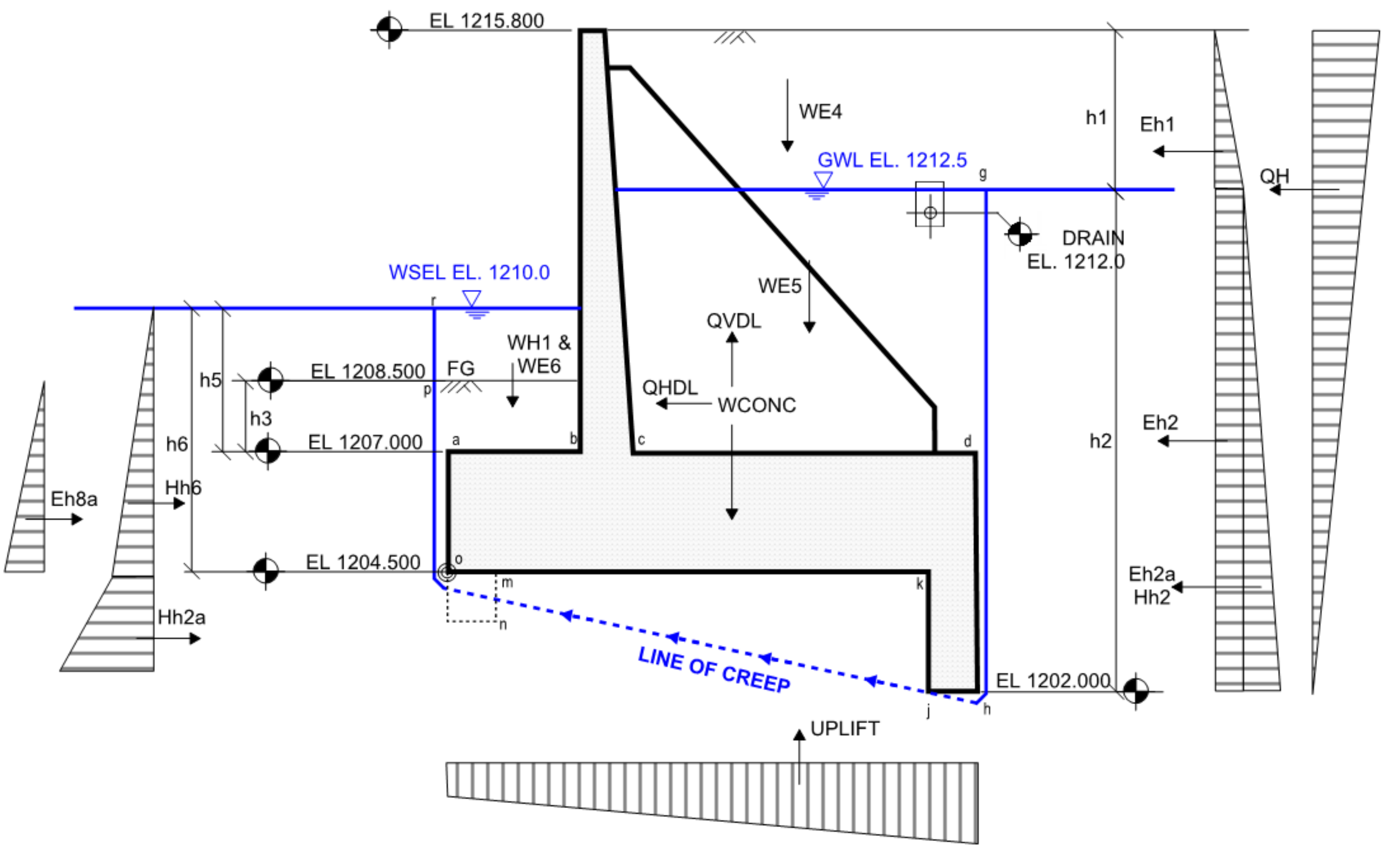
$$Bearing_{CheckheelUN2.OT} := \left(\begin{cases} \text{"OKAY "} & \text{if } \sigma_{ToeUN2.OT} < \sigma_{allowUN2} \wedge \sigma_{ToeUN2.OT} > 0 \\ \text{"NG - for reference only""} & \text{otherwise} \end{cases} \right) = \text{"OKAY "}$$

SUMMARY OF STABILITY ASSESSMENT:

LOAD CASE UN2

Sliding Factor of Safety: (Horizontal Plane - Ref only)	$FS_{Horiz.SlidingUN2} = 0.60$	$FS_{Sliding.check1.UN2} =$ "NG - key req""
Sliding Factor of Safety: (Inclined Plane)	$FS_{InclinedlSlidingUN2} = 1.31$	$FS_{Sliding.check2.UN2} =$ "OKAY "
Eccentricity: (Inclined Plane)	$ex_{UN2} = 1.29\ m$	$e_{check.UN2} =$ "Okay"
Bearing Pressure At Heel: (Inclined Plane)	$\sigma_{HeelUN2} = 49 \cdot kPa$	$Bearing_{CheckheelUN2} =$ "OKAY "
Bearing Pressure At Toe: (Inclined Plane)	$\sigma_{ToeUN2} = 258 \cdot kPa$	$Bearing_{ChecktoeUN2} =$ "OKAY "
Flotation Factor of Safety (horizontal plane)	$FS_{FloatationUN2} = 2.02$	$FS_{Floatation.UN2.check} =$ "OKAY "
Overturning Resultant Ratio: (horizontal plane)	$Ratio_{UN2.OT} = 0.45$	$Ratio_{UN2.OT.check} =$ "OKAY "
Eccentricity: (horizontal plane - Ref only)	$ex_{UN2.OT} = 0.59\ m$	$e_{check.UN2.OT} =$ "Okay"
Bearing Pressure At Heel: (horizontal plane - Ref only)	$\sigma_{HeelUN2.OT} = 82 \cdot kPa$	$Bearing_{CheckheelUN2.OT} =$ "OKAY "
Bearing Pressure At Toe: (horizontal plane - Ref only)	$\sigma_{ToeUN2.OT} = 160 \cdot kPa$	$Bearing_{ChecktoeUN2.OT} =$ "OKAY "

LOAD CASE E1 - SEISMIC LOADING



E1 DESIGN CASE

LOAD CASE E1 ACCEPTANCE PARAMETERS

FS sliding:

Extreme (E) loading) 1.0 (without cohesion, seismic (Table 3-3, USACE EM 1110-2-2100)

Resultant Location:

Extremem (E) Inside middle half ~75% base in compression

Required Factor of Safety for Sliding: $FS_{sliding.reqE1} := 1.0$ (Without Cohesion)

Allowable rock bearing pressure: $\sigma_{allowE1} := 1740kPa$ (Section 5.2, Design Criteria EM 1110-2-2100 Section 3-10)

Overturning Required Resultant Ratio: $X_{R.reqE1} := 0.25$ (EM 1110-2-2502, Figure 4-4)

Required Factor of Safety for Floatation $FS_{req.E1.flt} := 1.1$

SOIL HEIGHTS and Water Levels:

LOAD CASE E1

Heel Conditions:

Groundwater Elevation at Heel: $GWL_{E1} := 1212.5m$

Distance from Finish Grade to Groundwater at Heel: $h_{1E1} := \left[T_w - GWL_{E1} + \left(L_{cd} + t_{wb} - t_{wt}\right) \cdot \tan(\beta)\right] = 3.30\ m$

Distance from Water Surface to Bottom of Footing at Heel: $h_{2E1} := GWL_{E1} - Bot_{ftg} + Key_{h.d} = 10.50\ m$

Toe Conditions:

Water Surface Elevation at Toe: $WSEL_{E1} := 1210.0m$

Water Surface Elevation at Toe for Uplift: $UWSEL_{E1} := 1210.0 \cdot m$

Finish Grade at Toe providing lateral resistance: $FG_{toeE1} := 1208.5 \cdot m$

Soil Depth Above top of footing: $h_{3aE1} := FG_{toeE1} - Top_{ftg} = 1.5\ m$

$$h_{3E1} := \begin{array}{|l} h_{3aE1} \quad \text{if} \quad FG_{toeE1} - Top_{ftg} \geq 0 \\ 0 \quad \text{otherwise} \end{array} = 1.5$$

Resisting Fill at Toe: $h_{4E1} := FG_{toeE1} - Bot_{ftg} + Key_{t.d} = 4.00\ m$

Distance from Water Level to Top of Footing at Toe: $h_{5E1} := WSEL_{E1} - Top_{ftg} = 3.00\ m$

Distance from Water Surface to Bottom of Footing at Toe: $h_{6E1} := WSEL_{E1} - Bot_{ftg} + Key_{t.d} = 5.50\ m$

Soil Depth Above WSEL: $h_{7aE1} := FG_{toeE1} - WSEL_{E1} = -1.5\ m$

$$h_{7E1} := \begin{array}{|l} h_{7aE1} \quad \text{if} \quad FG_{toeE1} - WSEL_{E1} \geq 0 \\ 0 \quad \text{otherwise} \end{array} = 0$$

Soil Depth Below WSEL:

$$h_{8E1} := \begin{array}{|l} WSEL_{E1} - Bot_{ftg} + Key_{t.d} \quad \text{if} \quad FG_{toeE1} - WSEL_{E1} \geq 0 \\ h_{4E1} \quad \text{otherwise} \end{array} = 4$$

For Line of Creep Method: $L_{ho.E1} := \sqrt{b^2 + \left(Key_{h.d} - Key_{t.d}\right)^2} = 11.281\ m$

Head Loss from Point g:

$\Delta h_{g.hj.E1} := h_{2E1} = 10.5\ m$ (to point h & j)

$\Delta h_{g.km.E1} := GWL_{E1} - Bot_{ftg} = 8\ m$ (to point k & m)

$\Delta h_{g.no.E1} := GWL_{E1} - Bot_{ftg} + Key_{t.d} = 8\ m$ (to point n & o)

$\Delta h_{g.p.E1} := GWL_{E1} - FG_{toeE1} = 4\ m$ (to point p)

$\Delta h_{g.r.E1} := GWL_{E1} - UWSEL_{E1} = 2.5\ m$ (to point r)

Surcharge

Surcharge on Heel: $S1_{E1} := 0.0 \dfrac{kN}{m^2}$

Calculate Soil Lateral Pressure Coefficients:

LOAD CASE E1

Calculate at-rest pressure coefficient K_o based on Jaky's (1944) equation.

Soil At Rest Static Coefficient:
(apply to resisting soil loads)

$$K_o := \frac{1 - \sin(\phi)}{1 + \sin(\beta)} = 0.546$$

(Eq. 3-6, USACE EM 1110-2-2502)

Calculate active pressure coefficient K_A based on Coulumb equations.

Determine Slope of Active Wedge: (cohesionless backfill with water table)

$$c_1 := 2 \cdot \tan(\phi) = 1.019 \qquad c_2 := 1 - \tan(\phi) \cdot \tan(\beta) - \frac{\tan(\beta)}{\tan(\phi)} = 1$$

(Eq. G-14 / G-15, USACE EM 1110-2-2100)

$$\alpha := \operatorname{atan}\left(\frac{c_1 + \sqrt{c_1^{\,2} + 4 \cdot c_2}}{2}\right) = 1.021 \qquad \alpha_{deg} := \alpha \cdot \frac{180}{\pi} = 58.5 \text{ degrees}$$

(Eq. G-13, USACE EM 1110-2-2100)

Soil Active Coefficient above GWL:

$$K_{Aagwt} := \left(\frac{1 - \tan(\phi) \cdot \cot(\alpha)}{1 + \tan(\phi) \cdot \tan(\alpha)}\right) \cdot \left(\frac{\tan(\alpha)}{\tan(\alpha) - \tan(\beta)}\right) = 0.376$$

Soil Active Coefficient below GWL:

$$K_{Abgwt} := \frac{1 - \tan(\phi) \cdot \cot(\alpha)}{1 + \tan(\phi) \cdot \tan(\alpha)} \cdot \left[1 + \left(\frac{\tan(\alpha)}{\tan(\alpha) - \tan(\beta)} - 1\right) \cdot \left(\frac{\gamma_m}{\gamma_{sat} - \gamma_w}\right)\right] = 0.376$$

(Eq. G-29, USACE EM 1110-2-2100)

Lateral - Driving Force

Static Copmonent : Active Pressure:

Surcharge Load:

$$E_{s1E1} := S1_{E1} \cdot K_{Aagwt} \cdot \left(H_w + Key_{h.d}\right) \cdot B \cdot -1 = 0 \cdot kN$$

Moment Arm (from bottom of footing):

$$E_{s1locE1} := \frac{H_w + Key_{h.d}}{2} + Key_{vdist} = 4.40\ m$$

Moist Soil Load above GWL:

$$E_{h1E1} := \frac{\gamma_m \cdot K_{Aagwt} \cdot h_{1E1}^{\,2}}{2} \cdot B \cdot -1 = -40.9 \cdot kN$$

Moment Arm (from bottom of footing):

$$E_{h1locE1} := \frac{h_{1E1}}{3} + h_{2E1} + Key_{vdist} = 9.10\ m$$

Saturated Soil Load below GWL:
(rectangular component)

$$E_{h2E1} := \left(\gamma_m \cdot K_{Abgwt} \cdot h_{1E1}\right) \cdot h_{2E1} \cdot B \cdot -1 = -260.2 \cdot kN$$

Moment Arm (from bottom of footing):

$$E_{h2locE1} := \frac{h_{2E1}}{2} + Key_{vdist} = 2.75\ m$$

Saturated Soil Load below GWL:
(triangular component)

$$E_{h2aE1} := \frac{\left(\gamma_{sat} - \gamma_w\right) \cdot K_{Abgwt} \cdot h_{2E1}^{\,2}}{2} \cdot B \cdot -1 = -252.5 \cdot kN$$

Moment Arm (from bottom of footing):

$$E_{h2alocE1} := \frac{h_{2E1}}{3} + Key_{vdist} = 1.00\ m$$

Lateral Water Load:

Water Load GWL to Bottom of Key

$$H_{h2E1} := \frac{\gamma_w \cdot h_{2E1}^{\,2}}{2} \cdot B \cdot -1 = -540.2 \cdot kN$$

Moment Arm (from bottom of footing):

$$H_{h2locE1} := \frac{h_{2E1}}{3} + Key_{vdist} = 1.00\ m$$

$$\Sigma H_{SoildriveE1} := E_{s1E1} + E_{h1E1} + E_{h2E1} + E_{h2aE1} + H_{h2E1} = -1093.9 \cdot kN$$

$$\Sigma M_{LateralSoildriveE1} := E_{s1E1} \cdot E_{s1locE1} + E_{h1E1} \cdot E_{h1locE1} + E_{h2E1} \cdot E_{h2locE1} \cdots + E_{h2aE1} \cdot E_{h2alocE1} + H_{h2E1} \cdot H_{h2locE1} = -1880.6\ m \cdot kN$$

Lateral - Resisting Force

LOAD CASE E1

Note: **Due to the relatively shallow depth of resisting soil/rock, a conservative apporach using at-rest coefficient in lieu of a passive wedge is used to calculate resisting forces.**

Lateral Water Load:

Water Load WSEL to Bottom of Footing: $H_{h6E1} := H_{h6U1} = 148.2 \cdot kN$

Moment Arm (from bot. of toe key): $H_{h6locE1} := H_{h6locU1} = 1.83\ m$

Water Load Bot. of Footing to Bot. of H. Key: $H_{h2aE1} := \left[\left(UWSEL_{E1} - Bot_{ftg} + Key_{t.d}\right) + h_{2E1}\right] \cdot \frac{Key_{h.d}}{2} \cdot \gamma_w \cdot B = 196.0 \cdot kN$

Moment Arm (from bot. of toe key): $H_{h2alocE1} := \frac{Key_{h.d} \cdot \left[2 \cdot \left(UWSEL_{E1} - Bot_{ftg} + Key_{t.d}\right) + h_{2E1}\right]}{3\left[h_{2E1} + \left(UWSEL_{E1} - Bot_{ftg} + Key_{t.d}\right)\right]} \ldots = -1.38\ m$
$+ Key_{vdist}$

Lateral Soil Load:

Moist Soil Load above WSEL: $E_{h7E1} := \frac{\gamma_m \cdot K_o \cdot h_{7E1}^{\ 2}}{2} \cdot B = 0.0 \cdot kN$

Moment Arm (from bot. of toe key): $E_{h7locE1} := h_{6E1} + \frac{h_{7E1}}{3} + Key_{vdist} = 3.00\ m$

Saturated Soil Load below WSEL:
(rectangular component) $E_{h8E1} := \left(\gamma_m \cdot K_o \cdot h_{7E1}\right) \cdot h_{8E1} \cdot B = 0.0 \cdot kN$

Moment Arm (from bot. of toe key): $E_{h8locE1} := \frac{h_{8E1}}{2} = 2.00\ m$

Saturated Soil Load below WSEL:
(triangular component) $E_{h8aE1} := \frac{\left[\left(\gamma_{sat} - \gamma_w\right) \cdot K_o\right] \cdot h_{8E1}^{\ 2}}{2} \cdot B = 53.3 \cdot kN$

Moment Arm (from bot. of footing): $E_{h8alocE1} := \frac{h_{8E1}}{3} = 1.33\ m$

$\Sigma H_{SoilresistE1} := H_{h6E1} + H_{h2aE1} + E_{h7E1} + E_{h8E1} + E_{h8aE1} = 397.5 \cdot kN$

$\Sigma M_{HorizSoilResistE1} := H_{h6E1} \cdot H_{h6locE1} + H_{h2aE1} \cdot H_{h2alocE1} + E_{h7E1} \cdot E_{h7locE1} \ldots = 72.3\ m \cdot kN$
$+ E_{h8E1} \cdot E_{h8locE1} + E_{h8aE1} \cdot E_{h8alocE1}$

Vertical Force:

UPLIFT: Linear distribution from water at heel to water at toe:

$\Sigma V_{UpliftE1} := \left[\left(UWSEL_{E1} - Bot_{ftg} + Key_{t.d}\right) + h_{2E1}\right] \cdot \frac{b}{2} \cdot \gamma_w \cdot B \cdot -1 = -862.4 \cdot kN$

Moment Arm (from Point O): $V_{UpliftE1aloc} := \frac{b \cdot \left[2 \cdot h_{2E1} + \left(UWSEL_{E1} - Bot_{ftg} + Key_{t.d}\right)\right]}{3\left[h_{2E1} + \left(UWSEL_{E1} - Bot_{ftg} + Key_{t.d}\right)\right]} = 6.073\ m$

$\Sigma M_{UpliftE1} := \Sigma V_{UpliftE1} \cdot V_{UpliftE1aloc} = -5237.283 \cdot kN \cdot m$

Weight of soil and water over toe:

Water Above the Top of Footing: $W_{H1E1} := \gamma_w \cdot h_{5E1} \cdot L_{ab} \cdot B = 80.85 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E1locE1} := \dfrac{L_{ab}}{2} = 1.375\,m$

Soil above top of footing: $W_{E6E1} := \gamma_b \cdot h_{3E1} \cdot L_{ab} \cdot B = 50.3 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E6locE1} := \dfrac{L_{ab}}{2} = 1.375\,m$

Vertical Load Due to Surcharge: $S_{E1} := S1_{E1} \cdot L_{cd} \cdot B = 0 \cdot kN$ $\quad S_{E1loc} := b - \dfrac{L_{cd}}{2} = 7.47\,m$

Weight of soil and water over heel:

Moist Soil for sloped grade above top of wall:

Length of sloped portion of soil above top of wall: $L_{E3E1} := \left(L_{cd} + t_{wb} - t_{wt}\right) = 7.75\,m$

Height of sloped soil above top of wall over heel: $h_{E3locE1} := \left(L_{E3E1}\right) \cdot \tan(\beta) = 0.00\,m$

Weight of sloped soil above top of wall: $W_{E3E1} := \dfrac{\gamma_m}{2} \cdot h_{E3locE1} \cdot L_{E3E1} \cdot B = 0.0 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E3locE1} := L_{ab} + t_{wt} + \dfrac{2}{3} \cdot L_{E3E1} = 8.42\,m$

Moist soil from top of wall to groundwater level:

Height of soil from top of wall and top of GWL: $h_{1E1} = 3.30\,m$

Length from edge of wall at GWL to edge of heel: $L_{E4E1} := L_{E3E1} - \left(h_{1E1} \cdot S_{batter}\right) = 7.49\,m$

Weight of soil over heel from top of wall to GWL: $W_{E4E1} := \gamma_m \cdot h_{1E1} \cdot \dfrac{\left(L_{E3E1} + L_{E4E1}\right)}{2} \cdot B = 502.9 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E4locE1} := b - \dfrac{L_{E3E1}^{\;2} + L_{E3E1} \cdot L_{E4U1} + L_{E4E1}^{\;2}}{3\left(L_{E3E1} + L_{E4E1}\right)} = 7.19\,m$

Saturated soil from groundwater to top of footing:

Height of soil from GWL to top of heel: $h_{E4E1} := h_{2E1} - t_{ftg} - Key_{h.d} = 5.50\,m$

Weight of soil over heel from GWL to top of heel: $W_{E5E1} := \left(\gamma_{sat}\right) \cdot h_{E4E1} \cdot \dfrac{\left(L_{E4E1} + L_{cd}\right)}{2} \cdot B = 880.3 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E5locE1} := b - \dfrac{L_{E4E1}^{\;2} + L_{E4E1} \cdot L_{cd} + L_{cd}^{\;2}}{3\left(L_{E4E1} + L_{cd}\right)} = 7.36\,m$

$$\Sigma V_{SoilWaterE1} := W_{H1E1} + W_{E6E1} + W_{E3E1} + W_{E4E1} + W_{E5E1} + S_{E1} = 1514.4 \cdot kN$$

$$\Sigma M_{VertSoilWaterResistE1} := W_{H1E1} \cdot W_{E1locE1} + W_{E6E1} \cdot W_{E6locE1} \cdots + W_{E3E1} \cdot W_{E3locE1} + W_{E4E1} \cdot W_{E4locE1} + W_{E5E1} \cdot W_{E5locE1} + S_{E1} \cdot S_{E1loc} = 10276.3\,m \cdot kN$$

SESIMIC ANALYSIS:

LOAD CASE E1

Seismic coefficient will be applied to dead loads to calculate seismic force and force is applied at center of gravity of the mass. Vertical and Horizontal loads are applied in the "destabilizing direction"

SEISMIC PARAMETERS:

(Section 7.9, Design Criteria)

Peak Ground Acceleration for Seismic Load $PGA_{Horiz} := 0.26$ $PGA_{Vert} := 0.56 \cdot PGA_{Horiz} = 0.146$

In accordance with USACE EM 1110-2-2100 Section 4-7.b, consider 2/3 PGA as seismic coefficient for stabilitiy.

Horizontal Seismic coefficient for stabilty: $K_{hE1} := \frac{2}{3} PGA_{Horiz} = 0.173$

Vertical Seismic coefficient for stabilty: $K_{vE1} := \frac{2}{3} PGA_{Vert} = 0.097$

SEISMIC ACCELERATION OF RIGID MASSES (Q_D):

Vertical Load Application:

$\Sigma V_{conc} = 879.8 \cdot kN$

$Q_{v.conc} := \Sigma V_{conc} \cdot K_{vE1} \cdot -1 = -85.4 \cdot kN$ (assume acting upwards for adverse sliding effect)

Moment arm for siesmic load application (From Toe): $H_{cent} = 5.376\,m$

$M_{Qv.conc} := Q_{v.conc} \cdot H_{cent} = -459.1 \cdot kN \cdot m$

Lateral Load Application:

$Q_{h.conc} := \Sigma V_{conc} \cdot K_{hE1} \cdot -1 = -152.5 \cdot kN$

Moment arm for siesmic load application (Above Base of Footing): $V_{Cent} = 2.087\,m$

$M_{Q.conc} := Q_{h.conc} \cdot V_{Cent} = -318.2 \cdot kN \cdot m$

SEISMIC ACCELERATION OF SOIL WEDGE + WATER (Q_{EH}):

Vertical Load Application:

$\Sigma V_{SoilWaterE1} = 1514.4 \cdot kN$

$Q_{v.SoilWaterE1} := \Sigma V_{SoilWaterE1} \cdot K_{vE1} \cdot -1 = -147 \cdot kN$ (assume acting upwards for adverse sliding effect)

Moment arm for siesmic load application (From Toe): $e_{QE1} := \frac{\Sigma M_{VertSoilWaterResistE1}}{\Sigma V_{SoilWaterE1}} = 6.786\,m$

$M_{Qv.SoilWaterE1} := Q_{v.SoilWaterE1} \cdot e_{QE1} = -997.5 \cdot kN \cdot m$

Lateral Load Application:

Seismic soil load is calculated based on Mononobe-Okabe method to determine combined static and dynamic coefficient (K_{AE}). Coulomb's active component (K_A) is subtracted from K_{AE} to obtain the seismic coefficient (ΔK_{AE}) for dynamic component of soil force.

Glacial Till Internal Friction (radians): $\phi = 0.471$

Seismic Inertia Angle (radians): $\psi := \operatorname{atan}\left(\frac{K_{hE1}}{1 - K_{vE1}}\right) = 0.190$

Inclination of batter (radians): $\theta := 0.00$ assuming zero is conservative

Slope of retained ground surface: $\beta = 0.00$

$$K_{AE} := \frac{\cos(\phi - \psi - \theta) \cdot \cos(\phi - \psi - \theta)}{\cos(\psi) \cdot \cos(\theta) \cdot \cos(\theta)\ \cos(\psi + \theta) \cdot \left(1 + \sqrt{\frac{\sin(\phi)\ \sin(\phi - \psi - \beta)}{\cos(\beta - \theta) \cdot \cos(\psi + \theta)}}\right)^2} = 0.519$$

$\Delta K_{AE} := K_{AE} - K_{Abgwt} = 0.143$

Dynamic component of active seismic wedge:

(Eq. G-64, USACE EM 1110-2-2100)

$$Q_{h.SoilWaterE1} := \Delta K_{AE} \cdot \left[\frac{\gamma_m \cdot (H_w + Key_{h.d})^2}{2 \cdot (\tan(\alpha) - \tan(\beta))} + \frac{(\gamma_{sat} - \gamma_m) \cdot h_{2E1}^{\ 2}}{2 \cdot \tan(\alpha)}\right] \cdot B \cdot -1 = -176.5 \cdot kN$$

Moment arm for siesmic load application (About Point O): $Q_{h.SoilWaterlocE1} := \frac{2}{3} \cdot (H_w + Key_{h.d}) + Key_{vdist} = 6.70\,m$

$M_{Q.h.SoilWaterE1} := Q_{h.SoilWaterE1} \cdot Q_{h.SoilWaterlocE1} = -1182.7 \cdot kN \cdot m$

STABILITY ASSESSMENT:

LOAD CASE E1

CHECK SLIDING ALONG HORIZONTAL SLIDING PLANE:

Summation of the vertical forces: $\Sigma V_{E1} := \Sigma V_{conc} + \Sigma V_{SoilWaterE1} + \Sigma V_{UpliftE1} + Q_{v.conc} + Q_{v.SoilWaterE1} = 1299.4 \cdot kN$

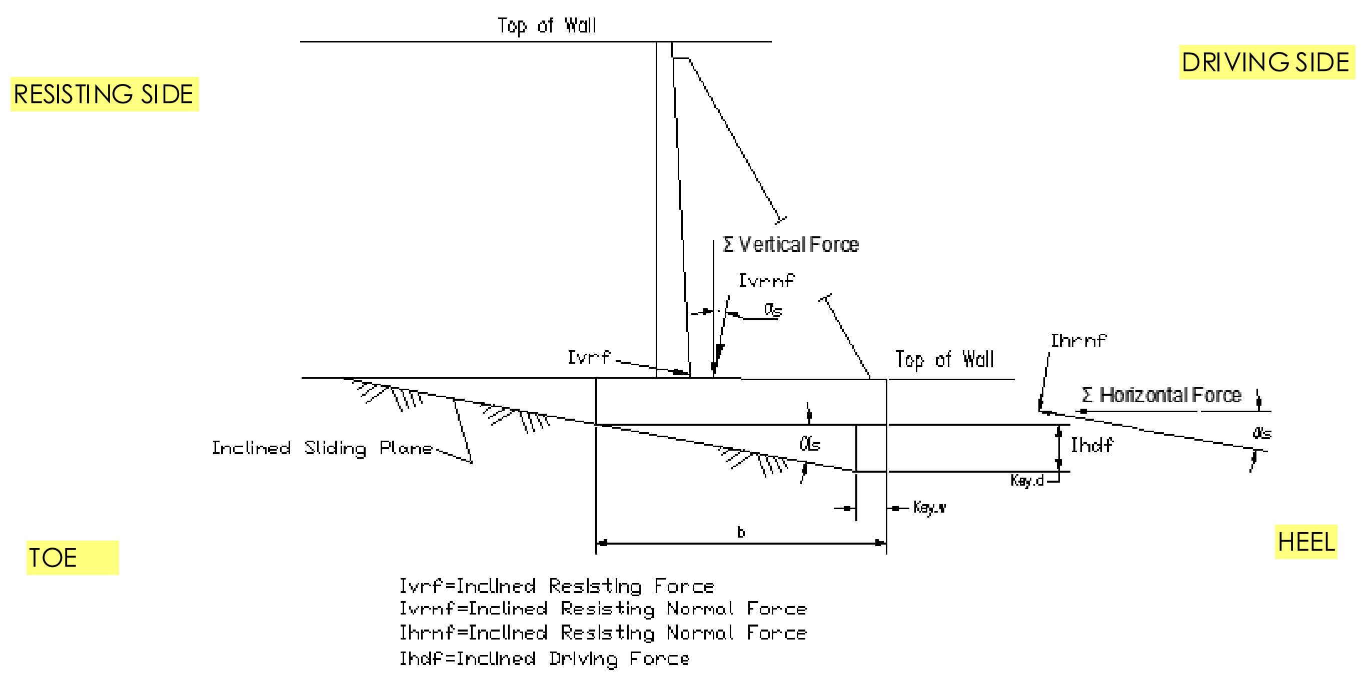
Summation of the horizontal forces: $\Sigma H_{E1} := \Sigma H_{SoildriveE1} + Q_{h.conc} + Q_{h.SoilWaterE1} + \Sigma H_{SoilresistE1} = -1025.4 \cdot kN$

Safety Factor for Sliding Horizontal Failure Plane

$$FS_{Horiz.SlidingE1} := \frac{\left|\Sigma V_{E1}\right| \cdot \tan\left(\phi_{rock} \cdot \frac{\pi}{180}\right)}{\left|\Sigma H_{E1}\right|} = 0.62$$

$$FS_{Sliding.check1.E1} := \begin{array}{|l} \text{"OKAY "} \quad \text{if} \quad FS_{Horiz.SlidingE1} > FS_{sliding.reqE1} \\ \text{"NG - key req""} \quad \text{otherwise} \end{array} = \text{"NG - key req""}$$

CHECK FACTOR OF SAFETY SLIDING WITH KEY (INCLINED SLIDING PLANE):



(With properly engineered reinforced concrete Key, horizontal sliding plane thru Toe is protected, critical sliding plane is relocated to the INCLINED SLIDING PLANE FROM HEEL KEY To TOE, Bedrock Mass above this examing plane is mobilized by reinforced concrete key and combined into Structural Wedge.)

Resolve ΣV_{E1} & ΣH_{E1}

$$\Sigma V_{InclinedE1} := \cos(\alpha s) \cdot \left(\left|\Sigma V_{E1} + V_{rocksection}\right|\right) + \sin(\alpha s) \cdot \left|\Sigma H_{E1}\right| = 1819.8 \cdot kN$$

$$\Sigma H_{InclinedE1} := \cos(\alpha s) \cdot \left|\Sigma H_{E1}\right| - \sin(\alpha s) \cdot \left(\left|\Sigma V_{E1} + V_{rocksection}\right|\right) = 602.0 \cdot kN$$

Safety Factor for Sliding Inclined Failure Plane

$$FS_{InclinedISlidingE1} := \frac{\Sigma V_{InclinedE1} \cdot \tan\left(\phi_r\right)}{\Sigma H_{InclinedE1}} = 1.35$$

$$FS_{Sliding.check2.E1} := \begin{array}{|l} \text{"OKAY "} \quad \text{if} \quad FS_{InclinedISlidingE1} > FS_{sliding.reqE1} \\ \text{"NG""} \quad \text{otherwise} \end{array} = \text{"OKAY "}$$

CHECK FOUNDATION ECCENTRICITY:

LOAD CASE E1

(Vertical seismic loads from concrete, soil and water are assumed acting downwards for adverse bearing effect)

Summation of the vertical forces: $\Sigma V_{seisE1} := \Sigma V_{conc} + \Sigma V_{SoilWaterE1} + \Sigma V_{UpliftE1} - Q_{v.conc} - Q_{v.SoilWaterE1} = 1764.2 \cdot kN$

Summation of the horizontal forces: $\Sigma H_{seisE1} := \Sigma H_{E1} = -1025.4 \cdot kN$

Resolve ΣV_{seisE1} & ΣH_{seisE1}

$$\Sigma V_{InclinedseisE1} := \cos(\alpha s) \cdot \left(\left| \Sigma V_{seisE1} + V_{rocksection} \right| \right) + \sin(\alpha s) \cdot \left| \Sigma H_{seisE1} \right| = 2270.7 \cdot kN$$

$$\Sigma H_{InclinedseisE1} := \cos(\alpha s) \cdot \left| \Sigma H_{seisE1} \right| - \sin(\alpha s) \cdot \left(\left| \Sigma V_{seisE1} + V_{rocksection} \right| \right) = 489.3 \cdot kN$$

Summation of the resisting moments about the toe:

$$\Sigma M_{resE1} := \Sigma M_{conc} + \Sigma M_{VertSoilWaterResistE1} + \Sigma M_{HorizSoilResistE1} + \Sigma M_{rocksection} = 17212 \cdot kN \cdot m$$

Summation of seismic moments about the toe:

$$\Sigma M_{seisE1} := -M_{Qv.conc} + M_{Q.conc} - M_{Qv.SoilWaterE1} + M_{Q.h.SoilWaterE1} = -44 \cdot kN \cdot m$$

Summation of the overturning moments about the toe:

$$\Sigma M_{oE1} := \Sigma M_{LateralSoildriveE1} + \Sigma M_{UpliftE1} = -7118 \cdot kN \cdot m$$

Total moment: $\Sigma M_{E1} := \Sigma M_{resE1} + \Sigma M_{seisE1} + \Sigma M_{oE1} = 10049.8 \cdot kN \cdot m$

Normal force to base: $\Sigma V_{InclinedseisE1} = 2270.7 \cdot kN$

Inclined Sliding Plane Length: $L_{incline} = 11.3 \cdot m$

Eccentricity (inclined plane): $ex_{E1} := \dfrac{L_{incline}}{2} - \dfrac{\Sigma M_{E1}}{\Sigma V_{InclinedseisE1}} = 1.24\,m$ $\quad Kern_{E1} := \dfrac{L_{incline}}{4} = 2.835\,m$

Eccentricity Check:

$$e_{check.E1} := \begin{cases} \text{"Okay"} & \text{if } ex_{E1} \le Kern_{E1} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"Okay"}$$

CHECK FOUNDATION BEARING CAPACITY:

Base Section Modulus: $S_b = 21.43\,m^3$

Bearing Pressure Under Toe:

$$\sigma_{ToeE1} := \begin{cases} \left(\dfrac{\Sigma V_{InclinedE1}}{L_{incline} \cdot B} + \dfrac{\Sigma V_{InclinedE1} \cdot ex_{E1}}{S_b} \right) & \text{if } \dfrac{\Sigma V_{InclinedE1} \cdot ex_{E1}}{S_b} \le \dfrac{\Sigma V_{InclinedE1}}{L_{incline} \cdot B} \\ \dfrac{2 \cdot \Sigma V_{InclinedE1}}{B \cdot 3 \left(\dfrac{b}{2} - ex_{E1} \right)} & \text{otherwise} \end{cases} = 266.1 \cdot kPa$$

$$Bearing_{CheckoeE1} := \begin{cases} \text{"OKAY "} & \text{if } \sigma_{ToeE1} < \sigma_{allowE1} \\ \text{"NG""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

Bearing Pressure Under Heel:

$$\sigma_{HeelE1} := \begin{cases} \left(\dfrac{\Sigma V_{InclinedE1}}{L_{incline} \cdot B} - \dfrac{\Sigma V_{InclinedE1} \cdot ex_{E1}}{S_b} \right) & \text{if } \dfrac{\Sigma V_{InclinedE1} \cdot ex_{E1}}{S_b} \le \dfrac{\Sigma V_{InclinedE1}}{L_{incline} \cdot B} \\ 0 & \text{otherwise} \end{cases} = 54.9 \cdot kPa$$

$$Bearing_{CheckheelE1} := \left(\begin{cases} \text{"OKAY "} & \text{if } \sigma_{HeelE1} < \sigma_{allowE1} \wedge \sigma_{HeelE1} > 0 \\ \text{"NG - perform cracked base analysis""} & \text{otherwise} \end{cases} \right) = \text{"OKAY "}$$

CHECK FLOATATION:

Safety Factor for Floatation:

$$FS_{FloatationE1} := \frac{\Sigma V_{conc} + \Sigma V_{SoilWaterE1} + Q_{v.conc} + Q_{v.SoilWaterE1}}{\left|\Sigma V_{UpliftE1}\right|} = 2.51$$

$$FS_{Floatation.E1.check} := \begin{cases} \text{"OKAY"} & \text{if } FS_{FloatationE1} > FS_{req.E1.flt} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

CHECK OVERTURNING

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.
Assumptions are made in order to compute overturning stablity of indetermine forces on monolith with key;
(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.
(b) The horizontal resisting force acting on the key, P.key, is that required for static equilibrium
(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1

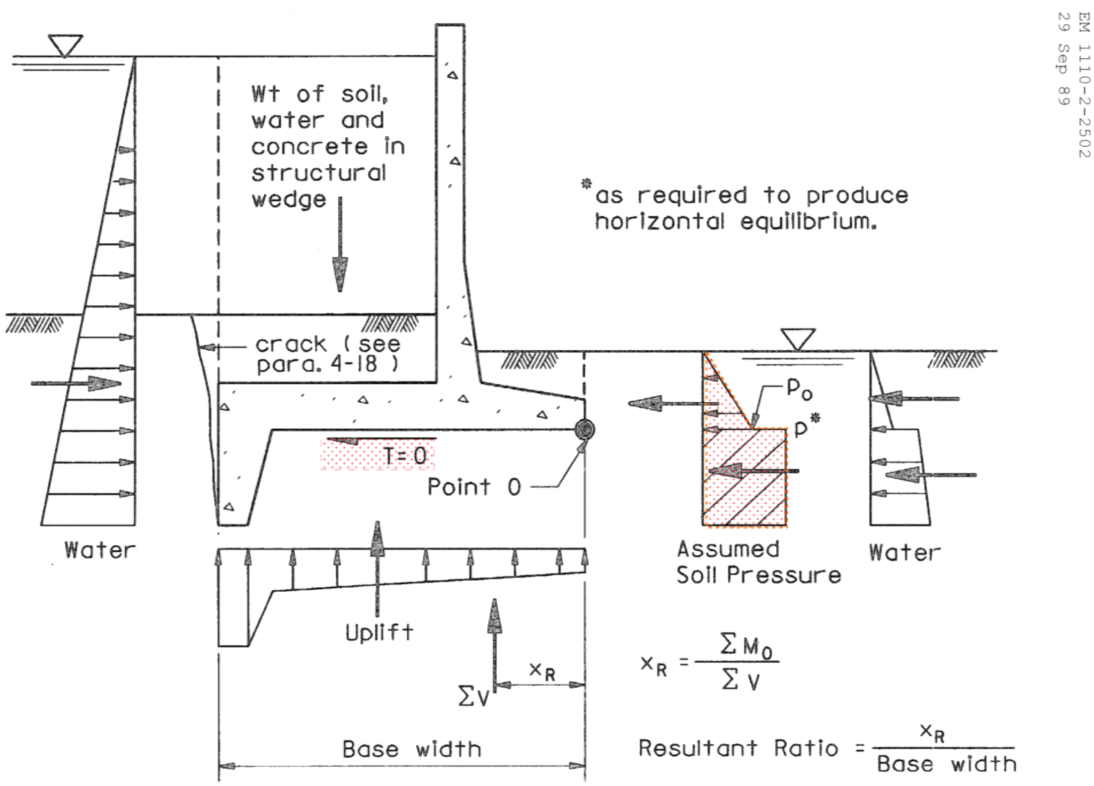


Figure 4-5. Forces for overturning analysis for wall with horizontal base and key

Modify Uplift for Overturning Analysis: **LOAD CASE E1**

(Uplift is calculated along the concrete/rock contact using the Line of Creep method)

Water Pressure at h: $u_{h.E1} := \Delta h_{g.hj.E1} \cdot \gamma_w = 102.90 \cdot kPa$

Water Pressure at o: $u_{o.E1} := \left(\Delta h_{g.no.E1} - \frac{\Delta h_{g.r.E1} \cdot L_{ho.E1}}{L_{ho.E1}}\right) \cdot \gamma_w = 53.9 \cdot kPa$

Head loss between point h and o: $\Delta h_{ho.E1} := \Delta h_{g.r.E1} \cdot \frac{L_{ho.E1}}{L_{ho.E1}} = 2.5\,m$

Length of concrete base (h -> o): $L_{baseho.E1} := Key_{h.w} + Key_{h.d} + Key_{hdist} + Key_{t.d} + Key_{t.w} = 13.5\,m$

Head loss along h -> j: $\Delta h_{hj.E1} := \Delta h_{ho.E1} \cdot \frac{Key_{h.w}}{L_{baseho.E1}} = 0.185\,m$

Water Pressure at j: $u_{j.E1} := \left(\Delta h_{g.hj.E1} - \Delta h_{hj.E1}\right) \cdot \gamma_w = 101.09 \cdot kPa$

Head loss along h -> k: $\Delta h_{hjk.E1} := \Delta h_{ho.E1} \cdot \left(\frac{Key_{h.w} + Key_{h.d}}{L_{baseho.E1}}\right) = 0.648\,m$

Water Pressure at k: $u_{k.E1} := \left(\Delta h_{g.km.E1} - \Delta h_{hjk.E1}\right) \cdot \gamma_w = 72.05 \cdot kPa$

Head loss along h -> m: $\Delta h_{hjkm.E1} := \Delta h_{ho.E1} \cdot \left(\frac{Key_{h.w} + Key_{h.d} + Key_{hdist}}{L_{baseho.E1}}\right) = 2.5\,m$

Water Pressure at m: $u_{m.E1} := \left(\Delta h_{g.km.E1} - \Delta h_{hjkm.E1}\right) \cdot \gamma_w = 53.90 \cdot kPa$

Head loss along h -> n: $\Delta h_{hjkmn.E1} := \Delta h_{ho.E1} \cdot \left(\frac{Key_{h.w} + Key_{h.d} + Key_{hdist} + Key_{t.d}}{L_{baseho.E1}}\right) = 2.5\,m$

Water Pressure at n: $u_{n.E1} := \left(\Delta h_{g.no.E1} - \Delta h_{hjkmn.E1}\right) \cdot \gamma_w = 53.90 \cdot kPa$

Uplift under key at heel: $V_{ulkeyhE1.OT} := \frac{\left(u_{h.E1} + u_{j.E1}\right) \cdot Key_{h.w}}{2} \cdot B \cdot -1 = -101.993 \cdot kN$

Moment Arm (from Point O): $V_{ulkeyhE1loc.OT} := b - \frac{Key_{h.w} \cdot \left(2 \cdot u_{j.E1} + u_{h.E1}\right)}{3 \cdot \left(u_{j.E1} + u_{h.E1}\right)} = 10.501\,m$

Uplift under base: $V_{ulbaseE1.OT} := \frac{\left(u_{k.E1} + u_{m.E1}\right) \cdot Key_{hdist}}{2} \cdot B \cdot -1 = -629.741 \cdot kN$

Moment Arm (from Point O): $V_{ulbaseE1loc.OT} := b - Key_{h.w} - \frac{Key_{hdist} \cdot \left(2 \cdot u_{m.E1} + u_{k.E1}\right)}{3 \cdot \left(u_{m.E1} + u_{k.E1}\right)} = 5.24\,m$

Uplift under key at toe: $V_{ulkeytE1.OT} := \frac{\left(u_{n.E1} + u_{o.E1}\right) \cdot Key_{t.w}}{2} \cdot B \cdot -1 = 0 \cdot kN$

Moment Arm (from Point O): $V_{ulkeytE1loc.OT} := \frac{Key_{t.w} \cdot \left(2 \cdot u_{n.E1} + u_{o.E1}\right)}{3 \cdot \left(u_{n.E1} + u_{o.E1}\right)} = 0$

$$\Sigma V_{UpliftE1.OT} := V_{ulkeyhE1.OT} + V_{ulbaseE1.OT} + V_{ulkeytE1.OT} = -732 \cdot kN$$

$$U_{E1.loc.OT} := \frac{V_{ulkeyhE1.OT} \cdot V_{ulkeyhE1loc.OT} + V_{ulbaseE1.OT} \cdot V_{ulbaseE1loc.OT} + V_{ulkeytE1.OT} \cdot V_{ulkeytE1loc.OT}}{\Sigma V_{UpliftE1.OT}} = 5.97\,m$$

$$\Sigma M_{UpliftE1.OT} := \Sigma V_{UpliftE1.OT} \cdot U_{E1.loc.OT} = -4371.0 \cdot kN \cdot m$$

Modify Lateral Water Pressure (Resisting) for Overturning Analysis:

(Resisting water pressure is calculated using the Line of Creep method)

Water Load at Key (heel):

$$H_{h2E1.OT} := \frac{u_{k.E1} + u_{j.E1}}{2} \cdot Key_{h.d} B = 216.4 \cdot kN$$

Moment Arm (from Point O):

$$H_{h2locE1.OT} := \frac{Key_{h.d} \cdot (2 \cdot u_{k.E1} + u_{j.E1})}{3(u_{k.E1} + u_{j.E1})} + Key_{vdist} = -1.32\ m$$

Water Load at Key (toe):

$$H_{h6E1.OT} := \frac{u_{o.E1} \cdot (UWSEL_{E1} - Bot_{ftg} + Key_{t.d})}{2} \cdot B = 148 \cdot kN$$

Moment Arm (from Point O):

$$H_{h6locE1.OT} := \frac{UWSEL_{E1} - Bot_{ftg} + Key_{t.d}}{3} = 1.83\ m$$

$$\Sigma H_{waterresistE1.OT} := H_{h2E1.OT} + H_{h6E1.OT} = 364.64 \cdot kN$$

$$H_{waterresistlocE1.OT} := \frac{H_{h2E1.OT} \cdot H_{h2locE1.OT} + H_{h6E1.OT} \cdot H_{h6locE1.OT}}{\Sigma H_{waterresistE1.OT}} = -0.038\ m$$

$$\Sigma M_{waterresistE1.OT} := \Sigma H_{waterresistE1.OT} \cdot H_{waterresistlocE1.OT} = -13.9 \cdot kN \cdot m$$

Modify Lateral Soil Loads for Overturning Analysis:

(Lateral soil loads are calculated down to Point O instead of bottom of shear key)

Driving Soil Load (Headwater Side):

Surcharge Load:

$$E_{s1E1.OT} := S1_{E1} \cdot K_{Aagwt} \cdot (H_w + Key_{h.d} + Key_{vdist}) \cdot B \cdot -1 = 0 \cdot kN$$

Moment Arm (from Point O):

$$E_{s1locE1.OT} := \frac{H_w + Key_{h.d} + Key_{vdist}}{2} = 5.65\ m$$

Moist Soil Load above GWL:

$$E_{h1E1.OT} := \frac{\gamma_m \cdot K_{Aagwt} \cdot h_{1E1}^{\ 2}}{2} \cdot B \cdot -1 = -40.9 \cdot kN$$

Moment Arm (from Point O):

$$E_{h1locE1.OT} := \frac{h_{1E1}}{3} + h_{2E1} + Key_{vdist} = 9.10\ m$$

Saturated Soil Load below GWL:
(rectangular component)

$$E_{h2E1.OT} := (\gamma_m \cdot K_{Aagwt} \cdot h_{1E1}) \cdot (h_{2E1} + Key_{vdist}) \cdot B \cdot -1 = -198.3 \cdot kN$$

Moment Arm (from Point O):

$$E_{h2locE1.OT} := \frac{h_{2E1} + Key_{vdist}}{2} = 4.00\ m$$

Saturated Soil Load below GWL:
(triangular component)

$$E_{h2aE1.OT} := \frac{(\gamma_{sat} - \gamma_w) \cdot K_{Aagwt} \cdot (h_{2E1} + Key_{vdist})^2}{2} \cdot B \cdot -1 = -146.6 \cdot kN$$

Moment Arm (from Point O):

$$E_{h2alocE1.OT} := \frac{h_{2E1} + Key_{vdist}}{3} = 2.67\ m$$

Resisting Soil Load (Tailwater Side):

LOAD CASE E1

(Determine resisting soil load based on depth variation between the keys (ie. Key_{vdist}). In case where key at heel is deeper than key at toe (ie. $Key_{vdist} < 0$), resisting soil load (p*) is assumed to produce horizontal equilibrium as per Figure 4-5 above. Resisting soil load (p_o) is neglected.)

Total Driving Force: $\Sigma H_{SoildriveE1.OT} := E_{s1E1.OT} + E_{h1E1.OT} + E_{h2E1.OT} + E_{h2aE1.OT} + H_{h2E1} \cdots + Q_{h.conc} + Q_{h.SoilWaterE1} = -1255.0 \cdot kN$

Total Resisting Force: $\Sigma H_{waterresistE1.OT} = 364.642 \cdot kN$

Assumed Soil Load p*: $E_{h8E1a.OT} := (\Sigma H_{SoildriveE1.OT} + \Sigma H_{waterresistE1.OT}) \cdot -1 = 890.395 \cdot kN$

Moment Arm (from Point O): $E_{h8E1a.loc.OT} := \frac{Key_{vdist}}{2} = -1.25\, m$

$$E_{h8E1.OT} := \begin{cases} E_{h8E1a.OT} & \text{if } Key_{vdist} < 0 \\ \Sigma H_{SoilresistE1} - H_{h6E1} - H_{h2aE1} & \text{otherwise} \end{cases} = 890.395 \cdot kN$$

$$\Sigma M_{SoilresistE1} := \begin{cases} E_{h8E1a.OT} \cdot E_{h8E1a.loc.OT} & \text{if } Key_{vdist} < 0 \\ \Sigma M_{HorizSoilResistE1} - H_{h6E1} \cdot H_{h6locE1} - H_{h2aE1} \cdot H_{h2alocE1} & \text{otherwise} \end{cases} = -1112.994 \cdot kN \cdot m$$

Sum of Moment about Point O:

$$\Sigma M_{LateraldriveE1.OT} := E_{s1E1.OT} \cdot E_{s1locE1.OT} + E_{h1E1.OT} \cdot E_{h1locE1.OT} + E_{h2E1.OT} \cdot E_{h2locE1.OT} \cdots + E_{h2aE1.OT} \cdot E_{h2alocE1.OT} + H_{h2E1} \cdot H_{h2locE1} = -2096.4 \cdot kN \cdot m$$

$$\Sigma M_{LateralresistE1.OT} := \Sigma M_{waterresistE1.OT} + \Sigma M_{SoilresistE1} = -1126.9 \cdot kN \cdot m$$

$$\Sigma M_{seisE1.OT} := M_{Qv.conc} + M_{Q.conc} + M_{Qv.SoilWaterE1} + M_{Q.h.SoilWaterE1} = -2958 \cdot kN \cdot m$$

(seismic moment modified for the most adverse overturning effect)

Total moment:

$$\Sigma M_{E1.OT} := \Sigma M_{conc} + \Sigma M_{VertSoilWaterResistE1} + \Sigma M_{UpliftE1.OT} + \Sigma M_{LateraldriveE1.OT} + \Sigma M_{LateralresistE1.OT} + \Sigma M_{seisE1.OT} = 4454.5 \cdot kN \cdot m$$

Total Vertical Force: $\Sigma V_{E1.OT} := \Sigma V_{conc} + \Sigma V_{SoilWaterE1} + \Sigma V_{UplliftE1.OT} + Q_{v.conc} + Q_{v.SoilWaterE1} = 1430.1 \cdot kN$

Distance X_R: EM 1110-2-2502 Eq.4-1 $X_{R.E1} := \frac{\Sigma M_{E1.OT}}{\Sigma V_{E1.OT}} = 3.115\, m$

Overturning Resultant Ratio $Ratio_{E1.OT} := \frac{X_{R.E1}}{b} = 0.28$

$$Ratio_{E1.OT.check} := \begin{cases} \text{"OKAY "} & \text{if } Ratio_{E1.OT} > X_{R.reqE1} \\ \text{"Revise Structure""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

CHECK FOUNDATION ECCENTRICITY (HORIZONTAL PLANE):

Eccentricity (horizontal plan): $ex_{E1.OT} := \frac{b}{2} - \frac{\Sigma M_{E1.OT}}{\Sigma V_{E1.OT}} = 2.39\, m$ $Kern_{E1.OT} := \frac{b}{4} = 2.75\, m$

Eccentricity Check:

$$e_{check.E1.OT} := \begin{cases} \text{"Okay"} & \text{if } ex_{E1.OT} \le Kern_{E1.OT} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"Okay"}$$

LOAD CASE E1

CHECK FOUNDATION BEARING CAPACITY (HORIZONTAL PLANE):

Base Section Modulus: $S_{b.OT} = 20.17\,m^3$

Bearing Pressure Under Toe:

$$\sigma_{ToeE1.OT} := \begin{cases} \left(\dfrac{\Sigma V_{E1.OT}}{b \cdot B} + \dfrac{\Sigma V_{E1.OT} \cdot ex_{E1.OT}}{S_{b.OT}}\right) & \text{if } \dfrac{\Sigma V_{E1.OT}}{b \cdot B} \geq \dfrac{\Sigma V_{E1.OT} \cdot ex_{E1.OT}}{S_{b.OT}} \\ \dfrac{2 \cdot \Sigma V_{E1.OT}}{B \cdot 3\left(\dfrac{b}{2} - ex_{E1.OT}\right)} & \text{otherwise} \end{cases} = 306.1 \cdot kPa$$

$$Bearing_{ChecktoeE1.OT} := \begin{cases} \text{"OKAY "} & \text{if } \sigma_{ToeE1.OT} < \sigma_{allowE1} \\ \text{"NG - for reference only""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

Bearing Pressure Under Heel:

$$\sigma_{HeelE1.OT} := \begin{cases} \left(\dfrac{\Sigma V_{E1.OT}}{b \cdot B} - \dfrac{\Sigma V_{E1.OT} \cdot ex_{E1.OT}}{S_{b.OT}}\right) & \text{if } \dfrac{\Sigma V_{E1.OT}}{b \cdot B} \geq \dfrac{\Sigma V_{E1.OT} \cdot ex_{E1.OT}}{S_{b.OT}} \\ 0 & \text{otherwise} \end{cases} = 0.0 \cdot kPa$$

$$Bearing_{CheckheelE1.OT} := \left(\begin{cases} \text{"OKAY "} & \text{if } \sigma_{HeelE1.OT} < \sigma_{allowE1} \wedge \sigma_{HeelE1.OT} > 0 \\ \text{"NG - for reference only""} & \text{otherwise} \end{cases}\right) = \text{"NG - for reference only""}$$

SUMMARY OF STABILITY ASSESSMENT:

LOAD CASE E1

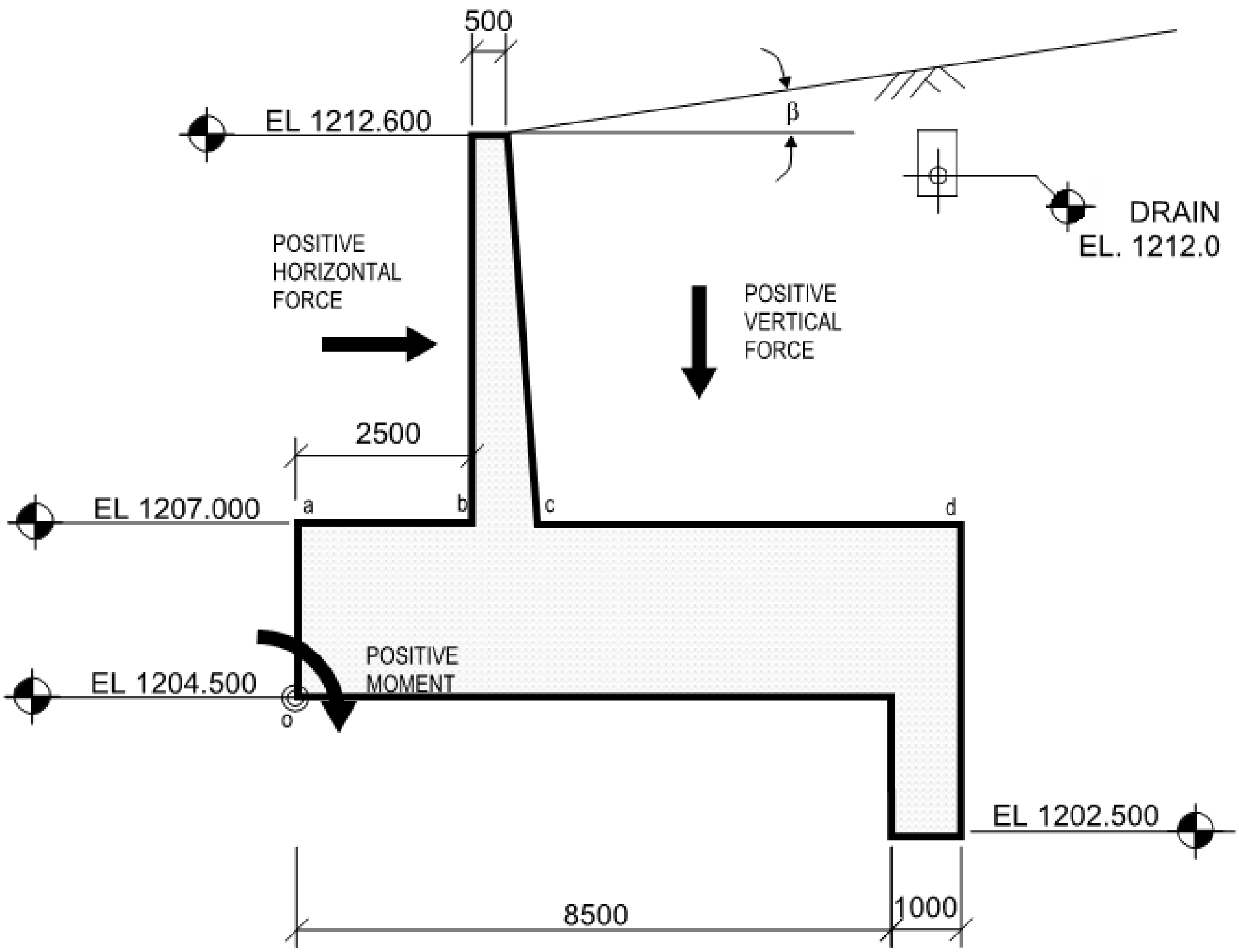
Sliding Factor of Safety: (Horizontal Plane - Ref only)	$FS_{Horiz.SlidingE1} = 0.62$	$FS_{Sliding.check1.E1}$ = "NG - key req""
Sliding Factor of Safety: (Inclined Plane)	$FS_{InclinedISlidingE1} = 1.35$	$FS_{Sliding.check2.E1}$ = "OKAY "
Eccentricity: (Inclined Plane)	$ex_{E1} = 1.24\ m$	$e_{check.E1}$ = "Okay"
Bearing Pressure At Heel: (Inclined Plane)	$\sigma_{HeelE1} = 55 \cdot kPa$	$Bearing_{CheckheelE1}$ = "OKAY "
Bearing Pressure At Toe: (Inclined Plane)	$\sigma_{ToeE1} = 266 \cdot kPa$	$Bearing_{ChecktoeE1}$ = "OKAY "
Flotation Factor of Safety (horizontal plane)	$FS_{FloatationE1} = 2.51$	$FS_{Floatation.E1.check}$ = "OKAY "
Overturning Resultant Ratio: (horizontal plane)	$Ratio_{E1.OT} = 0.28$	$Ratio_{E1.OT.check}$ = "OKAY "
Eccentricity: (horizontal plane - Ref only)	$ex_{E1.OT} = 2.39\ m$	$e_{check.E1.OT}$ = "Okay"
Bearing Pressure At Heel: (horizontal plane - Ref only)	$\sigma_{HeelE1.OT} = 0 \cdot kPa$	$Bearing_{CheckheelE1.OT}$ = "NG - for reference only""
Bearing Pressure At Toe: (horizontal plane - Ref only)	$\sigma_{ToeE1.OT} = 306 \cdot kPa$	$Bearing_{ChecktoeE1.OT}$ = "OKAY "

Calculation Section VI

SS-Block 5D (Downstream) Retaining Wall Stability Calculations

Project Number:	110773396		
Project Title:	SR1 - Diversion Structure		
Client:	Alberta Transportation		
Engineer:	Lawrence Choi	Date: 12/11/2018	
Checker:	Sean Xiao	Date: 12/18/2018	

Calculation for: Retaining Wall - Service Spillway Left - Block 5D (Downstream)



(DIMENSIONS BASED ON DOWNSTREAM SECTION)

REGION COLOR CONVENTION

User Input

Calulation Highlights

Results

WALL GEOMETRY:

Top of Wall Elevation: $T_w := 1212.6 \cdot m$

Top of Footing Elevation: $Top_{ftg} := 1207.0 \cdot m$

Thickness of Footing: $t_{ftg} := 2.5m$

Bottom of Footing Elevation: $Bot_{ftg} := Top_{ftg} - t_{ftg} = 1204.5\ m$

Overall Height of wall: $h_w := T_w - Bot_{ftg} = 8.10\ m$

Thickness of Wall: Base: $t_{wb} := 0.94 \cdot m$ Top: $t_{wt} := 0.50m$

Length of toe: $L_{ab} := 2.50m$

Total Length of Footing: $b := 9.5m$

Length of heel: $L_{cd} := b - L_{ab} - t_{wb} = 6.06\ m$

Unit Width of Wall for analysis: $B := 1.00m$

SHEAR KEY GEOMETRY:

	Toe	Heel
Key depth:	$Key_{t.d} := 0m$	$Key_{h.d} := 2.0m$ (Assumption: $Key_{h.d}$ >= $Key_{t.d}$)
Key width:	$Key_{t.w} := 0m$	$Key_{h.w} := 1m$
Face of Key from Point O:	$Key_{t.loc} := 0 \cdot m$	$Key_{h.loc} := b - Key_{h.w} = 8.5\ m$

Horizontal Distance between Keys: $Key_{hdist} := Key_{h.loc} - Key_{t.loc} - Key_{t.w} = 8.5\ m$

Key Depth Diff. (from point O): $Key_{vdist} := -Key_{h.d} + Key_{t.d} = -2\ m$

BASE PROPERTIES:

Base Area: $A_b := b \cdot B = 9.5\ m^2$

Centroidal Distance for Footing (from Toe): $Y_t := \frac{b}{2} = 4.75\ m$

RETAINED SOIL GEOMETRY:

Slope of retained ground surface: $\beta := 0 \cdot \frac{\pi}{180} = 0.00$

Height of retained earth at heel: $H_w := T_w - Bot_{ftg} + \left(t_{wb} + L_{cd} - t_{wt}\right) \cdot \tan(\beta) = 8.10\ m$

RETAINING WALL GEOMETRY CHECKS:

(Foundation Analysis & Design Bowles)

$$t_{bcheck} := \begin{cases} \text{"OKAY"} & \text{if } t_{ftg} \geq \frac{H_w}{12} \\ \text{"Warning"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

$$t_{wcheck} := \begin{cases} \text{"OKAY"} & \text{if } t_{wb} \geq \frac{H_w}{12} \\ \text{"Warning"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

$$b_{check} := \begin{cases} \text{"OKAY"} & \text{if } \frac{b}{H_w} \geq .4 \wedge \frac{b}{H_w} \leq 80 \\ \text{"Warning"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

$$L_{abcheck} := \begin{cases} \text{"OKAY"} & \text{if } \frac{L_{ab}}{b} \geq .25 \wedge \frac{L_{ab}}{b} \leq .4 \\ \text{"Warning"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

Material Properties:

Unit Weight of Water:	$\gamma_w := 9.8 \frac{kN}{m^3}$	(Section 7.2, Design Criteria)
Unit Weight of Concrete:	$\gamma_c := 23.5 \frac{kN}{m^3}$	
Unit Weight of Soil (Moist):	$\gamma_m := 20.0 \frac{kN}{m^3}$	(Section 5.3, Design Criteria) assumed moisture content (w) = 5%
Unit Weight Soil (Saturated):	$\gamma_{sat} := 22.0 \frac{kN}{m^3}$	(Assuming Specific Gravity = 2.7
Unit Weight Soil (buoyant):	$\gamma_b := \gamma_{sat} - \gamma_w = 12.2 \cdot \frac{kN}{m^3}$	
Weight of Soil/Concrete above toe:	$\gamma_{toe} := 22.0 \frac{kN}{m^3}$	
Unit Weight of Rock:	$\gamma_r := 25.6 \frac{kN}{m^3}$	(Section 7.2, Design Criteria)

Foundation Parameters:

Glacial Till Internal Friction:	$\phi := 27 \cdot \frac{\pi}{180} = 0.471$	
Bedrock Internal Friction Angle:	$\phi_r := 24 \cdot \frac{\pi}{180} = 0.419$	
Friction Angle at Base Concrete / Rock Interface:	$\phi_{rock} := 26$	
Base Friction Coefficient:	$tan_{\phi rock} := \tan\left(\phi_{rock} \frac{\pi}{180}\right) = 0.488$	radians
Rip Rap Backfill, Refer Dwg. C-214	$\phi_{backfill} := \left(20 \frac{\pi}{180}\right) = 0.349$	radians
Shear strength along rock Failure plane	$s_r := \frac{13100 \frac{kN}{m^2}}{2} = 6550 \cdot \frac{kN}{m^2}$	(Stantec Design Memo 8/8/16)

CONCRETE DEAD LOAD:

Area of Footing: $A_{ftg} := t_{ftg} \cdot b = 23.75\, m^2$

Weight of Footing: $D_{ftg} := A_{ftg} \cdot B \cdot \gamma_c = 558.1 \cdot kN$

Area of Stem (without batter): $A_{w1} := t_{wt} \cdot \left(h_w - t_{ftg}\right) = 2.8\, m^2$

Weight of Stem: $D_{w1} := A_{w1} \cdot B \cdot \gamma_c = 65.8 \cdot kN$

Area of stem Batter: $A_{w2} := \frac{\left(t_{wb} - t_{wt}\right)}{2} \left(h_w - t_{ftg}\right) = 1.23\, m^2$

Weight of Batter: $D_{w2} := A_{w2} \cdot B \cdot \gamma_c = 29 \cdot kN$

Slope of batter: $S_{batter} := \frac{t_{wb} - t_{wt}}{h_w - t_{ftg}} = 0.079$

Area of Key: $A_{t.key} := Key_{t.d} \cdot Key_{t.w} = 0$ $A_{h.key} := Key_{h.d} \cdot Key_{h.w} = 2\, m^2$

Weight of Key: $D_{t.key} := A_{t.key} \cdot B \cdot \gamma_c = 0 \cdot kN$ $D_{h.key} := A_{h.key} \cdot B \cdot \gamma_c = 47 \cdot kN$

Centroidal Horizontal Distance of Wall (From Toe):

$$H_{cent} := \frac{A_{w1} \cdot \left(L_{ab} + \frac{t_{wt}}{2}\right) + A_{w2} \cdot \left(L_{ab} + t_{wt} + \frac{t_{wb} - t_{wt}}{3}\right) + A_{ftg} \cdot \frac{b}{2} + A_{t.key} \cdot \left(Key_{t.loc} + \frac{Key_{t.w}}{2}\right) + A_{h.key} \cdot \left(Key_{h.loc} + \frac{Key_{h.w}}{2}\right)}{A_{w1} + A_{w2} + A_{ftg} + A_{t.key} + A_{h.key}} = 4.78\, m$$

Centroidal Vertical Distance of Wall (Above Base of Footing):

$$V_{Cent} := \frac{A_{ftg} \cdot \frac{t_{ftg}}{2} + A_{w1} \cdot \left[t_{ftg} + \frac{\left(h_w - t_{ftg}\right)}{2}\right] + A_{w2} \cdot \left[t_{ftg} + \frac{\left(h_w - t_{ftg}\right)}{3}\right] + A_{t.key} \cdot \left(\frac{-Key_{t.d}}{2}\right) + A_{h.key} \cdot \left(\frac{-Key_{h.d}}{2}\right)}{A_{ftg} + A_{w1} + A_{w2} + A_{t.key} + A_{h.key}} = 1.61\, m$$

$\Sigma V_{conc} := D_{ftg} + D_{w1} + D_{w2} + D_{t.key} + D_{h.key} = 699.9 \cdot kN$

$\Sigma M_{conc} := \Sigma V_{conc} \cdot H_{cent} = 3346.1\, m \cdot kN$

ROCK SECTION MOBILIZED FOR INCLINDED SLIDING FAILURE

Area of Rock Section Mobilized: $A_{rocksection} := \left(Key_{t.d} + Key_{h.d}\right) \cdot \frac{Key_{hdist}}{2} = 8.5\, m^2$

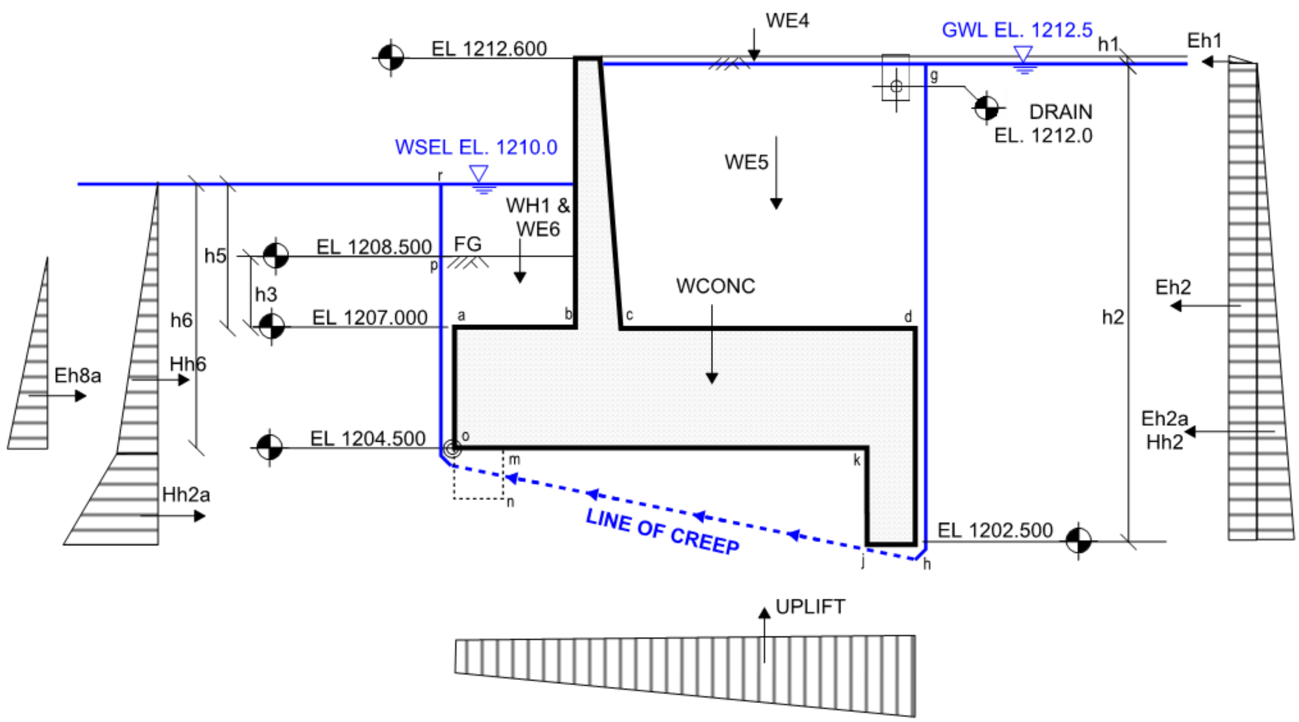
Rock Mass Mobilized: $V_{rocksection} := A_{rocksection} \cdot \gamma_r \cdot B = 217.6 \cdot kN$

(Pore pressure taken along assumed inclined sliding plane)

Distance from Toe to COG of Rock Section: $L_{rocksection} := \frac{Key_{hdist} \cdot \left(2 \cdot Key_{h.d} + Key_{t.d}\right)}{3\left(Key_{h.d} + Key_{t.d}\right)} + Key_{t.w} = 5.667\, m$

$\Sigma M_{rocksection} := V_{rocksection} \cdot L_{rocksection} = 1233.1\, m \cdot kN$

LOAD CASE U1 - NORMAL OPERATION



U1 DESIGN CASE

LOAD CASE U1 ACCEPTANCE PARAMETERS

FS sliding:

Usual (U) 1.5 (without cohesion) (Table 3-3, USACE EM 1110-2-2100)

Resultant Location:

Usual (U) Inside middle third ~100% base in compression

Required Factor of Safety for Sliding: $FS_{sliding.reqU1} := 1.5$ (Without Cohesion)

Allowable rock bearing pressure: $\sigma_{allowU1} := 1270kPa$ (Section 5.2, Design Criteria EM 1110-2-2100 Section 3-10)

Overturning Required Resultant Ratio: $X_{R.reqU1} := 0.333$ (EM 1110-2-2502, Figure 4-4)

Required Factor of Safety for Floatation $FS_{req.U1.flt} := 1.5$

SOIL HEIGHTS and Water Levels:

LOAD CASE U1

Heel Conditions:

Groundwater Elevation at Heel: $GWL_{U1} := 1212.5m$

Distance from Finish Grade to Groundwater at Heel: $h_{1U1} := \left[T_w - GWL_{U1} + \left(L_{cd} + t_{wb} - t_{wt}\right) \cdot \tan(\beta)\right] = 0.10\,m$

Distance from Water Surface to Bottom of Footing at Heel: $h_{2U1} := GWL_{U1} - Bot_{ftg} + Key_{h.d} = 10.00\,m$

Toe Conditions:

Water Surface Elevation at Toe: $WSEL_{U1} := 1210.0m$

Water Surface Elevation at Toe for Uplift: $UWSEL_{U1} := 1210.0 \cdot m$

Finish Grade at Toe providing lateral resistance: $FG_{toeU1} := 1208.5 \cdot m$

Soil Depth Above top of footing: $h_{3aU1} := FG_{toeU1} - Top_{ftg} = 1.5\,m$

$$h_{3U1} := \begin{cases} h_{3aU1} & \text{if } FG_{toeU1} - Top_{ftg} \geq 0 \\ 0 & \text{otherwise} \end{cases} = 1.5$$

Resisting Fill at Toe: $h_{4U1} := FG_{toeU1} - Bot_{ftg} + Key_{t.d} = 4.00\,m$

Distance from Water Level to Top of Footing: $h_{5U1} := WSEL_{U1} - Top_{ftg} = 3.00\,m$

Distance from Water Surface to Bottom of Footing: $h_{6U1} := WSEL_{U1} - Bot_{ftg} + Key_{t.d} = 5.50 \cdot m$

Soil Depth Above WSEL: $h_{7aU1} := FG_{toeU1} - WSEL_{U1} = -1.5\,m$

$$h_{7U1} := \begin{cases} h_{7aU1} & \text{if } FG_{toeU1} - WSEL_{U1} \geq 0 \\ 0 & \text{otherwise} \end{cases} = 0$$

Soil Depth Below WSEL:

$$h_{8U1} := \begin{cases} WSEL_{U1} - Bot_{ftg} + Key_{t.d} & \text{if } FG_{toeU1} - WSEL_{U1} \geq 0 \\ h_{4U1} & \text{otherwise} \end{cases} = 4$$

For Line of Creep Method: $L_{ho.U1} := \sqrt{b^2 + \left(Key_{h.d} - Key_{t.d}\right)^2} = 9.708\,m$

Head Loss from Point g:

$\Delta h_{g.hj.U1} := h_{2U1} = 10\,m$ (to point h & j)

$\Delta h_{g.km.U1} := GWL_{U1} - Bot_{ftg} = 8\,m$ (to point k & m)

$\Delta h_{g.no.U1} := GWL_{U1} - Bot_{ftg} + Key_{t.d} = 8\,m$ (to point n & o)

$\Delta h_{g.p.U1} := GWL_{U1} - FG_{toeU1} = 4\,m$ (to point p)

$\Delta h_{g.r.U1} := GWL_{U1} - UWSEL_{U1} = 2.5\,m$ (to point r)

Surcharge

Surcharge on Heel: $S1_{U1} := 0.0 \frac{kN}{m^2}$

LOAD CASE U1

Calculate Soil Lateral Pressure Coefficients:

For all load cases except seismic, soil loading to be based on At-Rest Condition.
Calculate at-rest pressure coefficient Ko based on Jaky's (1944) equation.

Soil At Rest Static Coefficient: $K_o := \frac{1 - \sin(\phi)}{1 + \sin(\beta)} = 0.546$ (Eq. 3-6, USACE EM 1110-2-2502)

Lateral - Driving Force (Headwater Side)

Lateral Soil Load:

Surcharge Load: $E_{s1U1} := S1_{U1} \cdot K_o \cdot \left(H_w + Key_{h.d}\right) \cdot B \cdot -1 = 0 \cdot kN$

Moment Arm (from bottom of footing): $E_{s1locU1} := \frac{H_w + Key_{h.d}}{2} + Key_{vdist} = 3.05\ m$

Moist Soil Load above GWL: $E_{h1U1} := \frac{\gamma_m \cdot K_o \cdot h_{1U1}^{\ 2}}{2} B \cdot -1 = -0.1 \cdot kN$

Moment Arm (from bottom of footing): $E_{h1locU1} := \frac{h_{1U1}}{3} + h_{2U1} + Key_{vdist} = 8.03\ m$

Saturated Soil Load below GWL:
(rectangular component)

$E_{h2U1} := \left(\gamma_m \cdot K_o \cdot h_{1U1}\right) \cdot \left(h_{2U1}\right) \cdot B \cdot -1 = -10.9 \cdot kN$

Moment Arm (from bottom of footing): $E_{h2locU1} := \frac{h_{2U1}}{2} + Key_{vdist} = 3.00\ m$

Saturated Soil Load below GWL:
(triangular component)

$E_{h2aU1} := \frac{\left(\gamma_{sat} - \gamma_w\right) \cdot K_o \cdot h_{2U1}^{\ 2}}{2} \cdot B \cdot -1 = -333.1 \cdot kN$

Moment Arm (from bottom of footing): $E_{h2alocU1} := \frac{h_{2U1}}{3} + Key_{vdist} = 1.33\ m$

Lateral Water Load:

Water Load GWL to Bottom of Key: $H_{h2U1} := \frac{\gamma_w \cdot h_{2U1}^{\ 2}}{2} \cdot B \cdot -1 = -490.0 \cdot kN$

Moment Arm (from bottom of footing): $H_{h2locU1} := \frac{h_{2U1}}{3} + Key_{vdist} = 1.33\ m$

$\Sigma H_{SoildriveU1} := E_{s1U1} + E_{h1U1} + E_{h2U1} + E_{h2aU1} + H_{h2U1} = -834.0 \cdot kN$

$$\Sigma M_{LateralSoildriveU1} := E_{s1U1} \cdot E_{s1locU1} + E_{h1U1} \cdot E_{h1locU1} + E_{h2U1} \cdot E_{h2locU1} \ \ldots = -1130.6\ m \cdot kN$$
$$+ E_{h2aU1} \cdot E_{h2alocU1} + H_{h2U1} \cdot H_{h2locU1}$$

Lateral - Resisting Force (Tailwater Side)

LOAD CASE U1

Lateral Water Load:

Water Load WSEL to Bot. of Footing:

$$H_{h6U1} := \frac{\gamma_w \cdot h_{6U1}^{\,2}}{2} \cdot B = 148.2 \cdot kN$$

Moment Arm (from bot. of toe key):

$$H_{h6locU1} := \frac{h_{6U1}}{3} = 1.83\ m$$

Water Load Bot. of Footing to Bot. of H. Key:

$$H_{h2aU1} := \left[\left(UWSEL_{U1} - Bot_{ftg} + Key_{t.d}\right) + h_{2U1}\right] \cdot \frac{Key_{h.d}}{2} \cdot \gamma_w \cdot B = 151.9 \cdot kN$$

Moment Arm (from bot. of toe key):

$$H_{h2alocU1} := \frac{Key_{h.d} \cdot \left[2 \cdot \left(UWSEL_{U1} - Bot_{ftg} + Key_{t.d}\right) + h_{2U1}\right]}{3\left[h_{2U1} + \left(UWSEL_{U1} - Bot_{ftg} + Key_{t.d}\right)\right]} \ldots = -1.10\ m$$
$$+ Key_{vdist}$$

Lateral Soil Load:

Moist Soil Load above WSEL:

$$E_{h7U1} := \frac{\gamma_m \cdot K_o \cdot h_{7U1}^{\,2}}{2} \cdot B = 0.0 \cdot kN$$

Moment Arm (from bot. of toe key):

$$E_{h7locU1} := h_{6U1} + \frac{h_{7U1}}{3} + Key_{vdist} = 3.50\ m$$

Saturated Soil Load below WSEL:
(rectangular component)

$$E_{h8U1} := \left(\gamma_m \cdot K_o \cdot h_{7U1}\right) \cdot h_{8U1} \cdot B = 0.0 \cdot kN$$

Moment Arm (from bot. of toe key):

$$E_{h8locU1} := \frac{h_{8U1}}{2} = 2.00\ m$$

Saturated Soil Load below WSEL:
(triangular component)

$$E_{h8aU1} := \frac{\left[\left(\gamma_{sat} - \gamma_w\right) \cdot K_o\right] \cdot h_{8U1}^{\,2}}{2} \cdot B = 53.3 \cdot kN$$

Moment Arm (from bot. of footing):

$$E_{h8alocU1} := \frac{h_{8U1}}{3} = 1.33\ m$$

$$\Sigma H_{SoilresistU1} := H_{h6U1} + H_{h2aU1} + E_{h7U1} + E_{h8U1} + E_{h8aU1} = 353.4 \cdot kN$$

$$\Sigma M_{HorizSoilResistU1} := H_{h6U1} \cdot H_{h6locU1} + H_{h2aU1} \cdot H_{h2alocU1} + E_{h7U1} \cdot E_{h7locU1} \ldots = 176.2\ m \cdot kN$$
$$+ E_{h8U1} \cdot E_{h8locU1} + E_{h8aU1} \cdot E_{h8alocU1}$$

Vertical Force:

UPLIFT: Linear distribution from water at heel to water at toe:

$$\Sigma V_{UpliftU1} := \left[\left(UWSEL_{U1} - Bot_{ftg} + Key_{t.d}\right) + h_{2U1}\right] \cdot \frac{b}{2} \cdot \gamma_w \cdot B \cdot -1 = -721.525 \cdot kN$$

Moment Arm (from Point O):

$$V_{UpliftU1aloc} := \frac{b \cdot \left[2 \cdot h_{2U1} + \left(UWSEL_{U1} - Bot_{ftg} + Key_{t.d}\right)\right]}{3\left[h_{2U1} + \left(UWSEL_{U1} - Bot_{ftg} + Key_{t.d}\right)\right]} = 5.21\ m$$

$$\Sigma M_{UpliftU1} := \Sigma V_{UpliftU1} \cdot V_{UpliftU1aloc} = -3758.912 \cdot kN \cdot m$$

Vertical Force (con't):

Weight of soil and water over toe:

Water Above the Top of Footing: $W_{H1U1} := \gamma_w \cdot h_{5U1} \cdot L_{ab} \cdot B = 73.5 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E1locU1} := \frac{L_{ab}}{2} = 1.25\,m$

Soil above top of footing: $W_{E6U1} := \gamma_b \cdot h_{3U1} \cdot L_{ab} \cdot B = 45.8 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E6locU1} := \frac{L_{ab}}{2} = 1.25\,m$

Vertical Load Due to Surcharge: $S_{U1} := S1_{U1} \cdot L_{cd} \cdot B = 0$ $\quad S_{U1loc} := b - \frac{L_{cd}}{2} = 6.47\,m$

Weight of soil and water over heel:

Moist Soil for sloped grade above top of wall:

Length of sloped portion of soil above top of wall: $L_{E3U1} := \left(L_{cd} + t_{wb} - t_{wt}\right) = 6.50\,m$

Height of sloped soil above top of wall over heel: $h_{E3locU1} := \left(L_{E3U1}\right) \cdot \tan(\beta) = 0.00\,m$

Weight of sloped soil above top of wall: $W_{E3U1} := \frac{\gamma_m}{2} \cdot h_{E3locU1} \cdot L_{E3U1} \cdot B = 0.0 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E3locU1} := L_{ab} + t_{wt} + \frac{2}{3} \cdot L_{E3U1} = 7.33\,m$

Moist soil from top of wall to groundwater level:

Height of soil from top of wall and top of GWL: $h_{1U1} = 0.10\,m$

Length from edge of wall at GWL to edge of heel: $L_{E4U1} := L_{E3U1} - \left(h_{1U1} \cdot S_{batter}\right) = 6.49\,m$

Weight of soil over heel from top of wall to GWL: $W_{E4U1} := \gamma_m \cdot h_{1U1} \cdot \frac{\left(L_{E3U1} + L_{E4U1}\right)}{2} \cdot B = 13.0 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E4locU1} := b - \frac{L_{E3U1}^2 + L_{E3U1} \cdot L_{E4U1} + L_{E4U1}^2}{3\left(L_{E3U1} + L_{E4U1}\right)} = 6.25\,m$

Saturated soil from groundwater to top of footing:

Height of soil from GWL to top of heel: $h_{E4U1} := h_{2U1} - t_{ftg} - Key_{h.d} = 5.50\,m$

Weight of soil over heel from GWL to top of heel: $W_{E5U1} := \left(\gamma_{sat}\right) \cdot h_{E4U1} \cdot \frac{\left(L_{E4U1} + L_{cd}\right)}{2} \cdot B = 759.4 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E5locU1} := b - \frac{L_{E4U1}^2 + L_{E4U1} \cdot L_{cd} + L_{cd}^2}{3\left(L_{E4U1} + L_{cd}\right)} = 6.36\,m$

$$\Sigma V_{SoilWaterU1} := W_{H1U1} + W_{E6U1} + W_{E3U1} + W_{E4U1} + W_{E5U1} + S_{U1} = 891.6 \cdot kN$$

$$\Sigma M_{VertSoilWaterResistU1} := W_{H1U1} \cdot W_{E1locU1} + W_{E6U1} \cdot W_{E6locU1} \cdots + W_{E3U1} \cdot W_{E3locU1} + W_{E4U1} \cdot W_{E4locU1} + W_{E5U1} \cdot W_{E5locU1} + S_{U1} \cdot S_{U1loc} = 5060.7\,m \cdot kN$$

THIS PAGE INTENTIONALLY LEFT BLANK
PLEASE GO TO THE NEXT PAGE

STABILITY ASSESSMENT:

LOAD CASE U1

CHECK SLIDING ALONG HORIZONTAL SLIDING PLANE:

Summation of the vertical forces:

$$\Sigma V_{U1} := \Sigma V_{conc} + \Sigma V_{SoilWaterU1} + \Sigma V_{UpliftU1} = 870.0 \cdot kN$$

Summation of the horizontal forces:

$$\Sigma H_{U1} := \Sigma H_{SoildriveU1} + \Sigma H_{SoilresistU1} = -480.6 \cdot kN$$

Safety Factor for Sliding Horizontal Failure Plane

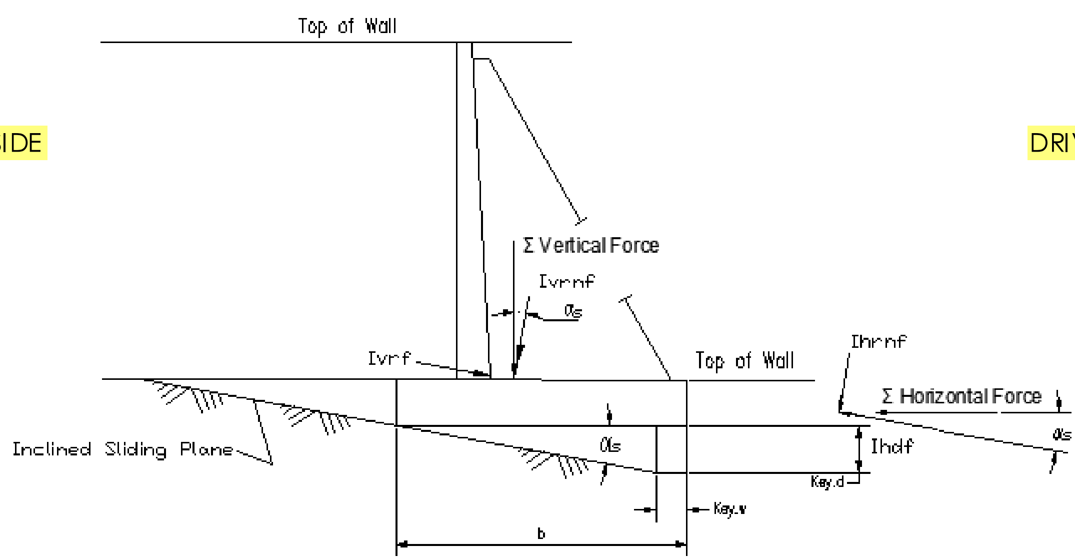
$$FS_{Horiz.SlidingU1} := \frac{\left|\Sigma V_{U1}\right| \cdot \tan\left(\phi_{rock} \cdot \frac{\pi}{180}\right)}{\left|\Sigma H_{U1}\right|} = 0.88$$

$$FS_{Sliding.check1.U1} := \begin{cases} \text{"OKAY "} & \text{if } FS_{Horiz.SlidingU1} > FS_{sliding.reqU1} \\ \text{"Key req'"} & \text{otherwise} \end{cases} = \text{"Key req'"}$$

CHECK FACTOR OF SAFETY SLIDING WITH KEY (INCLINED SLIDING PLANE):

RESISTING SIDE

DRIVING SIDE



TOE

HEEL

Ivrf=Inclined Resisting Force
Ivrnf=Inclined Resisting Normal Force
Ihrnf=Inclined Resisting Normal Force
Ihdf=Inclined Driving Force

$$\alpha s := \operatorname{atan}\left(\frac{-Key_{vdist}}{Key_{hdist}}\right) = 0.231 \qquad \text{as degrees=} \qquad \alpha s \cdot \left(\frac{180}{\pi}\right) = 13.24$$

(With properly engineered reinforced concrete Key, horizontal sliding plane thru Toe is protected, critical sliding plane is relocated to the INCLINED SLIDING PLANE FROM HEEL KEY To TOE, Bedrock Mass above this examing plane is mobilized by reinforced concrete key and combined into Structural Wedge.)

Resolve ΣV_{U1} & ΣH_{U1}

$$\Sigma V_{InclinedU1} := \cos(\alpha s) \cdot \left(\left|\Sigma V_{U1} + V_{rocksection}\right|\right) + \sin(\alpha s) \cdot \left|\Sigma H_{U1}\right| = 1168.8 \cdot kN$$

$$\Sigma H_{InclinedU1} := \cos(\alpha s) \cdot \left|\Sigma H_{U1}\right| - \sin(\alpha s) \cdot \left(\left|\Sigma V_{U1} + V_{rocksection}\right|\right) = 218.7 \cdot kN$$

Safety Factor for Sliding Inclined Failure Plane

$$FS_{InclinedISlidingU1} := \frac{\Sigma V_{InclinedU1} \cdot \tan(\phi_r)}{\Sigma H_{InclinedU1}} = 2.38$$

LOAD CASE U1

$$FS_{Sliding.check2.U1} := \begin{cases} \text{"OKAY"} & \text{if } FS_{InclinedISlidingU1} > FS_{sliding.reqU1} \\ \text{"NG - Revise Structure"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

CHECK FOUNDATION ECCENTRICITY:

Summation of the resisting moments about the toe:

$$\Sigma M_{resU1} := \Sigma M_{conc} + \Sigma M_{VertSoilWaterResistU1} + \Sigma M_{HorizSoilResistU1} + \Sigma M_{rocksection} = 9816 \cdot kN \cdot m$$

Summation of the overturning moments about the toe:

$$\Sigma M_{oU1} := \Sigma M_{LateralSoildriveU1} + \Sigma M_{UpliftU1} = -4890 \cdot kN \cdot m$$

Total moment: $\Sigma M_{U1} := \Sigma M_{resU1} + \Sigma M_{oU1} = 4926.5 \cdot kN \cdot m$

Normal force to base: $\Sigma V_{InclinedU1} = 1168.8 \cdot kN$

Inclined Sliding Plane Length: $L_{incline} := \dfrac{b}{\cos(\alpha s)} = 9.8\,m$

Eccentricity (inclined plane): $ex_{U1} := \dfrac{L_{incline}}{2} - \dfrac{\Sigma M_{U1}}{\Sigma V_{InclinedU1}} = 0.66\,m$ $\quad Kern := \dfrac{L_{incline}}{6} = 1.627\,m$

Eccentricity Check: $e_{check.U1} := \begin{cases} \text{"Okay"} & \text{if } ex_{U1} \le Kern \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"Okay"}$

CHECK FOUNDATION BEARING CAPACITY:

Base Section Modulus: $S_b := \frac{1}{6}\left(B \cdot L_{incline}^{\ 2}\right) = 15.87\,m^3$

Bearing Pressure Under Toe:

$$\sigma_{ToeU1} := \begin{cases} \left(\dfrac{\Sigma V_{InclinedU1}}{L_{incline} \cdot B} + \dfrac{\Sigma V_{InclinedU1} \cdot ex_{U1}}{S_b}\right) & \text{if } \dfrac{\Sigma V_{InclinedU1} \cdot ex_{U1}}{S_b} \le \dfrac{\Sigma V_{InclinedU1}}{L_{incline} \cdot B} \\ \dfrac{2 \cdot \Sigma V_{InclinedU1}}{B \cdot 3\left(\dfrac{b}{2} - ex_{U1}\right)} & \text{otherwise} \end{cases} = 168.7 \cdot kPa$$

$$Bearing_{ChecktoeU1} := \begin{cases} \text{"OKAY"} & \text{if } \sigma_{ToeU1} < \sigma_{allowU1} \\ \text{"NG"} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

Bearing Pressure Under Heel:

$$\sigma_{HeelU1} := \begin{cases} \left(\dfrac{\Sigma V_{InclinedU1}}{L_{incline} \cdot B} - \dfrac{\Sigma V_{InclinedU1} \cdot ex_{U1}}{S_b}\right) & \text{if } \dfrac{\Sigma V_{InclinedU1} \cdot ex_{U1}}{S_b} \le \dfrac{\Sigma V_{InclinedU1}}{L_{incline} \cdot B} \\ 0 & \text{otherwise} \end{cases} = 70.8 \cdot kPa$$

$$Bearing_{CheckheelU1} := \left(\begin{cases} \text{"OKAY"} & \text{if } \sigma_{HeelU1} < \sigma_{allowU1} \wedge \sigma_{HeelU1} > 0 \\ \text{"NG - perform cracked base analysis"} & \text{otherwise} \end{cases}\right) = \text{"OKAY"}$$

CHECK FLOATATION:

Safety Factor for Floatation: $FS_{FloatationU1} := \dfrac{\Sigma V_{conc} + \Sigma V_{SoilWaterU1}}{\left|\Sigma V_{UpliftU1}\right|} = 2.21$

$FS_{Floatation.U1.check} :=$ "OKAY" if $FS_{FloatationU1} > FS_{req.U1.flt}$ = "OKAY"
"Revise Structure"" otherwise

CHECK OVERTURNING

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.
Assumptions are made in order to compute overturning stablity of indetermine forces on monolith with key;
(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.
(b) The horizontal resisting force acting on the key, P.key, is that required for static equilibrium
(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1

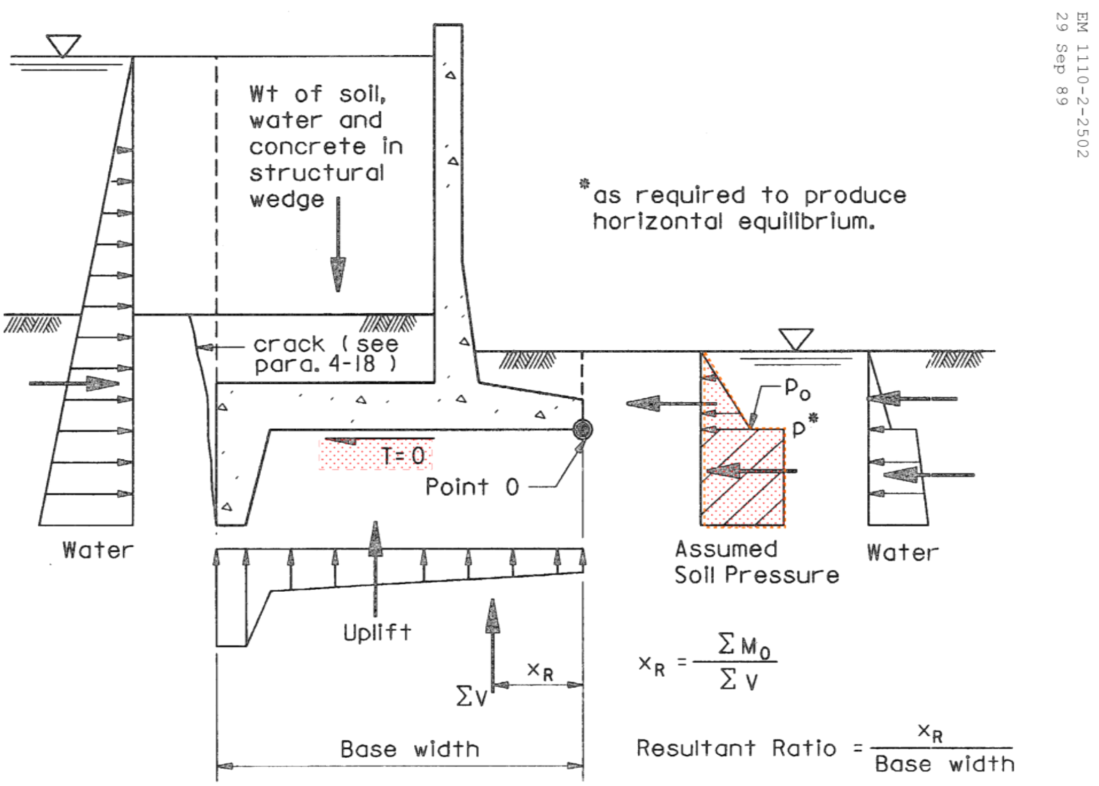


Figure 4-5. Forces for overturning analysis for wall with horizontal base and key

Modify Uplift for Overturning Analysis: **LOAD CASE U1**

(Uplift is calculated along the concrete/rock contact using the Line of Creep method)

Water Pressure at h: $u_{h.U1} := \Delta h_{g.hj.U1} \cdot \gamma_w = 98.00 \cdot kPa$

Water Pressure at o: $u_{o.U1} := \left(\Delta h_{g.no.U1} - \frac{\Delta h_{g.r.U1} \cdot L_{ho.U1}}{L_{ho.U1}}\right) \cdot \gamma_w = 53.9 \cdot kPa$

Head loss between point h and o: $\Delta h_{ho.U1} := \Delta h_{g.r.U1} \cdot \frac{L_{ho.U1}}{L_{ho.U1}} = 2.5\,m$

Length of concrete base (h -> o): $L_{baseho.U1} := Key_{h.w} + Key_{h.d} + Key_{hdist} + Key_{t.d} + Key_{t.w} = 11.5\,m$

Head loss along h -> j: $\Delta h_{hj.U1} := \Delta h_{ho.U1} \cdot \frac{Key_{h.w}}{L_{baseho.U1}} = 0.217\,m$

Water Pressure at j: $u_{j.U1} := \left(\Delta h_{g.hj.U1} - \Delta h_{hj.U1}\right) \cdot \gamma_w = 95.87 \cdot kPa$

Head loss along h -> k: $\Delta h_{hjk.U1} := \Delta h_{ho.U1} \cdot \left(\frac{Key_{h.w} + Key_{h.d}}{L_{baseho.U1}}\right) = 0.652\,m$

Water Pressure at k: $u_{k.U1} := \left(\Delta h_{g.km.U1} - \Delta h_{hjk.U1}\right) \cdot \gamma_w = 72.01 \cdot kPa$

Head loss along h -> m: $\Delta h_{hjkm.U1} := \Delta h_{ho.U1} \cdot \left(\frac{Key_{h.w} + Key_{h.d} + Key_{hdist}}{L_{baseho.U1}}\right) = 2.5\,m$

Water Pressure at m: $u_{m.U1} := \left(\Delta h_{g.km.U1} - \Delta h_{hjkm.U1}\right) \cdot \gamma_w = 53.90 \cdot kPa$

Head loss along h -> n: $\Delta h_{hjkmn.U1} := \Delta h_{ho.U1} \cdot \left(\frac{Key_{h.w} + Key_{h.d} + Key_{hdist} + Key_{t.d}}{L_{baseho.U1}}\right) = 2.5\,m$

Water Pressure at n: $u_{n.U1} := \left(\Delta h_{g.no.U1} - \Delta h_{hjkmn.U1}\right) \cdot \gamma_w = 53.90 \cdot kPa$

Uplift under key at heel: $V_{ulkeyhU1.OT} := \frac{\left(u_{h.U1} + u_{j.U1}\right) \cdot Key_{h.w}}{2} \cdot B \cdot -1 = -96.935 \cdot kN$

Moment Arm (from Point O): $V_{ulkeyhU1loc.OT} := b - \frac{Key_{h.w} \cdot \left(2 \cdot u_{j.U1} + u_{h.U1}\right)}{3 \cdot \left(u_{j.U1} + u_{h.U1}\right)} = 9.002\,m$

Uplift under base: $V_{ulbaseU1.OT} := \frac{\left(u_{k.U1} + u_{m.U1}\right) \cdot Key_{hdist}}{2} \cdot B \cdot -1 = -535.112 \cdot kN$

Moment Arm (from Point O): $V_{ulbaseU1loc.OT} := b - Key_{h.w} - \frac{Key_{hdist} \cdot \left(2 \cdot u_{m.U1} + u_{k.U1}\right)}{3 \cdot \left(u_{m.U1} + u_{k.U1}\right)} = 4.454\,m$

Uplift under key at toe: $V_{ulkeytU1.OT} := \frac{\left(u_{n.U1} + u_{o.U1}\right) \cdot Key_{t.w}}{2} \cdot B \cdot -1 = 0 \cdot kN$

Moment Arm (from Point O): $V_{ulkeytU1loc.OT} := \frac{Key_{t.w} \cdot \left(2 \cdot u_{n.U1} + u_{o.U1}\right)}{3 \cdot \left(u_{n.U1} + u_{o.U1}\right)} = 0$

$$\Sigma V_{UpliftU1.OT} := V_{ulkeyhU1.OT} + V_{ulbaseU1.OT} + V_{ulkeytU1.OT} = -632 \cdot kN$$

$$U_{U1.loc.OT} := \frac{V_{ulkeyhU1.OT} \cdot V_{ulkeyhU1loc.OT} + V_{ulbaseU1.OT} \cdot V_{ulbaseU1loc.OT} + V_{ulkeytU1.OT} \cdot V_{ulkeytU1loc.OT}}{\Sigma V_{UpliftU1.OT}} = 5.15\,m$$

$$\Sigma M_{UpliftU1.OT} := \Sigma V_{UpliftU1.OT} \cdot U_{U1.loc.OT} = -3255.8 \cdot kN \cdot m$$

Modify Lateral Water Pressure (Resisting) for Overturning Analysis:

(Resisting water pressure is calculated using the Line of Creep method)

Water Load at Key (heel): $H_{h2U1.OT} := \frac{u_{k.U1} + u_{j.U1}}{2} \cdot Key_{h.d} B = 167.9 \cdot kN$

Moment Arm (from Point O): $H_{h2locU1.OT} := \frac{Key_{h.d} \cdot (2 \cdot u_{k.U1} + u_{j.U1})}{3(u_{k.U1} + u_{j.U1})} + Key_{vdist} = -1.05 \, m$

Water Load at Key (toe): $H_{h6U1.OT} := \frac{u_{o.U1} \cdot (UWSEL_{U1} - Bot_{ftg} + Key_{t.d})}{2} \cdot B = 148 \cdot kN$

Moment Arm (from Point O): $H_{h6locU1.OT} := \frac{UWSEL_{U1} - Bot_{ftg} + Key_{t.d}}{3} = 1.83 \, m$

$$\Sigma H_{waterresistU1.OT} := H_{h2U1.OT} + H_{h6U1.OT} = 316.1 \cdot kN$$

$$H_{waterresistlocU1.OT} := \frac{H_{h2U1.OT} \cdot H_{h2locU1.OT} + H_{h6U1.OT} \cdot H_{h6locU1.OT}}{\Sigma H_{waterresistU1.OT}} = 0.303 \, m$$

$$\Sigma M_{waterresistU1.OT} := \Sigma H_{waterresistU1.OT} \cdot H_{waterresistlocU1.OT} = 95.91 \cdot kN \cdot m$$

Modify Lateral Soil Loads for Overturning Analysis:

(Lateral soil loads are calculated down to Point O instead of bottom of shear key)

<u>Driving Soil Load (Headwater Side):</u>

Surcharge Load: $E_{s1U1.OT} := S1_{U1} \cdot K_o \cdot (H_w + Key_{h.d} + Key_{vdist}) \cdot B \cdot -1 = 0 \cdot kN$

Moment Arm (from Point O): $E_{s1locU1.OT} := \frac{H_w + Key_{h.d} + Key_{vdist}}{2} = 4.05 \, m$

Moist Soil Load above GWL: $E_{h1U1.OT} := \frac{\gamma_m \cdot K_o \cdot h_{1U1}^{\,2}}{2} B \cdot -1 = -0.1 \cdot kN$

Moment Arm (from Point O): $E_{h1locU1.OT} := \frac{h_{1U1}}{3} + h_{2U1} + Key_{vdist} = 8.03 \, m$

Saturated Soil Load below GWL:
(rectangular component)
$E_{h2U1.OT} := (\gamma_m \cdot K_o \cdot h_{1U1}) \cdot (h_{2U1} + Key_{vdist}) \cdot B \cdot -1 = -8.7 \cdot kN$

Moment Arm (from Point O): $E_{h2locU1.OT} := \frac{h_{2U1} + Key_{vdist}}{2} = 4.00 \, m$

Saturated Soil Load below GWL:
(triangular component)
$E_{h2aU1.OT} := \frac{(\gamma_{sat} - \gamma_w) \cdot K_o \cdot (h_{2U1} + Key_{vdist})^2}{2} \cdot B \cdot -1 = -213.2 \cdot kN$

Moment Arm (from Point O): $E_{h2alocU1.OT} := \frac{h_{2U1} + Key_{vdist}}{3} = 2.67 \, m$

Resisting Soil Load (Tailwater Side):

(Determine resisting soil load based on depth variation between the keys (ie. Key_{vdist}). In case where key at heel is deeper than key at toe (ie. $Key_{vdist} < 0$), resisting soil load (p*) is assumed to produce horizontal equilibrium as per Figure 4-5 above. Resisting soil load (p_o) is neglected.)

Total Driving Force: $\Sigma H_{SoildriveU1.OT} := E_{s1U1.OT} + E_{h1U1.OT} + E_{h2U1.OT} + E_{h2aU1.OT} + H_{h2U1} = -712.0 \cdot kN$

Total Resisting Force: $\Sigma H_{waterresistU1.OT} = 316.1 \cdot kN$

Assumed Soil Load p*: $E_{h8U1a.OT} := \left(\Sigma H_{SoildriveU1.OT} + \Sigma H_{waterresistU1.OT}\right) \cdot -1 = 395.85 \cdot kN$

Moment Arm (from Point O): $E_{h8U1a.loc.OT} := \dfrac{Key_{vdist}}{2} = -1\,m$

$$E_{h8U1.OT} := \begin{cases} E_{h8U1a.OT} & \text{if } Key_{vdist} < 0 \\ \Sigma H_{SoilresistU1} - H_{h6U1} - H_{h2aU1} & \text{otherwise} \end{cases} = 395.85 \cdot kN$$

$$\Sigma M_{SoilresistU1} := \begin{cases} E_{h8U1a.OT} \cdot E_{h8U1a.loc.OT} & \text{if } Key_{vdist} < 0 \\ \Sigma M_{HorizSoilResistU1} - H_{h6U1} \cdot H_{h6locU1} - H_{h2aU1} \cdot H_{h2alocU1} & \text{otherwise} \end{cases} = -395.85 \cdot kN \cdot m$$

Sum of Moment about Point O:

$$\Sigma M_{LateraldriveU1.OT} := E_{s1U1.OT} \cdot E_{s1locU1.OT} + E_{h1U1.OT} \cdot E_{h1locU1.OT} + E_{h2U1.OT} \cdot E_{h2locU1.OT} \ldots + E_{h2aU1.OT} \cdot E_{h2alocU1.OT} + H_{h2U1} \cdot H_{h2locU1} = -1257.1 \cdot kN \cdot m$$

$$\Sigma M_{LateralresistU1.OT} := \Sigma M_{waterresistU1.OT} + \Sigma M_{SoilresistU1} = -299.9 \cdot kN \cdot m$$

Total moment:

$$\Sigma M_{U1.OT} := \Sigma M_{conc} + \Sigma M_{VertSoilWaterResistU1} + \Sigma M_{UpliftU1.OT} + \Sigma M_{LateraldriveU1.OT} + \Sigma M_{LateralresistU1.OT} = 3593.9 \cdot kN \cdot m$$

Total Vertical Force: $\Sigma V_{U1.OT} := \Sigma V_{conc} + \Sigma V_{SoilWaterU1} + \Sigma V_{UpliftU1.OT} = 959.5 \cdot kN$

Distance X_R: EM 1110-2-2502 Eq.4-1 $X_{R.U1} := \dfrac{\Sigma M_{U1.OT}}{\Sigma V_{U1.OT}} = 3.746\,m$

Overturning Resultant Ratio $Ratio_{U1.OT} := \dfrac{X_{R.U1}}{b} = 0.39$

$$Ratio_{U1.OT.check} := \begin{cases} \text{"OKAY "} & \text{if } Ratio_{U1.OT} > X_{R.reqU1} \\ \text{"Revise Structure""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

CHECK FOUNDATION ECCENTRICITY (HORIZONTAL PLANE):

Eccentricity (horizontal plan): $ex_{U1.OT} := \dfrac{b}{2} - \dfrac{\Sigma M_{U1.OT}}{\Sigma V_{U1.OT}} = 1.00\,m$ $\quad Kern_{OT} := \dfrac{b}{6} = 1.583\,m$

Eccentricity Check:

$$e_{check.U1.OT} := \begin{cases} \text{"Okay"} & \text{if } ex_{U1} \le Kern_{OT} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"Okay"}$$

CHECK FOUNDATION BEARING CAPACITY (HORIZONTAL PLANE):

Base Section Modulus: $S_{b.OT} := \frac{1}{6}\left(B \cdot b^2\right) = 15.04\,m^3$

Bearing Pressure Under Toe:

$$\sigma_{ToeU1.OT} := \begin{cases} \left(\frac{\Sigma V_{U1.OT}}{b \cdot B} + \frac{\Sigma V_{U1.OT} \cdot ex_{U1.OT}}{S_{b.OT}}\right) & \text{if } \frac{\Sigma V_{U1.OT}}{b \cdot B} \geq \frac{\Sigma V_{U1.OT} \cdot ex_{U1.OT}}{S_{b.OT}} \\ \frac{2 \cdot \Sigma V_{U1.OT}}{B \cdot 3\left(\frac{b}{2} - ex_{U1.OT}\right)} & \text{otherwise} \end{cases} = 165.1 \cdot kPa$$

$$Bearing_{ChecktoeU1.OT} := \begin{cases} \text{"OKAY "} & \text{if } \sigma_{ToeU1.OT} < \sigma_{allowU1} \\ \text{"NG - for reference only""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

Bearing Pressure Under Heel:

$$\sigma_{HeelU1.OT} := \begin{cases} \left(\frac{\Sigma V_{U1.OT}}{b \cdot B} - \frac{\Sigma V_{U1.OT} \cdot ex_{U1.OT}}{S_{b.OT}}\right) & \text{if } \frac{\Sigma V_{U1.OT}}{b \cdot B} \geq \frac{\Sigma V_{U1.OT} \cdot ex_{U1.OT}}{S_{b.OT}} \\ 0 & \text{otherwise} \end{cases} = 36.9 \cdot kPa$$

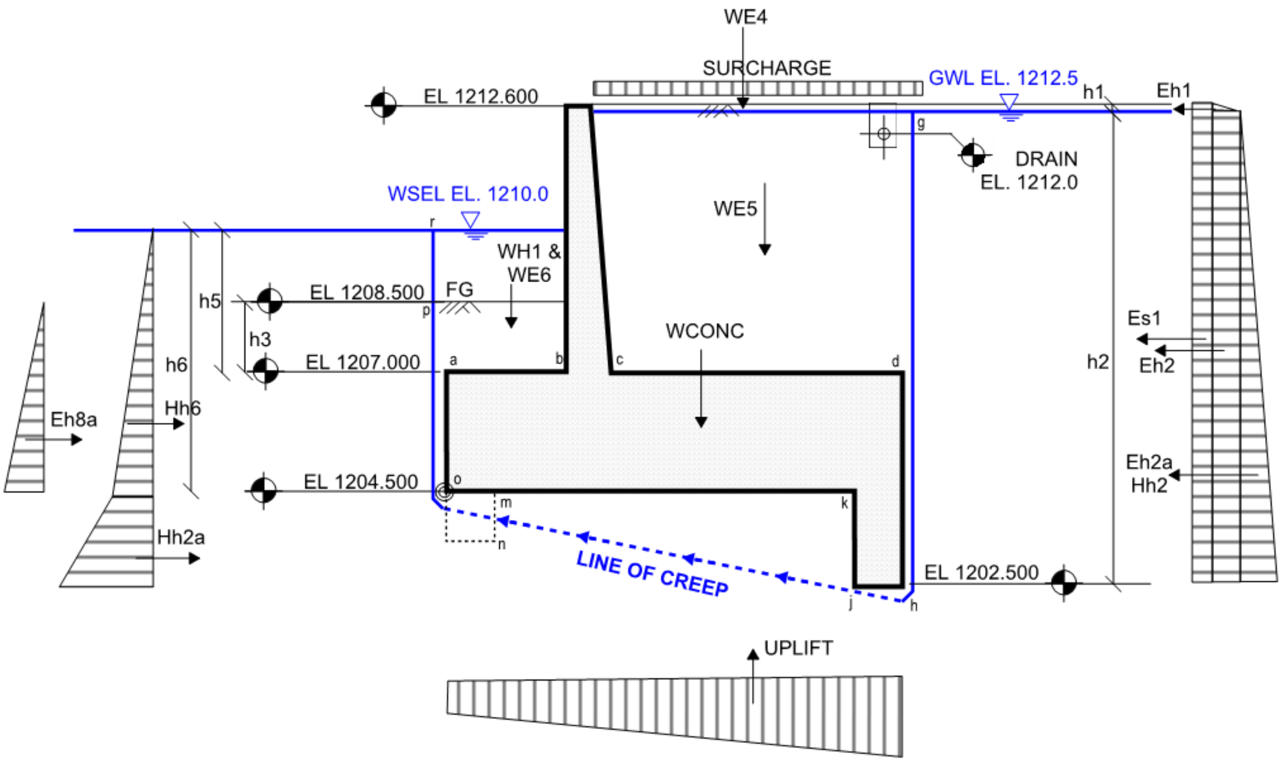
$$Bearing_{CheckheelU1.OT} := \left(\begin{cases} \text{"OKAY "} & \text{if } \sigma_{HeelU1.OT} < \sigma_{allowU1} \wedge \sigma_{HeelU1.OT} > 0 \\ \text{"NG - for reference only""} & \text{otherwise} \end{cases}\right) = \text{"OKAY "}$$

SUMMARY OF STABILITY ASSESSMENT:

LOAD CASE U1

Sliding Factor of Safety: (Horizontal Plane - Ref only)	$FS_{Horiz.SlidingU1} = 0.88$	$FS_{Sliding.check1.U1} =$ "Key req""
Sliding Factor of Safety: (Inclined Plane)	$FS_{InclinedlSlidingU1} = 2.38$	$FS_{Sliding.check2.U1} =$ "OKAY "
Eccentricity: (Inclined Plane)	$ex_{U1} = 0.66\ m$	$e_{check.U1} =$ "Okay"
Bearing Pressure At Heel: (Inclined Plane)	$\sigma_{HeelU1} = 71 \cdot kPa$	$Bearing_{CheckheelU1} =$ "OKAY "
Bearing Pressure At Toe: (Inclined Plane)	$\sigma_{ToeU1} = 169 \cdot kPa$	$Bearing_{ChecktoeU1} =$ "OKAY "
Flotation Factor of Safety (horizontal plane)	$FS_{FloatationU1} = 2.21$	$FS_{Floatation.U1.check} =$ "OKAY "
Overturning Resultant Ratio: (horizontal plane)	$Ratio_{U1.OT} = 0.39$	$Ratio_{U1.OT.check} =$ "OKAY "
Eccentricity: (horizontal plane - Ref only)	$ex_{U1.OT} = 1.00\ m$	$e_{check.U1.OT} =$ "Okay"
Bearing Pressure At Heel: (horizontal plane - Ref only)	$\sigma_{HeelU1.OT} = 37 \cdot kPa$	$Bearing_{CheckheelU1.OT} =$ "OKAY "
Bearing Pressure At Toe: (horizontal plane - Ref only)	$\sigma_{ToeU1.OT} = 165 \cdot kPa$	$Bearing_{ChecktoeU1.OT} =$ "OKAY "

LOAD CASE UN1 - NORMAL OPERATION + SURCHARGE



UN1 DESIGN CASE

LOAD CASE UN1 ACCEPTANCE PARAMETERS

FS sliding:

Unusual (UN) 1.3 (without cohesion) (Table 3-3, USACE EM 1110-2-2100)

Resultant Location:

Unsual (UN) Inside middle third ~100% base in compression

Required Factor of Safety for Sliding: $FS_{sliding.reqUN1} := 1.3$ (Without Cohesion)

Allowable rock bearing pressure: $\sigma_{allowUN1} := 1470kPa$ (Section 5.2, Design Criteria EM 1110-2-2100 Section 3-10)

Overturning Required Resultant Ratio: $X_{R.reqUN1} := 0.333$ (EM 1110-2-2502, Figure 4-4)

Required Factor of Safety for Floatation $FS_{req.UN1.flt} := 1.3$

SOIL HEIGHTS and Water Levels:

LOAD CASE UN1

Heel Conditions:

Groundwater Elevation at Heel: $GWL_{UN1} := 1212.5m$

Distance from Finish Grade to Groundwater at Heel: $h_{1UN1} := \left[T_w - GWL_{UN1} + \left(L_{cd} + t_{wb} - t_{wt}\right)\cdot \tan(\beta)\right] = 0.10\,m$

Distance from Water Surface to Bottom of Footing at Heel: $h_{2UN1} := GWL_{UN1} - Bot_{ftg} + Key_{h.d} = 10.00\,m$

Toe Conditions:

Water Surface Elevation at Toe: $WSEL_{UN1} := 1210.0m$

Water Surface Elevation at Toe for Uplift: $UWSEL_{UN1} := 1210.0\cdot m$

Finish Grade at Toe providing lateral resistance: $FG_{toeUN1} := 1208.5\cdot m$

Soil Depth Above top of footing: $h_{3aUN1} := FG_{toeUN1} - Top_{ftg} = 1.5\,m$

$$h_{3UN1} := \begin{cases} h_{3aUN1} & \text{if } FG_{toeUN1} - Top_{ftg} \geq 0 \\ 0 & \text{otherwise} \end{cases} = 1.5$$

Resisting Fill at Toe: $h_{4UN1} := FG_{toeUN1} - Bot_{ftg} + Key_{t.d} = 4.00\,m$

Distance from Water Level to Top of Footing at Toe: $h_{5UN1} := WSEL_{UN1} - Top_{ftg} = 3.00\,m$

Distance from Water Surface to Bottom of Footing at Toe: $h_{6UN1} := WSEL_{UN1} - Bot_{ftg} + Key_{t.d} = 5.50\,m$

Soil Depth Above WSEL: $h_{7aUN1} := FG_{toeUN1} - WSEL_{UN1} = -1.5\,m$

$$h_{7UN1} := \begin{cases} h_{7aUN1} & \text{if } FG_{toeUN1} - WSEL_{UN1} \geq 0 \\ 0 & \text{otherwise} \end{cases} = 0$$

Soil Depth Below WSEL:

$$h_{8UN1} := \begin{cases} WSEL_{UN1} - Bot_{ftg} + Key_{t.d} & \text{if } FG_{toeUN1} - WSEL_{UN1} \geq 0 \\ h_{4UN1} & \text{otherwise} \end{cases} = 4$$

For Line of Creep Method: $L_{ho.UN1} := \sqrt{b^2 + \left(Key_{h.d} - Key_{t.d}\right)^2} = 9.708\,m$

Head Loss from Point g:

$\Delta h_{g.hj.UN1} := h_{2UN1} = 10\,m$ (to point h & j)

$\Delta h_{g.km.UN1} := GWL_{UN1} - Bot_{ftg} = 8\,m$ (to point k & m)

$\Delta h_{g.no.UN1} := GWL_{UN1} - Bot_{ftg} + Key_{t.d} = 8\,m$ (to point n & o)

$\Delta h_{g.p.UN1} := GWL_{UN1} - FG_{toeUN1} = 4\,m$ (to point p)

$\Delta h_{g.r.UN1} := GWL_{UN1} - UWSEL_{UN1} = 2.5\,m$ (to point r)

Surcharge

Surcharge on Heel: $S1_{UN1} := 15.0\,\frac{kN}{m^2}$

Calculate Soil Lateral Pressure Coefficients:

LOAD CASE UN1

For all load cases except seismic, soil loading to be based on At-Rest Condition.
Calculate at-rest pressure coefficient Ko based on Jaky's (1944) equation.

Soil At Rest Static Coefficient: $K_o := \frac{1 - \sin(\phi)}{1 + \sin(\beta)} = 0.546$ (Eq. 3-6, USACE EM 1110-2-2502)

Lateral - Driving Force

Static At-Rest:

Surcharge Load: $E_{s1UN1} := S1_{UN1} \cdot K_o \cdot \left(H_w + Key_{h.d}\right) \cdot B \cdot -1 = -82.72 \cdot kN$

Moment Arm (from bottom of footing): $E_{s1locUN1} := \frac{H_w + Key_{h.d}}{2} + Key_{vdist} = 3.05\ m$

Moist Soil Load above GWL: $E_{h1UN1} := \frac{\gamma_m \cdot K_o \cdot {h_{1UN1}}^2}{2} B \cdot -1 = -0.1 \cdot kN$

Moment Arm (from bottom of footing): $E_{h1locUN1} := \frac{h_{1UN1}}{3} + h_{2UN1} + Key_{vdist} = 8.03\ m$

Saturated Soil Load below GWL:
(rectangular component) $E_{h2UN1} := \left(\gamma_m \cdot K_o \cdot h_{1UN1}\right) \cdot \left(h_{2UN1}\right) \cdot B \cdot -1 = -10.9 \cdot kN$

Moment Arm (from bottom of footing): $E_{h2locUN1} := \frac{h_{2UN1}}{2} + Key_{vdist} = 3.00\ m$

Saturated Soil Load below GWT:
(triangular L $E_{h2aUN1} := \frac{\left(\gamma_{sat} - \gamma_w\right) \cdot K_o \cdot {h_{2UN1}}^2}{2} \cdot B \cdot -1 = -333.1 \cdot kN$

Moment Arm (from bottom of footing): $E_{h2alocUN1} := \frac{h_{2UN1}}{3} + Key_{vdist} = 1.33\ m$

Lateral Water Load:

Water Load GWL to Bottom of Key $H_{h2UN1} := \frac{\gamma_w \cdot {h_{2UN1}}^2}{2} \cdot B \cdot -1 = -490.0 \cdot kN$

Moment Arm (from bottom of footing): $H_{h2locUN1} := \frac{h_{2UN1}}{3} + Key_{vdist} = 1.33\ m$

$$\Sigma H_{SoildriveUN1} := E_{s1UN1} + E_{h1UN1} + E_{h2UN1} + E_{h2aUN1} + H_{h2UN1} = -916.8 \cdot kN$$

$$\Sigma M_{LateralSoildriveUN1} := E_{s1UN1} \cdot E_{s1locUN1} + E_{h1UN1} \cdot E_{h1locUN1} + E_{h2UN1} \cdot E_{h2locUN1} \ldots = -1382.9\ m \cdot kN$$
$$+ E_{h2aUN1} \cdot E_{h2alocUN1} + H_{h2UN1} \cdot H_{h2locUN1}$$

Lateral - Resisting Force

LOAD CASE UN1

Lateral Water Load:

Water Load WSEL to Bottom of Footing:

$$H_{h6UN1} := \frac{\gamma_w \cdot h_{6UN1}^{\;2}}{2} \cdot B = 148.2 \cdot kN$$

Moment Arm (from bot. of toe key):

$$H_{h6locUN1} := \frac{h_{6UN1}}{3} = 1.83\ m$$

Water Load Bot. of Footing to Bot. of H. Key:

$$H_{h2aUN1} := \left[\left(UWSEL_{UN1} - Bot_{ftg} + Key_{t.d}\right) + h_{2UN1}\right] \cdot \frac{Key_{h.d}}{2} \cdot \gamma_w \cdot B = 151.9 \cdot kN$$

Moment Arm (from bot. of toe key):

$$H_{h2alocUN1} := \frac{Key_{h.d} \cdot \left[2 \cdot \left(UWSEL_{UN1} - Bot_{ftg} + Key_{t.d}\right) + h_{2UN1}\right]}{3\left[h_{2UN1} + \left(UWSEL_{UN1} - Bot_{ftg} + Key_{t.d}\right)\right]} \ldots = -1.10\ m$$
$$+ Key_{vdist}$$

Lateral Soil Load:

Moist Soil Load above WSEL:

$$E_{h7UN1} := \frac{\gamma_m \cdot K_o \cdot h_{7UN1}^{\;2}}{2} B = 0.0 \cdot kN$$

Moment Arm (from bot. of toe key):

$$E_{h7locUN1} := h_{6UN1} + \frac{h_{7UN1}}{3} + Key_{vdist} = 3.50\ m$$

Saturated Soil Load below WSEL:
(rectangular component)

$$E_{h8UN1} := \left(\gamma_m \cdot K_o \cdot h_{7UN1}\right) \cdot h_{8UN1} \cdot B = 0.0 \cdot kN$$

Moment Arm (from bot. of toe key):

$$E_{h8locUN1} := \frac{h_{8UN1}}{2} = 2.00\ m$$

Saturated Soil Load below WSEL:
(triangular component)

$$E_{h8aUN1} := \frac{\left[\left(\gamma_{sat} - \gamma_w\right) \cdot K_o\right] \cdot h_{8UN1}^{\;2}}{2} \cdot B = 53.3 \cdot kN$$

Moment Arm (from bot. of footing):

$$E_{h8alocUN1} := \frac{h_{8UN1}}{3} = 1.33\ m$$

$$\Sigma H_{SoilresistUN1} := H_{h6UN1} + H_{h2aUN1} + E_{h7UN1} + E_{h8UN1} + E_{h8aUN1} = 353.4 \cdot kN$$

$$\Sigma M_{HorizSoilResistUN1} := H_{h6UN1} \cdot H_{h6locUN1} + H_{h2aUN1} \cdot H_{h2alocUN1} + E_{h7UN1} \cdot E_{h7locUN1} \ldots = 176.2\ m \cdot kN$$
$$+ E_{h8UN1} \cdot E_{h8locUN1} + E_{h8aUN1} \cdot E_{h8alocUN1}$$

Vertical Force:

UPLIFT: Linear distribution from water at heel to water at toe:

$$\Sigma V_{UpliftUN1} := \left[\left(UWSEL_{UN1} - Bot_{ftg} + Key_{t.d}\right) + h_{2UN1}\right] \cdot \frac{b}{2} \cdot \gamma_w \cdot B \cdot -1 = -721.525 \cdot kN$$

Moment Arm (from Point O):

$$V_{UpliftUN1aloc} := \frac{b \cdot \left[2 \cdot h_{2UN1} + \left(UWSEL_{UN1} - Bot_{ftg} + Key_{t.d}\right)\right]}{3\left[h_{2UN1} + \left(UWSEL_{UN1} - Bot_{ftg} + Key_{t.d}\right)\right]} = 5.21\ m$$

$$\Sigma M_{UpliftUN1} := \Sigma V_{UpliftUN1} \cdot V_{UpliftUN1aloc} = -3758.912 \cdot kN \cdot m$$

Weight of soil and water over toe:

Water Above the Top of Footing: $W_{H1UN1} := \gamma_w \cdot h_{5UN1} \cdot L_{ab} \cdot B = 73.5 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E1locUN1} := \frac{L_{ab}}{2} = 1.25\ m$

Soil above top of footing: $W_{E6UN1} := \gamma_b \cdot h_{3UN1} \cdot L_{ab} \cdot B = 45.8 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E6locUN1} := \frac{L_{ab}}{2} = 1.25\ m$

Vertical Load Due to Surcharge: $S_{UN1} := S1_{UN1} \cdot L_{cd} \cdot B = 90.9 \cdot kN$ $\quad S_{UN1loc} := b - \frac{L_{cd}}{2} = 6.47\ m$

Weight of soil and water over heel:

Moist Soil for sloped grade above top of wall:

Length of sloped portion of soil above top of wall: $L_{E3UN1} := \left(L_{cd} + t_{wb} - t_{wt}\right) = 6.50\ m$

Height of sloped soil above top of wall over heel: $h_{E3locUN1} := \left(L_{E3UN1}\right) \cdot \tan(\beta) = 0.00\ m$

Weight of sloped soil above top of wall: $W_{E3UN1} := \frac{\gamma_m}{2} \cdot h_{E3locUN1} \cdot L_{E3UN1} \cdot B = 0.0 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E3locUN1} := L_{ab} + t_{wt} + \frac{2}{3} \cdot L_{E3UN1} = 7.33\ m$

Moist soil from top of wall to groundwater level:

Height of soil from top of wall and top of GWL: $h_{1UN1} = 0.10\ m$

Length from edge of wall at GWL to edge of heel: $L_{E4UN1} := L_{E3UN1} - \left(h_{1UN1} \cdot S_{batter}\right) = 6.49\ m$

Weight of soil over heel from top of wall to GWL: $W_{E4UN1} := \gamma_m \cdot h_{1UN1} \cdot \frac{\left(L_{E3UN1} + L_{E4UN1}\right)}{2} \cdot B = 13.0 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E4locUN1} := b - \frac{L_{E3UN1}^2 + L_{E3UN1} \cdot L_{E4UN1} + L_{E4UN1}^2}{3\left(L_{E3UN1} + L_{E4UN1}\right)} = 6.25\ m$

Saturated soil from groundwater to top of footing:

Height of soil from GWL to top of heel: $h_{E4UN1} := h_{2UN1} - t_{ftg} - Key_{h.d} = 5.50\ m$

Weight of soil over heel from GWL to top of heel: $W_{E5UN1} := \left(\gamma_{sat}\right) \cdot h_{E4UN1} \cdot \frac{\left(L_{E4UN1} + L_{cd}\right)}{2} \cdot B = 759.4 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E5locUN1} := b - \frac{L_{E4UN1}^2 + L_{E4UN1} \cdot L_{cd} + L_{cd}^2}{3\left(L_{E4UN1} + L_{cd}\right)} = 6.36\ m$

$$\Sigma V_{SoilWaterUN1} := W_{H1UN1} + W_{E6UN1} + W_{E3UN1} + W_{E4UN1} + W_{E5UN1} + S_{UN1} = 982.5 \cdot kN$$

$$\Sigma M_{VertSoilWaterResistUN1} := W_{H1UN1} \cdot W_{E1locUN1} + W_{E6UN1} \cdot W_{E6locUN1} \cdots + W_{E3UN1} \cdot W_{E3locUN1} + W_{E4UN1} \cdot W_{E4locUN1} + W_{E5UN1} \cdot W_{E5locUN1} + S_{UN1} \cdot S_{UN1loc} = 5648.8\ m \cdot kN$$

THIS PAGE INTENTIONALLY LEFT BLANK
PLEASE GO TO THE NEXT PAGE

STABILITY ASSESSMENT:

LOAD CASE UN1

CHECK SLIDING ALONG HORIZONTAL SLIDING PLANE:

Summation of the vertical forces:

$$\Sigma V_{UN1} := \Sigma V_{conc} + \Sigma V_{SoilWaterUN1} + \Sigma V_{UpliftUN1} = 960.9 \cdot kN$$

Summation of the horizontal forces:

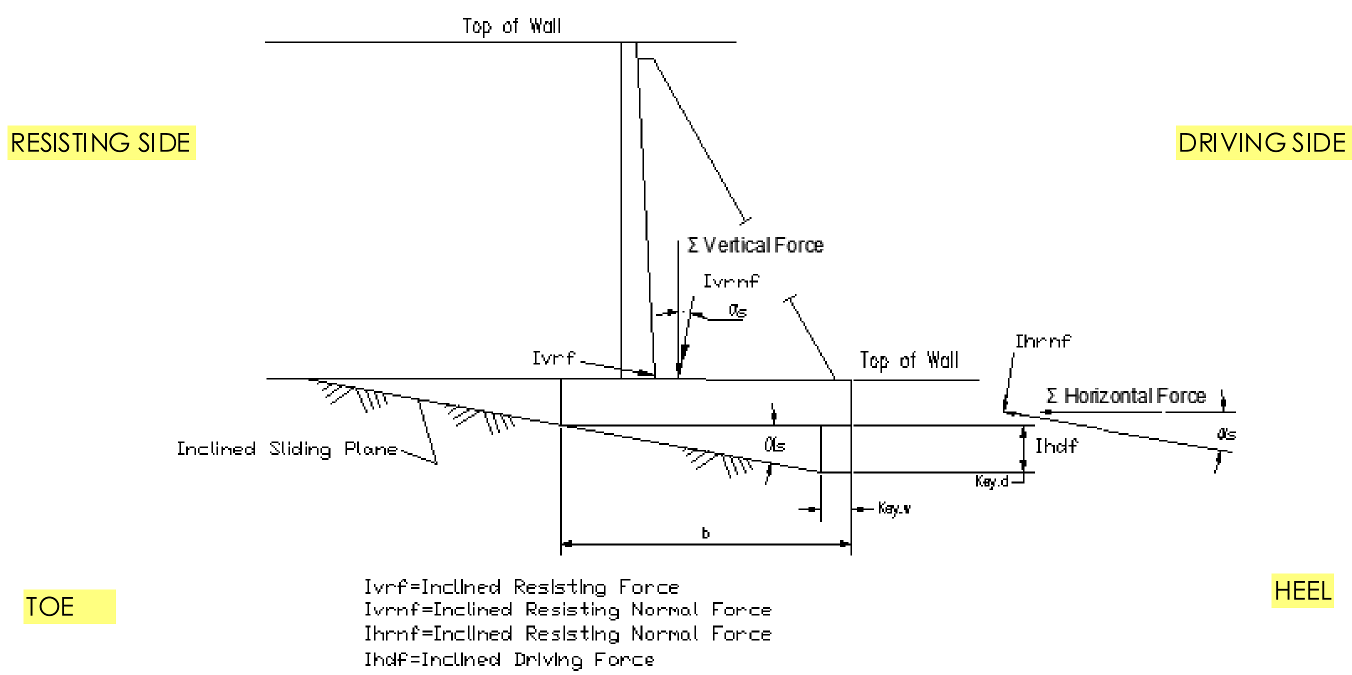
$$\Sigma H_{UN1} := \Sigma H_{SoildriveUN1} + \Sigma H_{SoilresistUN1} = -563.3 \cdot kN$$

Safety Factor for Sliding Horizontal Failure Plane

$$FS_{Horiz.SlidingUN1} := \frac{\left|\Sigma V_{UN1}\right| \cdot \tan\left(\phi_{rock} \cdot \frac{\pi}{180}\right)}{\left|\Sigma H_{UN1}\right|} = 0.83$$

$$FS_{Sliding.check1.UN1} := \begin{array}{|l} \text{"OKAY "} \quad \text{if} \quad FS_{Horiz.SlidingUN1} > FS_{sliding.reqUN1} \\ \text{"NG - key req'"} \quad \text{otherwise} \end{array} = \text{"NG - key req'"}$$

CHECK FACTOR OF SAFETY SLIDING WITH KEY (INCLINED SLIDING PLANE):



$\alpha s = 0.231$ as degrees= $\alpha s \cdot \left(\frac{180}{\pi}\right) = 13.24$

(With properly engineered reinforced concrete Key, horizontal sliding plane thru Toe is protected, critical sliding plane is relocated to the INCLINED SLIDING PLANE FROM HEEL KEY To TOE, Bedrock Mass above this examing plane is mobilized by reinforced concrete key and combined into Structural Wedge.)

Resolve ΣV_{UN1} & ΣH_{UN1}

$$\Sigma V_{InclinedUN1} := \cos(\alpha s) \cdot \left(\left|\Sigma V_{UN1} + V_{rocksection}\right|\right) + \sin(\alpha s) \cdot \left|\Sigma H_{UN1}\right| = 1276.2 \cdot kN$$

$$\Sigma H_{InclinedUN1} := \cos(\alpha s) \cdot \left|\Sigma H_{UN1}\right| - \sin(\alpha s) \cdot \left(\left|\Sigma V_{UN1} + V_{rocksection}\right|\right) = 278.4 \cdot kN$$

LOAD CASE UN1

Safety Factor for Sliding
Inclined Failure Plane

$$FS_{InclinedlSlidingUN1} := \frac{\Sigma V_{InclinedUN1} \cdot \tan(\phi_r)}{\Sigma H_{InclinedUN1}} = 2.04$$

$$FS_{Sliding.check2.UN1} := \begin{cases} \text{"OKAY "} & \text{if } FS_{InclinedlSlidingUN1} > FS_{sliding.reqUN1} \\ \text{"NG - Revise Structure""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

CHECK FOUNDATION ECCENTRICITY:

Summation of the resisting moments about the toe:

$$\Sigma M_{resUN1} := \Sigma M_{conc} + \Sigma M_{VertSoilWaterResistUN1} + \Sigma M_{HorizSoilResistUN1} + \Sigma M_{rocksection} = 10404 \cdot kN \cdot m$$

Summation of the overturning moments about the toe:

$$\Sigma M_{oUN1} := \Sigma M_{LateralSoildriveUN1} + \Sigma M_{UpliftUN1} = -5142 \cdot kN \cdot m$$

Total moment: $\Sigma M_{UN1} := \Sigma M_{resUN1} + \Sigma M_{oUN1} = 5262.4 \cdot kN \cdot m$

Normal force to base: $\Sigma V_{InclinedUN1} = 1276.2 \cdot kN$

Inclined Sliding Plane Length: $L_{incline} = 9.8 \cdot m$

Eccentricity (inclined plane): $ex_{UN1} := \frac{L_{incline}}{2} - \frac{\Sigma M_{UN1}}{\Sigma V_{InclinedUN1}} = 0.76\ m$

$Kern = 1.627\ m$

Eccentricity Check: $e_{check.UN1} := \begin{cases} \text{"Okay"} & \text{if } ex_{UN1} \le Kern \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"Okay"}$

CHECK FOUNDATION BEARING CAPACITY:

Base Section Modulus: $S_b = 15.87\ m^3$

Bearing Pressure Under Toe:

$$\sigma_{ToeUN1} := \begin{cases} \left(\frac{\Sigma V_{InclinedUN1}}{L_{incline} \cdot B} + \frac{\Sigma V_{InclinedUN1} \cdot ex_{UN1}}{S_b}\right) & \text{if } \frac{\Sigma V_{InclinedUN1} \cdot ex_{UN1}}{S_b} \le \frac{\Sigma V_{InclinedUN1}}{L_{incline} \cdot B} \\ \frac{2 \cdot \Sigma V_{InclinedUN1}}{B \cdot 3\left(\frac{b}{2} - ex_{UN1}\right)} & \text{otherwise} \end{cases} = 191.6 \cdot kPa$$

$$Bearing_{ChecktoeUN1} := \begin{cases} \text{"OKAY "} & \text{if } \sigma_{ToeUN1} < \sigma_{allowUN1} \\ \text{"NG""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

Bearing Pressure Under Heel:

$$\sigma_{HeelUN1} := \begin{cases} \left(\frac{\Sigma V_{InclinedUN1}}{L_{incline} \cdot B} - \frac{\Sigma V_{InclinedUN1} \cdot ex_{UN1}}{S_b}\right) & \text{if } \frac{\Sigma V_{InclinedUN1} \cdot ex_{UN1}}{S_b} \le \frac{\Sigma V_{InclinedUN1}}{L_{incline} \cdot B} \\ 0 & \text{otherwise} \end{cases} = 70.0 \cdot kPa$$

$$Bearing_{CheckheelUN1} := \left(\begin{cases} \text{"OKAY "} & \text{if } \sigma_{HeelUN1} < \sigma_{allowUN1} \wedge \sigma_{HeelUN1} > 0 \\ \text{"NG - perform cracked base analysis""} & \text{otherwise} \end{cases}\right) = \text{"OKAY "}$$

CHECK FLOATATION:

Safety Factor for Floatation:

$$FS_{FloatationUN1} := \frac{\Sigma V_{conc} + \Sigma V_{SoilWaterUN1}}{\left|\Sigma V_{UpliftUN1}\right|} = 2.33$$

$$FS_{Floatation.UN1.check} := \begin{cases} \text{"OKAY "} & \text{if } FS_{FloatationUN1} > FS_{req.UN1.flt} \\ \text{"Revise Structure""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

CHECK OVERTURNING

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.
Assumptions are made in order to compute overturning stablity of indetermine forces on monolith with key;
(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.
(b) The horizontal resisting force acting on the key, P.key, is that required for static equilibrium
(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1

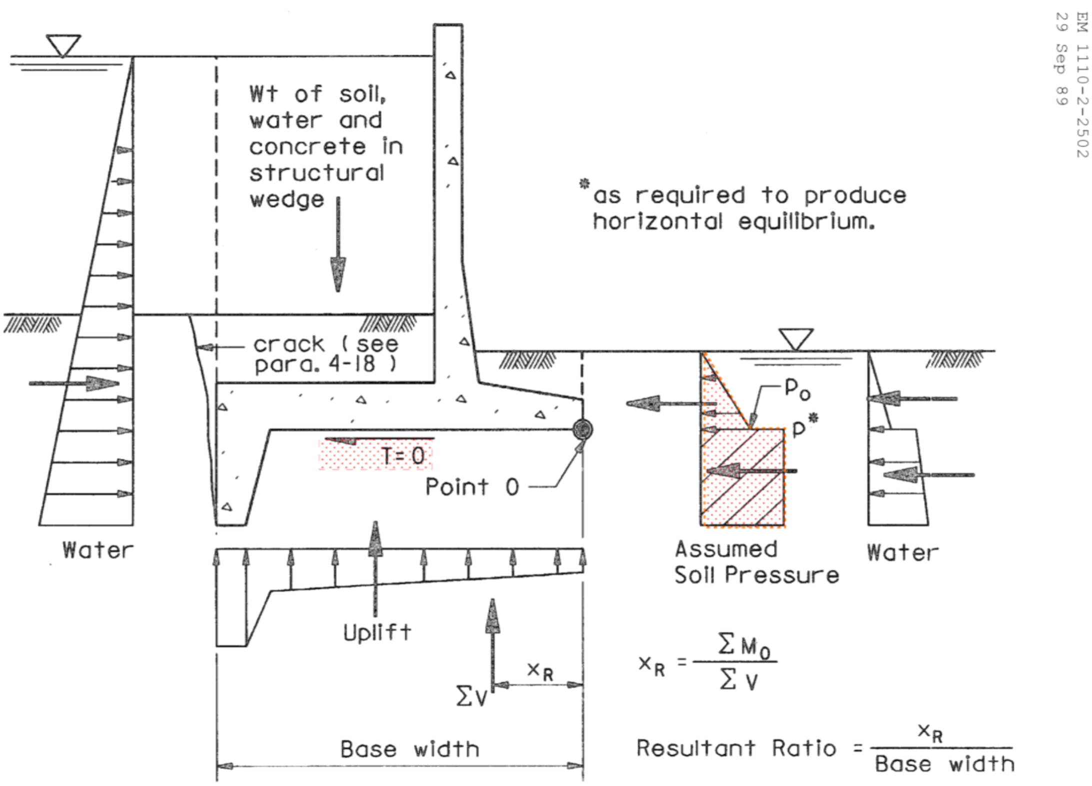


Figure 4-5. Forces for overturning analysis for wall with horizontal base and key

Modify Uplift for Overturning Analysis: **LOAD CASE UN1**

(Uplift is calculated along the concrete/rock contact using the Line of Creep method)

Water Pressure at h: $u_{h.UN1} := \Delta h_{g.hj.UN1} \cdot \gamma_w = 98.00 \cdot kPa$

Water Pressure at o: $u_{o.UN1} := \left(\Delta h_{g.no.UN1} - \frac{\Delta h_{g.r.UN1} \cdot L_{ho.UN1}}{L_{ho.UN1}}\right) \cdot \gamma_w = 53.9 \cdot kPa$

Head loss between point h and o: $\Delta h_{ho.UN1} := \Delta h_{g.r.UN1} \cdot \frac{L_{ho.UN1}}{L_{ho.UN1}} = 2.5\,m$

Length of concrete base (h -> o): $L_{baseho.UN1} := Key_{h.w} + Key_{h.d} + Key_{hdist} + Key_{t.d} + Key_{t.w} = 11.5\,m$

Head loss along h -> j: $\Delta h_{hj.UN1} := \Delta h_{ho.UN1} \cdot \frac{Key_{h.w}}{L_{baseho.UN1}} = 0.217\,m$

Water Pressure at j: $u_{j.UN1} := (\Delta h_{g.hj.UN1} - \Delta h_{hj.UN1}) \cdot \gamma_w = 95.87 \cdot kPa$

Head loss along h -> k: $\Delta h_{hjk.UN1} := \Delta h_{ho.UN1} \cdot \left(\frac{Key_{h.w} + Key_{h.d}}{L_{baseho.UN1}}\right) = 0.652\,m$

Water Pressure at k: $u_{k.UN1} := (\Delta h_{g.km.UN1} - \Delta h_{hjk.UN1}) \cdot \gamma_w = 72.01 \cdot kPa$

Head loss along h -> m: $\Delta h_{hjkm.UN1} := \Delta h_{ho.UN1} \cdot \left(\frac{Key_{h.w} + Key_{h.d} + Key_{hdist}}{L_{baseho.UN1}}\right) = 2.5\,m$

Water Pressure at m: $u_{m.UN1} := (\Delta h_{g.km.UN1} - \Delta h_{hjkm.UN1}) \cdot \gamma_w = 53.90 \cdot kPa$

Head loss along h -> n: $\Delta h_{hjkmn.UN1} := \Delta h_{ho.UN1} \cdot \left(\frac{Key_{h.w} + Key_{h.d} + Key_{hdist} + Key_{t.d}}{L_{baseho.UN1}}\right) = 2.5\,m$

Water Pressure at n: $u_{n.UN1} := (\Delta h_{g.no.UN1} - \Delta h_{hjkmn.UN1}) \cdot \gamma_w = 53.90 \cdot kPa$

Uplift under key at heel: $V_{ulkeyhUN1.OT} := \frac{(u_{h.UN1} + u_{j.UN1}) \cdot Key_{h.w}}{2} \cdot B \cdot -1 = -96.935 \cdot kN$

Moment Arm (from Point O): $V_{ulkeyhUN1loc.OT} := b - \frac{Key_{h.w} \cdot (2 \cdot u_{j.UN1} + u_{h.UN1})}{3 \cdot (u_{j.UN1} + u_{h.UN1})} = 9.002\,m$

Uplift under base: $V_{ulbaseUN1.OT} := \frac{(u_{k.UN1} + u_{m.UN1}) \cdot Key_{hdist}}{2} \cdot B \cdot -1 = -535.112 \cdot kN$

Moment Arm (from Point O): $V_{ulbaseUN1loc.OT} := b - Key_{h.w} - \frac{Key_{hdist} \cdot (2 \cdot u_{m.UN1} + u_{k.UN1})}{3 \cdot (u_{m.UN1} + u_{k.UN1})} = 4.454\,m$

Uplift under key at toe: $V_{ulkeytUN1.OT} := \frac{(u_{n.UN1} + u_{o.UN1}) \cdot Key_{t.w}}{2} \cdot B \cdot -1 = 0 \cdot kN$

Moment Arm (from Point O): $V_{ulkeytUN1loc.OT} := \frac{Key_{t.w} \cdot (2 \cdot u_{n.UN1} + u_{o.UN1})}{3 \cdot (u_{n.UN1} + u_{o.UN1})} = 0$

$$\Sigma V_{UpliftUN1.OT} := V_{ulkeyhUN1.OT} + V_{ulbaseUN1.OT} + V_{ulkeytUN1.OT} = -632 \cdot kN$$

$$U_{UN1.loc.OT} := \frac{V_{ulkeyhUN1.OT} \cdot V_{ulkeyhUN1loc.OT} + V_{ulbaseUN1.OT} \cdot V_{ulbaseUN1loc.OT} + V_{ulkeytUN1.OT} \cdot V_{ulkeytUN1loc.OT}}{\Sigma V_{UpliftUN1.OT}} = 5.15\,m$$

$$\Sigma M_{UpliftUN1.OT} := \Sigma V_{UpliftUN1.OT} \cdot U_{UN1.loc.OT} = -3255.8 \cdot kN \cdot m$$

Modify Lateral Water Pressure (Resisting) for Overturning Analysis:

(Resisting water pressure is calculated using the Line of Creep method)

Water Load at Key (heel): $H_{h2UN1.OT} := \frac{u_{k.UN1} + u_{j.UN1}}{2} \cdot Key_{h.d} B = 167.9 \cdot kN$

Moment Arm (from Point O): $H_{h2locUN1.OT} := \frac{Key_{h.d} \cdot (2 \cdot u_{k.UN1} + u_{j.UN1})}{3(u_{k.UN1} + u_{j.UN1})} + Key_{vdist} = -1.05\ m$

Water Load at Key (toe): $H_{h6UN1.OT} := \frac{u_{o.UN1} \cdot (UWSEL_{UN1} - Bot_{ftg} + Key_{t.d})}{2} \cdot B = 148 \cdot kN$

Moment Arm (from Point O): $H_{h6locUN1.OT} := \frac{UWSEL_{UN1} - Bot_{ftg} + Key_{t.d}}{3} = 1.83\ m$

$$\Sigma H_{waterresistUN1.OT} := H_{h2UN1.OT} + H_{h6UN1.OT} = 316.1 \cdot kN$$

$$H_{waterresistlocUN1.OT} := \frac{H_{h2UN1.OT} \cdot H_{h2locUN1.OT} + H_{h6UN1.OT} \cdot H_{h6locUN1.OT}}{\Sigma H_{waterresistUN1.OT}} = 0.303\ m$$

$$\Sigma M_{waterresistUN1.OT} := \Sigma H_{waterresistUN1.OT} \cdot H_{waterresistlocUN1.OT} = 95.91 \cdot kN \cdot m$$

Modify Lateral Soil Loads for Overturning Analysis:

(Lateral soil loads are calculated down to Point O instead of bottom of shear key)

Driving Soil Load (Headwater Side):

Surcharge Load: $E_{s1UN1.OT} := S1_{UN1} \cdot K_o \cdot (H_w + Key_{h.d} + Key_{vdist}) \cdot B \cdot -1 = -66.34 \cdot kN$

Moment Arm (from Point O): $E_{s1locUN1.OT} := \frac{H_w + Key_{h.d} + Key_{vdist}}{2} = 4.05\ m$

Moist Soil Load above GWL: $E_{h1UN1.OT} := \frac{\gamma_m \cdot K_o \cdot h_{1UN1}^{\ 2}}{2} B \cdot -1 = -0.1 \cdot kN$

Moment Arm (from Point O): $E_{h1locUN1.OT} := \frac{h_{1UN1}}{3} + h_{2UN1} + Key_{vdist} = 8.03\ m$

Saturated Soil Load below GWL: (rectangular component) $E_{h2UN1.OT} := (\gamma_m \cdot K_o \cdot h_{1UN1}) \cdot (h_{2UN1} + Key_{vdist}) \cdot B \cdot -1 = -8.7 \cdot kN$

Moment Arm (from Point O): $E_{h2locUN1.OT} := \frac{h_{2UN1} + Key_{vdist}}{2} = 4.00\ m$

Saturated Soil Load below GWL: (triangular component) $E_{h2aUN1.OT} := \frac{(\gamma_{sat} - \gamma_w) \cdot K_o \cdot (h_{2UN1} + Key_{vdist})^2}{2} \cdot B \cdot -1 = -213.2 \cdot kN$

Moment Arm (from Point O): $E_{h2alocUN1.OT} := \frac{h_{2UN1} + Key_{vdist}}{3} = 2.67\ m$

Resisting Soil Load (Tailwater Side):

(Determine resisting soil load based on depth variation between the keys (ie. Key_{vdist}). In case where key at heel is deeper than key at toe (ie. $Key_{vdist} < 0$), resisting soil load (p*) is assumed to produce horizontal equilibrium as per Figure 4-5 above. Resisting soil load (p_o) is neglected.)

Total Driving Force: $\Sigma H_{SoildriveUN1.OT} := E_{s1UN1.OT} + E_{h1UN1.OT} + E_{h2UN1.OT} + E_{h2aUN1.OT} + H_{h2UN1} = -778.3 \cdot kN$

Total Resisting Force: $\Sigma H_{waterresistUN1.OT} = 316.1 \cdot kN$

Assumed Soil Load p*: $E_{h8UN1a.OT} := (\Sigma H_{SoildriveUN1.OT} + \Sigma H_{waterresistU1.OT}) \cdot -1 = 462.19 \cdot kN$

Moment Arm (from Point O): $E_{h8UN1a.loc.OT} := \dfrac{Key_{vdist}}{2} = -1\ m$

$$E_{h8UN1.OT} := \begin{cases} E_{h8UN1a.OT} & \text{if } Key_{vdist} < 0 \\ \Sigma H_{SoilresistUN1} - H_{h6UN1} - H_{h2aUN1} & \text{otherwise} \end{cases} = 462.19 \cdot kN$$

$$\Sigma M_{SoilresistUN1} := \begin{cases} E_{h8UN1a.OT} \cdot E_{h8UN1a.loc.OT} & \text{if } Key_{vdist} < 0 \\ \Sigma M_{HorizSoilResistUN1} - H_{h6UN1} \cdot H_{h6locUN1} - H_{h2aUN1} \cdot H_{h2alocUN1} & \text{otherwise} \end{cases} = -462.19 \cdot kN \cdot m$$

Sum of Moment about Point O:

$$\Sigma M_{LateraldriveUN1.OT} := E_{s1UN1.OT} \cdot E_{s1locUN1.OT} + E_{h1UN1.OT} \cdot E_{h1locUN1.OT} + E_{h2UN1.OT} \cdot E_{h2locUN1.OT} \ldots + E_{h2aUN1.OT} \cdot E_{h2alocUN1.OT} + H_{h2UN1} \cdot H_{h2locUN1} = -1525.8 \cdot kN \cdot m$$

$$\Sigma M_{LateralresistUN1.OT} := \Sigma M_{waterresistUN1.OT} + \Sigma M_{SoilresistUN1} = -366.3 \cdot kN \cdot m$$

Total moment:

$$\Sigma M_{UN1.OT} := \Sigma M_{conc} + \Sigma M_{VertSoilWaterResistUN1} + \Sigma M_{UpliftUN1.OT} + \Sigma M_{LateraldriveUN1.OT} + \Sigma M_{LateralresistUN1.OT} = 3847.0 \cdot kN \cdot m$$

Total Vertical Force: $\Sigma V_{UN1.OT} := \Sigma V_{conc} + \Sigma V_{SoilWaterUN1} + \Sigma V_{UplliftUN1.OT} = 1050.4 \cdot kN$

Distance X_R: EM 1110-2-2502 Eq.4-1 $X_{R.UN1} := \dfrac{\Sigma M_{UN1.OT}}{\Sigma V_{UN1.OT}} = 3.662\ m$

Overturning Resultant Ratio $Ratio_{UN1.OT} := \dfrac{X_{R.UN1}}{b} = 0.39$

$$Ratio_{UN1.OT.check} := \begin{cases} \text{"OKAY "} & \text{if } Ratio_{UN1.OT} > X_{R.reqUN1} \\ \text{"Revise Structure""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

CHECK FOUNDATION ECCENTRICITY (HORIZONTAL PLANE):

Eccentricity (horizontal plan): $ex_{UN1.OT} := \dfrac{b}{2} - \dfrac{\Sigma M_{UN1.OT}}{\Sigma V_{UN1.OT}} = 1.09\ m$ $\quad Kern_{OT} = 1.583\ m$

Eccentricity Check: $e_{check.UN1.OT} := \begin{cases} \text{"Okay"} & \text{if } ex_{UN1} \le Kern_{OT} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"Okay"}$

CHECK FOUNDATION BEARING CAPACITY (HORIZONTAL PLANE):

Base Section Modulus: $S_{b.OT} = 15.04\,m^3$

Bearing Pressure Under Toe:

$$\sigma_{ToeUN1.OT} := \begin{cases} \left(\dfrac{\Sigma V_{UN1.OT}}{b \cdot B} + \dfrac{\Sigma V_{UN1.OT} \cdot ex_{UN1.OT}}{S_{b.OT}}\right) & \text{if } \dfrac{\Sigma V_{UN1.OT}}{b \cdot B} \geq \dfrac{\Sigma V_{UN1.OT} \cdot ex_{UN1.OT}}{S_{b.OT}} \\ \dfrac{2 \cdot \Sigma V_{UN1.OT}}{B \cdot 3\left(\dfrac{b}{2} - ex_{UN1.OT}\right)} & \text{otherwise} \end{cases} = 186.5 \cdot kPa$$

$$Bearing_{ChecktoeUN1.OT} := \begin{cases} \text{"OKAY "} & \text{if } \sigma_{ToeUN1.OT} < \sigma_{allowUN1} \\ \text{"NG - for reference only""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

Bearing Pressure Under Heel:

$$\sigma_{HeelUN1.OT} := \begin{cases} \left(\dfrac{\Sigma V_{UN1.OT}}{b \cdot B} - \dfrac{\Sigma V_{UN1.OT} \cdot ex_{UN1.OT}}{S_{b.OT}}\right) & \text{if } \dfrac{\Sigma V_{UN1.OT}}{b \cdot B} \geq \dfrac{\Sigma V_{UN1.OT} \cdot ex_{UN1.OT}}{S_{b.OT}} \\ 0 & \text{otherwise} \end{cases} = 34.6 \cdot kPa$$

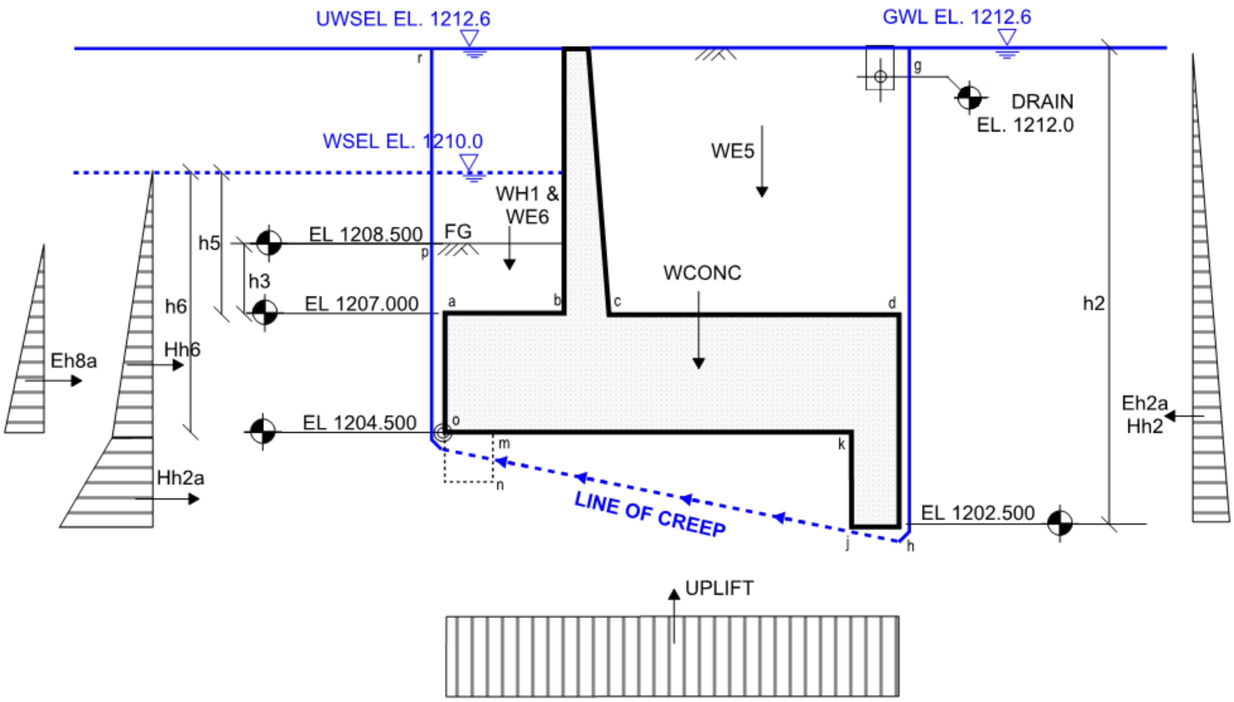
$$Bearing_{CheckheelUN1.OT} := \left(\begin{cases} \text{"OKAY "} & \text{if } \sigma_{HeelUN1.OT} < \sigma_{allowUN1} \wedge \sigma_{HeelUN1.OT} > 0 \\ \text{"NG - for reference only""} & \text{otherwise} \end{cases}\right) = \text{"OKAY "}$$

SUMMARY OF STABILITY ASSESSMENT:

LOAD CASE UN1

Sliding Factor of Safety: (Horizontal Plane - Ref only)	$FS_{Horiz.SlidingUN1} = 0.83$	$FS_{Sliding.check1.UN1}$ = "NG - key req""
Sliding Factor of Safety: (Inclined Plane)	$FS_{InclinedlSlidingUN1} = 2.04$	$FS_{Sliding.check2.UN1}$ = "OKAY "
Eccentricity: (Inclined Plane)	$ex_{UN1} = 0.76\ m$	$e_{check.UN1}$ = "Okay"
Bearing Pressure At Heel: (Inclined Plane)	$\sigma_{HeelUN1} = 70 \cdot kPa$	$Bearing_{CheckheelUN1}$ = "OKAY "
Bearing Pressure At Toe: (Inclined Plane)	$\sigma_{ToeUN1} = 192 \cdot kPa$	$Bearing_{ChecktoeUN1}$ = "OKAY "
Flotation Factor of Safety (horizontal plane)	$FS_{FloatationUN1} = 2.33$	$FS_{Floatation.UN1.check}$ = "OKAY "
Overturning Resultant Ratio: (horizontal plane)	$Ratio_{UN1.OT} = 0.39$	$Ratio_{UN1.OT.check}$ = "OKAY "
Eccentricity: (horizontal plane - Ref only)	$ex_{UN1.OT} = 1.09\ m$	$e_{check.UN1.OT}$ = "Okay"
Bearing Pressure At Heel: (horizontal plane - Ref only)	$\sigma_{HeelUN1.OT} = 35 \cdot kPa$	$Bearing_{CheckheelUN1.OT}$ = "OKAY "
Bearing Pressure At Toe: (horizontal plane - Ref only)	$\sigma_{ToeUN1.OT} = 187 \cdot kPa$	$Bearing_{ChecktoeUN1.OT}$ = "OKAY "

LOAD CASE UN2 - INEFFECTIVE DRAIN



UN2 DESIGN CASE

LOAD CASE UN2 ACCEPTANCE PARAMETERS

FS sliding:

Unusual (UN) 1.3 (without cohesion) (Table 3-3, USACE EM 1110-2-2100)

Resultant Location:

Unsual (UN) Inside middle third ~100% base in compression

Required Factor of Safety for Sliding: $FS_{sliding.reqUN2} := 1.3$ (Without Cohesion)

Allowable rock bearing pressure: $\sigma_{allowUN2} := 1470kPa$ (Section 5.2, Design Criteria EM 1110-2-2100 Section 3-10)

Overturning Required Resultant Ratio: $X_{R.reqUN2} := 0.333$ (EM 1110-2-2502, Figure 4-4)

Required Factor of Safety for Floatation $FS_{req.UN2.flt} := 1.3$

SOIL HEIGHTS and Water Levels:

LOAD CASE UN2

Heel Conditions:

Groundwater Elevation at Heel: $GWL_{UN2} := 1212.6m$

Distance from Finish Grade to Groundwater at Heel: $h_{1UN2} := \left[T_w - GWL_{UN2} + \left(L_{cd} + t_{wb} - t_{wt}\right)\cdot \tan(\beta)\right] = 0.00\ m$

Distance from Water Surface to Bottom of Footing at Heel: $h_{2UN2} := GWL_{UN2} - Bot_{ftg} + Key_{h.d} = 10.10\ m$

Toe Conditions:

Water Surface Elevation at Toe: $WSEL_{UN2} := 1210.0m$

Water Surface Elevation at Toe for Uplift: $UWSEL_{UN2} := 1212.6\cdot m$

Finish Grade at Toe providing lateral resistance: $FG_{toeUN2} := 1208.5\cdot m$

Soil Depth Above top of footing: $h_{3aUN2} := FG_{toeUN2} - Top_{ftg} = 1.5\ m$

$$h_{3UN2} := \begin{cases} h_{3aUN2} & \text{if } FG_{toeUN2} - Top_{ftg} \geq 0 \\ 0 & \text{otherwise} \end{cases} = 1.5$$

Resisting Fill at Toe: $h_{4UN2} := FG_{toeUN2} - Bot_{ftg} + Key_{t.d} = 4.00\ m$

Distance from Water Level to Top of Footing at Toe: $h_{5UN2} := WSEL_{UN2} - Top_{ftg} = 3.00\ m$

Distance from Water Surface to Bottom of Footing at Toe: $h_{6UN2} := WSEL_{UN2} - Bot_{ftg} + Key_{t.d} = 5.50\ m$

Soil Depth Above WSEL: $h_{7aUN2} := FG_{toeUN2} - WSEL_{UN2} = -1.5\ m$

$$h_{7UN2} := \begin{cases} h_{7aUN2} & \text{if } FG_{toeUN2} - WSEL_{UN2} \geq 0 \\ 0 & \text{otherwise} \end{cases} = 0$$

Soil Depth Below WSEL:

$$h_{8UN2} := \begin{cases} WSEL_{UN2} - Bot_{ftg} + Key_{t.d} & \text{if } FG_{toeUN2} - WSEL_{UN2} \geq 0 \\ h_{4UN2} & \text{otherwise} \end{cases} = 4$$

For Line of Creep Method: $L_{ho.UN2} := \sqrt{b^2 + \left(Key_{h.d} - Key_{t.d}\right)^2} = 9.708\ m$

Head Loss from Point g:

$\Delta h_{g.hj.UN2} := h_{2UN2} = 10.1\ m$ (to point h & j)

$\Delta h_{g.km.UN2} := GWL_{UN2} - Bot_{ftg} = 8.1\ m$ (to point k & m)

$\Delta h_{g.no.UN2} := GWL_{UN2} - Bot_{ftg} + Key_{t.d} = 8.1\ m$ (to point n & o)

$\Delta h_{g.p.UN2} := GWL_{UN2} - FG_{toeUN2} = 4.1\ m$ (to point p)

$\Delta h_{g.r.UN2} := GWL_{UN2} - UWSEL_{UN2} = 0\ m$ (to point r)

Surcharge

Surcharge on Heel: $S1_{UN2} := 0.0\ \frac{kN}{m^2}$

Calculate Soil Lateral Pressure Coefficients:

LOAD CASE UN2

For all load cases except seismic, soil loading to be based on At-Rest Condition.
Calculate at-rest pressure coefficient Ko based on Jaky's (1944) equation.

Soil At Rest Static Coefficient: $K_o := \frac{1 - \sin(\phi)}{1 + \sin(\beta)} = 0.546$ (Eq. 3-6, USACE EM 1110-2-2502)

Lateral - Driving Force

Static At-Rest:

Surcharge Load: $E_{s1UN2} := S1_{UN2} \cdot K_o \cdot \left(H_w + Key_{h.d}\right) \cdot B \cdot -1 = 0 \cdot kN$

Moment Arm (from bottom of footing): $E_{s1locUN2} := \frac{H_w + Key_{h.d}}{2} + Key_{vdist} = 3.05\ m$

Moist Soil Load above GWL: $E_{h1UN2} := \frac{\gamma_m \cdot K_o \cdot h_{1UN2}^{\ 2}}{2} \cdot B \cdot -1 = 0.0 \cdot kN$

Moment Arm (from bottom of footing): $E_{h1locUN2} := \frac{h_{1UN2}}{3} + h_{2UN2} + Key_{vdist} = 8.10\ m$

Saturated Soil Load below GWL:
(rectangular component) $E_{h2UN2} := \left(\gamma_m \cdot K_o \cdot h_{1UN2}\right) \cdot h_{2UN2} \cdot B \cdot -1 = 0.0 \cdot kN$

Moment Arm (from bottom of footing): $E_{h2locUN2} := \frac{h_{2UN2}}{2} + Key_{vdist} = 3.05\ m$

Saturated Soil Load below GWL:
(triangular component) $E_{h2aUN2} := \frac{\left(\gamma_{sat} - \gamma_w\right) \cdot K_o \cdot h_{2UN2}^{\ 2}}{2} \cdot B \cdot -1 = -339.8 \cdot kN$

Moment Arm (from bottom of footing): $E_{h2alocUN2} := \frac{h_{2UN2}}{3} + Key_{vdist} = 1.37\ m$

Lateral Water Load:

Water Load GWL to Bottom of Key $H_{h2UN2} := \frac{\gamma_w \cdot h_{2UN2}^{\ 2}}{2} \cdot B \cdot -1 = -499.8 \cdot kN$

Moment Arm (from bottom of footing): $H_{h2locUN2} := \frac{h_{2UN2}}{3} + Key_{vdist} = 1.37\ m$

$\Sigma H_{SoildriveUN2} := E_{s1UN2} + E_{h1UN2} + E_{h2UN2} + E_{h2aUN2} + H_{h2UN2} = -839.6 \cdot kN$

$$\Sigma M_{LateralSoildriveUN2} := E_{s1UN2} \cdot E_{s1locUN2} + E_{h1UN2} \cdot E_{h1locUN2} + E_{h2UN2} \cdot E_{h2locUN2} \ldots + E_{h2aUN2} \cdot E_{h2alocUN2} + H_{h2UN2} \cdot H_{h2locUN2} = -1147.5\ m \cdot kN$$

Lateral - Resisting Force

LOAD CASE UN2

Lateral Water Load:

Water Load WSEL to Bottom of Footing: $H_{h6UN2} := \dfrac{\gamma_w \cdot h_{6UN2}^{2}}{2} \cdot B = 148.2 \cdot kN$

Moment Arm (from bot. of toe key): $H_{h6locUN2} := \dfrac{h_{6UN2}}{3} = 1.83\ m$

Water Load Bot. of Footing to Bot. of H. Key: $H_{h2aUN2} := \left[\left(UWSEL_{UN2} - Bot_{ftg} + Key_{t.d}\right) + h_{2UN2}\right] \cdot \dfrac{Key_{h.d}}{2} \cdot \gamma_w \cdot B = 178.4 \cdot kN$

Moment Arm (from bot. of toe key):

$$H_{h2alocUN2} := \frac{Key_{h.d} \cdot \left[2 \cdot \left(UWSEL_{UN2} - Bot_{ftg} + Key_{t.d}\right) + h_{2UN2}\right]}{3\left[h_{2UN2} + \left(UWSEL_{UN2} - Bot_{ftg} + Key_{t.d}\right)\right]} \ldots = -1.04\ m$$
$$+ Key_{vdist}$$

Lateral Soil Load:

Moist Soil Load above WSEL: $E_{h7UN2} := \dfrac{\gamma_m \cdot K_o \cdot h_{7UN2}^{2}}{2} B = 0.0 \cdot kN$

Moment Arm (from bot. of toe key): $E_{h7locUN2} := h_{6UN2} + \dfrac{h_{7UN2}}{3} + Key_{vdist} = 3.50\ m$

Saturated Soil Load below WSEL: (rectangular component) $E_{h8UN2} := \left(\gamma_m \cdot K_o \cdot h_{7UN2}\right) \cdot h_{8UN2} \cdot B = 0.0 \cdot kN$

Moment Arm (from bot. of toe key): $E_{h8locUN2} := \dfrac{h_{8UN2}}{2} = 2.00\ m$

Saturated Soil Load below WSEL: (triangular component) $E_{h8aUN2} := \dfrac{\left[\left(\gamma_{sat} - \gamma_w\right) \cdot K_o\right] \cdot h_{8UN2}^{2}}{2} \cdot B = 53.3 \cdot kN$

Moment Arm (from bot. of footing): $E_{h8alocUN2} := \dfrac{h_{8UN2}}{3} = 1.33\ m$

$$\Sigma H_{SoilresistUN2} := H_{h6UN2} + H_{h2aUN2} + E_{h7UN2} + E_{h8UN2} + E_{h8aUN2} = 379.9 \cdot kN$$

$$\Sigma M_{HorizSoilResistUN2} := H_{h6UN2} \cdot H_{h6locUN2} + H_{h2aUN2} \cdot H_{h2alocUN2} + E_{h7UN2} \cdot E_{h7locUN2} \ldots = 157.9\ m \cdot kN$$
$$+ E_{h8UN2} \cdot E_{h8locUN2} + E_{h8aUN2} \cdot E_{h8alocUN2}$$

Vertical Force:

UPLIFT: Linear distribution from water at heel to water at toe:

$$\Sigma V_{UplliftUN2} := \left[\left(UWSEL_{UN2} - Bot_{ftg} + Key_{t.d}\right) + h_{2UN2}\right] \cdot \frac{b}{2} \cdot \gamma_w \cdot B \cdot -1 = -847.21 \cdot kN$$

Moment Arm (from Point O): $V_{UpliftUN2aloc} := \dfrac{b \cdot \left[2 \cdot h_{2UN2} + \left(UWSEL_{UN2} - Bot_{ftg} + Key_{t.d}\right)\right]}{3\left[h_{2UN2} + \left(UWSEL_{UN2} - Bot_{ftg} + Key_{t.d}\right)\right]} = 4.924\ m$

$$\Sigma M_{UpliftUN2} := \Sigma V_{UplliftUN2} \cdot V_{UpliftUN2aloc} = -4171.656 \cdot kN \cdot m$$

Weight of soil and water over toe:

Water Above the Top of Footing: $W_{H1UN2} := \gamma_w \cdot h_{5UN2} \cdot L_{ab} \cdot B = 73.5 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E1locUN2} := \dfrac{L_{ab}}{2} = 1.25\ m$

Soil above top of footing: $W_{E6UN2} := \gamma_b \cdot h_{3UN2} \cdot L_{ab} \cdot B = 45.8 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E6locUN2} := \dfrac{L_{ab}}{2} = 1.25\ m$

Vertical Load Due to Surcharge: $S_{UN2} := S1_{UN2} \cdot L_{cd} \cdot B = 0 \cdot kN$ $\quad S_{UN2loc} := b - \dfrac{L_{cd}}{2} = 6.47\ m$

Weight of soil and water over heel:

Moist Soil for sloped grade above top of wall:

Length of sloped portion of soil above top of wall: $L_{E3UN2} := \left(L_{cd} + t_{wb} - t_{wt}\right) = 6.50\ m$

Height of sloped soil above top of wall over heel: $h_{E3locUN2} := \left(L_{E3UN2}\right) \cdot \tan(\beta) = 0.00\ m$

Weight of sloped soil above top of wall: $W_{E3UN2} := \dfrac{\gamma_m}{2} \cdot h_{E3locUN2} \cdot L_{E3UN2} \cdot B = 0.0 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E3locUN2} := L_{ab} + t_{wt} + \dfrac{2}{3} \cdot L_{E3UN2} = 7.33\ m$

Moist soil from top of wall to groundwater level:

Height of soil from top of wall and top of GWL: $h_{1UN2} = 0.00\ m$

Length from edge of wall at GWL to edge of heel: $L_{E4UN2} := L_{E3UN2} - \left(h_{1UN2} \cdot S_{batter}\right) = 6.50\ m$

Weight of soil over heel from top of wall to GWL: $W_{E4UN2} := \gamma_m \cdot h_{1UN2} \cdot \dfrac{\left(L_{E3UN2} + L_{E4UN2}\right)}{2} \cdot B = 0.0 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E4locUN2} := b - \dfrac{L_{E3UN2}^2 + L_{E3UN2} \cdot L_{E4UN2} + L_{E4UN2}^2}{3\left(L_{E3UN2} + L_{E4UN2}\right)} = 6.25\ m$

Saturated soil from groundwater to top of footing:

Height of soil from GWL to top of heel: $h_{E4UN2} := h_{2UN2} - t_{ftg} - Key_{h.d} = 5.60\ m$

Weight of soil over heel from GWL to top of heel: $W_{E5UN2} := \left(\gamma_{sat}\right) \cdot h_{E4UN2} \cdot \dfrac{\left(L_{E4UN2} + L_{cd}\right)}{2} \cdot B = 773.7 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E5locUN2} := b - \dfrac{L_{E4UN2}^2 + L_{E4UN2} \cdot L_{cd} + L_{cd}^2}{3\left(L_{E4UN2} + L_{cd}\right)} = 6.36\ m$

$$\Sigma V_{SoilWaterUN2} := W_{H1UN2} + W_{E6UN2} + W_{E3UN2} + W_{E4UN2} + W_{E5UN2} + S_{UN2} = 892.9 \cdot kN$$

$$\Sigma M_{VertSoilWaterResistUN2} := W_{H1UN2} \cdot W_{E1locUN2} + W_{E6UN2} \cdot W_{E6locUN2} \cdots + W_{E3UN2} \cdot W_{E3locUN2} + W_{E4UN2} \cdot W_{E4locUN2} + W_{E5UN2} \cdot W_{E5locUN2} + S_{UN2} \cdot S_{UN2loc} = 5068.8\ m \cdot kN$$

THIS PAGE INTENTIONALLY LEFT BLANK
PLEASE GO TO THE NEXT PAGE

STABILITY ASSESSMENT:

LOAD CASE UN2

CHECK SLIDING ALONG HORIZONTAL SLIDING PLANE:

Summation of the vertical forces:

$$\Sigma V_{UN2} := \Sigma V_{conc} + \Sigma V_{SoilWaterUN2} + \Sigma V_{UpliftUN2} = 745.6 \cdot kN$$

Summation of the horizontal forces:

$$\Sigma H_{UN2} := \Sigma H_{SoildriveUN2} + \Sigma H_{SoilresistUN2} = -459.7 \cdot kN$$

Safety Factor for Sliding Horizontal Failure Plane

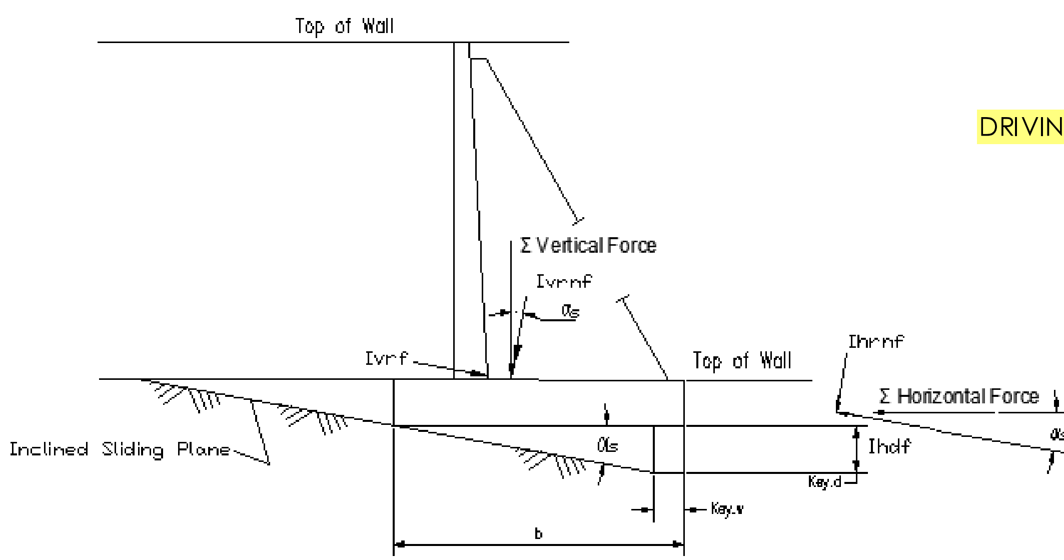
$$FS_{Horiz.SlidingUN2} := \frac{\left|\Sigma V_{UN2}\right| \cdot \tan\left(\phi_{rock} \cdot \frac{\pi}{180}\right)}{\left|\Sigma H_{UN2}\right|} = 0.79$$

$$FS_{Sliding.check1.UN2} := \begin{cases} \text{"OKAY "} & \text{if } FS_{Horiz.SlidingUN2} > FS_{sliding.reqUN2} \\ \text{"NG - key req'"} & \text{otherwise} \end{cases} = \text{"NG - key req'"}$$

CHECK FACTOR OF SAFETY SLIDING WITH KEY (INCLINED SLIDING PLANE):

RESISTING SIDE

DRIVING SIDE



TOE

HEEL

Ivrf=Inclined Resisting Force
Ivrnf=Inclined Resisting Normal Force
Ihrnf=Inclined Resisting Normal Force
Ihdf=Inclined Driving Force

$\alpha s = 0.231$ as degrees= $\alpha s \cdot \left(\frac{180}{\pi}\right) = 13.24$

(With properly engineered reinforced concrete Key, horizontal sliding plane thru Toe is protected, critical sliding plane is relocated to the INCLINED SLIDING PLANE FROM HEEL KEY To TOE, Bedrock Mass above this examing plane is mobilized by reinforced concrete key and combined into Structural Wedge.)

Resolve ΣV_{UN2} & ΣH_{UN2}

$$\Sigma V_{InclinedUN2} := \cos(\alpha s) \cdot \left(\left|\Sigma V_{UN2} + V_{rocksection}\right|\right) + \sin(\alpha s) \cdot \left|\Sigma H_{UN2}\right| = 1042.9 \cdot kN$$

$$\Sigma H_{InclinedUN2} := \cos(\alpha s) \cdot \left|\Sigma H_{UN2}\right| - \sin(\alpha s) \cdot \left(\left|\Sigma V_{UN2} + V_{rocksection}\right|\right) = 226.9 \cdot kN$$

LOAD CASE UN2

Safety Factor for Sliding Inclined Failure Plane

$$FS_{InclinedISlidingUN2} := \frac{\Sigma V_{InclinedUN2} \cdot \tan(\phi_r)}{\Sigma H_{InclinedUN2}} = 2.05$$

$$FS_{Sliding.check2.UN2} := \begin{cases} \text{"OKAY"} & \text{if } FS_{InclinedISlidingUN2} > FS_{sliding.reqUN2} \\ \text{"NG - Revise Structure""} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

CHECK FOUNDATION ECCENTRICITY:

Summation of the resisting moments about the toe:

$$\Sigma M_{resUN2} := \Sigma M_{conc} + \Sigma M_{VertSoilWaterResistUN2} + \Sigma M_{HorizSoilResistUN2} + \Sigma M_{rocksection} = 9806 \cdot kN \cdot m$$

Summation of the overturning moments about the toe:

$$\Sigma M_{oUN2} := \Sigma M_{LateralSoildriveUN2} + \Sigma M_{UpliftUN2} = -5319 \cdot kN \cdot m$$

Total moment: $\Sigma M_{UN2} := \Sigma M_{resUN2} + \Sigma M_{oUN2} = 4486.8 \, m \cdot kN$

Normal force to base: $\Sigma V_{InclinedUN2} = 1042.9 \cdot kN$

Inclined Sliding Plane Length: $L_{incline} = 9.8 \cdot m$

Eccentricity (inclined plane): $ex_{UN2} := \frac{L_{incline}}{2} - \frac{\Sigma M_{UN2}}{\Sigma V_{InclinedUN2}} = 0.58 \, m$

Kern = 1.627 m

Eccentricity Check: $e_{check.UN2} := \begin{cases} \text{"Okay"} & \text{if } ex_{UN2} \le Kern \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"Okay"}$

CHECK FOUNDATION BEARING CAPACITY:

Base Section Modulus: $S_b = 15.87 \, m^3$

Bearing Pressure Under Toe:

$$\sigma_{ToeUN2} := \begin{cases} \left(\frac{\Sigma V_{InclinedUN2}}{L_{incline} \cdot B} + \frac{\Sigma V_{InclinedUN2} \cdot ex_{UN2}}{S_b}\right) & \text{if } \frac{\Sigma V_{InclinedUN2} \cdot ex_{UN2}}{S_b} \le \frac{\Sigma V_{InclinedUN2}}{L_{incline} \cdot B} \\ \frac{2 \cdot \Sigma V_{InclinedUN2}}{B \cdot 3\left(\frac{b}{2} - ex_{UN2}\right)} & \text{otherwise} \end{cases} = 144.8 \cdot kPa$$

$$Bearing_{ChecktoeUN2} := \begin{cases} \text{"OKAY"} & \text{if } \sigma_{ToeUN2} < \sigma_{allowUN2} \\ \text{"NG""} & \text{otherwise} \end{cases} = \text{"OKAY"}$$

Bearing Pressure Under Heel:

$$\sigma_{HeelUN2} := \begin{cases} \left(\frac{\Sigma V_{InclinedUN2}}{L_{incline} \cdot B} - \frac{\Sigma V_{InclinedUN2} \cdot ex_{UN2}}{S_b}\right) & \text{if } \frac{\Sigma V_{InclinedUN2} \cdot ex_{UN2}}{S_b} \le \frac{\Sigma V_{InclinedUN2}}{L_{incline} \cdot B} \\ 0 & \text{otherwise} \end{cases} = 68.9 \cdot kPa$$

$$Bearing_{CheckheelUN2} := \left(\begin{cases} \text{"OKAY"} & \text{if } \sigma_{HeelUN2} < \sigma_{allowUN2} \wedge \sigma_{HeelUN2} > 0 \\ \text{"NG - perform cracked base analysis""} & \text{otherwise} \end{cases}\right) = \text{"OKAY"}$$

CHECK FLOATATION:

Safety Factor for Floatation: $FS_{FloatationUN2} := \dfrac{\Sigma V_{conc} + \Sigma V_{SoilWaterUN2}}{\left|\Sigma V_{UpliftUN2}\right|} = 1.88$

$FS_{Floatation.UN2.check} := \begin{cases} \text{"OKAY "} & \text{if } FS_{FloatationUN2} > FS_{req.UN2.flt} \\ \text{"Revise Structure""} & \text{otherwise} \end{cases} = \text{"OKAY "}$

CHECK OVERTURNING

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.
Assumptions are made in order to compute overturning stablity of indetermine forces on monolith with key;
(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.
(b) The horizontal resisting force acting on the key, P.key, is that required for static equilibrium
(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1

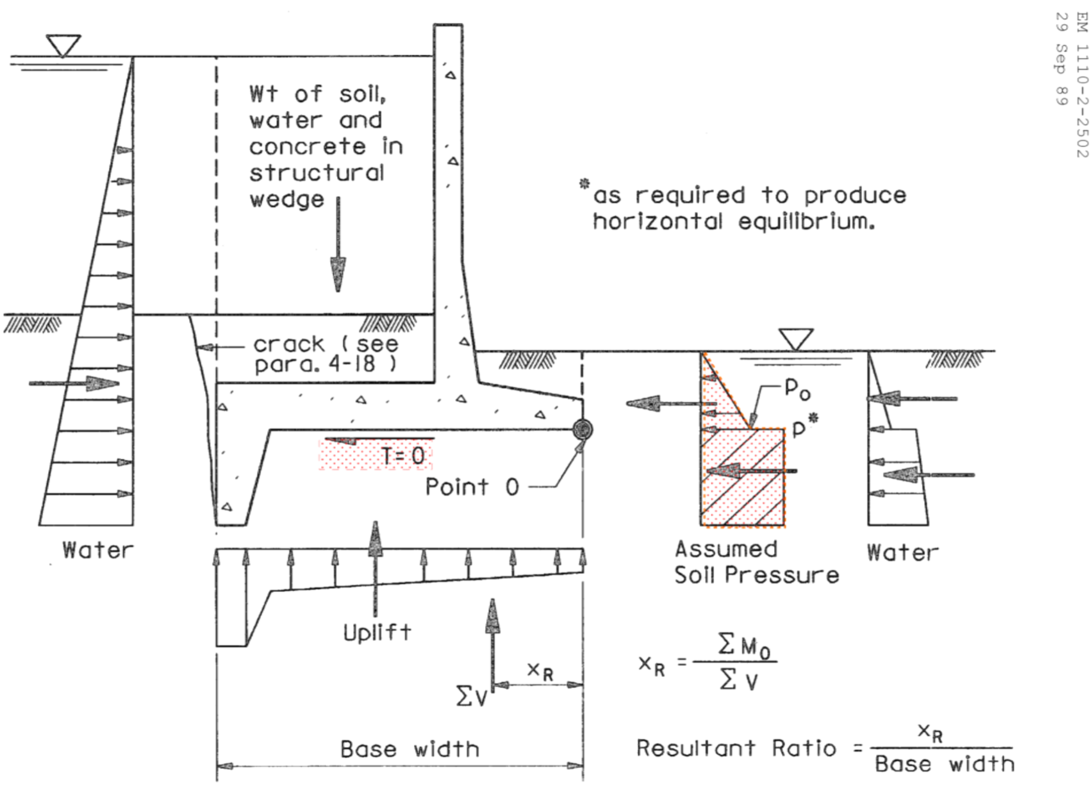


Figure 4-5. Forces for overturning analysis for wall with horizontal base and key

Modify Uplift for Overturning Analysis: **LOAD CASE UN2**

(Uplift is calculated along the concrete/rock contact using the Line of Creep method)

Water Pressure at h: $u_{h.UN2} := \Delta h_{g.hj.UN2} \cdot \gamma_w = 98.98 \cdot kPa$

Water Pressure at o: $u_{o.UN2} := \left(\Delta h_{g.no.UN2} - \frac{\Delta h_{g.r.UN2} \cdot L_{ho.UN2}}{L_{ho.UN2}}\right) \cdot \gamma_w = 79.38 \cdot kPa$

Head loss between point h and o: $\Delta h_{ho.UN2} := \Delta h_{g.r.UN2} \cdot \frac{L_{ho.UN2}}{L_{ho.UN2}} = 0\,m$

Length of concrete base (h -> o): $L_{baseho.UN2} := Key_{h.w} + Key_{h.d} + Key_{hdist} + Key_{t.d} + Key_{t.w} = 11.5\,m$

Head loss along h -> j: $\Delta h_{hj.UN2} := \Delta h_{ho.UN2} \cdot \frac{Key_{h.w}}{L_{baseho.UN2}} = 0\,m$

Water Pressure at j: $u_{j.UN2} := \left(\Delta h_{g.hj.UN2} - \Delta h_{hj.UN2}\right) \cdot \gamma_w = 98.98 \cdot kPa$

Head loss along h -> k: $\Delta h_{hjk.UN2} := \Delta h_{ho.UN2} \cdot \left(\frac{Key_{h.w} + Key_{h.d}}{L_{baseho.UN2}}\right) = 0\,m$

Water Pressure at k: $u_{k.UN2} := \left(\Delta h_{g.km.UN2} - \Delta h_{hjk.UN2}\right) \cdot \gamma_w = 79.38 \cdot kPa$

Head loss along h -> m: $\Delta h_{hjkm.UN2} := \Delta h_{ho.UN2} \cdot \left(\frac{Key_{h.w} + Key_{h.d} + Key_{hdist}}{L_{baseho.UN2}}\right) = 0\,m$

Water Pressure at m: $u_{m.UN2} := \left(\Delta h_{g.km.UN2} - \Delta h_{hjkm.UN2}\right) \cdot \gamma_w = 79.38 \cdot kPa$

Head loss along h -> n: $\Delta h_{hjkmn.UN2} := \Delta h_{ho.UN2} \cdot \left(\frac{Key_{h.w} + Key_{h.d} + Key_{hdist} + Key_{t.d}}{L_{baseho.UN2}}\right) = 0\,m$

Water Pressure at n: $u_{n.UN2} := \left(\Delta h_{g.no.UN2} - \Delta h_{hjkmn.UN2}\right) \cdot \gamma_w = 79.38 \cdot kPa$

Uplift under key at heel: $V_{ulkeyhUN2.OT} := \frac{\left(u_{h.UN2} + u_{j.UN2}\right) \cdot Key_{h.w}}{2} \cdot B \cdot -1 = -98.98 \cdot kN$

Moment Arm (from Point O): $V_{ulkeyhUN2loc.OT} := b - \frac{Key_{h.w} \cdot \left(2 \cdot u_{j.UN2} + u_{h.UN2}\right)}{3 \cdot \left(u_{j.UN2} + u_{h.UN2}\right)} = 9\,m$

Uplift under base: $V_{ulbaseUN2.OT} := \frac{\left(u_{k.UN2} + u_{m.UN2}\right) \cdot Key_{hdist}}{2} \cdot B \cdot -1 = -674.73 \cdot kN$

Moment Arm (from Point O): $V_{ulbaseUN2loc.OT} := b - Key_{h.w} - \frac{Key_{hdist} \cdot \left(2 \cdot u_{m.UN2} + u_{k.UN2}\right)}{3 \cdot \left(u_{m.UN2} + u_{k.UN2}\right)} = 4.25\,m$

Uplift under key at toe: $V_{ulkeytUN2.OT} := \frac{\left(u_{n.UN2} + u_{o.UN2}\right) \cdot Key_{t.w}}{2} \cdot B \cdot -1 = 0 \cdot kN$

Moment Arm (from Point O): $V_{ulkeytUN2loc.OT} := \frac{Key_{t.w} \cdot \left(2 \cdot u_{n.UN2} + u_{o.UN2}\right)}{3 \cdot \left(u_{n.UN2} + u_{o.UN2}\right)} = 0$

$$\Sigma V_{UpliftUN2.OT} := V_{ulkeyhUN2.OT} + V_{ulbaseUN2.OT} + V_{ulkeytUN2.OT} = -774 \cdot kN$$

$$U_{UN2.loc.OT} := \frac{V_{ulkeyhUN2.OT} \cdot V_{ulkeyhUN2loc.OT} + V_{ulbaseUN2.OT} \cdot V_{ulbaseUN2loc.OT} + V_{ulkeytUN2.OT} \cdot V_{ulkeytUN2loc.OT}}{\Sigma V_{UpliftUN2.OT}} = 4.86\,m$$

$$\Sigma M_{UpliftUN2.OT} := \Sigma V_{UpliftUN2.OT} \cdot U_{UN2.loc.OT} = -3758.4 \cdot kN \cdot m$$

Modify Lateral Water Pressure (Resisting) for Overturning Analysis:

(Resisting water pressure is calculated using the Line of Creep method)

Water Load at Key (heel):
$$H_{h2UN2.OT} := \frac{u_{k.UN2} + u_{j.UN2}}{2} \cdot Key_{h.d} B = 178.4 \cdot kN$$

Moment Arm (from Point O):
$$H_{h2locUN2.OT} := \frac{Key_{h.d} \cdot (2 \cdot u_{k.UN2} + u_{j.UN2})}{3(u_{k.UN2} + u_{j.UN2})} + Key_{vdist} = -1.04\ m$$

Water Load at Key (toe):
$$H_{h6UN2.OT} := \frac{u_{o.UN2} \cdot (UWSEL_{UN2} - Bot_{ftg} + Key_{t.d})}{2} \cdot B = 321 \cdot kN$$

Moment Arm (from Point O):
$$H_{h6locUN2.OT} := \frac{UWSEL_{UN2} - Bot_{ftg} + Key_{t.d}}{3} = 2.70\ m$$

$$\Sigma H_{waterresistUN2.OT} := H_{h2UN2.OT} + H_{h6UN2.OT} = 499.85 \cdot kN$$

$$H_{waterresistlocUN2.OT} := \frac{H_{h2UN2.OT} \cdot H_{h2locUN2.OT} + H_{h6UN2.OT} \cdot H_{h6locUN2.OT}}{\Sigma H_{waterresistUN2.OT}} = 1.367\ m$$

$$\Sigma M_{waterresistUN2.OT} := \Sigma H_{waterresistUN2.OT} \cdot H_{waterresistlocUN2.OT} = 683.13 \cdot kN \cdot m$$

Modify Lateral Soil Loads for Overturning Analysis:

(Lateral soil loads are calculated down to Point O instead of bottom of shear key)

<u>Driving Soil Load (Headwater Side):</u>

Surcharge Load:
$$E_{s1UN2.OT} := S1_{UN2} \cdot K_o \cdot (H_w + Key_{h.d} + Key_{vdist}) \cdot B \cdot -1 = 0 \cdot kN$$

Moment Arm (from Point O):
$$E_{s1locUN2.OT} := \frac{H_w + Key_{h.d} + Key_{vdist}}{2} = 4.05\ m$$

Moist Soil Load above GWL:
$$E_{h1UN2.OT} := \frac{\gamma_m \cdot K_o \cdot h_{1UN2}^{\ 2}}{2} B \cdot -1 = 0.0 \cdot kN$$

Moment Arm (from Point O):
$$E_{h1locUN2.OT} := \frac{h_{1UN2}}{3} + h_{2UN2} + Key_{vdist} = 8.10\ m$$

Saturated Soil Load below GWL:
(rectangular component)
$$E_{h2UN2.OT} := (\gamma_m \cdot K_o \cdot h_{1UN2}) \cdot (h_{2UN2} + Key_{vdist}) \cdot B \cdot -1 = 0.0 \cdot kN$$

Moment Arm (from Point O):
$$E_{h2locUN2.OT} := \frac{h_{2UN2} + Key_{vdist}}{2} = 4.05\ m$$

Saturated Soil Load below GWL:
(triangular component)
$$E_{h2aUN2.OT} := \frac{(\gamma_{sat} - \gamma_w) \cdot K_o \cdot (h_{2UN2} + Key_{vdist})^2}{2} \cdot B \cdot -1 = -218.5 \cdot kN$$

Moment Arm (from Point O):
$$E_{h2alocUN2.OT} := \frac{h_{2UN2} + Key_{vdist}}{3} = 2.70\ m$$

Resisting Soil Load (Tailwater Side):

(Determine resisting soil load based on depth variation between the keys (ie. Key_{vdist}). In case where key at heel is deeper than key at toe (ie. $Key_{vdist} < 0$), resisting soil load (p*) is assumed to produce horizontal equilibrium as per Figure 4-5 above. Resisting soil load (p_o) is neglected.)

Total Driving Force: $\Sigma H_{SoildriveUN2.OT} := E_{s1UN2.OT} + E_{h1UN2.OT} + E_{h2UN2.OT} + E_{h2aUN2.OT} + H_{h2UN2} = -718.4\cdot kN$

Total Resisting Force: $\Sigma H_{waterresistUN2.OT} = 499.8\cdot kN$

Assumed Soil Load p*: $E_{h8UN2a.OT} := \left(\Sigma H_{SoildriveUN2.OT} + \Sigma H_{waterresistUN2.OT}\right)\cdot -1 = 218.524\cdot kN$

Moment Arm (from Point O): $E_{h8UN2a.loc.OT} := \dfrac{Key_{vdist}}{2} = -1\ m$

$$E_{h8UN2.OT} := \begin{cases} E_{h8UN2a.OT} & \text{if } Key_{vdist} < 0 \\ \Sigma H_{SoilresistUN2} - H_{h6UN2} - H_{h2aUN2} & \text{otherwise} \end{cases} = 218.524\cdot kN$$

$$\Sigma M_{SoilresistUN2} := \begin{cases} E_{h8UN2a.OT}\cdot E_{h8UN2a.loc.OT} & \text{if } Key_{vdist} < 0 \\ \Sigma M_{HorizSoilResistUN2} - H_{h6UN2}\cdot H_{h6locUN2} - H_{h2aUN2}\cdot H_{h2alocUN2} & \text{otherwise} \end{cases} = -218.524\cdot kN\cdot m$$

Sum of Moment about Point O:

$$\Sigma M_{LateraldriveUN2.OT} := E_{s1UN2.OT}\cdot E_{s1locUN2.OT} + E_{h1UN2.OT}\cdot E_{h1locUN2.OT} + E_{h2UN2.OT}\cdot E_{h2locUN2.OT} \ldots + E_{h2aUN2.OT}\cdot E_{h2alocUN2.OT} + H_{h2UN2}\cdot H_{h2locUN2} = -1273.1\cdot kN\cdot m$$

$$\Sigma M_{LateralresistUN2.OT} := \Sigma M_{waterresistUN2.OT} + \Sigma M_{SoilresistUN2} = 464.6\cdot kN\cdot m$$

Total moment:

$$\Sigma M_{UN2.OT} := \Sigma M_{conc} + \Sigma M_{VertSoilWaterResistUN2} + \Sigma M_{UpliftUN2.OT} + \Sigma M_{LateraldriveUN2.OT} + \Sigma M_{LateralresistUN2.OT} = 3848.0\cdot kN\cdot m$$

Total Vertical Force: $\Sigma V_{UN2.OT} := \Sigma V_{conc} + \Sigma V_{SoilWaterUN2} + \Sigma V_{UplliftUN2.OT} = 819.1\cdot kN$

Distance X_R: EM 1110-2-2502 Eq.4-1 $X_{R.UN2} := \dfrac{\Sigma M_{UN2.OT}}{\Sigma V_{UN2.OT}} = 4.698\ m$

Overturning Resultant Ratio $Ratio_{UN2.OT} := \dfrac{X_{R.UN2}}{b} = 0.49$

$$Ratio_{UN2.OT.check} := \begin{cases} \text{"OKAY "} & \text{if } Ratio_{UN2.OT} > X_{R.reqUN2} \\ \text{"Revise Structure""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

CHECK FOUNDATION ECCENTRICITY (HORIZONTAL PLANE):

Eccentricity (horizontal plan): $ex_{UN2.OT} := \dfrac{b}{2} - \dfrac{\Sigma M_{UN2.OT}}{\Sigma V_{UN2.OT}} = 0.05\ m$ $Kern_{OT} = 1.583\ m$

Eccentricity Check:

$$e_{check.UN2.OT} := \begin{cases} \text{"Okay"} & \text{if } ex_{UN2} \le Kern_{OT} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"Okay"}$$

LOAD CASE UN2

CHECK FOUNDATION BEARING CAPACITY (HORIZONTAL PLANE):

Base Section Modulus: $S_{b.OT} = 15.04\,m^3$

Bearing Pressure Under Toe:

$$\sigma_{ToeUN2.OT} := \begin{cases} \left(\dfrac{\Sigma V_{UN2.OT}}{b \cdot B} + \dfrac{\Sigma V_{UN2.OT} \cdot ex_{UN2.OT}}{S_{b.OT}}\right) & \text{if } \dfrac{\Sigma V_{UN2.OT}}{b \cdot B} \geq \dfrac{\Sigma V_{UN2.OT} \cdot ex_{UN2.OT}}{S_{b.OT}} \\ \dfrac{2 \cdot \Sigma V_{UN2.OT}}{B \cdot 3\left(\dfrac{b}{2} - ex_{UN2.OT}\right)} & \text{otherwise} \end{cases} = 89.1 \cdot kPa$$

$$Bearing_{ChecktoeUN2.OT} := \begin{cases} \text{"OKAY "} & \text{if } \sigma_{ToeUN2.OT} < \sigma_{allowUN2} \\ \text{"NG - for reference only""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

Bearing Pressure Under Heel:

$$\sigma_{HeelUN2.OT} := \begin{cases} \left(\dfrac{\Sigma V_{UN2.OT}}{b \cdot B} - \dfrac{\Sigma V_{UN2.OT} \cdot ex_{UN2.OT}}{S_{b.OT}}\right) & \text{if } \dfrac{\Sigma V_{UN2.OT}}{b \cdot B} \geq \dfrac{\Sigma V_{UN2.OT} \cdot ex_{UN2.OT}}{S_{b.OT}} \\ 0 & \text{otherwise} \end{cases} = 83.4 \cdot kPa$$

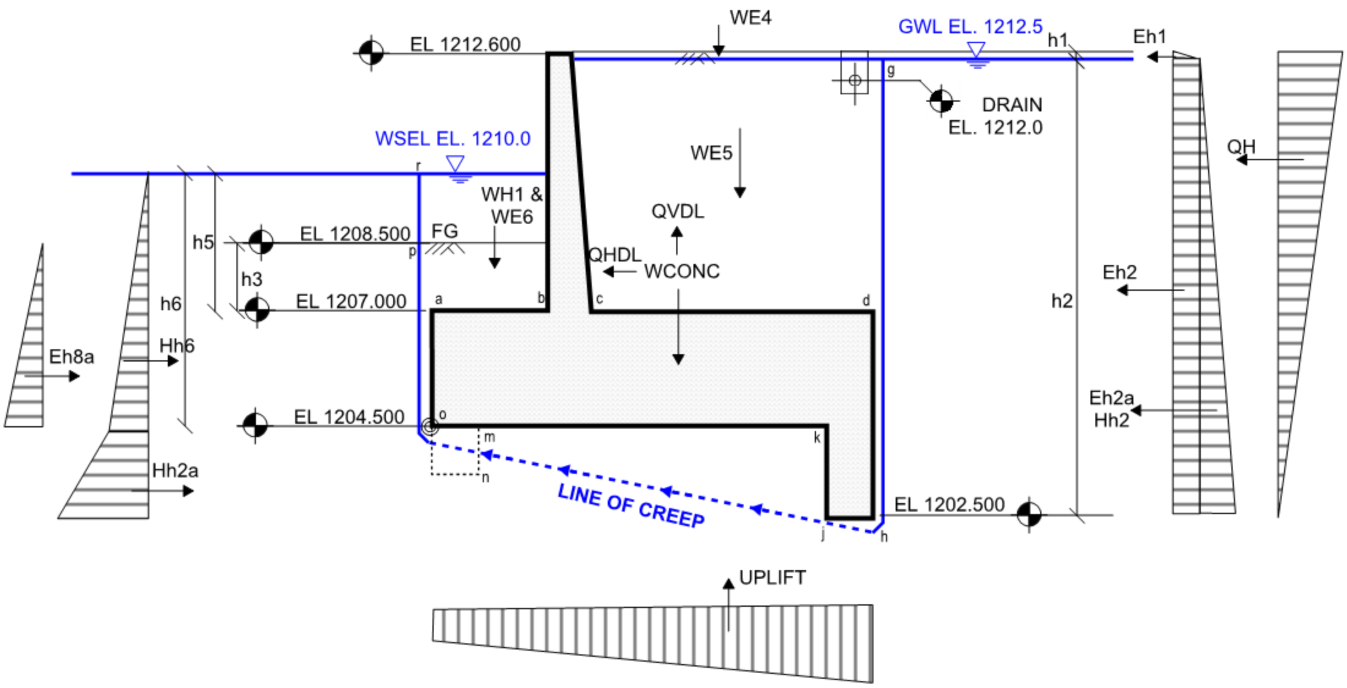
$$Bearing_{CheckheelUN2.OT} := \left(\begin{cases} \text{"OKAY "} & \text{if } \sigma_{ToeUN2.OT} < \sigma_{allowUN2} \wedge \sigma_{ToeUN2.OT} > 0 \\ \text{"NG - for reference only""} & \text{otherwise} \end{cases}\right) = \text{"OKAY "}$$

SUMMARY OF STABILITY ASSESSMENT:

LOAD CASE UN2

Sliding Factor of Safety: (Horizontal Plane - Ref only)	$FS_{Horiz.SlidingUN2} = 0.79$	$FS_{Sliding.check1.UN2}$ = "NG - key req""
Sliding Factor of Safety: (Inclined Plane)	$FS_{InclinedlSlidingUN2} = 2.05$	$FS_{Sliding.check2.UN2}$ = "OKAY "
Eccentricity: (Inclined Plane)	$ex_{UN2} = 0.58\ m$	$e_{check.UN2}$ = "Okay"
Bearing Pressure At Heel: (Inclined Plane)	$\sigma_{HeelUN2} = 69 \cdot kPa$	$Bearing_{CheckheelUN2}$ = "OKAY "
Bearing Pressure At Toe: (Inclined Plane)	$\sigma_{ToeUN2} = 145 \cdot kPa$	$Bearing_{ChecktoeUN2}$ = "OKAY "
Flotation Factor of Safety (horizontal plane)	$FS_{FloatationUN2} = 1.88$	$FS_{Floatation.UN2.check}$ = "OKAY "
Overturning Resultant Ratio: (horizontal plane)	$Ratio_{UN2.OT} = 0.49$	$Ratio_{UN2.OT.check}$ = "OKAY "
Eccentricity: (horizontal plane - Ref only)	$ex_{UN2.OT} = 0.05\ m$	$e_{check.UN2.OT}$ = "Okay"
Bearing Pressure At Heel: (horizontal plane - Ref only)	$\sigma_{HeelUN2.OT} = 83 \cdot kPa$	$Bearing_{CheckheelUN2.OT}$ = "OKAY "
Bearing Pressure At Toe: (horizontal plane - Ref only)	$\sigma_{ToeUN2.OT} = 89 \cdot kPa$	$Bearing_{ChecktoeUN2.OT}$ = "OKAY "

LOAD CASE E1 - SEISMIC LOADING



E1 DESIGN CASE

LOAD CASE E1 ACCEPTANCE PARAMETERS

FS sliding:

Extreme (E) loading) 1.0 (without cohesion, seismic (Table 3-3, USACE EM 1110-2-2100)

Resultant Location:

Extremem (E) Inside middle half ~75% base in compression

Required Factor of Safety for Sliding: $FS_{sliding.reqE1} := 1.0$ (Without Cohesion)

Allowable rock bearing pressure: $\sigma_{allowE1} := 1740kPa$ (Section 5.2, Design Criteria EM 1110-2-2100 Section 3-10)

Overturning Required Resultant Ratio: $X_{R.reqE1} := 0.25$ (EM 1110-2-2502, Figure 4-4)

Required Factor of Safety for Floatation $FS_{req.E1.flt} := 1.1$

SOIL HEIGHTS and Water Levels:

LOAD CASE E1

Heel Conditions:

Groundwater Elevation at Heel: $GWL_{E1} := 1212.5m$

Distance from Finish Grade to Groundwater at Heel: $h_{1E1} := \left[T_w - GWL_{E1} + \left(L_{cd} + t_{wb} - t_{wt}\right)\cdot\tan(\beta)\right] = 0.10\,m$

Distance from Water Surface to Bottom of Footing at Heel: $h_{2E1} := GWL_{E1} - Bot_{ftg} + Key_{h.d} = 10.00\,m$

Toe Conditions:

Water Surface Elevation at Toe: $WSEL_{E1} := 1210.0m$

Water Surface Elevation at Toe for Uplift: $UWSEL_{E1} := 1210.0\cdot m$

Finish Grade at Toe providing lateral resistance: $FG_{toeE1} := 1208.5\cdot m$

Soil Depth Above top of footing: $h_{3aE1} := FG_{toeE1} - Top_{ftg} = 1.5\,m$

$$h_{3E1} := \begin{cases} h_{3aE1} & \text{if } FG_{toeE1} - Top_{ftg} \ge 0 \\ 0 & \text{otherwise} \end{cases} = 1.5$$

Resisting Fill at Toe: $h_{4E1} := FG_{toeE1} - Bot_{ftg} + Key_{t.d} = 4.00\,m$

Distance from Water Level to Top of Footing at Toe: $h_{5E1} := WSEL_{E1} - Top_{ftg} = 3.00\,m$

Distance from Water Surface to Bottom of Footing at Toe: $h_{6E1} := WSEL_{E1} - Bot_{ftg} + Key_{t.d} = 5.50\,m$

Soil Depth Above WSEL: $h_{7aE1} := FG_{toeE1} - WSEL_{E1} = -1.5\,m$

$$h_{7E1} := \begin{cases} h_{7aE1} & \text{if } FG_{toeE1} - WSEL_{E1} \ge 0 \\ 0 & \text{otherwise} \end{cases} = 0$$

Soil Depth Below WSEL:

$$h_{8E1} := \begin{cases} WSEL_{E1} - Bot_{ftg} + Key_{t.d} & \text{if } FG_{toeE1} - WSEL_{E1} \ge 0 \\ h_{4E1} & \text{otherwise} \end{cases} = 4$$

For Line of Creep Method: $L_{ho.E1} := \sqrt{b^2 + \left(Key_{h.d} - Key_{t.d}\right)^2} = 9.708\,m$

Head Loss from Point g:

$\Delta h_{g.hj.E1} := h_{2E1} = 10\,m$ (to point h & j)

$\Delta h_{g.km.E1} := GWL_{E1} - Bot_{ftg} = 8\,m$ (to point k & m)

$\Delta h_{g.no.E1} := GWL_{E1} - Bot_{ftg} + Key_{t.d} = 8\,m$ (to point n & o)

$\Delta h_{g.p.E1} := GWL_{E1} - FG_{toeE1} = 4\,m$ (to point p)

$\Delta h_{g.r.E1} := GWL_{E1} - UWSEL_{E1} = 2.5\,m$ (to point r)

Surcharge

Surcharge on Heel: $S1_{E1} := 0.0\,\frac{kN}{m^2}$

Calculate Soil Lateral Pressure Coefficients:

LOAD CASE E1

Calculate at-rest pressure coefficient K_o based on Jaky's (1944) equation.

Soil At Rest Static Coefficient:
(apply to resisting soil loads)

$$K_o := \frac{1 - \sin(\phi)}{1 + \sin(\beta)} = 0.546$$

(Eq. 3-6, USACE EM 1110-2-2502)

Calculate active pressure coefficient K_A based on Coulumb equations.

Determine Slope of Active Wedge: (cohesionless backfill with water table)

$$c_1 := 2 \cdot \tan(\phi) = 1.019 \qquad c_2 := 1 - \tan(\phi) \cdot \tan(\beta) - \frac{\tan(\beta)}{\tan(\phi)} = 1$$

(Eq. G-14 / G-15, USACE EM 1110-2-2100)

$$\alpha := \operatorname{atan}\left(\frac{c_1 + \sqrt{c_1^2 + 4 \cdot c_2}}{2}\right) = 1.021 \qquad \alpha_{deg} := \alpha \cdot \frac{180}{\pi} = 58.5 \text{ degrees}$$

(Eq. G-13, USACE EM 1110-2-2100)

Soil Active Coefficient above GWL:

$$K_{Aagwt} := \left(\frac{1 - \tan(\phi) \cdot \cot(\alpha)}{1 + \tan(\phi) \cdot \tan(\alpha)}\right) \cdot \left(\frac{\tan(\alpha)}{\tan(\alpha) - \tan(\beta)}\right) = 0.376$$

Soil Active Coefficient below GWL:

$$K_{Abgwt} := \frac{1 - \tan(\phi) \cdot \cot(\alpha)}{1 + \tan(\phi) \cdot \tan(\alpha)} \cdot \left[1 + \left(\frac{\tan(\alpha)}{\tan(\alpha) - \tan(\beta)} - 1\right) \cdot \left(\frac{\gamma_m}{\gamma_{sat} - \gamma_w}\right)\right] = 0.376$$

(Eq. G-29, USACE EM 1110-2-2100)

Lateral - Driving Force

Static Copmonent : Active Pressure:

Surcharge Load:

$$E_{s1E1} := S1_{E1} \cdot K_{Aagwt} \cdot \left(H_w + Key_{h.d}\right) \cdot B \cdot -1 = 0 \cdot kN$$

Moment Arm (from bottom of footing):

$$E_{s1locE1} := \frac{H_w + Key_{h.d}}{2} + Key_{vdist} = 3.05\ m$$

Moist Soil Load above GWL:

$$E_{h1E1} := \frac{\gamma_m \cdot K_{Aagwt} \cdot h_{1E1}^2}{2} \cdot B \cdot -1 = -0.0 \cdot kN$$

Moment Arm (from bottom of footing):

$$E_{h1locE1} := \frac{h_{1E1}}{3} + h_{2E1} + Key_{vdist} = 8.03\ m$$

Saturated Soil Load below GWL:
(rectangular component)

$$E_{h2E1} := \left(\gamma_m \cdot K_{Abgwt} \cdot h_{1E1}\right) \cdot h_{2E1} \cdot B \cdot -1 = -7.5 \cdot kN$$

Moment Arm (from bottom of footing):

$$E_{h2locE1} := \frac{h_{2E1}}{2} + Key_{vdist} = 3.00\ m$$

Saturated Soil Load below GWL:
(triangular component)

$$E_{h2aE1} := \frac{\left(\gamma_{sat} - \gamma_w\right) \cdot K_{Abgwt} \cdot h_{2E1}^2}{2} \cdot B \cdot -1 = -229.1 \cdot kN$$

Moment Arm (from bottom of footing):

$$E_{h2alocE1} := \frac{h_{2E1}}{3} + Key_{vdist} = 1.33\ m$$

Lateral Water Load:

Water Load GWL to Bottom of Key

$$H_{h2E1} := \frac{\gamma_w \cdot h_{2E1}^2}{2} \cdot B \cdot -1 = -490.0 \cdot kN$$

Moment Arm (from bottom of footing):

$$H_{h2locE1} := \frac{h_{2E1}}{3} + Key_{vdist} = 1.33\ m$$

$$\Sigma H_{SoildriveE1} := E_{s1E1} + E_{h1E1} + E_{h2E1} + E_{h2aE1} + H_{h2E1} = -726.6 \cdot kN$$

$$\Sigma M_{LateralSoildriveE1} := E_{s1E1} \cdot E_{s1locE1} + E_{h1E1} \cdot E_{h1locE1} + E_{h2E1} \cdot E_{h2locE1} \cdots + E_{h2aE1} \cdot E_{h2alocE1} + H_{h2E1} \cdot H_{h2locE1} = -981.6\ m \cdot kN$$

Lateral - Resisting Force

LOAD CASE E1

Note: **Due to the relatively shallow depth of resisting soil/rock, a conservative apporach using at-rest coefficient in lieu of a passive wedge is used to calculate resisting forces.**

Lateral Water Load:

Water Load WSEL to Bottom of Footing: $H_{h6E1} := H_{h6U1} = 148.2 \cdot kN$

Moment Arm (from bot. of toe key): $H_{h6locE1} := H_{h6locU1} = 1.83\ m$

Water Load Bot. of Footing to Bot. of H. Key: $H_{h2aE1} := \left[\left(UWSEL_{E1} - Bot_{ftg} + Key_{t.d}\right) + h_{2E1}\right] \cdot \frac{Key_{h.d}}{2} \cdot \gamma_w \cdot B = 151.9 \cdot kN$

Moment Arm (from bot. of toe key):

$$H_{h2alocE1} := \frac{Key_{h.d} \cdot \left[2 \cdot \left(UWSEL_{E1} - Bot_{ftg} + Key_{t.d}\right) + h_{2E1}\right]}{3\left[h_{2E1} + \left(UWSEL_{E1} - Bot_{ftg} + Key_{t.d}\right)\right]} \ldots = -1.10\ m$$
$$+ Key_{vdist}$$

Lateral Soil Load:

Moist Soil Load above WSEL: $E_{h7E1} := \frac{\gamma_m \cdot K_o \cdot h_{7E1}^{\ 2}}{2} \cdot B = 0.0 \cdot kN$

Moment Arm (from bot. of toe key): $E_{h7locE1} := h_{6E1} + \frac{h_{7E1}}{3} + Key_{vdist} = 3.50\ m$

Saturated Soil Load below WSEL: (rectangular component) $E_{h8E1} := \left(\gamma_m \cdot K_o \cdot h_{7E1}\right) \cdot h_{8E1} \cdot B = 0.0 \cdot kN$

Moment Arm (from bot. of toe key): $E_{h8locE1} := \frac{h_{8E1}}{2} = 2.00\ m$

Saturated Soil Load below WSEL: (triangular component) $E_{h8aE1} := \frac{\left[\left(\gamma_{sat} - \gamma_w\right) \cdot K_o\right] \cdot h_{8E1}^{\ 2}}{2} \cdot B = 53.3 \cdot kN$

Moment Arm (from bot. of footing): $E_{h8alocE1} := \frac{h_{8E1}}{3} = 1.33\ m$

$$\Sigma H_{SoilresistE1} := H_{h6E1} + H_{h2aE1} + E_{h7E1} + E_{h8E1} + E_{h8aE1} = 353.4 \cdot kN$$

$$\Sigma M_{HorizSoilResistE1} := H_{h6E1} \cdot H_{h6locE1} + H_{h2aE1} \cdot H_{h2alocE1} + E_{h7E1} \cdot E_{h7locE1} \ldots = 176.2\ m \cdot kN$$
$$+ E_{h8E1} \cdot E_{h8locE1} + E_{h8aE1} \cdot E_{h8alocE1}$$

Vertical Force:

UPLIFT: Linear distribution from water at heel to water at toe:

$$\Sigma V_{UpliftE1} := \left[\left(UWSEL_{E1} - Bot_{ftg} + Key_{t.d}\right) + h_{2E1}\right] \cdot \frac{b}{2} \cdot \gamma_w \cdot B \cdot -1 = -721.525 \cdot kN$$

Moment Arm (from Point O):

$$V_{UpliftE1aloc} := \frac{b \cdot \left[2 \cdot h_{2E1} + \left(UWSEL_{E1} - Bot_{ftg} + Key_{t.d}\right)\right]}{3\left[h_{2E1} + \left(UWSEL_{E1} - Bot_{ftg} + Key_{t.d}\right)\right]} = 5.21\ m$$

$$\Sigma M_{UpliftE1} := \Sigma V_{UpliftE1} \cdot V_{UpliftE1aloc} = -3758.912 \cdot kN \cdot m$$

Weight of soil and water over toe:

Water Above the Top of Footing: $W_{H1E1} := \gamma_w \cdot h_{5E1} \cdot L_{ab} \cdot B = 73.5 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E1locE1} := \frac{L_{ab}}{2} = 1.25\ m$

Soil above top of footing: $W_{E6E1} := \gamma_b \cdot h_{3E1} \cdot L_{ab} \cdot B = 45.8 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E6locE1} := \frac{L_{ab}}{2} = 1.25\ m$

Vertical Load Due to Surcharge: $S_{E1} := S1_{E1} \cdot L_{cd} \cdot B = 0 \cdot kN$ $\quad S_{E1loc} := b - \frac{L_{cd}}{2} = 6.47\ m$

Weight of soil and water over heel:

Moist Soil for sloped grade above top of wall:

Length of sloped portion of soil above top of wall: $L_{E3E1} := \left(L_{cd} + t_{wb} - t_{wt}\right) = 6.50\ m$

Height of sloped soil above top of wall over heel: $h_{E3locE1} := \left(L_{E3E1}\right) \cdot \tan(\beta) = 0.00\ m$

Weight of sloped soil above top of wall: $W_{E3E1} := \frac{\gamma_m}{2} \cdot h_{E3locE1} \cdot L_{E3E1} \cdot B = 0.0 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E3locE1} := L_{ab} + t_{wt} + \frac{2}{3} \cdot L_{E3E1} = 7.33\ m$

Moist soil from top of wall to groundwater level:

Height of soil from top of wall and top of GWL: $h_{1E1} = 0.10\ m$

Length from edge of wall at GWL to edge of heel: $L_{E4E1} := L_{E3E1} - \left(h_{1E1} \cdot S_{batter}\right) = 6.49\ m$

Weight of soil over heel from top of wall to GWL: $W_{E4E1} := \gamma_m \cdot h_{1E1} \cdot \frac{\left(L_{E3E1} + L_{E4E1}\right)}{2} \cdot B = 13.0 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E4locE1} := b - \frac{L_{E3E1}^2 + L_{E3E1} \cdot L_{E4U1} + L_{E4E1}^2}{3\left(L_{E3E1} + L_{E4E1}\right)} = 6.25\ m$

Saturated soil from groundwater to top of footing:

Height of soil from GWL to top of heel: $h_{E4E1} := h_{2E1} - t_{ftg} - Key_{h.d} = 5.50\ m$

Weight of soil over heel from GWL to top of heel: $W_{E5E1} := \left(\gamma_{sat}\right) \cdot h_{E4E1} \cdot \frac{\left(L_{E4E1} + L_{cd}\right)}{2} \cdot B = 759.4 \cdot kN$

Horiz. Moment Arm (from toe): $W_{E5locE1} := b - \frac{L_{E4E1}^2 + L_{E4E1} \cdot L_{cd} + L_{cd}^2}{3\left(L_{E4E1} + L_{cd}\right)} = 6.36\ m$

$$\Sigma V_{SoilWaterE1} := W_{H1E1} + W_{E6E1} + W_{E3E1} + W_{E4E1} + W_{E5E1} + S_{E1} = 891.6 \cdot kN$$

$$\Sigma M_{VertSoilWaterResistE1} := W_{H1E1} \cdot W_{E1locE1} + W_{E6E1} \cdot W_{E6locE1} \cdots + W_{E3E1} \cdot W_{E3locE1} + W_{E4E1} \cdot W_{E4locE1} + W_{E5E1} \cdot W_{E5locE1} + S_{E1} \cdot S_{E1loc} = 5060.7\ m \cdot kN$$

SESIMIC ANALYSIS:

LOAD CASE E1

Seismic coefficient will be applied to dead loads to calculate seismic force and force is applied at center of gravity of the mass. Vertical and Horizontal loads are applied in the "destabilizing direction"

SEISMIC PARAMETERS:

(Section 7.9, Design Criteria)

Peak Ground Acceleration for Seismic Load $PGA_{Horiz} := 0.26$ $PGA_{Vert} := 0.56 \cdot PGA_{Horiz} = 0.146$

In accordance with USACE EM 1110-2-2100 Section 4-7.b, consider 2/3 PGA as seismic coefficient for stabilitiy.

Horizontal Seismic coefficient for stabilty: $K_{hE1} := \frac{2}{3} PGA_{Horiz} = 0.173$

Vertical Seismic coefficient for stabilty: $K_{vE1} := \frac{2}{3} PGA_{Vert} = 0.097$

SEISMIC ACCELERATION OF RIGID MASSES (Q_D):

Vertical Load Application:

$\Sigma V_{conc} = 699.9 \cdot kN$

$Q_{v.conc} := \Sigma V_{conc} \cdot K_{vE1} \cdot -1 = -67.9 \cdot kN$ (assume acting upwards for adverse sliding effect)

Moment arm for siesmic load application (From Toe): $H_{cent} = 4.781\ m$

$M_{Qv.conc} := Q_{v.conc} \cdot H_{cent} = -324.8 \cdot kN \cdot m$

Lateral Load Application:

$Q_{h.conc} := \Sigma V_{conc} \cdot K_{hE1} \cdot -1 = -121.3 \cdot kN$

Moment arm for siesmic load application (Above Base of Footing): $V_{Cent} = 1.609\ m$

$M_{Q.conc} := Q_{h.conc} \cdot V_{Cent} = -195.1 \cdot kN \cdot m$

SEISMIC ACCELERATION OF SOIL WEDGE + WATER (Q_{EH}):

Vertical Load Application:

$\Sigma V_{SoilWaterE1} = 891.6 \cdot kN$

$Q_{v.SoilWaterE1} := \Sigma V_{SoilWaterE1} \cdot K_{vE1} \cdot -1 = -86.5 \cdot kN$ (assume acting upwards for adverse sliding effect)

Moment arm for siesmic load application (From Toe): $e_{QE1} := \frac{\Sigma M_{VertSoilWaterResistE1}}{\Sigma V_{SoilWaterE1}} = 5.676\ m$

$M_{Qv.SoilWaterE1} := Q_{v.SoilWaterE1} \cdot e_{QE1} = -491.2 \cdot kN \cdot m$

Lateral Load Application:

Seismic soil load is calculated based on Mononobe-Okabe method to determine combined static and dynamic coefficient (K_{AE}). Coulomb's active component (K_A) is subtracted from K_{AE} to obtain the seismic coefficient (ΔK_{AE}) for dynamic component of soil force.

Glacial Till Internal Friction (radians): $\phi = 0.471$

Seismic Inertia Angle (radians): $\psi := \operatorname{atan}\left(\frac{K_{hE1}}{1 - K_{vE1}}\right) = 0.190$

Inclination of batter (radians): $\theta := 0.00$ assuming zero is conservative

Slope of retained ground surface: $\beta = 0.00$

$$K_{AE} := \frac{\cos(\phi - \psi - \theta) \cdot \cos(\phi - \psi - \theta)}{\cos(\psi) \cdot \cos(\theta) \cdot \cos(\theta)\ \cos(\psi + \theta) \cdot \left(1 + \sqrt{\frac{\sin(\phi)\ \sin(\phi - \psi - \beta)}{\cos(\beta - \theta) \cdot \cos(\psi + \theta)}}\right)^2} = 0.519$$

$\Delta K_{AE} := K_{AE} - K_{Abgwt} = 0.143$

Dynamic component of active seismic wedge:

$$Q_{h.SoilWaterE1} := \Delta K_{AE} \cdot \left[\frac{\gamma_m \cdot \left(H_w + Key_{h.d}\right)^2}{2 \cdot (\tan(\alpha) - \tan(\beta))} + \frac{\left(\gamma_{sat} - \gamma_m\right) \cdot h_{2E1}{}^2}{2 \cdot \tan(\alpha)}\right] \cdot B \cdot -1 = -98.1 \cdot kN$$

(Eq. G-64, USACE EM 1110-2-2100)

Moment arm for siesmic load application (About Point O): $Q_{h.SoilWaterlocE1} := \frac{2}{3} \cdot \left(H_w + Key_{h.d}\right) + Key_{vdist} = 4.73\ m$

$M_{Q.h.SoilWaterE1} := Q_{h.SoilWaterE1} \cdot Q_{h.SoilWaterlocE1} = -464.6 \cdot kN \cdot m$

STABILITY ASSESSMENT:

LOAD CASE E1

CHECK SLIDING ALONG HORIZONTAL SLIDING PLANE:

Summation of the vertical forces: $\Sigma V_{E1} := \Sigma V_{conc} + \Sigma V_{SoilWaterE1} + \Sigma V_{UpliftE1} + Q_{v.conc} + Q_{v.SoilWaterE1} = 715.5 \cdot kN$

Summation of the horizontal forces: $\Sigma H_{E1} := \Sigma H_{SoildriveE1} + Q_{h.conc} + Q_{h.SoilWaterE1} + \Sigma H_{SoilresistE1} = -592.7 \cdot kN$

Safety Factor for Sliding Horizontal Failure Plane

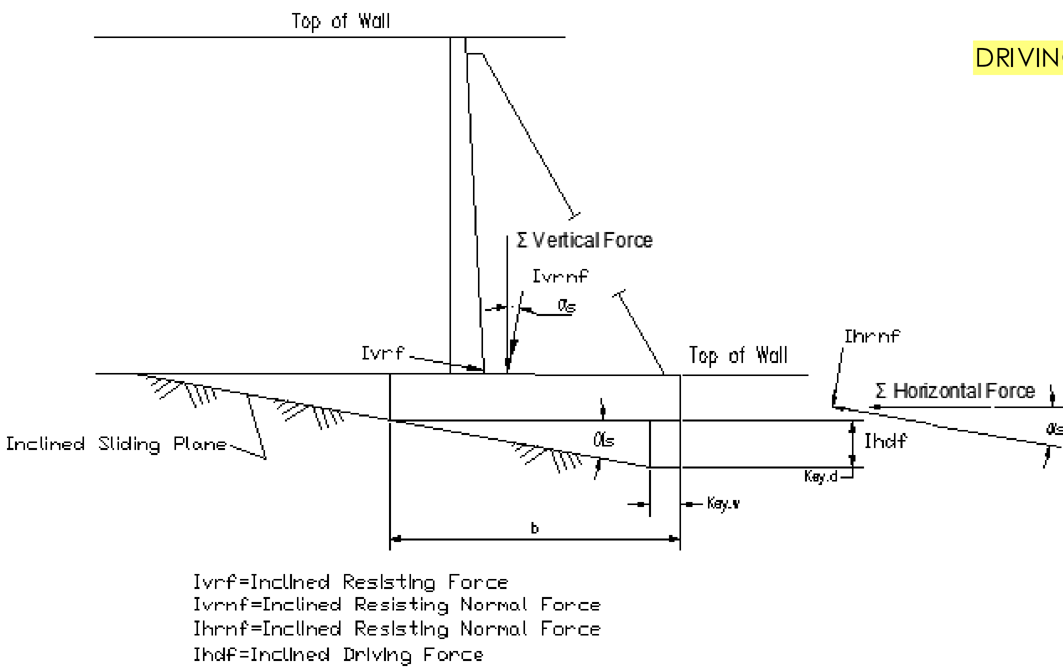
$$FS_{Horiz.SlidingE1} := \frac{\left|\Sigma V_{E1}\right| \cdot \tan\left(\phi_{rock} \cdot \frac{\pi}{180}\right)}{\left|\Sigma H_{E1}\right|} = 0.59$$

$$FS_{Sliding.check1.E1} := \begin{vmatrix} \text{"OKAY "} & \text{if } FS_{Horiz.SlidingE1} > FS_{sliding.reqE1} \\ \text{"NG - key req""} & \text{otherwise} \end{vmatrix} = \text{"NG - key req""}$$

CHECK FACTOR OF SAFETY SLIDING WITH KEY (INCLINED SLIDING PLANE):

RESISTING SIDE

DRIVING SIDE



TOE

HEEL

(With properly engineered reinforced concrete Key, horizontal sliding plane thru Toe is protected, critical sliding plane is relocated to the INCLINED SLIDING PLANE FROM HEEL KEY To TOE, Bedrock Mass above this examing plane is mobilized by reinforced concrete key and combined into Structural Wedge.)

Resolve ΣV_{E1} & ΣH_{E1}

$$\Sigma V_{InclinedE1} := \cos(\alpha s) \cdot \left(\left|\Sigma V_{E1} + V_{rocksection}\right|\right) + \sin(\alpha s) \cdot \left|\Sigma H_{E1}\right| = 1044.1 \cdot kN$$

$$\Sigma H_{InclinedE1} := \cos(\alpha s) \cdot \left|\Sigma H_{E1}\right| - \sin(\alpha s) \cdot \left(\left|\Sigma V_{E1} + V_{rocksection}\right|\right) = 363.2 \cdot kN$$

Safety Factor for Sliding Inclined Failure Plane

$$FS_{InclinedISlidingE1} := \frac{\Sigma V_{InclinedE1} \cdot \tan(\phi_r)}{\Sigma H_{InclinedE1}} = 1.28$$

$$FS_{Sliding.check2.E1} := \begin{vmatrix} \text{"OKAY "} & \text{if } FS_{InclinedISlidingE1} > FS_{sliding.reqE1} \\ \text{"NG""} & \text{otherwise} \end{vmatrix} = \text{"OKAY "}$$

CHECK FOUNDATION ECCENTRICITY:

LOAD CASE E1

(Vertical seismic loads from concrete, soil and water are assumed acting downwards for adverse bearing effect)

Summation of the vertical forces: $\Sigma V_{seisE1} := \Sigma V_{conc} + \Sigma V_{SoilWaterE1} + \Sigma V_{UpliftE1} - Q_{v.conc} - Q_{v.SoilWaterE1} = 1024.5 \cdot kN$

Summation of the horizontal forces: $\Sigma H_{seisE1} := \Sigma H_{E1} = -592.7 \cdot kN$

Resolve ΣV_{seisE1} & ΣH_{seisE1}

$$\Sigma V_{InclinedseisE1} := \cos(\alpha s) \cdot \left(\left| \Sigma V_{seisE1} + V_{rocksection} \right| \right) + \sin(\alpha s) \cdot \left| \Sigma H_{seisE1} \right| = 1344.8 \cdot kN$$

$$\Sigma H_{InclinedseisE1} := \cos(\alpha s) \cdot \left| \Sigma H_{seisE1} \right| - \sin(\alpha s) \cdot \left(\left| \Sigma V_{seisE1} + V_{rocksection} \right| \right) = 292.4 \cdot kN$$

Summation of the resisting moments about the toe:

$$\Sigma M_{resE1} := \Sigma M_{conc} + \Sigma M_{VertSoilWaterResistE1} + \Sigma M_{HorizSoilResistE1} + \Sigma M_{rocksection} = 9816 \cdot kN \cdot m$$

Summation of seismic moments about the toe:

$$\Sigma M_{seisE1} := -M_{Qv.conc} + M_{Q.conc} - M_{Qv.SoilWaterE1} + M_{Q.h.SoilWaterE1} = 156 \cdot kN \cdot m$$

Summation of the overturning moments about the toe:

$$\Sigma M_{oE1} := \Sigma M_{LateralSoildriveE1} + \Sigma M_{UpliftE1} = -4741 \cdot kN \cdot m$$

Total moment: $\Sigma M_{E1} := \Sigma M_{resE1} + \Sigma M_{seisE1} + \Sigma M_{oE1} = 5231.9 \cdot kN \cdot m$

Normal force to base: $\Sigma V_{InclinedseisE1} = 1344.8 \cdot kN$

Inclined Sliding Plane Length: $L_{incline} = 9.8 \cdot m$

Eccentricity (inclined plane): $ex_{E1} := \dfrac{L_{incline}}{2} - \dfrac{\Sigma M_{E1}}{\Sigma V_{InclinedseisE1}} = 0.99\ m$ $\qquad Kern_{E1} := \dfrac{L_{incline}}{4} = 2.44\ m$

Eccentricity Check: $e_{check.E1} := \begin{cases} \text{"Okay"} & \text{if } ex_{E1} \le Kern_{E1} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"Okay"}$

CHECK FOUNDATION BEARING CAPACITY:

Base Section Modulus: $S_b = 15.87\ m^3$

Bearing Pressure Under Toe:

$$\sigma_{ToeE1} := \begin{cases} \left(\dfrac{\Sigma V_{InclinedE1}}{L_{incline} \cdot B} + \dfrac{\Sigma V_{InclinedE1} \cdot ex_{E1}}{S_b} \right) & \text{if } \dfrac{\Sigma V_{InclinedE1} \cdot ex_{E1}}{S_b} \le \dfrac{\Sigma V_{InclinedE1}}{L_{incline} \cdot B} \\ \dfrac{2 \cdot \Sigma V_{InclinedE1}}{B \cdot 3 \left(\dfrac{b}{2} - ex_{E1} \right)} & \text{otherwise} \end{cases} = 172.0 \cdot kPa$$

$$Bearing_{ChecktoeE1} := \begin{cases} \text{"OKAY "} & \text{if } \sigma_{ToeE1} < \sigma_{allowE1} \\ \text{"NG""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

Bearing Pressure Under Heel:

$$\sigma_{HeelE1} := \begin{cases} \left(\dfrac{\Sigma V_{InclinedE1}}{L_{incline} \cdot B} - \dfrac{\Sigma V_{InclinedE1} \cdot ex_{E1}}{S_b} \right) & \text{if } \dfrac{\Sigma V_{InclinedE1} \cdot ex_{E1}}{S_b} \le \dfrac{\Sigma V_{InclinedE1}}{L_{incline} \cdot B} \\ 0 & \text{otherwise} \end{cases} = 41.9 \cdot kPa$$

$$Bearing_{CheckheelE1} := \left(\begin{cases} \text{"OKAY "} & \text{if } \sigma_{HeelE1} < \sigma_{allowE1} \wedge \sigma_{HeelE1} > 0 \\ \text{"NG - perform cracked base analysis""} & \text{otherwise} \end{cases} \right) = \text{"OKAY "}$$

CHECK FLOATATION:

Safety Factor for Floatation:

$$FS_{FloatationE1} := \frac{\Sigma V_{conc} + \Sigma V_{SoilWaterE1} + Q_{v.conc} + Q_{v.SoilWaterE1}}{\left|\Sigma V_{UpliftE1}\right|} = 1.99$$

$$FS_{Floatation.E1.check} := \begin{vmatrix} \text{"OKAY"} & \text{if } FS_{FloatationE1} > FS_{req.E1.flt} \\ \text{"Revise Structure"} & \text{otherwise} \end{vmatrix} = \text{"OKAY"}$$

CHECK OVERTURNING

Analysis of Overturning Stability is based on EM 1110-2-2502 Chapter 4 Section III. See figure below.
Assumptions are made in order to compute overturning stablity of indetermine forces on monolith with key;
(a) Shearing resistance of the monolith base is assumed to be zero, T = 0.
(b) The horizontal resisting force acting on the key, P.key, is that required for static equilibrium
(c) Effective soil pressure below Pont O (Toe) is conservatively assumed to be zero for non-reliable resistance.

Overturning Criteria per EM 1110-2-2502 Table 4-1

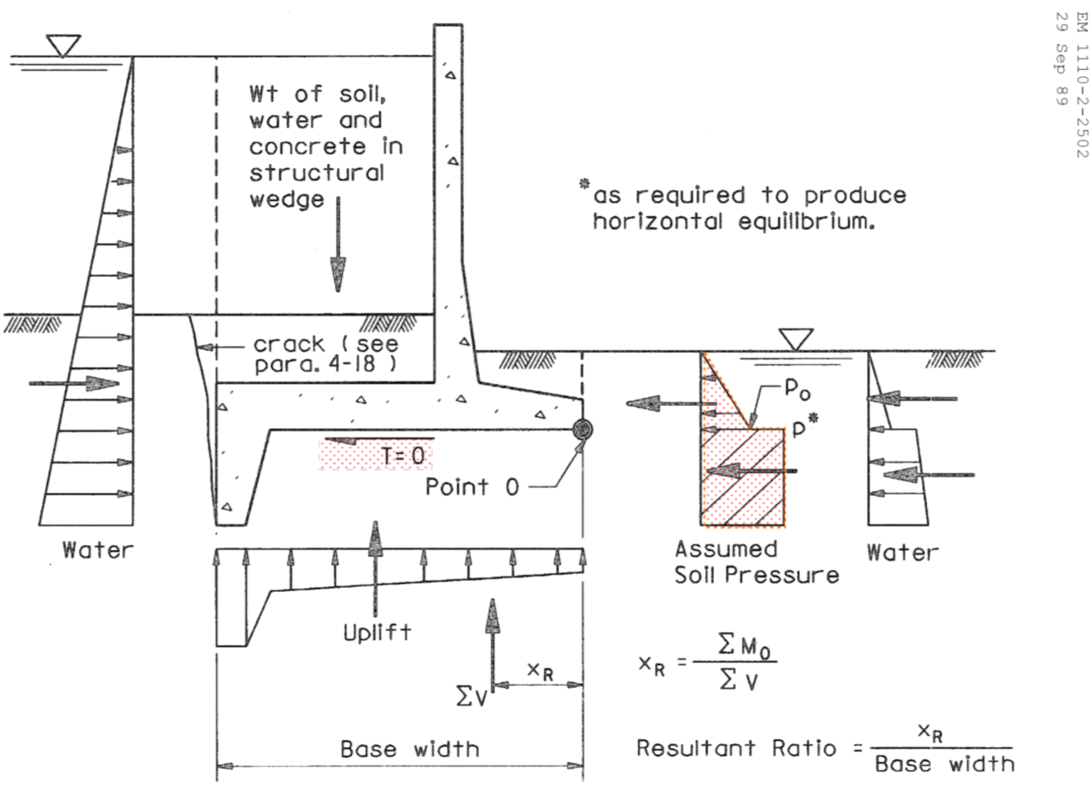


Figure 4-5. Forces for overturning analysis for wall with horizontal base and key

Modify Uplift for Overturning Analysis: **LOAD CASE E1**

(Uplift is calculated along the concrete/rock contact using the Line of Creep method)

Water Pressure at h: $u_{h.E1} := \Delta h_{g.hj.E1} \cdot \gamma_w = 98.00 \cdot kPa$

Water Pressure at o: $u_{o.E1} := \left(\Delta h_{g.no.E1} - \frac{\Delta h_{g.r.E1} \cdot L_{ho.E1}}{L_{ho.E1}} \right) \cdot \gamma_w = 53.9 \cdot kPa$

Head loss between point h and o: $\Delta h_{ho.E1} := \Delta h_{g.r.E1} \cdot \frac{L_{ho.E1}}{L_{ho.E1}} = 2.5\,m$

Length of concrete base (h -> o): $L_{baseho.E1} := Key_{h.w} + Key_{h.d} + Key_{hdist} + Key_{t.d} + Key_{t.w} = 11.5\,m$

Head loss along h -> j: $\Delta h_{hj.E1} := \Delta h_{ho.E1} \cdot \frac{Key_{h.w}}{L_{baseho.E1}} = 0.217\,m$

Water Pressure at j: $u_{j.E1} := \left(\Delta h_{g.hj.E1} - \Delta h_{hj.E1} \right) \cdot \gamma_w = 95.87 \cdot kPa$

Head loss along h -> k: $\Delta h_{hjk.E1} := \Delta h_{ho.E1} \cdot \left(\frac{Key_{h.w} + Key_{h.d}}{L_{baseho.E1}} \right) = 0.652\,m$

Water Pressure at k: $u_{k.E1} := \left(\Delta h_{g.km.E1} - \Delta h_{hjk.E1} \right) \cdot \gamma_w = 72.01 \cdot kPa$

Head loss along h -> m: $\Delta h_{hjkm.E1} := \Delta h_{ho.E1} \cdot \left(\frac{Key_{h.w} + Key_{h.d} + Key_{hdist}}{L_{baseho.E1}} \right) = 2.5\,m$

Water Pressure at m: $u_{m.E1} := \left(\Delta h_{g.km.E1} - \Delta h_{hjkm.E1} \right) \cdot \gamma_w = 53.90 \cdot kPa$

Head loss along h -> n: $\Delta h_{hjkmn.E1} := \Delta h_{ho.E1} \cdot \left(\frac{Key_{h.w} + Key_{h.d} + Key_{hdist} + Key_{t.d}}{L_{baseho.E1}} \right) = 2.5\,m$

Water Pressure at n: $u_{n.E1} := \left(\Delta h_{g.no.E1} - \Delta h_{hjkmn.E1} \right) \cdot \gamma_w = 53.90 \cdot kPa$

Uplift under key at heel: $V_{ulkeyhE1.OT} := \frac{\left(u_{h.E1} + u_{j.E1} \right) \cdot Key_{h.w}}{2} \cdot B \cdot -1 = -96.935 \cdot kN$

Moment Arm (from Point O): $V_{ulkeyhE1loc.OT} := b - \frac{Key_{h.w} \cdot \left(2 \cdot u_{j.E1} + u_{h.E1} \right)}{3 \cdot \left(u_{j.E1} + u_{h.E1} \right)} = 9.002\,m$

Uplift under base: $V_{ulbaseE1.OT} := \frac{\left(u_{k.E1} + u_{m.E1} \right) \cdot Key_{hdist}}{2} \cdot B \cdot -1 = -535.112 \cdot kN$

Moment Arm (from Point O): $V_{ulbaseE1loc.OT} := b - Key_{h.w} - \frac{Key_{hdist} \cdot \left(2 \cdot u_{m.E1} + u_{k.E1} \right)}{3 \cdot \left(u_{m.E1} + u_{k.E1} \right)} = 4.454\,m$

Uplift under key at toe: $V_{ulkeytE1.OT} := \frac{\left(u_{n.E1} + u_{o.E1} \right) \cdot Key_{t.w}}{2} \cdot B \cdot -1 = 0 \cdot kN$

Moment Arm (from Point O): $V_{ulkeytE1loc.OT} := \frac{Key_{t.w} \cdot \left(2 \cdot u_{n.E1} + u_{o.E1} \right)}{3 \cdot \left(u_{n.E1} + u_{o.E1} \right)} = 0$

$$\Sigma V_{UpliftE1.OT} := V_{ulkeyhE1.OT} + V_{ulbaseE1.OT} + V_{ulkeytE1.OT} = -632 \cdot kN$$

$$U_{E1.loc.OT} := \frac{V_{ulkeyhE1.OT} \cdot V_{ulkeyhE1loc.OT} + V_{ulbaseE1.OT} \cdot V_{ulbaseE1loc.OT} + V_{ulkeytE1.OT} \cdot V_{ulkeytE1loc.OT}}{\Sigma V_{UpliftE1.OT}} = 5.15\,m$$

$$\Sigma M_{UpliftE1.OT} := \Sigma V_{UpliftE1.OT} \cdot U_{E1.loc.OT} = -3255.8 \cdot kN \cdot m$$

LOAD CASE E1

Modify Lateral Water Pressure (Resisting) for Overturning Analysis:

(Resisting water pressure is calculated using the Line of Creep method)

Water Load at Key (heel):

$$H_{h2E1.OT} := \frac{u_{k.E1} + u_{j.E1}}{2} \cdot Key_{h.d} B = 167.9 \cdot kN$$

Moment Arm (from Point O):

$$H_{h2locE1.OT} := \frac{Key_{h.d} \cdot (2 \cdot u_{k.E1} + u_{j.E1})}{3(u_{k.E1} + u_{j.E1})} + Key_{vdist} = -1.05\ m$$

Water Load at Key (toe):

$$H_{h6E1.OT} := \frac{u_{o.E1} \cdot (UWSEL_{E1} - Bot_{ftg} + Key_{t.d})}{2} \cdot B = 148 \cdot kN$$

Moment Arm (from Point O):

$$H_{h6locE1.OT} := \frac{UWSEL_{E1} - Bot_{ftg} + Key_{t.d}}{3} = 1.83\ m$$

$$\Sigma H_{waterresistE1.OT} := H_{h2E1.OT} + H_{h6E1.OT} = 316.1 \cdot kN$$

$$H_{waterresistlocE1.OT} := \frac{H_{h2E1.OT} \cdot H_{h2locE1.OT} + H_{h6E1.OT} \cdot H_{h6locE1.OT}}{\Sigma H_{waterresistE1.OT}} = 0.303\ m$$

$$\Sigma M_{waterresistE1.OT} := \Sigma H_{waterresistE1.OT} \cdot H_{waterresistlocE1.OT} = 95.91 \cdot kN \cdot m$$

Modify Lateral Soil Loads for Overturning Analysis:

(Lateral soil loads are calculated down to Point O instead of bottom of shear key)

Driving Soil Load (Headwater Side):

Surcharge Load:

$$E_{s1E1.OT} := S1_{E1} \cdot K_{Aagwt} \cdot (H_w + Key_{h.d} + Key_{vdist}) \cdot B \cdot -1 = 0 \cdot kN$$

Moment Arm (from Point O):

$$E_{s1locE1.OT} := \frac{H_w + Key_{h.d} + Key_{vdist}}{2} = 4.05\ m$$

Moist Soil Load above GWL:

$$E_{h1E1.OT} := \frac{\gamma_m \cdot K_{Aagwt} \cdot h_{1E1}^{\ 2}}{2} \cdot B \cdot -1 = -0.0 \cdot kN$$

Moment Arm (from Point O):

$$E_{h1locE1.OT} := \frac{h_{1E1}}{3} + h_{2E1} + Key_{vdist} = 8.03\ m$$

Saturated Soil Load below GWL:
(rectangular component)

$$E_{h2E1.OT} := (\gamma_m \cdot K_{Aagwt} \cdot h_{1E1}) \cdot (h_{2E1} + Key_{vdist}) \cdot B \cdot -1 = -6.0 \cdot kN$$

Moment Arm (from Point O):

$$E_{h2locE1.OT} := \frac{h_{2E1} + Key_{vdist}}{2} = 4.00\ m$$

Saturated Soil Load below GWL:
(triangular component)

$$E_{h2aE1.OT} := \frac{(\gamma_{sat} - \gamma_w) \cdot K_{Aagwt} \cdot (h_{2E1} + Key_{vdist})^2}{2} \cdot B \cdot -1 = -146.6 \cdot kN$$

Moment Arm (from Point O):

$$E_{h2alocE1.OT} := \frac{h_{2E1} + Key_{vdist}}{3} = 2.67\ m$$

Resisting Soil Load (Tailwater Side):

LOAD CASE E1

(Determine resisting soil load based on depth variation between the keys (ie. Key_{vdist}). In case where key at heel is deeper than key at toe (ie. Key_{vdist}< 0), resisting soil load (p*) is assumed to produce horizontal equilibrium as per Figure 4-5 above. Resisting soil load (p_o) is neglected.)

Total Driving Force:
$$\Sigma H_{SoildriveE1.OT} := E_{s1E1.OT} + E_{h1E1.OT} + E_{h2E1.OT} + E_{h2aE1.OT} + H_{h2E1} \cdots + Q_{h.conc} + Q_{h.SoilWaterE1} = -862.1 \cdot kN$$

Total Resisting Force:
$$\Sigma H_{waterresistE1.OT} = 316.103 \cdot kN$$

Assumed Soil Load p*:
$$E_{h8E1a.OT} := \left(\Sigma H_{SoildriveE1.OT} + \Sigma H_{waterresistE1.OT}\right) \cdot -1 = 546.005 \cdot kN$$

Moment Arm (from Point O):
$$E_{h8E1a.loc.OT} := \frac{Key_{vdist}}{2} = -1\ m$$

$$E_{h8E1.OT} := \begin{cases} E_{h8E1a.OT} & \text{if } Key_{vdist} < 0 \\ \Sigma H_{SoilresistE1} - H_{h6E1} - H_{h2aE1} & \text{otherwise} \end{cases} = 546.005 \cdot kN$$

$$\Sigma M_{SoilresistE1} := \begin{cases} E_{h8E1a.OT} \cdot E_{h8E1a.loc.OT} & \text{if } Key_{vdist} < 0 \\ \Sigma M_{HorizSoilResistE1} - H_{h6E1} \cdot H_{h6locE1} - H_{h2aE1} \cdot H_{h2alocE1} & \text{otherwise} \end{cases} = -546.005 \cdot kN \cdot m$$

Sum of Moment about Point O:

$$\Sigma M_{LateraldriveE1.OT} := E_{s1E1.OT} \cdot E_{s1locE1.OT} + E_{h1E1.OT} \cdot E_{h1locE1.OT} + E_{h2E1.OT} \cdot E_{h2locE1.OT} \cdots + E_{h2aE1.OT} \cdot E_{h2alocE1.OT} + H_{h2E1} \cdot H_{h2locE1} = -1068.6 \cdot kN \cdot m$$

$$\Sigma M_{LateralresistE1.OT} := \Sigma M_{waterresistE1.OT} + \Sigma M_{SoilresistE1} = -450.1 \cdot kN \cdot m$$

$$\Sigma M_{seisE1.OT} := M_{Qv.conc} + M_{Q.conc} + M_{Qv.SoilWaterE1} + M_{Q.h.SoilWaterE1} = -1476 \cdot kN \cdot m$$

(seismic moment modified for the most adverse overturning effect)

Total moment:

$$\Sigma M_{E1.OT} := \Sigma M_{conc} + \Sigma M_{VertSoilWaterResistE1} + \Sigma M_{UpliftE1.OT} + \Sigma M_{LateraldriveE1.OT} + \Sigma M_{LateralresistE1.OT} + \Sigma M_{seisE1.OT} = 2156.5 \cdot kN \cdot m$$

Total Vertical Force:
$$\Sigma V_{E1.OT} := \Sigma V_{conc} + \Sigma V_{SoilWaterE1} + \Sigma V_{UpliftE1.OT} + Q_{v.conc} + Q_{v.SoilWaterE1} = 805.0 \cdot kN$$

Distance X_R: EM 1110-2-2502 Eq.4-1
$$X_{R.E1} := \frac{\Sigma M_{E1.OT}}{\Sigma V_{E1.OT}} = 2.679\ m$$

Overturning Resultant Ratio
$$Ratio_{E1.OT} := \frac{X_{R.E1}}{b} = 0.28$$

$$Ratio_{E1.OT.check} := \begin{cases} \text{"OKAY "} & \text{if } Ratio_{E1.OT} > X_{R.reqE1} \\ \text{"Revise Structure""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

CHECK FOUNDATION ECCENTRICITY (HORIZONTAL PLANE):

Eccentricity (horizontal plan):
$$ex_{E1.OT} := \frac{b}{2} - \frac{\Sigma M_{E1.OT}}{\Sigma V_{E1.OT}} = 2.07\ m \qquad Kern_{E1.OT} := \frac{b}{4} = 2.375\ m$$

Eccentricity Check:
$$e_{check.E1.OT} := \begin{cases} \text{"Okay"} & \text{if } ex_{E1.OT} \le Kern_{E1.OT} \\ \text{"Revise Structure"} & \text{otherwise} \end{cases} = \text{"Okay"}$$

LOAD CASE E1

CHECK FOUNDATION BEARING CAPACITY (HORIZONTAL PLANE):

Base Section Modulus: $S_{b.OT} = 15.04\,m^3$

Bearing Pressure Under Toe:

$$\sigma_{ToeE1.OT} := \begin{cases} \left(\dfrac{\Sigma V_{E1.OT}}{b \cdot B} + \dfrac{\Sigma V_{E1.OT} \cdot ex_{E1.OT}}{S_{b.OT}}\right) & \text{if } \dfrac{\Sigma V_{E1.OT}}{b \cdot B} \geq \dfrac{\Sigma V_{E1.OT} \cdot ex_{E1.OT}}{S_{b.OT}} \\ \dfrac{2 \cdot \Sigma V_{E1.OT}}{B \cdot 3\left(\dfrac{b}{2} - ex_{E1.OT}\right)} & \text{otherwise} \end{cases} = 200.3 \cdot kPa$$

$$Bearing_{ChecktoeE1.OT} := \begin{cases} \text{"OKAY "} & \text{if } \sigma_{ToeE1.OT} < \sigma_{allowE1} \\ \text{"NG - for reference only""} & \text{otherwise} \end{cases} = \text{"OKAY "}$$

Bearing Pressure Under Heel:

$$\sigma_{HeelE1.OT} := \begin{cases} \left(\dfrac{\Sigma V_{E1.OT}}{b \cdot B} - \dfrac{\Sigma V_{E1.OT} \cdot ex_{E1.OT}}{S_{b.OT}}\right) & \text{if } \dfrac{\Sigma V_{E1.OT}}{b \cdot B} \geq \dfrac{\Sigma V_{E1.OT} \cdot ex_{E1.OT}}{S_{b.OT}} \\ 0 & \text{otherwise} \end{cases} = 0.0 \cdot kPa$$

$$Bearing_{CheckheelE1.OT} := \left(\begin{cases} \text{"OKAY "} & \text{if } \sigma_{HeelE1.OT} < \sigma_{allowE1} \wedge \sigma_{HeelE1.OT} > 0 \\ \text{"NG - for reference only""} & \text{otherwise} \end{cases} \right) = \text{"NG - for reference only""}$$

SUMMARY OF STABILITY ASSESSMENT:

LOAD CASE E1

Sliding Factor of Safety: (Horizontal Plane - Ref only)	$FS_{Horiz.SlidingE1} = 0.59$	$FS_{Sliding.check1.E1}$ = "NG - key req""
Sliding Factor of Safety: (Inclined Plane)	$FS_{InclinedlSlidingE1} = 1.28$	$FS_{Sliding.check2.E1}$ = "OKAY "
Eccentricity: (Inclined Plane)	$ex_{E1} = 0.99\ m$	$e_{check.E1}$ = "Okay"
Bearing Pressure At Heel: (Inclined Plane)	$\sigma_{HeelE1} = 42 \cdot kPa$	$Bearing_{CheckheelE1}$ = "OKAY "
Bearing Pressure At Toe: (Inclined Plane)	$\sigma_{ToeE1} = 172 \cdot kPa$	$Bearing_{ChecktoeE1}$ = "OKAY "
Flotation Factor of Safety (horizontal plane)	$FS_{FloatationE1} = 1.99$	$FS_{Floatation.E1.check}$ = "OKAY "
Overturning Resultant Ratio: (horizontal plane)	$Ratio_{E1.OT} = 0.28$	$Ratio_{E1.OT.check}$ = "OKAY "
Eccentricity: (horizontal plane - Ref only)	$ex_{E1.OT} = 2.07\ m$	$e_{check.E1.OT}$ = "Okay"
Bearing Pressure At Heel: (horizontal plane - Ref only)	$\sigma_{HeelE1.OT} = 0 \cdot kPa$	$Bearing_{CheckheelE1.OT}$ = "NG - for reference only""
Bearing Pressure At Toe: (horizontal plane - Ref only)	$\sigma_{ToeE1.OT} = 200 \cdot kPa$	$Bearing_{ChecktoeE1.OT}$ = "OKAY "

Appendix E.2-5 PROJECT DRAWINGS

Refer to Preliminary Design Report - Appendix A for drawings.

Springbank Off-Stream Storage Project
Structural Design Report

Auxiliary Spillway

Prepared for:

Alberta Transportation
3rd Floor – Twin Atria Building
4999 – 98 Avenue
Edmonton, AB T6B 2X3

Prepared by:

Stantec Consulting Ltd
Calgary, AB

Project Number 110773396

September 25, 2020

Stantec

Table of Contents

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

1.0 INTRODUCTION

1.1 PURPOSE

This Structural Design Report (SDR) describes stability assessment, structural analyses and design of the Auxiliary Spillway, which is part of the Springbank Off-stream Storage Project (SR1) The SDR consolidates and documents the design philosophy, relevant criteria, primary design parameters, and reference source of data used for design. The Auxiliary Spillway was sized to meet stability requirements and major structural members were designed for conformance with structural criteria.

1.2 PROJECT OVERVIEW

SR1 is a flood diversion system comprised of a diversion structure, a diversion channel and off-stream dry storage reservoir (no permanent pool). When in operation, SR1 will divert and temporarily store excess flood water from the Elbow River and release it back into the river system in a controlled manner. SR1 will work in tandem with the downstream Glenmore Reservoir to limit flood flows downstream of Glenmore to less than 170 m^3/s, up to SR1's design event of the 2013 flood or its equivalent.

Elements of the project are:

- Diversion Structure on the Elbow River consisting of, from left to right when looking downstream, gated Diversion Inlet structure leading to a Diversion Channel, gated Service Spillway located on the Elbow River, adjacent Auxiliary Spillway and a Floodplain Berm. A Debris Deflection Barrier is in the headwater of the Diversion Structure to protect the Diversion Inlet from flood debris.

- Diversion Channel leading from the Elbow River at the Diversion Inlet to the Off-stream Storage Reservoir with an Emergency Spillway along the channel and Channel Outlet at end of the channel.

- Off-stream Storage Dam with Low Level Outlet Works.

1.3 DESIGN OBJECTIVES

The Service Spillway and Auxiliary Spillway function as the water level control structures for the Floodplain Berm. Per CDA Guidelines, the Inflow Design Flood (IDF) for a High Hazard structure, such as the Diversion Structure, is 1/3 between the 1:1000-year flood and the PMF. The PMF is the IDF for Extreme Hazard dams such as the Diversion Channel and Off-stream Storage Dam. Consequently, the Auxiliary Spillway and Service Spillway were designed to provide the capacity needed 1) to pass the IDF for the Diversion Structure (2210 m^3/s) with sufficient freeboard to the crest of the Floodplain Berm and 2) to pass the IDF for the Off-stream Storage Dam (2770 m^3/s) with sufficient freeboard to the top of the Diversion Inlet walls. Table 1 provides a summary of the inflow flood peak values.

Table 1. Inflow Flood Peak Values

Flood Event	Elbow River Discharge (m^3/s)
Design Flood Event (2013 Storm)	1240
1:1000 Year Event	1930
Diversion Structure IDF	2210
DC and OSSD IDF = PMF	2770

1.4 GENERAL ARRANGEMENT

The Auxiliary Spillway is located along the right bank of the Elbow River between the Service Spillway and Floodplain Berm. The Auxiliary Spillway consists of:

- Mass concrete "hardfill" overflow weir, 208 m long, approximately 8.8 m high, and with a crest set at Elevation 1215.8 m, which is the maximum headpond elevation for the 2013 Design Flood;
- Reinforced concrete transition wall separating the overflow weir and Floodplain Berm;
- An earthen fuse plug placed on top of the overflow weir with an overflow elevation of 1216.5 m., and;
- Upstream and downstream embankments overlaying the overflow weir to blend in with the Floodplain Berm and natural surroundings.

The typical section of the Auxiliary Spillway is presented in Figure 1. The general arrangement of the Auxiliary Spillway is depicted on Drawing C-213 with section presented on Drawing C-271. Structural arrangement and details of the overflow weir and transition wall are shown on Drawings S-260 to S-279.

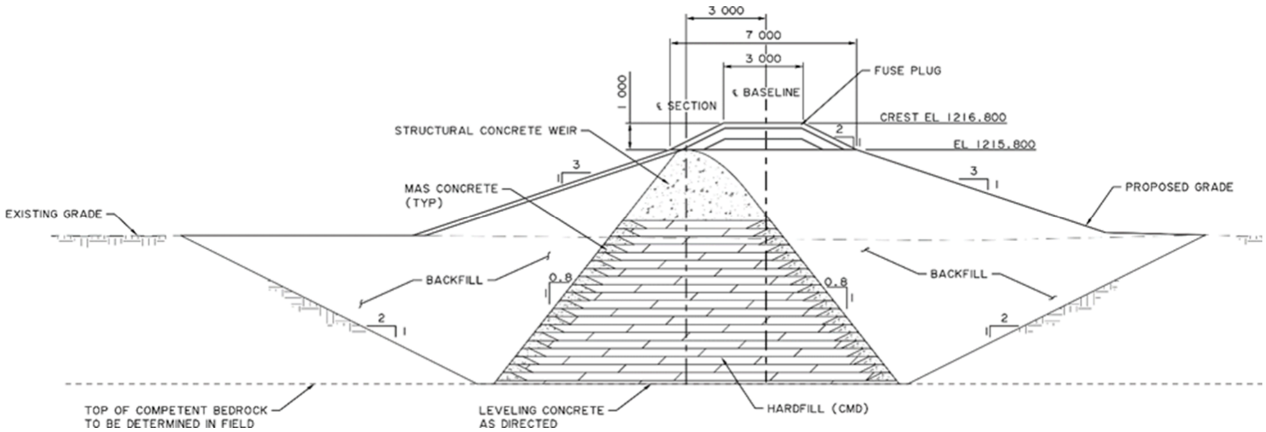


Figure 1. Overflow Weir Showing Concrete Hardfill, Fuse Plug and Backfill.

1.5 BASIS FOR STRUCTURE LAYOUT

The Auxiliary Spillway layout and sizing were based on hydrotechnical evaluation to establish overall geometry, crest elevation and length for the overflow weir in combination with a fuse plug that would meet the hydrotechnical design criteria. Other auxiliary spillways considered, such as articulated concrete blocks (ACB) and roller compacted concrete (RCC), were deemed too expensive or not sufficiently robust for use. The auxiliary spillway crest was set at EL 1215.8 m, which is the lowest without infringing upon the 2013 design flood maximum headwater. The use of a one metre high fuse plug provides additional freeboard during flood diversion regulation up to the 2013 design flood with no diversion.

The foundation elevation for the Auxiliary Spillway overflow weir and transition wall was selected based on existing bedrock profile, stability requirements, and constructability considerations. Along the Auxiliary Spillway alignment, geotechnical evaluations identified approximate top of rock below the hydraulic profile and established an upper bound for the concrete/rock interface at or below Elevation 1207.0 m. The concrete/rock interface was identified as a uniform bench to define the limit of excavation and simplify foundation preparation.

Lateral limits of individual blocks and possible contraction joint locations were selected to maintain plan area aspect ratios between 1:1 and 1.75:1, provide adequate toe for transition wall blocks, minimize thermal effects such as cracking from heat of hydration, and satisfy stability requirements.

The overflow weir is a mass concrete gravity structure using “hardfill” (cemented local sands and gravels, CSG). The trapezoidal gravity section was selected for the overflow weir to maximize sliding area in contact with the foundation, and use the upstream water and backfill load acting on the hardfill face to provide additional sliding resistance. Satisfying sliding was the controlling factor for design of the weir section. Hardfill was selected over RCC since compressive strength was not a primary consideration for this low head structure and the local river bed or aggregate sources can supply aggregate of sufficient quality and quantity for use as mass concrete. The transition wall is a concrete gravity structure using cantilever retaining walls for simplicity in forming and speed of construction. A significantly larger hardfill abutment would be needed and more difficult to construct.

2.0 CODES AND STANDARDS

In accordance with "terms of reference" for this project, the design complies with current Alberta Transportation (AT) Design Standards and current AT Design and Construction Bulletins. By reference in AT Standards, Canadian Dam Association (CDA) Dam Safety Guidelines and Technical Bulletin Nos. 1 through 9 provided primary guidance for design of the project including the hydraulic structures. Other recognized industry standards referenced in the AT/CDA Guidelines were used to supplement aspects of the design that the AT/CDA Guidelines do not address. Such references include the US Army Corps of Engineers (USACE) Engineering Manuals and US Bureau of Reclamation (USBR) Design Standards. In case of conflicting criteria, AT provisions were used unless a "more stringent" requirement was deemed appropriate based on engineering judgement.

Where referenced by AT and CDA, the National Building Code of Canada (NBCC) and Alberta Building Code (ABC) were used to obtain certain design loads (wind, snow, live, vehicle), and develop load combinations associated with strength and serviceability. NBCC and ABC provisions were used primarily for evaluation of individual elements such as railings, ladders, and other ancillary structures.

The following codes, guidelines, and standards were identified for use on this project:

2.1 PROJECT STANDARDS

- Alberta Government, Terms of Reference (TOR0015997) for "Flood Mitigation Works, Springbank Off-Stream Storage Project (SR1) (WAC0078983), Addendum No. 2," August 1, 2014.

- AT's "Engineering Consultant Guidelines for Highway Bridge and Water Projects, Volume 1- Design & Tender" - 2011.

- AT's "Engineering Consultant Guidelines for Highway Bridge and Water Projects, Volume 2- Design & Tender" - 2011.

- AT's Civil Works Master Specifications for Construction of Provincial Water Management Projects.

2.2 DAM DESIGN AND SAFETY

- Province of Alberta Water Act – Water (Ministerial) Regulation - Regulation 205/98 (consolidated up to 185/2015).

- AT's "Water Control Structures Selected Design Guidelines" – Nov. 2004

- Canadian Dam Association Dam Safety Guidelines (CDA) 2007 with 2013 Revisions.
- CDA – Technical Bulletins:
    1. Inundation, Consequences, and Classification for Dam Safety, 2007
    2. Surveillance of Dam Facilities, 2007
    3. Flow Control Equipment for Dam Safety, 2007
    4. Retracted & Replaced by "Guidelines for Public Safety Around Dams," 2011
    5. Dam Safety Analysis and Assessment, 2007
    6. Hydrotechnical Considerations for Dam Safety, 2007
    7. Seismic Hazard Considerations for Dam Safety, 2007
    8. Geotechnical Considerations for Dam Safety, 2007
    9. Structural Considerations for Dam Safety, 2007
- USACE - Stability Analysis of Concrete Structures - EM 1110-2-2100, December 2005
- USACE – Earthquake Design and Evaluation of Concrete Hydraulic Structures - EM 1110-2-6053, 1 May 2007
- USACE - Gravity Dam Design - EM 1110-2-2200, June 1995
- USACE – Retaining and Flood Walls – EM 1110-2-2502, 29 September 1989
- USBR – Design Standards No. 14, Appurtenant Structures for Dams (Spillways and Outlet Works) Design Standards, Chapters 1 to 3, August 2014
- USBR – Design of Small Dams, 3rd Edition, 1987
- FEMA – Best Practices Technical Manuals

2.3 BUILDING CODE & PERSONNEL SAFETY

- Alberta Building Code (ABC) 2014
- National Building Code of Canada (NBCC) 2015
- Alberta Occupational Health and Safety Code (OHS code).

2.4 STRUCTURAL ANALYSIS, DESIGN AND MATERIAL SPECIFICATIONS

- Concrete Materials and Methods of Concrete Construction, CSA A23.1-14 & A23.2 -14
- Design of Concrete Structures, CSA A23.3-14
- Design of Steel Structures, CSA S16-14
- Welded Steel Construction, CSA W59-13
- Canadian Foundation Engineering Manual, Canadian Geotechnical Society – 4th Ed., 2006
- Canadian Highway Bridge Design Code
- Alberta Transportation Bridge Design Criteria
- Reinforcing Steel Institute of Canada, Standards Practice Manual

3.0 PROJECT DATA

3.1 LOCATION

The project is located in the Springbank area of Rocky View County, Alberta, CA, southwest of the City of Calgary in Township 24 (Range 04/03, W5M).

Latitude	51.050504 N
Longitude	114.401436 W
Elevation	1180 to 1220 m

3.2 FOUNDATION PARAMETERS

Site characterization is based on geologic assessment of the project site, exploratory borings, laboratory testing of project samples, and geotechnical engineering judgement. The following foundation parameters, derived from Brazeau formation data, are described in Preliminary Design Report (PDR), Appendix D - Geotechnical Assessment Report, Chapter 10.

Rock Classification sandstone/mudstone/shale/claystone

Recommended Concrete/Bedrock Interface	EL. 1207 or lower	
Bedrock Unit Weight	25.6 kN/m^3	
Bedrock Friction Angle (Rock/Rock Interface) (φ)	26 Deg.	
Concrete/Rock Interface Friction Angle (φ)	26 Deg.	
Cross Bed Friction Angle (φ) – Passive Wedge	24 Deg.	
Ultimate Bearing Capacity (σ_{ult})	1915 kPa	
Allowable Bearing Capacity – Usual	1270 kPa	(σ_{ult}/1.5 $_{SF}$)
Allowable Bearing Capacity – Unusual	1470 kPa	(σ_{ult}/1.3 $_{SF}$)
Allowable Bearing Capacity – Extreme	1740 kPa	(σ_{ult}/1.1 $_{SF}$)

Cohesion: In accordance with CDA Guidelines Technical Bulletin No. 7 (Geotechnical) and Technical Bulletin No. 8 (Structural), cohesion was not included in the sliding stability analysis, and acceptance criteria is based on sliding factors for friction only resistance.

3.3 HYDROTECHNICAL PARAMETERS

Performance of the Diversion Structure and Diversion Channel was assessed using numerical and physical modeling. Hydraulic calculations and detailed modeling used in the design of individual hydraulic structures and other components are presented in the Preliminary Design Report, Appendices C and F. The various operating scenarios to be assessed for the Auxiliary Spillway were based on a High Hazard Dam Classification with the separation between the Usual and Unusual Conditions being the 50-year frequency flood and the 1000-year frequency flood dividing the Unusual and Extreme conditions.

Table 2 provides a summary of the hydrotechnical parameters for selected operating scenarios used in the design and stability analyses of the Auxiliary Spillway.

Table 2. Auxiliary Spillway Hydrotechnical Parameters

Operating Scenario	Auxiliary Spillway Discharge (m^3/s)	Headwater Elevation (m)	Tailwater Elevation (m)
Normal Operation (No Diversion) *160 m^3/s inflow*	0	1214.0	1211.9
Fuse Plug In-Place (No Diversion) 2013 Flood - 1240 m^3/s	0	1216.4	1213.1
Fuse Plug Erosion Beginning Diversion Inlet Gates Open *1850 m^3/s inflow*	0	1216.5	1213.1
1000-Year Event Fuse Plug Eroded (No Diversion) *1930 m^3/s inflow*	444	1217.0	1213.1
IDF - Fuse Plug Eroded (No Diversion) *2210 m^3/s inflow*	618	1217.3	1213.8

3.4 CLIMATE DATA

3.4.1 Snow

Snow Load data for this project was obtained from Ontario Climate Centre – Environment Canada.

- Ground snow load, snow component (S_s) = 1.7 kPa
- Ground snow load, rain component (S_r) = 0.1 kPa
- Snow load, Importance factor (I_s)=1.25

3.4.2 Frost Considerations

Frost depth was determined in accordance with ABC and is shown in PDR, Appendix D - Geotechnical Assessment Report.

- Minimum design frost depth of 2.0 m
- Non-frost susceptible backfill - Gravel and clean sands

3.4.3 Temperature Variations

Monthly temperature data for use in the evaluation was obtained from Calgary International Airport records, which is considered representative of typical temperature ranges at project site.

3.4.4 Wind

A wind load of 0.48 kPa was determined for use at the site based on the Alberta Building Code.

4.0 CONSTRUCTION MATERIALS

4.1 CONCRETE AND CONCRETE ACCESSORIES

- **Structural Concrete – Class A1**
  30 MPa @ 28 days, (AT Civil Works Specifications)
  General use reinforced concrete where thermal control and volume change are not a concern.

- **Structural Concrete – Class B1**
  30 MPa @ 90 days, (AT Civil Works Specifications)
  General use reinforced concrete where thermal control and volume change need to be considered (typically thickness > 600 mm)

- **Mass Concrete – Class M**
  20 MPa @ 90 days, 30 MPa @ 180 days (New mixture to be specified)
  Unreinforced concrete for monoliths, slabs, piers and retaining walls where thermal control and volume change need to be considered (typically thickness >1500 mm).

- **Foundation Concrete - Class F**
  15 MPa @ 28 days, (AT Civil Works Specifications)
  For use in foundation preparation such as mud mats and low strength fill.

- **Hardfill (Cemented Sands and Gravels) – Class CSG**
  7.5 MPa @ 90 days. (New mixture to be specified)
  For use in the interior of mass concrete structures, such as the AS interior concrete, where low compressive strength materials can be used but where thermal control, volume change, and permeability are the primary considerations.

- **Grout**
  Premixed structural non-shrink grout for equipment bases.

- **Preformed Expansion Joint Filler**
  ASTM D1752, Type I, Closed-cell sponge rubber.

- **Bond Breaker**
  Bituminous paint conforming to CGSB 37.2-88.

- **Waterstops**
  PVC ribbed profile with minimum rated hydrostatic head of 373 KPa based on joint type.

4.2 METALS

- **Reinforcement** - CAN/CSA-G30.18, Grade 400W deformed bars
- **Miscellaneous Metals** (gratings, stairs, ladders, handrails) - Galvanized steel

4.3 EARTHWORK MATERIALS

The Auxiliary Spillway will be constructed on a rock foundation. Soil backfill materials will be various embankment materials as listed below and included in the PDR, Appendix D - Geotechnical Assessment Report.

Design values for specified material include:

Impervious Fill

Unit Weight (-)	21 kN/m^3
Internal Friction Angle (-)	18 deg

Granular Fill

Unit Weight (-)	21 kN/m^3
Internal Friction Angle (-)	34 deg

Random Fill

Unit Weight (-)	20 kN/m^3
Internal Friction Angle (-)	27 deg

Rock Fill

Unit Weight (-)	22 kN/m^3
Internal Friction Angle (-)	20 deg

Siltation (Equivalent Fluid)

Unit Weight Vertical (-)	19 kN/m^3
Unit Weight Horizontal (-)	13 kN/m^3

Selected Fill

Unit Weight (-)	20 kN/m^3
Internal Friction Angle (-)	38 deg

5.0 STRUCTURAL ANALYSIS APPROACH

For the purposes of stability assessment, analysis and structural design, the Auxiliary Spillway was divided into individual monoliths based on structure geometry, size, joint location, and load considerations. The monoliths were analyzed as either concrete gravity sections or retaining walls. Each monolith was evaluated for global stability, strength, and serviceability.

Global stability was assessed using the rigid body analysis method and application of unfactored loads. This method uses the summation of forces applied to the monolith to determine resultant location, foundation bearing pressures, and sliding resistance along identified potential failure plane(s). Analysis methodology and acceptance criteria are described in further detail in later sections of this report.

Reinforced concrete design of members was performed according to Design of Concrete Structures, CSA A23.3-14 with the additional requirements of the CSA's SEED Document – *Structural Design of Wastewater Treatment Plants-2018* for revisions addressing service load conditions, water tightness, shrinkage and temperature reinforcement, and crack control. The Seed Document contains references to ACI 350M-06 for modifying CSA A23.3-14.

Finite Element Models (FEMs) were used to validate manual calculations, identify potential stress concentrations, and assess additional serviceability concerns such as localized deflection, need for thermal stress relief, and stress redistribution not captured in manual calculations. Mitigation of alkali-aggregate reaction (AAR) potential and thermal crack control for mass concrete placements were addressed through design detailing and material specifications.

5.1 DESIGN TOOLS AND SOFTWARE

- Microsoft Excel - 2010 - version: 14.0.7166.5000
- Mathcad 15.0 - 2013 - version: MC15_M030_20131216
- Autodesk Robot Structural Analysis Professional 2019 – version 32.0.2.6571 (x64)
- Autodesk AutoCAD 2017 – version 2017

6.0 LOADS

6.1 DEAD LOADS (D)

Permanent loads on the structure include concrete structure weight, backfill and water. Unit weights for principal materials are included in Table 3.

Table 3. Dead Load and Unit Weights

Material	Unit Weight	Source
Water	9.81 kN/m^3	CSA S6-14, Table 3.4
Reinforced Concrete	23.5 kN/m^3	AT WCS Design Guide 4.2
Mass Concrete, RCC and Hardfill	22.8 kN/m^3	USBR, Design of Gravity Dams, Section III.B
Steel	77.0 kN/m^3	AT WCS Design Guide 4.2

6.2 HYDROSTATIC LOADS (H)

Both horizontal and vertical components of water load were used based on water surface elevation for the load condition considered. Upstream and downstream water surface elevations are described in Hydrotechnical Parameters, Section 3.3. The water surface elevations were considered to be hydrostatic pressures without kinematic effects. Headwater was considered the water surface elevation at the upstream face of the structure. Tailwater elevation was either maximum tailwater indicated on tailwater rating curves, or a reduced tailwater elevation to account for hydraulic jump depending on load condition considered and which condition produced a more adverse effect on the structure.

6.3 UPLIFT PRESSURE (U)

For the Auxiliary Spillway, uplift was assumed to vary from 100 percent of the hydrostatic headwater pressure at the upstream edge of structure to 100 percent of hydrostatic tailwater pressure at the downstream edge of the structure with application over 100 percent of base. For retaining walls, the uplift is assumed to vary on a straight line from 100 percent of the water pressure at the face of the foundation heel to 100% of water pressure at the face of the foundation toe applied over 100% of the base in compression.

The foundation interface was assumed to have zero tensile capacity. For bases where stability calculations indicate bearing pressures less than zero, the foundation interface was assumed to crack, and 100 percent of the hydrostatic pressure was applied over the area of the cracked foundation, then vary linearly to 100 percent of tailwater pressure. For seismic evaluations, uplift loading remained unchanged from the pre-earthquake condition to the post-earthquake evaluation unless seismic loading resulted in a cracked foundation, in which case full hydrostatic pressure was applied to the entire area of the cracked foundation during the post-earthquake evaluation.

6.3.1 Seepage Reduction Measures

The underlying rock was identified as highly weathered and fractured. To minimize uplift potential, seepage reduction measures included using an upstream key. For stability analyses, the seepage reduction measures were conservatively neglected.

6.4 EARTH PRESSURE (E)

Soil loads include both vertical and horizontal forces due to backfill.

Vertical forces associated with soil mass above the structure were based on a vertical projection of footing or structure below the soil. Soil mass was based on moist unit weight for material above the waterline and buoyant unit weight for material below the waterline. Vertical force associated with water above the structure was calculated separate from the soil mass.

Horizontal forces associated with soil are based on the at-rest condition in accordance with EM 1110-2-2100 and EM 1110-2-2502 to use the at-rest Coefficient (K_o).

6.5 LIVE LOADS (V)

The principal live loads on the Auxiliary Spillway include Vehicle or Heavy Equipment Loads adjacent to retaining walls. Live loads are considered transitory loads.

Transitory loads were used for strength design of individual structure elements but were not included in stability analyses. Vehicle Loads were obtained from CSA-S6-14, Section 3.8.3

Vehicle (Vertical Application) CL-625

Vehicle (Horizontal Application) CL-625

Heavy Equipment Surcharge was applied to retaining wall design as a separate load condition to account for future modifications such as building additions, long-term material storage, or top-of-wall modifications. This load is not applied simultaneously with Vehicle Loads.

Equivalent Load Surcharge 15.0 kPa Equivalent 0.75 m soil

6.6 HYDRODYNAMIC LOADS (HD)

Hydrodynamic loads include wave action, sub-atmospheric pressure at the fixed crest, and hydraulic dissipater forces. For the Auxiliary Spillway, these forces have been excluded from stability analysis since they are considered insignificant or of a localized nature.

- Wave action is not included due to the short-term duration and relatively short fetch.
- Sub-atmospheric pressure is not included since there is insufficient head to develop sub-atmospheric pressure on the fixed crest.
- Hydraulic dissipater forces are localized forces addressed in the hydraulic design of stilling basin and chute blocks.

6.7 DEBRIS AND IMPACT LOADS

Impact loads associated with debris flows have been excluded from the analysis since they are considered insignificant or of a localized nature.

6.8 ICE LOAD (I)

No ice loads were used in the stability analyses for the Auxiliary Spillway since it is encased in fill and the Elbow River has little flow during the winter .

Vertical ice loading associated with "frost heave" is a realistic consideration. The Auxiliary Spillway is normally in a dewatered or low-water state with freeze/thaw action tending to open rock joints or concrete/rock interface and subject the structure to increased uplift potential. To reduce frost heave loading potential and remove this condition from the analysis, foundation interfaces were located below the identified frost depth (2 m) for the site.

6.9 SEISMIC - EARTHQUAKE LOADS (Q)

The seismic classification for the Auxiliary Spillway is based on Stantec's *Seismic Hazard Assessment - Springbank Off-Stream Dam and Reservoir Report* dated November 28, 2016. Since the hazard classification for this structure is Extreme (Off-stream Storage Dam), the seismic parameters are based on an Earthquake Design Ground Motion (EDGM) with an Annual Exceedance Probability (AEP) of 1/10,000 resulting in Peak Ground Acceleration (PGA) of 0.26 g for horizontal application and PGA of 0.15 for vertical application.

This project site is situated in an area of low to moderate seismic activity. Consequently, CDA Guidelines, Section 6.5 allow for the seismic stability analysis of concrete gravity structures to be completed using a pseudo-static approach (coefficient method). This method applies a seismic force to a rigid body with the objective of determining sliding and overturning response of the structure. Since the pseudo-static method does not recognize the oscillatory nature of seismic loads, accepted practice is to perform the stability calculations using sustained acceleration values equivalent to 2/3 of the peak acceleration values.

When performing concrete stress analyses, the objective is to determine the tensile crack length induced by the inertia forces applied to the structure, so peak acceleration is used to calculate seismic coefficients. This approach assumes an instantaneous acceleration spike can induce cracking but is not sustained long enough to develop significant displacement along the crack plane. If no significant displacement occurs, the dynamic stability is maintained.

6.9.1 Seismic Effects on Concrete Mass

The horizontal force required to accelerate the concrete mass is calculated as:

$Q_h = k_h \times W$ where:

Q_h = Horizontal seismic load (kN)
k_h = Horizontal seismic coefficient
W = Structure mass (kg)
PGA = Peak ground acceleration= 0.26g

For Stability Analysis (Table 4): k_h = 2/3 x 0.26 = 0.17
For Member Analysis (Table 5): k_h = 1.0 x 0.26 = 0.26

The vertical force required to accelerate the concrete mass is calculated as:

$Q_v = k_v \times W$ where:

Q_v = Vertical seismic load (kN)
k_v = Horizontal seismic coefficient = 0.56*k_h
W = Structure mass (kg)

For Stability Analysis (Table 4): k_v = 2/3 x (0.56*k_h) = 0.10
For Member Analysis (Table 5): k_v = 1.0 x (0.56*k_h) = 0.15

Since an earthquake produces oscillating forces, the horizontal PGA and vertical PGA cannot occur at the same time. To account for this in the stability calculations, three separate combinations of vertical and horizontal seismic combinations were considered, but only the maximum value was reported. The three combinations of vertical and horizontal seismic load are as follows:

Table 4. Stability Analysis – Seismic Coefficients

Seismic Combination	Horizontal	Vertical
100% Horiz., No Vert.	1.0*k_h = 0.17	-
100% Horiz., 30% Vert.	1.0*k_h = 0.17	0.3*k_v = 0.03
30% Horiz., 100% Vert.	0.3*k_h = 0.05	1.0*k_v = 0.10

Table 5. Stress Analysis – Seismic Coefficients

Seismic Combination	Horizontal	Vertical
100% Horiz., No Vert.	$1.0*k_h = 0.26$	-
100% Horiz., 30% Vert Horiz.	$1.0*k_h = 0.26$	$0.3*k_v = 0.05$
30% Horiz., 100% Vert.	$0.3*k_h = 0.08$	$1.0*k_v = 0.15$

6.9.2 Seismic Effects on Water (H_E)

No water loads are associated with seismic load cases for the Auxiliary Spillway.

6.9.3 Seismic Effect on Soils

Dynamic soil pressures and associated forces were analyzed assuming yielding backfills and an elastic response using the Mononobe-Okabe method. This method uses active soil pressure during seismic conditions to assess stability.

Mononobe-Okabe Method for Yielding Backfill: This method assumes a wedge of soil bounded by the structure and an assumed soil failure plane moves as a rigid body with the same horizontal acceleration. The driving (active) wedge force is calculated based on a combined static and dynamic pressure coefficient (K_{AE}), but must then be divided into static and dynamic components for cases where the water table is above the backfill. Detailed explanation of this method can be found in Appendix G, EM 1110-2-2100.

$$P_{PE} = \frac{1}{2} K_{PE} \gamma (1 - k_v) h^2 \qquad \text{(G-3)}$$

$$K_{PE} = \frac{\cos^2(\phi - \psi - \theta)}{\cos\psi \cos^2\theta \cos(\psi - \theta + \delta)\left[1 - \sqrt{\dfrac{\sin(\phi + \delta)\sin(\phi - \psi + \beta)}{\cos(\beta - \theta)\cos(\psi - \theta + \delta)}}\right]^2} \qquad \text{(G-4)}$$

γ = unit weight of soil
k_v = vertical acceleration in g's
h = height of structure
ϕ = internal friction angle of soil

$\psi = \tan\left(\dfrac{k_h}{1-k_v}\right)$ = seismic inertia angle

k_h = horizontal acceleration in g's
θ = inclination of interface with respect to vertical (this definition of θ is different from θ in Coulomb's equations)
δ = soil-structure friction angle
β = inclination of soil surface (upward slopes away from the structure are positive)

(c) Simplifying Conditions. For the usual case where k_v, δ, and θ are taken to be zero, the equations reduce to:

$$K_{AE} = \frac{\cos^2(\phi - \psi)}{\cos^2\psi\left[1 + \sqrt{\dfrac{\sin\phi\,\sin(\phi-\psi-\beta)}{\cos\beta\,\cos\psi}}\right]^2} \qquad \text{(G-5)}$$

6.10 CLIMATIC CONDITIONS

6.10.1 Snow Loads (S)

Snow loads were considered insignificant compared to hydrostatic loads and were not considered for the Auxiliary Spillway.

6.10.2 Thermal Loads (T)

Temperature changes will influence the overflow weir monoliths and retaining walls. Thermal effects and measures, such as placement of expansion/contraction joints in concrete structures, to relieve thermal loads will be addressed during Final Design.

6.10.3 Wind (W)

Wind loads were considered insignificant compared to hydrostatic loads and were not considered for the spillway structure.

7.0 STABILITY ANALYSIS

The overflow weir and transition wall were analyzed for load conditions applicable to the Auxiliary Spillway as identified in Section 7.3. Analysis methodology is as follows:

7.1 METHODOLOGY

7.1.1 Overturning and Bearing Stress

The Rigid Body Method (conventional gravity method) was used for the analysis of overturning and bearing stresses criteria. Overturning was evaluated as a percentage of base that remains in compression and not a safety factor. This method is outlined in Section 7.2 of CDA Technical Bulletin No. 9. It uses the vector summation of all forces, including uplift, acting on the monolith to determine the vector resultant force (V), resultant force eccentricity (e) within the base, and moment (Ve/S) based on an elastic and homogeneous rectangular beam analogy. Stresses were calculated as indicated below and stability was assured by maintaining the resultant force eccentricity within acceptance criteria limits for various loading conditions.

$$\sigma = \frac{V}{A} \pm \frac{Ve}{S}$$

Where: σ = Applied bearing pressure at each end of base (kN/m^2)
V = Summation of forces normal to base (kN)
A = Base area in compression (m^2)
e = Eccentricity of normal load about centroid of base in compression (m)
S = Section modulus of base area in compression (m^3)

7.1.2 Sliding

The sliding factor of safety was calculated for each load case using the limit equilibrium method as outlined in Section 7.2 of CDA Technical Bulletin No. 9. This method reduces to the equation shown below for a single wedge system with a horizontal sliding plane, along the concrete/rock interface or through rock/rock failure plane as identified for each hydraulic structure. For inclined sliding planes projecting from the base of shear key to bottom base slab at the toe, vertical and horizontal forces are resolved into components normal and parallel to the sliding plane. Rock mass between the inclined plane and structure base is included in the dead load summation (EM 1110-2-2100).

$$SSF = \frac{(V tan\varphi + c\ A)}{H}$$

Where: SSF = Sliding Safety Factor
V = Summation of vertical loads including uplift (kN)
$tan\ \varphi$ = Coefficient along sliding plane being considered
c = Cohesion at concrete/rock or rock/rock interface (assumed as 0) (kN/m^3)
A = Base area in compression (m^2)
H = Summation of horizontal forces (kN)

7.1.3 Floatation

The floatation factor of safety was determined for components of the project such as stilling basins and apron slabs as outlined in Section 8.5, AT WCS. The factor of safety against floatation is defined as ratio of resisting gravity force to driving uplift force. The possible resistance due to friction between adjacent structures or between structure and backfill was neglected unless shear provisions were provided.

$$FSF = \frac{\Sigma N}{\Sigma U}$$

Where: FSF = Factor of Safety against Floatation
ΣN = Summation of normal forces
ΣU = Summation of uplift forces

7.2 ACCEPTANCE CRITERIA

The following acceptance criteria are based on AT WCS Chapter 8, CDA Table 6-4, and CDA Technical Bulletin No. 8, Section 6.0. The load cases to be evaluated are divided into five categories as listed in Table 6:

Usual Condition: Those conditions under which the structure is intended to serve during normal operations and further defined as a condition that has a high likelihood of occurring within the design life of the structure. Usual load conditions include normal pool and winter conditions. For the hydraulic structures, this includes flood events up to the 50-year frequency flood for High Hazard classified structures and flood events up to the 100-year frequency flood for Extreme Hazard classified structures.

Unusual Condition: Those conditions that occur infrequently and may stress the structure more, under certain aspects, than normal conditions and may occur within the design life of the structure. Unusual load conditions include construction conditions, maintenance conditions, flood events between the 50-year (High) and 1000-year frequency, infrequent earthquake events other than the MDE, and plugged drain conditions for Usual Load Cases.

Extreme – Flood: Extreme Load Conditions have a very remote likelihood of occurring with the design life of the structure. For the SR1 project, it is defined as those floods that occur from the 1000-year frequency event up to the structure's IDF. For the Auxiliary Spillway structure, it would occur when the off-stream storage reservoir is at maximum pool, Elevation 1212.0 m, as a result of rare flood events or misoperation during flood diversion.

Extreme – Earthquake: For the SR1 project, the Extreme - Earthquake load condition to be assessed is the MDE as it has a very remote likelihood of occurring with the design life of the structure. The MDE is applied to the Usual Condition load cases. The Extreme – Earthquake condition is used to establish Post-Earthquake condition of the hydraulic structure. Thus, there are no stability acceptance criteria for this condition.

Post-Earthquake: The Post-Earthquake condition assesses the stability of the hydraulic structure following the applied seismic event based on earthquake induced cracking at the foundation structural interface and within the structure so that it is still capable of resisting the Usual Loading.

Table 6. Acceptance Criteria for Hydraulic Structures

Loading Combination	Position of Resultant Force (Percent of Base in Compression)[1]	Normal Compression Stress[2]	Sliding Safety Factor (Friction Only)	Floatation Safety Factor
Usual	Middle third of the base: 100% compression	<0.3 x f_c	≥1.5	≥1.5
Unusual	Middle third of the base: 100% compression	<0.5 x f_c	≥1.3	≥1.3
Extreme Flood	Within middle half of the base, and all other acceptance criteria must be met	<0.5 x f_c	≥1.1	≥1.1
Extreme Earthquake	Within the base, except where an instantaneous occurrence of resultant outside the base may be acceptable	<0.9 x f_c	Note [3]	
Post-Earthquake	Within middle half of the base	<0.5 x f_c	≥1.0	≥1.1

[1] Foundation bearing stress is compared to allowable stress determined from Geotechnical Investigation

[2] Where f_c = compressive strength of concrete

[3] The earthquake load case is used to establish post-earthquake condition of the structure

7.3 LOAD CONDITIONS

Load conditions varied for the Auxiliary Spillway structures based on configuration and location of applied load. The following sections summarize load conditions for various structures.

7.3.1 Auxiliary Spillway - Overflow Weir

Table 7. Overflow Weir – Load Conditions

Usual Load Cases:		
U1	Usual Condition 1 – River Flow with No Diversion Inflow 160 m³/s. Diversion Inlet gates closed and Service Spillway gates open. Headwater: EL 1214.0 Tailwater: EL 1211.9	D+H+E+U
Unusual Load Cases:		
UN1	Unusual Condition 1 – Auxiliary Spillway at Point of Overtopping Fuse Plug. Total Inflow 1850 m³/s. Diversion Inlet and Service Spillway gates open. Headwater: EL 1216.5 Tailwater: EL 1213.1	D+H+E+U
UN2	Unusual Condition 2 – 1000-Year Event with No Diversion (Dam Safety Condition) Fuse plug removed and toe scour occurring Total Inflow 1930 m³/s. No Diversion and Service Spillway gates fully open. Headwater: EL 1217.0 Tailwater: 1213.1	D+H+E+U
Extreme Load Cases:		
E1-F	Extreme Condition 1 – IDF with No Diversion (Dam Safety Condition) Total Inflow 2210 m³/s. No Diversion and Service Spillway gates fully open. Fuse plug removed and toe scour occurring Headwater: EL 1217.3 Tailwater: EL 1213.8	D+H+E+U
E2-Q	Extreme Condition 2 – Post-Seismic Load Normal Inflow. No Diversion and Service Spillway gates fully open. Headwater: EL 1213.5 Tailwater: EL 1211.9	D+H+E+U+Q
Notes:		
D	Dead Load: Weight of concrete	
H	Hydrostatic Load: Headwater and tailwater conditions specific for each load case. Includes horizontal and vertical loads	
E	Earth/Sediment/Silt Loads: Includes horizontal and vertical loads	
U	Uplift: Varies linearly from Headwater to Tailwater pressure across plane of analysis	
Q	Seismic Loads: Design Earthquake load – Includes evaluation for three combinations to consider simultaneous horizontal and vertical components.	

7.3.2 Auxiliary Spillway - Transition Wall

Table 8. Transition Wall – Load Conditions

Usual Load Case:		
U1	Usual Condition 1 – River Flow with No Diversion Residual Groundwater Levels Headwater: EL 1214.0 Tailwater: EL 1211.9	D+H+E+U
Unusual Load Cases:		
UN1	Unusual Condition 1 – Normal River Flow + Equipment Surcharge Residual Groundwater Levels Headwater: EL 1214.0 Tailwater: EL 1211.9	D+H+E+U+L
UN2	Unusual Condition 2 – Auxiliary Spillway at Point of Overtopping Fuse Plug. Total Inflow 1850 m^3/s. Diversion Inlet and Service Spillway gates open. Upstream Wall - Groundwater equal to HW Downstream Wall – Groundwater at TW (Weir side), Groundwater linearly varying from HW to TW (FB side). Headwater: EL 1216.5 Tailwater: EL 1213.1	D+H+E+U
UN3	Unusual Condition 3 – 1000-Year Event with No Diversion (Dam Safety Condition) Fuse plug removed and toe scour occurring Upstream Wall - Groundwater equal to HW Downstream Wall – Groundwater at TW (Weir side), Groundwater linearly varying from HW to TW (FB side). Headwater: EL 1217.0 Tailwater: 1213.1	D+H+E+U
Extreme Load Cases:		
E1-F	Extreme Condition 1 – IDF with No Diversion (Dam Safety Condition) Fuse plug removed and toe scour occurring Upstream Wall - Groundwater equal to HW Downstream Wall – Groundwater at TW (Weir side), Groundwater linearly varying from HW to TW (FB side). Headwater: EL 1217.3 Tailwater: EL 1213.7	D+H+E+U
E2-Q	Extreme Condition 2 – Normal River Flow + Seismic Load Residual Groundwater Levels Headwater: EL 1213.5 Tailwater: EL 1211.9	D+H+E+U+Q
Notes:		
D	Dead Load: Weight of concrete	
H	Hydrostatic Load: See each load case for headwater and tailwater conditions	
E	Earth/Sediment/Silt Loads: Includes horizontal and vertical loads	
U	Uplift: Varies linearly from Headwater to Tailwater pressure across plane of analysis	
L	Live Loads: Vehicle / equipment surcharge	
Q	Seismic Loads: Design Earthquake load – evaluation to consider simultaneous horizontal and vertical components for three combinations	

7.4 SUMMARY OF STABILITY ANALYSES

Stability analyses for the overflow weir and the transition wall were performed in accordance with criteria and procedures outlined in the CDA Technical Bulletin No. 9, "Structural Considerations for Dam Safety", and the USACE EM 1110-2-2100 "Stability Analysis of Concrete Structures". Each section was evaluated for Usual, Unusual, Extreme, and Post-Seismic loading conditions representing potential conditions the structure will experience during its design life. Summaries of the stability calculation results are presented in the sections that follow. Refer to the Appendices for stability calculations and results.

7.4.1 Overflow Weir

The overflow weir comprises segments A1 through A13 consisting of hardfill (CSG) mass concrete encased in conventional concrete facing for durability. The hardfill and facing concrete are placed in lifts of approximately 300 mm in thickness. The upstream and downstream faces of the overflow weir slope 0.8H:1V topping out with an ogee crest at Elevation 1215.8 m for a total height of 8.8 m. A concrete facing of approximately 600 mm thick is formed against the hardfill to form a seepage barrier and to provide freeze-thaw durability. The structure is to be placed on suitable bedrock encountered at approximately Elevation 1207.0 m.

The stability analyses for the overflow weir were performed according to the rigid body method using manual calculations. Results of the analyses are summarized in Table 9**Error! Reference source not found.** and calculations are included in Appendix E.3-1.

Stability analyses indicate a relatively light structure sensitive to sliding. Stability calculations indicate results within the limits of acceptance criteria using a horizontal plane. For all loading conditions considered, floatation factors of safety were above required, 100 percent of the base was in compression, and sliding factors of safety were above required. Stability results indicate that sliding stability was the primary concern due to the low friction angle at concrete/rock interface. The controlling load condition is Load Case E1-F (Inflow Design Flood).

Table 9. Overflow Weir – Stability Summary

Load Case	Headwater (Heel) Elevation (m)	Tailwater (Toe) Elevation For Uplift (m)	Uplift Force (MN)	Floatation Safety Factor (FSF)		Sliding Safety Factor (SSF)		Foundation Bearing Stress		% Base in Compression
				Req	Calc	Req	Calc	Upstream (Heel) (kPa)	Downstream (Toe) (kPa)	
U1 Normal Operation	1214.0	1211.9	0.9	1.5	3.11	1.5	9.62	159	87	100
UN1 Point of Fuse Plug Activation	1216.5	1213.1	1.2	1.3	2.38	1.3	1.67	124	86	100
UN2 1000-Year Flood	1217.0	1213.1	1.2	1.3	1.94	1.3	1.52	65	77	100
E1-F IDF 2210 m^3/s	1217.3	1213.8	1.3	1.1	1.77	1.1	1.12	72	57	100
E2-Q Normal Operation	1213.5	1211.9	0.7	1.1	4.12	1.1	1.56	226	48	100

7.4.2 Transition Wall

The transition wall provides a separation between the Floodplain Berm and overflow weir. It consists of Sections 1 through 3 (Figure 2). The elevation of the transition wall varies from Elevation 1212.723 m to Elevation 1218.440 m, following the surface contour of the Floodplain Berm. The cantilever walls thickness varies from 500 mm to 1700 mm, while the foundation slab ranges from 1200 mm to 1800 mm in thickness. A Load Case that represents equipment operating on top of the Floodplain Berm (UN1) was considered for the stability analysis of Section 2. Equipment loads were not considered for Sections 1 and 3 since the final grade is sloped.

The stability analyses for the structure were performed using an Excel spreadsheet. Results of the analyses are summarized in Table 10, and calculations are included in Appendix E.3-2.

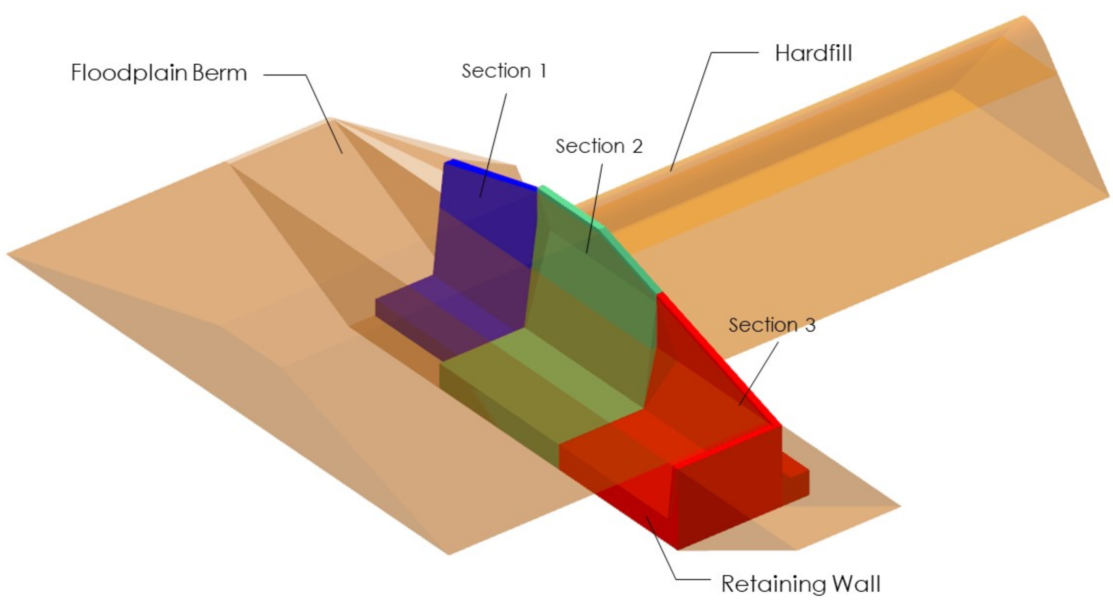


Figure 2. Transition Wall - Section Locations

Table 10. Transition Wall – Stability Summary

Load Case	Headwater (Heel) Elevation (m)	Tailwater (Toe) Elevation For Uplift (m)	Uplift Force (MN)	Floatation Safety Factor (FSF)		Sliding Safety Factor (SSF)		Foundation Bearing Stress		% Base in Compression
				Req	Calc	Req	Calc	Upstream (Heel) (kPa)	Downstream (Toe) (kPa)	
Section 1										
U1	1214.0	1211.9	3.4	1.5	3.17	1.5	1.80	21.2	261.3	100
UN1	1214.0	1211.9	-	-	-	-	-	-	-	-
UN2	1216.5	1213.1	4.9	1.3	2.24	1.3	1.57	3.8	225.2	100
UN3	1217.0	1213.1	5.1	1.3	2.14	1.3	1.63	8.2	211.6	100
E1-F	1217.3	1213.8	5.3	1.1	2.05	1.1	1.62	10.0	201.8	100
E2-Q	1213.5	1211.9	3.1	1.1	3.57	1.1	6.84	0.0	355.7	<100
Section 2										
U1	1214.0	1211.9	5.1	1.5	4.28	1.5	1.51	51.7	309.9	100
UN1	1214.0	1211.9	5.1	1.3	4.28	1.3	1.34	34.2	327.3	100
UN2	1216.5	1213.1	6.6	1.3	3.30	1.3	1.39	32.9	296.1	100
UN3	1217.0	1213.1	6.6	1.3	3.33	1.3	1.43	35.6	294.4	100
E1-F	1217.3	1213.8	7.3	1.1	2.92	1.1	1.37	20.9	281.0	100
E2-Q	1213.5	1211.9	5.0	1.1	4.39	1.1	1.48	0	395.4	<100
Section 3										
U1	1214.0	1211.9	5.69	1.5	3.06	1.5	3.27	56.3	155.9	100
UN1	1214.0	1211.9	-	-	-	-	-	-	-	-
UN2	1216.5	1213.1	7.04	1.3	2.47	1.3	2.01	35.2	152.5	100
UN3	1217.0	1213.1	7.21	1.3	2.35	1.3	1.32	42.3	147.5	100
E1-F	1217.3	1213.8	7.8	1.1	2.17	1.1	1.12	29.3	151.4	100
E2-Q	1213.5	1211.9	5.7	1.1	1.2	1.1	1.2	10.3	202.0	100

8.0 STRENGTH EVALUATION AND DESIGN

Strength evaluation of individual elements or members of structures and monoliths was used to verify member sizes based on application of factored loads as described in ABC with some adjustments for more severe conditions or loads not included in the ABC.

Reinforced concrete design was performed according to Design of Concrete Structures, CSA A23.3-14 with the additional requirements of the CSA's SEED Document – *Structural Design of Wastewater Treatment Plants-2018* for revisions addressing service load conditions, water tightness, shrinkage and temperature reinforcement, and crack control. The Seed Document contains references to ACI 350M-06 for modifying CSA A23.3-14.

In general, structural analysis and design was performed manually using MathCAD or Excel spreadsheets, For complex structures such as the transition wall blocks, a commercial Finite Element Model (FEM), such as Autodesk Robot, was used to evaluate multiple load combinations, identify stress concentrations, and generate shear and moment values for design of individual elements. The FEM was supplemented with manual calculations to verify/validate model results and, where necessary, refine the analysis of individual elements. Based on model output, a combination of manual calculation and commercial software were used for strength design. Additional elements evaluated as part of strength design included joint detailing and embedded parts.

For mass concrete structures, such as the hardfill overflow weir, thermal analyses for the construction condition and for seasonal temperature variations following construction will be performed during Final Design. These analyses are used to locate monolith joints, determine the type of joint treatment between lifts, and determine the lateral extent of mass concrete expansion and contraction due to seasonal influences.

9.0 SERVICEABILITY

Serviceability concerns with the Auxiliary Spillway overflow weir relate primarily to concrete durability including reducing crack potential, providing thermal stress relief, and incorporating measures to mitigate alkali-aggregate reaction (AAR) and other chemical attack. Because hardfill lacks long-term durability, particularly against freeze-thaw conditions, it must be protected. Various protection means include using cast-in-place concrete or precast blocks for facing, providing extra thickness beyond that needed as a sacrificial layer, and mixing grout with the hardfill mixture at the surface to increase its paste content. Currently, the overflow weir design uses cast-in-place facing concrete on both faces to protect the hardfill core. During final design, the use of concrete facing protection will be evaluated further, particularly if facing concrete is needed, since the overflow weir will be covered with soil.

Shrinkage control and volume changes are addressed primarily with placement sequence, mix design, surface reinforcement, and material specifications. The monolith layout and design include joint locations that define monoliths with balanced aspect ratios and placements less than 12 to 18 m in any one planar direction for mass concrete. Expanded guidance related to placement sequence and joint locations will be addressed as part of Final Design.

Serviceability concerns for the reinforced concrete transition wall relate to concrete durability, shrinkage, crack control, volume changes, and wall deflections. Durability, shrinkage, and crack control are achieved primarily through reinforcement placement, high reinforcement ratios, and use of high load factors that account for both strength and serviceability in accordance with the CSA SEED document. Volume changes are addressed primarily with placement sequence, mix design, surface reinforcement, and material specifications. The preliminary design includes vertical joints at locations of footing geometry change, and at locations needed to maintain horizontal wall lengths less than 12 m to 15 m. Expanded guidance related to placement sequence and horizontal joint locations will be addressed as part of constructability review during final design.

10.0 CONSTRUCTION CONSIDERATIONS

Construction specifications and details for the Auxiliary Spillway will be furthered during Final Design. The following construction considerations are noted:

- Dewatering of excavated areas will be required to sufficiently enable construction of the Auxiliary Spillway. The services of a specialist dewatering contractor may be needed.

- Excavation will be to competent bedrock. All soil, including alluvium, talus and other unconsolidated deposits should be removed to expose unweathered or slightly weathered bedrock. Excavation should be performed by mechanical means only; blasting will not be permitted.

- Foundation preparation will require special care in cleaning and preparation of concrete/rock interface. Care must be taken during excavation of the foundation to identify unsuitable rock conditions or weak bedding planes that could impact stability. Loose material and rock overhangs will need to be removed. Small voids will be filled with dental concrete.

- If extensive jointing/fracturing is observed after excavation of the foundation, consolidation grouting may be required.

- Use of a continuous hardfill batching-mixing plant or pugmill is likely. The area for Hardfill production requires approximately three to four acres to provide space for the Hardfill plant, aggregate stockpiles, cement and fly ash silos, feeding systems and material delivery and loading areas. In addition, a level area of approximately one acre should be planned for the equipment staging and maintenance area next to the production plant.

- Hardfill may be placed using either a conveyor system or an all truck transporting system. If an all truck system is used, provisions should be made to prevent truck tires from tracking dirt and other debris on the fresh Hardfill.

- It is envisioned that Hardfill will be spread using a dozer and compacted with a double drum or single drum, self-propelled vibratory steel drum roller. Small compaction equipment will likely be required in tight spaces such as next to forms.

- Adequate bonding between Hardfill lifts requires that the overlying lift of Hardfill be placed while the underlying lift is still "live" or has not become a cold joint. Where cold joints form between lifts- placement of a bonding mortar or grout will likely be required before succeeding lifts of Hardfill are placed.

- For the construction of the Auxiliary Spillway, the following construction sequence shall be observed.

  1. Construction of the transition wall shall be performed first so the wall can act as a vertical form for the construction of the overflow weir and facilitate the construction of the joint between these two structures.

  2. The overflow weir shall be constructed before the construction of the Floodplain Berm embankment closure.

  3. The Floodplain Bearn closure is constructed last in the construction sequence since the transition wall relies on the overflow weir for stability.

Appendix E.3-1 OVERFLOW WEIR STABILITY CALCULATIONS

Section Considered

Hard Fill section @ STA. 1+630 (Largest HW/TW Differential)

Ref. Drawing 73396S-260

Load Conditions

Water

	Elevation (m)		H (m)	T(m)
	Headwater	Tailwater	Headwater	Tailwater
1. Usual Condition (U1)	1214.0	1211.9	7	4.9
2. Unusual Condition (UN1)	1216.5	1213.1	9.5	6.1
3. Unusual Condition (UN2)	1217.0	1213.1	10	6.1
4. Extreme Condition 1 (E1)	1217.3	1213.8	10.3	6.8
5. Extreme Condition 2 (E2)	1213.5	1211.9	6.5	4.9
6. Extreme Condition (PMF)	1217.8	1214.0	10.8	7

Tailwater pressure was assumed to be 60% of static head due to retrogression

Fill

Fluvial fill placed on the upstream and earth fill on downstream of the slope of spillway. For the Unusual Condition face (UN2) and Extreme Condition 1 (E1), the downstream fill over the spillway toe will be eroded. Earthfill and foundation materials assumed to be homogeneous isotropic.

Uplift

A linear interpolation is used between the upstream and downstream water heads.

Earthquake

A acceleration equal of a=0.26g is considered for Hard Fill inertial load calculations.

Material Properties

	Fluvial Fill	Fluvial Soil
Water, γ_w = 9.81 kN/m3	Soil Fill, γ_s = 20 kN/m3	Soil Fill, γ_s = 20 kN/m3
HF, γ_{RHF} = 23.5 kN/m3	Soil Fill, ϕ = 38°	Soil Fill, ϕ = 38°
	Soil Coefficient, Ka = 0.21	Soil Coefficient, Ka = 0.21

Foundation:

Weathered Sandstone and Mudstone Bedrock

Allowable bedrock bearing capacity qa = 622 kPa

Friction Angle ϕ = 26°

Cohesion c = 0 kPa

Design Notes:

1.- For the earth resistance pressure acting behind the hardfill structure during the seismic load condition an active earth pressure was assumed as lower bound for the soil resistance. Under seismic loading a reduction in the seismic passive pressure occurs. Seismic passive earth pressures should be determined considering the amount of deformation required to mobilize this pressure.

References:

Anderson D., Martin, G., and Lam, I. (2008). Seismic Analysis and Design of Retaining Walls, Buried Structures, Slopes and Embankments. NCHRP Report 611. Transportations Research Board. Whashington D.C.

AT/WCG (2004). Guidelines on Extreme Flood Analysis. Alberta Transportation, Transportation and Civil Engineering Division, Civil Projects Branch. November 2004.

CDA (2007). Dam Safety Guidelines 2007. Canadian Dam Association

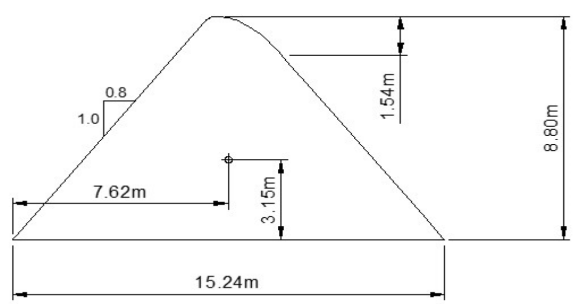
USACE (1989). Engineering and Design Retaining and Flood Walls. EM 1110-2-2502. 29 Sept 1989. US Army Corps of Engineers. Whashington D.C.

Stantec (2018). Internal Geotechnical Design Recommendations. Recommended Geotechnical Parameters, SR-1 Emergency Spillway Structures, Revision 12-September 2018.

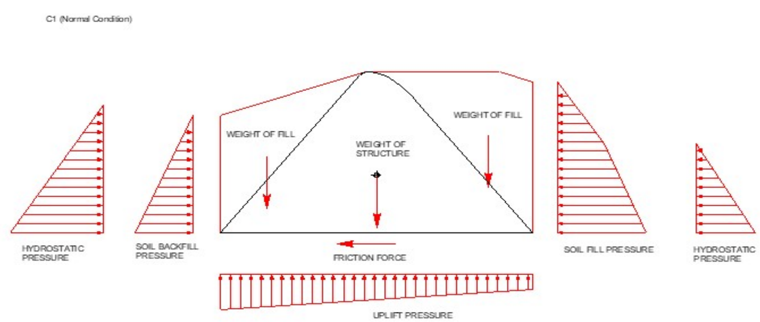
Summary of Stability Analyses
Auxiliary Spillway
Hard Fill Block Concept 2019

Load Condition	Description	∑ Vertical Forces (kN)		∑ Horizontal Forces (kN)	Effective Base (%)	Base Pressure (kPa)		Shear Friction Factor		Minimum Required Sliding FS	Factor of Safety Flotation
		V	U			Upstream	Downstream				
Usual (U1)	River Flow with No Diversion	1873.0	-889.6	95.4	100%	87	159	9.62	>	1.5	3.11
Unusual (UN1)	Auxiliary Spillway at Point of Overtopping	1603.9	-1158.7	471.4	100%	86	124	1.67	>	1.3	2.38
Unusual (UN2)	Auxiliary Spillway Cover Removed and Spilling	1084.8	-1158.7	349.4	100%	77	65	1.52	>	1.3	1.94
Extreme 1 (E1-F)	IDF with No Diversion (Capacity Required for High Hazard Dam)	980.3	-1278.3	429.6	100%	57	72	1.12	>	1.1	1.77
Extreme 2 (E2-Q)	Seismic under U1 Load Condition	2091.6	-671.0	656.8	100%	48	226	1.56	>	1.1	4.12
Extreme 3 (E3-PMF)	PMF with No Diversion	483.9	-1338.1	460.6	<100%	-54	117	0.51	>		1.36

Hard Fill Geometry:



Hard Fill Body Diagram:



SUMMARY OF FORCES

Load Case	U1

Headwater EL. =	1214	Base Friction angle (ϕ - deg) =	26
Tailwater EL. =	1211.9	tan (ϕ) =	0.49
Top of RCC EL. =	1215.8	Base cohesion (kPa) =	0
Base of RCC EL. =	1207	Allowable Bearing Pressure (kPa) =	622
Length of Base 'L' (m) =	15.24	Base Area (m^2) =	15.24
Width of Base 'w' (m) =	1	Retrogation factor for Tailwater =	0.6

Loading	Horizontal Forces		Vertical Forces		Stabilizing Moments (kN-m/m)	Overturning Moments (kN-m/m)
	Force (kN/m)	Arm (m)	Force (kN/m)	Arm (m)		
Weight of Dam (W)			1708.1	7.6	13015.7	
Uplift (U)			-889.6	8.1		7177.1
Headwater (Hh)	240.3	2.3				560.8
Tailwater (Ht)	-70.7	1.6			115.4	
Upstream Fill (Fu)	-118.5	3.0				354.1
Downstream Fill (Fd)	44.2	2.1			94.8	
Cover Fill (Fc)			1054.5	6.8	7212.6	
SUM	**95.4**		**1873.0**		**20438.5**	**8092.0**
					Net Moment	
					12346.5	

			Required FS
Factor of Safety for Sliding (∑V*δ)/∑H =	**9.62**	>	1.5
Factor of Safety for Flotation =	**3.11**	>	1.5
Excentrecity e =	0.8 m		('-' represents right of center)
Foundation Pressure			
Upstream =	87 kPa		
Downstream =	159 kPa		
Resultant Ratio (XR/Base Width)=	0.45		
Base Area in Compression =	100%		

Load Case	UN1

Headwater EL. =	1216.5	Base Friction angle (ϕ - deg) =	26
Tailwater EL. =	1211.9	tan (ϕ) =	0.49
Top of RCC EL. =	1215.8	Base cohesion (kPa) =	0
Base of RCC EL. =	1207	Allowable Bearing Pressure (kPa) =	622
Length of Base 'L' (m) =	15.24	Base Area (m^2) =	15.24
Width of Base 'w' (m) =	1	Retrogation factor for Tailwater =	0.6

Loading	Horizontal Forces		Vertical Forces		Stabilizing Moments (kN-m/m)	Overturning Moments (kN-m/m)
	Force (kN/m)	Arm (m)	Force (kN/m)	Arm (m)		
Weight of Dam (W)			1708.1	7.6	13015.7	
Uplift (U)			-1158.7	8.2		9493.5
Headwater (Hh)	426.9	3.1				1340.7
Tailwater (Ht)	-105.9	2.0			211.9	
Upstream Fill (Fu)	44.2	2.1				94.8
Downstream Fill (Fd)	106.2	3.0			320.3	
Cover Fill (Fc)			1054.5	8.4	8857.6	
SUM	**471.4**		**1603.9**		**22405.5**	**10929.1**
					Net Moment	
					11476.4	

			Required FS
Factor of Safety for Sliding (∑V*δ)/∑H =	**1.67**	>	1.3
Factor of Safety for Flotation =	**2.38**	>	1.3
Excentrecity e =	0.5 m		('+' represents right of center)
Foundation Pressure			
Upstream =	86 kPa		
Downstream =	124 kPa		
Resultant Ratio (XR/Base Width)=	0.47		
Base Area in Compression =	100%		

Load Case	UN2

Headwater EL. =	1216.3	Base Friction angle (ϕ - deg) =	26
Tailwater EL. =	1213.2	tan (ϕ) =	0.49
Top of RCC EL. =	1215.8	Base cohesion (kPa) =	0
Base of RCC EL. =	1207	Allowable Bearing Pressure (kPa) =	622
Length of Base 'L' (m) =	15.24	Base Area (m^2) =	15.24
Width of Base 'w' (m) =	1	Retrogation factor for Tailwater =	0.6

Loading	Horizontal Forces		Vertical Forces		Stabilizing Moments (kN-m/m)	Overturning Moments (kN-m/m)
	Force (kN/m)	Arm (m)	Force (kN/m)	Arm (m)		
Weight of Dam (W)			1708.1	7.6	13015.7	
Uplift (U)			-1158.7	8.1		9417.6
Headwater (Hh)	418.3	3.1				1290.2
Tailwater (Ht)	-113.1	2.1	90.5	3.3	533.1	
Upstream Fill (Fu)	44.2	2.1				94.8
Downstream Fill (Fd)						
Cover Fill (Fc)			444.8	12.9	5756.0	
SUM	**349.4**		**1084.8**		**19304.7**	**10802.5**
					Net Moment	
					8502.2	

			Required FS
Factor of Safety for Sliding (∑V*δ)/∑H =	**1.52**	>	1.3
Factor of Safety for Flotation =	**1.94**	>	1.3
Excentrecity e =	-0.2 m		('+' represents right of center)
Foundation Pressure			
Upstream =	77 kPa		
Downstream =	65 kPa		
Resultant Ratio (XR/Base Width)=	0.49		
Base Area in Compression =	100%		

Load Case	E1

Headwater EL. =	1217.4	Base Friction angle (ϕ - deg) =	26
Tailwater EL. =	1213.7	tan (ϕ) =	0.49
Top of RCC EL. =	1215.8	Base cohesion (kPa) =	0
Base of RCC EL. =	1207	Allowable Bearing Pressure (kPa) =	622
Length of Base 'L' (m) =	15.24	Base Area (m^2) =	15.24
Width of Base 'w' (m) =	1	Retrogation factor for Tailwater =	0.6

Loading	Horizontal Forces		Vertical Forces		Stabilizing Moments (kN-m/m)	Overturning Moments (kN-m/m)
	Force (kN/m)	Arm (m)	Force (kN/m)	Arm (m)		
Weight of Dam (W)			1708.1	7.6	13015.7	
Uplift (U)			-1278.3	8.2		10442.9
Headwater (Hh)	517.4	3.3				1720.2
Tailwater (Ht)	-132.1	2.2	105.7	3.6	672.7	
Upstream Fill (Fu)	44.2	2.1				94.8
Downstream Fill (Fd)						
Cover Fill (Fc)			444.8	12.9	5756.0	
SUM	**429.6**		**980.3**		**19444.4**	**12257.9**
					Net Moment	
					7186.5	

				Required FS
Factor of Safety for Sliding (∑V*δ)/∑H =	**1.12**		>	1.1
Factor of Safety for Flotation =	**1.77**		>	1.1
Excentrecity e =	0.3	m		('+' represents right of center)
Foundation Pressure				
Upstream =	57	kPa		
Downstream =	72	kPa		
Resultant Ratio (XR/Base Width)=	0.48			
Base Area in Compression =	100%			

Load Case	E2

Headwater EL. =	1213.5	Base Friction angle (ϕ - deg) =	26
Tailwater EL. =	1211.9	tan (ϕ) =	0.49
Top of RCC EL. =	1215.8	Base cohesion (kPa) =	0
Base of RCC EL. =	1207	Allowable Bearing Pressure (kPa) =	622
Length of Base 'L' (m) =	15.24	Base Area (m^2) =	15.24
Width of Base 'w' (m) =	1	Retrogation factor for Tailwater =	0.6

Loading	Horizontal Forces		Vertical Forces		Stabilizing Moments (kN-m/m)	Overturning Moments (kN-m/m)
	Force (kN/m)	Arm (m)	Force (kN/m)	Arm (m)		
Weight of Dam (W)			1708.1	7.6	13015.7	
Dynamic Inertia Force (Wd)	296.1	3.2				932.6
Uplift (U)			-671.0	8.0		5352.2
Headwater (Hh)	124.3	2.2				269.4
Tailwater (Ht)	-117.8	1.6			192.4	
Upstream Fill (Fu)	118.5	3.0				351.6
Dynamic Upstream Fill Force (Fud)	191.4	5.9				1123.0
Downstream Fill (Fd)	44.2	2.1			94.8	
Cover Fill (Fc)			1054.5	6.8	7212.6	
SUM	**656.8**		**2091.6**		**20515.5**	**8028.9**
					Net Moment	
					12486.6	

			Required FS
Factor of Safety for Sliding (∑V*δ) /∑H =	**1.56**	>	1.1
Factor of Safety for Flotation =	**4.12**	>	1.1
Excentrecity e =	1.7 m		('+' represents right of center)
Foundation Pressure			
Upstream =	48 kPa		
Downstream =	226 kPa		
Resultant Ratio (XR/Base Width)=	0.39		
Base Area in Compression =	100%		

Load Case	PMF

Headwater EL. =	1217.9	Base Friction angle (ϕ - deg) =	26
Tailwater EL. =	1214	tan (ϕ) =	0.49
Top of RCC EL. =	1215.8	Base cohesion (kPa) =	0
Base of RCC EL. =	1207	Allowable Bearing Pressure (kPa) =	622
Length of Base 'L' (m) =	15.24	Base Area (m^2) =	15.24
Width of Base 'w' (m) =	1	Retrogation factor for Tailwater =	0.6

Loading	Horizontal Forces		Vertical Forces		Stabilizing Moments (kN-m/m)	Overturning Moments (kN-m/m)
	Force (kN/m)	Arm (m)	Force (kN/m)	Arm (m)		
Weight of Dam (W)			1708.1	7.6	13015.7	
Uplift (U)			-1338.1	8.2		10936.5
Headwater (Hh)	560.6	3.4				1909.9
Tailwater (Ht)	-144.2	2.3	113.8		336.5	
Upstream Fill (Fu)	44.2	2.9				128.3
Downstream Fill (Fd)						
Cover Fill (Fc)						
SUM	**460.6**		**483.9**		**13352.2**	**12974.8**
					Net Moment	
					377.4	

			Required FS
Factor of Safety for Sliding (∑V*δ + C*A)/∑H =	**0.51**	<	1.1
Factor of Safety for Flotation =	**1.36**	>	1.1
Excentrecity e =	6.8 m		('+' represents right of center)
Foundation Pressure			
Upstream =	-54 kPa		
Downstream =	117 kPa		
Resultant Ratio (XR/Base Width)=	0.05		
Base Area in Compression =	<100%		

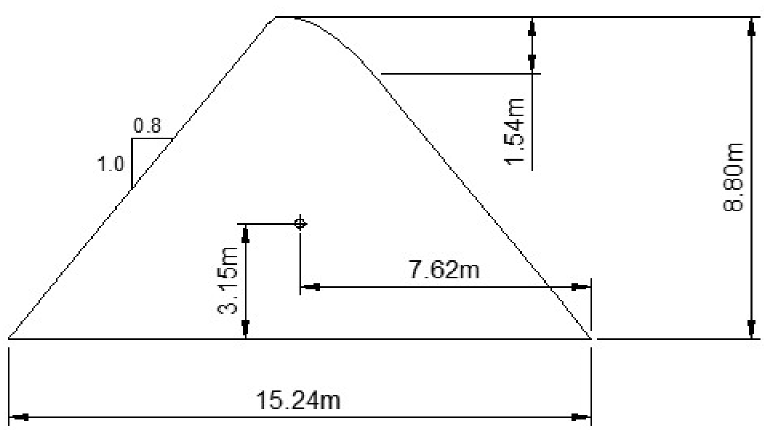
CALCULATIONS

Scope:
Evaluate the stablity of the RHF Spillway Structure, considering the following load cases:

	Elevation (m)		H (m)	
	Headwater	Tailwater	Headwater	Tailwater
1. Usual Condition (U1)	1214.0	1211.9	7	4.9
2. Unusual Condition (UN1)	1216.5	1213.0	9.5	6
3. Unusual Condition (UN2)	1216.3	1213.2	9.3	6.2
4. Extreme Condition 1 (E1)	1217.4	1213.7	10.4	6.7
5. Extreme Condition 2 (E2)	1213.5	1211.9	6.5	4.9
6. Extreme Condition (PMF)	1217.9	1214.0	10.9	7

Calculations:

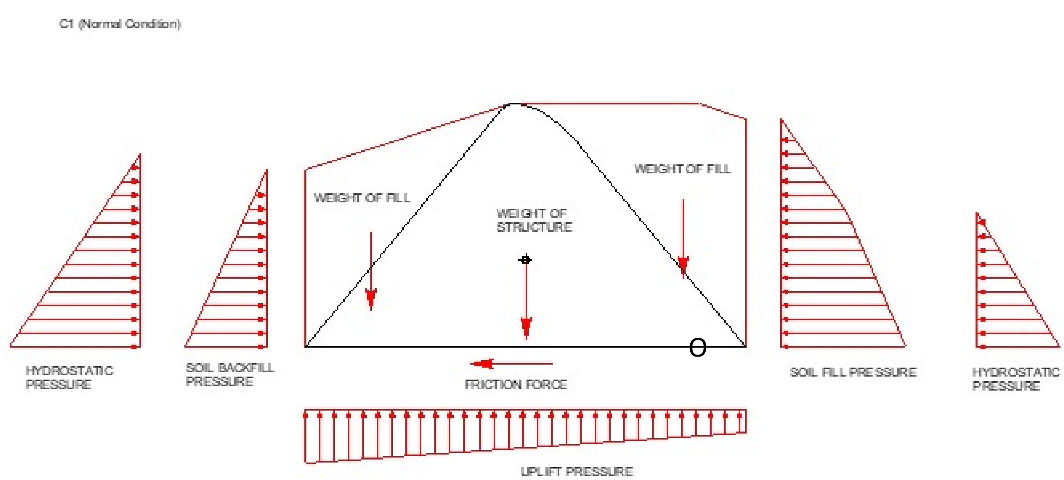
Dimensions



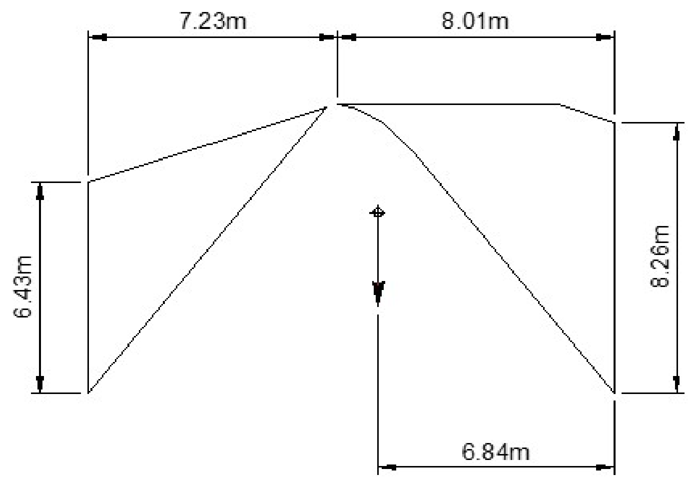
A = 72.7 m^3/m
L = 15.24 m
μ = 0.49
x = 7.62 m
y = 3.15 m

Retrogression factor for Tailwater
r = 0.6

1. Usual Condition (U1)

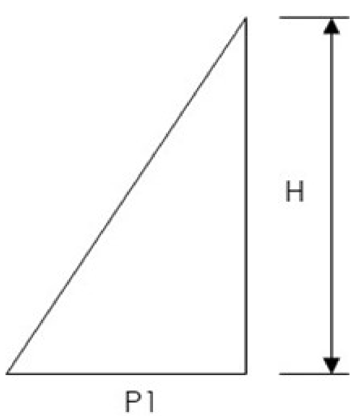


Cover Fill



A1 = 22.2 m^3/m
A2 = 30.5 m^3/m
A = 52.7 m^3/m
x = 6.84 m

Soil fill upstream



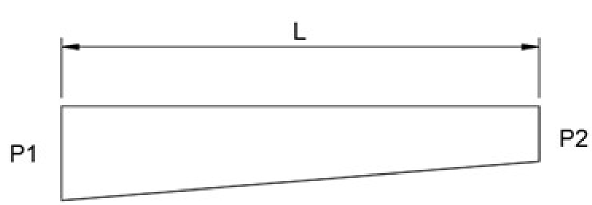
ϒ = 20 kN/m^3
ϒw = 9.81 kN/m^3
Ka = 0.21

H = 6.43 m

P1 = 13.8 kN/m^2

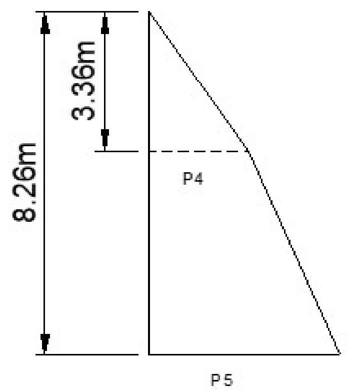
F = 44.2 kN/m
y = 2.14 m

Uplift force



ϒw = 9.81 kN/m^3
H1 (toe)= 7 m
H2 (heel)= 4.9 m
P1 (toe) = 68.7 kN/m^2
P2 (heel) = 48.1 kN/m^2
F = 889.6 kN/m
x = 8.1 m

Soil fill downstream



ϒ =	20	kN/m^3
Ka =	0.21	
H =	8.26	m
h=	3.36	m
P4 =	14.1	kN/m^2
P5 =	24.6	kN/m^2
F =	118.5	kN/m
y =	2.99	m

Usual Condition (U1)

	A (m^2)	H (m)	ϒ (kN/m^3)	Vert. (kN/m)	Hor. (kN/m)	Xo (m)	Yo (m)	Mo (kN m/m)
HF Structure	72.7		23.5	1708.1		7.62		13015.7
Hydrostatic upstr.		7	9.81		240.3		2.33	-560.8
Hydrostatic downstr.		4.9	9.81		-70.7		1.63	115.4
Soil fill downstr.		8.26	20		-118.5		2.987	354
Cover fill	52.7		20	1054.474		6.84		7212.602
Uplift			9.81	-889.6		8.1		-7177.1
Soil fill upstr.		6.43	20		44.2		2.143	-94.8
Resisting F				2762.6	-189.2			
Driving F				-889.6	284.6			
Sum F				**1873**	**95**			**12865.1**
Sliding (∑ V *μ)					**-918**			

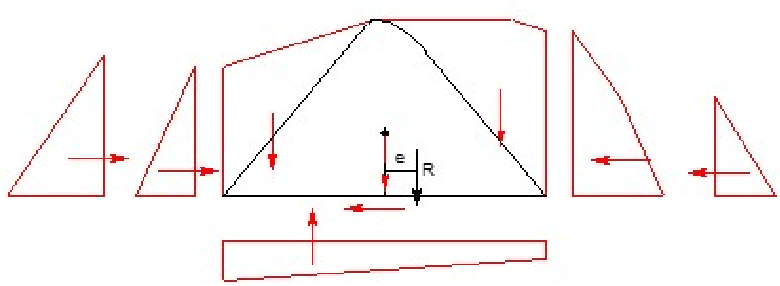
FS = ∑V/Uplift	Flotation	**FS =**	**3.1**
FS = (∑V*δ)/∑H	Sliding	**FS =**	**9.6**

Centerline Eccentricity

e= B/2 - ∑ M/∑ V

e = **0.8** m

('+' represents right of center)

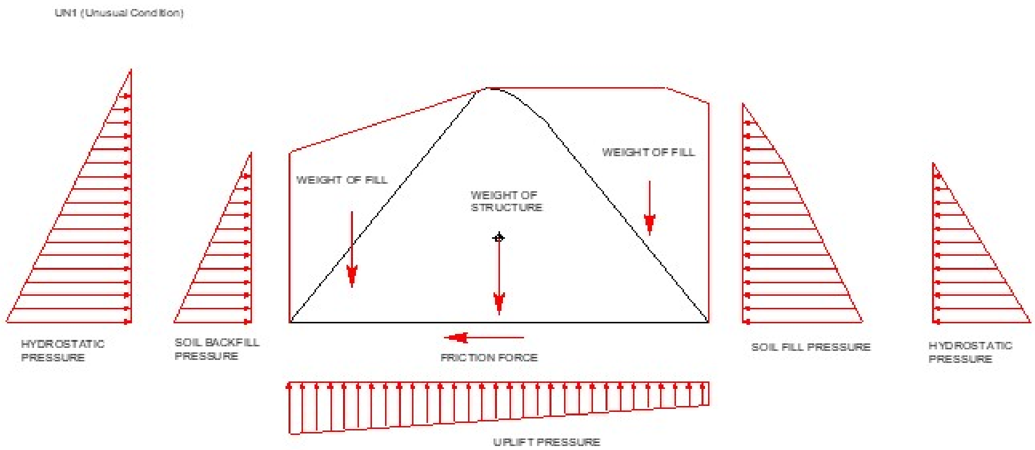


Foundation Pressure

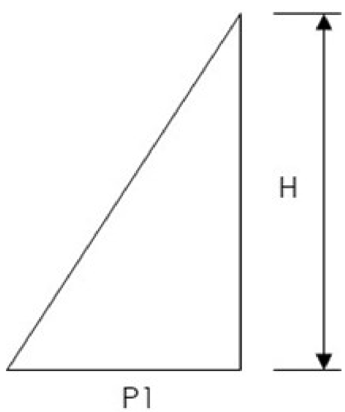
Upstream = 87 kPa

Downstream = 159 kPa

2. Unusual Condition (UN1)

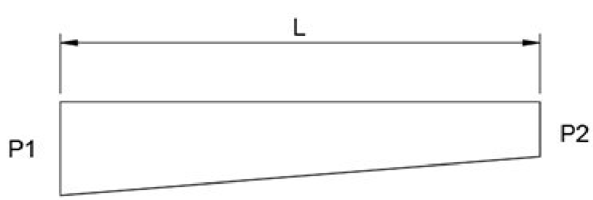


Soil fill upstream



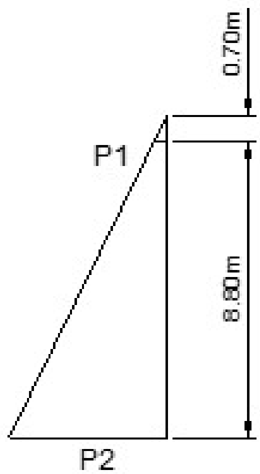
ϒ =	20	kN/m^3
ϒw =	9.81	kN/m^3
Ka =	0.21	
H =	6.43	m
P1 =	13.8	kN/m^2
F =	44.2	kN/m
y =	2.1	m

Uplift force



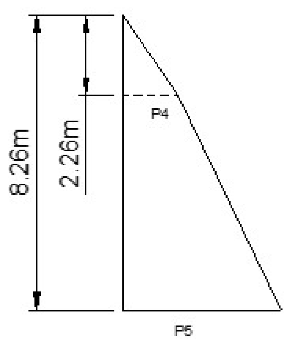
ϒw =	9.81	kN/m^3
H1 (toe)=	9.5	m
H2 (heel)=	6	m
P1 (toe) =	93.2	kN/m^2
P2 (heel) =	58.9	kN/m^2
F =	1158.7	kN/m
x =	8.2	m

Hydrostatic Pressure (upstream)



ϒ =	9.8	kN/m^3
h1 =	0.7	m
H =	8.8	m
P1 =	6.9	kN/m^2
P2 =	90.2	kN/m^2
F =	426.9	kN/m
y =	3.1	m

Soil fill downstream



ϒ =	20	kN/m^3
Ka =	0.21	
H =	8.26	m
h=	2.26	m
P4 =	9.5	kN/m^2
P5 =	22.3	kN/m^2
F =	106.2	kN/m
y =	3.02	m

Unusual Condition (UN1)

	A (m^2)	H (m)	Ɣ (kN/m^3)	Vert. (kN/m)	Hor. (kN/m)	Xo (m)	Yo (m)	Mo (kN m/m)
HF Structure	72.7		23.5	1708.1		7.6		13015.7
Hydrostatic upstr.					426.9		3.1	-1340.7
Hydrostatic downstr.		6.0	9.8		-105.9		2.0	211.9
Soil fill downstr.		8.3	20.0		106.2		3.0	320.3
Cover Fill	52.7		20.0	1054.5		8.4		8857.6
Uplift				-1158.7		8.2		-9493.5
Soil fill upstr.		6.4	20.0		44.2		2.1	-94.8
Resisting F				2762.6	-105.9			
Driving F				-1158.7	533.1			
Sum F				**1603.9**	**427.1**			**11476.4**
Sliding (∑ V *μ)					**785.9**			

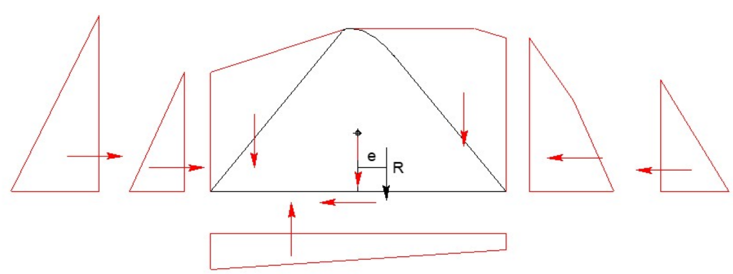
FS = ∑V/Uplift	Flotation	**FS =**	**2.4**
FS = (∑V*δ)/∑H	Sliding	**FS =**	**1.8**

Centerline Eccentricity

e= B/2 - ∑ M/∑ V

e = **0.5** m

('+' represents right of center)

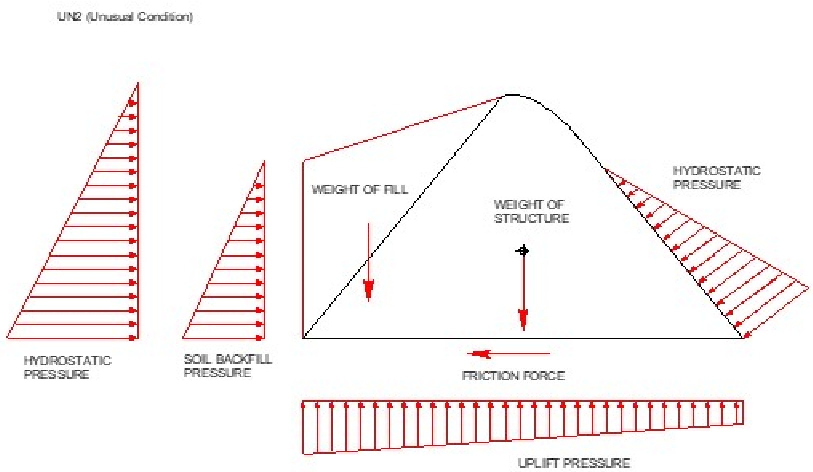


Foundation Pressure P = V/B±(1±6(e/B))

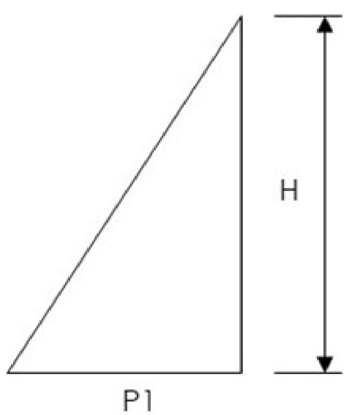
Upstream = 86 kPa

Downstream = 124 kPa

3. Unusual Condition (UN2)

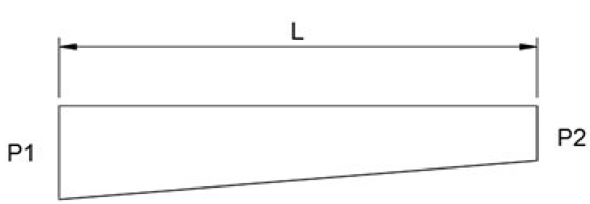


Soil fill upstream



Υ =	20	kN/m^3
Υw =	9.81	kN/m^3
Ka =	0.21	
H =	6.43	m
P1 =	13.8	kN/m^2
F =	44.2	kN/m
y =	2.1	m

Uplift force



Υw =	9.81	kN/m^3
H1 (toe)=	9.3	m
H2 (heel)=	6.2	m
P1 (toe) =	91.2	kN/m^2
P2 (heel) =	60.8	kN/m^2
F =	1158.7	kN/m
x =	8.1	m

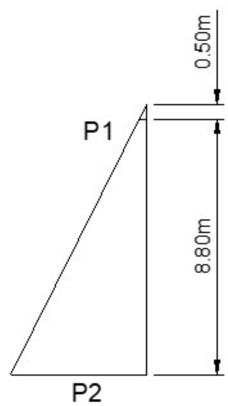
Project: SR-1

Cal.: Aux. Spillway Stabilitys
Project No:110773396

made by: EF ....
ckd by: TP..............................

Date: 9/17/2019

Hydrostatic Pressure (upstream)



Υ =	9.8	kN/m^3
h1 =	0.5	m
H =	8.8	m
P1 =	4.9	kN/m^2
P2 =	90.2	kN/m^2
F =	418.3	kN/m
y =	3.1	m

Unusual Condition (UN2)

	A (m^2)	H (m)	Υ (kN/m^3)	Vert. (kN/m)	Hor. (kN/m)	Xo (m)	Yo (m)	Mo (kN m/m)
HF Structure	72.7		23.5	1708.1		7.62		13015.7
Hydrostatic upstr.					418.3		3.1	-1290.2
Hydrostatic downstr.	15.4	6.2	9.81	90.5	-113.1	3.31	2.1	533.1
Soil fill downstr.								
Cover Fill	22.2		20	444.8		12.9		5756.0
Uplift				-1158.7		8.1		-9417.6
Soil fill upstr.		6.43	20		44.2		2.1	-94.8
Resisting F				2243.4	-113.1			
Driving F				-1158.7	418.3			
Sum F				1085	305			8502.2
Sliding (∑ V *μ)					-532			

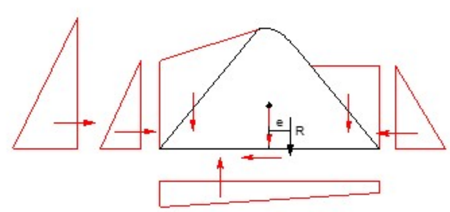
FS = ∑V/Uplift	Flotation	**FS =**	**1.9**
FS = (∑V*δ)/∑H	Sliding	**FS =**	**1.7**

Centerline Eccentricity

e= B/2 - ∑ M/∑ V

e = **-0.2** m

('+' represents right of center)

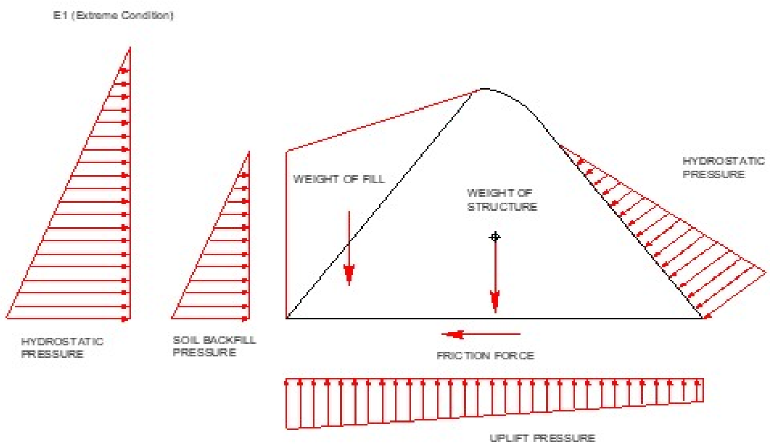


Foundation Pressure P = V/B±(1±6(e/B))

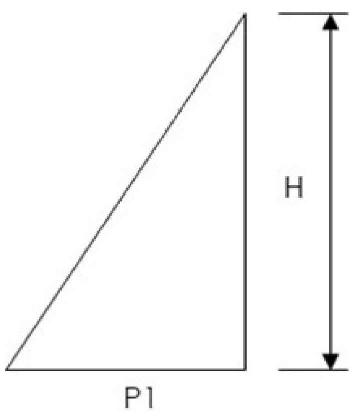
Upstream = 77 kPa

Downstream = 65 kPa

4. Extreme Condition 1 (E1)

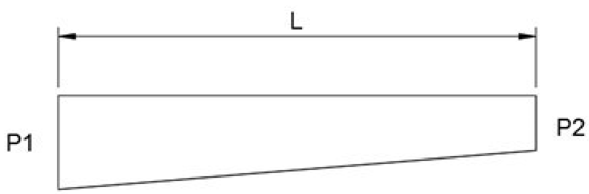


Soil fill upstream



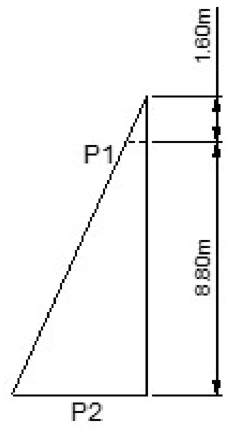
ϒ =	20	kN/m^3
ϒw =	9.81	kN/m^3
Ka =	0.21	
H =	6.43	m
P1 =	13.8	kN/m^2
F =	44.2	kN/m
y =	2.1	m

Uplift force



ϒw =	9.81	kN/m^3
H1 (toe)=	10.4	m
H2 (heel)=	6.7	m
P1 (toe) =	102.0	kN/m^2
P2 (heel) =	65.7	kN/m^2
F =	1278.3	kN/m
x =	8.2	m

Hydrostatic Pressure (upstream)



Υ = 9.8 kN/m^3
h1 = 1.6 m
H = 8.8 m

P1 = 15.7 kN/m^2
P2 = 101.9 kN/m^2

F = 517.4 kN/m
y = 3.3 m

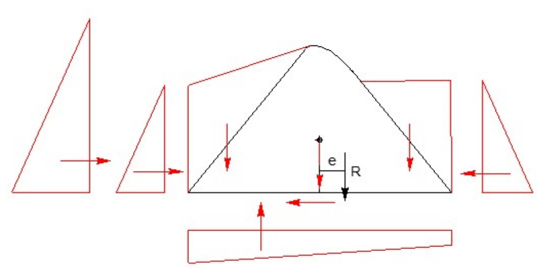
Extreme Condition 1 (E1)

	A (m^2)	H (m)	Υ (kN/m^3)	Vert. (kN/m)	Hor. (kN/m)	Xo (m)	Yo (m)	Mo (kN m/m)
HF Structure	72.68		23.5	1708.1		7.62		13015.7
Hydrostatic upstr.					517.4		3.3	-1720.2
Hydrostatic downstr.	17.96	6.7	9.81	105.7	-132.1	3.57	2.2	672.7
Soil fill upstr.		6.43	20.0		44.2		2.1	-95
Uplift				-1278.3		8.2		-10442.9
Cover Fill	22.2		20	444.8		12.94		5756.0
Resisting F				2258.6	-132.1			
Driving F				-1278.3	561.7			
Sum F				980	430			7186.5
Sliding ($\sum$ V *µ)					-480			0

FS = $\sum$V/Uplift — Flotation — **FS = 1.8**
FS = ($\sum$V*δ)/$\sum$H — Sliding — **FS = 1.1**

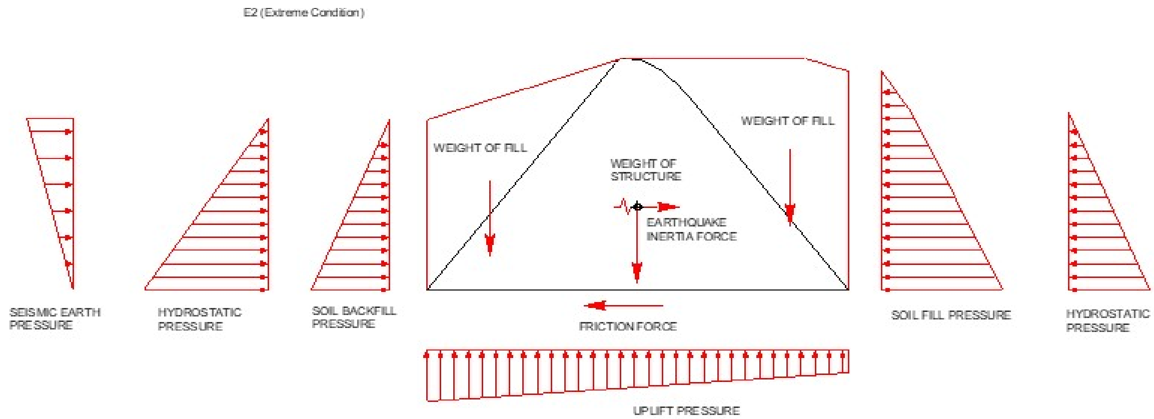
Centerline Eccentricity

e= B/2 - $\sum$ M/$\sum$ V
e = **0.3** m
('+' represents right of center)

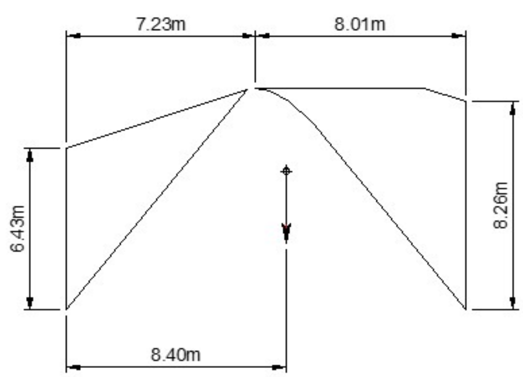


Foundation Pressure P = V/B±(1±6(e/B))
Upstream = 57 kPa
Downstream = 72 kPa

5. Extreme Condition 2 (E2)

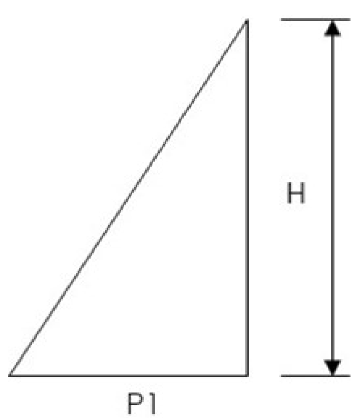


Fill



A = 52.7 m^3
x = 8.4 m

Soil fill upstream



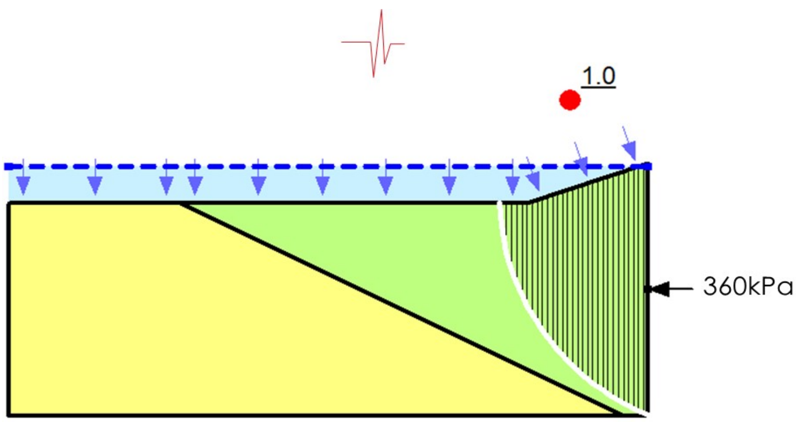
ϒ = 20 kN/m^3
ϒw = 9.81 kN/m^3
Ka = 0.21

H = 6.43 m

P1 = 13.8 kN/m^2

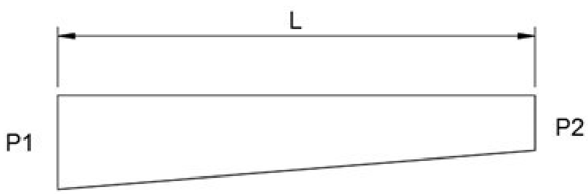
F = 44.2 kN/m
y = 2.1 m

Soil Dynamic Load



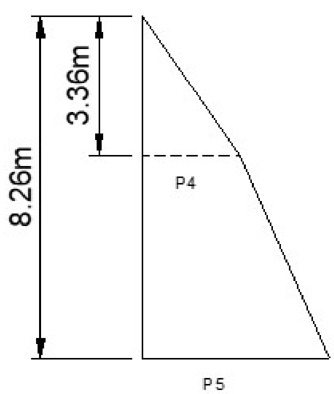
a =	0.26 g
P_{AE} =	360 kN
ΔP_{AE} =	191.4 kN
y =	5.87 m

Uplift force



ϒw =	9.81 kN/m^3
H1 (toe)=	6.5 m
H2 (heel)=	4.9 m
P1 (toe) =	63.8 kN/m^2
P2 (heel) =	48.1 kN/m^2
F =	852.2 kN/m
x =	8.0 m

Soil fill downstream



ϒ =	20 kN/m^3
Ka =	0.21
H =	8.26 m
h=	3.36 m
P4 =	14.1 kN/m^2
P5 =	24.6 kN/m^2
F =	118.5 kN/m
y =	2.966 m

Extreme Condition 2 (E2)

	A (m^2)	H (m)	Υ (kN/m^3)	Vert. (kN/m)	Hor. (kN/m)	Xo (m)	Yo (m)	Mo (kN m/m)
HF Structure	72.7		23.5	1708.1		7.62		13015.7
Dynamic RCC Load	72.7		23.5		296.1		3.15	-932.6
Hydrostatic upstr.		6.5	9.81		124.3		2.17	-269.4
Hydrostatic downstr.		4.9	9.81		-117.8		1.63	192.4
Soil fill downstr.		8.26	20		118.5		2.97	-352
Soil dynamic load					191.4		5.87	-1123.0
Cover fill	52.7		20	1054.474		6.84		7212.602
Uplift			9.81	-671.0		8.0		-5352.2
Soil fill upstr.		6.43	20		44.2		2.14	94.8
Resisting F				2762.6	-117.8			
Driving F				-671.0	774.6			
Sum F				**2092**	**657**			**12486.6**
Sliding (∑ V *μ)					**-1025**			

FS = ∑V/Uplift Flotation **FS = 4.1**
FS = (∑V*δ)/∑H Sliding **FS = 1.6**

Centerline Eccentricity

e= B/2 - ∑ M/∑ V

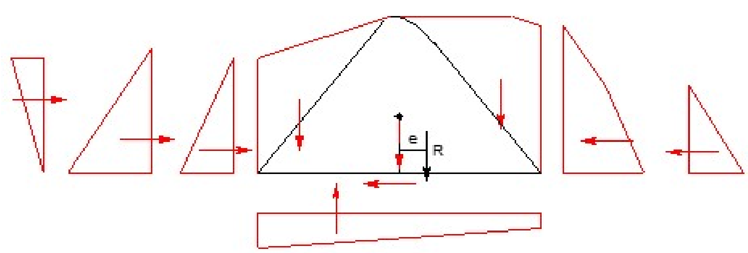
e = **1.7** m

('+' represents right of center)

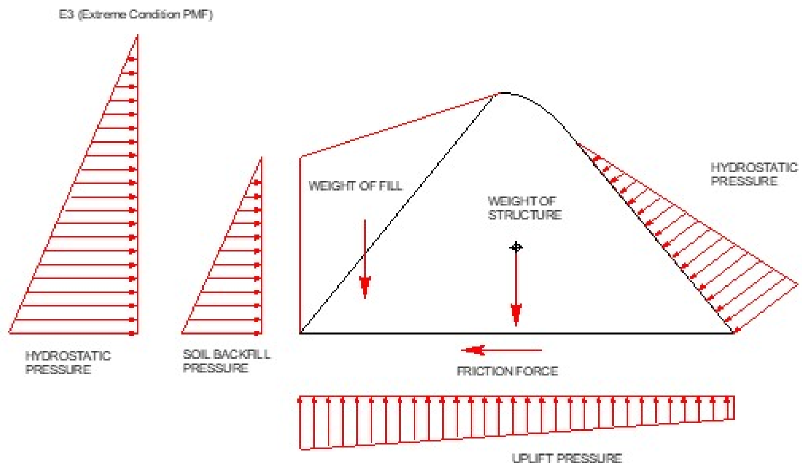
Foundation Pressure P = V/B±(1±6(e/B))

Upstream = 48 kPa

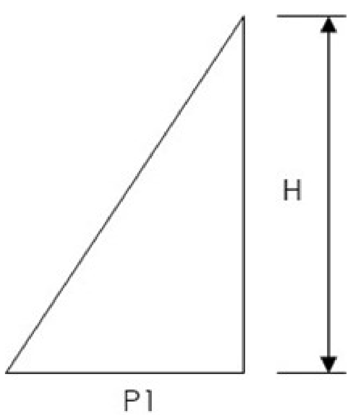
Downstream = 226 kPa



6. Extreme Condition (PMF)

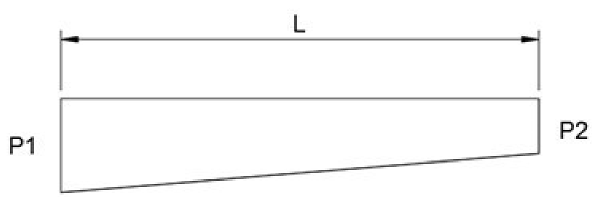


Soil fill upstream



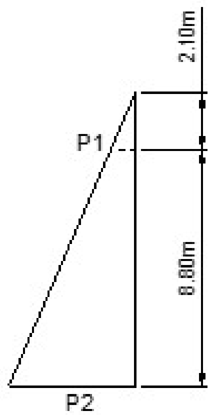
ϒ =	20	kN/m^3
ϒw =	9.81	kN/m^3
Ka =	0.21	
H =	6.43	m
P1 =	13.8	kN/m^2
F =	44.2	kN/m
y =	2.1	m

Uplift force



ϒw =	9.81	kN/m^3
H1 (toe)=	10.9	m
H2 (heel)=	7	m
P1 (toe) =	106.9	kN/m^2
P2 (heel) =	68.7	kN/m^2
F =	1338.1	kN/m
x =	8.2	m

Hydrostatic Pressure (upstream)



ϒ =	9.8	kN/m^3
h1 =	2.1	m
H =	8.8	m
P1 =	20.6	kN/m^2
P2 =	106.8	kN/m^2
F =	560.6	kN/m
y =	3.4	m

Extreme Condition (PMF)

	A (m^2)	H (m)	ϒ (kN/m^3)	Vert. (kN/m)	Hor. (kN/m)	Xo (m)	Yo (m)	Mo (kN m/m)
HF Structure	72.7		23.5	1708.1		7.62		13015.7
Hydrostatic upstr.					560.6		3.4	-1909.9
Hydrostatic downstr.	19.34	7	9.81	113.8	-144.2		2.3	336.5
Soil fill upstr.		6.43	20.0		44.2		2.9	-128
Uplift				-1338.1		8.2		-10936.5
Soil fill downstr.								
Resisting F				1821.9	-144.2			
Driving F				-1338.1	604.8			
Sum F				484	461			377.4
Sliding (∑ V *µ)					-237			

FS = ∑V/Uplift	Flotation	**FS =**	**1.4**
FS = (∑V*δ)/∑H	Sliding	**FS =**	**0.5**

Centerline Eccentricity

e= B/2 - ∑ M/∑ V

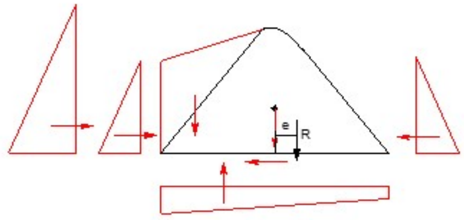
e = **6.8** m

('+' represents right of center)

Foundation Pressure P = V/B±(1±6(e/B))

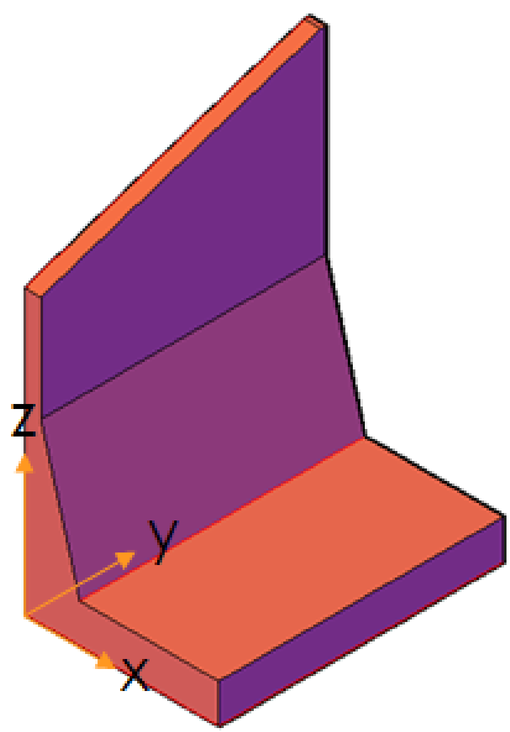
Upstream = -54 kPa

Downstream = 117 kPa



Appendix E.3-2 TRANSITION WALL STABILITY CALCULATIONS

SECTION 1



Section 1

	U1	UN1	UN2	UN3	E1	E2
Sliding FS	1.80	-	1.57	1.63	1.62	2.03
Uplift FS	3.17	-	2.24	2.14	2.05	3.57
Excentricity (m)	0.76	-	0.60	0.71	0.67	1.99
Max. Foundation pressure (kPa)	261.3	-	225.2	211.6	201.8	406.8
Min. Foundation Pressure (KPa)	21.2	-	3.8	8.2	10.0	0.0
Hardfill δ (mm)	0.70	-	0.80	1.50	1.30	1.90

Section 1: Usual Condition (U1)

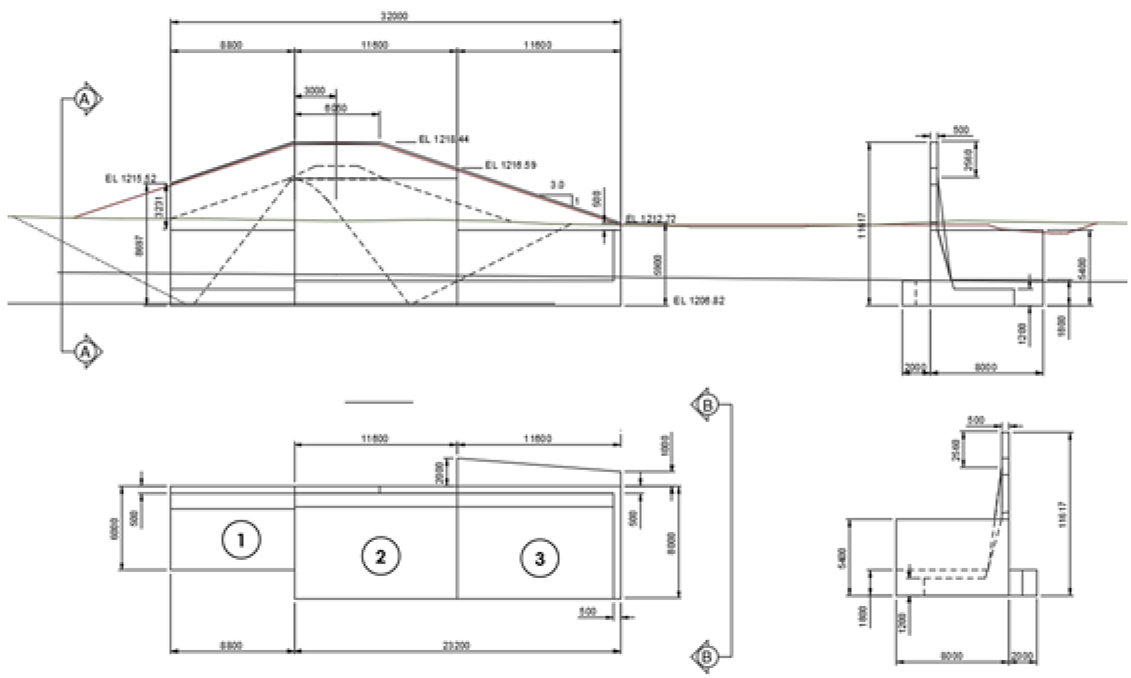
Loading	Horizontal Forces Force (MN)	Horizontal Forces Arm (m)	Vertical Forces Force (MN)	Vertical Forces Arm (m)	Stabilizing Moments (MN-m)	Overturning Moments (MN-m)
Weight of Structure			3.0	1.8	5.2	
Earthquake Inertia Force						
Soil Mass, front of wall						
Soil Mass, back of wall			8.0	3.4	26.9	
Soil Pressure, front of wall	0.79	3.14			2.5	
Soil Pressure, back of wall	-2.97	3.38				10.0
Soil Dynamic Pressure, back of wall						
Uplift			-3.4	3.0		10.3
Hydrostatic pressure, front of wall	0.82	2.87			2.4	
Hydrostatic pressure, back of wall	-1.91	2.22				4.2
Hydrostatic weight, front of wall						
Hardfill	1.41	3.13			4.42	
SUM	**-1.86**		**7.46**		**41.32**	**24.59**
					Net Moment	
					16.73	

Stability Calculations
Retaining Wall - Auxiliary Spillway
Right Abutment Transition to Berm

Scope:

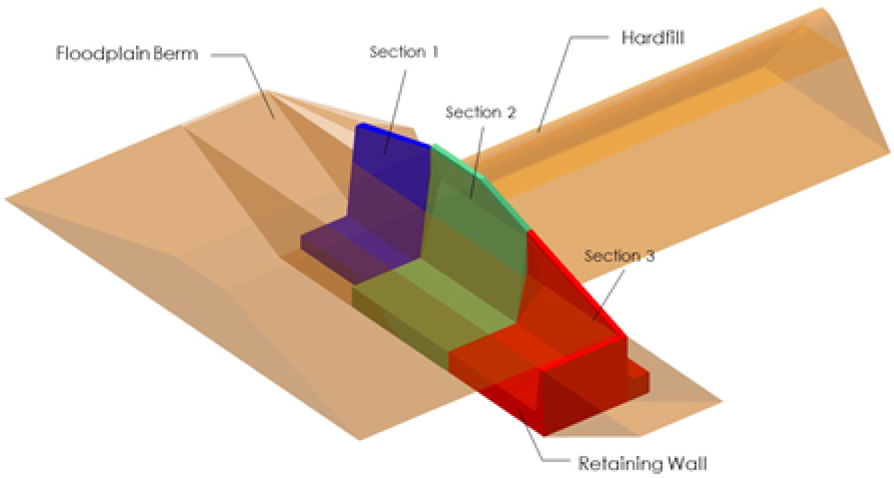
Evaluate the stability of the transition wall of the Auxiliary Spillway. Consider the 3D effects on the structure's stability.

Structure Geometry:



dimensions in mm

Isometric View:



Load Condition

	Elevation (m)			
	Headwater	**Tailwater**	**Headwater**	**Tailwater**
1. Usual Condition (U1)	1214.0	1211.9	7.0	4.9
2. Unusual Condition 1 (UN1)	1214.0	1211.9	7.0	4.9
3. Unusual Condition 2 (UN2)	1216.5	1213.1	9.5	6.1
4. Unusual Condition 3 (UN3)	1217.0	1213.1	10.0	6.1
5. Extreme Condition 1 (E1-F)	1217.3	1213.8	10.3	6.8
6. Extreme Condition 2 (E2-Q)	1213.5	1211.9	6.5	4.9

User Input

Material Properties:

Unit Weight of Water: $\gamma_w := 9.81 \frac{kN}{m^3}$ (Section 7.2, Design Criteria)

Unit Weight of Concrete: $\gamma_c := \mathbf{23.5} \frac{kN}{m^3}$

Unit Weight of Soil (Moist): $\gamma_m := 20.0 \frac{kN}{m^3}$ (Section 5.3, Design Criteria) assumed moisture content (w) = 5%

Unit Weight Soil (Saturated): $\gamma_{sat} := 22.0 \frac{kN}{m^3}$ (Assuming Specific Gravity = 2.7)

Unit Weight Soil (buoyant): $\gamma_b := \gamma_{sat} - \gamma_w = 12.19 \cdot \frac{kN}{m^3}$

Weight of Soil/Concrete above toe: $\gamma_{toe} := 22.0 \frac{kN}{m^3}$

Unit Weight of Rock: $\gamma_r := 25.6 \frac{kN}{m^3}$ (Section 7.2, Design Criteria)

Usual Condition (U1)

Acceptance Parameters

Resultant Location (Overturning and Bearing Pressure):

Unusual (UN) Resultant located inside middle third (kern) equals 100% base in compression (AT/WCS Guidelines, Section 8.4)

$$\mathbf{B}_{\mathbf{\%basecomp.req}} := 100\%$$

Allowable rock bearing pressure: $\mathbf{qall} := 622 \frac{\mathbf{kN}}{\mathbf{m}^2}$ (Internal Geotechnical Design Recommendations Rev. Sept 12, 2018, Section 5.3)

FS Sliding:

Usual (U1) 1.5 (without cohesion) (CDA Guidelines, Table 6-4, AT/WCS Guidelines, Section 8.3)

Req'd Factor of Safety for Sliding: $\mathbf{FS}_{\mathbf{sliding.req}} := 1.5$ (Without Cohesion)

FS Floatation:

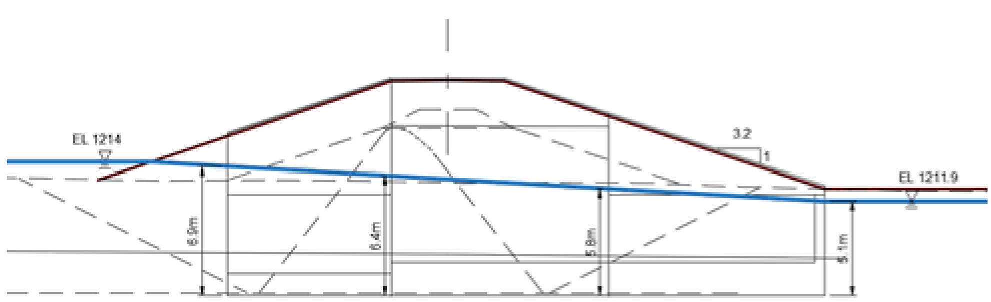
Usual (U1) 1.5 (AT/WCS Guidelines, Section 8.5)

Req'd Factor of Safety for Floatation: $\mathbf{FS}_{\mathbf{float.req}} := 1.5$

Water Surface Elevations

Headwater $\mathbf{H}_{\mathbf{H}} := 1214\mathbf{m}$

Tailwater $\mathbf{H}_{\mathbf{T}} := 1211.9\mathbf{m}$



$\mathbf{h}_{\mathbf{1}} := 6.9\mathbf{m}$ $\mathbf{h}_{\mathbf{2}} := 6.4\mathbf{m}$ $\mathbf{h}_{\mathbf{3}} := 5.8\mathbf{m}$ $\mathbf{h}_{\mathbf{4}} := 5.1\mathbf{m}$

Interpolated water table heights from retaining wall base.

Section 1

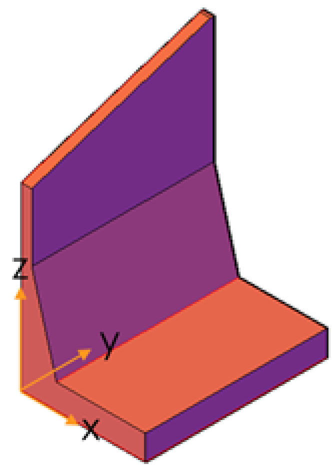
Wall Geometry:

User Input

Top of Wall Elevation:	$T_w := 1218.44 \cdot m$
Top of Footing Elevation:	$Top_{ftg} := 1208.02 \cdot m$
Thickness of Footing:	$t_{ftg} := 1.20m$
Bottom of Footing Elevation:	$Bot_{ftg} := Top_{ftg} - t_{ftg} = 1206.82\ m$
Overall Height of wall:	$h_w := T_w - Bot_{ftg} = 11.620\ m$
Thickness of Stem Wall at Top:	$t_{wt} := 0.5m$
Slope of Heel Batter:	$S_{batter} := 0.125$
Thickness of Stem Wall at Base:	$t_{wb} := 1.7m$
Length of toe:	$L_{ab} := 0m$
Total Length of Footing:	$b := 6m$
Length of heel:	$L_{cd} := b - L_{ab} - t_{wb} = 4.3\ m$
Width of Wall:	$B := 8.8m$

Retaining Wall

Retaining Wall Volume and Gravity Center (Using AutoCAD 3D: File: 3D Transition Wall Analysis Section 1.dwg)



Isometric View

Volume

$Vol_{RW} := 125.447\ m^3$

$X_{RW} := 1.756m$

$Y_{RW} := 4.475m$

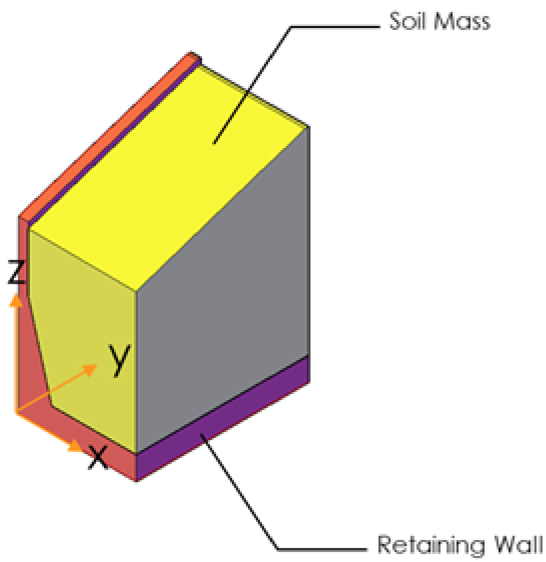
$Z_{RW} := 0m$

Retaining wall total weight $W_{RW} := Vol_{RW} \cdot \gamma_c = 2.95 \cdot MN$

Soil Mass

Retained Soil Volume and Gravity Center (Using AutoCAD 3D: File 3D Transition Wall Analysis Section 1.dwg)

Isometric View:



$\mathbf{Vol_{soil}} := \mathbf{397.702\ m^3}$

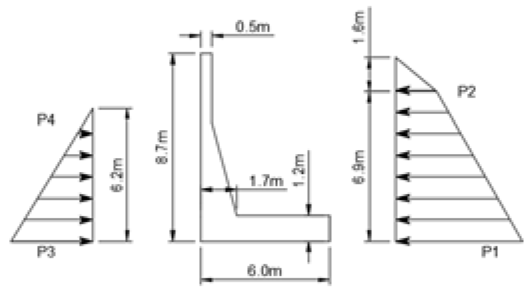
$\mathbf{X_{soil}} := \mathbf{3.382m}$

$\mathbf{Y_{soil}} := \mathbf{4.662m}$

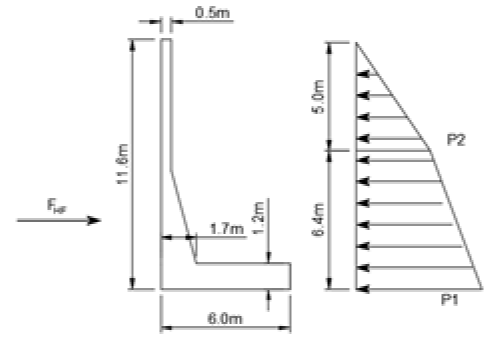
$\mathbf{Z_{soil}} := 0\mathbf{m}$

Soil mass total weight $\quad \mathbf{W_{soilb}} := \mathbf{Vol_{soil}} \cdot \gamma_{\mathbf{m}} = 7.95 \cdot \mathbf{MN}$

Soil Pressure



Section1



Section 2

Section 1

Back of Retaining Wall

depth to water table $\mathbf{dw} := 1.6\mathbf{m}$

saturated soil depth $\mathbf{ds} := 6.9\mathbf{m}$

soil pressure at rest coefficient $\mathbf{Ko} := 0.55$

$$\mathbf{P2} := \gamma_{\mathbf{m}} \cdot \mathbf{dw} \cdot \mathbf{Ko} = 17.6 \cdot \mathbf{kPa}$$

$$\mathbf{P1} := \mathbf{P2} + \gamma_{\mathbf{b}} \cdot \mathbf{ds} \cdot \mathbf{Ko} = 63.861 \cdot \mathbf{kPa}$$

Front of Retaining Wall

depth to water table $\mathbf{dw} := 0$

saturated soil depth $\mathbf{ds} := 6.2\mathbf{m}$

soil pressure at rest coefficient $\mathbf{Ko} := 0.55$

$$\mathbf{P4} := \gamma_{\mathbf{m}} \cdot \mathbf{dw} \cdot \mathbf{Ko} = 0 \cdot \mathbf{kPa}$$

$$\mathbf{P3} := \mathbf{P2} + \gamma_{\mathbf{b}} \cdot \mathbf{ds} \cdot \mathbf{Ko} = 59.168 \cdot \mathbf{kPa}$$

Section 2

depth to water table $\mathbf{dw} := 5.0\mathbf{m}$

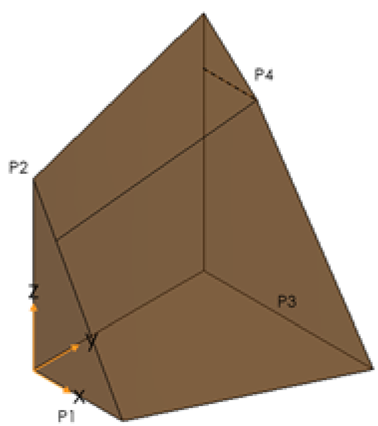
saturated soil depth $\mathbf{ds} := 6.4\mathbf{m}$

soil pressure at rest coefficient $\mathbf{Ko} := 0.55$

$$\mathbf{P1} := \gamma_{\mathbf{m}} \cdot \mathbf{dw} \cdot \mathbf{Ko} = 55 \cdot \mathbf{kPa}$$

$$\mathbf{P2} := \mathbf{P1} + \gamma_{\mathbf{b}} \cdot \mathbf{ds} \cdot \mathbf{Ko} = 97.909 \cdot \mathbf{kPa}$$

Isometric view of the prism representing soil pressures against the retaining wall (Using AutoCAD 3D: 3D Transition Wall Analysis Section 1.dwg). The volume of the prism is equal to the equivalent total force.



Isometric View

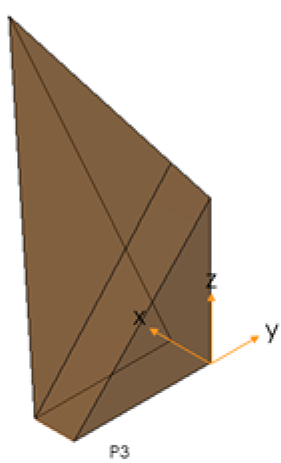
Total Force Back Soil

$\mathbf{F_{soilb}} := \mathbf{2966.57\ kN}$

$\mathbf{X_{Fsoilb}} := 0\mathbf{m}$

$\mathbf{Y_{Fsoilb}} := \mathbf{5.257\,m}$

$\mathbf{Z_{Fsoilb}} := \mathbf{3.376\,m}$



Total Force Front Soil

$\mathbf{F_{soilf}} := \mathbf{787.47kN}$

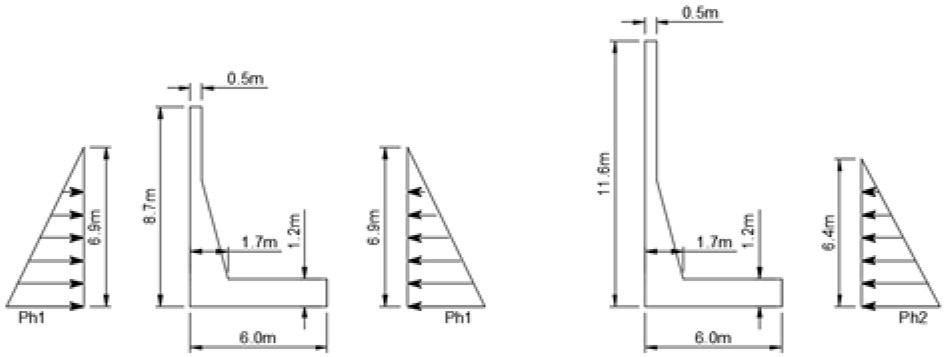
$\mathbf{X_{Fsoilf}} := 0\mathbf{m}$

$\mathbf{Y_{Fsoilf}} := \mathbf{2.391m}$

$\mathbf{Z_{Fsoilf}} := \mathbf{3.144m}$

Hydrostatic Forces

Side View



Section 1 Section 2

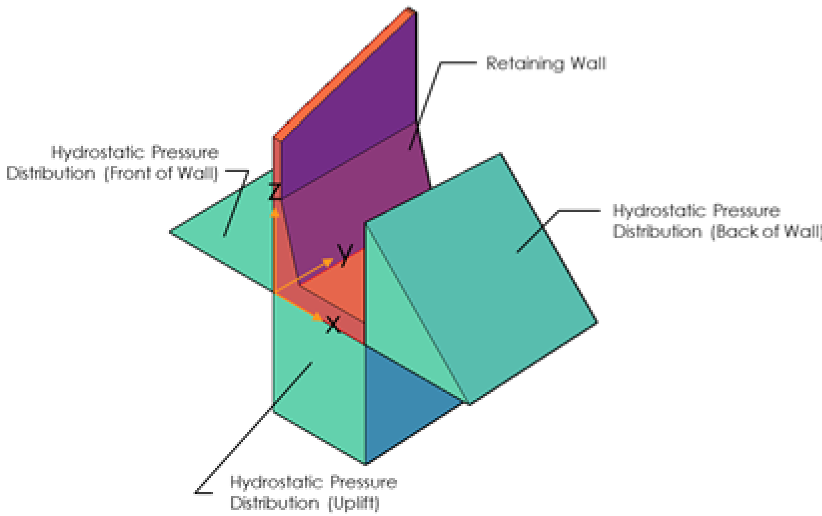
Front of Wall $\mathbf{h_f} := 6.9\mathbf{m}$

Back of Wall $\mathbf{h_b} := 6.4\mathbf{m}$

$$\mathbf{Ph1} := \mathbf{h_f} \cdot \gamma_{\mathbf{w}} = 67.69 \cdot \mathbf{kPa}$$

$$\mathbf{Ph2} := \mathbf{h_b} \cdot \gamma_{\mathbf{w}} = 62.78 \cdot \mathbf{kPa}$$

Isometric View



Total Hydrostatic Force

Back of Wall

$H_{Fu} := 1909.68\,kN$

$X_{Fu} := 0m$

$Y_{Fu} := 4.290m$

$Z_{Fu} := 2.219m$

Volume and centroid of hydrostatic pressure was determined using AutoCAD 3D: File: 3D Transition Wall Analysis Section 1.dwg

Total Hydrostatic Force

Front of Wal

$H_{Ft} := 820.24\,kN$

$X_{Ft} := 0m$

$Y_{Ft} := 1.971m$

$Z_{Ft} := 2.869m$

Volume and centroid of hydrostatic pressure was determined using AutoCAD 3D: File: 3D Transition Wall Analysis Section 1.dwg

Uplift

Total Uplift Force

$F_{uplift} := 3444.41\,kN$

$X_{uplift} := 3.000m$

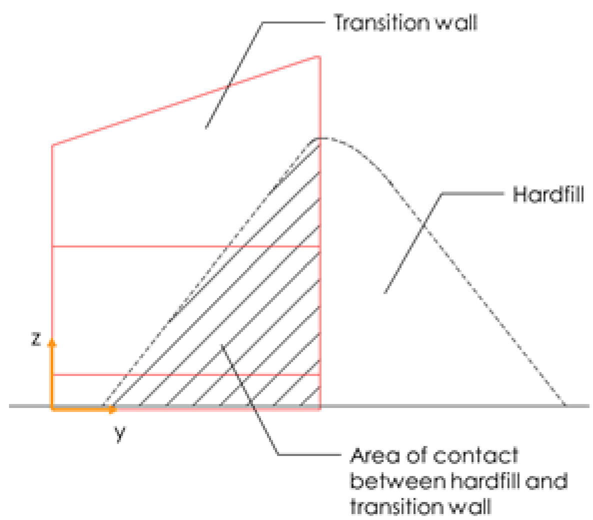
$Y_{uplift} := 4.345m$

$Z_{uplift} := 0m$

Volume and centroid of hydrostatic pressure was determined using AutoCAD 3D: File: 3D Transition Wall Analysis Section 1.dwg

Hardfill Contact Area and Resultant Resistant Force

Front View



Area of Contact $Ac := 32.1753\ m^2$

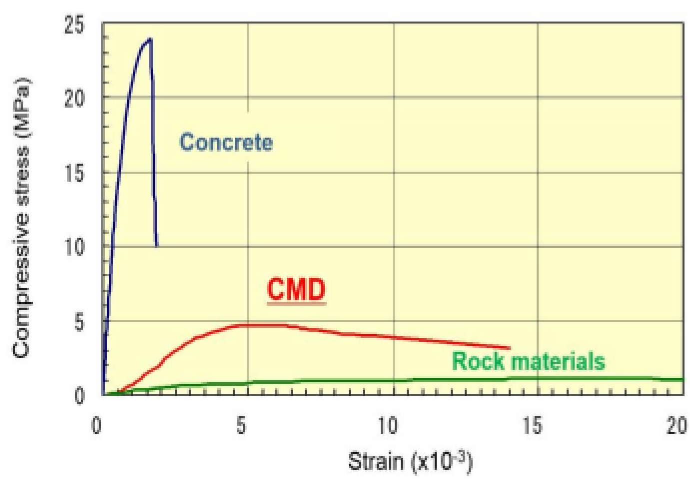
Centroid of contact area was determined using Autocad: File Training Wall.dwg

$X_{HF} := 0m$

$Y_{HF} := 6.4208m$

$Z_{HF} := 3.1349m$

Hard Fill Stiffness



Source: Noorzad et al. (2017). An Innovative Approach toward Dam Design and Construction. 2nd Workshop on Cement Materials Dams (CMD). July 3, 2017.

$$E_{HF} := \frac{5\mathbf{MPa}}{5 \times \mathbf{10}^{-3}} = 1 \cdot \mathbf{GPa}$$ Approximate Hardfill Modulus of Elasticity

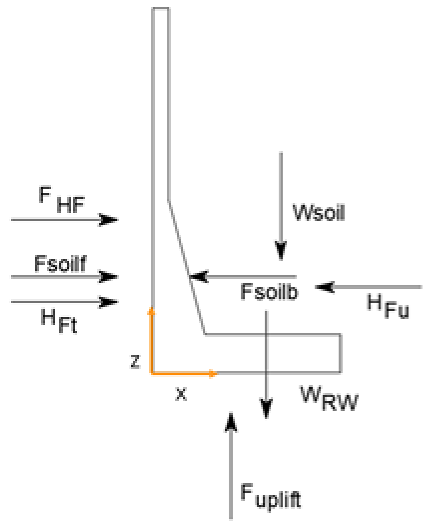
$L_{HF} := 16\mathbf{m}$ Hardfill section length (between construction joints)

Approximate hardfill stiffness $$k_{HF} := \frac{E_{HF}}{L_{HF}} = 62500 \cdot \frac{\mathbf{kN}}{\mathbf{m}^3}$$

Considering a deformation of the hardfill of : $\delta_{HF} := 0.7\mathbf{mm}$

The total reaction of the hardfill is: $F_{HF} := k_{HF} \cdot Ac \cdot \delta_{HF} = 1.41 \cdot \mathbf{MN}$ < 5MPa

Vector Forces Summary



Body diagram, side view

Weight Retaining Wall $\mathbf{W_{RW}} := \begin{pmatrix} 0 & 0 & -\mathbf{W_{RW}} \end{pmatrix} = (0 \quad 0 \quad -2.95)\cdot\mathbf{MN}$

Weight Soil (Back of Wall) $\mathbf{W_{soilb}} := \begin{pmatrix} 0 & 0 & -\mathbf{W_{soilb}} \end{pmatrix} = (0 \quad 0 \quad -7.95)\cdot\mathbf{MN}$

Soil Pressure (Back of Wall) $\mathbf{F_{soilb}} := \begin{pmatrix} -\mathbf{F_{soilb}} & 0 & 0 \end{pmatrix} = (-2.97 \quad 0 \quad 0)\cdot\mathbf{MN}$

Soil Pressure (Front of Wall) $\mathbf{F_{soilf}} := \begin{pmatrix} \mathbf{F_{soilf}} & 0 & 0 \end{pmatrix} = (0.79 \quad 0 \quad 0)\cdot\mathbf{MN}$

Hydrostatic Force (Back of Wall) $\mathbf{H_{Fu}} := \begin{pmatrix} -\mathbf{H_{Fu}} & \mathbf{0} & 0 \end{pmatrix} = (-1.91 \quad 0 \quad 0)\cdot\mathbf{MN}$

Hydrostatic Force (Front of Wall) $\mathbf{H_{Ft}} := \begin{pmatrix} \mathbf{H_{Ft}} & 0 & 0 \end{pmatrix} = (0.82 \quad 0 \quad 0)\cdot\mathbf{MN}$

Uplift Force $\mathbf{F_{uplift}} := \begin{pmatrix} 0 & 0 & \mathbf{F_{uplift}} \end{pmatrix} = (0 \quad 0 \quad 3.44)\cdot\mathbf{MN}$

Resistance force by Hardfill $\mathbf{F_{HF}} := \begin{pmatrix} \mathbf{F_{HF}} & 0 & 0 \end{pmatrix} = (1.41 \quad 0 \quad 0)\cdot\mathbf{MN}$

Resultant Total Force

$$\mathbf{F} := \mathbf{W_{RW}} + \mathbf{W_{soilb}} + \mathbf{F_{soilb}} + \mathbf{F_{soilf}} + \mathbf{H_{Fu}} + \mathbf{H_{Ft}} + \mathbf{F_{uplift}} + \mathbf{F_{HF}}$$

$$\mathbf{F} = (-1.86 \quad 0 \quad -7.46)\cdot\mathbf{MN}$$

Structure Stability

1. Sliding

$$236.6\mathbf{m}^3\cdot\gamma_\mathbf{w} = 2.32\cdot\mathbf{MN}$$

Coefficient of sliding friction $\mu := 0.45$

$$\mathbf{FoS} := \frac{\mathbf{F}_{0,2}\cdot\mu}{\mathbf{F}_{0,0}} = 1.8 \qquad > \qquad \mathbf{FS_{sliding.req}} = 1.5 \qquad \mathbf{OK}$$

2. Uplift

Summatory of Axial Resistant Forces

$$\mathbf{F_R} := \mathbf{W_{RW}} + \mathbf{W_{soilb}} = (0 \quad 0 \quad -10.9)\cdot\mathbf{MN}$$

Uplift Force

$$\mathbf{F_{uplift}} = (0 \quad 0 \quad 3.44)\cdot\mathbf{MN}$$

$$\mathbf{FoS_{uplift}} := \frac{\left|\mathbf{F_R}_{0,2}\right|}{\left|\mathbf{F_{uplift}}_{0,2}\right|} = 3.17 \qquad > \qquad \mathbf{FS_{float.req}} = 1.5 \qquad \mathbf{OK}$$

3. Overturning

$\mathbf{r_{RW}} := \left(\mathbf{X_{RW}} \quad Y_{RW} \quad Z_{RW} \right) = (1.76 \quad 4.47 \quad 0)\,\mathbf{m}$

$\mathbf{r_{soilb}} := \left(X_{soil} \quad Y_{soil} \quad Z_{soil} \right) = (3.38 \quad 4.66 \quad 0)\,\mathbf{m}$

$\mathbf{r_{Fsoilb}} := \left(X_{Fsoilb} \quad Y_{Fsoilb} \quad Z_{Fsoilb} \right) = (0 \quad 5.26 \quad 3.38)\,\mathbf{m}$

$\mathbf{r_{Fsoilf}} := \left(X_{Fsoilf} \quad Y_{Fsoilf} \quad Z_{Fsoilf} \right) = (0 \quad 2.39 \quad 3.14)\,\mathbf{m}$

$\mathbf{r_{Fu}} := \left(X_{Fu} \quad Y_{Fu} \quad Z_{Fu} \right) = (0 \quad 4.29 \quad 2.22)\,\mathbf{m}$

$\mathbf{r_{Ft}} := \left(X_{Ft} \quad Y_{Ft} \quad Z_{Ft} \right) = (0 \quad 1.97 \quad 2.87)\,\mathbf{m}$

$\mathbf{r_{uplift}} := \left(X_{uplift} \quad Y_{uplift} \quad Z_{uplift} \right) = (3 \quad 4.34 \quad 0)\,\mathbf{m}$

$\mathbf{r_{HF}} := \left(\mathbf{X_{HF}} \quad \mathbf{Y_{HF}} \quad \mathbf{Z_{HF}} \right) = (0 \quad 6.42 \quad 3.13)\,\mathbf{m}$

$$\mathbf{M} := \mathbf{W_{RW}}^T \times \mathbf{r_{RW}}^T + \mathbf{W_{soilb}}^T \times \mathbf{r_{soilb}}^T + \mathbf{F_{soilb}}^T \times \mathbf{r_{Fsoilb}}^T + \mathbf{F_{HF}}^T \times \mathbf{r_{HF}}^T \cdots$$
$$+ \mathbf{F_{soilf}}^T \times \mathbf{r_{Fsoilf}}^T + \mathbf{H_{Fu}}^T \times \mathbf{r_{Fu}}^T + \mathbf{H_{Ft}}^T \times \mathbf{r_{Ft}}^T + \mathbf{F_{uplift}}^T \times \mathbf{r_{uplift}}^T$$

$$\mathbf{M} = \begin{pmatrix} 35.31 \\ -16.73 \\ -11.25 \end{pmatrix} \cdot \mathbf{MN} \cdot \mathbf{m}$$

$$\mathbf{F} = (-1.86 \quad 0 \quad -7.46) \cdot \mathbf{MN}$$

Location of resultant force:

$$\mathbf{X_R} := \left| \frac{\mathbf{M}_{1,0}}{\mathbf{F}_{0,2}} \right| = 2.24 \cdot \mathbf{m}$$

$$\mathbf{x} := \left| \mathbf{X_R} - \frac{\mathbf{b}}{2} \right| = 0.76\,\mathbf{m} \quad < \quad \frac{\mathbf{b}}{6} = 1\,\mathbf{m} \qquad \mathbf{OK}$$

4. **Bearing Capacity**

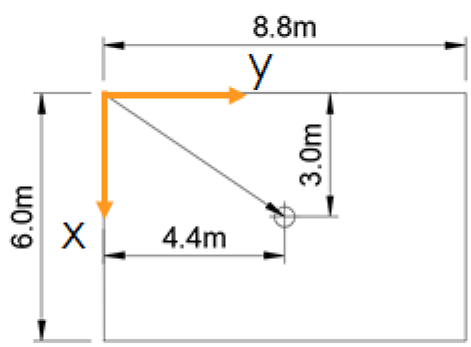
$$\mathbf{q_{all}} := 622\,\mathbf{kPa}$$

Force and Moment at origin:

$$\mathbf{F} = \begin{pmatrix} -1.86 & 0 & -7.46 \end{pmatrix} \cdot \mathbf{MN} \qquad \mathbf{M} = \begin{pmatrix} 35.31 \\ -16.73 \\ -11.25 \end{pmatrix} \mathbf{m} \cdot \mathbf{MN}$$

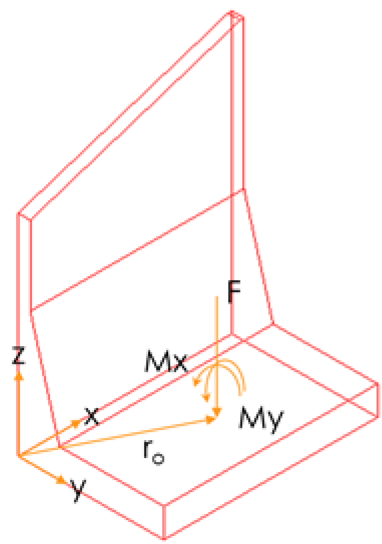
Vector to center of foundation:

$$\mathbf{r_o} := \begin{pmatrix} 3 & 4.4 & 0 \end{pmatrix} \mathbf{m}$$



Moment at center of Foundation

$$\mathbf{M_o} := \mathbf{M} - \mathbf{F}^{\mathbf{T}} \times \mathbf{r_o}^{\mathbf{T}} = \begin{pmatrix} 2.49 \\ 5.64 \\ -3.06 \end{pmatrix} \mathbf{m} \cdot \mathbf{MN}$$



$$\mathbf{Ix_o} := \frac{1}{12} \cdot \mathbf{b}^3 \cdot \mathbf{B} = 158.4\,\mathbf{m}^4$$

$$\mathbf{Iy_o} := \frac{1}{12} \cdot \mathbf{b} \cdot \mathbf{B}^3 = 340.736\,\mathbf{m}^4$$

$$\mathbf{A} := \mathbf{b} \cdot \mathbf{B} = 52.8\,\mathbf{m}^2$$

$$\sigma_{\mathbf{max}} := \left|\frac{\mathbf{F}_{0,2}}{\mathbf{A}}\right| + \left|\frac{\mathbf{M_o}_{0,0} \cdot \mathbf{b}}{2 \cdot \mathbf{Ix_o}}\right| + \left|\frac{\mathbf{M_o}_{1,0} \cdot \mathbf{B}}{2 \cdot \mathbf{Iy_o}}\right| = 261.313 \cdot \mathbf{kPa} < \quad \mathbf{q_{all}} = 622 \cdot \mathbf{kPa} \qquad \mathbf{OK}$$

$$\sigma_{\mathbf{min}} := \left|\frac{\mathbf{F}_{0,2}}{\mathbf{A}}\right| - \left|\frac{\mathbf{M_o}_{0,0} \cdot \mathbf{b}}{2 \cdot \mathbf{Ix_o}}\right| - \left|\frac{\mathbf{M_o}_{1,0} \cdot \mathbf{B}}{2 \cdot \mathbf{Iy_o}}\right| = 21.173 \cdot \mathbf{kPa} \quad < \quad \mathbf{q_{all}} = 622 \cdot \mathbf{kPa} \qquad \mathbf{OK}$$

TP **Section 1: Unusual Condition 2 (UN2)**

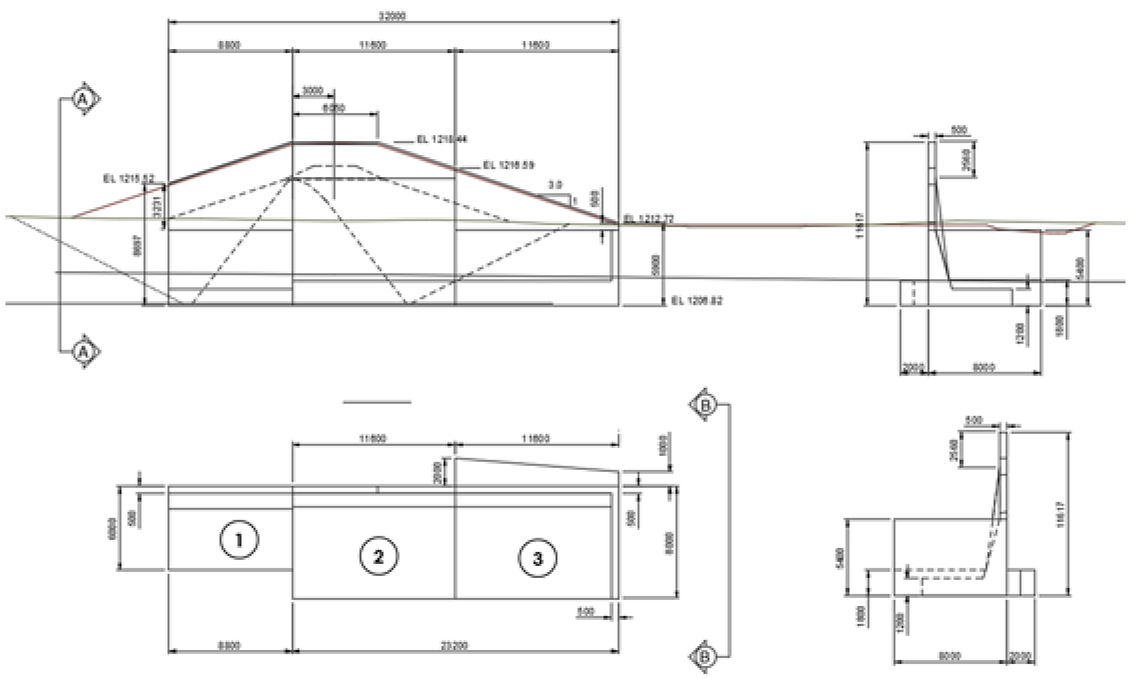
Loading	Horizontal Forces Force (MN)	Horizontal Forces Arm (m)	Vertical Forces Force (MN)	Vertical Forces Arm (m)	Stabilizing Moments (MN-m)	Overturning Moments (MN-m)
Weight of Structure			3.0	1.8	5.2	
Earthquake Inertia Force						
Soil Mass, front of wall						
Soil Mass, back of wall			8.0	3.4	26.9	
Soil Pressure, front of wall	0.79	3.14			2.5	
Soil Pressure, back of wall	-2.97	3.38				10.0
Soil Dynamic Pressure, back of wall						
Uplift			-4.9	3.0		14.6
Hydrostatic pressure, front of wall	1.88	4.20			7.9	
Hydrostatic pressure, back of wall	-3.89	3.16				12.3
Hydrostatic weight, front of wall						
Hardfill	2.41	3.13			7.5433	
SUM	**-1.78**		**6.04**		**50.00**	**36.85**
					Net Moment	
					13.15	

Stability Calculations
Retaining Wall - Auxiliary Spillway
Right Abutment Transition to Berm

Scope:

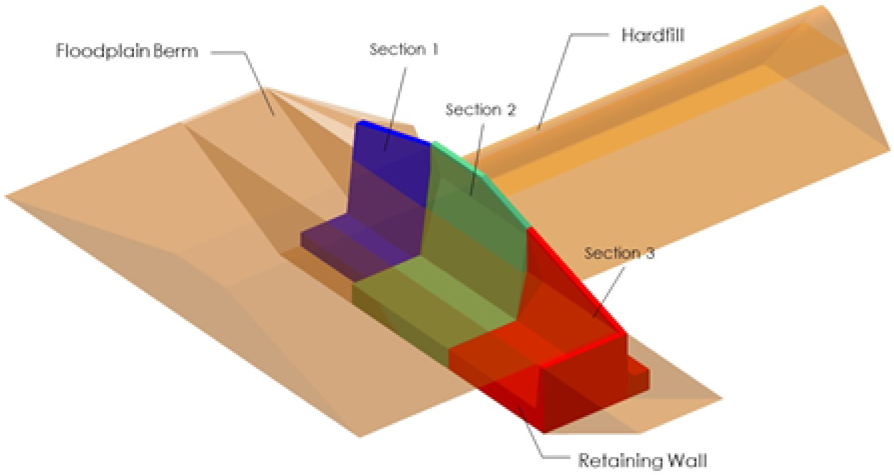
Evaluate the stability of the transition wall of the Auxiliary Spillway. Consider the 3D effects on the structure's stability.

Structure Geometry:



dimensions in mm

Isometric View:



Load Condition

	Elevation (m)			
	Headwater	Tailwater	Headwater	Tailwater
1. Usual Condition (U1)	1214.0	1211.9	7.0	4.9
2. Unusual Condition 1 (UN1)	1214.0	1211.9	7.0	4.9
3. Unusual Condition 2 (UN2)	1216.5	1213.1	9.5	6.1
4. Unusual Condition 3 (UN3)	1217.0	1213.1	10.0	6.1
5. Extreme Condition 1 (E1-F)	1217.3	1213.8	10.3	6.8
6. Extreme Condition 2 (E2-Q)	1213.5	1211.9	6.5	4.9

User Input

Material Properties:

Unit Weight of Water: $\gamma_w := 9.81 \frac{kN}{m^3}$ (Section 7.2, Design Criteria)

Unit Weight of Concrete: $\gamma_c := 23.5 \frac{kN}{m^3}$

Unit Weight of Soil (Moist): $\gamma_m := 20.0 \frac{kN}{m^3}$ (Section 5.3, Design Criteria) assumed moisture content (w) = 5%

Unit Weight Soil (Saturated): $\gamma_{sat} := 22.0 \frac{kN}{m^3}$ (Assuming Specific Gravity = 2.7)

Unit Weight Soil (buoyant): $\gamma_b := \gamma_{sat} - \gamma_w = 12.19 \cdot \frac{kN}{m^3}$

Weight of Soil/Concrete above toe: $\gamma_{toe} := 22.0 \frac{kN}{m^3}$

Unit Weight of Rock: $\gamma_r := 25.6 \frac{kN}{m^3}$ (Section 7.2, Design Criteria)

Unusual Condition 2 (UN2)

Acceptance Parameters

Resultant Location (Overturning and Bearing Pressure):

Unusual (UN) Resultant located inside middle third (kern) equals 100% base in compression (AT/WCS Guidelines, Section 8.4)

$$B_{\%basecomp.req} := 100\%$$

Allowable rock bearing pressure: $qall := 622 \frac{kN}{m^2}$ (Internal Geotechnical Design Recommendations Rev. Sept 12, 2018, Section 5.3)

FS Sliding:

Usual (U1) 1.5 (without cohesion) (CDA Guidelines, Table 6-4, AT/WCS Guidelines, Section 8.3)

Req'd Factor of Safety for Sliding: $FS_{sliding.req} := 1.5$ (Without Cohesion)

FS Floatation:

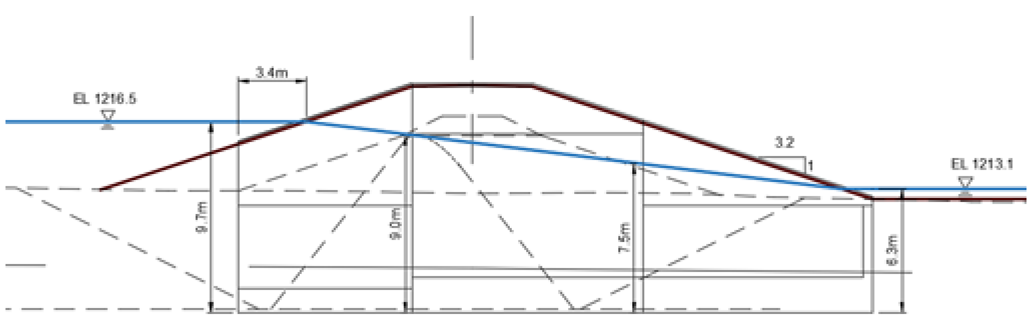
Usual (U1) 1.5 (AT/WCS Guidelines, Section 8.5)

Req'd Factor of Safety for Floatation: $FS_{float.req} := 1.5$

Water Surface Elevations

Headwater $H_H := 1216.5m$

Tailwater $H_T := 1213.1m$



$h_1 := 9.7m$ $h_2 := 9.0m$ $h_3 := 7.5m$ $h_4 := 6.3m$

Interpolated water table heights from retaining wall base.

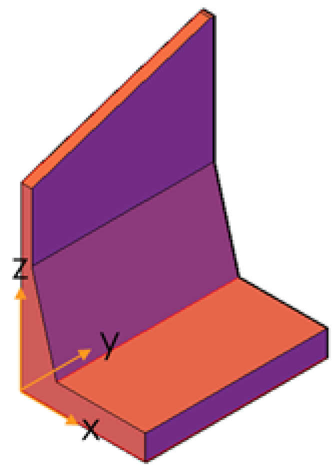
Section 1

Wall Geometry: User Input

Top of Wall Elevation:	$T_w := 1218.44 \cdot m$
Top of Footing Elevation:	$Top_{ftg} := 1208.02 \cdot m$
Thickness of Footing:	$t_{ftg} := 1.20m$
Bottom of Footing Elevation:	$Bot_{ftg} := Top_{ftg} - t_{ftg} = 1206.82\ m$
Overall Height of wall:	$h_w := T_w - Bot_{ftg} = 11.620\ m$
Thickness of Stem Wall at Top:	$t_{wt} := 0.5m$
Slope of Heel Batter:	$S_{batter} := 0.125$
Thickness of Stem Wall at Base:	$t_{wb} := 1.7m$
Length of toe:	$L_{ab} := 0m$
Total Length of Footing:	$b := 6m$
Length of heel:	$L_{cd} := b - L_{ab} - t_{wb} = 4.3\ m$
Width of Wall:	$B := 8.8m$

Retaining Wall

Retaining Wall Volume and Gravity Center (Using AutoCAD 3D: File: 3D Transition Wall Analysis Section 1.dwg)



Volume

$Vol_{RW} := 125.447\ m^3$

$X_{RW} := 1.756m$

$Y_{RW} := 4.475m$

$Z_{RW} := 0m$

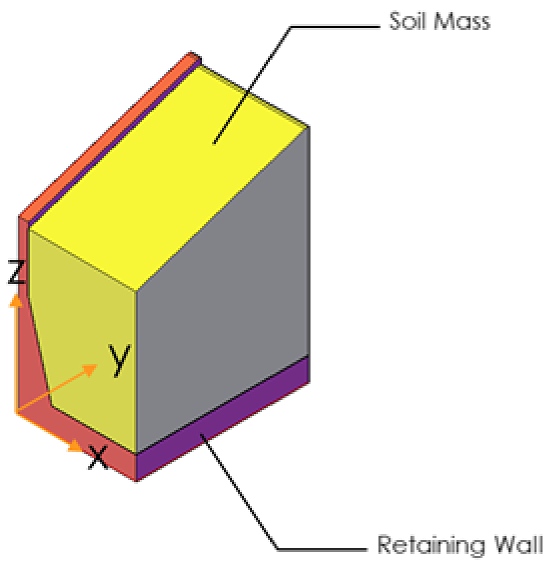
Isometric View

Retaining wall total weight $\quad W_{RW} := Vol_{RW} \cdot \gamma_c = 2.95 \cdot MN$

Soil Mass

Retained Soil Volume and Gravity Center (Using AutoCAD 3D: File 3D Transition Wall Analysis Section 1.dwg)

Isometric View:



$\mathbf{Vol_{soil}} := \mathbf{397.702\ m^3}$

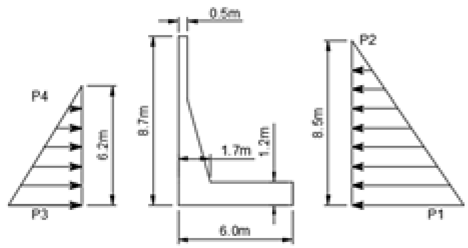
$\mathbf{X_{soil}} := \mathbf{3.382m}$

$\mathbf{Y_{soil}} := \mathbf{4.662m}$

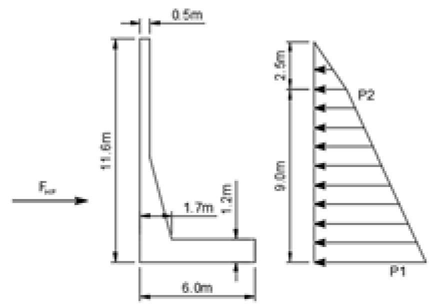
$\mathbf{Z_{soil}} := 0\mathbf{m}$

Soil mass total weight $\quad \mathbf{W_{soilb}} := \mathbf{Vol_{soil}} \cdot \gamma_{\mathbf{m}} = 7.95 \cdot \mathbf{MN}$

Soil Pressure



Section1



Section 2

Section 1

Back of Retaining Wall

depth to water table $\mathbf{dw} := 0\mathbf{m}$

saturated soil depth $\mathbf{ds} := 6.9\mathbf{m}$

soil pressure at rest coefficient $\mathbf{Ko} := 0.55$

$$\mathbf{P2} := \gamma_{\mathbf{m}} \cdot \mathbf{dw} \cdot \mathbf{Ko} = 0 \cdot \mathbf{kPa}$$

$$\mathbf{P1} := \mathbf{P2} + \gamma_{\mathbf{b}} \cdot \mathbf{ds} \cdot \mathbf{Ko} = 46.261 \cdot \mathbf{kPa}$$

Front of Retaining Wall

depth to water table $\mathbf{dw} := 0$

saturated soil depth $\mathbf{ds} := 8.5\mathbf{m}$

soil pressure at rest coefficient $\mathbf{Ko} := 0.55$

$$\mathbf{P4} := \gamma_{\mathbf{m}} \cdot \mathbf{dw} \cdot \mathbf{Ko} = 0 \cdot \mathbf{kPa}$$

$$\mathbf{P3} := \mathbf{P2} + \gamma_{\mathbf{b}} \cdot \mathbf{ds} \cdot \mathbf{Ko} = 56.988 \cdot \mathbf{kPa}$$

Section 2

depth to water table $\mathbf{dw} := 2.5\mathbf{m}$

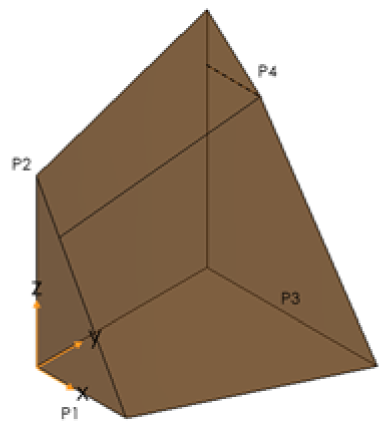
saturated soil depth $\mathbf{ds} := 9.0\mathbf{m}$

soil pressure at rest coefficient $\mathbf{Ko} := 0.55$

$$\mathbf{P1} := \gamma_{\mathbf{m}} \cdot \mathbf{dw} \cdot \mathbf{Ko} = 27.5 \cdot \mathbf{kPa}$$

$$\mathbf{P2} := \mathbf{P1} + \gamma_{\mathbf{b}} \cdot \mathbf{ds} \cdot \mathbf{Ko} = 87.841 \cdot \mathbf{kPa}$$

Isometric view of the prism representing soil pressures against the retaining wall (Using AutoCAD 3D: 3D Transition Wall Analysis Section 1.dwg). The volume of the prism is equal to the equivalent total force.



Isometric View

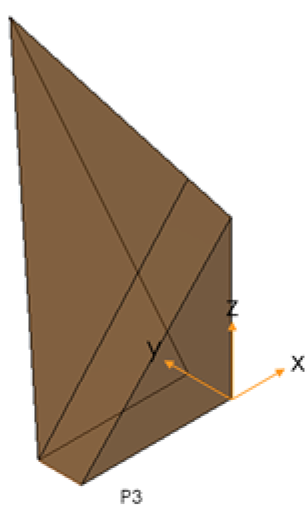
Total Force Back Soil

$\mathbf{F_{soilb}} := \mathbf{2966.57kN}$

$\mathbf{X_{Fsoilb}} := 0\mathbf{m}$

$\mathbf{Y_{Fsoilb}} := \mathbf{5.257m}$

$\mathbf{Z_{Fsoilb}} := \mathbf{3.376m}$



Total Force Front Soil

$\mathbf{F_{soilf}} := \mathbf{787.47kN}$

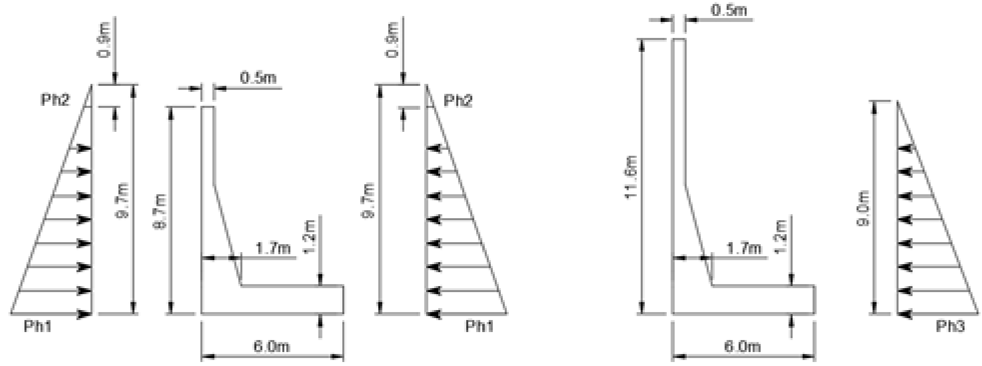
$\mathbf{X_{Fsoilf}} := 0\mathbf{m}$

$\mathbf{Y_{Fsoilf}} := \mathbf{2.391m}$

$\mathbf{Z_{Fsoilf}} := \mathbf{3.144m}$

Hydrostatic Forces

Side View



Section 1 Section 2

Front of Wall $h_f := 9.7\mathbf{m}$

Back of Wall $h_b := 9.0\mathbf{m}$

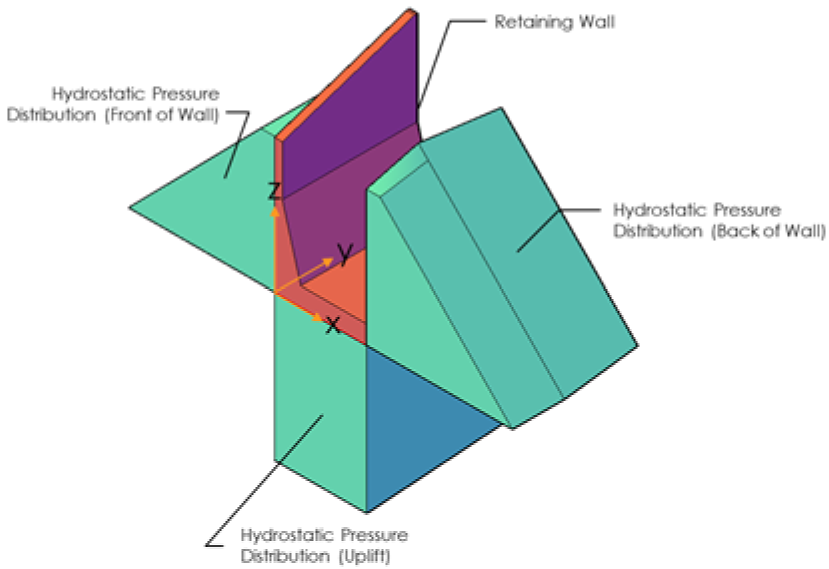
Depth to top of wall $h_{tw} := 0.9\mathbf{m}$

$$\mathbf{Ph1} := h_f \cdot \gamma_w = 95.16 \cdot \mathbf{kPa}$$

$$\mathbf{Ph2} := h_{tw} \cdot \gamma_w = 8.83 \cdot \mathbf{kPa}$$

$$\mathbf{Ph3} := h_b \cdot \gamma_w = 88.29 \cdot \mathbf{kPa}$$

Isometric View



Total Hydrostatic Force

Back of Wall

$H_{Fu} := 3886.46\,kN$

$X_{Fu} := 0\,m$

$Y_{Fu} := 4.293\,m$

$Z_{Fu} := 3.156\,m$

Volume and centroid of hydrostatic pressure was determined using AutoCAD 3D: File Water Pressure.dwg

Total Hydrostatic Force

Front of Wal

$H_{Ft} := 1876.10\,kN$

$X_{Ft} := 0\,m$

$Y_{Ft} := 2.449\,m$

$Z_{Ft} := 4.204\,m$

Volume and centroid of hydrostatic pressure was determined using AutoCAD 3D: File Water Pressure.dwg

Uplift

Total Uplift Force

$F_{uplift} := 4857.31\,kN$

$X_{uplift} := 3.000\,m$

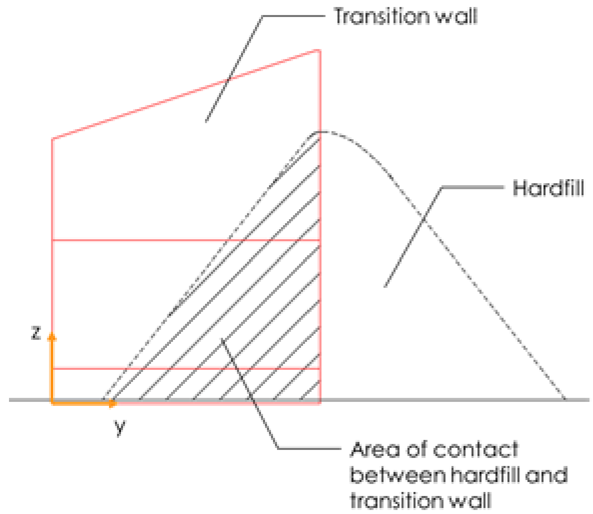
$Y_{uplift} := 4.350\,m$

$Z_{uplift} := 0\,m$

Volume and centroid of hydrostatic pressure was determined using AutoCAD 3D: File Water Pressure.dwg

Hardfill Contact Area and Resultant Resistant Force

Front View



Area of Contact

$Ac := 32.1753\ m^2$

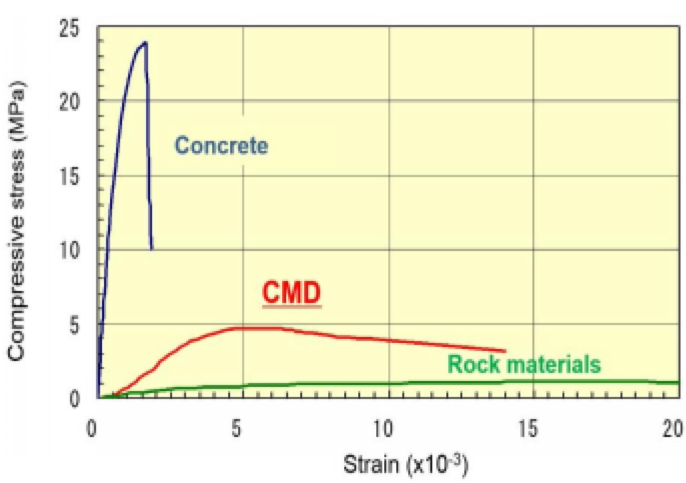
$X_{HF} := 0m$

$Y_{HF} := 6.4208m$

$Z_{HF} := 3.1349m$

Centroid of contact area was determined using Autocad: File Wall Pressure Diagrams.dwg

Hard Fill Stiffness



Source: Noorzad et al. (2017). An Innovative Approach toward Dam Design and Construction. 2nd Workshop on Cement Materials Dams (CMD). July 3, 2017.

$$E_{HF} := \frac{5\,MPa}{5 \times 10^{-3}} = 1 \cdot GPa$$ Approximate Hardfill Modulus of Elasticity

$L_{HF} := 17m$ Hardfill section length (between construction joints)

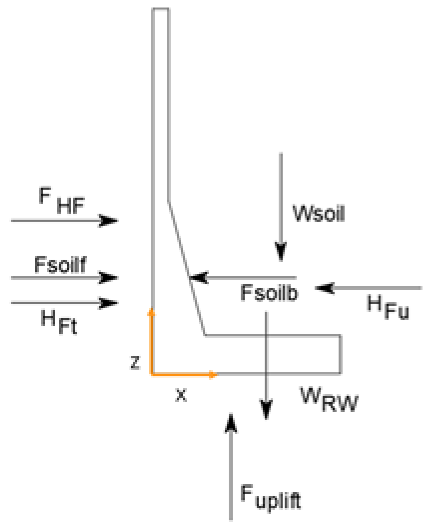
Approximate hardfill stiffness $$k_{HF} := \frac{E_{HF}}{L_{HF}} = 58823.53 \cdot \frac{kN}{m^3}$$

$$\delta_{max} := L_{HF} \cdot 5 \cdot 10^{-3} = 85\,mm$$

Considering a deformation of the hardfill of : $\delta_{HF} := 1.3mm$ < $\delta_{max} = 85\,mm$

The total reaction of the hardfill is: $F_{HF} := k_{HF} \cdot Ac \cdot \delta_{HF} = 2.46 \cdot MN$

Vector Forces Summary



Body diagram, side view

Weight Retaining Wall $\mathbf{W_{RW}} := \begin{pmatrix} 0 & 0 & -\mathbf{W_{RW}} \end{pmatrix} = \begin{pmatrix} 0 & 0 & -2.95 \end{pmatrix} \cdot \mathbf{MN}$

Weight Soil (Back of Wall) $\mathbf{W_{soilb}} := \begin{pmatrix} 0 & 0 & -\mathbf{W_{soilb}} \end{pmatrix} = \begin{pmatrix} 0 & 0 & -7.95 \end{pmatrix} \cdot \mathbf{MN}$

Soil Pressure (Back of Wall) $\mathbf{F_{soilb}} := \begin{pmatrix} -\mathbf{F_{soilb}} & 0 & 0 \end{pmatrix} = \begin{pmatrix} -2.97 & 0 & 0 \end{pmatrix} \cdot \mathbf{MN}$

Soil Pressure (Front of Wall) $\mathbf{F_{soilf}} := \begin{pmatrix} \mathbf{F_{soilf}} & 0 & 0 \end{pmatrix} = \begin{pmatrix} 0.79 & 0 & 0 \end{pmatrix} \cdot \mathbf{MN}$

Hydrostatic Force (Back of Wall) $\mathbf{H_{Fu}} := \begin{pmatrix} -\mathbf{H_{Fu}} & \mathbf{0} & 0 \end{pmatrix} = \begin{pmatrix} -3.89 & 0 & 0 \end{pmatrix} \cdot \mathbf{MN}$

Hydrostatic Force (Front of Wall) $\mathbf{H_{Ft}} := \begin{pmatrix} \mathbf{H_{Ft}} & 0 & 0 \end{pmatrix} = \begin{pmatrix} 1.88 & 0 & 0 \end{pmatrix} \cdot \mathbf{MN}$

Uplift Force $\mathbf{F_{uplift}} := \begin{pmatrix} 0 & 0 & \mathbf{F_{uplift}} \end{pmatrix} = \begin{pmatrix} 0 & 0 & 4.86 \end{pmatrix} \cdot \mathbf{MN}$

Resistance force by Hardfill $\mathbf{F_{HF}} := \begin{pmatrix} \mathbf{F_{HF}} & 0 & 0 \end{pmatrix} = \begin{pmatrix} 2.46 & 0 & 0 \end{pmatrix} \cdot \mathbf{MN}$

Resultant Total Force

$$\mathbf{F} := \mathbf{W_{RW}} + \mathbf{W_{soilb}} + \mathbf{F_{soilb}} + \mathbf{F_{soilf}} + \mathbf{H_{Fu}} + \mathbf{H_{Ft}} + \mathbf{F_{uplift}} + \mathbf{F_{HF}}$$

$$\mathbf{F} = (-1.73 \quad 0 \quad -6.04) \cdot \mathbf{MN}$$

Structure Stability

1. Sliding

$$236.6\mathbf{m}^3 \cdot \gamma_{\mathbf{w}} = 2.32 \cdot \mathbf{MN}$$

Coefficient of sliding friction $\mu := 0.45$

$$\mathbf{FoS} := \frac{\mathbf{F}_{0,2} \cdot \mu}{\mathbf{F}_{0,0}} = 1.57 \quad > \quad \mathbf{FS_{sliding.req}} = 1.5 \quad \mathbf{OK}$$

2. Uplift

Summatory of Axial Resistant Forces

$$\mathbf{F_R} := \mathbf{W_{RW}} + \mathbf{W_{soilb}} = (0 \quad 0 \quad -10.9) \cdot \mathbf{MN}$$

Uplift Force

$$\mathbf{F_{uplift}} = (0 \quad 0 \quad 4.86) \cdot \mathbf{MN}$$

$$\mathbf{FoS_{uplift}} := \frac{\left|\mathbf{F_R}_{0,2}\right|}{\left|\mathbf{F_{uplift}}_{0,2}\right|} = 2.24 \quad > \quad \mathbf{FS_{float.req}} = 1.5 \quad \mathbf{OK}$$

3. Overturning

$\mathbf{r_{RW}} := \left(\mathbf{X_{RW}} \quad Y_{RW} \quad Z_{RW}\right) = (1.76 \quad 4.47 \quad 0)\,\mathbf{m}$

$\mathbf{r_{soilb}} := \left(X_{soil} \quad Y_{soil} \quad Z_{soil}\right) = (3.38 \quad 4.66 \quad 0)\,\mathbf{m}$

$\mathbf{r_{Fsoilb}} := \left(X_{Fsoilb} \quad Y_{Fsoilb} \quad Z_{Fsoilb}\right) = (0 \quad 5.26 \quad 3.38)\,\mathbf{m}$

$\mathbf{r_{Fsoilf}} := \left(X_{Fsoilf} \quad Y_{Fsoilf} \quad Z_{Fsoilf}\right) = (0 \quad 2.39 \quad 3.14)\,\mathbf{m}$

$\mathbf{r_{Fu}} := \left(X_{Fu} \quad Y_{Fu} \quad Z_{Fu}\right) = (0 \quad 4.29 \quad 3.16)\,\mathbf{m}$

$\mathbf{r_{Ft}} := \left(X_{Ft} \quad Y_{Ft} \quad Z_{Ft}\right) = (0 \quad 2.45 \quad 4.2)\,\mathbf{m}$

$\mathbf{r_{uplift}} := \left(X_{uplift} \quad Y_{uplift} \quad Z_{uplift}\right) = (3 \quad 4.35 \quad 0)\,\mathbf{m}$

$\mathbf{r_{HF}} := \left(\mathbf{X_{HF}} \quad \mathbf{Y_{HF}} \quad \mathbf{Z_{HF}}\right) = (0 \quad 6.42 \quad 3.13)\,\mathbf{m}$

$$\mathbf{M} := \mathbf{W_{RW}}^T \times \mathbf{r_{RW}}^T + \mathbf{W_{soilb}}^T \times \mathbf{r_{soilb}}^T + \mathbf{F_{soilb}}^T \times \mathbf{r_{Fsoilb}}^T + \mathbf{F_{HF}}^T \times \mathbf{r_{HF}}^T \cdots$$
$$+ \mathbf{F_{soilf}}^T \times \mathbf{r_{Fsoilf}}^T + \mathbf{H_{Fu}}^T \times \mathbf{r_{Fu}}^T + \mathbf{H_{Ft}}^T \times \mathbf{r_{Ft}}^T + \mathbf{F_{uplift}}^T \times \mathbf{r_{uplift}}^T$$

$$\mathbf{M} = \begin{pmatrix} 29.14 \\ -13.3 \\ -10 \end{pmatrix} \cdot \mathbf{MN} \cdot \mathbf{m}$$

$\mathbf{F} = (-1.73 \quad 0 \quad -6.04) \cdot \mathbf{MN}$

Location of resultant force:

$$\mathbf{X_R} := \left| \frac{\mathbf{M}_{1,0}}{\mathbf{F}_{0,2}} \right| = 2.2 \cdot \mathbf{m}$$

$$\mathbf{x} := \left| \mathbf{X_R} - \frac{\mathbf{b}}{2} \right| = 0.8\,\mathbf{m} \quad < \quad \frac{\mathbf{b}}{6} = 1\,\mathbf{m} \qquad \mathbf{OK}$$

4. **Bearing Capacity**

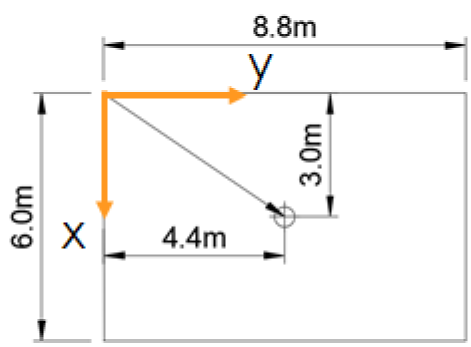
$$q_{all} := 622\,\mathbf{kPa}$$

Force and Moment at origin:

$$\mathbf{F} = (-1.73 \quad 0 \quad -6.04)\cdot\mathbf{MN} \qquad \mathbf{M} = \begin{pmatrix} 29.14 \\ -13.3 \\ -10 \end{pmatrix}\mathbf{m}\cdot\mathbf{MN}$$

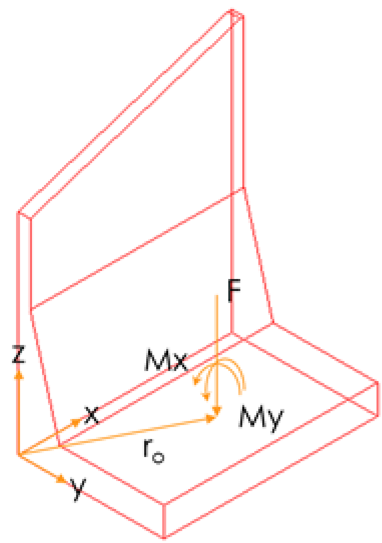
Vector to center of foundation:

$$\mathbf{r_o} := (3 \quad 4.4 \quad 0)\,\mathbf{m}$$



Moment at center of Foundation

$$\mathbf{M_o} := \mathbf{M} - \mathbf{F}^{\mathbf{T}} \times \mathbf{r_o}^{\mathbf{T}} = \begin{pmatrix} 2.55 \\ 4.83 \\ -2.4 \end{pmatrix} \mathbf{m} \cdot \mathbf{MN}$$



$$\mathbf{Ix_o} := \frac{1}{12} \cdot \mathbf{b}^3 \cdot \mathbf{B} = 158.4\,\mathbf{m}^4$$

$$\mathbf{Iy_o} := \frac{1}{12} \cdot \mathbf{b} \cdot \mathbf{B}^3 = 340.736\,\mathbf{m}^4$$

$$\mathbf{A} := \mathbf{b} \cdot \mathbf{B} = 52.8\,\mathbf{m}^2$$

$$\sigma_{\mathbf{max}} := \left| \frac{\mathbf{F}_{0,2}}{\mathbf{A}} \right| + \left| \frac{\mathbf{M_o}_{0,0} \cdot \mathbf{b}}{2 \cdot \mathbf{Ix_o}} \right| + \left| \frac{\mathbf{M_o}_{1,0} \cdot \mathbf{B}}{2 \cdot \mathbf{Iy_o}} \right| = 225.155 \cdot \mathbf{kPa} < \quad \mathbf{q_{all}} = 622 \cdot \mathbf{kPa} \quad \mathbf{OK}$$

$$\sigma_{\mathbf{min}} := \left| \frac{\mathbf{F}_{0,2}}{\mathbf{A}} \right| - \left| \frac{\mathbf{M_o}_{0,0} \cdot \mathbf{b}}{2 \cdot \mathbf{Ix_o}} \right| - \left| \frac{\mathbf{M_o}_{1,0} \cdot \mathbf{B}}{2 \cdot \mathbf{Iy_o}} \right| = 3.812 \cdot \mathbf{kPa} \quad < \quad \mathbf{q_{all}} = 622 \cdot \mathbf{kPa} \quad \mathbf{OK}$$

TP **Section 1: Unusual Condition (UN2)**

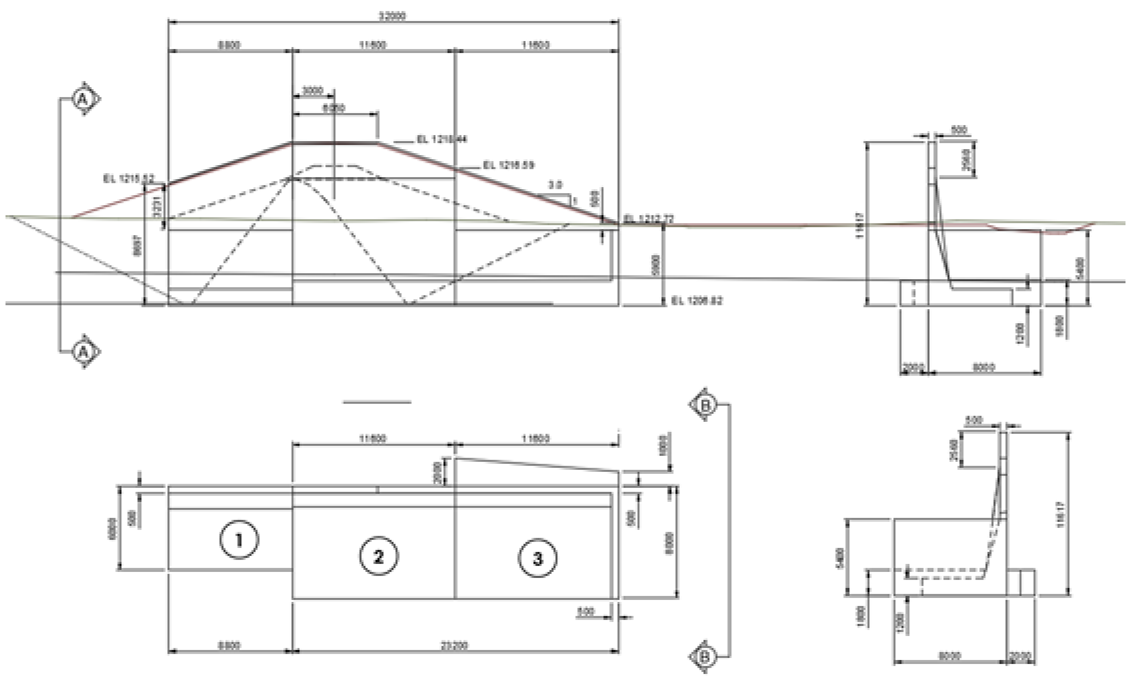
Loading	Horizontal Forces		Vertical Forces		Stabilizing	Overturning
	Force (MN)	Arm (m)	Force (MN)	Arm (m)	Moments (MN-m)	Moments (MN-m)
Weight of Structure			3.0	1.8	5.2	
Earthquake Inertia Force						
Soil Mass, front of wall						
Soil Mass, back of wall			8.0	3.4	26.9	
Soil Pressure, front of wall	0.52	3.03			1.6	
Soil Pressure, back of wall	-2.98	3.29				9.8
Soil Dynamic Pressure, back of wall						
Uplift			-5.1	3.0		15.3
Hydrostatic pressure, front of wall	2.14	4.44			9.5	
Hydrostatic pressure, back of wall	-4.30	3.30				14.2
Hydrostatic weight, front of wall						
Hardfill	3.02	3.13			9.5	
SUM	**-1.60**		**5.80**		**52.61**	**39.31**
					Net Moment	
					13.30	

Stability Calculations
Retaining Wall - Auxiliary Spillway
Right Abutment Transition to Berm

Scope:

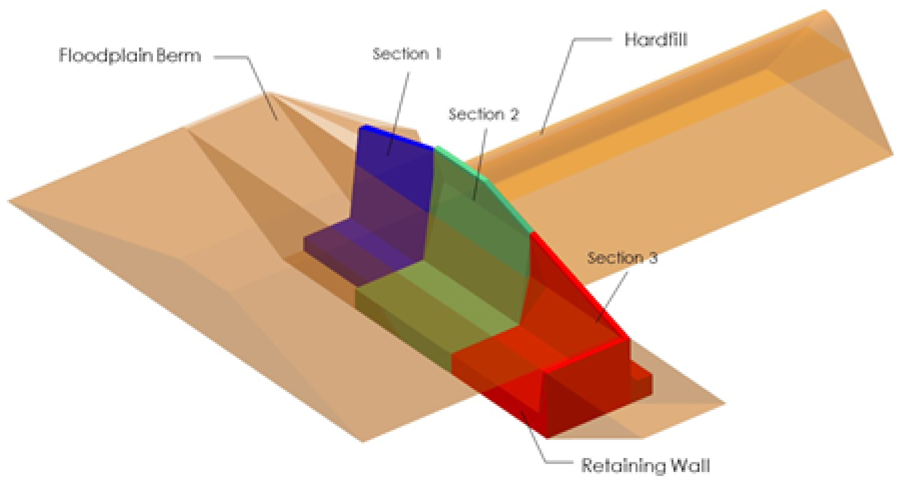
Evaluate the stability of the transition wall of the Auxiliary Spillway. Consider the 3D effects on the structure's stability.

Structure Geometry:



dimensions in mm

Isometric View:



<u>Load Condition</u>

	Elevation (m)			
	Headwater	**Tailwater**	**Headwater**	**Tailwater**
1. Usual Condition (U1)	1214.0	1211.9	7.0	4.9
2. Unusual Condition 1 (UN1)	1214.0	1211.9	7.0	4.9
3. Unusual Condition 2 (UN2)	1216.5	1213.1	9.5	6.1
4. Unusual Condition 3 (UN3)	1217.0	1213.1	10.0	6.1
5. Extreme Condition 1 (E1-F)	1217.3	1213.8	10.3	6.8
6. Extreme Condition 2 (E2-Q)	1213.5	1211.9	6.5	4.9

User Input

Material Properties:

Unit Weight of Water: $\gamma_w := 9.81 \frac{kN}{m^3}$ (Section 7.2, Design Criteria)

Unit Weight of Concrete: $\gamma_c := 23.5 \frac{kN}{m^3}$

Unit Weight of Soil (Moist): $\gamma_m := 20.0 \frac{kN}{m^3}$ (Section 5.3, Design Criteria) assumed moisture content (w) = 5%

Unit Weight Soil (Saturated): $\gamma_{sat} := 22.0 \frac{kN}{m^3}$ (Assuming Specific Gravity = 2.7)

Unit Weight Soil (buoyant): $\gamma_b := \gamma_{sat} - \gamma_w = 12.19 \cdot \frac{kN}{m^3}$

Weight of Soil/Concrete above toe: $\gamma_{toe} := 22.0 \frac{kN}{m^3}$

Unit Weight of Rock: $\gamma_r := 25.6 \frac{kN}{m^3}$ (Section 7.2, Design Criteria)

Unusual Condition 3 (UN3)

Acceptance Parameters

Resultant Location (Overturning and Bearing Pressure):

Unusual (UN) Resultant located inside middle third (kern) equals 100% base in compression (AT/WCS Guidelines, Section 8.4)

$$B_{\%basecomp.req} := 100\%$$

Allowable rock bearing pressure: $qall := 622\,\dfrac{kN}{m^2}$ (Internal Geotechnical Design Recommendations Rev. Sept 12, 2018, Section 5.3)

FS Sliding:

Usual (U1) 1.5 (without cohesion) (CDA Guidelines, Table 6-4, AT/WCS Guidelines, Section 8.3)

Req'd Factor of Safety for Sliding: $FS_{sliding.req} := 1.5$ (Without Cohesion)

FS Floatation:

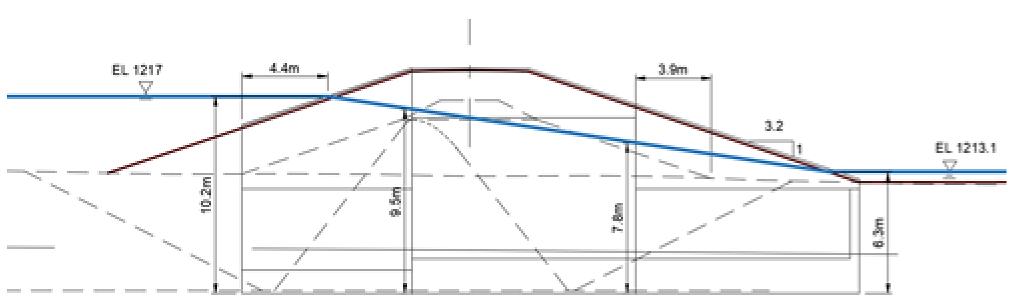
Usual (U1) 1.5 (AT/WCS Guidelines, Section 8.5)

Req'd Factor of Safety for Floatation: $FS_{float.req} := 1.5$

Water Surface Elevations

Headwater $H_H := 1217m$

Tailwater $H_T := 1213.1m$



$h_1 := 10.2m$ $h_2 := 9.5m$ $h_3 := 7.8m$ $h_4 := 6.3m$

Interpolated water table heights from retaining wall base.

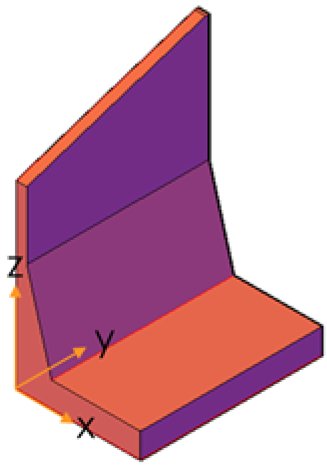
Section 1

Wall Geometry: User Input

Top of Wall Elevation:	$\mathbf{T_w} := 1218.44 \cdot \mathbf{m}$
Top of Footing Elevation:	$\mathbf{Top_{ftg}} := 1208.02 \cdot \mathbf{m}$
Thickness of Footing:	$\mathbf{t_{ftg}} := 1.20\mathbf{m}$
Bottom of Footing Elevation:	$\mathbf{Bot_{ftg}} := \mathbf{Top_{ftg}} - t_{ftg} = 1206.82\ \mathbf{m}$
Overall Height of wall:	$\mathbf{h_w} := \mathbf{T_w} - \mathbf{Bot_{ftg}} = 11.620\ \mathbf{m}$
Thickness of Stem Wall at Top:	$\mathbf{t_{wt}} := 0.5\mathbf{m}$
Slope of Heel Batter:	$\mathbf{S_{batter}} := 0.125$
Thickness of Stem Wall at Base:	$\mathbf{t_{wb}} := 1.7\mathbf{m}$
Length of toe:	$\mathbf{L_{ab}} := 0\mathbf{m}$
Total Length of Footing:	$\mathbf{b} := 6\mathbf{m}$
Length of heel:	$\mathbf{L_{cd}} := \mathbf{b} - \mathbf{L_{ab}} - \mathbf{t_{wb}} = 4.3\ \mathbf{m}$
Width of Wall:	$\mathbf{B} := 8.8\mathbf{m}$

Retaining Wall

Retaining Wall Volume and Gravity Center (Using AutoCAD 3D: File: 3D Transition Wall Analysis Section 1.dwg)



Isometric View

Volume

$Vol_{RW} := 125.447\ m^3$

$X_{RW} := 1.756m$

$Y_{RW} := 4.475m$

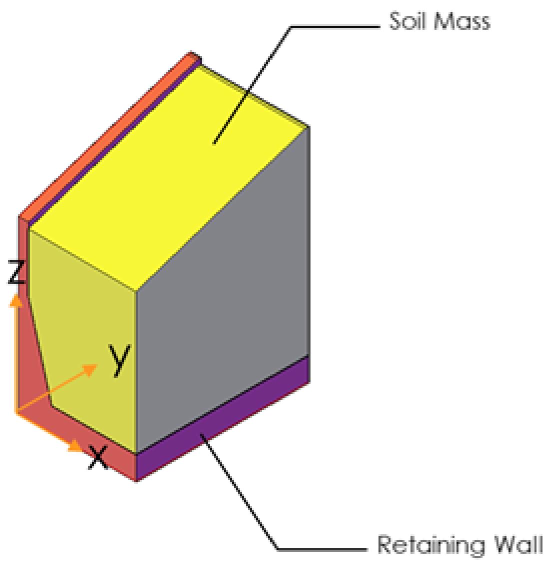
$Z_{RW} := 0m$

Retaining wall total weight $\quad W_{RW} := Vol_{RW} \cdot \gamma_c = 2.95 \cdot MN$

Soil Mass

Retained Soil Volume and Gravity Center (Using AutoCAD 3D: File 3D Transition Wall Analysis Section 1.dwg)

Isometric View:



$\mathbf{Vol_{soil}} := \mathbf{397.702\ m^3}$

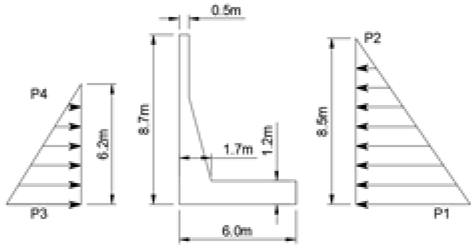
$\mathbf{X_{soil}} := \mathbf{3.382m}$

$\mathbf{Y_{soil}} := \mathbf{4.662m}$

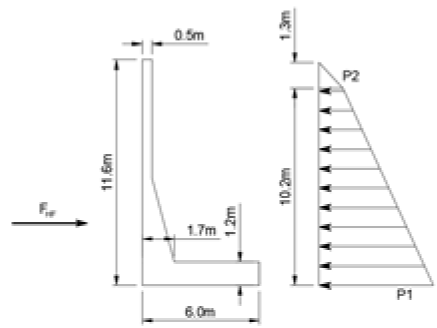
$\mathbf{Z_{soil}} := 0\mathbf{m}$

Soil mass total weight $\mathbf{W_{soilb}} := \mathbf{Vol_{soil}} \cdot \gamma_{\mathbf{m}} = 7.95 \cdot \mathbf{MN}$

Soil Pressure



Section1



Section 2

Section 1

Back of Retaining Wall

depth to water table $\mathbf{dw} := 0\mathbf{m}$

saturated soil depth $\mathbf{ds} := 8.5\mathbf{m}$

soil pressure at rest coefficient $\mathbf{Ko} := 0.55$

$$\mathbf{P2} := \gamma_{\mathbf{m}} \cdot \mathbf{dw} \cdot \mathbf{Ko} = 0 \cdot \mathbf{kPa}$$

$$\mathbf{P1} := \mathbf{P2} + \gamma_{\mathbf{b}} \cdot \mathbf{ds} \cdot \mathbf{Ko} = 56.988 \cdot \mathbf{kPa}$$

Front of Retaining Wall

depth to water table $\mathbf{dw} := 0$

saturated soil depth $\mathbf{ds} := 6.2\mathbf{m}$

soil pressure at rest coefficient $\mathbf{Ko} := 0.55$

$$\mathbf{P4} := \gamma_{\mathbf{m}} \cdot \mathbf{dw} \cdot \mathbf{Ko} = 0 \cdot \mathbf{kPa}$$

$$\mathbf{P3} := \mathbf{P2} + \gamma_{\mathbf{b}} \cdot \mathbf{ds} \cdot \mathbf{Ko} = 41.568 \cdot \mathbf{kPa}$$

Section 2

depth to water table $\mathbf{dw} := 1.3\mathbf{m}$

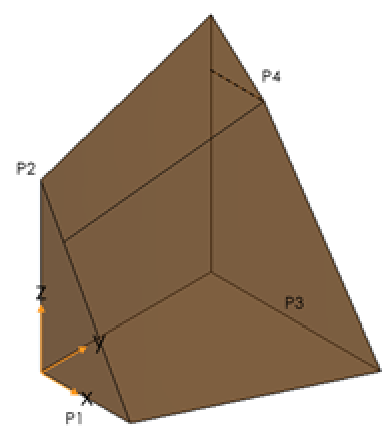
saturated soil depth $\mathbf{ds} := 10.2\mathbf{m}$

soil pressure at rest coefficient $\mathbf{Ko} := 0.55$

$$\mathbf{P1} := \gamma_m \cdot \mathbf{dw} \cdot \mathbf{Ko} = 14.3 \cdot \mathbf{kPa}$$

$$\mathbf{P2} := \mathbf{P1} + \gamma_b \cdot \mathbf{ds} \cdot \mathbf{Ko} = 82.686 \cdot \mathbf{kPa}$$

Isometric view of the prism representing soil pressures against the retaining wall (Using AutoCAD 3D: 3D Transition Wall Analysis Section 1.dwg). The volume of the prism is equal to the equivalent total force.



Isometric View

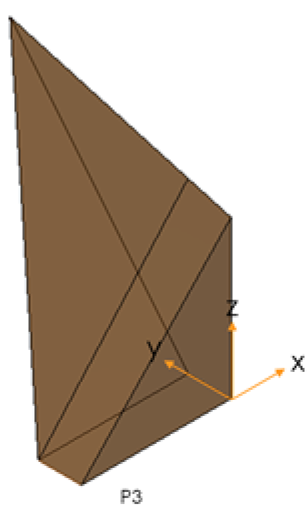
Total Force Back Soil

$\mathbf{F_{soilb}} := \mathbf{2980.37kN}$

$\mathbf{X_{Fsoilb}} := 0\mathbf{m}$

$\mathbf{Y_{Fsoilb}} := \mathbf{5.065m}$

$\mathbf{Z_{Fsoilb}} := \mathbf{3.292m}$



Total Force Front Soil

$\mathbf{F_{soilf}} := \mathbf{521.51kN}$

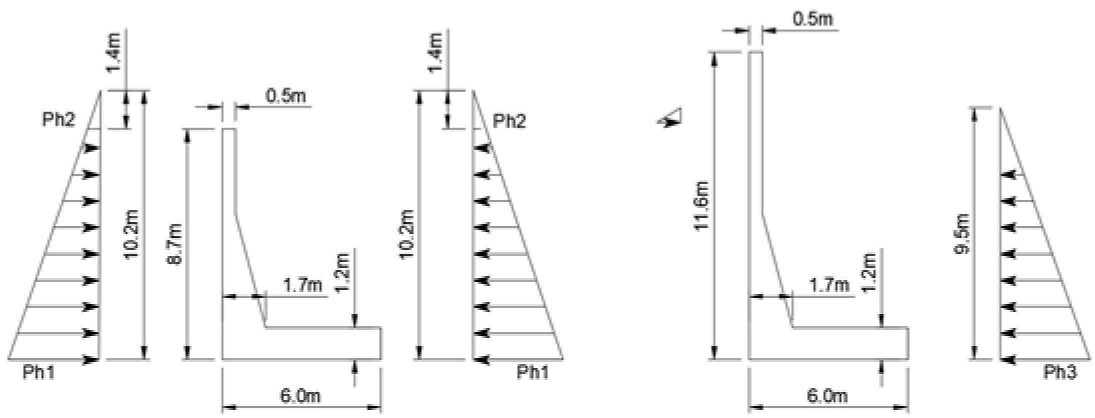
$\mathbf{X_{Fsoilf}} := 0\mathbf{m}$

$\mathbf{Y_{Fsoilf}} := \mathbf{2.364m}$

$\mathbf{Z_{Fsoilf}} := \mathbf{3.026m}$

Hydrostatic Forces

Side View



Section 1 Section 2

Front of Wall $\mathbf{h_f} := 10.2\mathbf{m}$

Back of Wall $\mathbf{h_b} := 9.5\mathbf{m}$

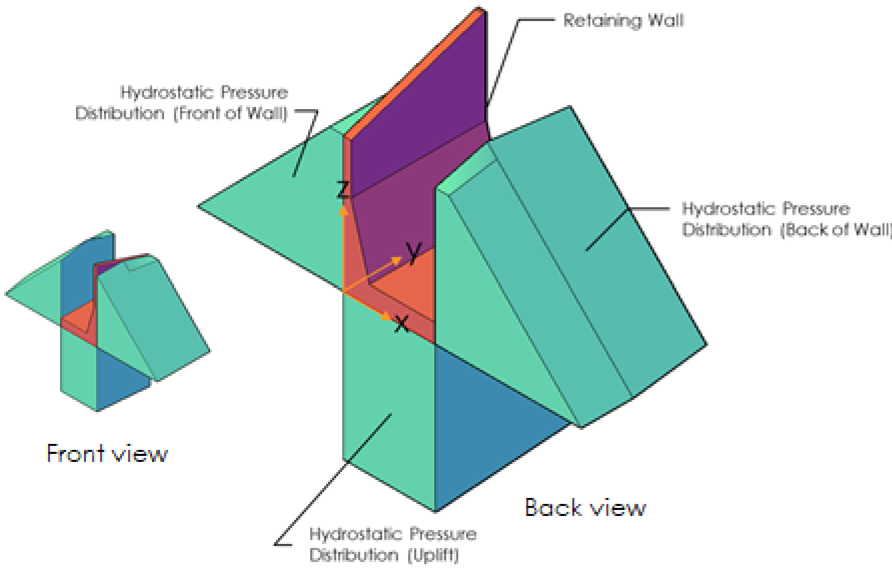
Depth to top of wall $\mathbf{h_{tw}} := 1.4\mathbf{m}$

$$\mathbf{Ph1} := \mathbf{h_f} \cdot \gamma_w = 100.06 \cdot \mathbf{kPa}$$

$$\mathbf{Ph2} := \mathbf{h_{tw}} \cdot \gamma_w = 13.73 \cdot \mathbf{kPa}$$

$$\mathbf{Ph3} := \mathbf{h_b} \cdot \gamma_w = 93.19 \cdot \mathbf{kPa}$$

Isometric View



Total Hydrostatic Force

Back of Wall

$H_{Fu} := 4297.64\,kN$

$X_{Fu} := 0\,m$

$Y_{Fu} := 4.327\,m$

$Z_{Fu} := 3.303\,m$

Volume and centroid of hydrostatic pressure was determined using AutoCAD 3D: File Water Pressure.dwg

Total Hydrostatic Force

Front of Wal

$H_{Ft} := 2139.50\,kN$

$X_{Ft} := 0\,m$

$Y_{Ft} := 2.555\,m$

$Z_{Ft} := 4.438\,m$

Volume and centroid of hydrostatic pressure was determined using AutoCAD 3D: File Water Pressure.dwg

Uplift

Total Uplift Force

$F_{uplift} := 5101.80\,kN$

$X_{uplift} := 3.000\,m$

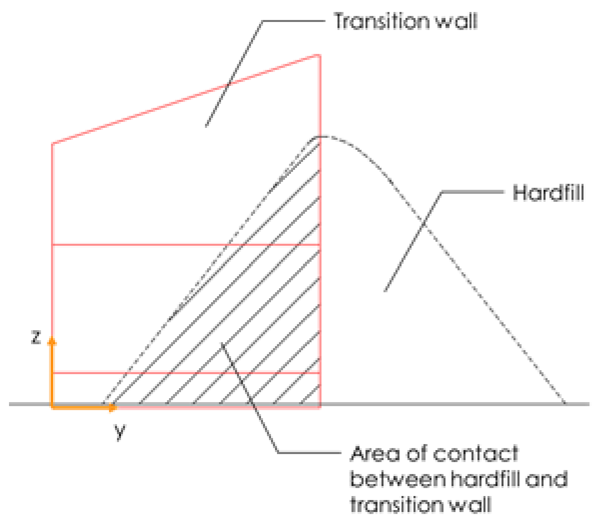
$Y_{uplift} := 4.348\,m$

$Z_{uplift} := 0\,m$

Volume and centroid of hydrostatic pressure was determined using AutoCAD 3D: File Water Pressure.dwg

Hardfill Contact Area and Resultant Resistant Force

Front View



Area of Contact

$Ac := 32.1753\ m^2$

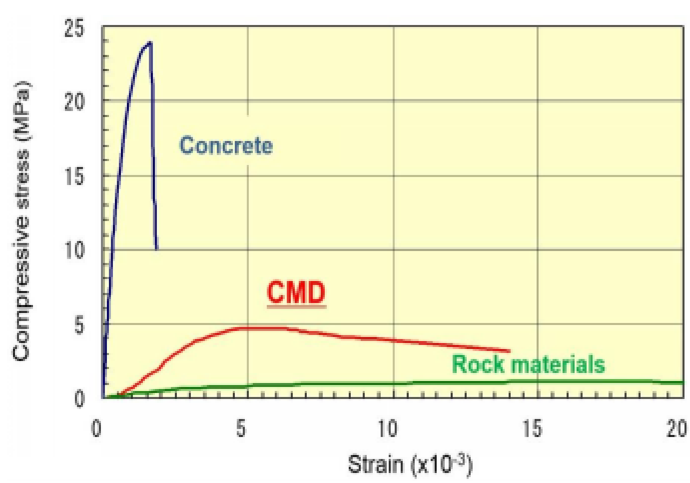
$X_{HF} := 0m$

$Y_{HF} := 6.4208m$

$Z_{HF} := 3.1349m$

Centroid of contact area was determined using Autocad: File Wall Pressure Diagrams.dwg

Hard Fill Stiffness



Source: Noorzad et al. (2017). An Innovative Approach toward Dam Design and Construction. 2nd Workshop on Cement Materials Dams (CMD). July 3, 2017.

$\mathbf{E_{HF}} := \dfrac{5\,\mathbf{MPa}}{5 \times \mathbf{10}^{-3}} = 1 \cdot \mathbf{GPa}$ Approximate Hardfill Modulus of Elasticity

$\mathbf{L_{HF}} := 16\mathbf{m}$ Hardfill section length (between construction joints)

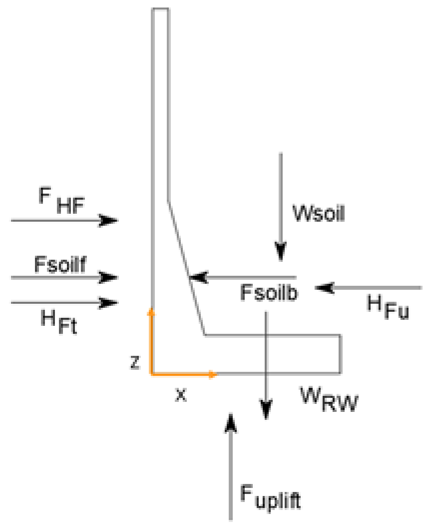
Approximate hardfill stiffness $\mathbf{k_{HF}} := \dfrac{\mathbf{E_{HF}}}{\mathbf{L_{HF}}} = 62500 \cdot \dfrac{\mathbf{kN}}{\mathbf{m}^3}$

$\delta_{\mathbf{max}} := \mathbf{L_{HF}} \cdot 5 \cdot 10^{-3} = 80\,\mathbf{mm}$

Considering a deformation of the hardfill of : $\delta_{\mathbf{HF}} := 1.5\mathbf{mm} \quad < \quad \delta_{\mathbf{max}} = 80\,\mathbf{mm}$

The total reaction of the hardfill is: $\mathbf{F_{HF}} := \mathbf{k_{HF}} \cdot \mathbf{Ac} \cdot \delta_{\mathbf{HF}} = 3.02 \cdot \mathbf{MN}$

Vector Forces Summary



Body diagram, side view

Weight Retaining Wall $\mathbf{W_{RW}} := \begin{pmatrix} 0 & 0 & -\mathbf{W_{RW}} \end{pmatrix} = (0 \quad 0 \quad -2.95)\cdot\mathbf{MN}$

Weight Soil (Back of Wall) $\mathbf{W_{soilb}} := \begin{pmatrix} 0 & 0 & -\mathbf{W_{soilb}} \end{pmatrix} = (0 \quad 0 \quad -7.95)\cdot\mathbf{MN}$

Soil Pressure (Back of Wall) $\mathbf{F_{soilb}} := \begin{pmatrix} -\mathbf{F_{soilb}} & 0 & 0 \end{pmatrix} = (-2.98 \quad 0 \quad 0)\cdot\mathbf{MN}$

Soil Pressure (Front of Wall) $\mathbf{F_{soilf}} := \begin{pmatrix} \mathbf{F_{soilf}} & 0 & 0 \end{pmatrix} = (0.52 \quad 0 \quad 0)\cdot\mathbf{MN}$

Hydrostatic Force (Back of Wall) $\mathbf{H_{Fu}} := \begin{pmatrix} -\mathbf{H_{Fu}} & \mathbf{0} & 0 \end{pmatrix} = (-4.3 \quad 0 \quad 0)\cdot\mathbf{MN}$

Hydrostatic Force (Front of Wall) $\mathbf{H_{Ft}} := \begin{pmatrix} \mathbf{H_{Ft}} & 0 & 0 \end{pmatrix} = (2.14 \quad 0 \quad 0)\cdot\mathbf{MN}$

Uplift Force $\mathbf{F_{uplift}} := \begin{pmatrix} 0 & 0 & \mathbf{F_{uplift}} \end{pmatrix} = (0 \quad 0 \quad 5.1)\cdot\mathbf{MN}$

Resistance force by Hardfill $\mathbf{F_{HF}} := \begin{pmatrix} \mathbf{F_{HF}} & 0 & 0 \end{pmatrix} = (3.02 \quad 0 \quad 0)\cdot\mathbf{MN}$

Resultant Total Force

$$\mathbf{F} := \mathbf{W_{RW}} + \mathbf{W_{soilb}} + \mathbf{F_{soilb}} + \mathbf{F_{soilf}} + \mathbf{H_{Fu}} + \mathbf{H_{Ft}} + \mathbf{F_{uplift}} + \mathbf{F_{HF}}$$

$$\mathbf{F} = (-1.6 \quad 0 \quad -5.8)\cdot\mathbf{MN}$$

Structure Stability

1. Sliding

$$236.6\mathbf{m}^3\cdot\gamma_\mathbf{w} = 2.32\cdot\mathbf{MN}$$

Coefficient of sliding friction $\mu := 0.45$

$$\mathbf{FoS} := \frac{\mathbf{F}_{0,2}\cdot\mu}{\mathbf{F}_{0,0}} = 1.63 \quad > \quad \mathbf{FS_{sliding.req}} = 1.5 \quad \mathbf{OK}$$

2. Uplift

Summatory of Axial Resistant Forces

$$\mathbf{F_R} := \mathbf{W_{RW}} + \mathbf{W_{soilb}} = (0 \quad 0 \quad -10.9)\cdot\mathbf{MN}$$

Uplift Force

$$\mathbf{F_{uplift}} = (0 \quad 0 \quad 5.1)\cdot\mathbf{MN}$$

$$\mathbf{FoS_{uplift}} := \frac{\left|\mathbf{F_R}_{0,2}\right|}{\left|\mathbf{F_{uplift}}_{0,2}\right|} = 2.14 \quad > \quad \mathbf{FS_{float.req}} = 1.5 \quad \mathbf{OK}$$

3. Overturning

$$\mathbf{r_{RW}} := \left(\mathbf{X_{RW}}\ \ \mathrm{Y_{RW}}\ \ \mathrm{Z_{RW}}\right) = (1.76\ \ 4.47\ \ 0)\ \mathbf{m}$$

$$\mathbf{r_{soilb}} := \left(\mathrm{X_{soil}}\ \ \mathrm{Y_{soil}}\ \ \mathrm{Z_{soil}}\right) = (3.38\ \ 4.66\ \ 0)\ \mathbf{m}$$

$$\mathbf{r_{Fsoilb}} := \left(\mathrm{X_{Fsoilb}}\ \ \mathrm{Y_{Fsoilb}}\ \ \mathrm{Z_{Fsoilb}}\right) = (0\ \ 5.07\ \ 3.29)\ \mathbf{m}$$

$$\mathbf{r_{Fsoilf}} := \left(\mathrm{X_{Fsoilf}}\ \ \mathrm{Y_{Fsoilf}}\ \ \mathrm{Z_{Fsoilf}}\right) = (0\ \ 2.36\ \ 3.03)\ \mathbf{m}$$

$$\mathbf{r_{Fu}} := \left(\mathrm{X_{Fu}}\ \ \mathrm{Y_{Fu}}\ \ \mathrm{Z_{Fu}}\right) = (0\ \ 4.33\ \ 3.3)\ \mathbf{m}$$

$$\mathbf{r_{Ft}} := \left(\mathrm{X_{Ft}}\ \ \mathrm{Y_{Ft}}\ \ \mathrm{Z_{Ft}}\right) = (0\ \ 2.56\ \ 4.44)\ \mathbf{m}$$

$$\mathbf{r_{uplift}} := \left(\mathrm{X_{uplift}}\ \ \mathrm{Y_{uplift}}\ \ \mathrm{Z_{uplift}}\right) = (3\ \ 4.35\ \ 0)\ \mathbf{m}$$

$$\mathbf{r_{HF}} := \left(\mathbf{X_{HF}}\ \ \mathbf{Y_{HF}}\ \ \mathbf{Z_{HF}}\right) = (0\ \ 6.42\ \ 3.13)\ \mathbf{m}$$

$$\mathbf{M} := \mathbf{W_{RW}}^{T} \times \mathbf{r_{RW}}^{T} + \mathbf{W_{soilb}}^{T} \times \mathbf{r_{soilb}}^{T} + \mathbf{F_{soilb}}^{T} \times \mathbf{r_{Fsoilb}}^{T} + \mathbf{F_{HF}}^{T} \times \mathbf{r_{HF}}^{T} \cdots$$
$$+ \mathbf{F_{soilf}}^{T} \times \mathbf{r_{Fsoilf}}^{T} + \mathbf{H_{Fu}}^{T} \times \mathbf{r_{Fu}}^{T} + \mathbf{H_{Ft}}^{T} \times \mathbf{r_{Ft}}^{T} + \mathbf{F_{uplift}}^{T} \times \mathbf{r_{uplift}}^{T}$$

$$\mathbf{M} = \begin{pmatrix} 28.09 \\ -13.29 \\ -7.62 \end{pmatrix} \cdot \mathbf{MN} \cdot \mathbf{m}$$

$$\mathbf{F} = (-1.6\ \ 0\ \ -5.8) \cdot \mathbf{MN}$$

Location of resultant force:

$$\mathbf{X_R} := \left| \frac{\mathbf{M}_{1,0}}{\mathbf{F}_{0,2}} \right| = 2.29 \cdot \mathbf{m}$$

$$\mathbf{x} := \left| \mathbf{X_R} - \frac{\mathbf{b}}{2} \right| = 0.71\ \mathbf{m} \quad < \quad \frac{\mathbf{b}}{6} = 1\ \mathbf{m} \qquad \mathbf{OK}$$

4. **Bearing Capacity**

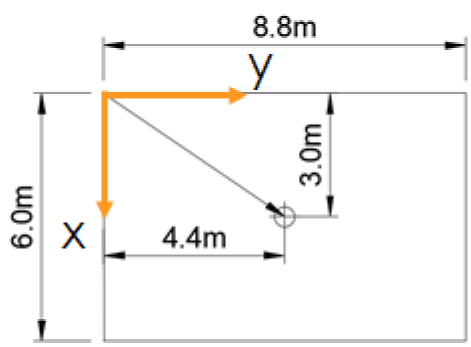
$$\mathbf{q_{all}} := 622\,\mathbf{kPa}$$

Force and Moment at origin:

$$\mathbf{F} = (-1.6 \quad 0 \quad -5.8)\cdot\mathbf{MN} \qquad\qquad \mathbf{M} = \begin{pmatrix} 28.09 \\ -13.29 \\ -7.62 \end{pmatrix}\mathbf{m}\cdot\mathbf{MN}$$

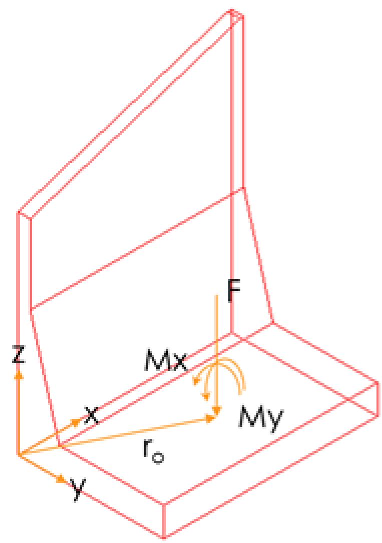
Vector to center of foundation:

$$\mathbf{r_o} := (3 \quad 4.4 \quad 0)\,\mathbf{m}$$



Moment at center of Foundation

$$\mathbf{M_o} := \mathbf{M} - \mathbf{F}^{\mathbf{T}} \times \mathbf{r_o}^{\mathbf{T}} = \begin{pmatrix} 2.57 \\ 4.11 \\ -0.58 \end{pmatrix} \mathbf{m} \cdot \mathbf{MN}$$



$$\mathbf{Ix_o} := \frac{1}{12} \cdot \mathbf{b}^3 \cdot \mathbf{B} = 158.4\,\mathbf{m}^4$$

$$\mathbf{Iy_o} := \frac{1}{12} \cdot \mathbf{b} \cdot \mathbf{B}^3 = 340.736\,\mathbf{m}^4$$

$$\mathbf{A} := \mathbf{b} \cdot \mathbf{B} = 52.8\,\mathbf{m}^2$$

$$\sigma_{\mathbf{max}} := \left|\frac{\mathbf{F}_{0,2}}{\mathbf{A}}\right| + \left|\frac{\mathbf{M_o}_{0,0} \cdot \mathbf{b}}{2 \cdot \mathbf{Ix_o}}\right| + \left|\frac{\mathbf{M_o}_{1,0} \cdot \mathbf{B}}{2 \cdot \mathbf{Iy_o}}\right| = 211.555 \cdot \mathbf{kPa} < \quad \mathbf{q_{all}} = 622 \cdot \mathbf{kPa} \qquad \mathbf{OK}$$

$$\sigma_{\mathbf{min}} := \left|\frac{\mathbf{F}_{0,2}}{\mathbf{A}}\right| - \left|\frac{\mathbf{M_o}_{0,0} \cdot \mathbf{b}}{2 \cdot \mathbf{Ix_o}}\right| - \left|\frac{\mathbf{M_o}_{1,0} \cdot \mathbf{B}}{2 \cdot \mathbf{Iy_o}}\right| = 8.151 \cdot \mathbf{kPa} \quad < \quad \mathbf{q_{all}} = 622 \cdot \mathbf{kPa} \qquad \mathbf{OK}$$

TP **Section 1: Extreme Condition (E1)**

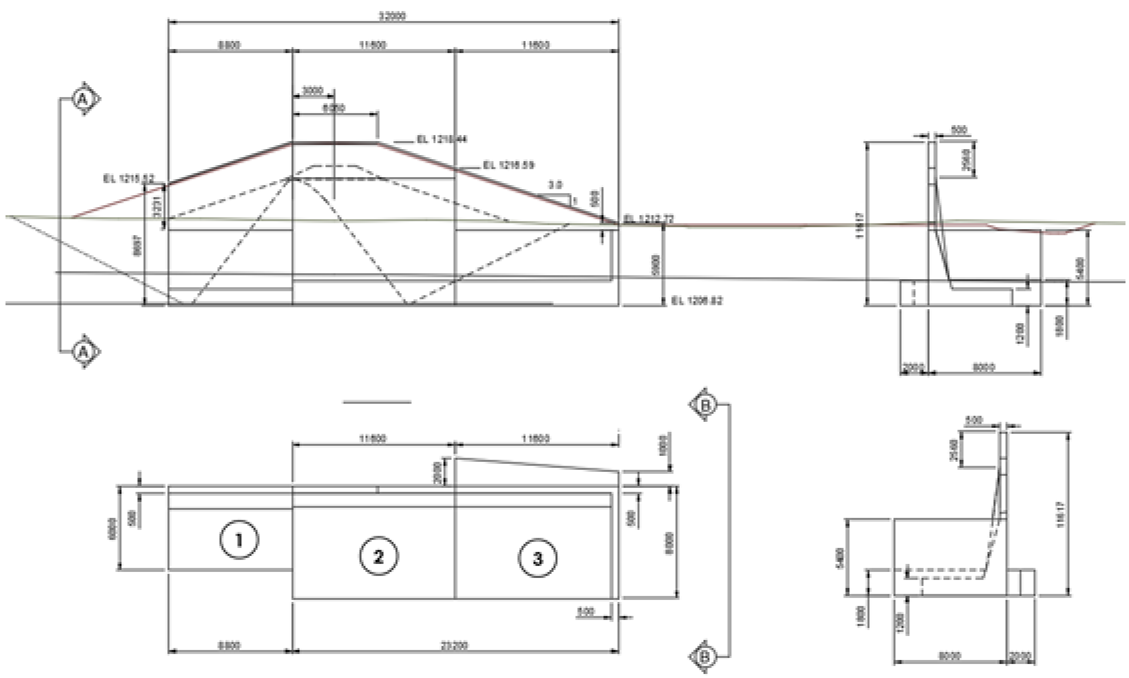
Loading	Horizontal Forces Force (MN)	Horizontal Forces Arm (m)	Vertical Forces Force (MN)	Vertical Forces Arm (m)	Stabilizing Moments (MN-m)	Overturning Moments (MN-m)
Weight of Structure			3.0	1.8	5.2	
Earthquake Inertia Force						
Soil Mass, front of wall						
Soil Mass, back of wall			8.0	3.4	26.9	
Soil Pressure, front of wall	0.79	3.14			2.5	
Soil Pressure, back of wall	-2.75	3.30				9.1
Soil Dynamic Pressure, back of wall						
Uplift			-5.3	3.0		15.9
Hydrostatic pressure, front of wall	2.27	4.51			10.2	
Hydrostatic pressure, back of wall	-4.48	3.34				15.0
Hydrostatic weight, front of wall						
Hardfill	2.21	3.13			6.9	
SUM	**-1.96**		**5.59**		**51.70**	**39.97**
					Net Moment	
					11.74	

Stability Calculations
Retaining Wall - Auxiliary Spillway
Right Abutment Transition to Berm

Scope:

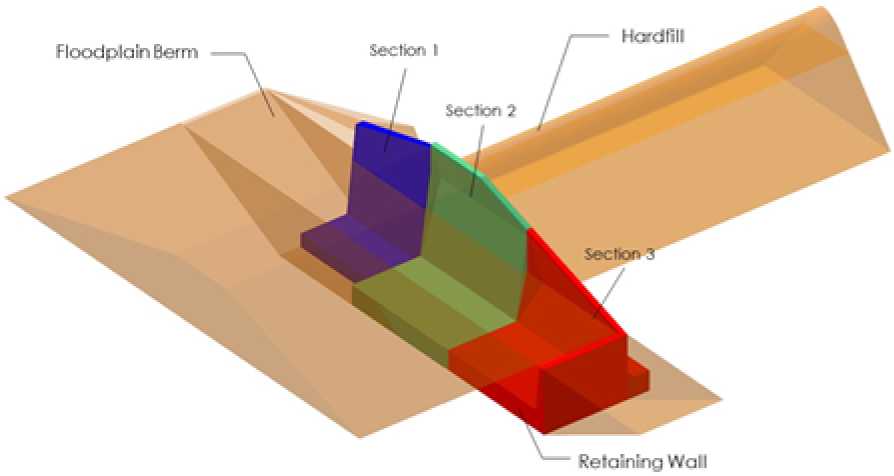
Evaluate the stability of the transition wall of the Auxiliary Spillway. Consider the 3D effects on the structure's stability.

Structure Geometry:



dimensions in mm

Isometric View:



Load Condition

	Elevation (m)			
	Headwater	**Tailwater**	**Headwater**	**Tailwater**
1. Usual Condition (U1)	1214.0	1211.9	7.0	4.9
2. Unusual Condition 1 (UN1)	1214.0	1211.9	7.0	4.9
3. Unusual Condition 2 (UN2)	1216.5	1213.1	9.5	6.1
4. Unusual Condition 3 (UN3)	1217.0	1213.1	10.0	6.1
5. Extreme Condition 1 (E1-F)	1217.3	1213.8	10.3	6.8
6. Extreme Condition 2 (E2-Q)	1213.5	1211.9	6.5	4.9

User Input

Material Properties:

Unit Weight of Water: $\gamma_w := 9.81 \frac{kN}{m^3}$ (Section 7.2, Design Criteria)

Unit Weight of Concrete: $\gamma_c := 23.5 \frac{kN}{m^3}$

Unit Weight of Soil (Moist): $\gamma_m := 20.0 \frac{kN}{m^3}$ (Section 5.3, Design Criteria) assumed moisture content (w) = 5%

Unit Weight Soil (Saturated): $\gamma_{sat} := 22.0 \frac{kN}{m^3}$ (Assuming Specific Gravity = 2.7)

Unit Weight Soil (buoyant): $\gamma_b := \gamma_{sat} - \gamma_w = 12.19 \cdot \frac{kN}{m^3}$

Weight of Soil/Concrete above toe: $\gamma_{toe} := 22.0 \frac{kN}{m^3}$

Unit Weight of Rock: $\gamma_r := 25.6 \frac{kN}{m^3}$ (Section 7.2, Design Criteria)

Extreme Condition 1 (E1)

Acceptance Parameters

Resultant Location (Overturning and Bearing Pressure):

Extreme (E1) Resultant located inside middle half (AT/WCS Guidelines, Section 8.4)

Allowable rock bearing pressure: $qall := 622 \frac{kN}{m^2}$ (Internal Geotechnical Design Recommendations Rev. Sept 12, 2018, Section 5.3)

FS Sliding:

Extreme (E1) 1.1 (without cohesion) (CDA Guidelines, Table 6-4, AT/WCS Guidelines, Section 8.3)

Req'd Factor of Safety for Sliding: $FS_{sliding.req} := 1.1$ (Without Cohesion)

FS Floatation:

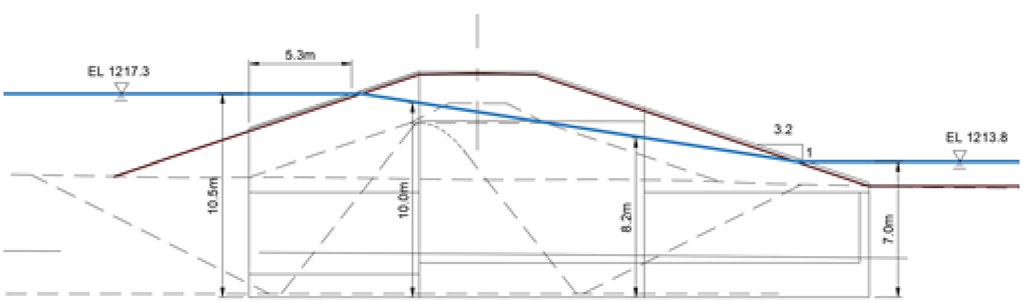
Extreme (E1) 1.1 (AT/WCS Guidelines, Section 8.5)

Req'd Factor of Safety for Floatation: $FS_{float.req} := 1.1$

Water Surface Elevations

Headwater $H_H := 1217.3m$

Tailwater $H_T := 1213.8m$



$h_1 := 10.5m$ $h_2 := 10.m$ $h_3 := 8.2m$ $h_4 := 7.0m$

Interpolated water table heights from retaining wall base.

Section 1

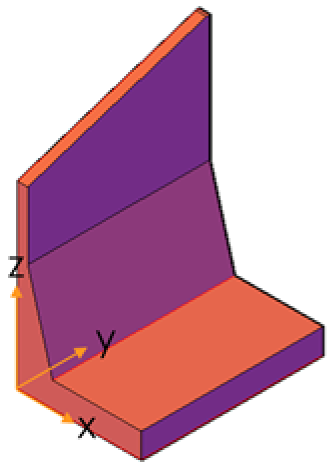
Wall Geometry:

User Input

Top of Wall Elevation:	$\mathbf{T_w} := 1218.44 \cdot \mathbf{m}$
Top of Footing Elevation:	$\mathbf{Top_{ftg}} := 1208.02 \cdot \mathbf{m}$
Thickness of Footing:	$\mathbf{t_{ftg}} := 1.20\mathbf{m}$
Bottom of Footing Elevation:	$\mathbf{Bot_{ftg}} := \mathbf{Top_{ftg}} - t_{ftg} = 1206.82\ \mathbf{m}$
Overall Height of wall:	$\mathbf{h_w} := \mathbf{T_w} - \mathbf{Bot_{ftg}} = 11.620\ \mathbf{m}$
Thickness of Stem Wall at Top:	$\mathbf{t_{wt}} := 0.5\mathbf{m}$
Slope of Heel Batter:	$\mathbf{S_{batter}} := 0.125$
Thickness of Stem Wall at Base:	$\mathbf{t_{wb}} := 1.7\mathbf{m}$
Length of toe:	$\mathbf{L_{ab}} := 0\mathbf{m}$
Total Length of Footing:	$\mathbf{b} := 6\mathbf{m}$
Length of heel:	$\mathbf{L_{cd}} := \mathbf{b} - \mathbf{L_{ab}} - \mathbf{t_{wb}} = 4.3\ \mathbf{m}$
Width of Wall:	$\mathbf{B} := 8.8\mathbf{m}$

Retaining Wall

Retaining Wall Volume and Gravity Center (Using AutoCAD 3D: File: 3D Transition Wall Analysis Section 1.dwg)



Volume

$\mathbf{Vol_{RW}} := \mathbf{125.447\ m^3}$

$\mathbf{X_{RW}} := \mathbf{1.756m}$

$\mathbf{Y_{RW}} := \mathbf{4.475m}$

$\mathbf{Z_{RW}} := 0\mathbf{m}$

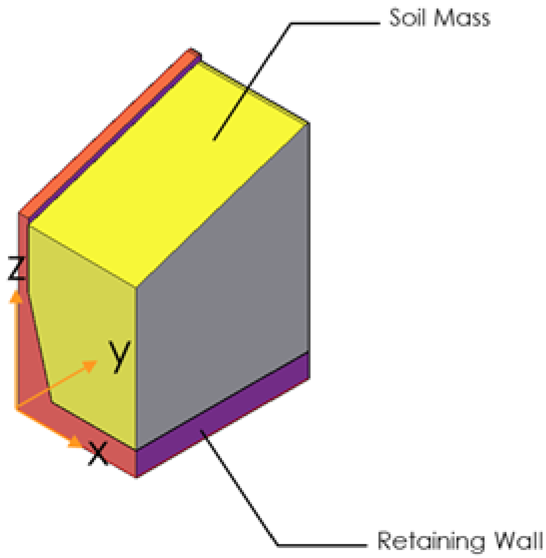
Isometric View

Retaining wall total weight $\quad \mathbf{W_{RW}} := \mathbf{Vol_{RW}} \cdot \gamma_{\mathbf{c}} = 2.95 \cdot \mathbf{MN}$

Soil Mass

Retained Soil Volume and Gravity Center (Using AutoCAD 3D: File 3D Transition Wall Analysis Section 1.dwg)

Isometric View:



$$\mathbf{Vol_{soil}} := \mathbf{397.702\ m^3}$$

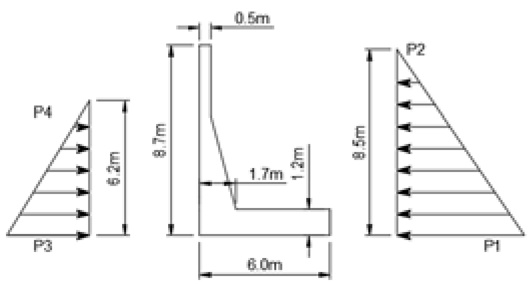
$$\mathbf{X_{soil}} := \mathbf{3.382m}$$

$$\mathbf{Y_{soil}} := \mathbf{4.662m}$$

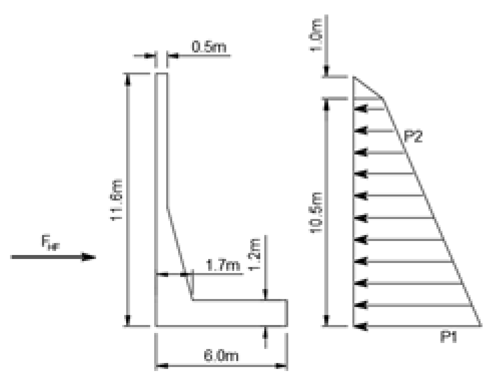
$$\mathbf{Z_{soil}} := 0\mathbf{m}$$

Soil mass total weight $\qquad \mathbf{W_{soilb}} := \mathbf{Vol_{soil}} \cdot \gamma_{\mathbf{m}} = 7.95 \cdot \mathbf{MN}$

Soil Pressure



Section1



Section 2

Section 1

Back of Retaining Wall

depth to water table $\mathbf{dw} := 0\mathbf{m}$

saturated soil depth $\mathbf{ds} := 8.5\mathbf{m}$

soil pressure at rest coefficient $\mathbf{Ko} := 0.55$

$$\mathbf{P2} := \gamma_{\mathbf{m}} \cdot \mathbf{dw} \cdot \mathbf{Ko} = 0 \cdot \mathbf{kPa}$$

$$\mathbf{P1} := \mathbf{P2} + \gamma_{\mathbf{b}} \cdot \mathbf{ds} \cdot \mathbf{Ko} = 56.988 \cdot \mathbf{kPa}$$

Front of Retaining Wall

depth to water table $\mathbf{dw} := 0$

saturated soil depth $\mathbf{ds} := 6.2\mathbf{m}$

soil pressure at rest coefficient $\mathbf{Ko} := 0.55$

$$\mathbf{P4} := \gamma_{\mathbf{m}} \cdot \mathbf{dw} \cdot \mathbf{Ko} = 0 \cdot \mathbf{kPa}$$

$$\mathbf{P3} := \mathbf{P2} + \gamma_{\mathbf{b}} \cdot \mathbf{ds} \cdot \mathbf{Ko} = 41.568 \cdot \mathbf{kPa}$$

Section 2

depth to water table $\mathbf{dw} := 1.0\mathbf{m}$

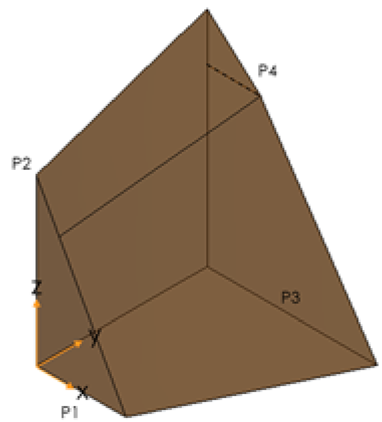
saturated soil depth $\mathbf{ds} := 10.5\mathbf{m}$

soil pressure at rest coefficient $\mathbf{Ko} := 0.55$

$$\mathbf{P1} := \gamma_{\mathbf{m}} \cdot \mathbf{dw} \cdot \mathbf{Ko} = 11 \cdot \mathbf{kPa}$$

$$\mathbf{P2} := \mathbf{P1} + \gamma_{\mathbf{b}} \cdot \mathbf{ds} \cdot \mathbf{Ko} = 81.397 \cdot \mathbf{kPa}$$

Isometric view of the prism representing soil pressures against the retaining wall (Using AutoCAD 3D: 3D Transition Wall Analysis Section 3.dwg). The volume of the prism is equal to the equivalent total force.



Isometric View

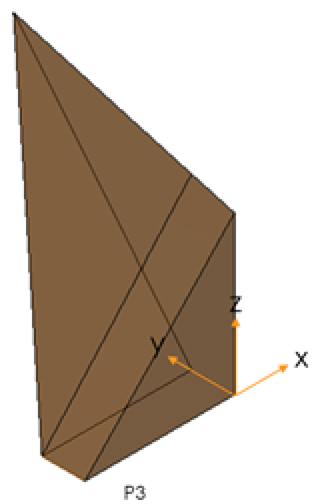
Total Force Back Soil

$F_{soilb} := 2748.29kN$

$X_{Fsoilb} := 0m$

$Y_{Fsoilb} := 5.189m$

$Z_{Fsoilb} := 3.299m$



Total Force Front Soil

$F_{soilf} := 787.47kN$

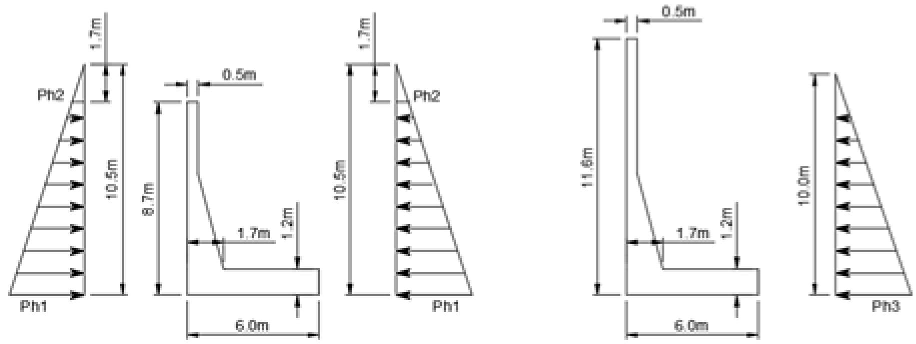
$X_{Fsoilf} := 0m$

$Y_{Fsoilf} := 2.391m$

$Z_{Fsoilf} := 3.144m$

Hydrostatic Forces

Side View



Section 1 Section 2

Front of Wall $\mathbf{h_f} := 10.5\mathbf{m}$

Back of Wall $\mathbf{h_b} := 10.0\mathbf{m}$

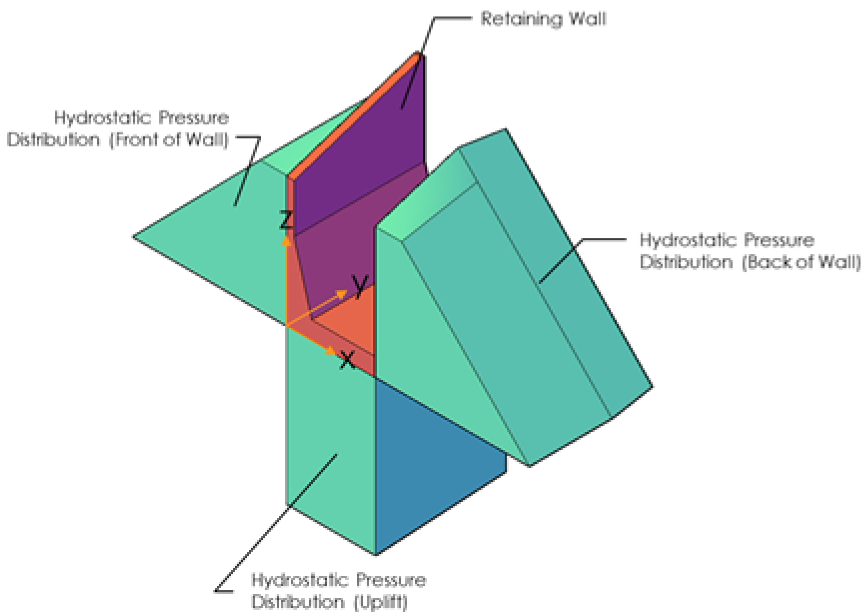
Depth to top of wall $\mathbf{h_{tw}} := 1.7\mathbf{m}$

$$\mathbf{Ph1} := \mathbf{h_f} \cdot \gamma_w = 103 \cdot \mathbf{kPa}$$

$$\mathbf{Ph2} := \mathbf{h_{tw}} \cdot \gamma_w = 16.68 \cdot \mathbf{kPa}$$

$$\mathbf{Ph3} := \mathbf{h_b} \cdot \gamma_w = 98.1 \cdot \mathbf{kPa}$$

Isometric View



Total Hydrostatic Force

Back of Wall

$H_{Fu} := 4479.62\,kN$

$X_{Fu} := 0m$

$Y_{Fu} := 4.348m$

$Z_{Fu} := 3.343m$

Volume and centroid of hydrostatic pressure was determined using AutoCAD 3D: File Water Pressure.dwg

Total Hydrostatic Force

Front of Wal

$H_{Ft} := 2271.63\,kN$

$X_{Ft} := 0m$

$Y_{Ft} := 2.563m$

$Z_{Ft} := 4.505m$

Volume and centroid of hydrostatic pressure was determined using AutoCAD 3D: File Water Pressure.dwg

Uplift

Total Uplift Force

$F_{uplift} := 5309.04\,kN$

$X_{uplift} := 3.000m$

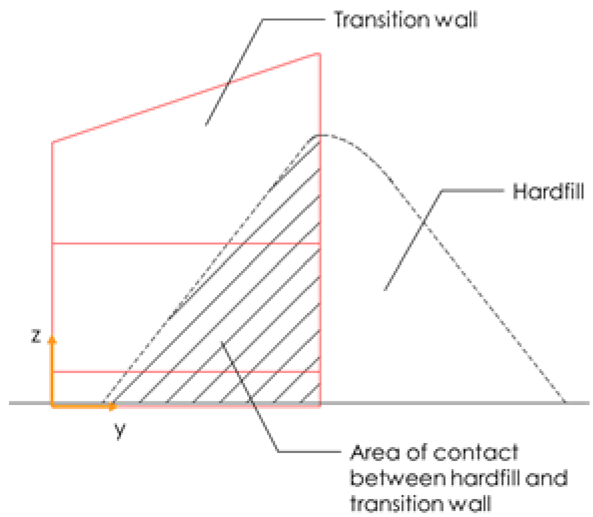
$Y_{uplift} := 4.364m$

$Z_{uplift} := 0m$

Volume and centroid of hydrostatic pressure was determined using AutoCAD 3D: File Water Pressure.dwg

Hardfill Contact Area and Resultant Resistant Force

Front View



Area of Contact

$\mathbf{Ac} := 32.1753\ \mathbf{m}^2$

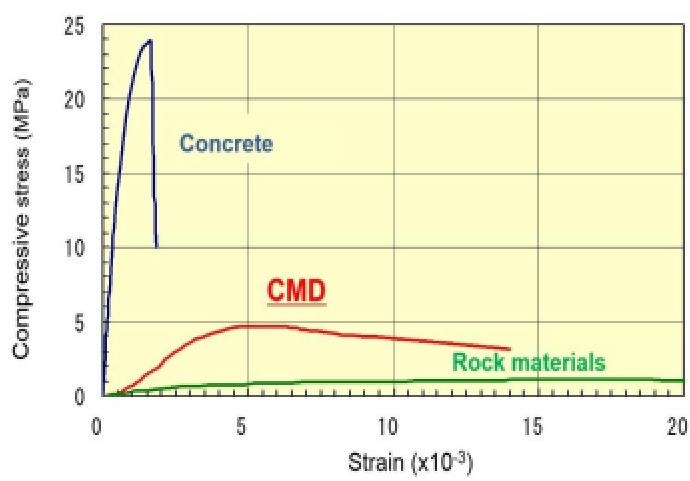
Centroid of contact area was determined using Autocad: File Training Wall.dwg

$\mathbf{X_{HF}} := 0\mathbf{m}$

$\mathbf{Y_{HF}} := 6.4208\mathbf{m}$

$\mathbf{Z_{HF}} := 3.1349\mathbf{m}$

Hard Fill Stiffness



Source: Noorzad et al. (2017). An Innovative Approach toward Dam Design and Construction. 2nd Workshop on Cement Materials Dams (CMD). July 3, 2017.

$E_{HF} := \dfrac{5\mathbf{MPa}}{5 \times \mathbf{10}^{-3}} = 1 \cdot \mathbf{GPa}$ Approximate Hardfill Modulus of Elasticity

$L_{HF} := 16\mathbf{m}$ Hardfill section length (between construction joints)

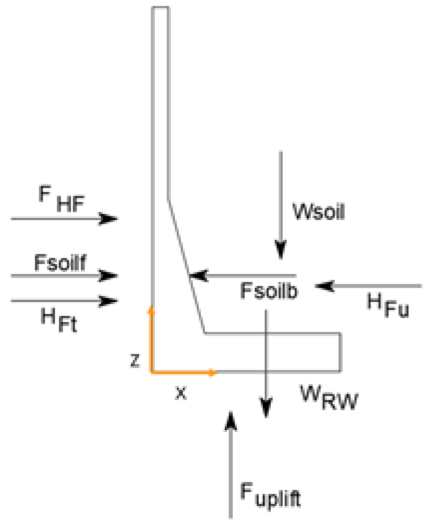
Approximate hardfill stiffness $k_{HF} := \dfrac{E_{HF}}{L_{HF}} = 62500 \cdot \dfrac{\mathbf{kN}}{\mathbf{m}^3}$

$\delta_{max} := L_{HF} \cdot 5 \cdot 10^{-3} = 80 \cdot \mathbf{mm}$

Considering a deformation of the hardfill of : $\delta_{HF} := 1.3\mathbf{mm}$ < $\delta_{max} = 80 \cdot \mathbf{mm}$

The total reaction of the hardfill is: $F_{HF} := k_{HF} \cdot Ac \cdot \delta_{HF} = 2.61 \cdot \mathbf{MN}$

Vector Forces Summary



Body diagram, side view

Weight Retaining Wall $\mathbf{W_{RW}} := \left(0 \quad 0 \quad -\mathbf{W_{RW}}\right) = (0 \quad 0 \quad -2.95)\cdot\mathbf{MN}$

Weight Soil (Back of Wall) $\mathbf{W_{soilb}} := \left(0 \quad 0 \quad -\mathbf{W_{soilb}}\right) = (0 \quad 0 \quad -7.95)\cdot\mathbf{MN}$

Soil Pressure (Back of Wall) $\mathbf{F_{soilb}} := \left(-\mathbf{F_{soilb}} \quad 0 \quad 0\right) = (-2.75 \quad 0 \quad 0)\cdot\mathbf{MN}$

Soil Pressure (Front of Wall) $\mathbf{F_{soilf}} := \left(\mathbf{F_{soilf}} \quad 0 \quad 0\right) = (0.79 \quad 0 \quad 0)\cdot\mathbf{MN}$

Hydrostatic Force (Back of Wall) $\mathbf{H_{Fu}} := \left(-\mathbf{H_{Fu}} \quad \mathbf{0} \quad 0\right) = (-4.48 \quad 0 \quad 0)\cdot\mathbf{MN}$

Hydrostatic Force (Front of Wall) $\mathbf{H_{Ft}} := \left(\mathbf{H_{Ft}} \quad 0 \quad 0\right) = (2.27 \quad 0 \quad 0)\cdot\mathbf{MN}$

Uplift Force $\mathbf{F_{uplift}} := \left(0 \quad 0 \quad \mathbf{F_{uplift}}\right) = (0 \quad 0 \quad 5.31)\cdot\mathbf{MN}$

Resistance force by Hardfill $\mathbf{F_{HF}} := \left(\mathbf{F_{HF}} \quad 0 \quad 0\right) = (2.61 \quad 0 \quad 0)\cdot\mathbf{MN}$

Resultant Total Force

$$F := W_{RW} + W_{soilb} + F_{soilb} + F_{soilf} + H_{Fu} + H_{Ft} + F_{uplift} + F_{HF}$$

$$F = (-1.55 \quad 0 \quad -5.59)\cdot MN$$

Structure Stability

1. Sliding

$$236.6m^3\cdot\gamma_w = 2.32\cdot MN$$

Coefficient of sliding friction $\mu := 0.45$

$$FoS := \frac{F_{0,2}\cdot\mu}{F_{0,0}} = 1.62 \quad > \quad FS_{sliding.req} = 1.1 \quad \textbf{OK}$$

2. Uplift

Summatory of Axial Resistant Forces

$$F_R := W_{RW} + W_{soilb} = (0 \quad 0 \quad -10.9)\cdot MN$$

Uplift Force

$$F_{uplift} = (0 \quad 0 \quad 5.31)\cdot MN$$

$$FoS_{uplift} := \frac{\left|F_{R_{0,2}}\right|}{\left|F_{uplift_{0,2}}\right|} = 2.05 \quad > \quad FS_{float.req} = 1.1 \quad \textbf{OK}$$

3. Overturning

$$\mathbf{r_{RW}} := \left(\mathbf{X_{RW}}\ \ Y_{RW}\ \ Z_{RW}\right) = (1.76\ \ 4.47\ \ 0)\ \mathbf{m}$$

$$\mathbf{r_{soilb}} := \left(X_{soil}\ \ Y_{soil}\ \ Z_{soil}\right) = (3.38\ \ 4.66\ \ 0)\ \mathbf{m}$$

$$\mathbf{r_{Fsoilb}} := \left(X_{Fsoilb}\ \ Y_{Fsoilb}\ \ Z_{Fsoilb}\right) = (0\ \ 5.19\ \ 3.3)\ \mathbf{m}$$

$$\mathbf{r_{Fsoilf}} := \left(X_{Fsoilf}\ \ Y_{Fsoilf}\ \ Z_{Fsoilf}\right) = (0\ \ 2.39\ \ 3.14)\ \mathbf{m}$$

$$\mathbf{r_{Fu}} := \left(X_{Fu}\ \ Y_{Fu}\ \ Z_{Fu}\right) = (0\ \ 4.35\ \ 3.34)\ \mathbf{m}$$

$$\mathbf{r_{Ft}} := \left(X_{Ft}\ \ Y_{Ft}\ \ Z_{Ft}\right) = (0\ \ 2.56\ \ 4.5)\ \mathbf{m}$$

$$\mathbf{r_{uplift}} := \left(X_{uplift}\ \ Y_{uplift}\ \ Z_{uplift}\right) = (3\ \ 4.36\ \ 0)\ \mathbf{m}$$

$$\mathbf{r_{HF}} := \left(\mathbf{X_{HF}}\ \ \mathbf{Y_{HF}}\ \ \mathbf{Z_{HF}}\right) = (0\ \ 6.42\ \ 3.13)\ \mathbf{m}$$

$$\mathbf{M} := \mathbf{W_{RW}}^{\mathbf{T}} \times \mathbf{r_{RW}}^{\mathbf{T}} + \mathbf{W_{soilb}}^{\mathbf{T}} \times \mathbf{r_{soilb}}^{\mathbf{T}} + \mathbf{F_{soilb}}^{\mathbf{T}} \times \mathbf{r_{Fsoilb}}^{\mathbf{T}} + \mathbf{F_{HF}}^{\mathbf{T}} \times \mathbf{r_{HF}}^{\mathbf{T}} \ \cdots$$
$$+ \mathbf{F_{soilf}}^{\mathbf{T}} \times \mathbf{r_{Fsoilf}}^{\mathbf{T}} + \mathbf{H_{Fu}}^{\mathbf{T}} \times \mathbf{r_{Fu}}^{\mathbf{T}} + \mathbf{H_{Ft}}^{\mathbf{T}} \times \mathbf{r_{Ft}}^{\mathbf{T}} + \mathbf{F_{uplift}}^{\mathbf{T}} \times \mathbf{r_{uplift}}^{\mathbf{T}}$$

$$\mathbf{M} = \begin{pmatrix} 27.11 \\ -13.01 \\ -9.25 \end{pmatrix} \cdot \mathbf{MN} \cdot \mathbf{m}$$

$$\mathbf{F} = (-1.55\ \ 0\ \ -5.59) \cdot \mathbf{MN}$$

Location of resultant force:

$$\mathbf{X_R} := \left| \frac{\mathbf{M}_{1,0}}{\mathbf{F}_{0,2}} \right| = 2.33 \cdot \mathbf{m}$$

$$\mathbf{x} := \left| \mathbf{X_R} - \frac{\mathbf{b}}{2} \right| = 0.67\ \mathbf{m} \quad < \quad \frac{\mathbf{b}}{4} = 1.5\ \mathbf{m} \qquad \mathbf{OK}$$

4. **Bearing Capacity**

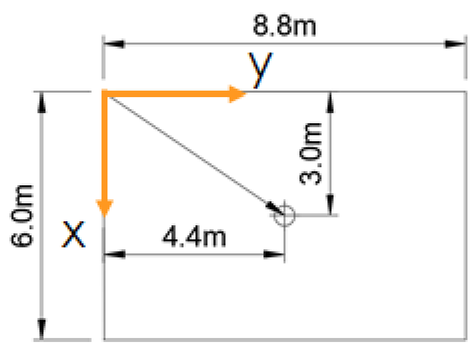
$$\mathbf{q_{all}} := 622\,\mathbf{kPa}$$

Force and Moment at origin:

$$\mathbf{F} = (-1.55 \quad 0 \quad -5.59)\cdot\mathbf{MN} \qquad \mathbf{M} = \begin{pmatrix} 27.11 \\ -13.01 \\ -9.25 \end{pmatrix}\mathbf{m}\cdot\mathbf{MN}$$

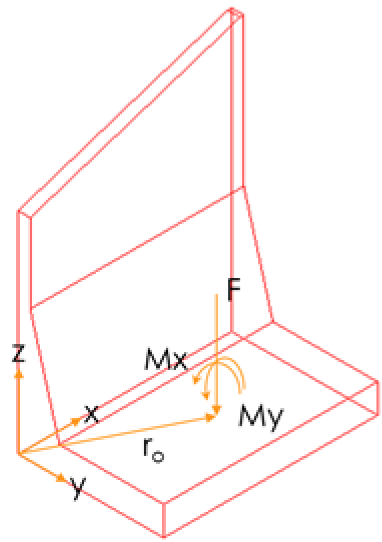
Vector to center of foundation:

$$\mathbf{r_o} := (3 \quad 4.4 \quad 0)\,\mathbf{m}$$



Moment at center of Foundation

$$M_o := M - F^T \times r_o{}^T = \begin{pmatrix} 2.5 \\ 3.77 \\ -2.41 \end{pmatrix} m \cdot MN$$



$$Ix_o := \frac{1}{12} \cdot b^3 \cdot B = 158.4\, m^4$$

$$Iy_o := \frac{1}{12} \cdot b \cdot B^3 = 340.736\, m^4$$

$$A := b \cdot B = 52.8\, m^2$$

$$\sigma_{max} := \left| \frac{F_{0,2}}{A} \right| + \left| \frac{M_{o_{0,0}} \cdot b}{2 \cdot Ix_o} \right| + \left| \frac{M_{o_{1,0}} \cdot B}{2 \cdot Iy_o} \right| = 201.835 \cdot kPa < \quad q_{all} = 622 \cdot kPa \quad \textbf{OK}$$

$$\sigma_{min} := \left| \frac{F_{0,2}}{A} \right| - \left| \frac{M_{o_{0,0}} \cdot b}{2 \cdot Ix_o} \right| - \left| \frac{M_{o_{1,0}} \cdot B}{2 \cdot Iy_o} \right| = 10.021 \cdot kPa \ < \quad q_{all} = 622 \cdot kPa \quad \textbf{OK}$$

TP **Section 1: Extreme Condition (E2)**

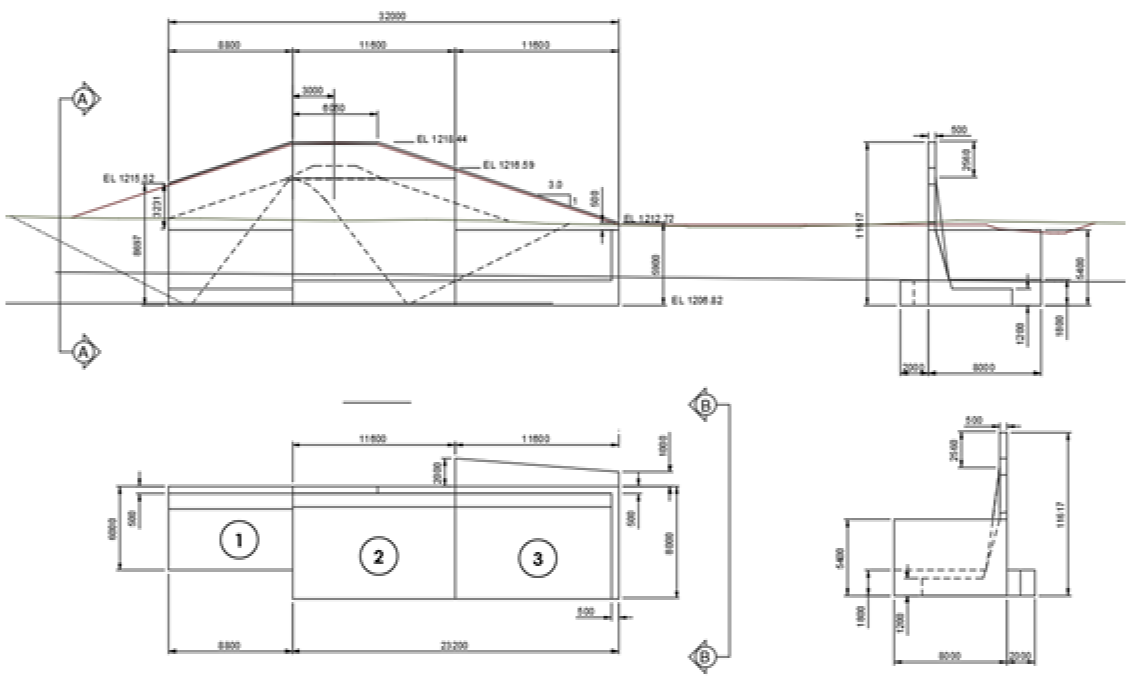
Loading	Horizontal Forces Force (MN)	Horizontal Forces Arm (m)	Vertical Forces Force (MN)	Vertical Forces Arm (m)	Stabilizing Moments (MN-m)	Overturning Moments (MN-m)
Weight of Structure			3.0	1.8	5.2	
Earthquake Inertia Force	-0.5	2.6				1.3
Soil Mass, front of wall						
Soil Mass, front of wall, Inertial Force						
Soil Mass, back of wall			8.0	3.4	26.9	
Soil Mass, back of wall, Inertial Force	-1.35	5.75				7.8
Soil Pressure, front of wall	0.33	3.15			1.0	
Soil Pressure, back of wall	-1.56	3.64				5.7
Soil Dynamic Pressure, back of wall	-1.70	7.25				12.3
Uplift			-3.1	3.0		9.2
Hydrostatic pressure, front of wall	0.73	2.83			2.1	
Hydrostatic pressure, back of wall	-1.51	1.99				-3.0
Hydrostatic weight, front of wall						
Hardfill	3.82	3.13			12.0	
SUM	**-1.7**		**7.8**		**47.1**	**33.2**
					Net Moment	
					13.95	

Stability Calculations
Retaining Wall - Auxiliary Spillway
Right Abutment Transition to Berm

Scope:

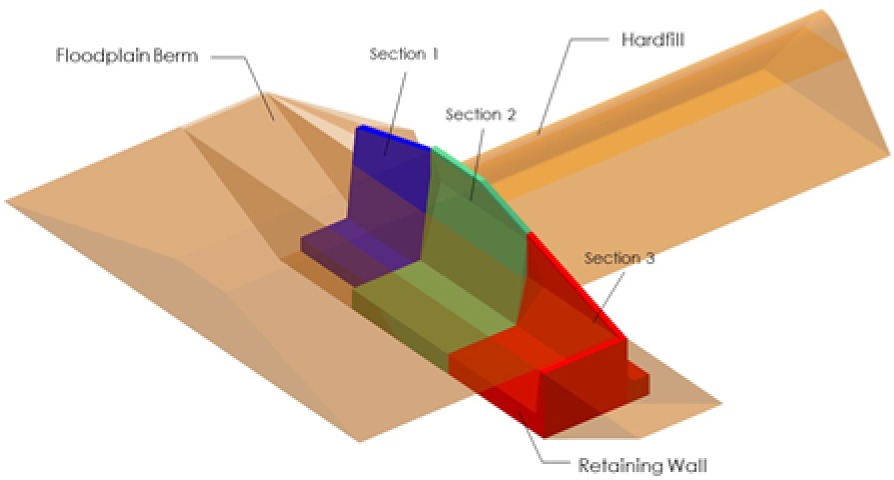
Evaluate the stability of the transition wall of the Auxiliary Spillway. Consider the 3D effects on the structure's stability.

Structure Geometry:



dimensions in mm

Isometric View:



Load Condition

	Elevation (m)			
	Headwater	**Tailwater**	**Headwater**	**Tailwater**
1. Usual Condition (U1)	1214.0	1211.9	7.0	4.9
2. Unusual Condition 1 (UN1)	1214.0	1211.9	7.0	4.9
3. Unusual Condition 2 (UN2)	1216.5	1213.1	9.5	6.1
4. Unusual Condition 3 (UN3)	1217.0	1213.1	10.0	6.1
5. Extreme Condition 1 (E1-F)	1217.3	1213.8	10.3	6.8
6. Extreme Condition 2 (E2-Q)	1213.5	1211.9	6.5	4.9

User Input

Material Properties:

Unit Weight of Water: $\gamma_w := 9.81 \dfrac{kN}{m^3}$ (Section 7.2, Design Criteria)

Unit Weight of Concrete: $\gamma_c := \mathbf{23.5} \dfrac{kN}{m^3}$

Unit Weight of Soil (Moist): $\gamma_m := 20.0 \dfrac{kN}{m^3}$ (Section 5.3, Design Criteria) assumed moisture content (w) = 5%

Unit Weight Soil (Saturated): $\gamma_{sat} := 22.0 \dfrac{kN}{m^3}$ (Assuming Specific Gravity = 2.7)

Unit Weight Soil (buoyant): $\gamma_b := \gamma_{sat} - \gamma_w = 12.19 \cdot \dfrac{kN}{m^3}$

Weight of Soil/Concrete above toe: $\gamma_{toe} := 22.0 \dfrac{kN}{m^3}$

Unit Weight of Rock: $\gamma_r := 25.6 \dfrac{kN}{m^3}$ (Section 7.2, Design Criteria)

Extreme Condition 2 (E2)

Acceptance Parameters

Resultant Location (Overturning and Bearing Pressure):

Extreme (E1) Resultant located inside middle half (AT/WCS Guidelines, Section 8.4)

Allowable rock bearing pressure: $qall := 622 \frac{kN}{m^2}$ (Internal Geotechnical Design Recommendations Rev. Sept 12, 2018, Section 5.3)

FS Sliding:

Extreme (E1) 1.1 (without cohesion) (CDA Guidelines, Table 6-4, AT/WCS Guidelines, Section 8.3)

Req'd Factor of Safety for Sliding: $FS_{sliding.req} := 1.1$ (Without Cohesion)

FS Floatation:

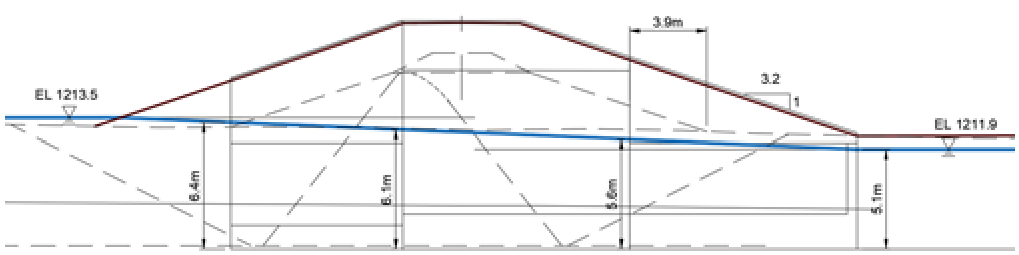
Extreme (E1) 1.1 (AT/WCS Guidelines, Section 8.5)

Req'd Factor of Safety for Floatation: $FS_{float.req} := 1.1$

Water Surface Elevations

Headwater $H_H := 1213.5m$

Tailwater $H_T := 1211.9m$



$h_1 := 6.4m$ $h_2 := 6.1m$ $h_3 := 5.6m$ $h_4 := 5.1m$

Interpolated water table heights from retaining wall base.

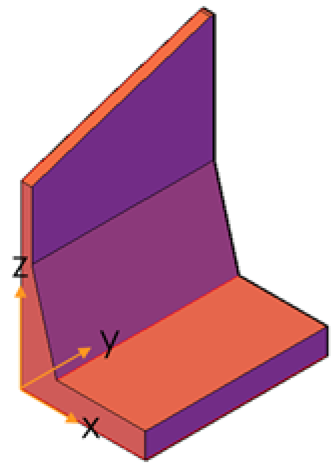
Section 1

Wall Geometry: User Input

Top of Wall Elevation:	$\mathbf{T_w} := 1218.44 \cdot \mathbf{m}$
Top of Footing Elevation:	$\mathbf{Top_{ftg}} := 1208.02 \cdot \mathbf{m}$
Thickness of Footing:	$\mathbf{t_{ftg}} := 1.20\mathbf{m}$
Bottom of Footing Elevation:	$\mathbf{Bot_{ftg}} := \mathbf{Top_{ftg}} - t_{ftg} = 1206.82\ \mathbf{m}$
Overall Height of wall:	$\mathbf{h_w} := \mathbf{T_w} - \mathbf{Bot_{ftg}} = 11.620\ \mathbf{m}$
Thickness of Stem Wall at Top:	$\mathbf{t_{wt}} := 0.5\mathbf{m}$
Slope of Heel Batter:	$\mathbf{S_{batter}} := 0.125$
Thickness of Stem Wall at Base:	$\mathbf{t_{wb}} := 1.7\mathbf{m}$
Length of toe:	$\mathbf{L_{ab}} := 0\mathbf{m}$
Total Length of Footing:	$\mathbf{b} := 6\mathbf{m}$
Length of heel:	$\mathbf{L_{cd}} := \mathbf{b} - \mathbf{L_{ab}} - \mathbf{t_{wb}} = 4.3\ \mathbf{m}$
Width of Wall:	$\mathbf{B} := 8.8\mathbf{m}$

Retaining Wall

Retaining Wall Volume and Gravity Center (Using AutoCAD 3D: File: 3D Transition Wall Analysis Section 1.dwg)



Isometric View

Volume

$\mathbf{Vol_{RW}} := \mathbf{125.447\ m^3}$

$\mathbf{X_{RW}} := \mathbf{1.756m}$

$\mathbf{Y_{RW}} := \mathbf{4.475m}$

$\mathbf{Z_{RW}} := \mathbf{2.583m}$

Retaining wall total weight $\quad \mathbf{W_{RW}} := \mathbf{Vol_{RW}} \cdot \gamma_c = 2.95 \cdot \mathbf{MN}$

Earthquake Inertial Force

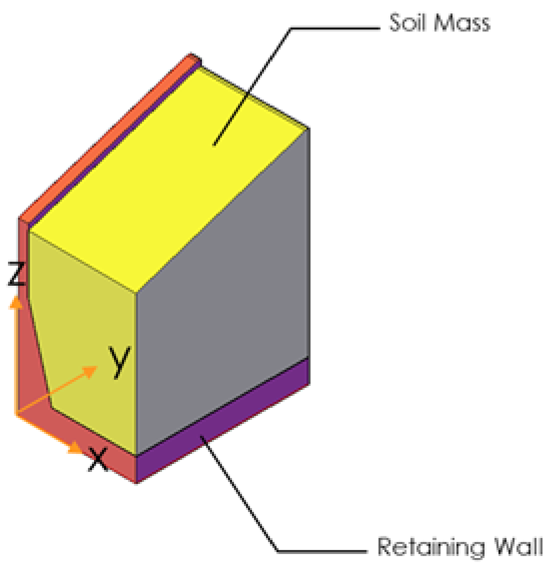
$\mathbf{kh} := 0.17$

$\mathbf{F_{RW}} := \mathrm{kh} \cdot \mathbf{W_{RW}} = 0.5 \cdot \mathbf{MN}$

Soil Mass

Retained Soil Volume and Gravity Center (Using AutoCAD 3D: File 3D Transition Wall Analysis Section 1.dwg)

Isometric View:



$$\mathbf{Vol_{soil}} := \mathbf{397.702\ m^3}$$

$$\mathbf{X_{soil}} := \mathbf{3.382m}$$

$$\mathbf{Y_{soil}} := \mathbf{4.662m}$$

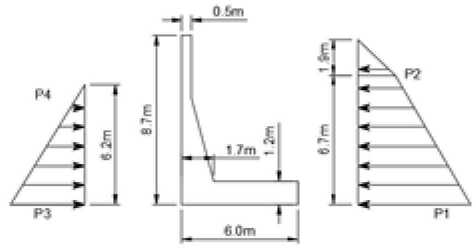
$$\mathbf{Z_{soil}} := \mathbf{5.750m}$$

Soil mass total weight $\mathbf{W_{soilb}} := \mathbf{Vol_{soil}} \cdot \gamma_{\mathbf{m}} = 7.95 \cdot \mathbf{MN}$

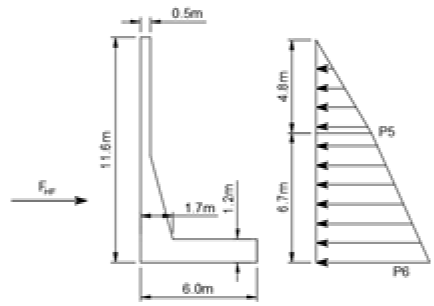
Earthquake Inertial Force

$$\mathbf{Fsoilb_{AE}} := \mathbf{kh} \cdot \mathbf{W_{soilb}} = 1.35 \cdot \mathbf{MN}$$

Soil Pressure



Section1



Section 2

Section 1

Back of Retaining Wall

depth to water table $\mathbf{dw} := 1.9\mathbf{m}$

saturated soil depth $\mathbf{ds} := 6.7\mathbf{m}$

soil pressure at rest coefficient $\mathbf{Ka} := 0.21$

$$\mathbf{P2} := \gamma_{\mathbf{m}} \cdot \mathbf{dw} \cdot \mathbf{Ka} = 7.98 \cdot \mathbf{kPa}$$

$$\mathbf{P1} := \mathbf{P2} + \gamma_{\mathbf{b}} \cdot \mathbf{ds} \cdot \mathbf{Ka} = 25.131 \cdot \mathbf{kPa}$$

Front of Retaining Wall

depth to water table $\mathbf{dw} := 0\mathbf{m}$

saturated soil depth $\mathbf{ds} := 6.2\mathbf{m}$

soil pressure at rest coefficient $\mathbf{Ka} := 0.21$

$$\mathbf{P4} := \gamma_{\mathbf{m}} \cdot \mathbf{dw} \cdot \mathbf{Ka} = 0 \cdot \mathbf{kPa}$$

$$\mathbf{P3} := \mathbf{P2} + \gamma_{\mathbf{b}} \cdot \mathbf{ds} \cdot \mathbf{Ka} = 23.851 \cdot \mathbf{kPa}$$

Section 2

depth to water table $\mathbf{dw} := 4.8\mathbf{m}$

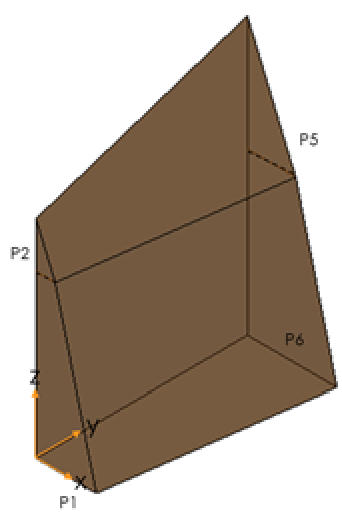
saturated soil depth $\mathbf{ds} := 6.7\mathbf{m}$

soil pressure at rest coefficient $\mathbf{Ka} := 0.21$

$$\mathbf{P5} := \gamma_{\mathbf{m}} \cdot \mathbf{dw} \cdot \mathbf{Ka} = 20.16 \cdot \mathbf{kPa}$$

$$\mathbf{P6} := \mathbf{P5} + \gamma_{\mathbf{b}} \cdot \mathbf{ds} \cdot \mathbf{Ka} = 37.311 \cdot \mathbf{kPa}$$

Isometric view of the prism representing soil pressures against the retaining wall (Using AutoCAD 3D: 3D Transition Wall Analysis Section 3.dwg). The volume of the prism is equal to the equivalent total force.



Total Force Back Soil

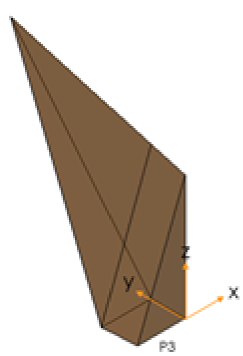
$\mathbf{F_{soilb}} := 1555.52\mathbf{kN}$

$\mathbf{X_{Fsoilb}} := 0\mathbf{m}$

$\mathbf{Y_{Fsoilb}} := \mathbf{4.908m}$

$\mathbf{Z_{Fsoilb}} := \mathbf{3.638m}$

Isometric View



Total Force Front Soil

$\mathbf{F_{soilf}} := \mathbf{328.30kN}$

$\mathbf{X_{Fsoilf}} := 0\mathbf{m}$

$\mathbf{Y_{Fsoilf}} := \mathbf{2.407m}$

$\mathbf{Z_{Fsoilf}} := \mathbf{3.153m}$

Seismic Loading

$\phi_w := 38\,\mathbf{deg}$ internal friction angle of soil

$\psi := \mathbf{atan}\left(\frac{0.28}{1-0.16}\right) = 18.43\cdot\mathbf{deg}$ seismic inertia angle

$\beta := 0\,\mathbf{deg}$ inclination of soil surface

$$\mathbf{K_{AE}} := \frac{\mathbf{cos}(\phi_w - \psi)^2}{\mathbf{cos}(\psi)^2\cdot\left(1+\sqrt{\frac{\mathbf{sin}(\phi_w)\cdot\mathbf{sin}(\phi_w-\psi-\beta)}{\mathbf{cos}(\beta)\cdot\mathbf{cos}(\psi)}}\right)^2}$$

$\mathbf{K_{AE}} = 0.46$

Section 1

Back of Retaining Wall

depth to water table $\mathbf{dw} := 1.9\mathbf{m}$

saturated soil depth $\mathbf{ds} := 6.7\mathbf{m}$

$$\mathbf{\Delta P2} := \gamma_m\cdot\mathbf{dw}\cdot\mathbf{K_{AE}} - \mathbf{P2} = 9.46\cdot\mathbf{kPa}$$

$$\mathbf{\Delta P1} := (\mathbf{P2} + \mathbf{\Delta P2}) + \gamma_b\cdot\mathbf{ds}\cdot\mathbf{K_{AE}} - \mathbf{P1} = 29.788\cdot\mathbf{kPa}$$

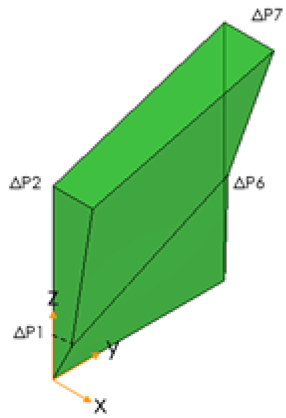
Section 2

depth to water table $\mathbf{dw} := 4.8\mathbf{m}$

saturated soil depth $\mathbf{ds} := 6.7\mathbf{m}$

$$\mathbf{\Delta P6} := \gamma_m\cdot\mathbf{dw}\cdot\mathbf{K_{AE}} - \mathbf{P6} = 6.74\cdot\mathbf{kPa}$$

$$\mathbf{\Delta P5} := (\mathbf{P6} + \mathbf{\Delta P6}) + \gamma_b\cdot\mathbf{ds}\cdot\mathbf{K_{AE}} - \mathbf{P5} = 61.376\cdot\mathbf{kPa}$$



Total Force Dynamic Soil Pressure

$$F_{AE} := 1699.05\,\mathbf{kN}$$

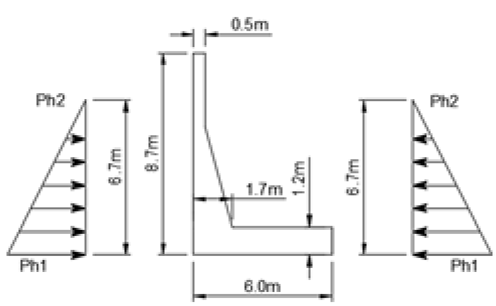
$$X_{AE} := 0\,\mathbf{m}$$

$$Y_{AE} := 4.795\,\mathbf{m}$$

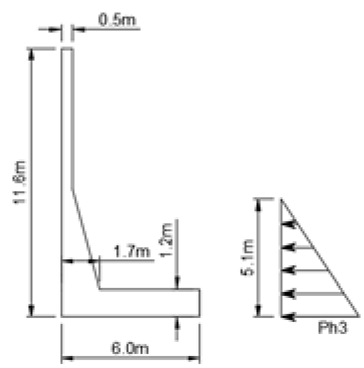
$$Z_{AE} := 7.247\,\mathbf{m}$$

Hydrostatic Forces

Side View



Section 1



Section 2

Front of Wall $\quad h_f := 6.7\,\mathbf{m}$

Back of Wall $\quad h_b := 5.1\,\mathbf{m}$

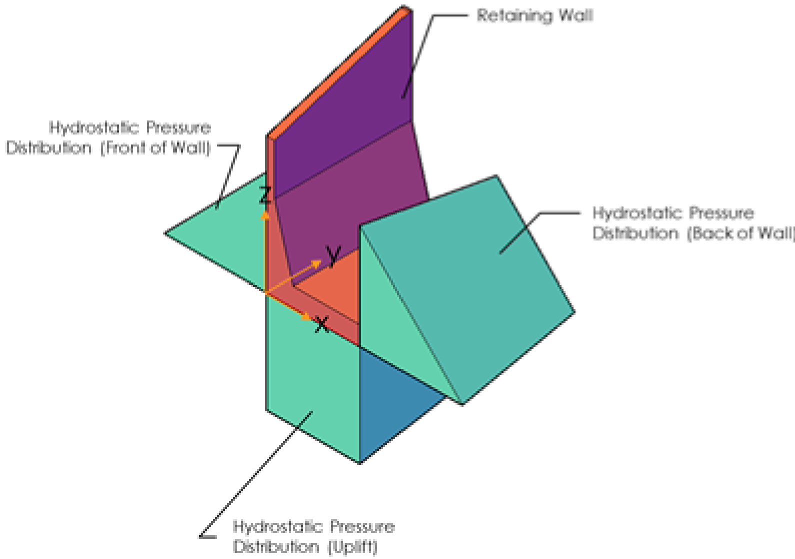
Depth to top of wall $\quad h_{tw} := 0\,\mathbf{m}$

$$Ph1 := h_f \cdot \gamma_w = 65.73 \cdot \mathbf{kPa}$$

$$Ph2 := h_{tw} \cdot \gamma_w = 0 \cdot \mathbf{kPa}$$

$$Ph3 := h_b \cdot \gamma_w = 50.03 \cdot \mathbf{kPa}$$

Isometric View



Total Hydrostatic Force

Back of Wall

$H_{Fu} := 1511.78kN$

$X_{Fu} := 0m$

$Y_{Fu} := 4.005m$

$Z_{Fu} := 1.991m$

Volume and centroid of hydrostatic pressure was determined using AutoCAD 3D: 3D Transition Wall Analysis Section 1.dwg

Total Hydrostatic Force

Front of Wal

$H_{Ft} := 727.81kN$

$X_{Ft} := 0m$

$Y_{Ft} := 1.888m$

$Z_{Ft} := 2.829m$

Volume and centroid of hydrostatic pressure was determined using AutoCAD 3D: 3D Transition Wall Analysis Section 1.dwg

Uplift

Total Uplift Force

$F_{uplift} := 3056.06kN$

$X_{uplift} := 3.000m$

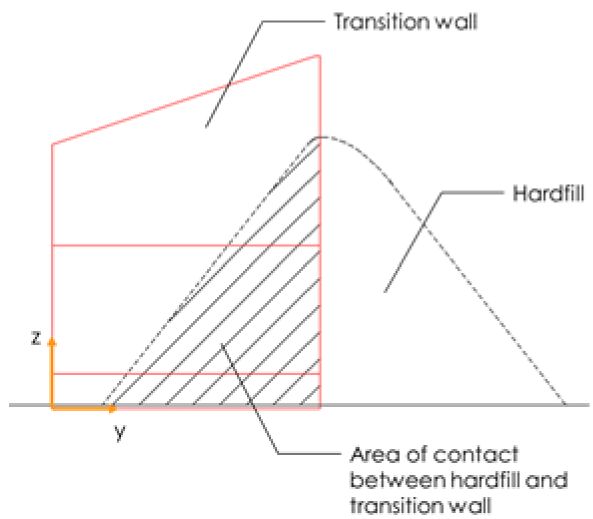
$Y_{uplift} := 4.201m$

$Z_{uplift} := 0m$

Volume and centroid of hydrostatic pressure was determined using AutoCAD 3D: File 3D Transition Wall Analysis Section 1.dwg

Hardfill Contact Area and Resultant Resistant Force

Front View



Area of Contact

$Ac := 32.1753\ \mathbf{m}^2$

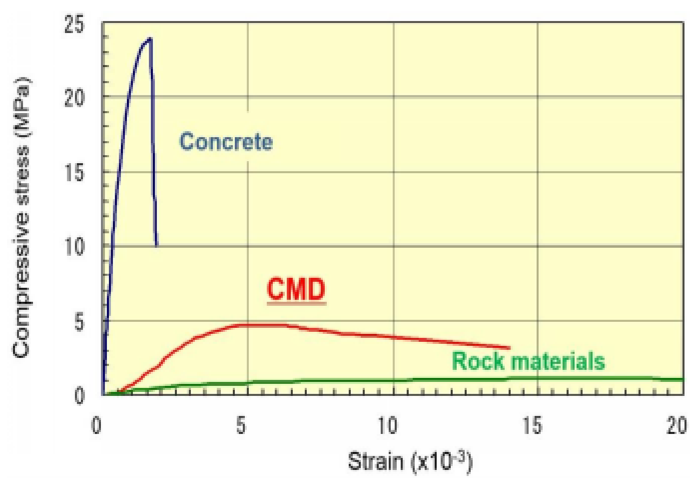
Centroid of contact area was determined using Autocad: File Wall Pressure Diagrams.dwg

$X_{HF} := 0\mathbf{m}$

$Y_{HF} := 6.4208\mathbf{m}$

$Z_{HF} := 3.1349\mathbf{m}$

Hard Fill Stiffness



Source: Noorzad et al. (2017). An Innovative Approach toward Dam Design and Construction. 2nd Workshop on Cement Materials Dams (CMD). July 3, 2017.

$$E_{HF} := \frac{5\mathbf{MPa}}{5 \times \mathbf{10}^{-3}} = 1 \cdot \mathbf{GPa}$$ Approximate Hardfill Modulus of Elasticity

$$L_{HF} := 16\mathbf{m}$$ Hardfill section length (between construction joints)

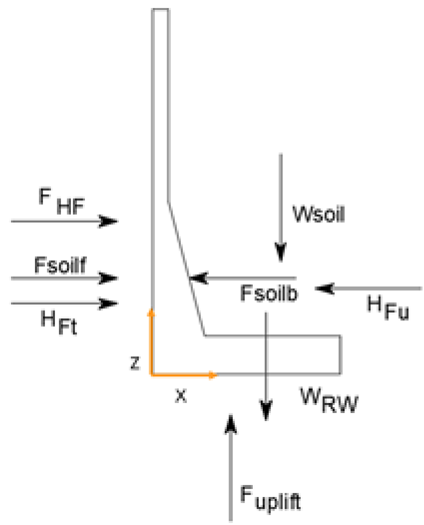
Approximate hardfill stiffness $$k_{HF} := \frac{E_{HF}}{L_{HF}} = 62500 \cdot \frac{\mathbf{kN}}{\mathbf{m}^3}$$

$$\delta_{max} := L_{HF} \cdot 5 \cdot 10^{-3} = 80 \cdot \mathbf{mm}$$

Considering a deformation of the hardfill of : $\delta_{HF} := 2.6\mathbf{mm} \quad < \quad \delta_{max} = 80 \cdot \mathbf{mm}$

The total reaction of the hardfill is: $F_{HF} := k_{HF} \cdot Ac \cdot \delta_{HF} = 5.23 \cdot \mathbf{MN}$

Vector Forces Summary



Body diagram, side view

Weight Retaining Wall $\mathbf{W_{RW}} := \begin{pmatrix} -F_{RW} & 0 & -\mathbf{W_{RW}} \end{pmatrix} = \begin{pmatrix} -0.5 & 0 & -2.95 \end{pmatrix} \cdot \mathbf{MN}$

Weight Soil (Back of Wall) $\mathbf{W_{soilb}} := \begin{pmatrix} -\mathrm{Fsoilb}_{AE} & 0 & -\mathbf{W_{soilb}} \end{pmatrix} = \begin{pmatrix} -1.35 & 0 & -7.95 \end{pmatrix} \cdot \mathbf{MN}$

Soil Pressure (Back of Wall) $\mathbf{F_{soilb}} := \begin{pmatrix} -\mathbf{F_{soilb}} & 0 & 0 \end{pmatrix} = \begin{pmatrix} -1.56 & 0 & 0 \end{pmatrix} \cdot \mathbf{MN}$

Soil Pressure (Front of Wall) $\mathbf{F_{soilf}} := \begin{pmatrix} \mathbf{F_{soilf}} & 0 & 0 \end{pmatrix} = \begin{pmatrix} 0.33 & 0 & 0 \end{pmatrix} \cdot \mathbf{MN}$

Hydrostatic Force (Back of Wal) $\mathbf{H_{Fu}} := \begin{pmatrix} -\mathbf{H_{Fu}} & \mathbf{0} & 0 \end{pmatrix} = \begin{pmatrix} -1.51 & 0 & 0 \end{pmatrix} \cdot \mathbf{MN}$

Hydrostatic Force (Front of Wall) $\mathbf{H_{Ft}} := \begin{pmatrix} \mathbf{H_{Ft}} & 0 & 0 \end{pmatrix} = \begin{pmatrix} 0.73 & 0 & 0 \end{pmatrix} \cdot \mathbf{MN}$

Uplift Force $\mathbf{F_{uplift}} := \begin{pmatrix} 0 & 0 & \mathbf{F_{uplift}} \end{pmatrix} = \begin{pmatrix} 0 & 0 & 3.06 \end{pmatrix} \cdot \mathbf{MN}$

Resistance force by Hardfill $\mathbf{F_{HF}} := \begin{pmatrix} \mathbf{F_{HF}} & 0 & 0 \end{pmatrix} = \begin{pmatrix} 5.23 & 0 & 0 \end{pmatrix} \cdot \mathbf{MN}$

Soil Dynamic Pressure $\mathbf{F_{AE}} := \begin{pmatrix} -\mathbf{F_{AE}} & 0 & 0 \end{pmatrix} = \begin{pmatrix} -1.7 & 0 & 0 \end{pmatrix} \cdot \mathbf{MN}$

Resultant Total Force

$$F := W_{RW} + W_{soilb} + F_{soilb} + F_{soilf} + H_{Fu} + H_{Ft} + F_{uplift} + F_{HF} + F_{AE}$$

$$F = (-0.34 \quad 0 \quad -7.85)\cdot MN$$

Structure Stability

1. Sliding

$$236.6m^3 \cdot \gamma_w = 2.32\cdot MN$$

Coefficient of sliding friction $\mu := 0.45$

$$FoS := \frac{F_{0,2}\cdot\mu}{F_{0,0}} = 10.54 \qquad > \qquad FS_{sliding.req} = 1.1 \qquad \textbf{OK}$$

2. Uplift

Summatory of Axial Resistant Forces

$$F_R := W_{RW} + W_{soilb} = (-1.85 \quad 0 \quad -10.9)\cdot MN$$

Uplift Force

$$F_{uplift} = (0 \quad 0 \quad 3.06)\cdot MN$$

$$FoS_{uplift} := \frac{\left|F_{R_{0,2}}\right|}{\left|F_{uplift_{0,2}}\right|} = 3.57 \qquad > \qquad FS_{float.req} = 1.1 \qquad \textbf{OK}$$

3. Overturning

$\mathbf{r_{RW}} := \left(\mathbf{X_{RW}} \quad Y_{RW} \quad Z_{RW}\right) = (1.76 \quad 4.47 \quad 2.58)\ \mathbf{m}$

$\mathbf{r_{soilb}} := \left(X_{soil} \quad Y_{soil} \quad Z_{soil}\right) = (3.38 \quad 4.66 \quad 5.75)\ \mathbf{m}$

$\mathbf{r_{Fsoilb}} := \left(X_{Fsoilb} \quad Y_{Fsoilb} \quad Z_{Fsoilb}\right) = (0 \quad 4.91 \quad 3.64)\ \mathbf{m}$

$\mathbf{r_{Fsoilf}} := \left(X_{Fsoilf} \quad Y_{Fsoilf} \quad Z_{Fsoilf}\right) = (0 \quad 2.41 \quad 3.15)\ \mathbf{m}$

$\mathbf{r_{Fu}} := \left(X_{Fu} \quad Y_{Fu} \quad Z_{Fu}\right) = (0 \quad 4 \quad 1.99)\ \mathbf{m}$

$\mathbf{r_{Ft}} := \left(X_{Ft} \quad Y_{Ft} \quad Z_{Ft}\right) = (0 \quad 1.89 \quad 2.83)\ \mathbf{m}$

$\mathbf{r_{uplift}} := \left(X_{uplift} \quad Y_{uplift} \quad Z_{uplift}\right) = (3 \quad 4.2 \quad 0)\ \mathbf{m}$

$\mathbf{r_{HF}} := \left(\mathbf{X_{HF}} \quad \mathbf{Y_{HF}} \quad \mathbf{Z_{HF}}\right) = (0 \quad 6.42 \quad 3.13)\ \mathbf{m}$

$\mathbf{r_{AE}} := \left(\mathbf{X_{AE}} \quad \mathbf{Y_{AE}} \quad \mathbf{Z_{AE}}\right) = (0 \quad 4.8 \quad 7.25)\ \mathbf{m}$

$$\mathbf{M} := \mathbf{W_{RW}}^{\mathbf{T}} \times \mathbf{r_{RW}}^{\mathbf{T}} + \mathbf{W_{soilb}}^{\mathbf{T}} \times \mathbf{r_{soilb}}^{\mathbf{T}} + \mathbf{F_{soilb}}^{\mathbf{T}} \times \mathbf{r_{Fsoilb}}^{\mathbf{T}} + \mathbf{F_{HF}}^{\mathbf{T}} \times \mathbf{r_{HF}}^{\mathbf{T}} \ \cdots$$
$$+ \mathbf{F_{soilf}}^{\mathbf{T}} \times \mathbf{r_{Fsoilf}}^{\mathbf{T}} + \mathbf{H_{Fu}}^{\mathbf{T}} \times \mathbf{r_{Fu}}^{\mathbf{T}} + \mathbf{H_{Ft}}^{\mathbf{T}} \times \mathbf{r_{Ft}}^{\mathbf{T}} + \mathbf{F_{uplift}}^{\mathbf{T}} \times \mathbf{r_{uplift}}^{\mathbf{T}} + \mathbf{F_{AE}}^{\mathbf{T}} \times \mathbf{r_{AE}}^{\mathbf{T}}$$

$$\mathbf{M} = \begin{pmatrix} 37.44 \\ -12.34 \\ 5.35 \end{pmatrix} \cdot \mathbf{MN} \cdot \mathbf{m}$$

$$\mathbf{F} = (-0.34 \quad 0 \quad -7.85) \cdot \mathbf{MN}$$

Location of resultant force:

$$\mathbf{X_R} := \left| \frac{\mathbf{M}_{1,0}}{\mathbf{F}_{0,2}} \right| = 1.57 \cdot \mathbf{m}$$

$$\mathbf{x} := \left| \mathbf{X_R} - \frac{\mathbf{b}}{2} \right| = 1.43\ \mathbf{m} \quad < \quad \frac{\mathbf{b}}{4} = 1.5\ \mathbf{m} \qquad \mathbf{OK}$$

4. **Bearing Capacity**

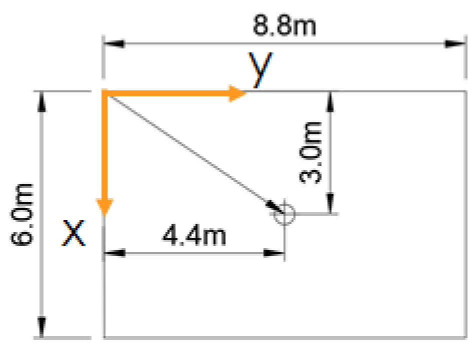
$$q_{all} := 622\,\mathbf{kPa}$$

Force and Moment at origin:

$$\mathbf{F} = (-0.34 \quad 0 \quad -7.85)\cdot\mathbf{MN} \qquad \mathbf{M} = \begin{pmatrix} 37.44 \\ -12.34 \\ 5.35 \end{pmatrix} \mathbf{m}\cdot\mathbf{MN}$$

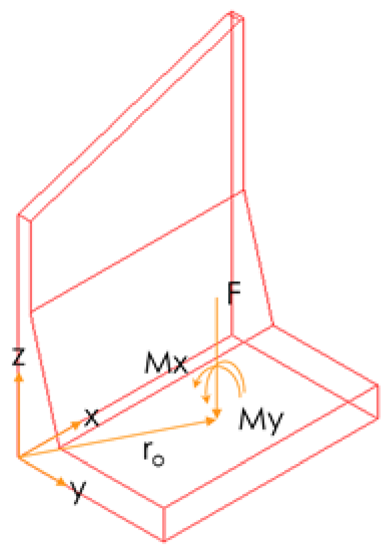
Vector to center of foundation:

$$\mathbf{r_o} := (3 \quad 4.4 \quad 0)\,\mathbf{m}$$



Moment at center of Foundation

$$\mathbf{M_o} := \mathbf{M} - \mathbf{F}^{\mathbf{T}} \times \mathbf{r_o}^{\mathbf{T}} = \begin{pmatrix} 2.91 \\ 11.2 \\ 6.83 \end{pmatrix} \mathbf{m} \cdot \mathbf{MN}$$



$$\mathbf{Ix_o} := \frac{1}{12} \cdot \mathbf{b}^3 \cdot \mathbf{B} = 158.4\,\mathbf{m}^4$$

$$\mathbf{Iy_o} := \frac{1}{12} \cdot \mathbf{b} \cdot \mathbf{B}^3 = 340.736\,\mathbf{m}^4$$

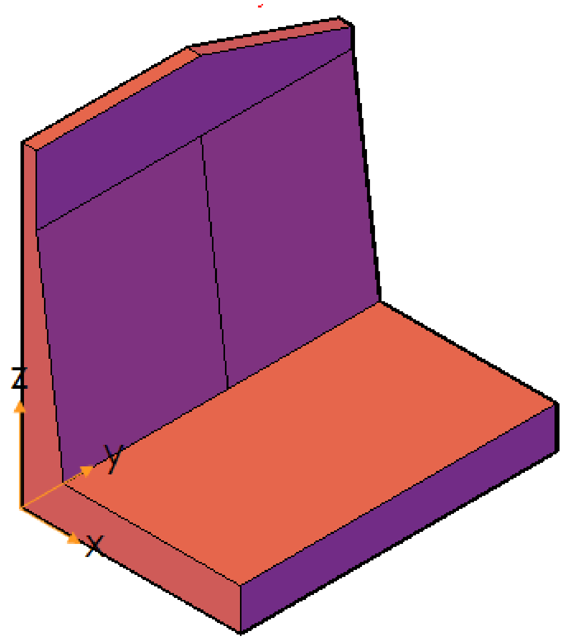
$$\mathbf{A} := \mathbf{b} \cdot \mathbf{B} = 52.8\,\mathbf{m}^2$$

$$\sigma_{max} := \left| \frac{\mathbf{F}_{0,2}}{\mathbf{A}} \right| + \left| \frac{\mathbf{M_o}_{0,0} \cdot \mathbf{b}}{2 \cdot \mathbf{Ix_o}} \right| + \left| \frac{\mathbf{M_o}_{1,0} \cdot \mathbf{B}}{2 \cdot \mathbf{Iy_o}} \right| = 348.343 \cdot \mathbf{kPa} < \quad q_{all} = 622 \cdot \mathbf{kPa} \qquad \mathbf{OK}$$

$$\sigma_{min} := \left| \frac{\mathbf{F}_{0,2}}{\mathbf{A}} \right| - \left| \frac{\mathbf{M_o}_{0,0} \cdot \mathbf{b}}{2 \cdot \mathbf{Ix_o}} \right| - \left| \frac{\mathbf{M_o}_{1,0} \cdot \mathbf{B}}{2 \cdot \mathbf{Iy_o}} \right| = -51.146 \cdot \mathbf{kPa} < \quad q_{all} = 622 \cdot \mathbf{kPa} \qquad \mathbf{OK}$$

TP

SECTION 2



TP Section 2

	U1	UN1	UN2	UN3	E1	E2
Sliding	1.51	1.34	1.39	1.43	1.37	1.48
Uplift	4.28	4.28	3.30	3.33	2.92	4.39
Excentricity (m)	1.12	1.31	1.30	1.27	1.41	1.70
Max. Foundation pressure (kPa)	309.9	327.3	296.1	294.4	281.0	395.4
Min. Foundation Pressure (KPa)	51.7	34.2	32.9	35.6	20.9	-31.1
Hardfill δ (mm)	0.40	1.00	0.80	1.40	0.30	2.10

TP **Section 2: Usual Condition (U1)**

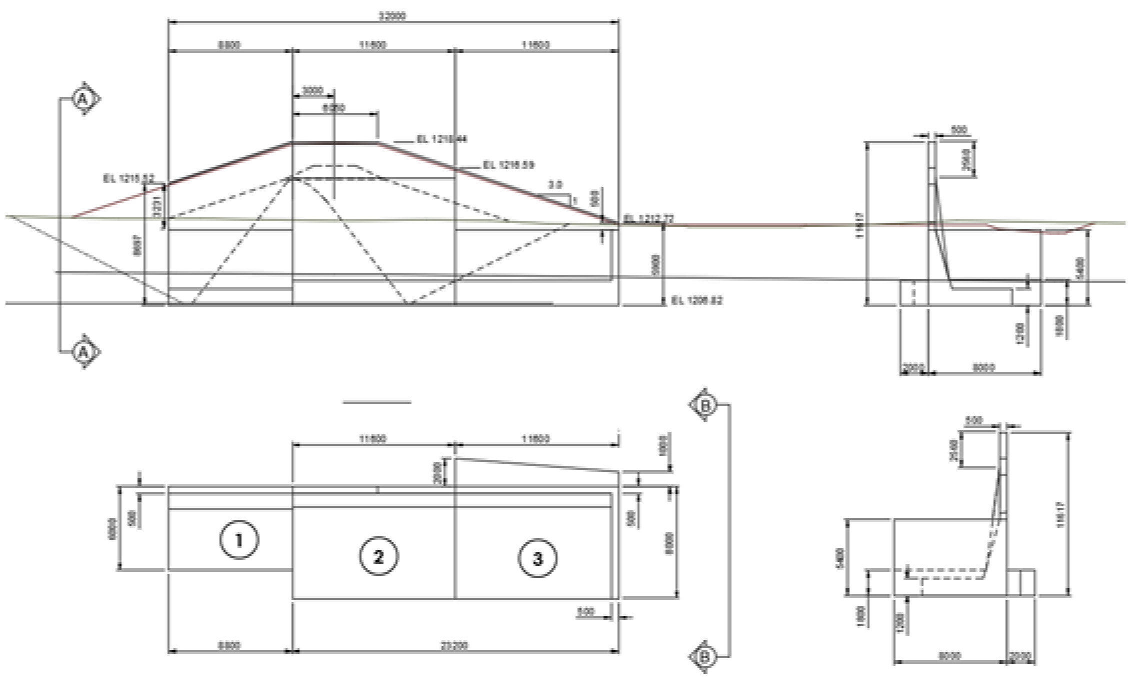
Loading	Horizontal Forces Force (MN)	Horizontal Forces Arm (m)	Vertical Forces Force (MN)	Vertical Forces Arm (m)	Stabilizing Moments (MN-m)	Overturning Moments (MN-m)
Weight of Structure			6.2	2.7	16.8	
Earthquake Inertia Force						
Soil Mass, front of wall						
Soil Mass, back of wall			15.7	4.4	69.7	
Soil Pressure, front of wall	1.58	3.23			5.1	
Soil Pressure, back of wall	-6.12	3.70				22.7
Equipment Load, back of wall						
Soil Dynamic Pressure, back of wall						
Uplift			-5.1	4.1		21.0
Hydrostatic pressure, front of wall	0.66	1.82			1.2	
Hydrostatic pressure, back of wall	-2.12	2.04				4.3
Hardfill	1.01	3.43			3.46	
SUM	**-4.99**		**16.78**		**96.33**	**48.00**
					Net Moment	
					48.32	

Stability Calculations
Retaining Wall - Auxiliary Spillway
Right Abutment Transition to Berm

Scope:

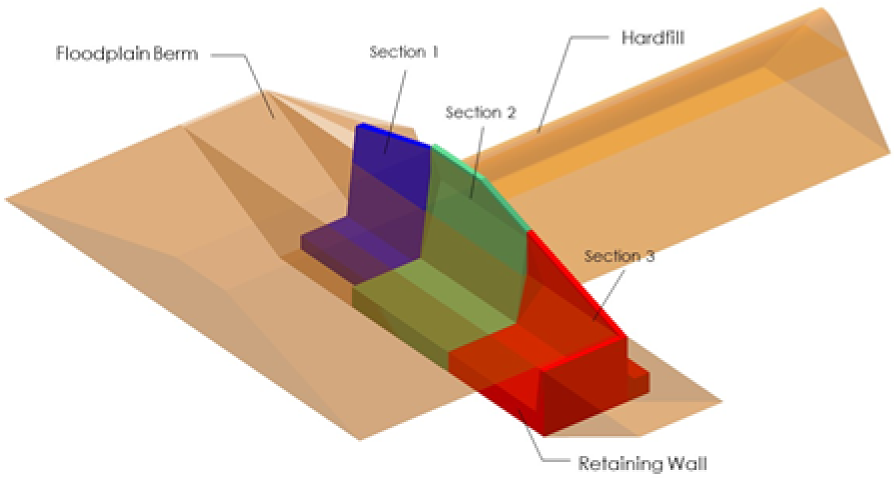
Evaluate the stability of the transition wall of the Auxiliary Spillway. Consider the 3D effects on the structure's stability.

Structure Geometry:



dimensions in mm

Isometric View:



Load Condition

	Elevation (m)			
	Headwater	**Tailwater**	**Headwater**	**Tailwater**
1. Usual Condition (U1)	1214.0	1211.9	7.0	4.9
2. Unusual Condition 1 (UN1)	1214.0	1211.9	7.0	4.9
3. Unusual Condition 2 (UN2)	1216.5	1213.1	9.5	6.1
4. Unusual Condition 3 (UN3)	1217.0	1213.1	10.0	6.1
5. Extreme Condition 1 (E1-F)	1217.3	1213.8	10.3	6.8
6. Extreme Condition 2 (E2-Q)	1213.5	1211.9	6.5	4.9

User Input

Material Properties:

Unit Weight of Water: $\gamma_w := 9.81 \frac{kN}{m^3}$ (Section 7.2, Design Criteria)

Unit Weight of Concrete: $\gamma_c := \mathbf{23.5} \frac{kN}{m^3}$

Unit Weight of Soil (Moist): $\gamma_m := 20.0 \frac{kN}{m^3}$ (Section 5.3, Design Criteria) assumed moisture content (w) = 5%

Unit Weight Soil (Saturated): $\gamma_{sat} := 22.0 \frac{kN}{m^3}$ (Assuming Specific Gravity = 2.7)

Unit Weight Soil (buoyant): $\gamma_b := \gamma_{sat} - \gamma_w = 12.19 \cdot \frac{kN}{m^3}$

Weight of Soil/Concrete above toe: $\gamma_{toe} := 22.0 \frac{kN}{m^3}$

Unit Weight of Rock: $\gamma_r := 25.6 \frac{kN}{m^3}$ (Section 7.2, Design Criteria)

Usual Condition 1 (U1)

Acceptance Parameters

Resultant Location (Overturning and Bearing Pressure):

Unusual (UN) Resultant located inside middle third (kern) equals 100% base in compression (AT/WCS Guidelines, Section 8.4)

$$B_{\%basecomp.req} := 100\%$$

Allowable rock bearing pressure: $qall := 622 \frac{kN}{m^2}$ (Internal Geotechnical Design Recommendations Rev. Sept 12, 2018, Section 5.3)

FS Sliding:

Usual (U1) 1.5 (without cohesion) (CDA Guidelines, Table 6-4, AT/WCS Guidelines, Section 8.3)

Req'd Factor of Safety for Sliding: $FS_{sliding.req} := 1.5$ (Without Cohesion)

FS Floatation:

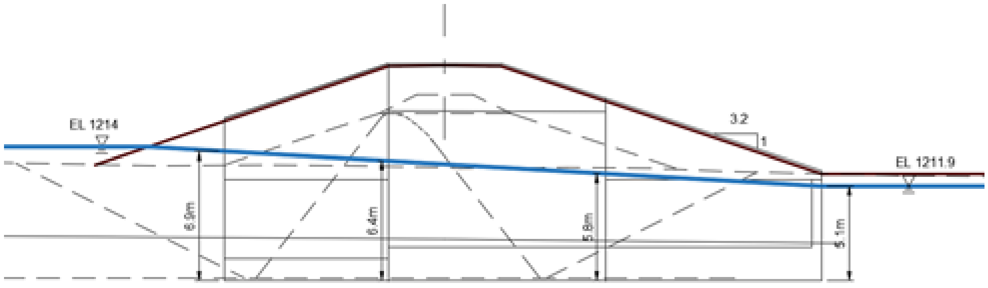
Usual (U1) 1.5 (AT/WCS Guidelines, Section 8.5)

Req'd Factor of Safety for Floatation: $FS_{float.req} := 1.5$

Water Surface Elevations

Headwater $H_H := 1214\mathbf{m}$

Tailwater $H_T := 1211.9\mathbf{m}$



$h_1 := 6.9\mathbf{m}$ $h_2 := 6.4\mathbf{m}$ $h_3 := 5.8\mathbf{m}$ $h_4 := 5.1\mathbf{m}$

Interpolated water table heights from retaining wall base.

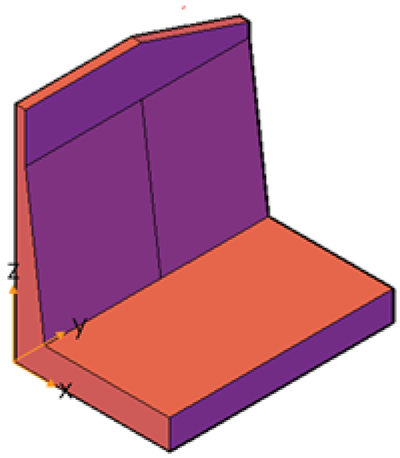
Section 2

Wall Geometry: User Input

Top of Wall Elevation:	$T_w := 1218.44 \cdot m$
Top of Footing Elevation:	$Top_{ftg} := 1208.62 \cdot m$
Thickness of Footing:	$t_{ftg} := 1.80m$
Bottom of Footing Elevation:	$Bot_{ftg} := Top_{ftg} - t_{ftg} = 1206.82\ m$
Overall Height of wall:	$h_w := T_w - Bot_{ftg} = 11.620\ m$
Thickness of Stem Wall at Top:	$t_{wt} := 0.5m$
Slope of Heel Batter:	$S_{batter} := 0.125$
Thickness of Stem Wall at Base:	$t_{wb} := 1.5m$
Length of toe:	$L_{ab} := 0m$
Total Length of Footing:	$b := 8m$
Length of heel:	$L_{cd} := b - L_{ab} - t_{wb} = 6.5\ m$
Width of Wall:	$B := 11.6m$

Retaining Wall

Retaining Wall Volume and Gravity Center (Using AutoCAD 3D: File: 3D Transition Wall Analysis Section 2.dwg)



Isometric View

Volume

$Vol_{RW} := 263.5\ m^3$

$X_{RW} := 2.72m$

$Y_{RW} := 5.762m$

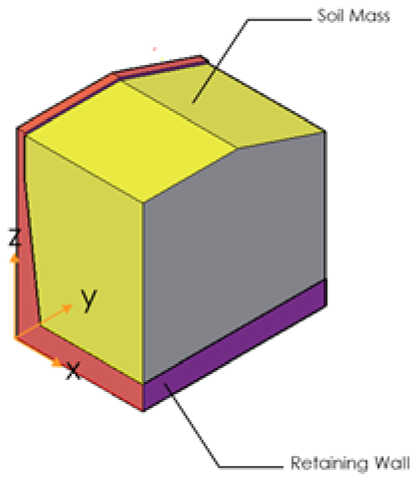
$Z_{RW} := 0m$

Retaining wall total weight $\quad W_{RW} := Vol_{RW} \cdot \gamma_c = 6.19 \cdot MN$

Soil Mass

Retained Soil Volume and Gravity Center (Using AutoCAD 3D: File 3D Transition Wall Analysis Section 1.dwg)

Isometric View:



$Vol_{soil} := 784.755\ m^3$

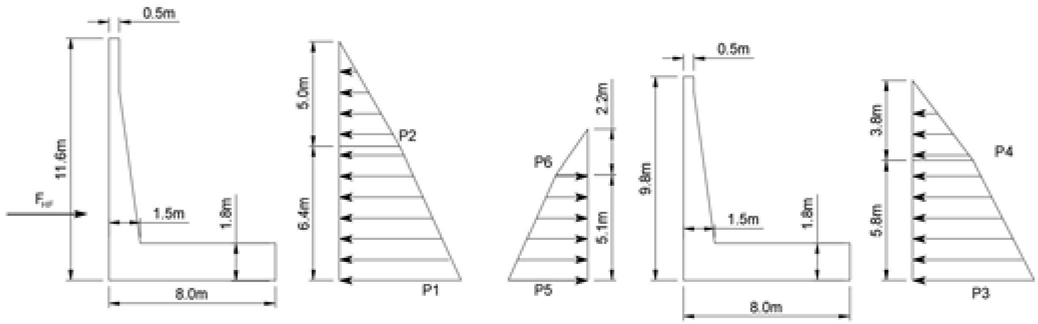
$X_{soil} := 4.441m$

$Y_{soil} := 5.606m$

$Z_{soil} := 0m$

Soil mass total weight $W_{soilb} := Vol_{soil} \cdot \gamma_m = 15.7 \cdot MN$

Soil Pressure



Section1 Section 2

Section 1

Back of Retaining Wall

depth to water table $\mathbf{dw} := 5.0\mathbf{m}$

saturated soil depth $\mathbf{ds} := 6.4\mathbf{m}$

soil pressure at rest coefficient $\mathbf{Ko} := 0.55$

$$\mathbf{P2} := \gamma_{\mathbf{m}} \cdot \mathbf{dw} \cdot \mathbf{Ko} = 55 \cdot \mathbf{kPa}$$

$$\mathbf{P1} := \mathbf{P2} + \gamma_{\mathbf{b}} \cdot \mathbf{ds} \cdot \mathbf{Ko} = 97.909 \cdot \mathbf{kPa}$$

Section 2

depth to water table $\mathbf{dw} := 3.8\mathbf{m}$

saturated soil depth $\mathbf{ds} := 5.8\mathbf{m}$

soil pressure at rest coefficient $\mathbf{Ko} := 0.55$

$$\mathbf{P4} := \gamma_{\mathbf{m}} \cdot \mathbf{dw} \cdot \mathbf{Ko} = 41.8 \cdot \mathbf{kPa}$$

$$\mathbf{P3} := \mathbf{P4} + \gamma_{\mathbf{b}} \cdot \mathbf{ds} \cdot \mathbf{Ko} = 80.686 \cdot \mathbf{kPa}$$

Front of Retaining Wall

depth to water table $\mathbf{dw} := 2.2\mathbf{m}$

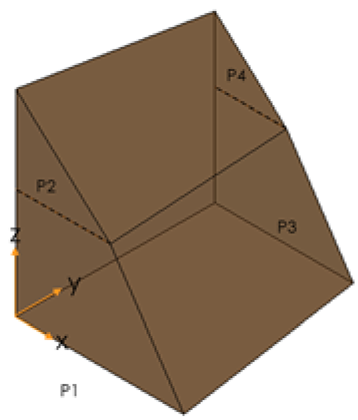
saturated soil depth $\mathbf{ds} := 5.1\mathbf{m}$

soil pressure at rest coefficient $\mathbf{Ko} := 0.55$

$$\mathbf{P6} := \gamma_{\mathbf{m}} \cdot \mathbf{dw} \cdot \mathbf{Ko} = 24.2 \cdot \mathbf{kPa}$$

$$\mathbf{P5} := \mathbf{P6} + \gamma_{\mathbf{b}} \cdot \mathbf{ds} \cdot \mathbf{Ko} = 58.393 \cdot \mathbf{kPa}$$

Isometric view of the prism representing soil pressures against the retaining wall (Using AutoCAD 3D: 3D Transition Wall Analysis Section 2.dwg). The volume of the prism is equal to the equivalent total force.



Total Force Back Soil

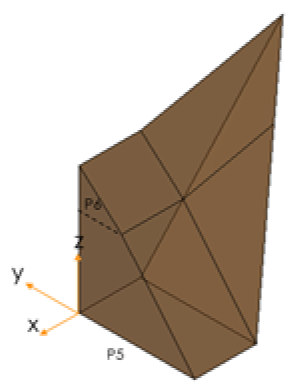
$\mathbf{F_{soilb}} := \mathbf{6123.38kN}$

$\mathbf{X_{Fsoilb}} := 0\mathbf{m}$

$\mathbf{Y_{Fsoilb}} := \mathbf{5.448m}$

$\mathbf{Z_{Fsoilb}} := \mathbf{3.700m}$

Isometric View



Total Force Front Soil

$\mathbf{F_{soilf}} := \mathbf{1580.27kN}$

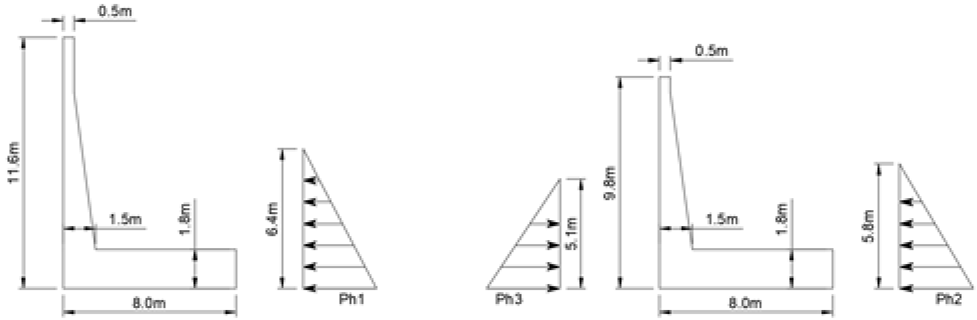
$\mathbf{X_{Fsoilf}} := 0\mathbf{m}$

$\mathbf{Y_{Fsoilf}} := \mathbf{8.223m}$

$\mathbf{Z_{Fsoilf}} := \mathbf{3.226m}$

Hydrostatic Forces

Side View



Section 1 Section 2

Section 1

Back of Wall $\mathbf{h_b} := 6.4\mathbf{m}$

$$\mathbf{Ph1} := \mathbf{h_b} \cdot \gamma_\mathbf{w} = 62.78 \cdot \mathbf{kPa}$$

Section 2

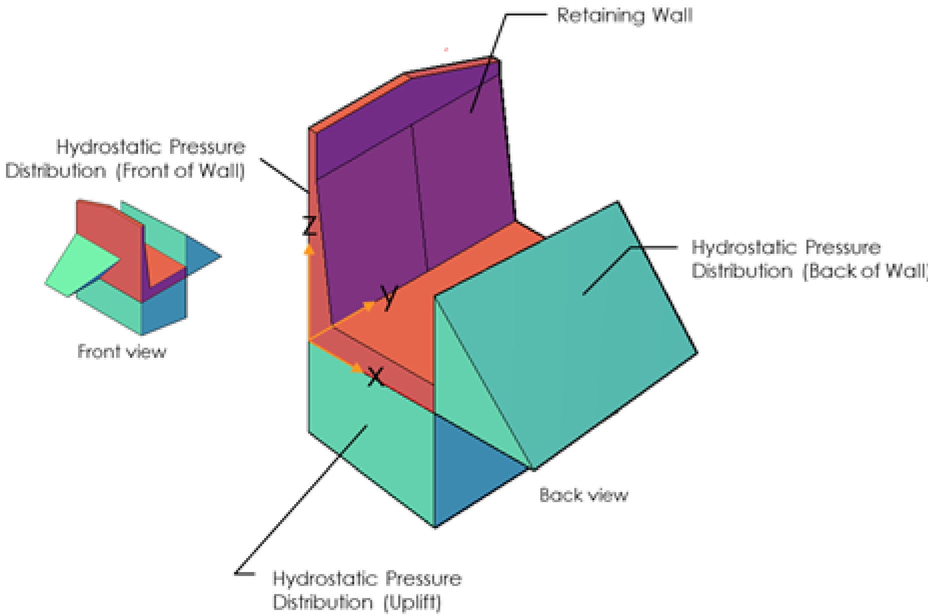
Back of Wall $\mathbf{h_b} := 5.8\mathbf{m}$

Front of Wall $\mathbf{h_f} := 5.1\mathbf{m}$

$$\mathbf{Ph2} := \mathbf{h_b} \cdot \gamma_\mathbf{w} = 56.9 \cdot \mathbf{kPa}$$

$$\mathbf{Ph3} := \mathbf{h_f} \cdot \gamma_\mathbf{w} = 50.03 \cdot \mathbf{kPa}$$

Isometric View



Total Hydrostatic Force

Back of Wall

$H_{Fu} := 2118.84kN$

$X_{Fu} := 0m$

$Y_{Fu} := 5.610m$

$Z_{Fu} := 2.037m$

Volume and centroid of hydrostatic pressure was determined using AutoCAD 3D: File 3D Transition Wall Analysis Section 2.dwg

Total Hydrostatic Force

Front of Wal

$H_{Ft} := 660.99kN$

$X_{Ft} := 0m$

$Y_{Ft} := 8.832m$

$Z_{Ft} := 1.822m$

Volume and centroid of hydrostatic pressure was determined using AutoCAD 3D: File 3D Transition Wall Analysis Section 2.dwg

Uplift

Total Uplift Force

$F_{uplift} := 5110.50kN$

$X_{uplift} := 4.115m$

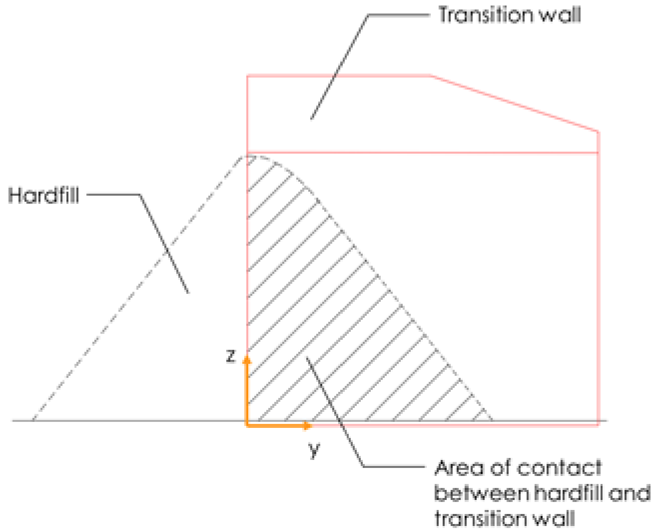
$Y_{uplift} := 5.748m$

$Z_{uplift} := 0m$

Volume and centroid of hydrostatic pressure was determined using AutoCAD 3D: File 3D Transition Wall Analysis Section 2.dwg

Hardfill Contact Area and Resultant Resistant Force

Front View



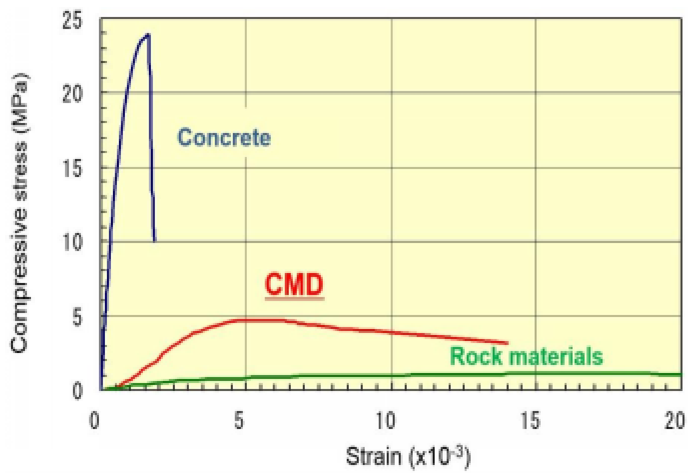
Area of Contact $\quad Ac := 40.4917\ m^2$ $\quad$ Centroid of contact area was determined using Autocad: File Wall Pressure Diagrams.dwg

$X_{HF} := 0m$

$Y_{HF} := 2.7626m$

$Z_{HF} := 3.4299m$

Hard Fill Stiffness



Source: Noorzad et al. (2017). An Innovative Approach toward Dam Design and Construction. 2nd Workshop on Cement Materials Dams (CMD). July 3, 2017.

$$E_{HF} := \frac{5\,\mathbf{MPa}}{5 \times \mathbf{10}^{-3}} = 1 \cdot \mathbf{GPa}$$ Approximate Hardfill Modulus of Elasticity

$$L_{HF} := 16\mathbf{m}$$ Hardfill section length (between construction joints)

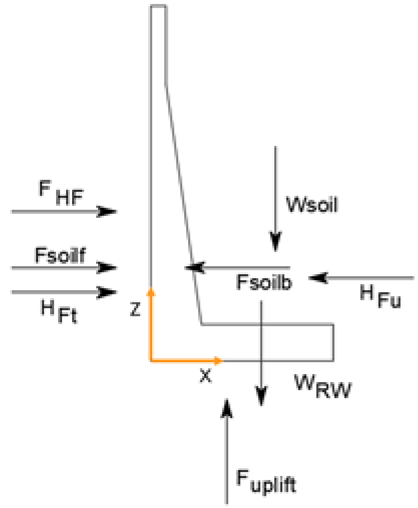
Approximate hardfill stiffness $$k_{HF} := \frac{E_{HF}}{L_{HF}} = 62500 \cdot \frac{\mathbf{kN}}{\mathbf{m}^3}$$

$$\delta_{max} := L_{HF} \cdot 5 \cdot 10^{-3} = 80 \cdot \mathbf{mm}$$

Considering a deformation of the hardfill of : $\delta_{HF} := 0.4\mathbf{mm}$ < $\delta_{max} = 80 \cdot \mathbf{mm}$

The total reaction of the hardfill is: $$F_{HF} := k_{HF} \cdot Ac \cdot \delta_{HF} = 1.01 \cdot \mathbf{MN}$$

Vector Forces Summary



Body diagram, side view

Weight Retaining Wall $\quad \mathbf{W_{RW}} := \begin{pmatrix} 0 & 0 & -\mathbf{W_{RW}} \end{pmatrix} = (0 \quad 0 \quad -6.19) \cdot \mathbf{MN}$

Weight Soil (Back of Wall) $\quad \mathbf{W_{soilb}} := \begin{pmatrix} 0 & 0 & -\mathbf{W_{soilb}} \end{pmatrix} = (0 \quad 0 \quad -15.7) \cdot \mathbf{MN}$

Soil Pressure (Back of Wall) $\quad \mathbf{F_{soilb}} := \begin{pmatrix} -\mathbf{F_{soilb}} & 0 & 0 \end{pmatrix} = (-6.12 \quad 0 \quad 0) \cdot \mathbf{MN}$

Soil Pressure (Front of Wall) $\quad \mathbf{F_{soilf}} := \begin{pmatrix} \mathbf{F_{soilf}} & 0 & 0 \end{pmatrix} = (1.58 \quad 0 \quad 0) \cdot \mathbf{MN}$

Hydrostatic Force (Back of Wall) $\quad \mathbf{H_{Fu}} := \begin{pmatrix} -\mathbf{H_{Fu}} & \mathbf{0} & 0 \end{pmatrix} = (-2.12 \quad 0 \quad 0) \cdot \mathbf{MN}$

Hydrostatic Force (Front of Wall) $\quad \mathbf{H_{Ft}} := \begin{pmatrix} \mathbf{H_{Ft}} & 0 & 0 \end{pmatrix} = (0.66 \quad 0 \quad 0) \cdot \mathbf{MN}$

Uplift Force $\quad \mathbf{F_{uplift}} := \begin{pmatrix} 0 & 0 & \mathbf{F_{uplift}} \end{pmatrix} = (0 \quad 0 \quad 5.11) \cdot \mathbf{MN}$

Resistance force by Hardfill $\quad \mathbf{F_{HF}} := \begin{pmatrix} \mathbf{F_{HF}} & 0 & 0 \end{pmatrix} = (1.01 \quad 0 \quad 0) \cdot \mathbf{MN}$

Resultant Total Force

$$\mathbf{F} := \mathbf{W_{RW}} + \mathbf{W_{soilb}} + \mathbf{F_{soilb}} + \mathbf{F_{soilf}} + \mathbf{H_{Fu}} + \mathbf{H_{Ft}} + \mathbf{F_{uplift}} + \mathbf{F_{HF}}$$

$$\mathbf{F} = (-4.99 \quad 0 \quad -16.78) \cdot \mathbf{MN}$$

Structure Stability

1. Sliding

$$236.6\mathbf{m}^3 \cdot \gamma_w = 2.32 \cdot \mathbf{MN}$$

Coefficient of sliding friction $\mu := 0.45$

$$\mathbf{FoS} := \frac{\mathbf{F}_{0,2} \cdot \mu}{\mathbf{F}_{0,0}} = 1.51 \quad > \quad \mathbf{FS_{sliding.req}} = 1.5 \quad \mathbf{OK}$$

2. Uplift

Summatory of Axial Resistant Forces

$$\mathbf{F_R} := \mathbf{W_{RW}} + \mathbf{W_{soilb}} = (0 \quad 0 \quad -21.89) \cdot \mathbf{MN}$$

Uplift Force

$$\mathbf{F_{uplift}} = (0 \quad 0 \quad 5.11) \cdot \mathbf{MN}$$

$$\mathbf{FoS_{uplift}} := \frac{\left|\mathbf{F_R}_{0,2}\right|}{\left|\mathbf{F_{uplift}}_{0,2}\right|} = 4.28 \quad > \quad \mathbf{FS_{float.req}} = 1.5 \quad \mathbf{OK}$$

3. Overturning

$$\mathbf{r_{RW}} := \left(\mathbf{X_{RW}} \quad Y_{RW} \quad Z_{RW}\right) = (2.72 \quad 5.76 \quad 0)\ \mathbf{m}$$

$$\mathbf{r_{soilb}} := \left(X_{soil} \quad Y_{soil} \quad Z_{soil}\right) = (4.44 \quad 5.61 \quad 0)\ \mathbf{m}$$

$$\mathbf{r_{Fsoilb}} := \left(X_{Fsoilb} \quad Y_{Fsoilb} \quad Z_{Fsoilb}\right) = (0 \quad 5.45 \quad 3.7)\ \mathbf{m}$$

$$\mathbf{r_{Fsoilf}} := \left(X_{Fsoilf} \quad Y_{Fsoilf} \quad Z_{Fsoilf}\right) = (0 \quad 8.22 \quad 3.23)\ \mathbf{m}$$

$$\mathbf{r_{Fu}} := \left(X_{Fu} \quad Y_{Fu} \quad Z_{Fu}\right) = (0 \quad 5.61 \quad 2.04)\ \mathbf{m}$$

$$\mathbf{r_{Ft}} := \left(X_{Ft} \quad Y_{Ft} \quad Z_{Ft}\right) = (0 \quad 8.83 \quad 1.82)\ \mathbf{m}$$

$$\mathbf{r_{uplift}} := \left(X_{uplift} \quad Y_{uplift} \quad Z_{uplift}\right) = (4.12 \quad 5.75 \quad 0)\ \mathbf{m}$$

$$\mathbf{r_{HF}} := \left(\mathbf{X_{HF}} \quad \mathbf{Y_{HF}} \quad \mathbf{Z_{HF}}\right) = (0 \quad 2.76 \quad 3.43)\ \mathbf{m}$$

$$\mathbf{M} := \mathbf{W_{RW}}^{T} \times \mathbf{r_{RW}}^{T} + \mathbf{W_{soilb}}^{T} \times \mathbf{r_{soilb}}^{T} + \mathbf{F_{soilb}}^{T} \times \mathbf{r_{Fsoilb}}^{T} + \mathbf{F_{HF}}^{T} \times \mathbf{r_{HF}}^{T} \cdots$$
$$+ \mathbf{F_{soilf}}^{T} \times \mathbf{r_{Fsoilf}}^{T} + \mathbf{H_{Fu}}^{T} \times \mathbf{r_{Fu}}^{T} + \mathbf{H_{Ft}}^{T} \times \mathbf{r_{Ft}}^{T} + \mathbf{F_{uplift}}^{T} \times \mathbf{r_{uplift}}^{T}$$

$$\mathbf{M} = \begin{pmatrix} 94.29 \\ -48.32 \\ -23.62 \end{pmatrix} \cdot \mathbf{MN} \cdot \mathbf{m}$$

$$\mathbf{F} = (-4.99 \quad 0 \quad -16.78) \cdot \mathbf{MN}$$

Location of resultant force:

$$\mathbf{X_R} := \left| \frac{\mathbf{M}_{1,0}}{\mathbf{F}_{0,2}} \right| = 2.88 \cdot \mathbf{m}$$

$$\mathbf{x} := \left| \mathbf{X_R} - \frac{\mathbf{b}}{2} \right| = 1.12\ \mathbf{m} \quad < \quad \frac{\mathbf{b}}{6} = 1.33\ \mathbf{m} \qquad \mathbf{OK}$$

4. **Bearing Capacity**

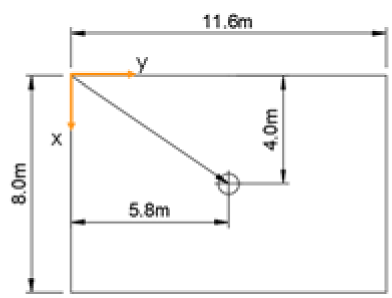
$$q_{all} := 622\,\mathbf{kPa}$$

Force and Moment at origin:

$$\mathbf{F} = \begin{pmatrix} -4.99 & 0 & -16.78 \end{pmatrix} \cdot \mathbf{MN} \qquad \mathbf{M} = \begin{pmatrix} 94.29 \\ -48.32 \\ -23.62 \end{pmatrix} \mathbf{m} \cdot \mathbf{MN}$$

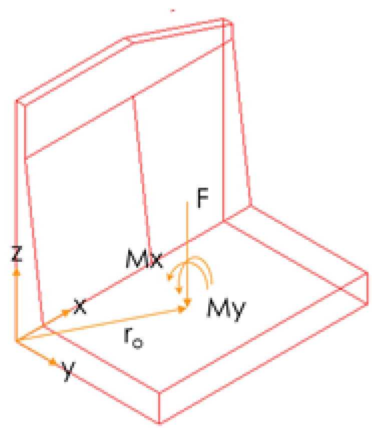
Vector to center of foundation:

$$\mathbf{r_o} := \begin{pmatrix} 4 & 5.8 & 0 \end{pmatrix} \mathbf{m}$$



Moment at center of Foundation

$$M_o := M - F^T \times r_o^T = \begin{pmatrix} -3.01 \\ 18.79 \\ 5.32 \end{pmatrix} m \cdot MN$$



$$Ix_o := \frac{1}{12} \cdot b^3 \cdot B = 494.93\ m^4$$

$$Iy_o := \frac{1}{12} \cdot b \cdot B^3 = 1040.597\ m^4$$

$$A := b \cdot B = 92.8\ m^2$$

$$\sigma_{max} := \left|\frac{F_{0,2}}{A}\right| + \left|\frac{M_{o_{0,0}} \cdot b}{2 \cdot Ix_o}\right| + \left|\frac{M_{o_{1,0}} \cdot B}{2 \cdot Iy_o}\right| = 309.88 \cdot kPa \quad < \quad q_{all} = 622 \cdot kPa \quad \mathbf{OK}$$

$$\sigma_{min} := \left|\frac{F_{0,2}}{A}\right| - \left|\frac{M_{o_{0,0}} \cdot b}{2 \cdot Ix_o}\right| - \left|\frac{M_{o_{1,0}} \cdot B}{2 \cdot Iy_o}\right| = 51.69 \cdot kPa \quad < \quad q_{all} = 622 \cdot kPa \quad \mathbf{OK}$$

Section 2: Unusual Condition (UN1)

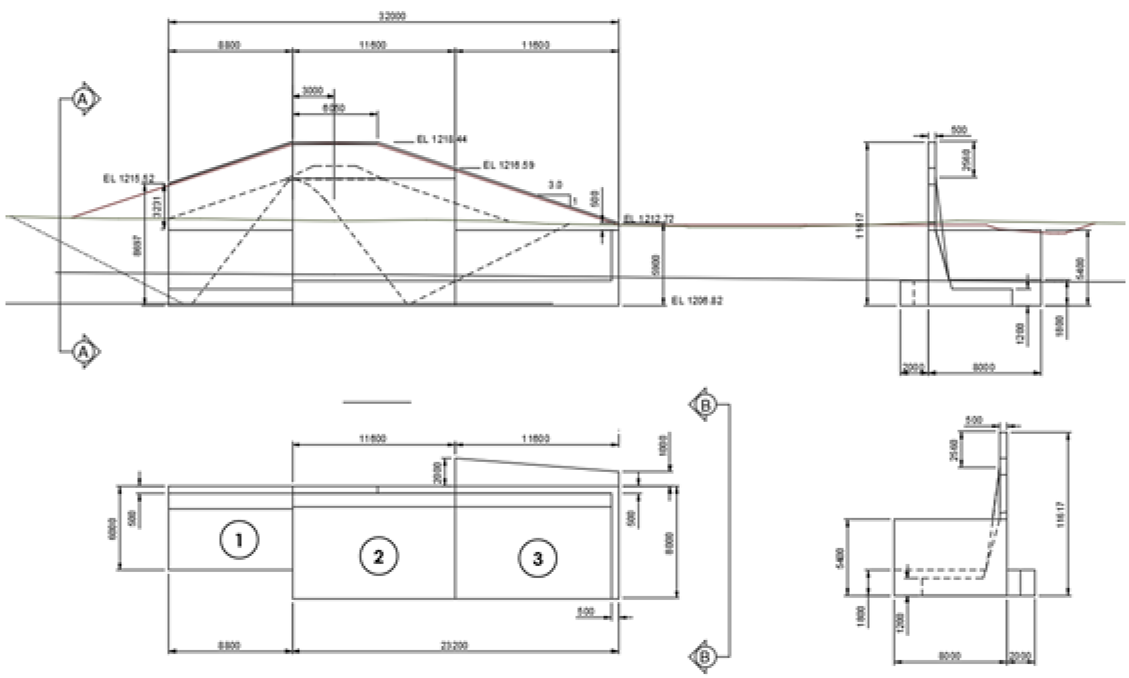
Loading	Horizontal Forces Force (MN)	Horizontal Forces Arm (m)	Vertical Forces Force (MN)	Vertical Forces Arm (m)	Stabilizing Moments (MN-m)	Overturning Moments (MN-m)
Weight of Structure			6.2	2.7	16.8	
Earthquake Inertia Force						
Soil Mass, front of wall						
Soil Mass, back of wall			15.7	4.4	69.7	
Soil Pressure, front of wall						
Soil Pressure, back of wall	-6.12	3.70				22.7
Equipment Load, back of wall	-0.57	5.70				3.2
Soil Dynamic Pressure, back of wall						
Uplift			-5.1	4.1		21.0
Hydrostatic pressure, front of wall	0.66	1.82			1.2	
Hydrostatic pressure, back of wall	-2.12	2.04				4.3
Hardfill	2.53	3.43			8.68	
SUM	**-5.62**		**16.78**		**96.44**	**51.25**
					Net Moment	
					45.20	

Stability Calculations
Retaining Wall - Auxiliary Spillway
Right Abutment Transition to Berm

Scope:

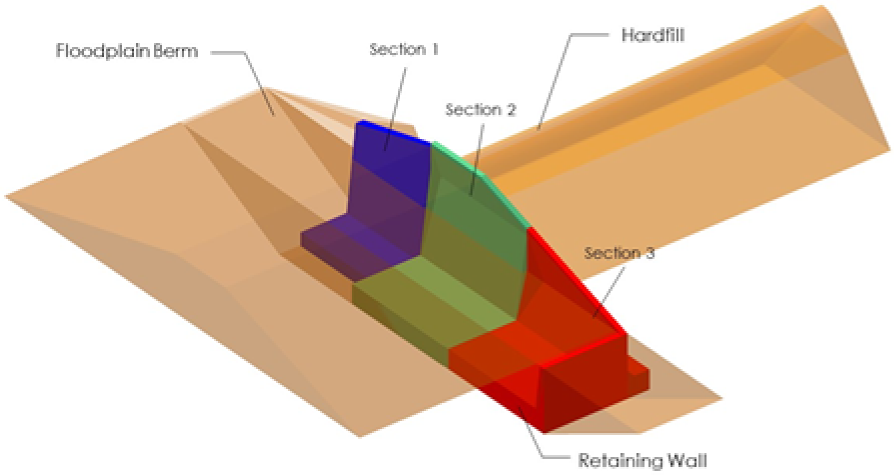
Evaluate the stability of the transition wall of the Auxiliary Spillway. Consider the 3D effects on the structure's stability.

Structure Geometry:



dimensions in mm

Isometric View:



Load Condition

	Elevation (m)			
	Headwater	**Tailwater**	**Headwater**	**Tailwater**
1. Usual Condition (U1)	1214.0	1211.9	7.0	4.9
2. Unusual Condition 1 (UN1)	1214.0	1211.9	7.0	4.9
3. Unusual Condition 2 (UN2)	1216.5	1213.1	9.5	6.1
4. Unusual Condition 3 (UN3)	1217.0	1213.1	10.0	6.1
5. Extreme Condition 1 (E1-F)	1217.3	1213.8	10.3	6.8
6. Extreme Condition 2 (E2-Q)	1213.5	1211.9	6.5	4.9

User Input

Material Properties:

Unit Weight of Water:	$\gamma_w := 9.81 \dfrac{kN}{m^3}$	(Section 7.2, Design Criteria)
Unit Weight of Concrete:	$\gamma_c := 23.5 \dfrac{kN}{m^3}$	
Unit Weight of Soil (Moist):	$\gamma_m := 20.0 \dfrac{kN}{m^3}$	(Section 5.3, Design Criteria) assumed moisture content (w) = 5%
Unit Weight Soil (Saturated):	$\gamma_{sat} := 22.0 \dfrac{kN}{m^3}$	(Assuming Specific Gravity = 2.7)
Unit Weight Soil (buoyant):	$\gamma_b := \gamma_{sat} - \gamma_w = 12.19 \cdot \dfrac{kN}{m^3}$	
Weight of Soil/Concrete above toe:	$\gamma_{toe} := 22.0 \dfrac{kN}{m^3}$	
Unit Weight of Rock:	$\gamma_r := 25.6 \dfrac{kN}{m^3}$	(Section 7.2, Design Criteria)

Unusual Condition 1 (UN1)

Acceptance Parameters

Resultant Location (Overturning and Bearing Pressure):

Unusual (UN) Resultant located inside middle third (kern) equals 100% base in compression (AT/WCS Guidelines, Section 8.4)

$$B_{\%basecomp.req} := 100\%$$

Allowable rock bearing pressure: $qall := 622 \frac{kN}{m^2}$ (Internal Geotechnical Design Recommendations Rev. Sept 12, 2018, Section 5.3)

FS Sliding:

Unusual (UN1) 1.3 (without cohesion) (CDA Guidelines, Table 6-4, AT/WCS Guidelines, Section 8.3)

Req'd Factor of Safety for Sliding: $FS_{sliding.req} := 1.3$ (Without Cohesion)

FS Floatation:

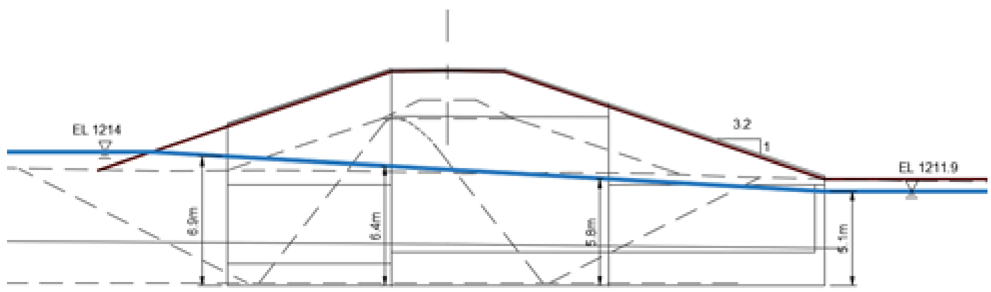
Unusual (UN1) 1.3 (AT/WCS Guidelines, Section 8.5)

Req'd Factor of Safety for Floatation: $FS_{float.req} := 1.3$

Water Surface Elevations

Headwater $H_H := 1214m$

Tailwater $H_T := 1211.9m$



$h_1 := 6.9m$ $h_2 := 6.4m$ $h_3 := 5.8m$ $h_4 := 5.1m$

Interpolated water table heights from retaining wall base.

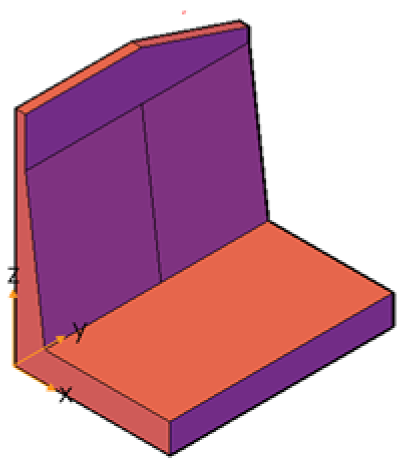
Section 2

Wall Geometry: User Input

Top of Wall Elevation:	$\mathbf{T_w} := 1218.44 \cdot \mathbf{m}$
Top of Footing Elevation:	$\mathbf{Top_{ftg}} := 1208.62 \cdot \mathbf{m}$
Thickness of Footing:	$\mathbf{t_{ftg}} := 1.80\mathbf{m}$
Bottom of Footing Elevation:	$\mathbf{Bot_{ftg}} := \mathbf{Top_{ftg}} - t_{ftg} = 1206.82\ \mathbf{m}$
Overall Height of wall:	$\mathbf{h_w} := \mathbf{T_w} - \mathbf{Bot_{ftg}} = 11.620\ \mathbf{m}$
Thickness of Stem Wall at Top:	$\mathbf{t_{wt}} := 0.5\mathbf{m}$
Slope of Heel Batter:	$\mathbf{S_{batter}} := 0.125$
Thickness of Stem Wall at Base:	$\mathbf{t_{wb}} := 1.5\mathbf{m}$
Length of toe:	$\mathbf{L_{ab}} := 0\mathbf{m}$
Total Length of Footing:	$\mathbf{b} := 8\mathbf{m}$
Length of heel:	$\mathbf{L_{cd}} := \mathbf{b} - \mathbf{L_{ab}} - \mathbf{t_{wb}} = 6.5\ \mathbf{m}$
Width of Wall:	$\mathbf{B} := 11.6\mathbf{m}$

Retaining Wall

Retaining Wall Volume and Gravity Center (Using AutoCAD 3D: File: 3D Transition Wall Analysis Section 2.dwg)



Isometric View

Volume

$Vol_{RW} := 263.5\ m^3$

$X_{RW} := 2.72m$

$Y_{RW} := 5.762m$

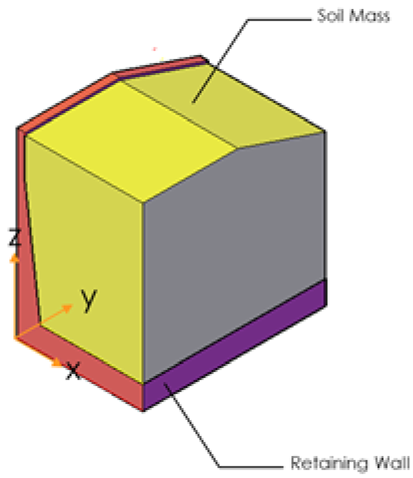
$Z_{RW} := 0m$

Retaining wall total weight $\quad W_{RW} := Vol_{RW} \cdot \gamma_c = 6.19 \cdot MN$

Soil Mass

Retained Soil Volume and Gravity Center (Using AutoCAD 3D: File 3D Transition Wall Analysis Section 1.dwg)

Isometric View:



$Vol_{soil} := 784.755\ m^3$

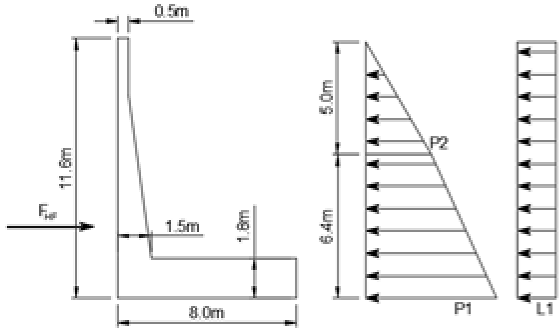
$X_{soil} := 4.441m$

$Y_{soil} := 5.606m$

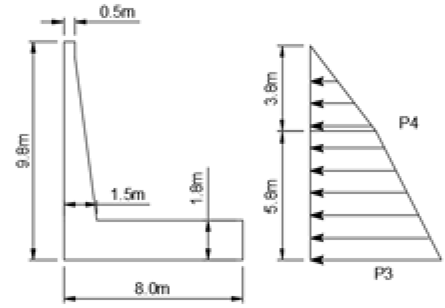
$Z_{soil} := 0m$

Soil mass total weight $\quad W_{soilb} := Vol_{soil} \cdot \gamma_m = 15.7 \cdot MN$

Soil Pressure



Section1



Section 2

Section 1

Back of Retaining Wall

depth to water table $\quad \mathbf{dw} := 5.0\mathbf{m}$

saturated soil depth $\quad \mathbf{ds} := 6.4\mathbf{m}$

soil pressure at rest coefficient $\quad \mathbf{Ko} := 0.55$

$$\mathbf{P2} := \gamma_{\mathbf{m}} \cdot \mathbf{dw} \cdot \mathbf{Ko} = 55 \cdot \mathbf{kPa}$$

$$\mathbf{P1} := \mathbf{P2} + \gamma_{\mathbf{b}} \cdot \mathbf{ds} \cdot \mathbf{Ko} = 97.909 \cdot \mathbf{kPa}$$

Equipment Surcharge

$$\mathbf{L} := 15\mathbf{kPa}$$

$$\mathbf{L1} := \mathbf{Ko} \cdot \mathbf{L} = 8.25 \cdot \mathbf{kPa}$$

Section 2

depth to water table $\mathbf{dw} := 3.8\mathbf{m}$

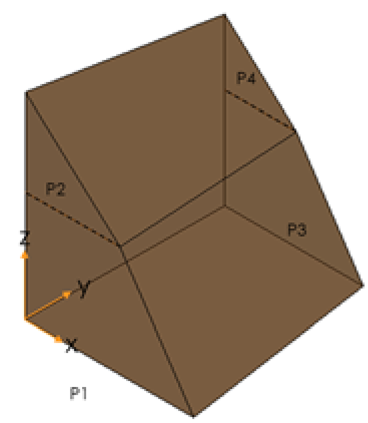
saturated soil depth $\mathbf{ds} := 5.8\mathbf{m}$

soil pressure at rest coefficient $\mathbf{Ko} := 0.55$

$$\mathbf{P4} := \gamma_{\mathbf{m}} \cdot \mathbf{dw} \cdot \mathbf{Ko} = 41.8 \cdot \mathbf{kPa}$$

$$\mathbf{P3} := \mathbf{P4} + \gamma_{\mathbf{b}} \cdot \mathbf{ds} \cdot \mathbf{Ko} = 80.686 \cdot \mathbf{kPa}$$

Isometric view of the prism representing soil pressures against the retaining wall (Using AutoCAD 3D: 3D Transition Wall Analysis Section 2.dwg). The volume of the prism is equal to the equivalent total force.



Isometric View

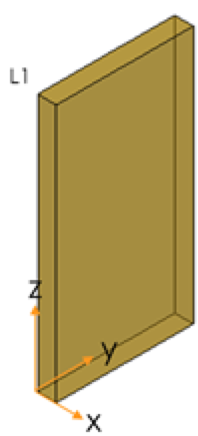
Total Force Back Soil

$\mathbf{F_{soilb}} := \mathbf{6123.38kN}$

$\mathbf{X_{Fsoilb}} := 0\mathbf{m}$

$\mathbf{Y_{Fsoilb}} := \mathbf{5.448m}$

$\mathbf{Z_{Fsoilb}} := \mathbf{3.700m}$



Total Force Equipment Load

$\mathbf{F_{equip}} := \mathbf{569.00kN}$

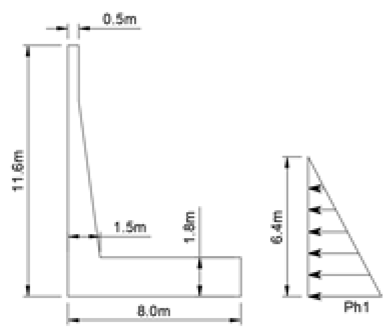
$\mathbf{X_{Fequip}} := 0\mathbf{m}$

$\mathbf{Y_{Fequip}} := \mathbf{3.025m}$

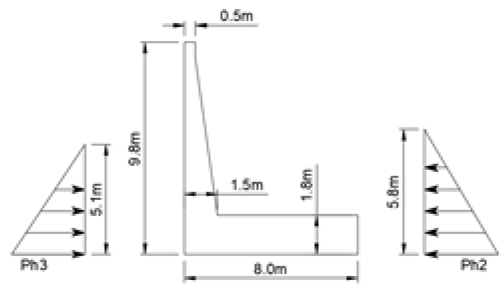
$\mathbf{Z_{Fequip}} := \mathbf{5.700m}$

Hydrostatic Forces

Side View



Section 1



Section 2

Section 1

Back of Wall $\mathbf{h_b} := 6.4\mathbf{m}$

$$\mathbf{Ph1} := \mathbf{h_b} \cdot \gamma_\mathbf{w} = 62.78 \cdot \mathbf{kPa}$$

Section 2

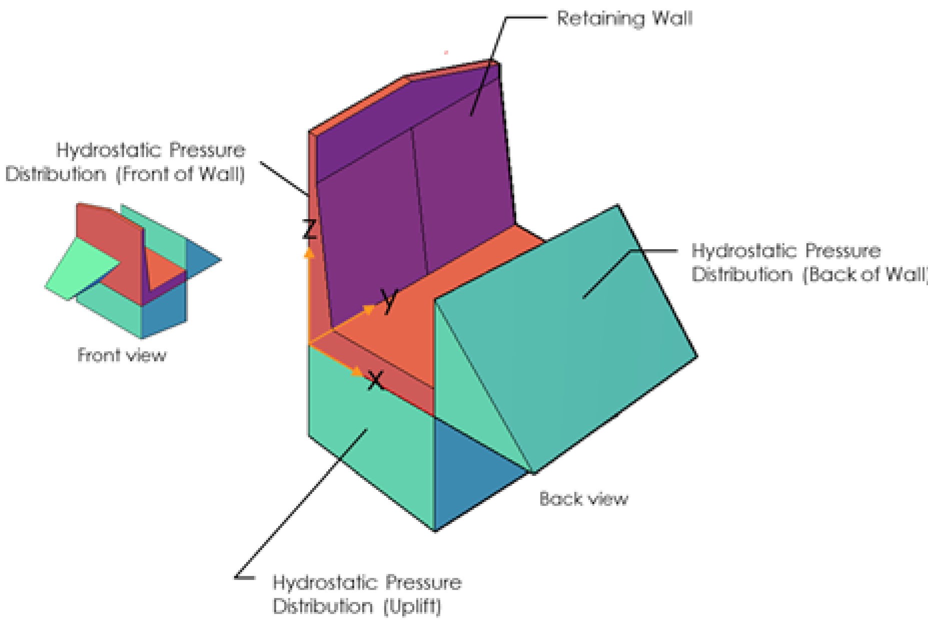
Back of Wall $\mathbf{h_b} := 5.8\mathbf{m}$

Front of Wal $\mathbf{h_f} := 5.1\mathbf{m}$

$$\mathbf{Ph2} := \mathbf{h_b} \cdot \gamma_\mathbf{w} = 56.9 \cdot \mathbf{kPa}$$

$$\mathbf{Ph3} := \mathbf{h_f} \cdot \gamma_\mathbf{w} = 50.03 \cdot \mathbf{kPa}$$

Isometric View



Total Hydrostatic Force

Back of Wall

$H_{Fu} := 2118.84\,kN$

$X_{Fu} := 0\,m$

$Y_{Fu} := 5.610\,m$

$Z_{Fu} := 2.037\,m$

Volume and centroid of hydrostatic pressure was determined using AutoCAD 3D: File 3D Transition Wall Analysis Section 2.dwg

Total Hydrostatic Force

Front of Wal

$H_{Ft} := 660.99\,kN$

$X_{Ft} := 0\,m$

$Y_{Ft} := 8.832\,m$

$Z_{Ft} := 1.822\,m$

Volume and centroid of hydrostatic pressure was determined using AutoCAD 3D: File 3D Transition Wall Analysis Section 2.dwg

Uplift

Total Uplift Force

$F_{uplift} := 5110.50\,kN$

$X_{uplift} := 4.115\,m$

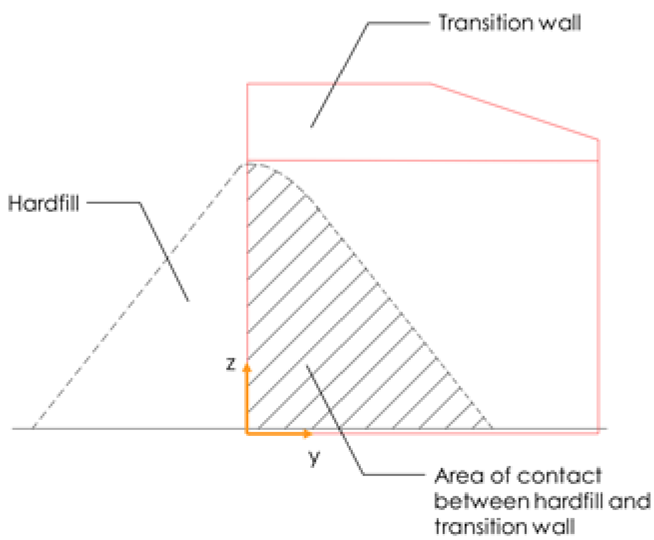
$Y_{uplift} := 5.748\,m$

$Z_{uplift} := 0\,m$

Volume and centroid of hydrostatic pressure was determined using AutoCAD 3D: File 3D Transition Wall Analysis Section 2.dwg

Hardfill Contact Area and Resultant Resistant Force

Front View



Area of Contact $Ac := 40.4917\ m^2$

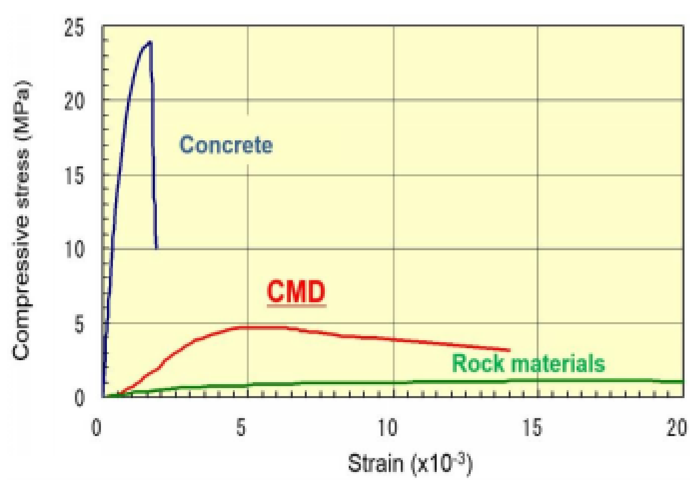
Centroid of contact area was determined using Autocad: File Wall Pressure Diagrams.dwg

$X_{HF} := 0m$

$Y_{HF} := 2.7626m$

$Z_{HF} := 3.4299m$

Hard Fill Stiffness



Source: Noorzad et al. (2017). An Innovative Approach toward Dam Design and Construction. 2nd Workshop on Cement Materials Dams (CMD). July 3, 2017.

$E_{HF} := \frac{5\mathbf{MPa}}{5 \times \mathbf{10}^{-3}} = 1 \cdot \mathbf{GPa}$ Approximate Hardfill Modulus of Elasticity

$L_{HF} := 16\mathbf{m}$ Hardfill section length (between construction joints)

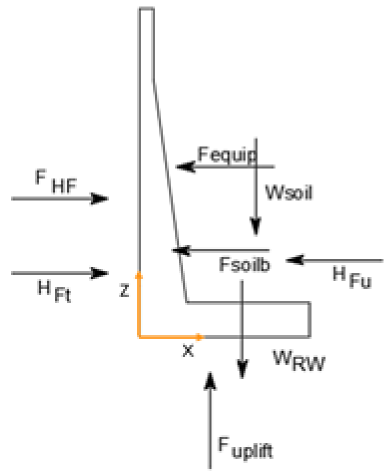
Approximate hardfill stiffness $k_{HF} := \frac{E_{HF}}{L_{HF}} = 62500 \cdot \frac{\mathbf{kN}}{\mathbf{m}^3}$

$\delta_{max} := L_{HF} \cdot 5 \cdot 10^{-3} = 80 \cdot \mathbf{mm}$

Considering a deformation of the hardfill of : $\delta_{HF} := 1.0\mathbf{mm}$ < $\delta_{max} = 80 \cdot \mathbf{mm}$

The total reaction of the hardfill is: $F_{HF} := k_{HF} \cdot Ac \cdot \delta_{HF} = 2.53 \cdot \mathbf{MN}$

Vector Forces Summary



Body diagram, side view

Weight Retaining Wall $\mathbf{W_{RW}} := \begin{pmatrix} 0 & 0 & -\mathbf{W_{RW}} \end{pmatrix} = \begin{pmatrix} 0 & 0 & -6.19 \end{pmatrix} \cdot \mathbf{MN}$

Weight Soil (Back of Wall) $\mathbf{W_{soilb}} := \begin{pmatrix} 0 & 0 & -\mathbf{W_{soilb}} \end{pmatrix} = \begin{pmatrix} 0 & 0 & -15.7 \end{pmatrix} \cdot \mathbf{MN}$

Soil Pressure (Back of Wall) $\mathbf{F_{soilb}} := \begin{pmatrix} -\mathbf{F_{soilb}} & 0 & 0 \end{pmatrix} = \begin{pmatrix} -6.12 & 0 & 0 \end{pmatrix} \cdot \mathbf{MN}$

Equipment Pressure (Back of Wall) $\mathbf{F_{equip}} := \begin{pmatrix} -\mathbf{F_{equip}} & 0 & 0 \end{pmatrix} = \begin{pmatrix} -0.57 & 0 & 0 \end{pmatrix} \cdot \mathbf{MN}$

Hydrostatic Force (Back of Wall) $\mathbf{H_{Fu}} := \begin{pmatrix} -\mathbf{H_{Fu}} & \mathbf{0} & 0 \end{pmatrix} = \begin{pmatrix} -2.12 & 0 & 0 \end{pmatrix} \cdot \mathbf{MN}$

Hydrostatic Force (Front of Wall) $\mathbf{H_{Ft}} := \begin{pmatrix} \mathbf{H_{Ft}} & 0 & 0 \end{pmatrix} = \begin{pmatrix} 0.66 & 0 & 0 \end{pmatrix} \cdot \mathbf{MN}$

Uplift Force $\mathbf{F_{uplift}} := \begin{pmatrix} 0 & 0 & \mathbf{F_{uplift}} \end{pmatrix} = \begin{pmatrix} 0 & 0 & 5.11 \end{pmatrix} \cdot \mathbf{MN}$

Resistance force by Hardfill $\mathbf{F_{HF}} := \begin{pmatrix} \mathbf{F_{HF}} & 0 & 0 \end{pmatrix} = \begin{pmatrix} 2.53 & 0 & 0 \end{pmatrix} \cdot \mathbf{MN}$

Resultant Total Force

$$\mathbf{F} := \mathbf{W_{RW}} + \mathbf{W_{soilb}} + \mathbf{F_{soilb}} + \mathbf{F_{equip}} + \mathbf{H_{Fu}} + \mathbf{H_{Ft}} + \mathbf{F_{uplift}} + \mathbf{F_{HF}}$$

$$\mathbf{F} = (-5.62 \quad 0 \quad -16.78)\cdot\mathbf{MN}$$

Structure Stability

1. Sliding

$$236.6\mathbf{m}^3\cdot\gamma_{\mathbf{w}} = 2.32\cdot\mathbf{MN}$$

Coefficient of sliding friction $\mu := 0.45$

$$\mathbf{FoS} := \frac{\mathbf{F}_{0,2}\cdot\mu}{\mathbf{F}_{0,0}} = 1.34 \quad > \quad \mathbf{FS_{sliding.req}} = 1.3 \qquad \mathbf{OK}$$

2. Uplift

Summatory of Axial Resistant Forces

$$\mathbf{F_R} := \mathbf{W_{RW}} + \mathbf{W_{soilb}} = (0 \quad 0 \quad -21.89)\cdot\mathbf{MN}$$

Uplift Force

$$\mathbf{F_{uplift}} = (0 \quad 0 \quad 5.11)\cdot\mathbf{MN}$$

$$\mathbf{FoS_{uplift}} := \frac{\left|\mathbf{F_R}_{0,2}\right|}{\left|\mathbf{F_{uplift}}_{0,2}\right|} = 4.28 \quad > \quad \mathbf{FS_{float.req}} = 1.3 \qquad \mathbf{OK}$$

3. Overturning

$$\mathbf{r_{RW}} := \left(\mathbf{X_{RW}} \quad Y_{RW} \quad Z_{RW}\right) = (2.72 \quad 5.76 \quad 0)\ \mathbf{m}$$

$$\mathbf{r_{soilb}} := \left(X_{soil} \quad Y_{soil} \quad Z_{soil}\right) = (4.44 \quad 5.61 \quad 0)\ \mathbf{m}$$

$$\mathbf{r_{Fsoilb}} := \left(X_{Fsoilb} \quad Y_{Fsoilb} \quad Z_{Fsoilb}\right) = (0 \quad 5.45 \quad 3.7)\ \mathbf{m}$$

$$\mathbf{r_{Fequip}} := \left(X_{Fequip} \quad Y_{Fequip} \quad Z_{Fequip}\right) = (0 \quad 3.03 \quad 5.7)\ \mathbf{m}$$

$$\mathbf{r_{Fu}} := \left(X_{Fu} \quad Y_{Fu} \quad Z_{Fu}\right) = (0 \quad 5.61 \quad 2.04)\ \mathbf{m}$$

$$\mathbf{r_{Ft}} := \left(X_{Ft} \quad Y_{Ft} \quad Z_{Ft}\right) = (0 \quad 8.83 \quad 1.82)\ \mathbf{m}$$

$$\mathbf{r_{uplift}} := \left(X_{uplift} \quad Y_{uplift} \quad Z_{uplift}\right) = (4.12 \quad 5.75 \quad 0)\ \mathbf{m}$$

$$\mathbf{r_{HF}} := \left(\mathbf{X_{HF}} \quad \mathbf{Y_{HF}} \quad \mathbf{Z_{HF}}\right) = (0 \quad 2.76 \quad 3.43)\ \mathbf{m}$$

$$\mathbf{M} := \mathbf{W_{RW}}^{\mathbf{T}} \times \mathbf{r_{RW}}^{\mathbf{T}} + \mathbf{W_{soilb}}^{\mathbf{T}} \times \mathbf{r_{soilb}}^{\mathbf{T}} + \mathbf{F_{soilb}}^{\mathbf{T}} \times \mathbf{r_{Fsoilb}}^{\mathbf{T}} + \mathbf{F_{HF}}^{\mathbf{T}} \times \mathbf{r_{HF}}^{\mathbf{T}} \cdots$$
$$+ \mathbf{F_{equip}}^{\mathbf{T}} \times \mathbf{r_{Fequip}}^{\mathbf{T}} + \mathbf{H_{Fu}}^{\mathbf{T}} \times \mathbf{r_{Fu}}^{\mathbf{T}} + \mathbf{H_{Ft}}^{\mathbf{T}} \times \mathbf{r_{Ft}}^{\mathbf{T}} + \mathbf{F_{uplift}}^{\mathbf{T}} \times \mathbf{r_{uplift}}^{\mathbf{T}}$$

$$\mathbf{M} = \begin{pmatrix} 94.29 \\ -45.18 \\ -34.14 \end{pmatrix} \cdot \mathbf{MN} \cdot \mathbf{m}$$

$$\mathbf{F} = (-5.62 \quad 0 \quad -16.78) \cdot \mathbf{MN}$$

Location of resultant force:

$$\mathbf{X_R} := \left| \frac{\mathbf{M}_{1,0}}{\mathbf{F}_{0,2}} \right| = 2.69 \cdot \mathbf{m}$$

$$\mathbf{x} := \left| \mathbf{X_R} - \frac{\mathbf{b}}{2} \right| = 1.31\ \mathbf{m} \quad < \quad \frac{\mathbf{b}}{6} = 1.33\ \mathbf{m} \qquad \mathbf{OK}$$

4. **Bearing Capacity**

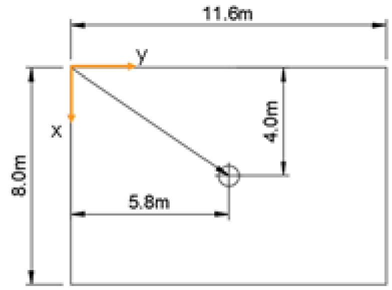
$$q_{all} := 622\,\mathbf{kPa}$$

Force and Moment at origin:

$$\mathbf{F} = (-5.62 \quad 0 \quad -16.78)\cdot\mathbf{MN} \qquad \mathbf{M} = \begin{pmatrix} 94.29 \\ -45.18 \\ -34.14 \end{pmatrix}\mathbf{m}\cdot\mathbf{MN}$$

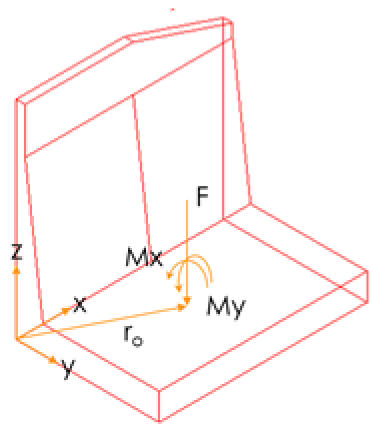
Vector to center of foundation:

$$\mathbf{r_o} := (4 \quad 5.8 \quad 0)\,\mathbf{m}$$



Moment at center of Foundation

$$\mathbf{M_o} := \mathbf{M} - \mathbf{F}^{\mathbf{T}} \times \mathbf{r_o}^{\mathbf{T}} = \begin{pmatrix} -3.01 \\ 21.92 \\ -1.55 \end{pmatrix} \mathbf{m} \cdot \mathbf{MN}$$



$$\mathbf{Ix_o} := \frac{1}{12} \cdot \mathbf{b}^3 \cdot \mathbf{B} = 494.93\ \mathbf{m}^4$$

$$\mathbf{Iy_o} := \frac{1}{12} \cdot \mathbf{b} \cdot \mathbf{B}^3 = 1040.597\ \mathbf{m}^4$$

$$\mathbf{A} := \mathbf{b} \cdot \mathbf{B} = 92.8\ \mathbf{m}^2$$

$$\sigma_{\mathbf{max}} := \left| \frac{\mathbf{F}_{0,2}}{\mathbf{A}} \right| + \left| \frac{{\mathbf{M_o}}_{0,0} \cdot \mathbf{b}}{2 \cdot \mathbf{Ix_o}} \right| + \left| \frac{{\mathbf{M_o}}_{1,0} \cdot \mathbf{B}}{2 \cdot \mathbf{Iy_o}} \right| = 327.344 \cdot \mathbf{kPa} < \quad \mathbf{q_{all}} = 622 \cdot \mathbf{kPa} \qquad \mathbf{OK}$$

$$\sigma_{\mathbf{min}} := \left| \frac{\mathbf{F}_{0,2}}{\mathbf{A}} \right| - \left| \frac{{\mathbf{M_o}}_{0,0} \cdot \mathbf{b}}{2 \cdot \mathbf{Ix_o}} \right| - \left| \frac{{\mathbf{M_o}}_{1,0} \cdot \mathbf{B}}{2 \cdot \mathbf{Iy_o}} \right| = 34.227 \cdot \mathbf{kPa} \quad < \quad \mathbf{q_{all}} = 622 \cdot \mathbf{kPa} \qquad \mathbf{OK}$$

Section 2: Unusual Condition (UN2)

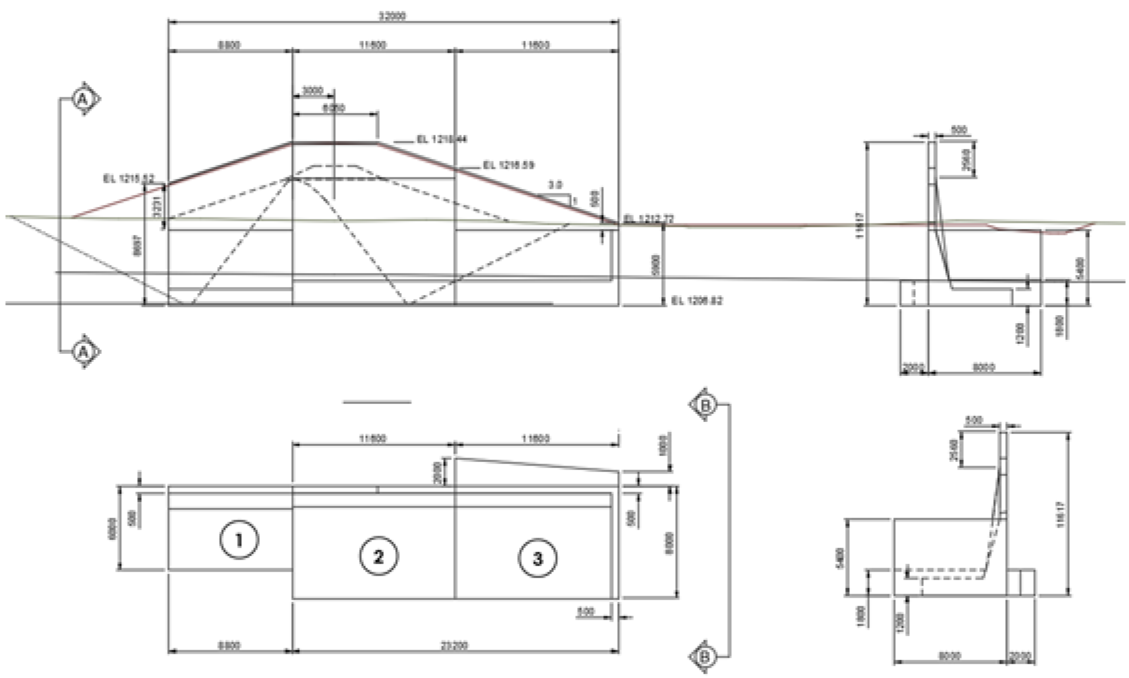
Loading	Horizontal Forces Force (MN)	Horizontal Forces Arm (m)	Vertical Forces Force (MN)	Vertical Forces Arm (m)	Stabilizing Moments (MN-m)	Overturning Moments (MN-m)
Weight of Structure			6.2	2.7	16.8	
Earthquake Inertia Force						
Soil Mass, front of wall						
Soil Mass, back of wall			15.7	4.4	69.7	
Soil Pressure, front of wall	1.28	3.24			4.2	
Soil Pressure, back of wall	-5.42	3.78				20.5
Soil Dynamic Pressure, back of wall						
Uplift			-6.6	4.2		27.7
Hydrostatic pressure, front of wall	1.12	2.36			2.6	
Hydrostatic pressure, back of wall	-3.96	2.77				10.9
Hardfill	2.02	3.43			6.9	
SUM	**-4.96**		**15.27**		**100.29**	**59.09**
					Net Moment	
					41.20	

Stability Calculations
Retaining Wall - Auxiliary Spillway
Right Abutment Transition to Berm

Scope:

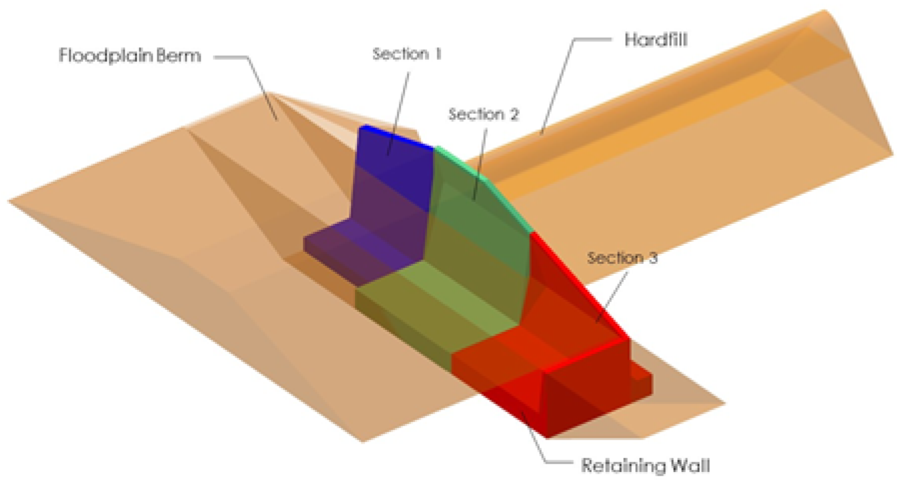
Evaluate the stability of the transition wall of the Auxiliary Spillway. Consider the 3D effects on the structure's stability.

Structure Geometry:



dimensions in mm

Isometric View:



Load Condition

	Elevation (m)			
	Headwater	**Tailwater**	**Headwater**	**Tailwater**
1. Usual Condition (U1)	1214.0	1211.9	7.0	4.9
2. Unusual Condition 1 (UN1)	1214.0	1211.9	7.0	4.9
3. Unusual Condition 2 (UN2)	1216.5	1213.1	9.5	6.1
4. Unusual Condition 3 (UN3)	1217.0	1213.1	10.0	6.1
5. Extreme Condition 1 (E1-F)	1217.3	1213.8	10.3	6.8
6. Extreme Condition 2 (E2-Q)	1213.5	1211.9	6.5	4.9

User Input

Material Properties:

Unit Weight of Water: $\gamma_w := 9.81 \frac{kN}{m^3}$ (Section 7.2, Design Criteria)

Unit Weight of Concrete: $\gamma_c := 23.5 \frac{kN}{m^3}$

Unit Weight of Soil (Moist): $\gamma_m := 20.0 \frac{kN}{m^3}$ (Section 5.3, Design Criteria) assumed moisture content (w) = 5%

Unit Weight Soil (Saturated): $\gamma_{sat} := 22.0 \frac{kN}{m^3}$ (Assuming Specific Gravity = 2.7)

Unit Weight Soil (buoyant): $\gamma_b := \gamma_{sat} - \gamma_w = 12.19 \cdot \frac{kN}{m^3}$

Weight of Soil/Concrete above toe: $\gamma_{toe} := 22.0 \frac{kN}{m^3}$

Unit Weight of Rock: $\gamma_r := 25.6 \frac{kN}{m^3}$ (Section 7.2, Design Criteria)

Unusual Condition 2 (UN2)

Acceptance Parameters

Resultant Location (Overturning and Bearing Pressure):

Unusual (UN) Resultant located inside middle third (kern) equals 100% base in compression (AT/WCS Guidelines, Section 8.4)

$$\mathbf{B_{\%basecomp.req}} := 100\%$$

Allowable rock bearing pressure: $\mathbf{qall} := 622 \frac{\mathbf{kN}}{\mathbf{m}^2}$ (Internal Geotechnical Design Recommendations Rev. Sept 12, 2018, Section 5.3)

FS Sliding:

Usual (U1) 1.3 (without cohesion) (CDA Guidelines, Table 6-4, AT/WCS Guidelines, Section 8.3)

Req'd Factor of Safety for Sliding: $\mathbf{FS_{sliding.req}} := 1.3$ (Without Cohesion)

FS Floatation:

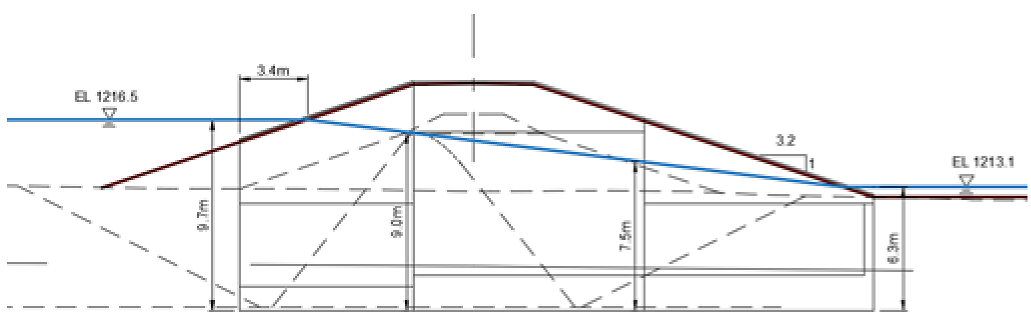
Usual (U1) 1.3 (AT/WCS Guidelines, Section 8.5)

Req'd Factor of Safety for Floatation: $\mathbf{FS_{float.req}} := 1.3$

Water Surface Elevations

Headwater $\mathbf{H_H} := 1216.5\mathbf{m}$

Tailwater $\mathbf{H_T} := 1213.1\mathbf{m}$



$\mathbf{h_1} := 9.7\mathbf{m}$ $\mathbf{h_2} := 9.0\mathbf{m}$ $\mathbf{h_3} := 7.5\mathbf{m}$ $\mathbf{h_4} := 6.3\mathbf{m}$

Interpolated water table heights from retaining wall base.

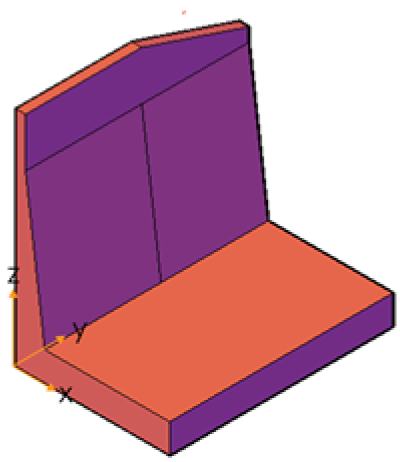
Section 2

Wall Geometry: User Input

Top of Wall Elevation:	$T_w := 1218.44 \cdot m$
Top of Footing Elevation:	$Top_{ftg} := 1208.62 \cdot m$
Thickness of Footing:	$t_{ftg} := 1.80m$
Bottom of Footing Elevation:	$Bot_{ftg} := Top_{ftg} - t_{ftg} = 1206.82\ m$
Overall Height of wall:	$h_w := T_w - Bot_{ftg} = 11.620\ m$
Thickness of Stem Wall at Top:	$t_{wt} := 0.5m$
Slope of Heel Batter:	$S_{batter} := 0.125$
Thickness of Stem Wall at Base:	$t_{wb} := 1.5m$
Length of toe:	$L_{ab} := 0m$
Total Length of Footing:	$b := 8m$
Length of heel:	$L_{cd} := b - L_{ab} - t_{wb} = 6.5\ m$
Width of Wall:	$B := 11.6m$

Retaining Wall

Retaining Wall Volume and Gravity Center (Using AutoCAD 3D: File: 3D Transition Wall Analysis Section 2.dwg)



Isometric View

Volume

$Vol_{RW} := 263.5\ m^3$

$X_{RW} := 2.72m$

$Y_{RW} := 5.762m$

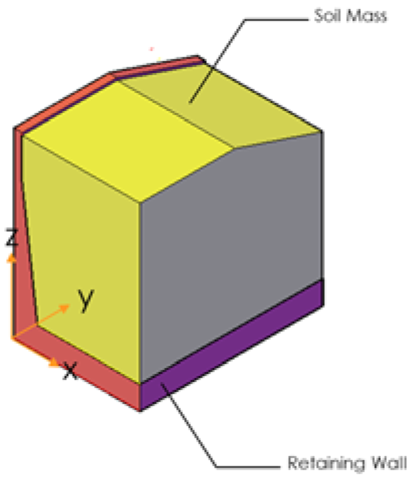
$Z_{RW} := 0m$

Retaining wall total weight $\quad W_{RW} := Vol_{RW} \cdot \gamma_c = 6.19 \cdot MN$

Soil Mass

Retained Soil Volume and Gravity Center (Using AutoCAD 3D: File 3D Transition Wall Analysis Section 1.dwg)

Isometric View:



$\mathbf{Vol_{soil}} := \mathbf{784.755\ m^3}$

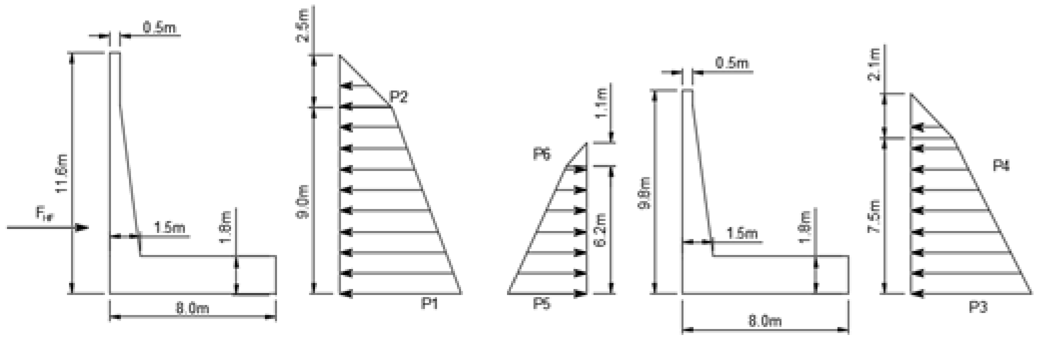
$\mathbf{X_{soil}} := \mathbf{4.441m}$

$\mathbf{Y_{soil}} := \mathbf{5.606m}$

$\mathbf{Z_{soil}} := 0\mathbf{m}$

Soil mass total weight $\mathbf{W_{soilb}} := \mathbf{Vol_{soil}} \cdot \gamma_{\mathbf{m}} = 15.7 \cdot \mathbf{MN}$

Soil Pressure



Section1 Section 2

Section 1

Back of Retaining Wall

depth to water table $\mathbf{dw} := 2.5\mathbf{m}$

saturated soil depth $\mathbf{ds} := 9.0\mathbf{m}$

soil pressure at rest coefficient $\mathbf{Ko} := 0.55$

$$\mathbf{P2} := \gamma_{\mathbf{m}} \cdot \mathbf{dw} \cdot \mathbf{Ko} = 27.5 \cdot \mathbf{kPa}$$

$$\mathbf{P1} := \mathbf{P2} + \gamma_{\mathbf{b}} \cdot \mathbf{ds} \cdot \mathbf{Ko} = 87.841 \cdot \mathbf{kPa}$$

Section 2

Back of the Retaining Wall

depth to water table $\mathbf{dw} := 2.1\mathbf{m}$

saturated soil depth $\mathbf{ds} := 7.5\mathbf{m}$

soil pressure at rest coefficient $\mathbf{Ko} := 0.55$

$$\mathbf{P4} := \gamma_{\mathbf{m}} \cdot \mathbf{dw} \cdot \mathbf{Ko} = 23.1 \cdot \mathbf{kPa}$$

$$\mathbf{P3} := \mathbf{P4} + \gamma_{\mathbf{b}} \cdot \mathbf{ds} \cdot \mathbf{Ko} = 73.384 \cdot \mathbf{kPa}$$

Front of Retaining Wall

depth to water table $\mathbf{dw} := 1.1\mathbf{m}$

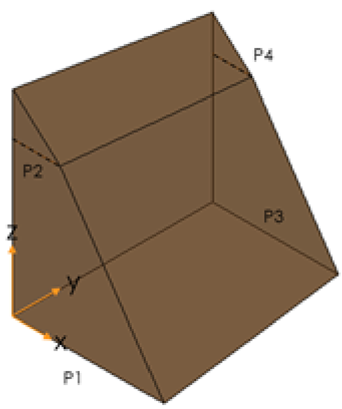
saturated soil depth $\mathbf{ds} := 6.2\mathbf{m}$

soil pressure at rest coefficient $\mathbf{Ko} := 0.55$

$$\mathbf{P6} := \gamma_{\mathbf{m}} \cdot \mathbf{dw} \cdot \mathbf{Ko} = 12.1 \cdot \mathbf{kPa}$$

$$\mathbf{P5} := \mathbf{P6} + \gamma_{\mathbf{b}} \cdot \mathbf{ds} \cdot \mathbf{Ko} = 53.668 \cdot \mathbf{kPa}$$

Isometric view of the prism representing soil pressures against the retaining wall (Using AutoCAD 3D: 3D Transition Wall Analysis Section 2.dwg). The volume of the prism is equal to the equivalent total force.



Total Force Back Soil

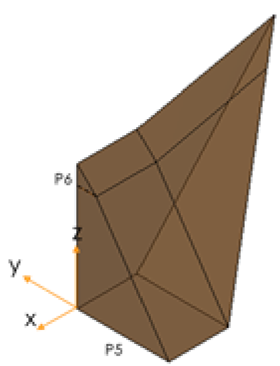
$\mathbf{F_{soilb}} := \mathbf{5419.94kN}$

$\mathbf{X_{Fsoilb}} := 0\mathbf{m}$

$\mathbf{Y_{Fsoilb}} := \mathbf{5.454m}$

$\mathbf{Z_{Fsoilb}} := \mathbf{3.777m}$

Isometric View



Total Force Front Soil

$\mathbf{F_{soilf}} := \mathbf{1282.52kN}$

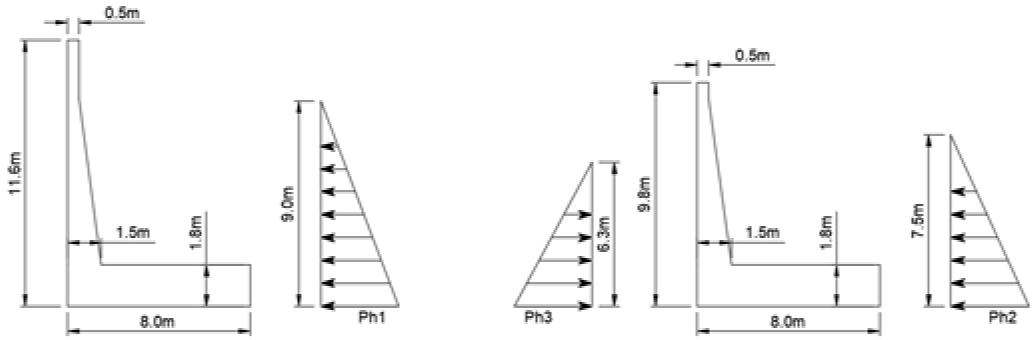
$\mathbf{X_{Fsoilf}} := 0\mathbf{m}$

$\mathbf{Y_{Fsoilf}} := \mathbf{8.214m}$

$\mathbf{Z_{Fsoilf}} := \mathbf{3.243m}$

Hydrostatic Forces

Side View



Section 1 Section 2

Section 1

Back of Wall $h_b := 9m$

$$Ph1 := h_b \cdot \gamma_w = 88.29 \cdot kPa$$

Section 2

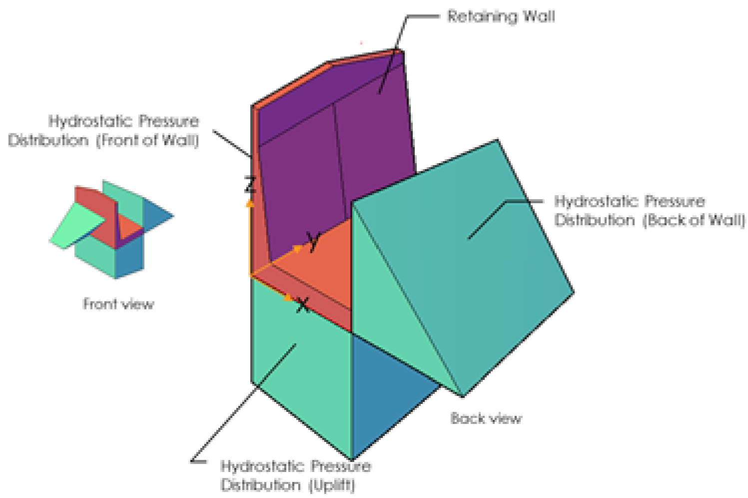
Back of Wall $h_b := 7.5m$

Front of Wall $h_f := 6.3m$

$$Ph2 := h_b \cdot \gamma_w = 73.58 \cdot kPa$$

$$Ph3 := h_f \cdot \gamma_w = 61.8 \cdot kPa$$

Isometric View



Total Hydrostatic Force

Back of Wall

$H_{Fu} := 3958.50\,kN$

$X_{Fu} := 0m$

$Y_{Fu} := 5.449m$

$Z_{Fu} := 2.765m$

Volume and centroid of hydrostatic pressure was determined using AutoCAD 3D: File 3D Transition Wall Analysis Section 2.dwg

Total Hydrostatic Force

Front of Wal

$H_{Ft} := 1120.44\,kN$

$X_{Ft} := 0m$

$Y_{Ft} := 8.603m$

$Z_{Ft} := 2.404m$

Volume and centroid of hydrostatic pressure was determined using AutoCAD 3D: File 3D Transition Wall Analysis Section 2.dwg

Uplift

Total Uplift Force

$F_{uplift} := 6622.90\,kN$

$X_{uplift} := 4.179m$

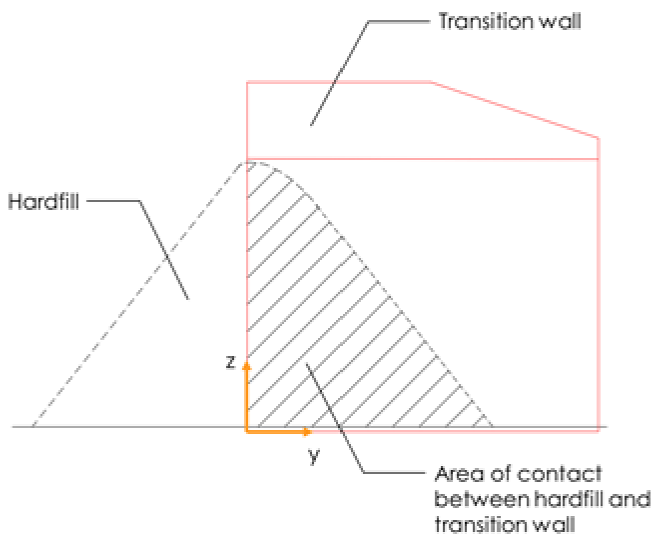
$Y_{uplift} := 5.700m$

$Z_{uplift} := 0m$

Volume and centroid of hydrostatic pressure was determined using AutoCAD 3D: File 3D Transition Wall Analysis Section 2.dwg

Hardfill Contact Area and Resultant Resistant Force

Front View



Area of Contact

$Ac := 40.4917\ m^2$

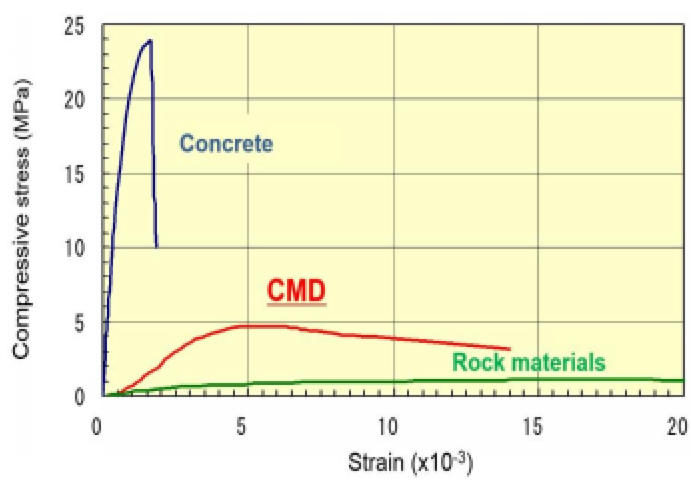
Centroid of contact area was determined using Autocad: File Wall Pressure Diagrams.dwg

$X_{HF} := 0m$

$Y_{HF} := 2.7626m$

$Z_{HF} := 3.4299m$

Hard Fill Stiffness



Source: Noorzad et al. (2017). An Innovative Approach toward Dam Design and Construction. 2nd Workshop on Cement Materials Dams (CMD). July 3, 2017.

$E_{HF} := \dfrac{5\mathbf{MPa}}{5 \times \mathbf{10}^{-3}} = 1 \cdot \mathbf{GPa}$ Approximate Hardfill Modulus of Elasticity

$L_{HF} := 16\mathbf{m}$ Hardfill section length (between construction joints)

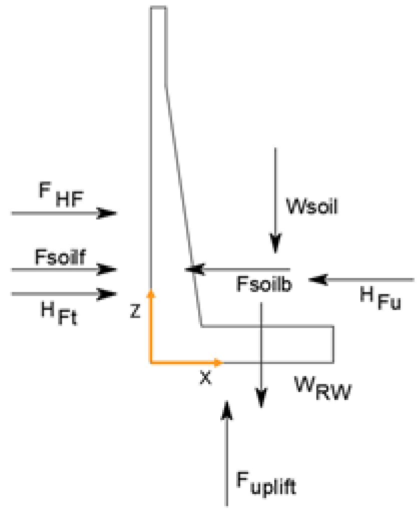
Approximate hardfill stiffness $k_{HF} := \dfrac{E_{HF}}{L_{HF}} = 62500 \cdot \dfrac{\mathbf{kN}}{\mathbf{m}^3}$

$\delta_{max} := L_{HF} \cdot 5 \cdot 10^{-3} = 80 \cdot \mathbf{mm}$

Considering a deformation of the hardfill of : $\delta_{HF} := 0.80\mathbf{mm}$ < $\delta_{max} = 80 \cdot \mathbf{mm}$

The total reaction of the hardfill is: $F_{HF} := k_{HF} \cdot Ac \cdot \delta_{HF} = 2.02 \cdot \mathbf{MN}$

Vector Forces Summary



Body diagram, side view

Weight Retaining Wall $\mathbf{W_{RW}} := \left(0 \quad 0 \quad -\mathbf{W_{RW}}\right) = (0 \quad 0 \quad -6.19)\cdot\mathbf{MN}$

Weight Soil (Back of Wall) $\mathbf{W_{soilb}} := \left(0 \quad 0 \quad -\mathbf{W_{soilb}}\right) = (0 \quad 0 \quad -15.7)\cdot\mathbf{MN}$

Soil Pressure (Back of Wall) $\mathbf{F_{soilb}} := \left(-\mathbf{F_{soilb}} \quad 0 \quad 0\right) = (-5.42 \quad 0 \quad 0)\cdot\mathbf{MN}$

Soil Pressure (Front of Wall) $\mathbf{F_{soilf}} := \left(\mathbf{F_{soilf}} \quad 0 \quad 0\right) = (1.28 \quad 0 \quad 0)\cdot\mathbf{MN}$

Hydrostatic Force (Back of Wall) $\mathbf{H_{Fu}} := \left(-\mathbf{H_{Fu}} \quad \mathbf{0} \quad 0\right) = (-3.96 \quad 0 \quad 0)\cdot\mathbf{MN}$

Hydrostatic Force (Front of Wall) $\mathbf{H_{Ft}} := \left(\mathbf{H_{Ft}} \quad 0 \quad 0\right) = (1.12 \quad 0 \quad 0)\cdot\mathbf{MN}$

Uplift Force $\mathbf{F_{uplift}} := \left(0 \quad 0 \quad \mathbf{F_{uplift}}\right) = (0 \quad 0 \quad 6.62)\cdot\mathbf{MN}$

Resistance force by Hardfill $\mathbf{F_{HF}} := \left(\mathbf{F_{HF}} \quad 0 \quad 0\right) = (2.02 \quad 0 \quad 0)\cdot\mathbf{MN}$

Resultant Total Force

$$\mathbf{F} := \mathbf{W_{RW}} + \mathbf{W_{soilb}} + \mathbf{F_{soilb}} + \mathbf{F_{soilf}} + \mathbf{H_{Fu}} + \mathbf{H_{Ft}} + \mathbf{F_{uplift}} + \mathbf{F_{HF}}$$

$$\mathbf{F} = (-4.95 \quad 0 \quad -15.26)\cdot\mathbf{MN}$$

Structure Stability

1. Sliding

$$236.6\mathbf{m}^3\cdot\gamma_{\mathbf{w}} = 2.32\cdot\mathbf{MN}$$

Coefficient of sliding friction $\mu := 0.45$

$$\mathbf{FoS} := \frac{\mathbf{F}_{0,2}\cdot\mu}{\mathbf{F}_{0,0}} = 1.39 \quad > \quad \mathbf{FS_{sliding.req}} = 1.3 \quad \mathbf{OK}$$

2. Uplift

Summatory of Axial Resistant Forces

$$\mathbf{F_R} := \mathbf{W_{RW}} + \mathbf{W_{soilb}} = (0 \quad 0 \quad -21.89)\cdot\mathbf{MN}$$

Uplift Force

$$\mathbf{F_{uplift}} = (0 \quad 0 \quad 6.62)\cdot\mathbf{MN}$$

$$\mathbf{FoS_{uplift}} := \frac{\left|\mathbf{F_R}_{0,2}\right|}{\left|\mathbf{F_{uplift}}_{0,2}\right|} = 3.3 \quad > \quad \mathbf{FS_{float.req}} = 1.3 \quad \mathbf{OK}$$

3. Overturning

$$\mathbf{r_{RW}} := \left(\mathbf{X_{RW}} \quad Y_{RW} \quad Z_{RW}\right) = (2.72 \quad 5.76 \quad 0)\,\mathbf{m}$$

$$\mathbf{r_{soilb}} := \left(X_{soil} \quad Y_{soil} \quad Z_{soil}\right) = (4.44 \quad 5.61 \quad 0)\,\mathbf{m}$$

$$\mathbf{r_{Fsoilb}} := \left(X_{Fsoilb} \quad Y_{Fsoilb} \quad Z_{Fsoilb}\right) = (0 \quad 5.45 \quad 3.78)\,\mathbf{m}$$

$$\mathbf{r_{Fsoilf}} := \left(X_{Fsoilf} \quad Y_{Fsoilf} \quad Z_{Fsoilf}\right) = (0 \quad 8.21 \quad 3.24)\,\mathbf{m}$$

$$\mathbf{r_{Fu}} := \left(X_{Fu} \quad Y_{Fu} \quad Z_{Fu}\right) = (0 \quad 5.45 \quad 2.77)\,\mathbf{m}$$

$$\mathbf{r_{Ft}} := \left(X_{Ft} \quad Y_{Ft} \quad Z_{Ft}\right) = (0 \quad 8.6 \quad 2.4)\,\mathbf{m}$$

$$\mathbf{r_{uplift}} := \left(X_{uplift} \quad Y_{uplift} \quad Z_{uplift}\right) = (4.18 \quad 5.7 \quad 0)\,\mathbf{m}$$

$$\mathbf{r_{HF}} := \left(\mathbf{X_{HF}} \quad \mathbf{Y_{HF}} \quad \mathbf{Z_{HF}}\right) = (0 \quad 2.76 \quad 3.43)\,\mathbf{m}$$

$$\mathbf{M} := \mathbf{W_{RW}}^{\mathbf{T}} \times \mathbf{r_{RW}}^{\mathbf{T}} + \mathbf{W_{soilb}}^{\mathbf{T}} \times \mathbf{r_{soilb}}^{\mathbf{T}} + \mathbf{F_{soilb}}^{\mathbf{T}} \times \mathbf{r_{Fsoilb}}^{\mathbf{T}} + \mathbf{F_{HF}}^{\mathbf{T}} \times \mathbf{r_{HF}}^{\mathbf{T}} \;\cdots$$
$$+ \mathbf{F_{soilf}}^{\mathbf{T}} \times \mathbf{r_{Fsoilf}}^{\mathbf{T}} + \mathbf{H_{Fu}}^{\mathbf{T}} \times \mathbf{r_{Fu}}^{\mathbf{T}} + \mathbf{H_{Ft}}^{\mathbf{T}} \times \mathbf{r_{Ft}}^{\mathbf{T}} + \mathbf{F_{uplift}}^{\mathbf{T}} \times \mathbf{r_{uplift}}^{\mathbf{T}}$$

$$\mathbf{M} = \begin{pmatrix} 85.92 \\ -41.25 \\ -25.36 \end{pmatrix} \cdot \mathbf{MN} \cdot \mathbf{m}$$

$$\mathbf{F} = (-4.95 \quad 0 \quad -15.26) \cdot \mathbf{MN}$$

Location of resultant force:

$$\mathbf{X_R} := \left| \frac{\mathbf{M}_{1,0}}{\mathbf{F}_{0,2}} \right| = 2.7 \cdot \mathbf{m}$$

$$\mathbf{x} := \left| \mathbf{X_R} - \frac{\mathbf{b}}{2} \right| = 1.3\,\mathbf{m} \quad < \quad \frac{\mathbf{b}}{6} = 1.33\,\mathbf{m} \qquad \mathbf{OK}$$

4. **Bearing Capacity**

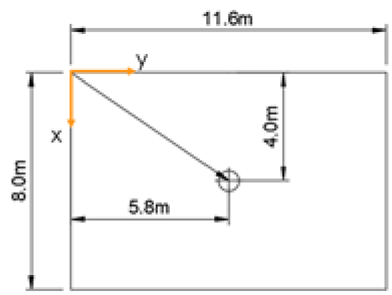
$$\mathbf{q_{all}} := 622\,\mathbf{kPa}$$

Force and Moment at origin:

$$\mathbf{F} = \begin{pmatrix} -4.95 & 0 & -15.26 \end{pmatrix}\cdot\mathbf{MN} \qquad \mathbf{M} = \begin{pmatrix} 85.92 \\ -41.25 \\ -25.36 \end{pmatrix}\mathbf{m}\cdot\mathbf{MN}$$

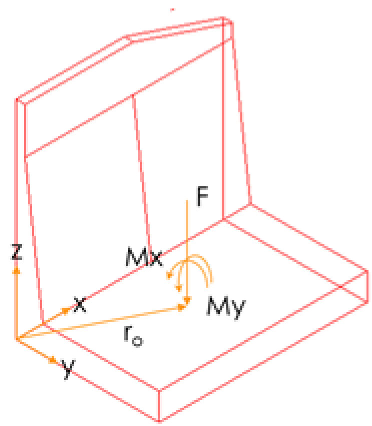
Vector to center of foundation:

$$\mathbf{r_o} := \begin{pmatrix} 4 & 5.8 & 0 \end{pmatrix}\mathbf{m}$$



Moment at center of Foundation

$$\mathbf{M_o} := \mathbf{M} - \mathbf{F}^{\mathbf{T}} \times \mathbf{r_o}^{\mathbf{T}} = \begin{pmatrix} -2.62 \\ 19.81 \\ 3.35 \end{pmatrix} \mathbf{m} \cdot \mathbf{MN}$$



$$\mathbf{Ix_o} := \frac{1}{12} \cdot \mathbf{b}^3 \cdot \mathbf{B} = 494.93\,\mathbf{m}^4$$

$$\mathbf{Iy_o} := \frac{1}{12} \cdot \mathbf{b} \cdot \mathbf{B}^3 = 1040.597\,\mathbf{m}^4$$

$$\mathbf{A} := \mathbf{b} \cdot \mathbf{B} = 92.8\,\mathbf{m}^2$$

$$\sigma_{\mathbf{max}} := \left| \frac{\mathbf{F}_{0,2}}{\mathbf{A}} \right| + \left| \frac{\mathbf{M_o}_{0,0} \cdot \mathbf{b}}{2 \cdot \mathbf{Ix_o}} \right| + \left| \frac{\mathbf{M_o}_{1,0} \cdot \mathbf{B}}{2 \cdot \mathbf{Iy_o}} \right| = 296.058 \cdot \mathbf{kPa} < \quad \mathbf{q_{all}} = 622 \cdot \mathbf{kPa} \qquad \mathbf{OK}$$

$$\sigma_{\mathbf{min}} := \left| \frac{\mathbf{F}_{0,2}}{\mathbf{A}} \right| - \left| \frac{\mathbf{M_o}_{0,0} \cdot \mathbf{b}}{2 \cdot \mathbf{Ix_o}} \right| - \left| \frac{\mathbf{M_o}_{1,0} \cdot \mathbf{B}}{2 \cdot \mathbf{Iy_o}} \right| = 32.917 \cdot \mathbf{kPa} \quad < \quad \mathbf{q_{all}} = 622 \cdot \mathbf{kPa} \qquad \mathbf{OK}$$

TP **Section 2: Unusual Condition (UN3)**

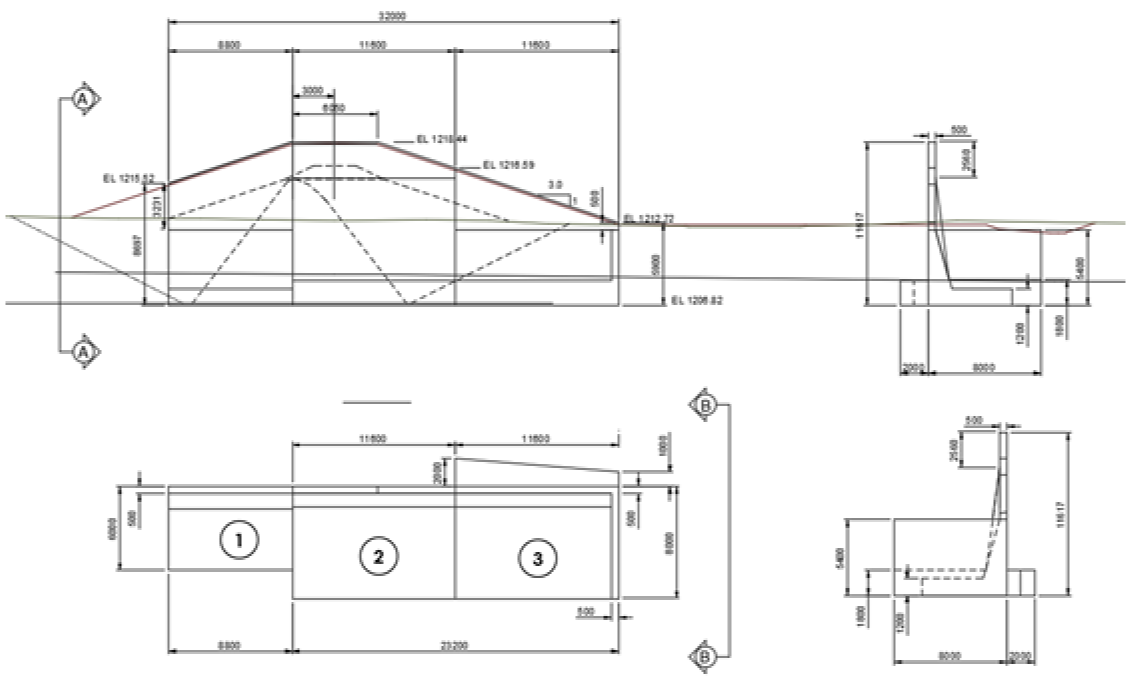
Loading	Horizontal Forces Force (MN)	Horizontal Forces Arm (m)	Vertical Forces Force (MN)	Vertical Forces Arm (m)	Stabilizing Moments (MN-m)	Overturning Moments (MN-m)
Weight of Structure			6.2	2.7	16.8	
Earthquake Inertia Force						
Soil Mass, front of wall						
Soil Mass, back of wall			15.7	4.4	69.7	
Soil Pressure, front of wall						
Soil Pressure, back of wall	-5.21	3.76				19.6
Soil Dynamic Pressure, back of wall						
Uplift			-6.6	4.2		27.6
Hydrostatic pressure, front of wall	1.12	2.39			2.7	
Hydrostatic pressure, back of wall	-4.27	2.90				12.4
Hardfill	3.54	3.43			12.1	
SUM	**-4.83**		**15.31**		**101.37**	**59.54**
					Net Moment	
					41.83	

Stability Calculations
Retaining Wall - Auxiliary Spillway
Right Abutment Transition to Berm

Scope:

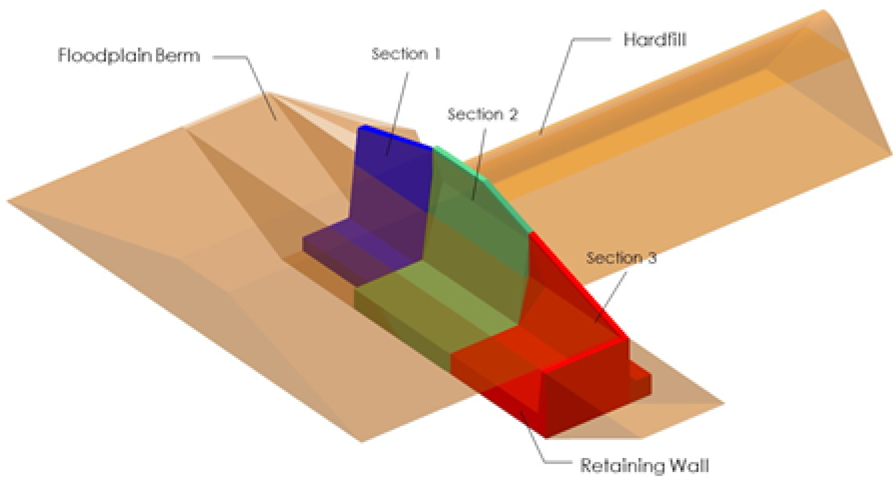
Evaluate the stability of the transition wall of the Auxiliary Spillway. Consider the 3D effects on the structure's stability.

Structure Geometry:



dimensions in mm

Isometric View:



Load Condition

	Elevation (m)			
	Headwater	**Tailwater**	**Headwater**	**Tailwater**
1. Usual Condition (U1)	1214.0	1211.9	7.0	4.9
2. Unusual Condition 1 (UN1)	1214.0	1211.9	7.0	4.9
3. Unusual Condition 2 (UN2)	1216.5	1213.1	9.5	6.1
4. Unusual Condition 3 (UN3)	1217.0	1213.1	10.0	6.1
5. Extreme Condition 1 (E1-F)	1217.3	1213.8	10.3	6.8
6. Extreme Condition 2 (E2-Q)	1213.5	1211.9	6.5	4.9

User Input

Material Properties:

Unit Weight of Water: $\gamma_w := 9.81 \frac{kN}{m^3}$ (Section 7.2, Design Criteria)

Unit Weight of Concrete: $\gamma_c := 23.5 \frac{kN}{m^3}$

Unit Weight of Soil (Moist): $\gamma_m := 20.0 \frac{kN}{m^3}$ (Section 5.3, Design Criteria) assumed moisture content (w) = 5%

Unit Weight Soil (Saturated): $\gamma_{sat} := 22.0 \frac{kN}{m^3}$ (Assuming Specific Gravity = 2.7)

Unit Weight Soil (buoyant): $\gamma_b := \gamma_{sat} - \gamma_w = 12.19 \cdot \frac{kN}{m^3}$

Weight of Soil/Concrete above toe: $\gamma_{toe} := 22.0 \frac{kN}{m^3}$

Unit Weight of Rock: $\gamma_r := 25.6 \frac{kN}{m^3}$ (Section 7.2, Design Criteria)

Unusual Condition 3 (UN3)

Acceptance Parameters

Resultant Location (Overturning and Bearing Pressure):

Unusual (UN) Resultant located inside middle third (kern) equals 100% base in compression (AT/WCS Guidelines, Section 8.4)

$$B_{\%basecomp.req} := 100\%$$

Allowable rock bearing pressure: $qall := 622 \frac{kN}{m^2}$ (Internal Geotechnical Design Recommendations Rev. Sept 12, 2018, Section 5.3)

FS Sliding:

Usual (U1) 1.3 (without cohesion) (CDA Guidelines, Table 6-4, AT/WCS Guidelines, Section 8.3)

Req'd Factor of Safety for Sliding: $FS_{sliding.req} := 1.3$ (Without Cohesion)

FS Floatation:

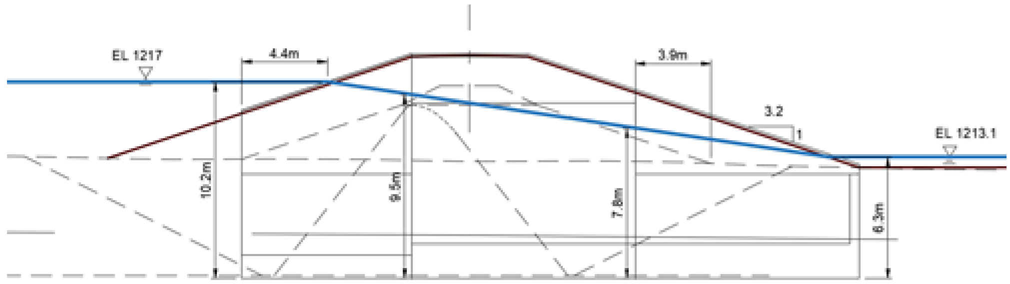
Usual (U1) 1.3 (AT/WCS Guidelines, Section 8.5)

Req'd Factor of Safety for Floatation: $FS_{float.req} := 1.3$

Water Surface Elevations

Headwater $H_H := 1217m$

Tailwater $H_T := 1213.1m$



$h_1 := 10.2m$ $h_2 := 9.5m$ $h_3 := 7.8m$ $h_4 := 6.3m$

Interpolated water table heights from retaining wall base.

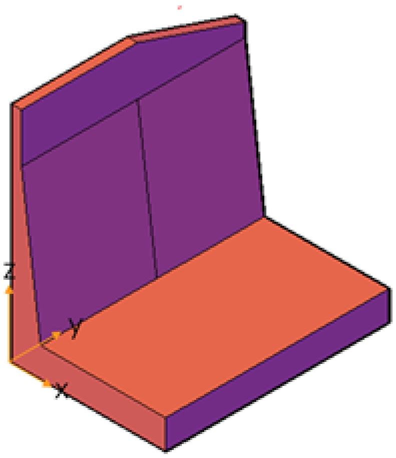
Section 2

Wall Geometry: User Input

Top of Wall Elevation:	$\mathbf{T_w} := 1218.44 \cdot \mathbf{m}$
Top of Footing Elevation:	$\mathbf{Top_{ftg}} := 1208.62 \cdot \mathbf{m}$
Thickness of Footing:	$\mathbf{t_{ftg}} := 1.80\mathbf{m}$
Bottom of Footing Elevation:	$\mathbf{Bot_{ftg}} := \mathbf{Top_{ftg}} - t_{ftg} = 1206.82\ \mathbf{m}$
Overall Height of wall:	$\mathbf{h_w} := \mathbf{T_w} - \mathbf{Bot_{ftg}} = 11.620\ \mathbf{m}$
Thickness of Stem Wall at Top:	$\mathbf{t_{wt}} := 0.5\mathbf{m}$
Slope of Heel Batter:	$\mathbf{S_{batter}} := 0.125$
Thickness of Stem Wall at Base:	$\mathbf{t_{wb}} := 1.5\mathbf{m}$
Length of toe:	$\mathbf{L_{ab}} := 0\mathbf{m}$
Total Length of Footing:	$\mathbf{b} := 8\mathbf{m}$
Length of heel:	$\mathbf{L_{cd}} := \mathbf{b} - \mathbf{L_{ab}} - \mathbf{t_{wb}} = 6.5\ \mathbf{m}$
Width of Wall:	$\mathbf{B} := 11.6\mathbf{m}$

Retaining Wall

Retaining Wall Volume and Gravity Center (Using AutoCAD 3D: File: 3D Transition Wall Analysis Section 2.dwg)



Isometric View

Volume

$Vol_{RW} := 263.5\ m^3$

$X_{RW} := 2.72m$

$Y_{RW} := 5.762m$

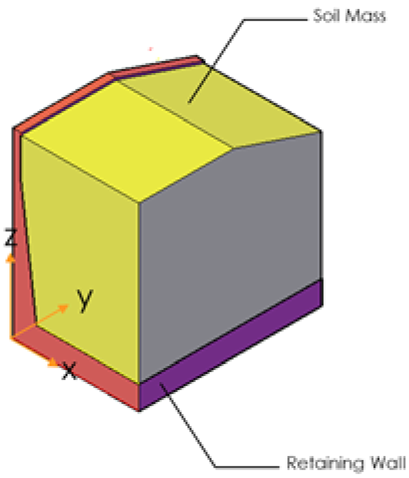
$Z_{RW} := 0m$

Retaining wall total weight $\quad W_{RW} := Vol_{RW} \cdot \gamma_c = 6.19 \cdot MN$

Soil Mass

Retained Soil Volume and Gravity Center (Using AutoCAD 3D: File 3D Transition Wall Analysis Section 1.dwg)

Isometric View:



$\mathbf{Vol_{soil}} := \mathbf{784.755\ m^3}$

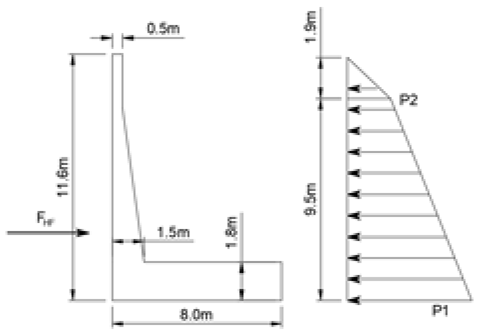
$\mathbf{X_{soil}} := \mathbf{4.441m}$

$\mathbf{Y_{soil}} := \mathbf{5.606m}$

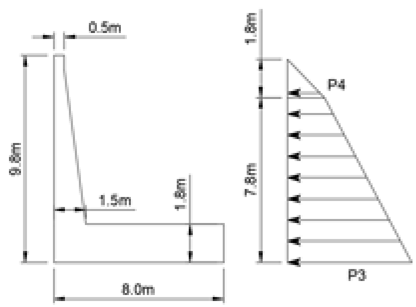
$\mathbf{Z_{soil}} := 0\mathbf{m}$

Soil mass total weight $\quad \mathbf{W_{soilb}} := \mathbf{Vol_{soil}} \cdot \gamma_{\mathbf{m}} = 15.7 \cdot \mathbf{MN}$

Soil Pressure



Section1



Section 2

Section 1

Back of Retaining Wall

depth to water table $\mathbf{dw} := 1.9\mathbf{m}$

saturated soil depth $\mathbf{ds} := 9.5\mathbf{m}$

soil pressure at rest coefficient $\mathbf{Ko} := 0.55$

$$\mathbf{P2} := \gamma_{\mathbf{m}} \cdot \mathbf{dw} \cdot \mathbf{Ko} = 20.9 \cdot \mathbf{kPa}$$

$$\mathbf{P1} := \mathbf{P2} + \gamma_{\mathbf{b}} \cdot \mathbf{ds} \cdot \mathbf{Ko} = 84.593 \cdot \mathbf{kPa}$$

Section 2

Back of the Retaining Wall

depth to water table $\mathbf{dw} := 1.8\mathbf{m}$

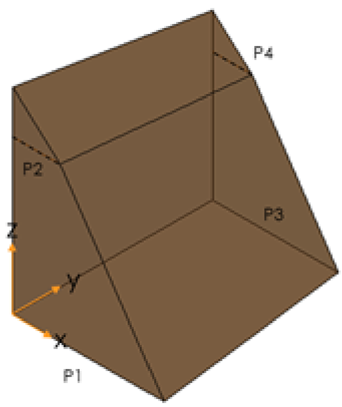
saturated soil depth $\mathbf{ds} := 7.8\mathbf{m}$

soil pressure at rest coefficient $\mathbf{Ko} := 0.55$

$$\mathbf{P4} := \gamma_{\mathbf{m}} \cdot \mathbf{dw} \cdot \mathbf{Ko} = 19.8 \cdot \mathbf{kPa}$$

$$\mathbf{P3} := \mathbf{P4} + \gamma_{\mathbf{b}} \cdot \mathbf{ds} \cdot \mathbf{Ko} = 72.095 \cdot \mathbf{kPa}$$

Isometric view of the prism representing soil pressures against the retaining wall (Using AutoCAD 3D: 3D Transition Wall Analysis Section 2.dwg). The volume of the prism is equal to the equivalent total force.



Isometric View

Total Force Back Soil

$$F_{soilb} := 5210.34\mathbf{kN}$$

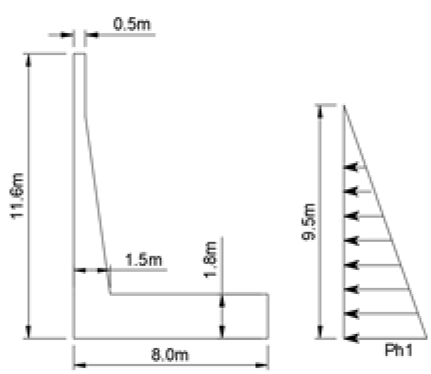
$$X_{Fsoilb} := 0\mathbf{m}$$

$$Y_{Fsoilb} := 5.477\mathbf{m}$$

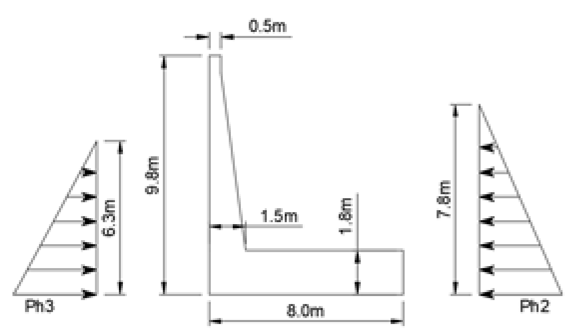
$$Z_{Fsoilb} := 3.761\mathbf{m}$$

Hydrostatic Forces

Side View



Section 1



Section 2

Section 1

Back of Wall $\quad h_b := 9.5\mathbf{m}$

$$\mathbf{Ph1} := h_b \cdot \gamma_w = 93.19 \cdot \mathbf{kPa}$$

Section 2

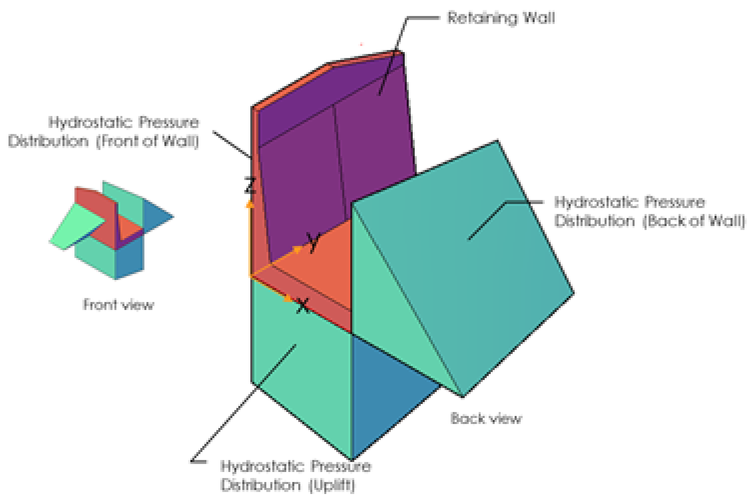
Back of Wall $\mathbf{h_b} := 7.8\mathbf{m}$

Front of Wal $\mathbf{h_f} := 6.3\mathbf{m}$

$$\mathbf{Ph2} := \mathbf{h_b}\cdot\gamma_w = 76.52\cdot\mathbf{kPa}$$

$$\mathbf{Ph3} := \mathbf{h_f}\cdot\gamma_w = 61.8\cdot\mathbf{kPa}$$

Isometric View



Total Hydrostatic Force
Back of Wall

$\mathbf{H_{Fu}} := \mathbf{4270.87kN}$

$\mathbf{X_{Fu}} := 0\mathbf{m}$

$\mathbf{Y_{Fu}} := \mathbf{5.421m}$

$\mathbf{Z_{Fu}} := \mathbf{2.902m}$

Volume and centroid of hydrostatic pressure was determined using AutoCAD 3D: File 3D Transition Wall Analysis Section 2.dwg

Total Hydrostatic Force
Front of Wal

$\mathbf{H_{Ft}} := \mathbf{1115.12kN}$

$\mathbf{X_{Ft}} := 0\mathbf{m}$

$\mathbf{Y_{Ft}} := \mathbf{8.620m}$

$\mathbf{Z_{Ft}} := \mathbf{2.392m}$

Volume and centroid of hydrostatic pressure was determined using AutoCAD 3D: File 3D Transition Wall Analysis Section 2.dwg

Uplift

Total Uplift Force

$F_{uplift} := 6577.43\,kN$

$X_{uplift} := 4.189m$

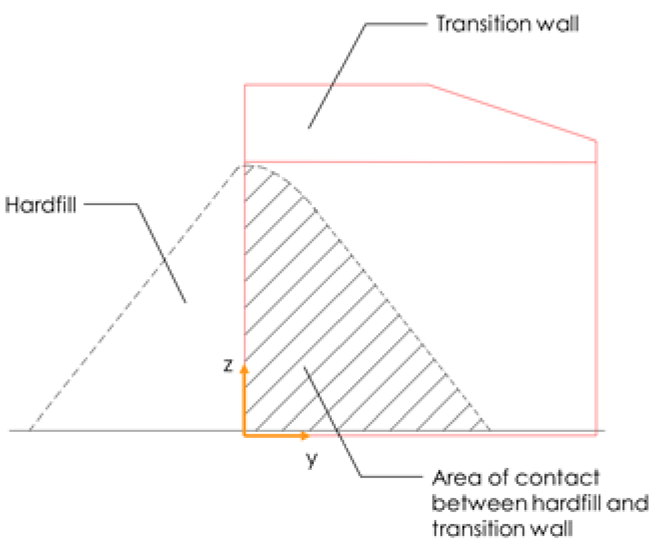
$Y_{uplift} := 5.700m$

$Z_{uplift} := 0m$

Volume and centroid of hydrostatic pressure was determined using AutoCAD 3D: File 3D Transition Wall Analysis Section 2.dwg

Hardfill Contact Area and Resultant Resistant Force

Front View



Area of Contact

$Ac := 40.4917\ m^2$

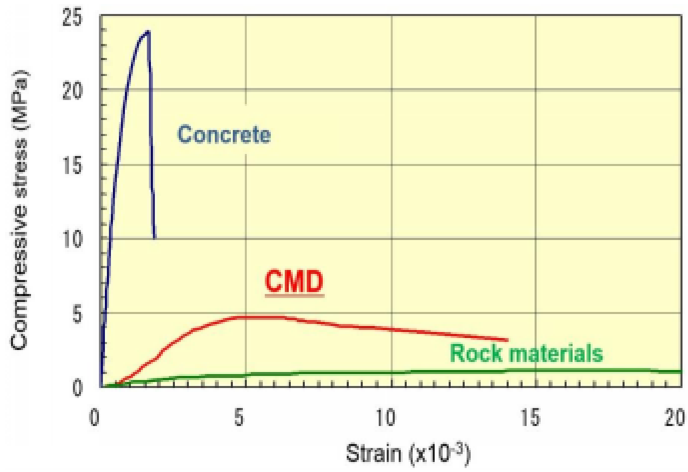
$X_{HF} := 0m$

$Y_{HF} := 2.7626m$

$Z_{HF} := 3.4299m$

Centroid of contact area was determined using Autocad: File Wall Pressure Diagrams.dwg

Hard Fill Stiffness



Source: Noorzad et al. (2017). An Innovative Approach toward Dam Design and Construction. 2nd Workshop on Cement Materials Dams (CMD). July 3, 2017.

$$E_{HF} := \frac{5\mathbf{MPa}}{5 \times \mathbf{10}^{-3}} = 1 \cdot \mathbf{GPa}$$ Approximate Hardfill Modulus of Elasticity

$L_{HF} := 16\mathbf{m}$ Hardfill section length (between construction joints)

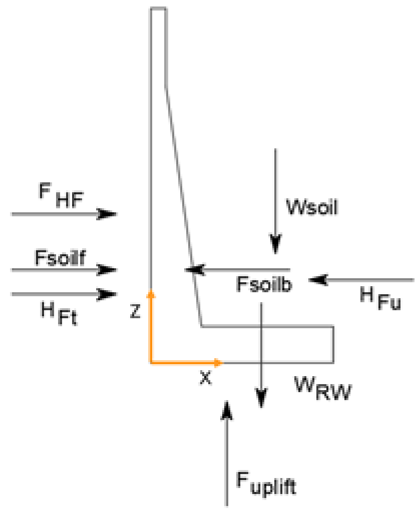
Approximate hardfill stiffness $$k_{HF} := \frac{E_{HF}}{L_{HF}} = 62500 \cdot \frac{\mathbf{kN}}{\mathbf{m}^3}$$

$$\delta_{max} := L_{HF} \cdot 5 \cdot 10^{-3} = 80 \cdot \mathbf{mm}$$

Considering a deformation of the hardfill of : $\delta_{HF} := 1.4\mathbf{mm} \quad < \quad \delta_{max} = 80 \cdot \mathbf{mm}$

The total reaction of the hardfill is: $F_{HF} := k_{HF} \cdot Ac \cdot \delta_{HF} = 3.54 \cdot \mathbf{MN}$

Vector Forces Summary



Body diagram, side view

Weight Retaining Wall $\mathbf{W_{RW}} := \begin{pmatrix} 0 & 0 & -\mathbf{W_{RW}} \end{pmatrix} = \begin{pmatrix} 0 & 0 & -6.19 \end{pmatrix} \cdot \mathbf{MN}$

Weight Soil (Back of Wall) $\mathbf{W_{soilb}} := \begin{pmatrix} 0 & 0 & -\mathbf{W_{soilb}} \end{pmatrix} = \begin{pmatrix} 0 & 0 & -15.7 \end{pmatrix} \cdot \mathbf{MN}$

Soil Pressure (Back of Wall) $\mathbf{F_{soilb}} := \begin{pmatrix} -\mathbf{F_{soilb}} & 0 & 0 \end{pmatrix} = \begin{pmatrix} -5.21 & 0 & 0 \end{pmatrix} \cdot \mathbf{MN}$

Hydrostatic Force (Back of Wall) $\mathbf{H_{Fu}} := \begin{pmatrix} -\mathbf{H_{Fu}} & \mathbf{0} & 0 \end{pmatrix} = \begin{pmatrix} -4.27 & 0 & 0 \end{pmatrix} \cdot \mathbf{MN}$

Hydrostatic Force (Front of Wall) $\mathbf{H_{Ft}} := \begin{pmatrix} \mathbf{H_{Ft}} & 0 & 0 \end{pmatrix} = \begin{pmatrix} 1.12 & 0 & 0 \end{pmatrix} \cdot \mathbf{MN}$

Uplift Force $\mathbf{F_{uplift}} := \begin{pmatrix} 0 & 0 & \mathbf{F_{uplift}} \end{pmatrix} = \begin{pmatrix} 0 & 0 & 6.58 \end{pmatrix} \cdot \mathbf{MN}$

Resistance force by Hardfill $\mathbf{F_{HF}} := \begin{pmatrix} \mathbf{F_{HF}} & 0 & 0 \end{pmatrix} = \begin{pmatrix} 3.54 & 0 & 0 \end{pmatrix} \cdot \mathbf{MN}$

Resultant Total Force

$$\mathbf{F} := \mathbf{W_{RW}} + \mathbf{W_{soilb}} + \mathbf{F_{soilb}} + \mathbf{H_{Fu}} + \mathbf{H_{Ft}} + \mathbf{F_{uplift}} + \mathbf{F_{HF}}$$

$$\mathbf{F} = (-4.82 \quad 0 \quad -15.31)\cdot\mathbf{MN}$$

Structure Stability

1. Sliding

$$236.6\mathbf{m}^3\cdot\gamma_\mathbf{w} = 2.32\cdot\mathbf{MN}$$

Coefficient of sliding friction $\mu := 0.45$

$$\mathbf{FoS} := \frac{\mathbf{F}_{0,2}\cdot\mu}{\mathbf{F}_{0,0}} = 1.43 \quad > \quad \mathbf{FS_{sliding.req}} = 1.3 \quad \mathbf{OK}$$

2. Uplift

Summatory of Axial Resistant Forces

$$\mathbf{F_R} := \mathbf{W_{RW}} + \mathbf{W_{soilb}} = (0 \quad 0 \quad -21.89)\cdot\mathbf{MN}$$

Uplift Force

$$\mathbf{F_{uplift}} = (0 \quad 0 \quad 6.58)\cdot\mathbf{MN}$$

$$\mathbf{FoS_{uplift}} := \frac{\left|\mathbf{F_R}_{0,2}\right|}{\left|\mathbf{F_{uplift}}_{0,2}\right|} = 3.33 \quad > \quad \mathbf{FS_{float.req}} = 1.3 \quad \mathbf{OK}$$

3. Overturning

$$\mathbf{r_{RW}} := \left(\mathbf{X_{RW}} \quad Y_{RW} \quad Z_{RW}\right) = (2.72 \quad 5.76 \quad 0)\,\mathbf{m}$$

$$\mathbf{r_{soilb}} := \left(X_{soil} \quad Y_{soil} \quad Z_{soil}\right) = (4.44 \quad 5.61 \quad 0)\,\mathbf{m}$$

$$\mathbf{r_{Fsoilb}} := \left(X_{Fsoilb} \quad Y_{Fsoilb} \quad Z_{Fsoilb}\right) = (0 \quad 5.48 \quad 3.76)\,\mathbf{m}$$

$$\mathbf{r_{Fu}} := \left(X_{Fu} \quad Y_{Fu} \quad Z_{Fu}\right) = (0 \quad 5.42 \quad 2.9)\,\mathbf{m}$$

$$\mathbf{r_{Ft}} := \left(X_{Ft} \quad Y_{Ft} \quad Z_{Ft}\right) = (0 \quad 8.62 \quad 2.39)\,\mathbf{m}$$

$$\mathbf{r_{uplift}} := \left(X_{uplift} \quad Y_{uplift} \quad Z_{uplift}\right) = (4.19 \quad 5.7 \quad 0)\,\mathbf{m}$$

$$\mathbf{r_{HF}} := \left(\mathbf{X_{HF}} \quad \mathbf{Y_{HF}} \quad \mathbf{Z_{HF}}\right) = (0 \quad 2.76 \quad 3.43)\,\mathbf{m}$$

$$\mathbf{M} := \mathbf{W_{RW}}^{\mathbf{T}} \times \mathbf{r_{RW}}^{\mathbf{T}} + \mathbf{W_{soilb}}^{\mathbf{T}} \times \mathbf{r_{soilb}}^{\mathbf{T}} + \mathbf{F_{soilb}}^{\mathbf{T}} \times \mathbf{r_{Fsoilb}}^{\mathbf{T}} + \mathbf{F_{HF}}^{\mathbf{T}} \times \mathbf{r_{HF}}^{\mathbf{T}} \cdots$$
$$+ \mathbf{H_{Fu}}^{\mathbf{T}} \times \mathbf{r_{Fu}}^{\mathbf{T}} + \mathbf{H_{Ft}}^{\mathbf{T}} \times \mathbf{r_{Ft}}^{\mathbf{T}} + \mathbf{F_{uplift}}^{\mathbf{T}} \times \mathbf{r_{uplift}}^{\mathbf{T}}$$

$$\mathbf{M} = \begin{pmatrix} 86.18 \\ -41.82 \\ -32.29 \end{pmatrix} \cdot \mathbf{MN} \cdot \mathbf{m}$$

$$\mathbf{F} = (-4.82 \quad 0 \quad -15.31) \cdot \mathbf{MN}$$

Location of resultant force:

$$\mathbf{X_R} := \left| \frac{\mathbf{M}_{1,0}}{\mathbf{F}_{0,2}} \right| = 2.73 \cdot \mathbf{m}$$

$$\mathbf{x} := \left| \mathbf{X_R} - \frac{\mathbf{b}}{2} \right| = 1.27\,\mathbf{m} \quad < \quad \frac{\mathbf{b}}{6} = 1.33\,\mathbf{m} \qquad \mathbf{OK}$$

4. **Bearing Capacity**

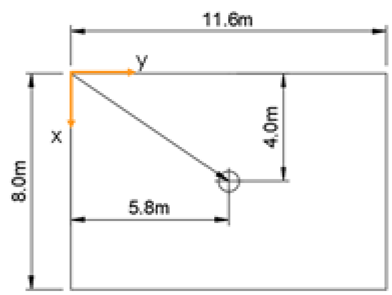
$$\mathbf{q_{all}} := 622\mathbf{kPa}$$

Force and Moment at origin:

$$\mathbf{F} = (-4.82 \quad 0 \quad -15.31)\cdot\mathbf{MN} \qquad \mathbf{M} = \begin{pmatrix} 86.18 \\ -41.82 \\ -32.29 \end{pmatrix}\mathbf{m}\cdot\mathbf{MN}$$

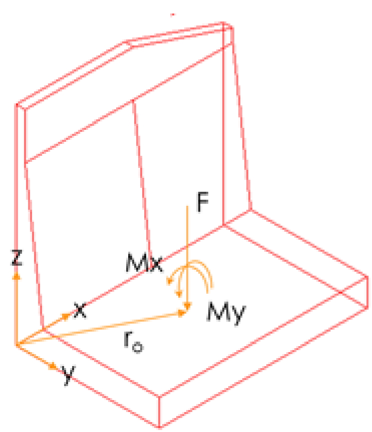
Vector to center of foundation:

$$\mathbf{r_o} := (4 \quad 5.8 \quad 0)\mathbf{m}$$



Moment at center of Foundation

$$\mathbf{M_o} := \mathbf{M} - \mathbf{F}^{\mathbf{T}} \times \mathbf{r_o}^{\mathbf{T}} = \begin{pmatrix} -2.62 \\ 19.42 \\ -4.32 \end{pmatrix} \mathbf{m} \cdot \mathbf{MN}$$



$$\mathbf{Ix_o} := \frac{1}{12} \cdot \mathbf{b}^3 \cdot \mathbf{B} = 494.93\ \mathbf{m}^4$$

$$\mathbf{Iy_o} := \frac{1}{12} \cdot \mathbf{b} \cdot \mathbf{B}^3 = 1040.597\ \mathbf{m}^4$$

$$\mathbf{A} := \mathbf{b} \cdot \mathbf{B} = 92.8\ \mathbf{m}^2$$

$$\sigma_{\mathbf{max}} := \left| \frac{\mathbf{F}_{0,2}}{\mathbf{A}} \right| + \left| \frac{\mathbf{M_o}_{0,0} \cdot \mathbf{b}}{2 \cdot \mathbf{Ix_o}} \right| + \left| \frac{\mathbf{M_o}_{1,0} \cdot \mathbf{B}}{2 \cdot \mathbf{Iy_o}} \right| = 294.404 \cdot \mathbf{kPa} < \quad \mathbf{q_{all}} = 622 \cdot \mathbf{kPa} \quad \mathbf{OK}$$

$$\sigma_{\mathbf{min}} := \left| \frac{\mathbf{F}_{0,2}}{\mathbf{A}} \right| - \left| \frac{\mathbf{M_o}_{0,0} \cdot \mathbf{b}}{2 \cdot \mathbf{Ix_o}} \right| - \left| \frac{\mathbf{M_o}_{1,0} \cdot \mathbf{B}}{2 \cdot \mathbf{Iy_o}} \right| = 35.552 \cdot \mathbf{kPa} \quad < \quad \mathbf{q_{all}} = 622 \cdot \mathbf{kPa} \quad \mathbf{OK}$$

Section 2: Extreme Condition (E1)

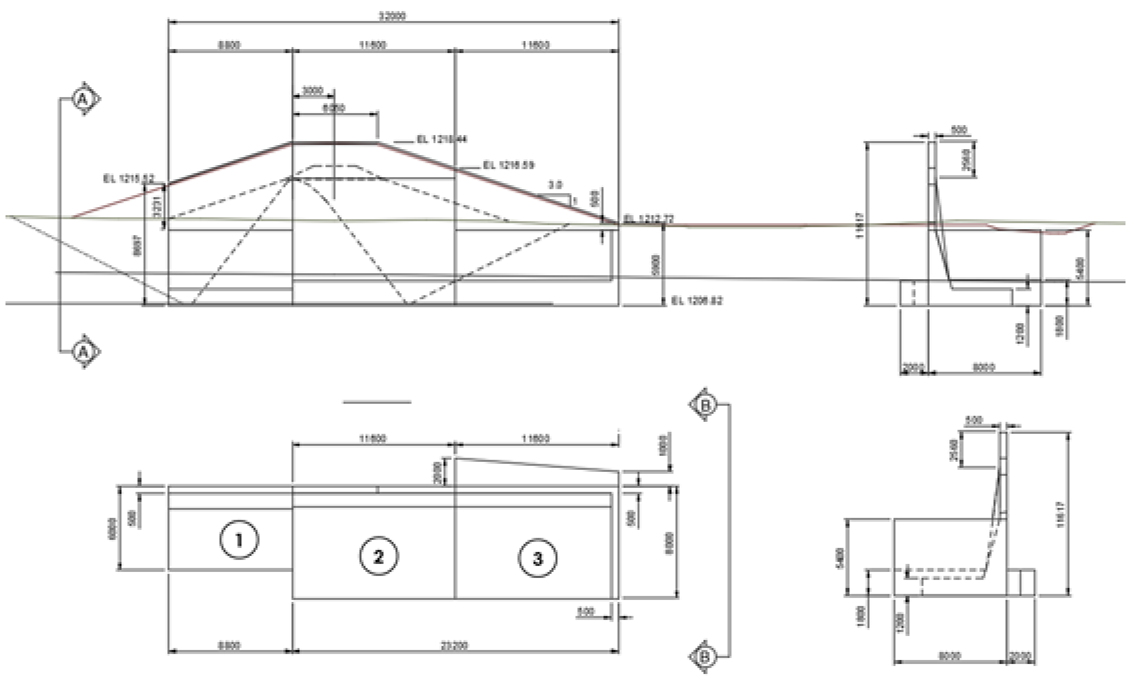
Loading	Horizontal Forces Force (MN)	Horizontal Forces Arm (m)	Vertical Forces Force (MN)	Vertical Forces Arm (m)	Stabilizing Moments (MN-m)	Overturning Moments (MN-m)
Weight of Structure			6.2	2.7	16.8	
Earthquake Inertia Force						
Soil Mass, front of wall						
Soil Mass, back of wall			15.7	4.4	69.7	
Soil Pressure, front of wall						
Soil Pressure, back of wall	-4.96	3.71				18.4
Soil Dynamic Pressure, back of wall						
Uplift			-7.3	4.2		30.6
Hydrostatic pressure, front of wall	1.38	2.65			3.7	
Hydrostatic pressure, back of wall	-4.78	3.07				14.7
Hardfill	3.54	3.43			12.1	
SUM	**-4.82**		**14.58**		**102.37**	**63.64**
					Net Moment	
					38.72	

Stability Calculations
Retaining Wall - Auxiliary Spillway
Right Abutment Transition to Berm

Scope:

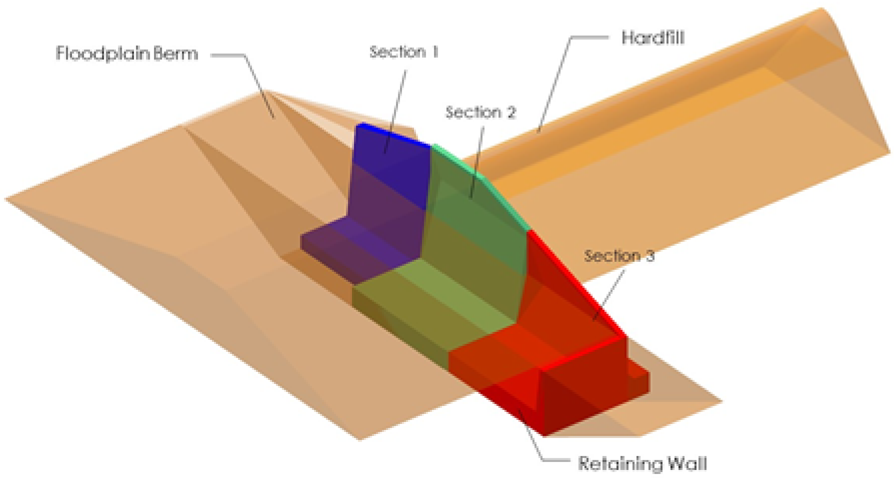
Evaluate the stability of the transition wall of the Auxiliary Spillway. Consider the 3D effects on the structure's stability.

Structure Geometry:



dimensions in mm

Isometric View:



Load Condition

	Elevation (m)			
	Headwater	**Tailwater**	**Headwater**	**Tailwater**
1. Usual Condition (U1)	1214.0	1211.9	7.0	4.9
2. Unusual Condition 1 (UN1)	1214.0	1211.9	7.0	4.9
3. Unusual Condition 2 (UN2)	1216.5	1213.1	9.5	6.1
4. Unusual Condition 3 (UN3)	1217.0	1213.1	10.0	6.1
5. Extreme Condition 1 (E1-F)	1217.3	1213.8	10.3	6.8
6. Extreme Condition 2 (E2-Q)	1213.5	1211.9	6.5	4.9

User Input

Material Properties:

Unit Weight of Water: $\gamma_w := 9.81 \frac{kN}{m^3}$ (Section 7.2, Design Criteria)

Unit Weight of Concrete: $\gamma_c := \mathbf{23.5} \frac{kN}{m^3}$

Unit Weight of Soil (Moist): $\gamma_m := 20.0 \frac{kN}{m^3}$ (Section 5.3, Design Criteria) assumed moisture content (w) = 5%

Unit Weight Soil (Saturated): $\gamma_{sat} := 22.0 \frac{kN}{m^3}$ (Assuming Specific Gravity = 2.7)

Unit Weight Soil (buoyant): $\gamma_b := \gamma_{sat} - \gamma_w = 12.19 \cdot \frac{kN}{m^3}$

Weight of Soil/Concrete above toe: $\gamma_{toe} := 22.0 \frac{kN}{m^3}$

Unit Weight of Rock: $\gamma_r := 25.6 \frac{kN}{m^3}$ (Section 7.2, Design Criteria)

Extreme Condition 1 (E1)

Acceptance Parameters

Resultant Location (Overturning and Bearing Pressure):

Extreme (E1) Resultant located inside middle half (AT/WCS Guidelines, Section 8.4)

Allowable rock bearing pressure: $qall := 622 \frac{kN}{m^2}$ (Internal Geotechnical Design Recommendations Rev. Sept 12, 2018, Section 5.3)

FS Sliding:

Extreme (E1) 1.1 (without cohesion) (CDA Guidelines, Table 6-4, AT/WCS Guidelines, Section 8.3)

Req'd Factor of Safety for Sliding: $FS_{sliding.req} := 1.3$ (Without Cohesion)

FS Floatation:

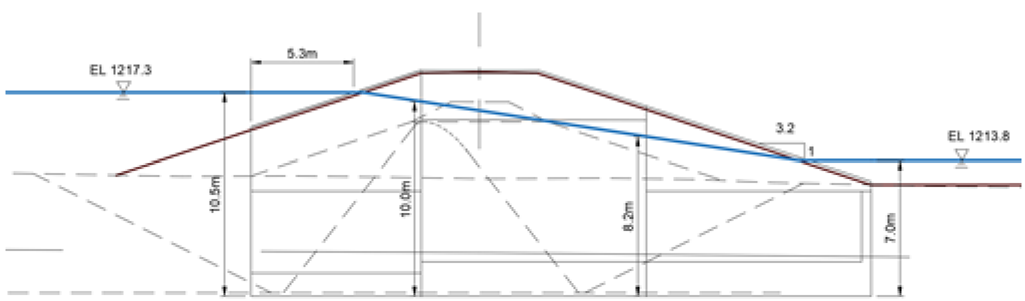
Extreme 1 (E1) 1.1 (AT/WCS Guidelines, Section 8.5)

Req'd Factor of Safety for Floatation: $FS_{float.req} := 1.1$

Water Surface Elevations

Headwater $H_H := 1217.3m$

Tailwater $H_T := 1213.8m$



$h_1 := 10.5m$ $h_2 := 10.m$ $h_3 := 8.2m$ $h_4 := 7.0m$

Interpolated water table heights from retaining wall base.

Section 2

Wall Geometry:

User Input

Top of Wall Elevation: $\mathbf{T_w} := 1218.44 \cdot \mathbf{m}$

Top of Footing Elevation: $\mathbf{Top_{ftg}} := 1208.62 \cdot \mathbf{m}$

Thickness of Footing: $\mathbf{t_{ftg}} := 1.80\mathbf{m}$

Bottom of Footing Elevation: $\mathbf{Bot_{ftg}} := \mathbf{Top_{ftg}} - t_{ftg} = 1206.82\ \mathbf{m}$

Overall Height of wall: $\mathbf{h_w} := \mathbf{T_w} - \mathbf{Bot_{ftg}} = 11.620\ \mathbf{m}$

Thickness of Stem Wall at Top: $\mathbf{t_{wt}} := 0.5\mathbf{m}$

Slope of Heel Batter: $\mathbf{S_{batter}} := 0.125$

Thickness of Stem Wall at Base: $\mathbf{t_{wb}} := 1.5\mathbf{m}$

Length of toe: $\mathbf{L_{ab}} := 0\mathbf{m}$

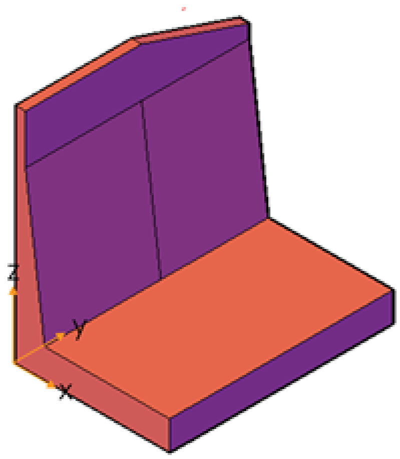
Total Length of Footing: $\mathbf{b} := 8\mathbf{m}$

Length of heel: $\mathbf{L_{cd}} := \mathbf{b} - \mathbf{L_{ab}} - \mathbf{t_{wb}} = 6.5\ \mathbf{m}$

Width of Wall: $\mathbf{B} := 11.6\mathbf{m}$

Retaining Wall

Retaining Wall Volume and Gravity Center (Using AutoCAD 3D: File: 3D Transition Wall Analysis Section 2.dwg)



Isometric View

Volume

$$Vol_{RW} := 263.5\ m^3$$

$$X_{RW} := 2.72m$$

$$Y_{RW} := 5.762 \cdot m$$

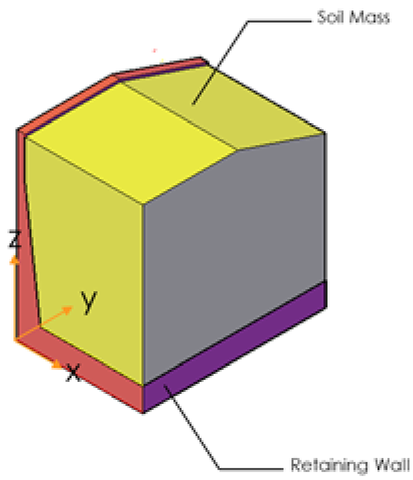
$$Z_{RW} := 0m$$

Retaining wall total weight $\qquad W_{RW} := Vol_{RW} \cdot \gamma_c = 6.19 \cdot MN$

Soil Mass

Retained Soil Volume and Gravity Center (Using AutoCAD 3D: File 3D Transition Wall Analysis Section 1.dwg)

Isometric View:



$\mathbf{Vol_{soil}} := \mathbf{784.755\ m^3}$

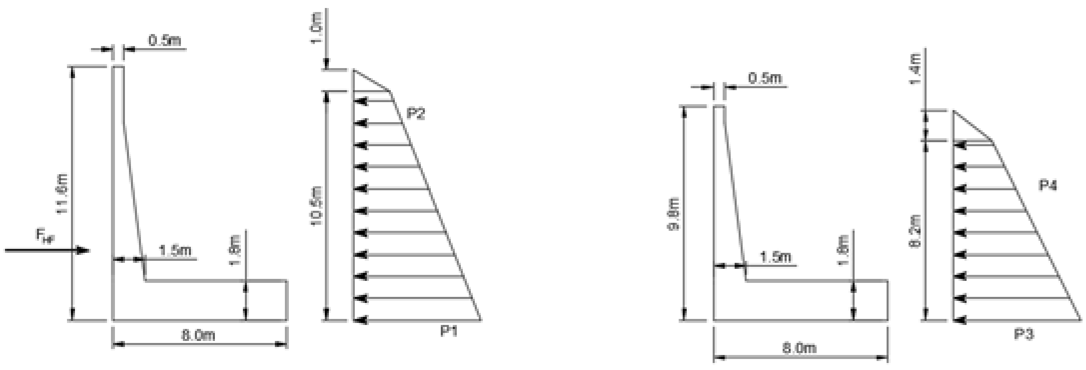
$\mathbf{X_{soil}} := \mathbf{4.441m}$

$\mathbf{Y_{soil}} := \mathbf{5.606m}$

$\mathbf{Z_{soil}} := 0\mathbf{m}$

Soil mass total weight $\quad \mathbf{W_{soilb}} := \mathbf{Vol_{soil}} \cdot \gamma_{\mathbf{m}} = 15.7 \cdot \mathbf{MN}$

Soil Pressure



Section1 Section 2

Section 1

Back of Retaining Wall

depth to water table $\mathbf{dw} := 1.0\mathbf{m}$

saturated soil depth $\mathbf{ds} := 10.5\mathbf{m}$

soil pressure at rest coefficient $\mathbf{Ko} := 0.55$

$$\mathbf{P2} := \gamma_{\mathbf{m}} \cdot \mathbf{dw} \cdot \mathbf{Ko} = 11 \cdot \mathbf{kPa}$$

$$\mathbf{P1} := \mathbf{P2} + \gamma_{\mathbf{b}} \cdot \mathbf{ds} \cdot \mathbf{Ko} = 81.397 \cdot \mathbf{kPa}$$

Section 2

Back of the Retaining Wall

depth to water table $\mathbf{dw} := 1.4\mathbf{m}$

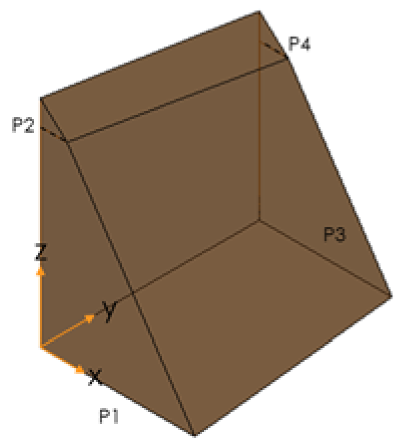
saturated soil depth $\mathbf{ds} := 8.2\mathbf{m}$

soil pressure at rest coefficient $\mathbf{Ko} := 0.55$

$$\mathbf{P4} := \gamma_{\mathbf{m}} \cdot \mathbf{dw} \cdot \mathbf{Ko} = 15.4 \cdot \mathbf{kPa}$$

$$\mathbf{P3} := \mathbf{P4} + \gamma_{\mathbf{b}} \cdot \mathbf{ds} \cdot \mathbf{Ko} = 70.377 \cdot \mathbf{kPa}$$

Isometric view of the prism representing soil pressures against the retaining wall (Using AutoCAD 3D: 3D Transition Wall Analysis Section 2.dwg). The volume of the prism is equal to the equivalent total force.



Isometric View

Total Force Back Soil

$$F_{soilb} := 4957.82\,kN$$

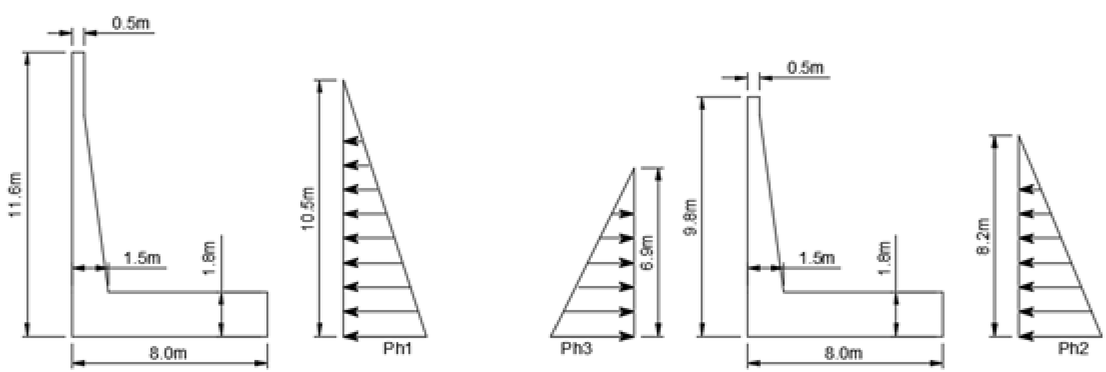
$$X_{Fsoilb} := 0\,m$$

$$Y_{Fsoilb} := 5.499\,m$$

$$Z_{Fsoilb} := 3.705\,m$$

Hydrostatic Forces

Side View



Section 1

Section 2

Section 1

Back of Wall $h_b := 10.5\,m$

$$Ph1 := h_b \cdot \gamma_w = 103 \cdot kPa$$

Section 2

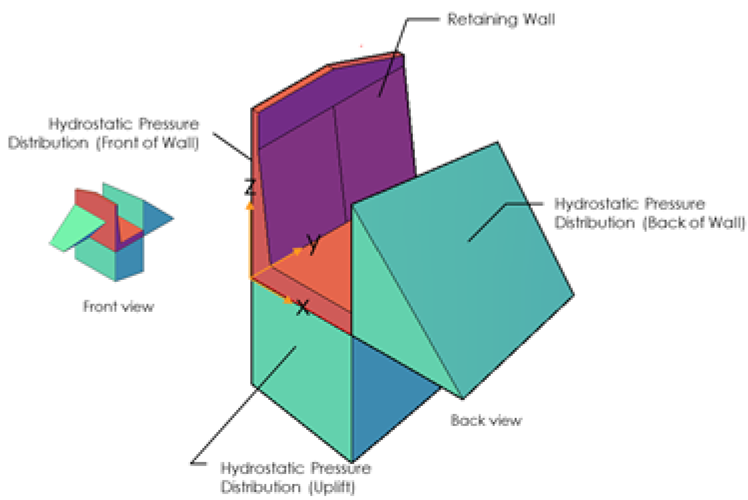
Back of Wall $h_b := 8.2m$

Front of Wal $h_f := 6.9m$

$$Ph2 := h_b \cdot \gamma_w = 80.44 \cdot kPa$$

$$Ph3 := h_f \cdot \gamma_w = 67.69 \cdot kPa$$

Isometric View



Total Hydrostatic Force Back of Wall

$H_{Fu} := 4780.68kN$

$X_{Fu} := 0m$

$Y_{Fu} := 5.400m$

$Z_{Fu} := 3.072m$

Volume and centroid of hydrostatic pressure was determined using AutoCAD 3D: File 3D Transition Wall Analysis Section 2.dwg

Total Hydrostatic Force Front of Wal

$H_{Ft} := 1380.75kN$

$X_{Ft} := 0m$

$Y_{Ft} := 8.504m$

$Z_{Ft} := 2.653m$

Volume and centroid of hydrostatic pressure was determined using AutoCAD 3D: File 3D Transition Wall Analysis Section 2.dwg

Uplift

Total Uplift Force

$F_{uplift} := 7305.68\text{kN}$

$X_{uplift} := 4.187\text{m}$

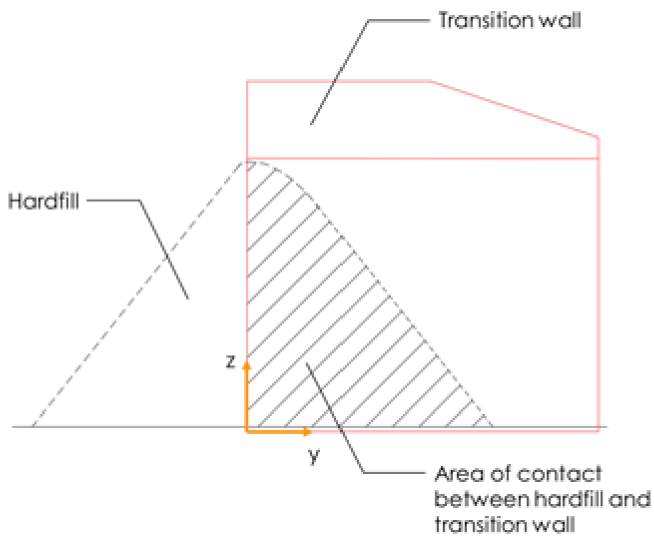
$Y_{uplift} := 5.686\text{m}$

$Z_{uplift} := 0\text{m}$

Volume and centroid of hydrostatic pressure was determined using AutoCAD 3D: File 3D Transition Wall Analysis Section 2.dwg

Hardfill Contact Area and Resultant Resistant Force

Front View



Area of Contact

$Ac := 40.4917\ \text{m}^2$

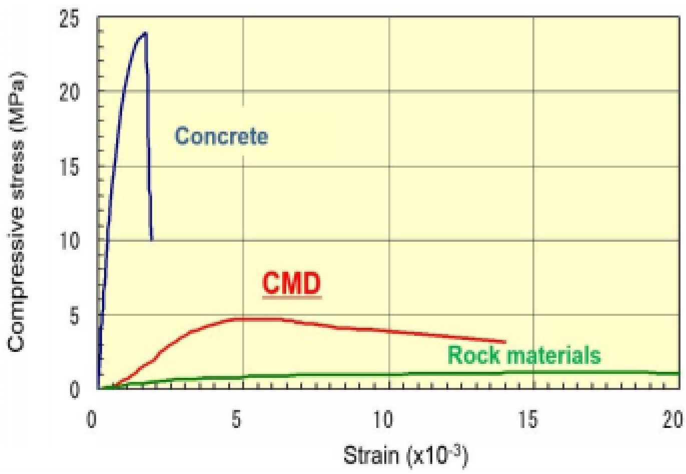
$X_{HF} := 0\text{m}$

$Y_{HF} := 2.7626\text{m}$

$Z_{HF} := 3.4299\text{m}$

Centroid of contact area was determined using Autocad: File Wall Pressure Diagrams.dwg

Hard Fill Stiffness



Source: Noorzad et al. (2017). An Innovative Approach toward Dam Design and Construction. 2nd Workshop on Cement Materials Dams (CMD). July 3, 2017.

$E_{HF} := \dfrac{5\,\mathbf{MPa}}{5 \times \mathbf{10}^{-3}} = 1 \cdot \mathbf{GPa}$ Approximate Hardfill Modulus of Elasticity

$L_{HF} := 16\,\mathbf{m}$ Hardfill section length (between construction joints)

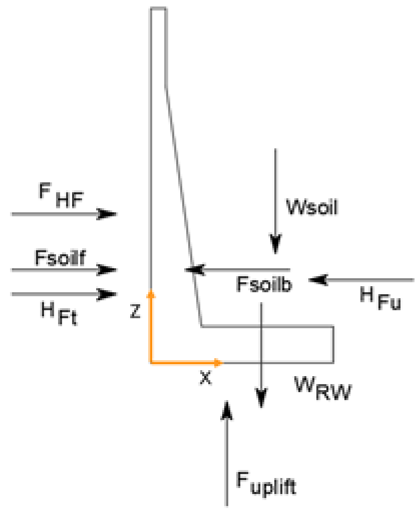
Approximate hardfill stiffness $k_{HF} := \dfrac{E_{HF}}{L_{HF}} = 62500 \cdot \dfrac{\mathbf{kN}}{\mathbf{m}^3}$

$\delta_{max} := L_{HF} \cdot 5 \cdot 10^{-3} = 80 \cdot \mathbf{mm}$

Considering a deformation of the hardfill of : $\delta_{HF} := 1.4\,\mathbf{mm} \quad < \quad \delta_{max} = 80 \cdot \mathbf{mm}$

The total reaction of the hardfill is: $F_{HF} := k_{HF} \cdot Ac \cdot \delta_{HF} = 3.54 \cdot \mathbf{MN}$

Vector Forces Summary



Body diagram, side view

Weight Retaining Wall	$\mathbf{W_{RW}} := \begin{pmatrix} 0 & 0 & -\mathbf{W_{RW}} \end{pmatrix} = (0 \quad 0 \quad -6.19)\cdot\mathbf{MN}$
Weight Soil (Back of Wall)	$\mathbf{W_{soilb}} := \begin{pmatrix} 0 & 0 & -\mathbf{W_{soilb}} \end{pmatrix} = (0 \quad 0 \quad -15.7)\cdot\mathbf{MN}$
Soil Pressure (Back of Wall)	$\mathbf{F_{soilb}} := \begin{pmatrix} -\mathbf{F_{soilb}} & 0 & 0 \end{pmatrix} = (-4.96 \quad 0 \quad 0)\cdot\mathbf{MN}$
Hydrostatic Force (Back of Wall)	$\mathbf{H_{Fu}} := \begin{pmatrix} -\mathbf{H_{Fu}} & \mathbf{0} & 0 \end{pmatrix} = (-4.78 \quad 0 \quad 0)\cdot\mathbf{MN}$
Hydrostatic Force (Front of Wall)	$\mathbf{H_{Ft}} := \begin{pmatrix} \mathbf{H_{Ft}} & 0 & 0 \end{pmatrix} = (1.38 \quad 0 \quad 0)\cdot\mathbf{MN}$
Uplift Force	$\mathbf{F_{uplift}} := \begin{pmatrix} 0 & 0 & \mathbf{F_{uplift}} \end{pmatrix} = (0 \quad 0 \quad 7.31)\cdot\mathbf{MN}$
Resistance force by Hardfill	$\mathbf{F_{HF}} := \begin{pmatrix} \mathbf{F_{HF}} & 0 & 0 \end{pmatrix} = (3.54 \quad 0 \quad 0)\cdot\mathbf{MN}$

Resultant Total Force

$$\mathbf{F} := \mathbf{W_{RW}} + \mathbf{W_{soilb}} + \mathbf{F_{soilb}} + \mathbf{H_{Fu}} + \mathbf{H_{Ft}} + \mathbf{F_{uplift}} + \mathbf{F_{HF}}$$

$$\mathbf{F} = (-4.81 \quad 0 \quad -14.58)\cdot\mathbf{MN}$$

Structure Stability

1. Sliding

$$236.6\mathbf{m}^3\cdot\gamma_{\mathbf{w}} = 2.32\cdot\mathbf{MN}$$

Coefficient of sliding friction $\mu := 0.45$

$$\mathbf{FoS} := \frac{\mathbf{F}_{0,2}\cdot\mu}{\mathbf{F}_{0,0}} = 1.36 \qquad > \qquad \mathbf{FS_{sliding.req}} = 1.3 \qquad \mathbf{OK}$$

2. Uplift

Summatory of Axial Resistant Forces

$$\mathbf{F_R} := \mathbf{W_{RW}} + \mathbf{W_{soilb}} = (0 \quad 0 \quad -21.89)\cdot\mathbf{MN}$$

Uplift Force

$$\mathbf{F_{uplift}} = (0 \quad 0 \quad 7.31)\cdot\mathbf{MN}$$

$$\mathbf{FoS_{uplift}} := \frac{\left|\mathbf{F_R}_{0,2}\right|}{\left|\mathbf{F_{uplift}}_{0,2}\right|} = 3 \qquad > \qquad \mathbf{FS_{float.req}} = 1.1 \qquad \mathbf{OK}$$

3. Overturning

$$\mathbf{r_{RW}} := \left(\mathbf{X_{RW}} \quad Y_{RW} \quad Z_{RW} \right) = (2.72 \quad 5.76 \quad 0)\ \mathbf{m}$$

$$\mathbf{r_{soilb}} := \left(X_{soil} \quad Y_{soil} \quad Z_{soil} \right) = (4.44 \quad 5.61 \quad 0)\ \mathbf{m}$$

$$\mathbf{r_{Fsoilb}} := \left(X_{Fsoilb} \quad Y_{Fsoilb} \quad Z_{Fsoilb} \right) = (0 \quad 5.5 \quad 3.71)\ \mathbf{m}$$

$$\mathbf{r_{Fu}} := \left(X_{Fu} \quad Y_{Fu} \quad Z_{Fu} \right) = (0 \quad 5.4 \quad 3.07)\ \mathbf{m}$$

$$\mathbf{r_{Ft}} := \left(X_{Ft} \quad Y_{Ft} \quad Z_{Ft} \right) = (0 \quad 8.5 \quad 2.65)\ \mathbf{m}$$

$$\mathbf{r_{uplift}} := \left(X_{uplift} \quad Y_{uplift} \quad Z_{uplift} \right) = (4.19 \quad 5.69 \quad 0)\ \mathbf{m}$$

$$\mathbf{r_{HF}} := \left(\mathbf{X_{HF}} \quad \mathbf{Y_{HF}} \quad \mathbf{Z_{HF}} \right) = (0 \quad 2.76 \quad 3.43)\ \mathbf{m}$$

$$\mathbf{M} := \mathbf{W_{RW}}^{\mathbf{T}} \times \mathbf{r_{RW}}^{\mathbf{T}} + \mathbf{W_{soilb}}^{\mathbf{T}} \times \mathbf{r_{soilb}}^{\mathbf{T}} + \mathbf{F_{soilb}}^{\mathbf{T}} \times \mathbf{r_{Fsoilb}}^{\mathbf{T}} + \mathbf{F_{HF}}^{\mathbf{T}} \times \mathbf{r_{HF}}^{\mathbf{T}} \cdots$$
$$+ \mathbf{H_{Fu}}^{\mathbf{T}} \times \mathbf{r_{Fu}}^{\mathbf{T}} + \mathbf{H_{Ft}}^{\mathbf{T}} \times \mathbf{r_{Ft}}^{\mathbf{T}} + \mathbf{F_{uplift}}^{\mathbf{T}} \times \mathbf{r_{uplift}}^{\mathbf{T}}$$

$$\mathbf{M} = \begin{pmatrix} 82.13 \\ -38.72 \\ -31.55 \end{pmatrix} \cdot \mathbf{MN} \cdot \mathbf{m}$$

$$\mathbf{F} = (-4.81 \quad 0 \quad -14.58) \cdot \mathbf{MN}$$

Location of resultant force:

$$\mathbf{X_R} := \left| \frac{\mathbf{M}_{1,0}}{\mathbf{F}_{0,2}} \right| = 2.66 \cdot \mathbf{m}$$

$$\mathbf{x} := \left| \mathbf{X_R} - \frac{\mathbf{b}}{2} \right| = 1.34\ \mathbf{m} \quad < \quad \frac{\mathbf{b}}{4} = 2\ \mathbf{m} \qquad \mathbf{OK}$$

4. **Bearing Capacity**

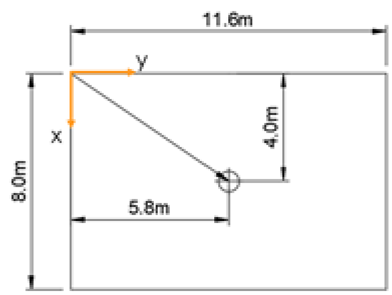
$$q_{all} := 622\mathbf{kPa}$$

Force and Moment at origin:

$$\mathbf{F} = (-4.81 \quad 0 \quad -14.58)\cdot\mathbf{MN} \qquad \mathbf{M} = \begin{pmatrix} 82.13 \\ -38.72 \\ -31.55 \end{pmatrix}\mathbf{m}\cdot\mathbf{MN}$$

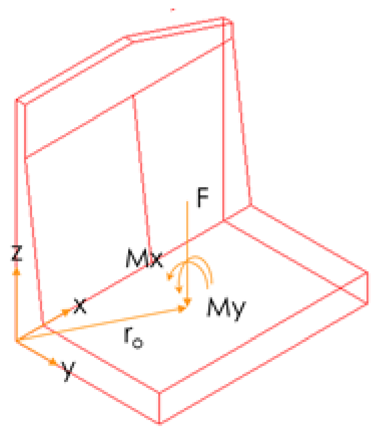
Vector to center of foundation:

$$\mathbf{r_o} := (4 \quad 5.8 \quad 0)\mathbf{m}$$



Moment at center of Foundation

$$\mathbf{M_o} := \mathbf{M} - \mathbf{F}^T \times \mathbf{r_o}^T = \begin{pmatrix} -2.45 \\ 19.61 \\ -3.62 \end{pmatrix} \mathbf{m} \cdot \mathbf{MN}$$



$$\mathbf{Ix_o} := \frac{1}{12} \cdot \mathbf{b}^3 \cdot \mathbf{B} = 494.93\,\mathbf{m}^4$$

$$\mathbf{Iy_o} := \frac{1}{12} \cdot \mathbf{b} \cdot \mathbf{B}^3 = 1040.597\,\mathbf{m}^4$$

$$\mathbf{A} := \mathbf{b} \cdot \mathbf{B} = 92.8\,\mathbf{m}^2$$

$$\sigma_{max} := \left| \frac{\mathbf{F}_{0,2}}{\mathbf{A}} \right| + \left| \frac{\mathbf{M_o}_{0,0} \cdot \mathbf{b}}{2 \cdot \mathbf{Ix_o}} \right| + \left| \frac{\mathbf{M_o}_{1,0} \cdot \mathbf{B}}{2 \cdot \mathbf{Iy_o}} \right| = 286.211 \cdot \mathbf{kPa} < \quad \mathbf{q_{all}} = 622 \cdot \mathbf{kPa} \quad \mathbf{OK}$$

$$\sigma_{min} := \left| \frac{\mathbf{F}_{0,2}}{\mathbf{A}} \right| - \left| \frac{\mathbf{M_o}_{0,0} \cdot \mathbf{b}}{2 \cdot \mathbf{Ix_o}} \right| - \left| \frac{\mathbf{M_o}_{1,0} \cdot \mathbf{B}}{2 \cdot \mathbf{Iy_o}} \right| = 28.049 \cdot \mathbf{kPa} \quad < \quad \mathbf{q_{all}} = 622 \cdot \mathbf{kPa} \quad \mathbf{OK}$$

Section 2: Extreme Condition (E2)

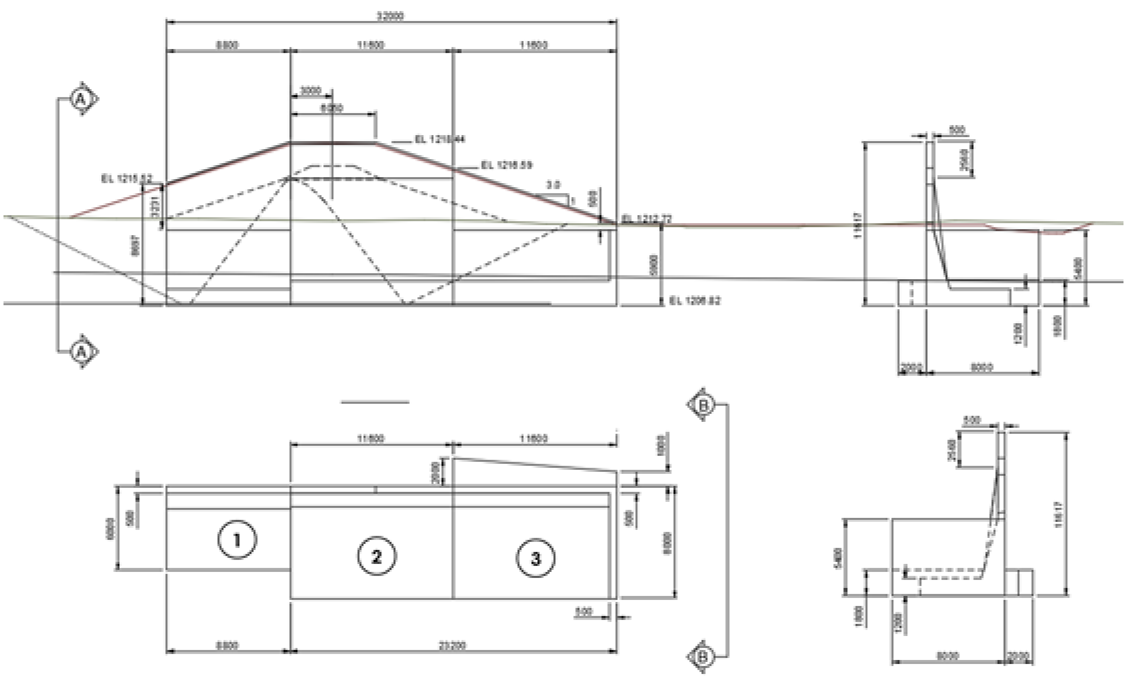
Loading	Horizontal Forces Force (MN)	Horizontal Forces Arm (m)	Vertical Forces Force (MN)	Vertical Forces Arm (m)	Stabilizing Moments (MN-m)	Overturning Moments (MN-m)
Weight of Structure			6.2	2.7	16.8	
Earthquake Inertia Force	-0.96	2.7				2.56
Soil Mass, front of wall			15.7	4.4	69.7	
Soil Mass, front of wall, Inertial Force	-2.67	6.4				17.11
Soil Mass, back of wall						
Soil Mass, back of wall, Inertial Force						
Soil Pressure, front of wall	0.56	3.28			1.8	
Soil Pressure, back of wall	-2.41	3.77				9.1
Soil Dynamic Pressure, back of wall	-2.63	6.69				17.6
Uplift			-5.0	4.1		20.4
Hydrostatic pressure, front of wall	0.69	1.91			1.3	
Hydrostatic pressure, back of wall	-1.95	1.95				3.8
Hydrostatic weight, front of wall						
Hardfill	4.30	3.43			14.7	
SUM	**-5.1**		**16.9**		**104.5**	**70.5**
					Net Moment	
					33.95	

Stability Calculations
Retaining Wall - Auxiliary Spillway
Right Abutment Transition to Berm

Scope:

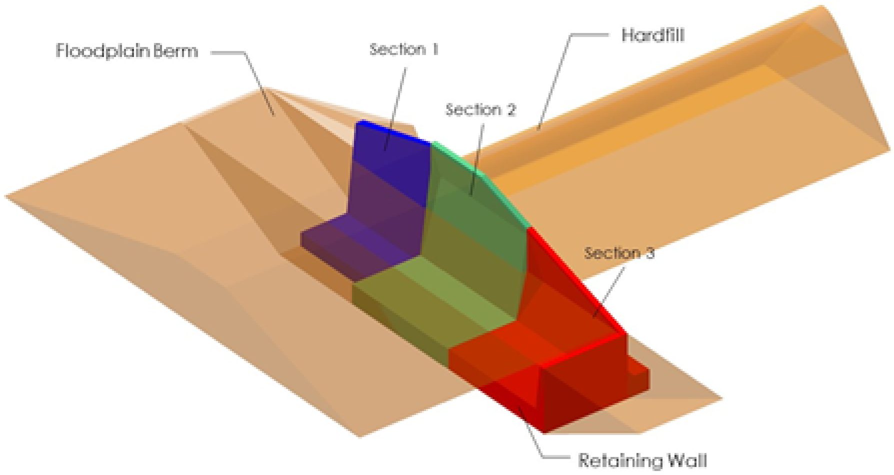
Evaluate the stability of the transition wall of the Auxiliary Spillway. Consider the 3D effects on the structure's stability.

Structure Geometry:



dimensions in mm

Isometric View:



Load Condition

	Elevation (m)			
	Headwater	Tailwater	Headwater	Tailwater
1. Usual Condition (U1)	1214.0	1211.9	7.0	4.9
2. Unusual Condition 1 (UN1)	1214.0	1211.9	7.0	4.9
3. Unusual Condition 2 (UN2)	1216.5	1213.1	9.5	6.1
4. Unusual Condition 3 (UN3)	1217.0	1213.1	10.0	6.1
5. Extreme Condition 1 (E1-F)	1217.3	1213.8	10.3	6.8
6. Extreme Condition 2 (E2-Q)	1213.5	1211.9	6.5	4.9

User Input

Material Properties:

Unit Weight of Water: $\gamma_w := 9.81 \frac{kN}{m^3}$ (Section 7.2, Design Criteria)

Unit Weight of Concrete: $\gamma_c := \mathbf{23.5} \frac{kN}{m^3}$

Unit Weight of Soil (Moist): $\gamma_m := 20.0 \frac{kN}{m^3}$ (Section 5.3, Design Criteria) assumed moisture content (w) = 5%

Unit Weight Soil (Saturated): $\gamma_{sat} := 22.0 \frac{kN}{m^3}$ (Assuming Specific Gravity = 2.7)

Unit Weight Soil (buoyant): $\gamma_b := \gamma_{sat} - \gamma_w = 12.19 \cdot \frac{kN}{m^3}$

Weight of Soil/Concrete above toe: $\gamma_{toe} := 22.0 \frac{kN}{m^3}$

Unit Weight of Rock: $\gamma_r := 25.6 \frac{kN}{m^3}$ (Section 7.2, Design Criteria)

Extreme Condition 2 (E2)

Acceptance Parameters

Resultant Location (Overturning and Bearing Pressure):

Extreme (E1) Resultant located inside middle half (AT/WCS Guidelines, Section 8.4)

Allowable rock bearing pressure: $\mathbf{qall} := 622 \frac{\mathbf{kN}}{\mathbf{m}^2}$ (Internal Geotechnical Design Recommendations Rev. Sept 12, 2018, Section 5.3)

FS Sliding:

Extreme (E2) 1.1 (without cohesion) (CDA Guidelines, Table 6-4, AT/WCS Guidelines, Section 8.3)

Req'd Factor of Safety for Sliding: $\mathbf{FS_{sliding.req}} := 1.1$ (Without Cohesion)

FS Floatation:

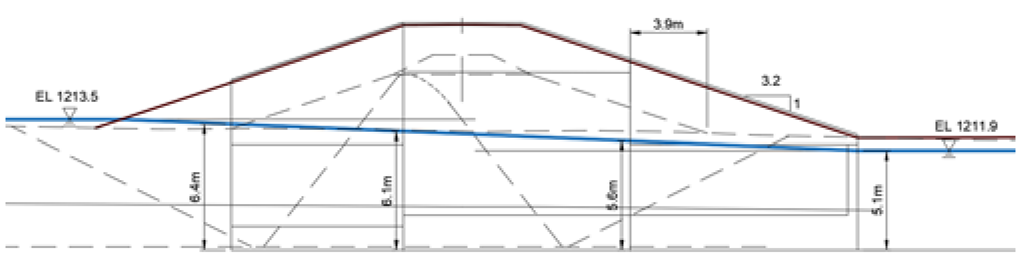
Extreme (E2) 1.1 (AT/WCS Guidelines, Section 8.5)

Req'd Factor of Safety for Floatation: $\mathbf{FS_{float.req}} := 1.1$

Water Surface Elevations

Headwater $\mathbf{H_H} := 1213.5\mathbf{m}$

Tailwater $\mathbf{H_T} := 1211.9\mathbf{m}$



$\mathbf{h_1} := 6.4\mathbf{m}$ $\mathbf{h_2} := 6.1\mathbf{m}$ $\mathbf{h_3} := 5.6\mathbf{m}$ $\mathbf{h_4} := 5.1\mathbf{m}$

Interpolated water table heights from retaining wall base.

Section 2

Wall Geometry: User Input

Top of Wall Elevation: $\mathbf{T_w} := 1218.44 \cdot \mathbf{m}$

Top of Footing Elevation: $\mathbf{Top_{ftg}} := 1208.62 \cdot \mathbf{m}$

Thickness of Footing: $\mathbf{t_{ftg}} := 1.80\mathbf{m}$

Bottom of Footing Elevation: $\mathbf{Bot_{ftg}} := \mathbf{Top_{ftg}} - t_{ftg} = 1206.82\ \mathbf{m}$

Overall Height of wall: $\mathbf{h_w} := \mathbf{T_w} - \mathbf{Bot_{ftg}} = 11.620\ \mathbf{m}$

Thickness of Stem Wall at Top: $\mathbf{t_{wt}} := 0.5\mathbf{m}$

Slope of Heel Batter: $\mathbf{S_{batter}} := 0.125$

Thickness of Stem Wall at Base: $\mathbf{t_{wb}} := 1.5\mathbf{m}$

Length of toe: $\mathbf{L_{ab}} := 0\mathbf{m}$

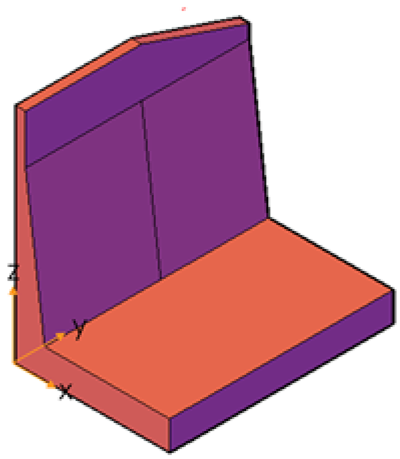
Total Length of Footing: $\mathbf{b} := 8\mathbf{m}$

Length of heel: $\mathbf{L_{cd}} := \mathbf{b} - \mathbf{L_{ab}} - \mathbf{t_{wb}} = 6.5\ \mathbf{m}$

Width of Wall: $\mathbf{B} := 11.6\mathbf{m}$

Retaining Wall

Retaining Wall Volume and Gravity Center (Using AutoCAD 3D: File: 3D Transition Wall Analysis Section 2.dwg)



Isometric View

Volume

$\mathbf{Vol_{RW}} := 263.5\ \mathbf{m}^3$

$\mathbf{X_{RW}} := \mathbf{2.72m}$

$\mathbf{Y_{RW}} := \mathbf{5.762m}$

$\mathbf{Z_{RW}} := 2.587\mathbf{m}$

Retaining wall total weight $\qquad \mathbf{W_{RW}} := \mathbf{Vol_{RW}} \cdot \gamma_{\mathbf{c}} = 6.19 \cdot \mathbf{MN}$

Earthquake Inertial Force

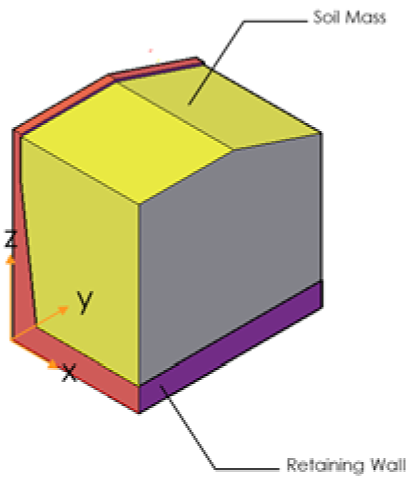
$\mathbf{kh} := 0.17$

$\mathbf{F_{RW}} := \mathrm{kh} \cdot \mathbf{W_{RW}} = 1.05 \cdot \mathbf{MN}$

Soil Mass

Retained Soil Volume and Gravity Center (Using AutoCAD 3D: File 3D Transition Wall Analysis Section 1.dwg)

Isometric View:



$\mathbf{Vol_{soil}} := \mathbf{784.755\ m^3}$

$\mathbf{X_{soil}} := \mathbf{4.441m}$

$\mathbf{Y_{soil}} := \mathbf{5.606m}$

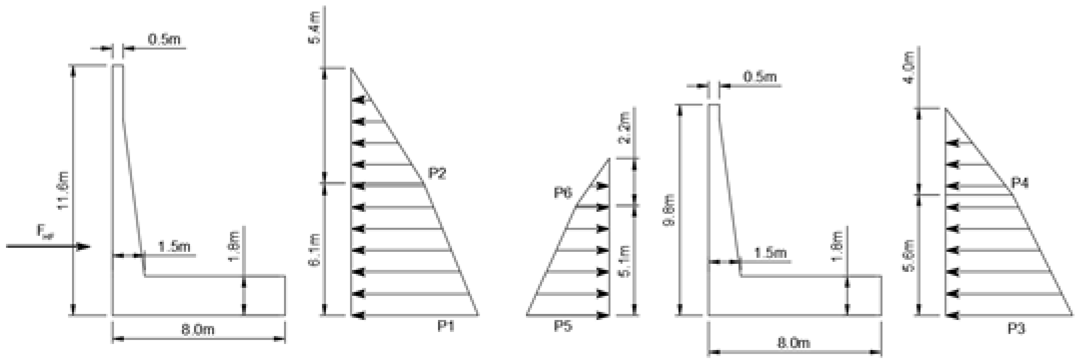
$\mathbf{Z_{soil}} := 6.407\mathbf{m}$

Soil mass total weight $\quad \mathbf{W_{soilb}} := \mathbf{Vol_{soil}} \cdot \gamma_{\mathbf{m}} = 15.7 \cdot \mathbf{MN}$

Earthquake Inertial Force

$\mathbf{Fsoilb_{AE}} := \mathbf{kh} \cdot \mathbf{W_{soilb}} = 2.67 \cdot \mathbf{MN}$

Soil Pressure



Section1 Section 2

Section 1

Back of Retaining Wall

depth to water table $\mathbf{dw} := 5.4\mathbf{m}$

saturated soil depth $\mathbf{ds} := 6.1\mathbf{m}$

soil pressure at rest coefficient $\mathbf{Ka} := 0.21$

$$\mathbf{P2} := \gamma_{\mathbf{m}} \cdot \mathbf{dw} \cdot \mathbf{Ka} = 22.68 \cdot \mathbf{kPa}$$

$$\mathbf{P1} := \mathbf{P2} + \gamma_{\mathbf{b}} \cdot \mathbf{ds} \cdot \mathbf{Ka} = 38.295 \cdot \mathbf{kPa}$$

Section 2

depth to water table $\mathbf{dw} := 4\mathbf{m}$

saturated soil depth $\mathbf{ds} := 5.6\mathbf{m}$

soil pressure at rest coefficient $\mathbf{Ka} := 0.21$

$$\mathbf{P4} := \gamma_{\mathbf{m}} \cdot \mathbf{dw} \cdot \mathbf{Ka} = 16.8 \cdot \mathbf{kPa}$$

$$\mathbf{P3} := \mathbf{P4} + \gamma_{\mathbf{b}} \cdot \mathbf{ds} \cdot \mathbf{Ka} = 31.135 \cdot \mathbf{kPa}$$

Front of Retaining Wall

depth to water table $\mathbf{dw} := 2.2\mathbf{m}$

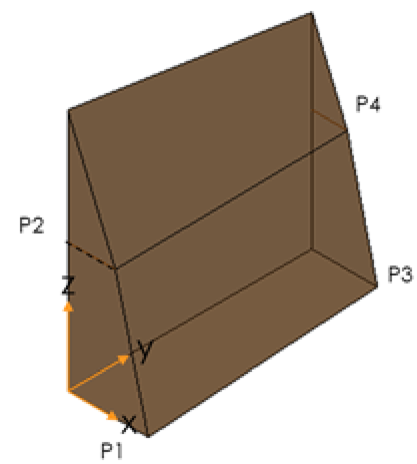
saturated soil depth $\mathbf{ds} := 5.1\mathbf{m}$

soil pressure at rest coefficient $\mathbf{Ka} := 0.21$

$$\mathbf{P6} := \gamma_{\mathbf{m}} \cdot \mathbf{dw} \cdot \mathbf{Ka} = 9.24 \cdot \mathbf{kPa}$$

$$\mathbf{P5} := \mathbf{P6} + \gamma_{\mathbf{b}} \cdot \mathbf{ds} \cdot \mathbf{Ka} = 22.295 \cdot \mathbf{kPa}$$

Isometric view of the prism representing soil pressures against the retaining wall (Using AutoCAD 3D: 3D Transition Wall Analysis Section 2.dwg). The volume of the prism is equal to the equivalent total force.



Total Force Back Soil

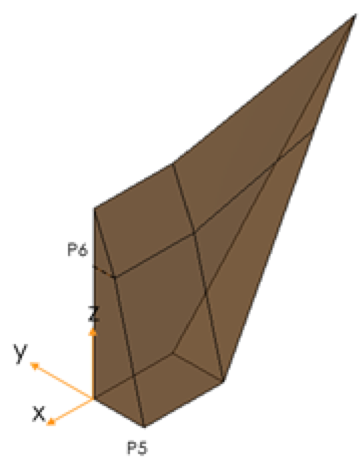
$\mathbf{F_{soilb}} := \mathbf{2409.75kN}$

$\mathbf{X_{Fsoilb}} := 0\mathbf{m}$

$\mathbf{Y_{Fsoilb}} := \mathbf{5.443m}$

$\mathbf{Z_{Fsoilb}} := \mathbf{3.773m}$

Isometric View



Total Force Front Soil

$\mathbf{F_{soilf}} := \mathbf{557.71kN}$

$\mathbf{X_{Fsoilf}} := 0\mathbf{m}$

$\mathbf{Y_{Fsoilf}} := \mathbf{8.232m}$

$\mathbf{Z_{Fsoilf}} := \mathbf{3.277m}$

Seismic Loading

$\phi_w := 38\text{deg}$ internal friction angle of soil

$\psi := \text{atan}\left(\frac{0.28}{1-0.16}\right) = 18.43 \cdot \text{deg}$ seismic inertia angle

$\beta := 0\text{deg}$ inclination of soil surface

$$K_{AE} := \frac{\cos(\phi_w - \psi)^2}{\cos(\psi)^2 \cdot \left(1 + \sqrt{\frac{\sin(\phi_w)\cdot\sin(\phi_w - \psi - \beta)}{\cos(\beta)\cdot\cos(\psi)}}\right)^2}$$

$K_{AE} = 0.46$

Section 1

Back of Retaining Wall

depth to water table $dw := 5.4\text{m}$

saturated soil depth $ds := 6.1\text{m}$

$\Delta P2 := \gamma_m \cdot dw \cdot K_{AE} - P2 = 26.88 \cdot \text{kPa}$

$\Delta P1 := (P2 + \Delta P2) + \gamma_b \cdot ds \cdot K_{AE} - P1 = 45.391 \cdot \text{kPa}$

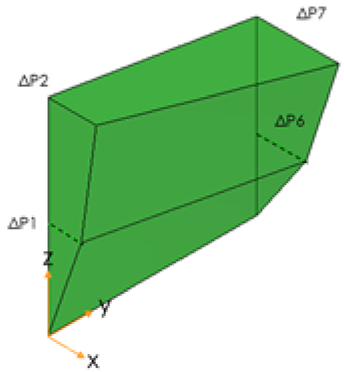
Section 2

depth to water table $dw := 4\text{m}$

saturated soil depth $ds := 5.6\text{m}$

$\Delta P6 := \gamma_m \cdot dw \cdot K_{AE} - P6 = 27.47 \cdot \text{kPa}$

$\Delta P5 := (P6 + \Delta P6) + \gamma_b \cdot ds \cdot K_{AE} - P5 = 45.744 \cdot \text{kPa}$



Total Force Dynamic Soil Pressure

$F_{AE} := 2626.01\,\mathbf{kN}$

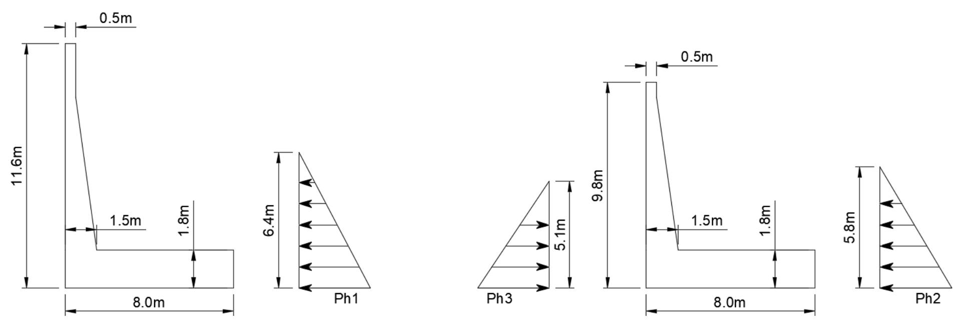
$X_{AE} := 0\,\mathbf{m}$

$Y_{AE} := 6.105\,\mathbf{m}$

$Z_{AE} := 6.687\,\mathbf{m}$

Hydrostatic Forces

Side View



Section 1 | Section 2

Section 1

Back of Wall $h_b := 6.1\,\mathbf{m}$

$$Ph1 := h_b \cdot \gamma_w = 59.84 \cdot \mathbf{kPa}$$

Section 2

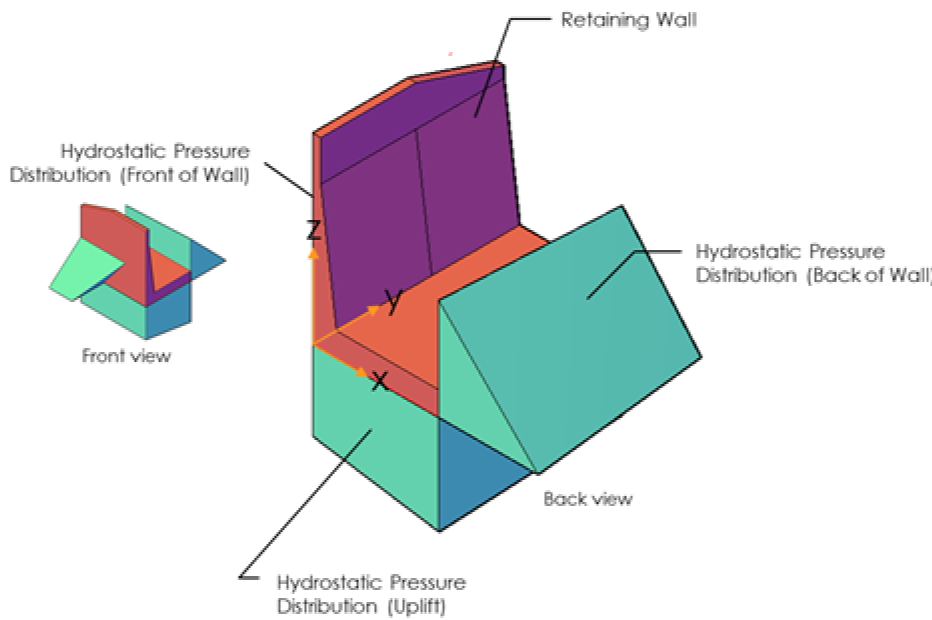
Back of Wall $h_b := 5.6\,\mathbf{m}$

Front of Wall $h_f := 5.1\,\mathbf{m}$

$$\mathbf{Ph2} := \mathbf{h_b} \cdot \gamma_{\mathbf{w}} = 54.94 \cdot \mathbf{kPa}$$

$$\mathbf{Ph3} := \mathbf{h_f} \cdot \gamma_{\mathbf{w}} = 50.03 \cdot \mathbf{kPa}$$

Isometric View



Total Hydrostatic Force

Back of Wall

$\mathbf{H_{Fu}} := \mathbf{1948.43kN}$

$\mathbf{X_{Fu}} := 0\mathbf{m}$

$\mathbf{Y_{Fu}} := \mathbf{5.635m}$

$\mathbf{Z_{Fu}} := \mathbf{1.952m}$

Volume and centroid of hydrostatic pressure was determined using AutoCAD 3D: File 3D Transition Wall Analysis Section 2.dwg

Total Hydrostatic Force

Front of Wall

$\mathbf{H_{Ft}} := \mathbf{693.86kN}$

$\mathbf{X_{Ft}} := 0\mathbf{m}$

$\mathbf{Y_{Ft}} := \mathbf{8.798m}$

$\mathbf{Z_{Ft}} := \mathbf{1.910m}$

Volume and centroid of hydrostatic pressure was determined using AutoCAD 3D: File 3D Transition Wall Analysis Section 2.dwg

Uplift

Total Uplift Force

$F_{uplift} := 4984.29kN$

$X_{uplift} := 4.091m$

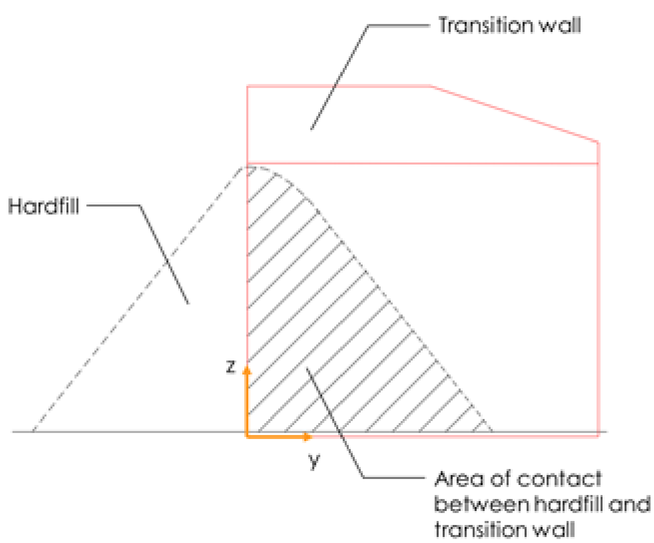
$Y_{uplift} := 5.756m$

$Z_{uplift} := 0m$

Volume and centroid of hydrostatic pressure was determined using AutoCAD 3D: File 3D Transition Wall Analysis Section 2.dwg

Hardfill Contact Area and Resultant Resistant Force

Front View



Area of Contact

$Ac := 40.4917\ m^2$

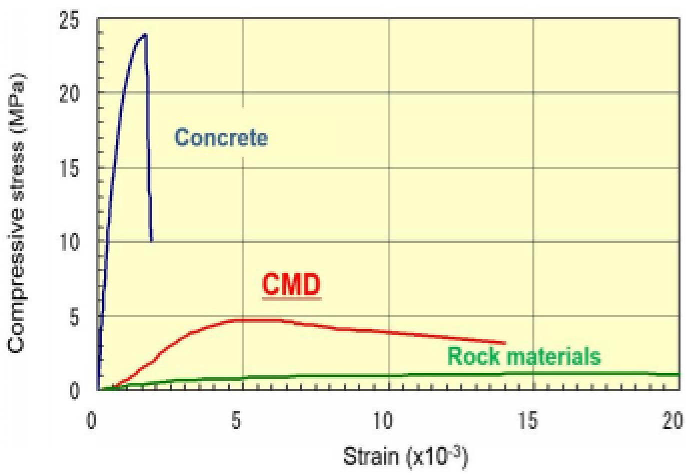
$X_{HF} := 0m$

$Y_{HF} := 2.7626m$

$Z_{HF} := 3.4299m$

Centroid of contact area was determined using Autocad: File Wal Pressure Diagrams.dwg

Hard Fill Stiffness



Source: Noorzad et al. (2017). An Innovative Approach toward Dam Design and Construction. 2nd Workshop on Cement Materials Dams (CMD). July 3, 2017.

$$E_{HF} := \frac{5\,MPa}{5 \times 10^{-3}} = 1 \cdot GPa$$ Approximate Hardfill Modulus of Elasticity

$L_{HF} := 16m$ Hardfill section length (between construction joints)

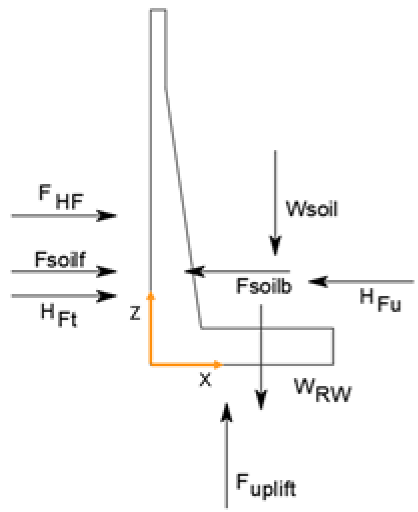
Approximate hardfill stiffness $$k_{HF} := \frac{E_{HF}}{L_{HF}} = 62500 \cdot \frac{kN}{m^3}$$

$$\delta_{max} := L_{HF} \cdot 5 \cdot 10^{-3} = 80 \cdot mm$$

Considering a deformation of the hardfill of : $\delta_{HF} := 2.5mm$ < $\delta_{max} = 80 \cdot mm$

The total reaction of the hardfill is: $F_{HF} := k_{HF} \cdot Ac \cdot \delta_{HF} = 6.33 \cdot MN$

Vector Forces Summary



Body diagram, side view

Weight Retaining Wall $\mathbf{W_{RW}} := \left(-F_{RW} \quad 0 \quad -\mathbf{W_{RW}} \right) = \left(-1.05 \quad 0 \quad -6.19 \right) \cdot \mathbf{MN}$

Weight Soil (Back of Wall) $\mathbf{W_{soilb}} := \left(-Fsoilb_{AE} \quad 0 \quad -\mathbf{W_{soilb}} \right) = \left(-2.67 \quad 0 \quad -15.7 \right) \cdot \mathbf{MN}$

Soil Pressure (Back of Wall) $\mathbf{F_{soilb}} := \left(-\mathbf{F_{soilb}} \quad 0 \quad 0 \right) = \left(-2.41 \quad 0 \quad 0 \right) \cdot \mathbf{MN}$

Soil Pressure (Front of Wall) $\mathbf{F_{soilf}} := \left(\mathbf{F_{soilf}} \quad 0 \quad 0 \right) = \left(0.56 \quad 0 \quad 0 \right) \cdot \mathbf{MN}$

Hydrostatic Force (Back of Wall) $\mathbf{H_{Fu}} := \left(-\mathbf{H_{Fu}} \quad \mathbf{0} \quad 0 \right) = \left(-1.95 \quad 0 \quad 0 \right) \cdot \mathbf{MN}$

Hydrostatic Force (Front of Wall) $\mathbf{H_{Ft}} := \left(\mathbf{H_{Ft}} \quad 0 \quad 0 \right) = \left(0.69 \quad 0 \quad 0 \right) \cdot \mathbf{MN}$

Uplift Force $\mathbf{F_{uplift}} := \left(0 \quad 0 \quad \mathbf{F_{uplift}} \right) = \left(0 \quad 0 \quad 4.98 \right) \cdot \mathbf{MN}$

Resistance force by Hardfill $\mathbf{F_{HF}} := \left(\mathbf{F_{HF}} \quad 0 \quad 0 \right) = \left(6.33 \quad 0 \quad 0 \right) \cdot \mathbf{MN}$

Soil Dynamic Pressure $\mathbf{F_{AE}} := \left(-\mathbf{F_{AE}} \quad 0 \quad 0 \right) = \left(-2.63 \quad 0 \quad 0 \right) \cdot \mathbf{MN}$

Resultant Total Force

$$\mathbf{F} := \mathbf{W_{RW}} + \mathbf{W_{soilb}} + \mathbf{F_{soilb}} + \mathbf{F_{soilf}} + \mathbf{H_{Fu}} + \mathbf{H_{Ft}} + \mathbf{F_{uplift}} + \mathbf{F_{HF}} + \mathbf{F_{AE}}$$

$$\mathbf{F} = (-3.13 \quad 0 \quad -16.9)\cdot\mathbf{MN}$$

Structure Stability

1. Sliding

$$236.6\mathbf{m}^3\cdot\gamma_{\mathbf{w}} = 2.32\cdot\mathbf{MN}$$

Coefficient of sliding friction $\mu := 0.45$

$$\mathbf{FoS} := \frac{\mathbf{F}_{0,2}\cdot\mu}{\mathbf{F}_{0,0}} = 2.43 \qquad > \qquad \mathbf{FS_{sliding.req}} = 1.1 \qquad \mathbf{OK}$$

2. Uplift

Summatory of Axial Resistant Forces

$$\mathbf{F_R} := \mathbf{W_{RW}} + \mathbf{W_{soilb}} = (-3.72 \quad 0 \quad -21.89)\cdot\mathbf{MN}$$

Uplift Force

$$\mathbf{F_{uplift}} = (0 \quad 0 \quad 4.98)\cdot\mathbf{MN}$$

$$\mathbf{FoS_{uplift}} := \frac{\left|\mathbf{F_R}_{0,2}\right|}{\left|\mathbf{F_{uplift}}_{0,2}\right|} = 4.39 \qquad > \qquad \mathbf{FS_{float.req}} = 1.1 \qquad \mathbf{OK}$$

3. Overturning

$$\mathbf{r_{RW}} := \left(\mathbf{X_{RW}} \quad Y_{RW} \quad Z_{RW}\right) = (2.72 \quad 5.76 \quad 2.59)\ \mathbf{m}$$

$$\mathbf{r_{soilb}} := \left(X_{soil} \quad Y_{soil} \quad Z_{soil}\right) = (4.44 \quad 5.61 \quad 6.41)\ \mathbf{m}$$

$$\mathbf{r_{Fsoilb}} := \left(X_{Fsoilb} \quad Y_{Fsoilb} \quad Z_{Fsoilb}\right) = (0 \quad 5.44 \quad 3.77)\ \mathbf{m}$$

$$\mathbf{r_{Fsoilf}} := \left(X_{Fsoilf} \quad Y_{Fsoilf} \quad Z_{Fsoilf}\right) = (0 \quad 8.23 \quad 3.28)\ \mathbf{m}$$

$$\mathbf{r_{Fu}} := \left(X_{Fu} \quad Y_{Fu} \quad Z_{Fu}\right) = (0 \quad 5.63 \quad 1.95)\ \mathbf{m}$$

$$\mathbf{r_{Ft}} := \left(X_{Ft} \quad Y_{Ft} \quad Z_{Ft}\right) = (0 \quad 8.8 \quad 1.91)\ \mathbf{m}$$

$$\mathbf{r_{uplift}} := \left(X_{uplift} \quad Y_{uplift} \quad Z_{uplift}\right) = (4.09 \quad 5.76 \quad 0)\ \mathbf{m}$$

$$\mathbf{r_{HF}} := \left(\mathbf{X_{HF}} \quad \mathbf{Y_{HF}} \quad \mathbf{Z_{HF}}\right) = (0 \quad 2.76 \quad 3.43)\ \mathbf{m}$$

$$\mathbf{r_{AE}} := \left(\mathbf{X_{AE}} \quad \mathbf{Y_{AE}} \quad \mathbf{Z_{AE}}\right) = (0 \quad 6.11 \quad 6.69)\ \mathbf{m}$$

$$\mathbf{M} := \mathbf{W_{RW}}^{\mathbf{T}} \times \mathbf{r_{RW}}^{\mathbf{T}} + \mathbf{W_{soilb}}^{\mathbf{T}} \times \mathbf{r_{soilb}}^{\mathbf{T}} + \mathbf{F_{soilb}}^{\mathbf{T}} \times \mathbf{r_{Fsoilb}}^{\mathbf{T}} + \mathbf{F_{HF}}^{\mathbf{T}} \times \mathbf{r_{HF}}^{\mathbf{T}} \cdots$$
$$+ \mathbf{F_{soilf}}^{\mathbf{T}} \times \mathbf{r_{Fsoilf}}^{\mathbf{T}} + \mathbf{H_{Fu}}^{\mathbf{T}} \times \mathbf{r_{Fu}}^{\mathbf{T}} + \mathbf{H_{Ft}}^{\mathbf{T}} \times \mathbf{r_{Ft}}^{\mathbf{T}} + \mathbf{F_{uplift}}^{\mathbf{T}} \times \mathbf{r_{uplift}}^{\mathbf{T}} + \mathbf{F_{AE}}^{\mathbf{T}} \times \mathbf{r_{AE}}^{\mathbf{T}}$$

$$\mathbf{M} = \begin{pmatrix} 94.98 \\ -40.73 \\ -32.98 \end{pmatrix} \cdot \mathbf{MN} \cdot \mathbf{m}$$

$$\mathbf{F} = (-3.13 \quad 0 \quad -16.9) \cdot \mathbf{MN}$$

Location of resultant force:

$$\mathbf{X_R} := \left| \frac{\mathbf{M}_{1,0}}{\mathbf{F}_{0,2}} \right| = 2.41 \cdot \mathbf{m}$$

$$\mathbf{x} := \left| \mathbf{X_R} - \frac{\mathbf{b}}{2} \right| = 1.59\ \mathbf{m} \quad < \quad \frac{\mathbf{b}}{4} = 2\ \mathbf{m} \qquad \mathbf{OK}$$

4. **Bearing Capacity**

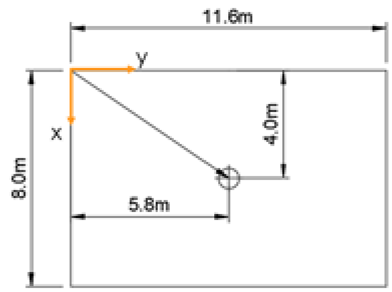
$$q_{all} := 622\,\mathbf{kPa}$$

Force and Moment at origin:

$$\mathbf{F} = \begin{pmatrix} -3.13 & 0 & -16.9 \end{pmatrix} \cdot \mathbf{MN} \qquad \mathbf{M} = \begin{pmatrix} 94.98 \\ -40.73 \\ -32.98 \end{pmatrix} \mathbf{m} \cdot \mathbf{MN}$$

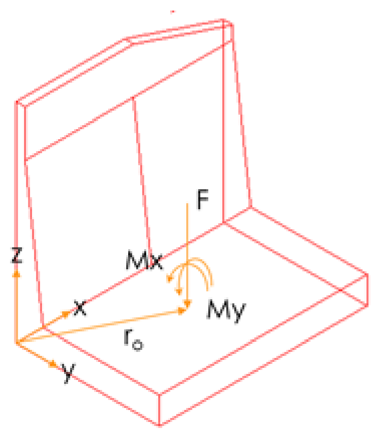
Vector to center of foundation:

$$\mathbf{r_o} := \begin{pmatrix} 4 & 5.8 & 0 \end{pmatrix} \mathbf{m}$$



Moment at center of Foundation

$$\mathbf{M_o} := \mathbf{M} - \mathbf{F}^{\mathbf{T}} \times \mathbf{r_o}^{\mathbf{T}} = \begin{pmatrix} -3.06 \\ 26.88 \\ -14.84 \end{pmatrix} \mathbf{m} \cdot \mathbf{MN}$$



$$\mathbf{Ix_o} := \frac{1}{12} \cdot \mathbf{b}^3 \cdot \mathbf{B} = 494.93\,\mathbf{m}^4$$

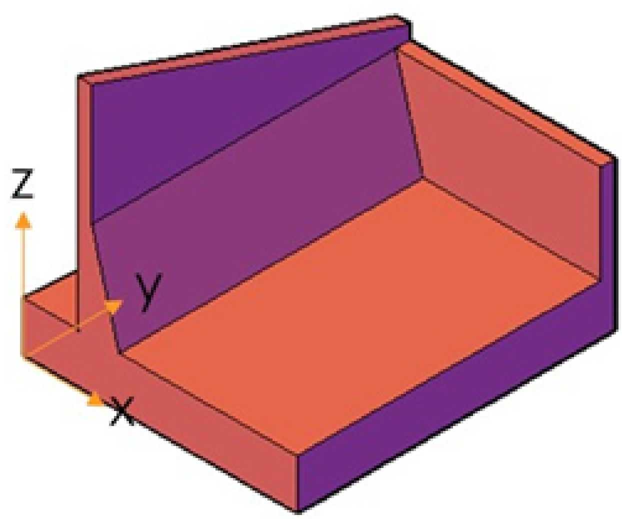
$$\mathbf{Iy_o} := \frac{1}{12} \cdot \mathbf{b} \cdot \mathbf{B}^3 = 1040.597\,\mathbf{m}^4$$

$$\mathbf{A} := \mathbf{b} \cdot \mathbf{B} = 92.8\,\mathbf{m}^2$$

$$\sigma_{\mathbf{max}} := \left|\frac{\mathbf{F}_{0,2}}{\mathbf{A}}\right| + \left|\frac{\mathbf{M_o}_{0,0} \cdot \mathbf{b}}{2 \cdot \mathbf{Ix_o}}\right| + \left|\frac{\mathbf{M_o}_{1,0} \cdot \mathbf{B}}{2 \cdot \mathbf{Iy_o}}\right| = 356.696 \cdot \mathbf{kPa} < \quad \mathbf{q_{all}} = 622 \cdot \mathbf{kPa} \qquad \mathbf{OK}$$

$$\sigma_{\mathbf{min}} := \left|\frac{\mathbf{F}_{0,2}}{\mathbf{A}}\right| - \left|\frac{\mathbf{M_o}_{0,0} \cdot \mathbf{b}}{2 \cdot \mathbf{Ix_o}}\right| - \left|\frac{\mathbf{M_o}_{1,0} \cdot \mathbf{B}}{2 \cdot \mathbf{Iy_o}}\right| = 7.594 \cdot \mathbf{kPa} \quad < \quad \mathbf{q_{all}} = 622 \cdot \mathbf{kPa} \qquad \mathbf{OK}$$

SECTION 3



Section 3

	U1	UN1	UN2	UN3	E1	E2
Sliding	3.3	-	2.0	1.3	1.1	1.2
Uplift	3.1	-	2.5	2.4	2.2	3.1
Excentricity (m)	0.11	-	0.4	0.2	0.4	0.9
Max. Foundation pressure (kPa)	155.9	-	152.5	147.5	151.4	202.0
Min. Foundation Pressure (KPa)	56.3	-	35.2	42.3	29.3	10.3
Hardfill δ (mm)	-	-	-	-	-	-

Section 3: Usual Condition (U1)

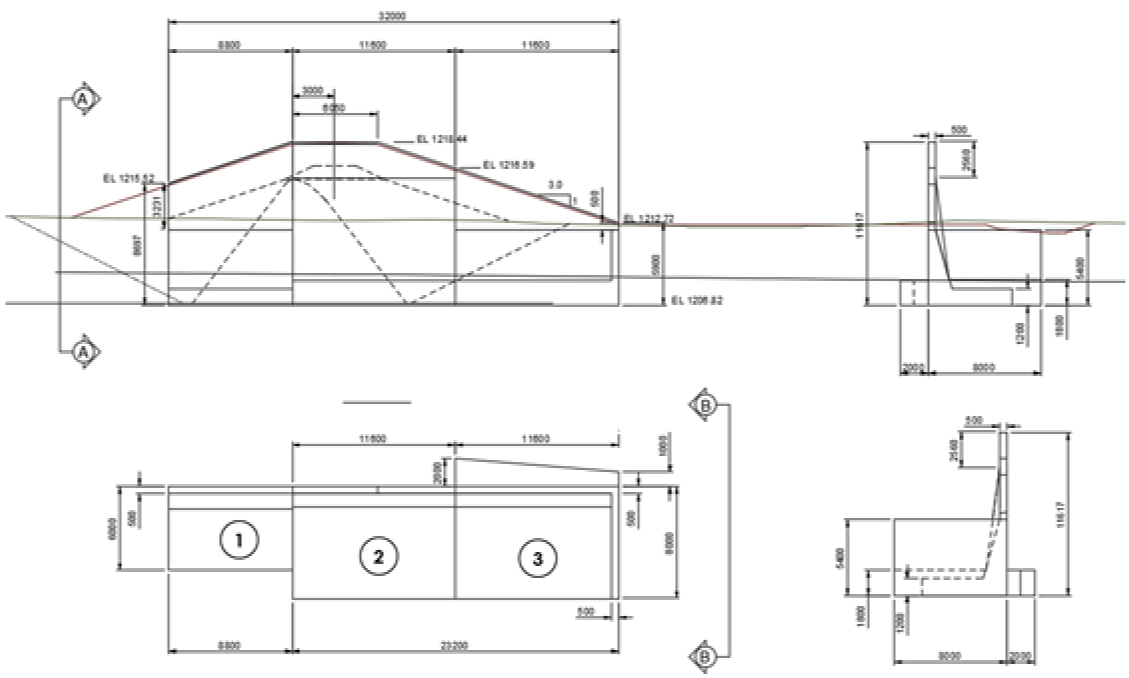
Loading	Horizontal Forces Force (MN)	Horizontal Forces Arm (m)	Vertical Forces Force (MN)	Vertical Forces Arm (m)	Stabilizing Moments (MN-m)	Overturning Moments (MN-m)
Weight of Structure			-6.3	4.7	29.6	
Earthquake Inertia Force						
Soil Mass, front of wall			-1.5	1.2	1.8	
Soil Mass, back of wall			-9.7	6.4	61.8	
Soil Pressure, front of wall	1.56	2.03			3.2	
Soil Pressure, back of wall	-2.95	2.82				8.3
Soil Dynamic Pressure, back of wall						
Uplift			5.7	5.3		30.2
Hydrostatic pressure, front of wall	1.47	1.82				
Hydrostatic pressure, back of wall	-1.70	1.70				2.9
Hydrostatic weight, front of wall						
SUM	**-1.62**		**-11.72**		**96.40**	**41.36**
					Net Moment	
					55.04	

Stability Calculations
Retaining Wall - Auxiliary Spillway
Right Abutment Transition to Berm

Scope:

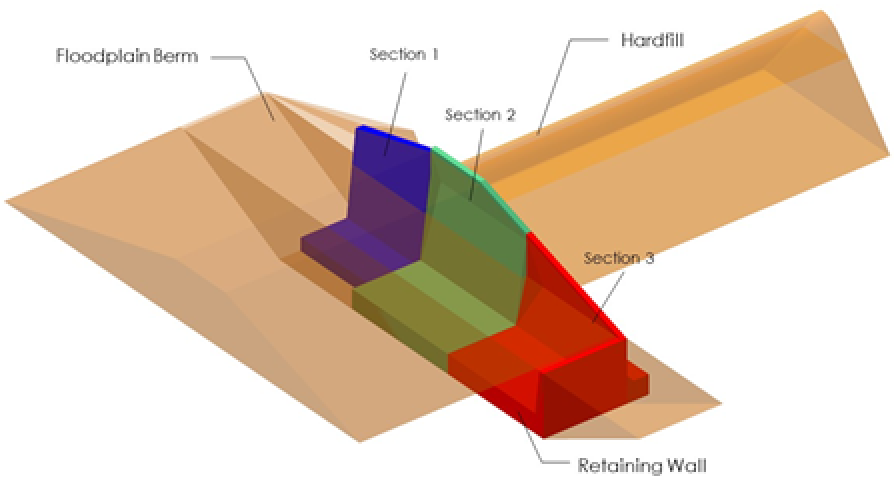
Evaluate the stability of the transition wall of the Auxiliary Spillway. Consider the 3D effects on the structure's stability.

Structure Geometry:



dimensions in mm

Isometric View:



Load Condition

	Elevation (m)			
	Headwater	Tailwater	Headwater	Tailwater
1. Usual Condition (U1)	1214.0	1211.9	7.0	4.9
2. Unusual Condition 1 (UN1)	1214.0	1211.9	7.0	4.9
3. Unusual Condition 2 (UN2)	1216.5	1213.1	9.5	6.1
4. Unusual Condition 3 (UN3)	1217.0	1213.1	10.0	6.1
5. Extreme Condition 1 (E1-F)	1217.3	1213.8	10.3	6.8
6. Extreme Condition 2 (E2-Q)	1213.5	1211.9	6.5	4.9

User Input

Material Properties:

Unit Weight of Water: $\gamma_w := 9.81 \frac{kN}{m^3}$ (Section 7.2, Design Criteria)

Unit Weight of Concrete: $\gamma_c := 23.5 \frac{kN}{m^3}$

Unit Weight of Soil (Moist): $\gamma_m := 20.0 \frac{kN}{m^3}$ (Section 5.3, Design Criteria) assumed moisture content (w) = 5%

Unit Weight Soil (Saturated): $\gamma_{sat} := 22.0 \frac{kN}{m^3}$ (Assuming Specific Gravity = 2.7)

Unit Weight Soil (buoyant): $\gamma_b := \gamma_{sat} - \gamma_w = 12.19 \cdot \frac{kN}{m^3}$

Weight of Soil/Concrete above toe: $\gamma_{toe} := 22.0 \frac{kN}{m^3}$

Unit Weight of Rock: $\gamma_r := 25.6 \frac{kN}{m^3}$ (Section 7.2, Design Criteria)

Usual Condition 1 (U1)

Acceptance Parameters

Resultant Location (Overturning and Bearing Pressure):

Unusual (UN) Resultant located inside middle third (kern) equals 100% base in compression (AT/WCS Guidelines, Section 8.4)

$$B_{\%basecomp.req} := 100\%$$

Allowable rock bearing pressure: $qall := 622 \frac{kN}{m^2}$ (Internal Geotechnical Design Recommendations Rev. Sept 12, 2018, Section 5.3)

FS Sliding:

Usual (U1) 1.5 (without cohesion) (CDA Guidelines, Table 6-4, AT/WCS Guidelines, Section 8.3)

Req'd Factor of Safety for Sliding: $FS_{sliding.req} := 1.5$ (Without Cohesion)

FS Floatation:

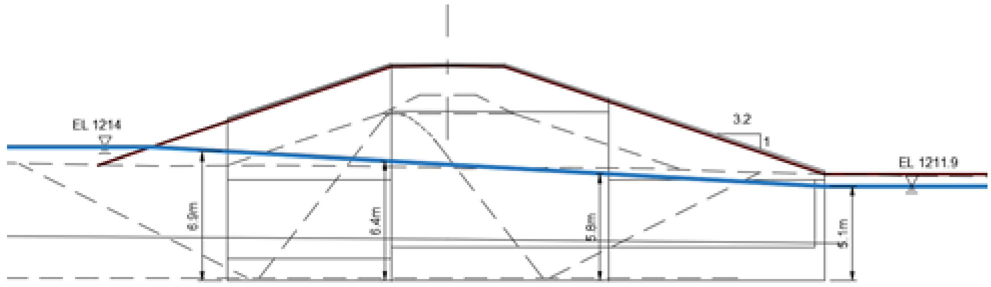
Usual (U1) 1.5 (AT/WCS Guidelines, Section 8.5)

Req'd Factor of Safety for Floatation: $FS_{float.req} := 1.5$

Water Surface Elevations

Headwater $H_H := 1214m$

Tailwater $H_T := 1211.9m$



$h_1 := 6.9m$ $h_2 := 6.4m$ $h_3 := 5.8m$ $h_4 := 5.1m$

Interpolated water table heights from retaining wall base.

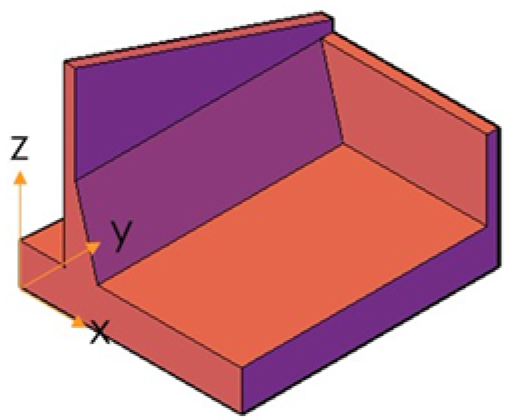
Section 2

Wall Geometry: User Input

Top of Wall Elevation:	$T_w := 1216.59 \cdot m$
Top of Footing Elevation:	$Top_{ftg} := 1208.62 \cdot m$
Thickness of Footing:	$t_{ftg} := 1.80m$
Bottom of Footing Elevation:	$Bot_{ftg} := Top_{ftg} - t_{ftg} = 1206.82\ m$
Overall Height of wall:	$h_w := T_w - Bot_{ftg} = 9.770\ m$
Thickness of Stem Wall at Top:	$t_{wt} := 0.5m$
Slope of Heel Batter:	$S_{batter} := 0.125$
Thickness of Stem Wall at Base:	$t_{wb} := 1.5m$
Length of toe:	$L_{ab} := 4m$
Total Length of Footing:	$b := 10m \quad (max)$
Length of heel:	$L_{cd} := b - L_{ab} - t_{wb} = 4.5\ m$
Width of Wall:	$B := 11.6m$

Retaining Wall

Retaining Wall Volume and Gravity Center (Using AutoCAD 3D: File: 3D Transition Wall Analysis Section 3.dwg)



Isometric View

Volume

$Vol_{RW} := 266.863\ m^3$

$X_{RW} := 4.723m$

$Y_{RW} := 5.905m$

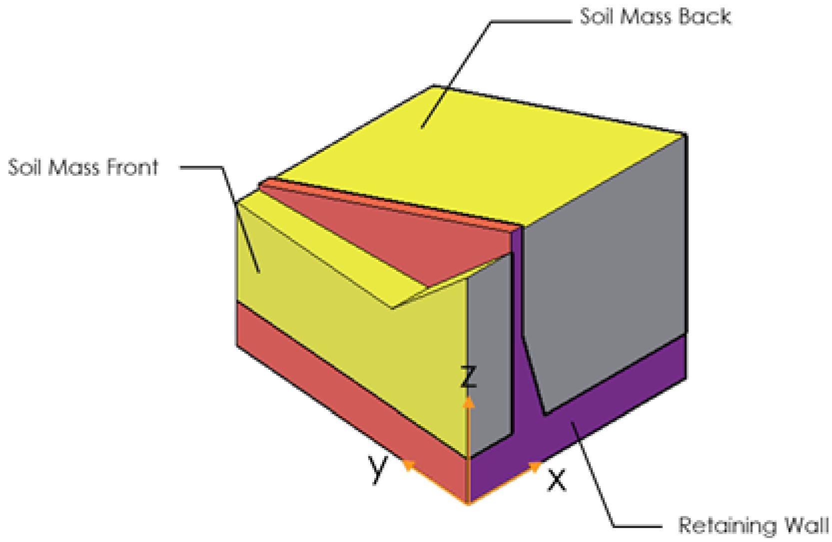
$Z_{RW} := 0m$

Retaining wall total weight $\quad W_{RW} := Vol_{RW} \cdot \gamma_c = 6.27 \cdot MN$

Soil Mass

Retained Soil Volume and Gravity Center (Using AutoCAD 3D: File 3D Transition Wall Analysis Section 3.dwg)

Isometric View:



Front of Wal

$\mathbf{Vol_{soilf}} := \mathbf{73.588\ m^3}$

$\mathbf{X_{soilf}} := \mathbf{1.209m}$

$\mathbf{Y_{soilf}} := \mathbf{4.850\,m}$

$\mathbf{Z_{soilf}} := 0\mathbf{m}$

Soil mass total weight

$\mathbf{W_{soilf}} := \mathbf{Vol_{soilf}} \cdot \gamma_m = 1.47 \cdot \mathbf{MN}$

Back of Wall

$\mathbf{Vol_{soilb}} := 483.3\ \mathbf{m^3}$

$\mathbf{X_{soilb}} := 6.396\mathbf{m}$

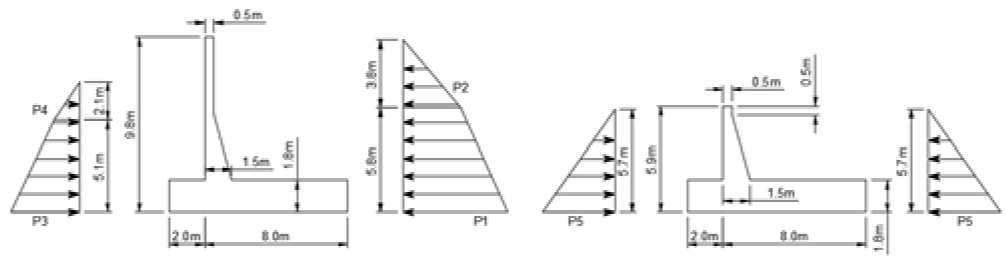
$\mathbf{Y_{soilb}} := \mathbf{4.956m}$

$\mathbf{Z_{soilb}} := 0\mathbf{m}$

Soil mass total weight

$\mathbf{W_{soilb}} := \mathbf{Vol_{soilb}} \cdot \gamma_m = 9.67 \cdot \mathbf{MN}$

Soil Pressure



Section1 Section 2

Section 1

Back of Retaining Wall

depth to water table $\mathbf{dw} := 3.8\mathbf{m}$

saturated soil depth $\mathbf{ds} := 5.8\mathbf{m}$

soil pressure at rest coefficient $\mathbf{Ko} := 0.55$

$$\mathbf{P2} := \gamma_{\mathbf{m}} \cdot \mathbf{dw} \cdot \mathbf{Ko} = 41.8 \cdot \mathbf{kPa}$$

$$\mathbf{P1} := \mathbf{P2} + \gamma_{\mathbf{b}} \cdot \mathbf{ds} \cdot \mathbf{Ko} = 80.686 \cdot \mathbf{kPa}$$

Front of Retaining Wall

depth to water table $\mathbf{dw} := 2.1\mathbf{m}$

saturated soil depth $\mathbf{ds} := 5.1\mathbf{m}$

soil pressure at rest coefficient $\mathbf{Ko} := 0.55$

$$\mathbf{P4} := \gamma_{\mathbf{m}} \cdot \mathbf{dw} \cdot \mathbf{Ko} = 23.1 \cdot \mathbf{kPa}$$

$$\mathbf{P3} := \mathbf{P2} + \gamma_{\mathbf{b}} \cdot \mathbf{ds} \cdot \mathbf{Ko} = 75.993 \cdot \mathbf{kPa}$$

Section 2

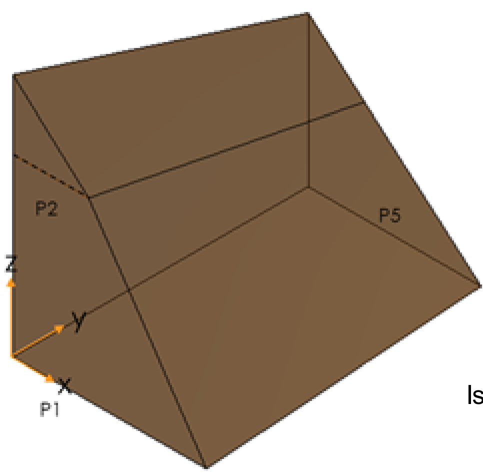
depth to water table $\mathbf{dw} := 0$

saturated soil depth $\mathbf{ds} := 5.7\mathbf{m}$

soil pressure at rest coefficient $\mathbf{Ko} := 0.55$

$$\mathbf{P5} := \gamma_b \cdot \mathbf{ds} \cdot \mathbf{Ko} = 38.216 \cdot \mathbf{kPa}$$

Isometric view of the prism representing soil pressures against the retaining wall (Using AutoCAD 3D: 3D Transition Wall Analysis Section 3.dwg). The volume of the prism is equal to the equivalent total force.



Isometric View

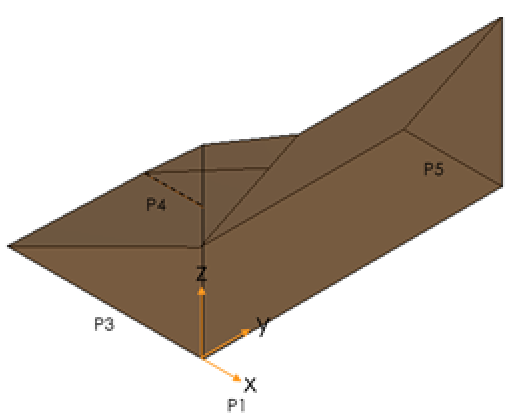
Total Force Back Soil

$\mathbf{F_{soilb}} := \mathbf{2950.65kN}$

$\mathbf{X_{Fsoilb}} := 0\mathbf{m}$

$\mathbf{Y_{Fsoilb}} := \mathbf{4.562m}$

$\mathbf{Z_{Fsoilb}} := \mathbf{2.820m}$



Total Force Front Soil

$\mathbf{F_{soilf}} := \mathbf{1556.05kN}$

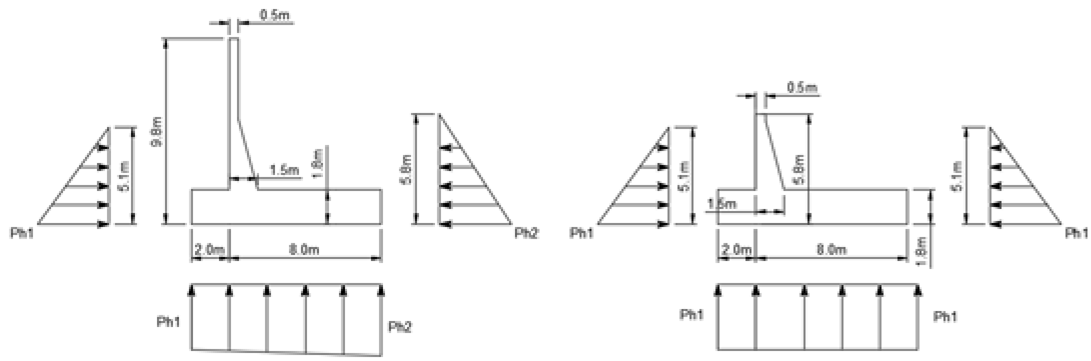
$\mathbf{X_{Fsoilf}} := 0\mathbf{m}$

$\mathbf{Y_{Fsoilf}} := \mathbf{4.934m}$

$\mathbf{Z_{Fsoilf}} := \mathbf{2.034m}$

Hydrostatic Forces

Side View



Section 1 Section 2

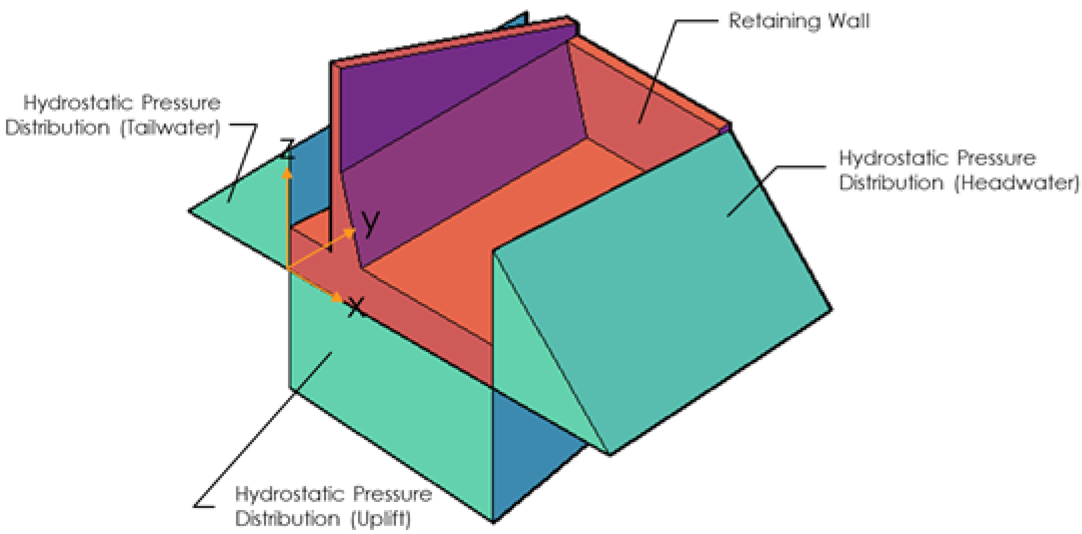
Headwater height $\mathbf{h_{Hh}} := 5.8\mathbf{m}$

Tailwater height $\mathbf{h_{Th}} := \mathbf{H_T} - \mathbf{Bot_{ftg}} = 5.08\,\mathbf{m}$

$$\mathbf{Ph1} := \mathbf{h_{Th}} \cdot \gamma_{\mathbf{w}} = 49.83 \cdot \mathbf{kPa}$$

$$\mathbf{Ph2} := \mathbf{h_{Hh}} \cdot \gamma_{\mathbf{w}} = 56.9 \cdot \mathbf{kPa}$$

Isometric View



Total Hydrostatic Force

Headwater

$H_{Fu} := 1687.87\,kN$

$X_{Fu} := 0\,m$

$Y_{Fu} := 5.546\,m$

$Z_{Fu} := 1.822\,m$

Volume and centroid of hydrostatic pressure was determined using AutoCAD 3D: File Water Pressure.dwg

Total Hydrostatic Force

Tailwater

$H_{Ft} := 1471.31\,kN$

$X_{Ft} := 0\,m$

$Y_{Ft} := 5.800\,m$

$Z_{Ft} := 1.700\,m$

Volume and centroid of hydrostatic pressure was determined using AutoCAD 3D: File Water Pressure.dwg

Uplift

Total Uplift Force

$F_{uplift} := 5689.46\,kN$

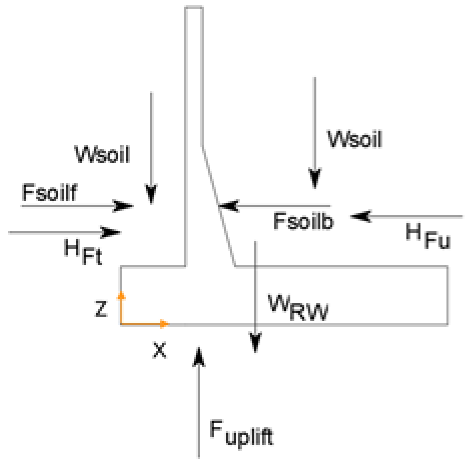
$X_{uplift} := 5.299\,m$

$Y_{uplift} := 5.632\,m$

$Z_{uplift} := 0\,m$

Volume and centroid of hydrostatic pressure was determined using AutoCAD 3D: File Water Pressure.dwg

Vector Forces Summary



Body diagram, side view

Weight Retaining Wall $\quad \mathbf{W_{RW}} := \begin{pmatrix} 0 & 0 & -\mathbf{W_{RW}} \end{pmatrix} = (0 \quad 0 \quad -6.27)\cdot\mathbf{MN}$

Weight Soil (Back of Wall) $\quad \mathbf{W_{soilb}} := \begin{pmatrix} 0 & 0 & -\mathbf{W_{soilb}} \end{pmatrix} = (0 \quad 0 \quad -9.67)\cdot\mathbf{MN}$

Weight Soil (Front of Wall) $\quad \mathbf{W_{soilf}} := \begin{pmatrix} 0 & 0 & -\mathbf{W_{soilf}} \end{pmatrix} = (0 \quad 0 \quad -1.47)\cdot\mathbf{MN}$

Soil Pressure (Back of Wall) $\quad \mathbf{F_{soilb}} := \begin{pmatrix} -\mathbf{F_{soilb}} & 0 & 0 \end{pmatrix} = (-2.95 \quad 0 \quad 0)\cdot\mathbf{MN}$

Soil Pressure (Front of Wall) $\quad \mathbf{F_{soilf}} := \begin{pmatrix} \mathbf{F_{soilf}} & 0 & 0 \end{pmatrix} = (1.56 \quad 0 \quad 0)\cdot\mathbf{MN}$

Hydrostatic Force Headwater $\quad \mathbf{H_{Fu}} := \begin{pmatrix} -\mathbf{H_{Fu}} & \mathbf{0} & 0 \end{pmatrix} = (-1.69 \quad 0 \quad 0)\cdot\mathbf{MN}$

Hydrostatic Force Tailwater $\quad \mathbf{H_{Ft}} := \begin{pmatrix} \mathbf{H_{Ft}} & 0 & 0 \end{pmatrix} = (1.47 \quad 0 \quad 0)\cdot\mathbf{MN}$

Uplift Force $\quad \mathbf{F_{uplift}} := \begin{pmatrix} 0 & 0 & \mathbf{F_{uplift}} \end{pmatrix} = (0 \quad 0 \quad 5.69)\cdot\mathbf{MN}$

Resultant Total Force

$$\mathbf{F} := \mathbf{W_{RW}} + \mathbf{W_{soilb}} + \mathbf{W_{soilf}} + \mathbf{F_{soilb}} + \mathbf{F_{soilf}} + \mathbf{H_{Fu}} + \mathbf{H_{Ft}} + \mathbf{F_{uplift}}$$

$$\mathbf{F} = (-1.61 \quad 0 \quad -11.72)\cdot\mathbf{MN}$$

Structure Stability

1. Sliding

$$236.6\mathbf{m}^3\cdot\gamma_w = 2.32\cdot\mathbf{MN}$$

Coefficient of sliding friction $\mu := 0.45$

$$\mathbf{FoS} := \frac{\mathbf{F}_{0,2}\cdot\mu}{\mathbf{F}_{0,0}} = 3.27 \quad > \quad \mathbf{FS_{sliding.req}} = 1.5 \quad \mathbf{OK}$$

2. Uplift

Summatory of Axial Resistant Forces

$$\mathbf{F_R} := \mathbf{W_{RW}} + \mathbf{W_{soilf}} + \mathbf{W_{soilb}} = (0 \quad 0 \quad -17.41)\cdot\mathbf{MN}$$

Uplift Force

$$\mathbf{F_{uplift}} = (0 \quad 0 \quad 5.69)\cdot\mathbf{MN}$$

$$\mathbf{FoS_{uplift}} := \frac{\left|\mathbf{F_R}_{0,2}\right|}{\left|\mathbf{F_{uplift}}_{0,2}\right|} = 3.06 \quad > \quad \mathbf{FS_{float.req}} = 1.5 \quad \mathbf{OK}$$

3. Overturning

$$\mathbf{r_{RW}} := \begin{pmatrix} \mathbf{X_{RW}} & Y_{RW} & Z_{RW} \end{pmatrix} = (4.72 \quad 5.91 \quad 0)\,\mathbf{m}$$

$$\mathbf{r_{soilb}} := \begin{pmatrix} X_{soilb} & Y_{soilb} & Z_{soilb} \end{pmatrix} = (6.4 \quad 4.96 \quad 0)\,\mathbf{m}$$

$$\mathbf{r_{soilf}} := \begin{pmatrix} X_{soilf} & Y_{soilf} & Z_{soilf} \end{pmatrix} = (1.21 \quad 4.85 \quad 0)\,\mathbf{m}$$

$$\mathbf{r_{Fsoilb}} := \begin{pmatrix} X_{Fsoilb} & Y_{Fsoilb} & Z_{Fsoilb} \end{pmatrix} = (0 \quad 4.56 \quad 2.82)\,\mathbf{m}$$

$$\mathbf{r_{Fsoilf}} := \begin{pmatrix} X_{Fsoilf} & Y_{Fsoilf} & Z_{Fsoilf} \end{pmatrix} = (0 \quad 4.93 \quad 2.03)\,\mathbf{m}$$

$$\mathbf{r_{Fu}} := \begin{pmatrix} X_{Fu} & Y_{Fu} & Z_{Fu} \end{pmatrix} = (0 \quad 5.55 \quad 1.82)\,\mathbf{m}$$

$$\mathbf{r_{Ft}} := \begin{pmatrix} X_{Ft} & Y_{Ft} & Z_{Ft} \end{pmatrix} = (0 \quad 5.8 \quad 1.7)\,\mathbf{m}$$

$$\mathbf{r_{uplift}} := \begin{pmatrix} X_{uplift} & Y_{uplift} & Z_{uplift} \end{pmatrix} = (5.3 \quad 5.63 \quad 0)\,\mathbf{m}$$

$$\mathbf{M} := \mathbf{W_{RW}}^T \times \mathbf{r_{RW}}^T + \mathbf{W_{soilb}}^T \times \mathbf{r_{soilb}}^T + \mathbf{W_{soilf}}^T \times \mathbf{r_{soilf}}^T + \mathbf{F_{soilb}}^T \times \mathbf{r_{Fsoilb}}^T \cdots$$
$$+ \mathbf{F_{soilf}}^T \times \mathbf{r_{Fsoilf}}^T + \mathbf{H_{Fu}}^T \times \mathbf{r_{Fu}}^T + \mathbf{H_{Ft}}^T \times \mathbf{r_{Ft}}^T + \mathbf{F_{uplift}}^T \times \mathbf{r_{uplift}}^T$$

$$\mathbf{M} = \begin{pmatrix} 60.03 \\ -57.34 \\ -6.61 \end{pmatrix} \cdot \mathbf{MN} \cdot \mathbf{m}$$

$$\mathbf{F} = (-1.61 \quad 0 \quad -11.72) \cdot \mathbf{MN}$$

Location of resultant force:

$$\mathbf{X_R} := \left| \frac{\mathbf{M}_{1,0}}{\mathbf{F}_{0,2}} \right| = 4.89 \cdot \mathbf{m}$$

$$\mathbf{x} := \left| \mathbf{X_R} - \frac{\mathbf{b}}{2} \right| = 0.11\,\mathbf{m} \quad < \quad \frac{\mathbf{b}}{6} = 1.67\,\mathbf{m} \qquad \mathbf{OK}$$

4. **Bearing Capacity**

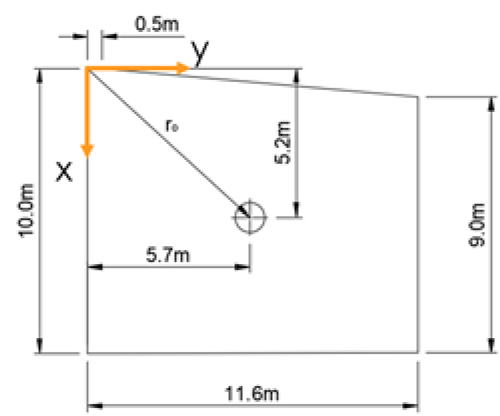
$$\mathbf{q_{all}} := 622\,\mathbf{kPa}$$

Force and Moment at origin:

$$\mathbf{F} = \begin{pmatrix} -1.61 & 0 & -11.72 \end{pmatrix} \cdot \mathbf{MN} \qquad \mathbf{M} = \begin{pmatrix} 60.03 \\ -57.34 \\ -6.61 \end{pmatrix} \mathbf{m} \cdot \mathbf{MN}$$

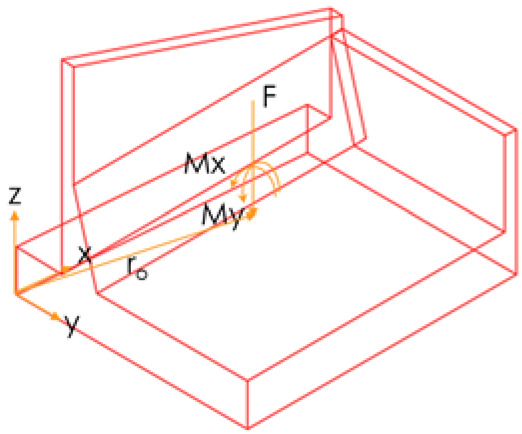
Vector to center of foundation:

$$\mathbf{r_o} := \begin{pmatrix} \mathbf{5.7} & \mathbf{5.2} & 0 \end{pmatrix} \mathbf{m}$$



Moment at center of Foundation

$$\mathbf{M_o} := \mathbf{M} - \mathbf{F}^{\mathbf{T}} \times \mathbf{r_o}^{\mathbf{T}} = \begin{pmatrix} -0.91 \\ 9.46 \\ 1.77 \end{pmatrix} \mathbf{m} \cdot \mathbf{MN}$$



$$\mathbf{Ix_o} := \mathbf{839.8m^4}$$

$$\mathbf{Iy_o} := \mathbf{1235.5m^4}$$

$$\mathbf{A} := \mathbf{110.43m^2}$$

$$\sigma_{\mathbf{max}} := \left|\frac{\mathbf{F}_{0,2}}{\mathbf{A}}\right| + \left|\frac{\mathbf{M_o}_{0,0} \cdot \mathbf{b}}{2 \cdot \mathbf{Ix_o}}\right| + \left|\frac{\mathbf{M_o}_{1,0} \cdot \mathbf{B}}{2 \cdot \mathbf{Iy_o}}\right| = 155.944 \cdot \mathbf{kPa} < \quad \mathbf{q_{all}} = 622 \cdot \mathbf{kPa} \quad \mathbf{OK}$$

$$\sigma_{\mathbf{min}} := \left|\frac{\mathbf{F}_{0,2}}{\mathbf{A}}\right| - \left|\frac{\mathbf{M_o}_{0,0} \cdot \mathbf{b}}{2 \cdot \mathbf{Ix_o}}\right| - \left|\frac{\mathbf{M_o}_{1,0} \cdot \mathbf{B}}{2 \cdot \mathbf{Iy_o}}\right| = 56.309 \cdot \mathbf{kPa} < \quad \mathbf{q_{all}} = 622 \cdot \mathbf{kPa} \quad \mathbf{OK}$$

Section 3: Unusual Condition (UN2)

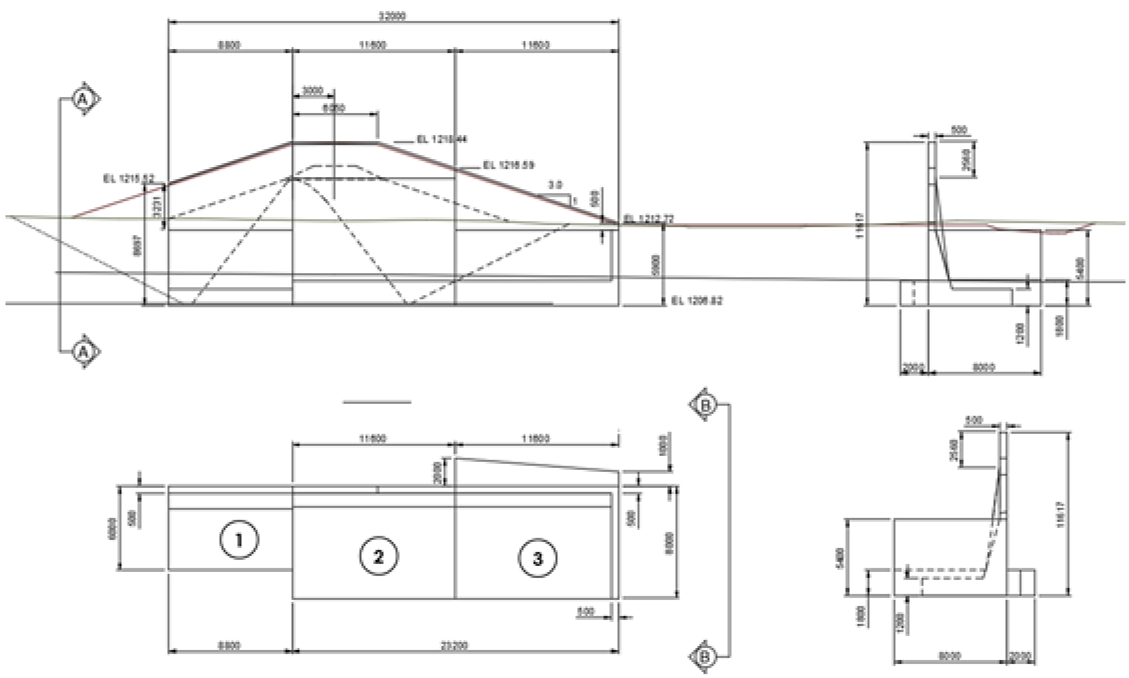
Loading	Horizontal Forces Force (MN)	Horizontal Forces Arm (m)	Vertical Forces Force (MN)	Vertical Forces Arm (m)	Stabilizing Moments (MN-m)	Overturning Moments (MN-m)
Weight of Structure			-6.3	4.7	29.6	
Earthquake Inertia Force						
Soil Mass, front of wall			-1.5	1.2	1.8	
Soil Mass, back of wall			-9.7	6.4	61.8	
Soil Pressure, front of wall	1.58	2.17			3.4	
Soil Pressure, back of wall	-3.41	2.73				9.3
Soil Dynamic Pressure, back of wall						
Uplift			7.0	5.3		37.5
Hydrostatic pressure, front of wall	2.17	2.06			4.47	
Hydrostatic pressure, back of wall	-2.67	2.29				6.1
Hydrostatic weight, front of wall						
SUM	**-2.3**		**-10.4**		**101.1**	**52.9**
					Net Moment 48.22	

Stability Calculations
Retaining Wall - Auxiliary Spillway
Right Abutment Transition to Berm

Scope:

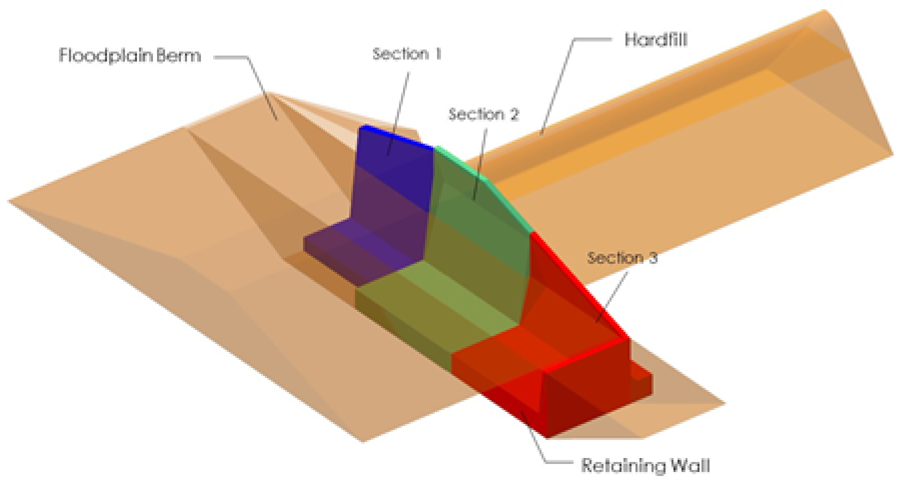
Evaluate the stability of the transition wall of the Auxiliary Spillway. Consider the 3D effects on the structure's stability.

Structure Geometry:



dimensions in mm

Isometric View:



Load Condition

	Elevation (m)			
	Headwater	**Tailwater**	**Headwater**	**Tailwater**
1. Usual Condition (U1)	1214.0	1211.9	7.0	4.9
2. Unusual Condition 1 (UN1)	1214.0	1211.9	7.0	4.9
3. Unusual Condition 2 (UN2)	1216.5	1213.1	9.5	6.1
4. Unusual Condition 3 (UN3)	1217.0	1213.1	10.0	6.1
5. Extreme Condition 1 (E1-F)	1217.3	1213.8	10.3	6.8
6. Extreme Condition 2 (E2-Q)	1213.5	1211.9	6.5	4.9

User Input

Material Properties:

Unit Weight of Water: $\gamma_w := 9.81 \frac{kN}{m^3}$ (Section 7.2, Design Criteria)

Unit Weight of Concrete: $\gamma_c := \mathbf{23.5} \frac{kN}{m^3}$

Unit Weight of Soil (Moist): $\gamma_m := 20.0 \frac{kN}{m^3}$ (Section 5.3, Design Criteria) assumed moisture content (w) = 5%

Unit Weight Soil (Saturated): $\gamma_{sat} := 22.0 \frac{kN}{m^3}$ (Assuming Specific Gravity = 2.7)

Unit Weight Soil (buoyant): $\gamma_b := \gamma_{sat} - \gamma_w = 12.19 \cdot \frac{kN}{m^3}$

Weight of Soil/Concrete above toe: $\gamma_{toe} := 22.0 \frac{kN}{m^3}$

Unit Weight of Rock: $\gamma_r := 25.6 \frac{kN}{m^3}$ (Section 7.2, Design Criteria)

Unusual Condition 2 (UN2)

Acceptance Parameters

Resultant Location (Overturning and Bearing Pressure):

Unusual (UN1) Resultant located inside middle third (kern) equals 100% base in compression (AT/WCS Guidelines, Section 8.4)

$$B_{\%basecomp.req} := 100\%$$

Allowable rock bearing pressure: $qall := 622 \frac{kN}{m^2}$ (Internal Geotechnical Design Recommendations Rev. Sept 12, 2018, Section 5.3)

FS Sliding:

Unusual (UN1) 1.3 (without cohesion) (CDA Guidelines, Table 6-4, AT/WCS Guidelines, Section 8.3)

Req'd Factor of Safety for Sliding: $FS_{sliding.req} := 1.3$ (Without Cohesion)

FS Floatation:

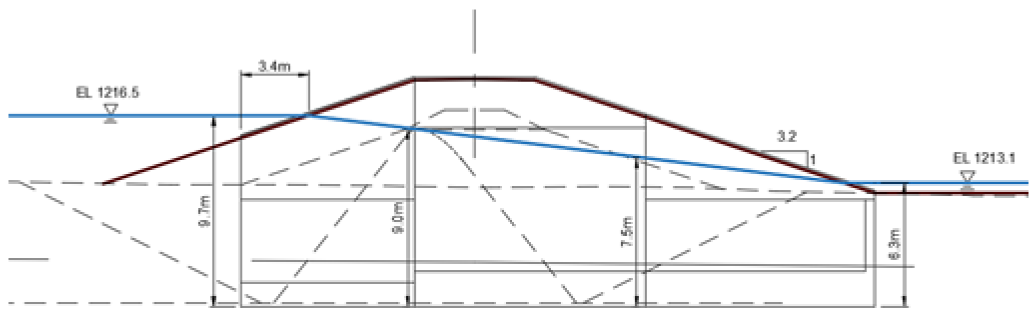
Unusual (UN1) 1.3 (AT/WCS Guidelines, Section 8.5)

Req'd Factor of Safety for Floatation: $FS_{float.req} := 1.3$

Water Surface Elevations

Headwater $H_H := 1216.5m$

Tailwater $H_T := 1213.1m$



$h_1 := 9.7m$ $h_2 := 9.0m$ $h_3 := 7.5m$ $h_4 := 6.3m$

Interpolated water table heights from retaining wall base.

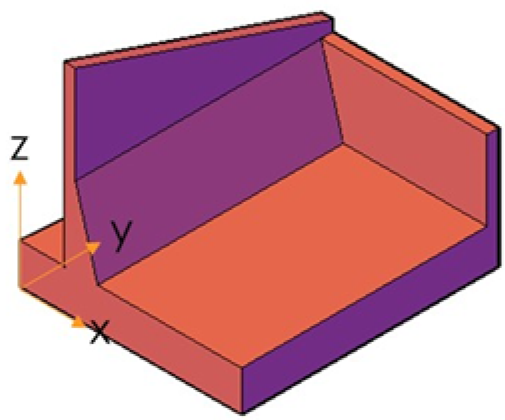
Section 3

Wall Geometry: User Input

Top of Wall Elevation:	$\mathbf{T_w} := 1216.59 \cdot \mathbf{m}$
Top of Footing Elevation:	$\mathbf{Top_{ftg}} := 1208.62 \cdot \mathbf{m}$
Thickness of Footing:	$\mathbf{t_{ftg}} := 1.80\mathbf{m}$
Bottom of Footing Elevation:	$\mathbf{Bot_{ftg}} := \mathbf{Top_{ftg}} - t_{ftg} = 1206.82\ \mathbf{m}$
Overall Height of wall:	$\mathbf{h_w} := \mathbf{T_w} - \mathbf{Bot_{ftg}} = 9.770\,\mathbf{m}$
Thickness of Stem Wall at Top:	$\mathbf{t_{wt}} := 0.5\mathbf{m}$
Slope of Heel Batter:	$\mathbf{S_{batter}} := 0.125$
Thickness of Stem Wall at Base:	$\mathbf{t_{wb}} := 1.5\mathbf{m}$
Length of toe:	$\mathbf{L_{ab}} := 4\mathbf{m}$
Total Length of Footing:	$\mathbf{b} := 10\mathbf{m} \quad (\mathbf{max})$
Length of heel:	$\mathbf{L_{cd}} := \mathbf{b} - \mathbf{L_{ab}} - \mathbf{t_{wb}} = 4.5\,\mathbf{m}$
Width of Wall:	$\mathbf{B} := 11.6\mathbf{m}$

Retaining Wall

Retaining Wall Volume and Gravity Center (Using AutoCAD 3D: File: 3D Transition Wall Analysis Section 3.dwg)



Isometric View

Volume

$\mathbf{Vol_{RW} := 266.863\ m^3}$

$\mathbf{X_{RW} := 4.723m}$

$\mathbf{Y_{RW} := 5.905m}$

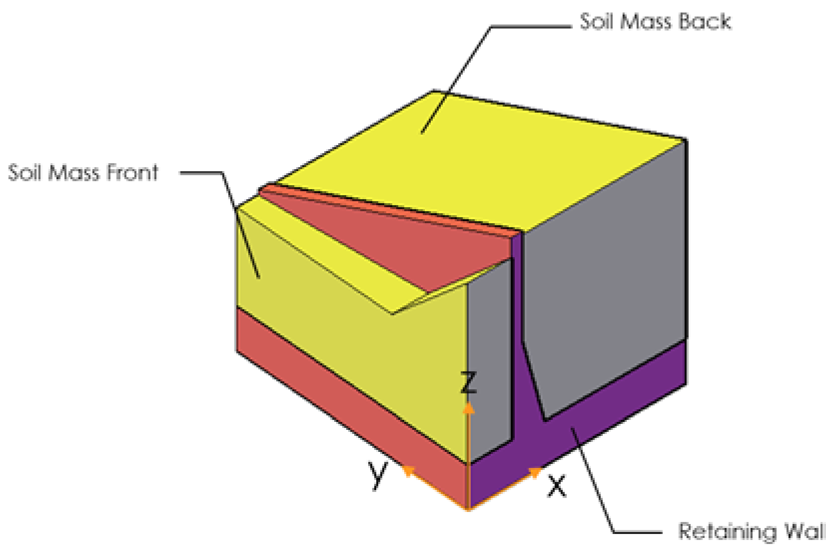
$\mathbf{Z_{RW} :=} 0\mathbf{m}$

Retaining wall total weight $\quad \mathbf{W_{RW} := Vol_{RW} \cdot \gamma_c} = 6.27 \cdot \mathbf{MN}$

Soil Mass

Retained Soil Volume and Gravity Center (Using AutoCAD 3D: File: 3D Transition Wall Analysis Section 3.dwg)

Isometric View:



Front of Wal

$\mathbf{Vol_{soilf}} := \mathbf{73.588\ m^3}$

$\mathbf{X_{soilf}} := \mathbf{1.209m}$

$\mathbf{Y_{soilf}} := \mathbf{4.850m}$

$\mathbf{Z_{soilf}} := 0\mathbf{m}$

Soil mass total weight

$\mathbf{W_{soilf}} := \mathbf{Vol_{soilf}} \cdot \gamma_{\mathbf{m}} = 1.47 \cdot \mathbf{MN}$

Back of Wall

$\mathbf{Vol_{soilb}} := 483.3\ \mathbf{m^3}$

$\mathbf{X_{soilb}} := 6.396\mathbf{m}$

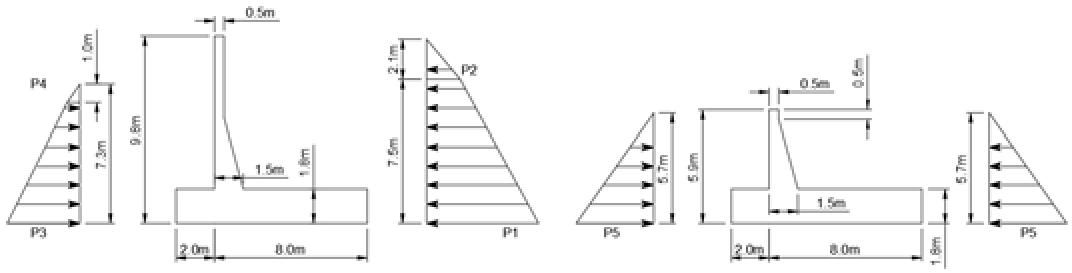
$\mathbf{Y_{soilb}} := \mathbf{4.956m}$

$\mathbf{Z_{soilb}} := 0\mathbf{m}$

Soil mass total weight

$\mathbf{W_{soilb}} := \mathbf{Vol_{soilb}} \cdot \gamma_{\mathbf{m}} = 9.67 \cdot \mathbf{MN}$

Soil Pressure



Section1 Section 2

Section 1

Back of Retaining Wall

depth to water table $\mathbf{dw} := 2.1\mathbf{m}$

saturated soil depth $\mathbf{ds} := 7.5\mathbf{m}$

soil pressure at rest coefficient $\mathbf{Ko} := 0.55$

$$\mathbf{P2} := \gamma_{\mathbf{m}} \cdot \mathbf{dw} \cdot \mathbf{Ko} = 23.1 \cdot \mathbf{kPa}$$

$$\mathbf{P1} := \mathbf{P2} + \gamma_{\mathbf{b}} \cdot \mathbf{ds} \cdot \mathbf{Ko} = 73.384 \cdot \mathbf{kPa}$$

Front of Retaining Wall

depth to water table $\mathbf{dw} := 1.0\mathbf{m}$

saturated soil depth $\mathbf{ds} := 6.3\mathbf{m}$

soil pressure at rest coefficient $\mathbf{Ko} := 0.55$

$$\mathbf{P4} := \gamma_{\mathbf{m}} \cdot \mathbf{dw} \cdot \mathbf{Ko} = 11 \cdot \mathbf{kPa}$$

$$\mathbf{P3} := \mathbf{P2} + \gamma_{\mathbf{b}} \cdot \mathbf{ds} \cdot \mathbf{Ko} = 65.338 \cdot \mathbf{kPa}$$

Section 2

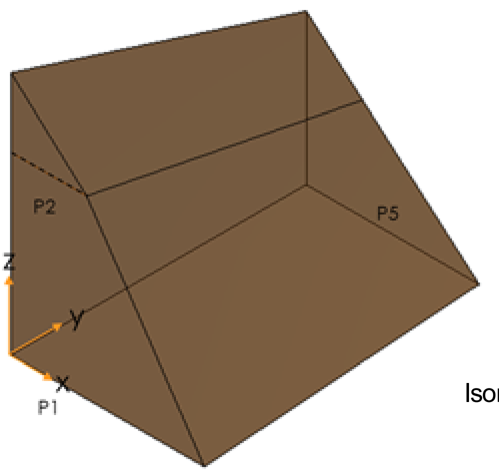
depth to water table $\mathbf{dw} := 0$

saturated soil depth $\mathbf{ds} := 5.7\mathbf{m}$

soil pressure at rest coefficient $\mathbf{Ko} := 0.55$

$$\mathbf{P5} := \gamma_{\mathbf{b}} \cdot \mathbf{ds} \cdot \mathbf{Ko} = 38.216 \cdot \mathbf{kPa}$$

Isometric view of the prism representing soil pressures against the retaining wall (Using AutoCAD 3D: File: 3D Transition Wall Analysis Section 3.dwg). The volume of the prism is equal to the equivalent total force.



Isometric View

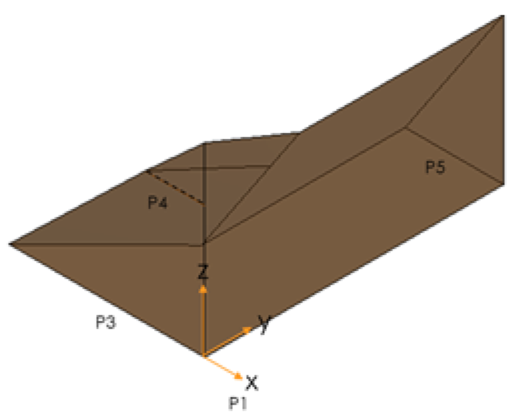
Total Force Back Soil

$\mathbf{F_{soilb}} := \mathbf{3408.54kN}$

$\mathbf{X_{Fsoilb}} := 0\mathbf{m}$

$\mathbf{Y_{Fsoilb}} := \mathbf{5.205m}$

$\mathbf{Z_{Fsoilb}} := \mathbf{2.730m}$



Total Force Front Soil

$\mathbf{F_{soilf}} := \mathbf{1579.18kN}$

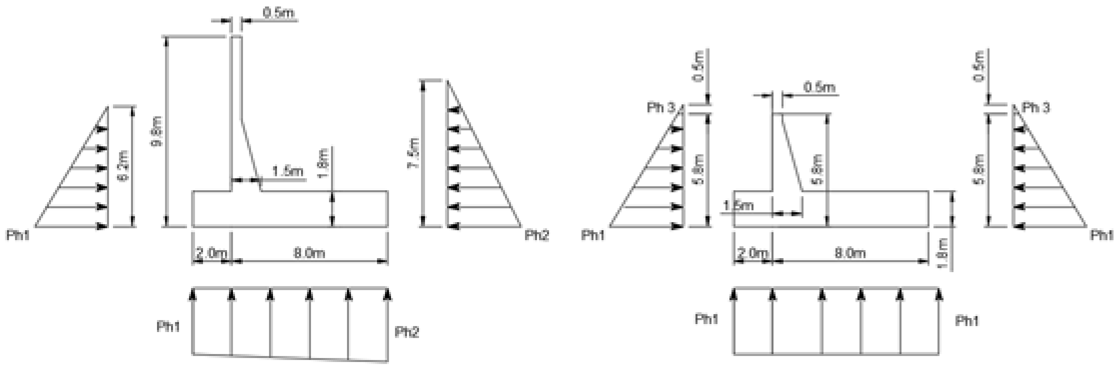
$\mathbf{X_{Fsoilf}} := 0\mathbf{m}$

$\mathbf{Y_{Fsoilf}} := \mathbf{4.890m}$

$\mathbf{Z_{Fsoilf}} := \mathbf{2.165m}$

Hydrostatic Forces

Side View



Section 1 Section 2

Headwater height $\mathbf{h_{Hh}} := 7.5\mathbf{m}$

Tailwater height $\mathbf{h_{Th}} := \mathbf{H_T} - \mathbf{Bot_{ftg}} = 6.28\ \mathbf{m}$

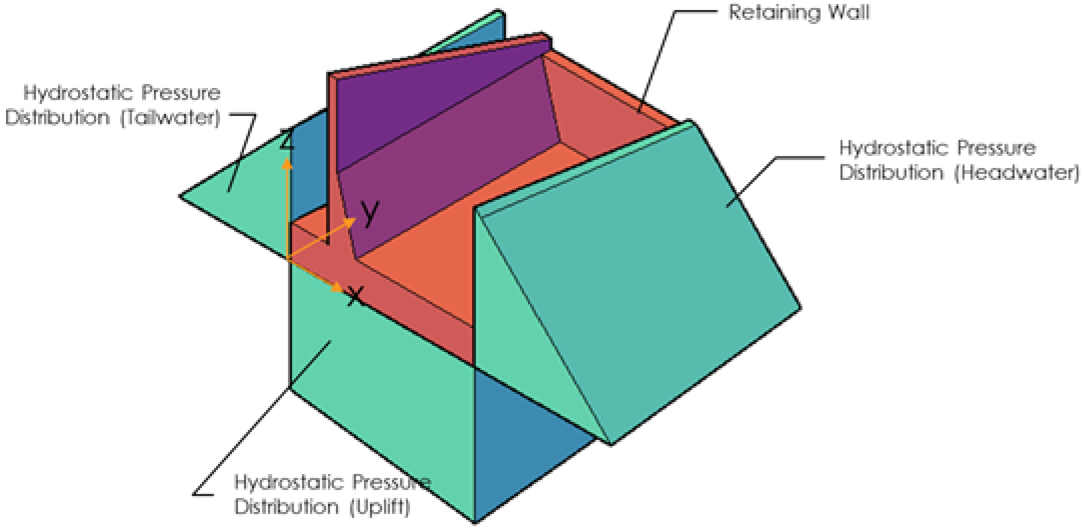
Depth to top of wall $\mathbf{h_{TW}} := \mathbf{h_{Th}} - 5.8\mathbf{m} = 0.48\ \mathbf{m}$

$$\mathbf{Ph1} := \mathbf{h_{Th}} \cdot \gamma_{\mathbf{w}} = 61.61 \cdot \mathbf{kPa}$$

$$\mathbf{Ph2} := \mathbf{h_{Hh}} \cdot \gamma_{\mathbf{w}} = 73.58 \cdot \mathbf{kPa}$$

$$\mathbf{Ph3} := \mathbf{h_{TW}} \cdot \gamma_{\mathbf{w}} = 4.71 \cdot \mathbf{kPa}$$

Isometric View



Total Hydrostatic Force

Headwater

$\mathbf{H_{Fu}} := \mathbf{2666.56kN}$

$\mathbf{X_{Fu}} := 0\mathbf{m}$

$\mathbf{Y_{Fu}} := \mathbf{5.425m}$

$\mathbf{Z_{Fu}} := \mathbf{2.288m}$

Volume and centroid of hydrostatic pressure was determined using AutoCAD 3D: File: 3D Transition Wall Analysis Section 3.dwg

Total Hydrostatic Force

Tailwater

$\mathbf{H_{Ft}} := \mathbf{2173.08kN}$

$\mathbf{X_{Ft}} := 0\mathbf{m}$

$\mathbf{Y_{Ft}} := \mathbf{5.793m}$

$\mathbf{Z_{Ft}} := \mathbf{2.057m}$

Volume and centroid of hydrostatic pressure was determined using AutoCAD 3D: File: 3D Transition Wall Analysis Section 3.dwg

Uplift

Total Uplift Force

$\mathbf{F_{uplift}} := \mathbf{7044.46kN}$

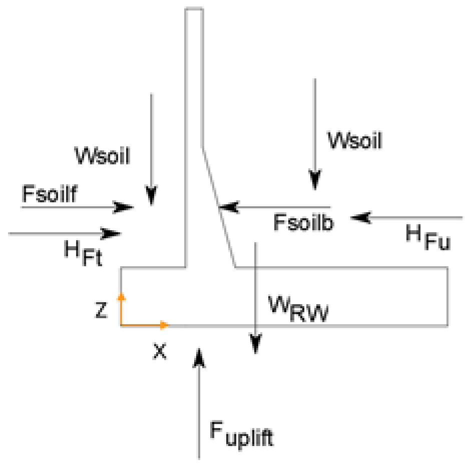
$\mathbf{X_{uplift}} := \mathbf{5.324m}$

$\mathbf{Y_{uplift}} := \mathbf{5.600m}$

$\mathbf{Z_{uplift}} := 0\mathbf{m}$

Volume and centroid of hydrostatic pressure was determined using AutoCAD 3D: File: 3D Transition Wall Analysis Section 3.dwg

Vector Forces Summary



Body diagram, side view

Weight Retaining Wall $\mathbf{W_{RW}} := \begin{pmatrix} 0 & 0 & -\mathbf{W_{RW}} \end{pmatrix} = (0 \quad 0 \quad -6.27)\cdot\mathbf{MN}$

Weight Soil (Back of Wall) $\mathbf{W_{soilb}} := \begin{pmatrix} 0 & 0 & -\mathbf{W_{soilb}} \end{pmatrix} = (0 \quad 0 \quad -9.67)\cdot\mathbf{MN}$

Weight Soil (Front of Wall) $\mathbf{W_{soilf}} := \begin{pmatrix} 0 & 0 & -\mathbf{W_{soilf}} \end{pmatrix} = (0 \quad 0 \quad -1.47)\cdot\mathbf{MN}$

Soil Pressure (Back of Wall) $\mathbf{F_{soilb}} := \begin{pmatrix} -\mathbf{F_{soilb}} & 0 & 0 \end{pmatrix} = (-3.41 \quad 0 \quad 0)\cdot\mathbf{MN}$

Soil Pressure (Front of Wall) $\mathbf{F_{soilf}} := \begin{pmatrix} \mathbf{F_{soilf}} & 0 & 0 \end{pmatrix} = (1.58 \quad 0 \quad 0)\cdot\mathbf{MN}$

Hydrostatic Force Headwater $\mathbf{H_{Fu}} := \begin{pmatrix} -\mathbf{H_{Fu}} & \mathbf{0} & 0 \end{pmatrix} = (-2.67 \quad 0 \quad 0)\cdot\mathbf{MN}$

Hydrostatic Force Tailwater $\mathbf{H_{Ft}} := \begin{pmatrix} \mathbf{H_{Ft}} & 0 & 0 \end{pmatrix} = (2.17 \quad 0 \quad 0)\cdot\mathbf{MN}$

Uplift Force $\mathbf{F_{uplift}} := \begin{pmatrix} 0 & 0 & \mathbf{F_{uplift}} \end{pmatrix} = (0 \quad 0 \quad 7.04)\cdot\mathbf{MN}$

Resultant Total Force

$$\mathbf{F} := \mathbf{W_{RW}} + \mathbf{W_{soilb}} + \mathbf{W_{soilf}} + \mathbf{F_{soilb}} + \mathbf{F_{soilf}} + \mathbf{H_{Fu}} + \mathbf{H_{Ft}} + \mathbf{F_{uplift}}$$

$$\mathbf{F} = (-2.32 \quad 0 \quad -10.36)\cdot\mathbf{MN}$$

Structure Stability

1. Sliding

$$236.6\mathbf{m}^3\cdot\gamma_{\mathbf{w}} = 2.32\cdot\mathbf{MN}$$

Coefficient of sliding friction $\mu := 0.45$

$$\mathbf{FoS} := \frac{\mathbf{F}_{0,2}\cdot\mu}{\mathbf{F}_{0,0}} = 2.01 \quad > \quad \mathbf{FS_{sliding.req}} = 1.3 \quad \mathbf{OK}$$

2. Uplift

Summatory of Axial Resistant Forces

$$\mathbf{F_R} := \mathbf{W_{RW}} + \mathbf{W_{soilf}} + \mathbf{W_{soilb}} = (0 \quad 0 \quad -17.41)\cdot\mathbf{MN}$$

Uplift Force

$$\mathbf{F_{uplift}} = (0 \quad 0 \quad 7.04)\cdot\mathbf{MN}$$

$$\mathbf{FoS_{uplift}} := \frac{\left|\mathbf{F_R}_{0,2}\right|}{\left|\mathbf{F_{uplift}}_{0,2}\right|} = 2.47 \quad > \quad \mathbf{FS_{float.req}} = 1.3 \quad \mathbf{OK}$$

3. Overturning

$\mathbf{r_{RW}} := \left(\mathbf{X_{RW}} \quad Y_{RW} \quad Z_{RW}\right) = (4.72 \quad 5.91 \quad 0)\,\mathbf{m}$

$\mathbf{r_{soilb}} := \left(X_{soilb} \quad Y_{soilb} \quad Z_{soilb}\right) = (6.4 \quad 4.96 \quad 0)\,\mathbf{m}$

$\mathbf{r_{soilf}} := \left(X_{soilf} \quad Y_{soilf} \quad Z_{soilf}\right) = (1.21 \quad 4.85 \quad 0)\,\mathbf{m}$

$\mathbf{r_{Fsoilb}} := \left(X_{Fsoilb} \quad Y_{Fsoilb} \quad Z_{Fsoilb}\right) = (0 \quad 5.21 \quad 2.73)\,\mathbf{m}$

$\mathbf{r_{Fsoilf}} := \left(X_{Fsoilf} \quad Y_{Fsoilf} \quad Z_{Fsoilf}\right) = (0 \quad 4.89 \quad 2.17)\,\mathbf{m}$

$\mathbf{r_{Fu}} := \left(X_{Fu} \quad Y_{Fu} \quad Z_{Fu}\right) = (0 \quad 5.42 \quad 2.29)\,\mathbf{m}$

$\mathbf{r_{Ft}} := \left(X_{Ft} \quad Y_{Ft} \quad Z_{Ft}\right) = (0 \quad 5.79 \quad 2.06)\,\mathbf{m}$

$\mathbf{r_{uplift}} := \left(X_{uplift} \quad Y_{uplift} \quad Z_{uplift}\right) = (5.32 \quad 5.6 \quad 0)\,\mathbf{m}$

$$\mathbf{M} := \mathbf{W_{RW}}^T \times \mathbf{r_{RW}}^T + \mathbf{W_{soilb}}^T \times \mathbf{r_{soilb}}^T + \mathbf{W_{soilf}}^T \times \mathbf{r_{soilf}}^T + \mathbf{F_{soilb}}^T \times \mathbf{r_{Fsoilb}}^T \cdots$$
$$+ \mathbf{F_{soilf}}^T \times \mathbf{r_{Fsoilf}}^T + \mathbf{H_{Fu}}^T \times \mathbf{r_{Fu}}^T + \mathbf{H_{Ft}}^T \times \mathbf{r_{Ft}}^T + \mathbf{F_{uplift}}^T \times \mathbf{r_{uplift}}^T$$

$$\mathbf{M} = \begin{pmatrix} 52.63 \\ -48.2 \\ -11.9 \end{pmatrix} \cdot \mathbf{MN} \cdot \mathbf{m}$$

$\mathbf{F} = (-2.32 \quad 0 \quad -10.36) \cdot \mathbf{MN}$

Location of resultant force:

$$\mathbf{X_R} := \left| \frac{\mathbf{M}_{1,0}}{\mathbf{F}_{0,2}} \right| = 4.65 \cdot \mathbf{m}$$

$$\mathbf{x} := \left| \mathbf{X_R} - \frac{\mathbf{b}}{2} \right| = 0.35\,\mathbf{m} \quad < \quad \frac{\mathbf{b}}{6} = 1.67\,\mathbf{m} \qquad \textbf{OK}$$

4. **Bearing Capacity**

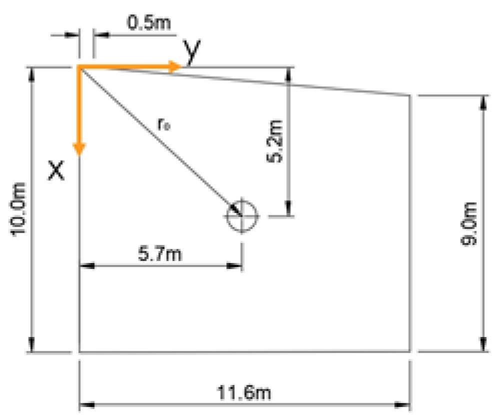
$$q_{all} := 622\,\mathbf{kPa}$$

Force and Moment at origin:

$$\mathbf{F} = (-2.32 \quad 0 \quad -10.36)\cdot\mathbf{MN} \qquad\qquad \mathbf{M} = \begin{pmatrix} 52.63 \\ -48.2 \\ -11.9 \end{pmatrix}\mathbf{m}\cdot\mathbf{MN}$$

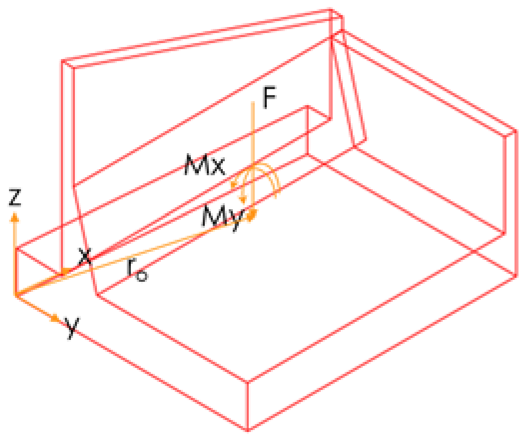
Vector to center of foundation:

$$\mathbf{r_o} := (\mathbf{5.7} \quad \mathbf{5.2} \quad 0)\,\mathbf{m}$$



Moment at center of Foundation

$$\mathbf{M_o} := \mathbf{M} - \mathbf{F}^{\mathbf{T}} \times \mathbf{r_o}^{\mathbf{T}} = \begin{pmatrix} -1.27 \\ 10.88 \\ 0.18 \end{pmatrix} \mathbf{m} \cdot \mathbf{MN}$$



$$\mathbf{Ix_o} := \mathbf{839.8m}^4$$

$$\mathbf{Iy_o} := \mathbf{1235.5m}^4$$

$$\mathbf{A} := \mathbf{110.43m}^2$$

$$\sigma_{\mathbf{max}} := \left| \frac{\mathbf{F}_{0,2}}{\mathbf{A}} \right| + \left| \frac{\mathbf{M_o}_{0,0} \cdot \mathbf{b}}{2 \cdot \mathbf{Ix_o}} \right| + \left| \frac{\mathbf{M_o}_{1,0} \cdot \mathbf{B}}{2 \cdot \mathbf{Iy_o}} \right| = 152.485 \cdot \mathbf{kPa} < \quad \mathbf{q_{all}} = 622 \cdot \mathbf{kPa} \qquad \mathbf{OK}$$

$$\sigma_{\mathbf{min}} := \left| \frac{\mathbf{F}_{0,2}}{\mathbf{A}} \right| - \left| \frac{\mathbf{M_o}_{0,0} \cdot \mathbf{b}}{2 \cdot \mathbf{Ix_o}} \right| - \left| \frac{\mathbf{M_o}_{1,0} \cdot \mathbf{B}}{2 \cdot \mathbf{Iy_o}} \right| = 35.228 \cdot \mathbf{kPa} \quad < \quad \mathbf{q_{all}} = 622 \cdot \mathbf{kPa} \qquad \mathbf{OK}$$

Section 3: Unusual Condition (UN3)

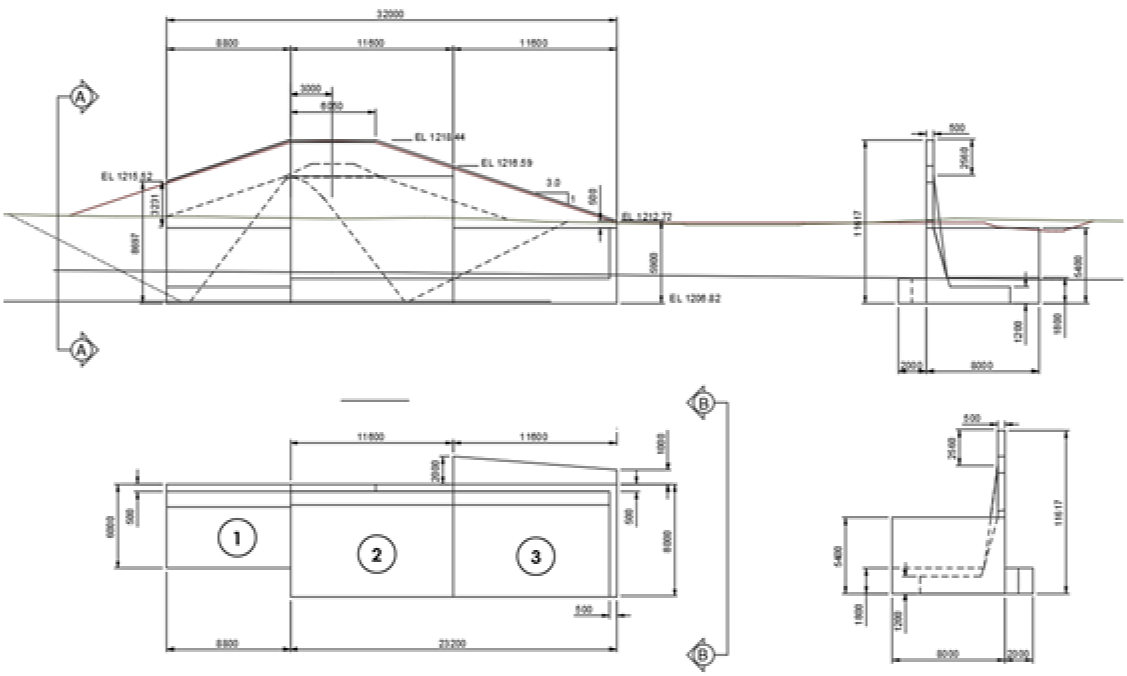
Loading	Horizontal Forces Force (MN)	Horizontal Forces Arm (m)	Vertical Forces Force (MN)	Vertical Forces Arm (m)	Stabilizing Moments (MN-m)	Overturning Moments (MN-m)
Weight of Structure			-6.3	4.7	29.6	
Earthquake Inertia Force						
Soil Mass, front of wall						
Soil Mass, back of wall			-10.6	6.4	68.0	
Soil Pressure, front of wall						
Soil Pressure, back of wall	-3.09	2.76				8.5
Soil Dynamic Pressure, back of wall						
Uplift			7.2	5.3		38.3
Hydrostatic pressure, front of wall	-2.78	2.37				6.59
Hydrostatic pressure, back of wall	2.31	2.12			4.90	
Hydrostatic weight, front of wall			-0.79	1.22	1.0	
SUM	**-3.6**		**-10.5**		**103.5**	**53.4**
					Net Moment	
					50.09	

Stability Calculations
Retaining Wall - Auxiliary Spillway
Right Abutment Transition to Berm

Scope:

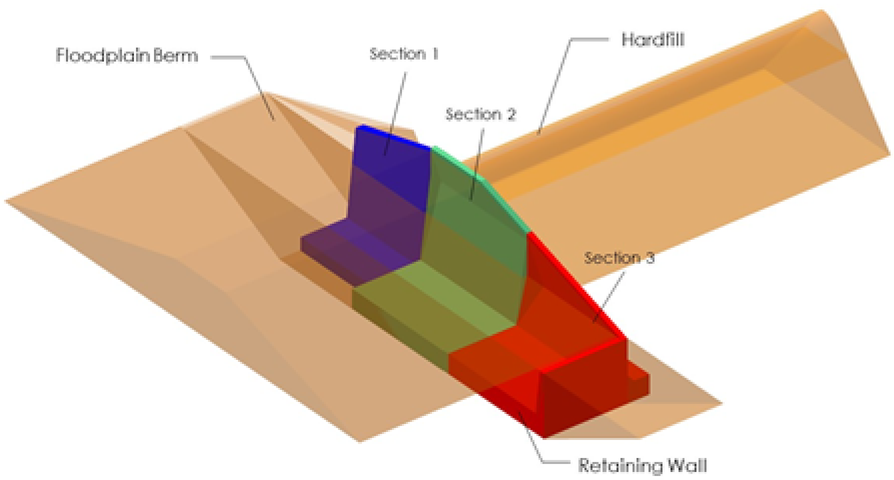
Evaluate the stability of the transition wall of the Auxiliary Spillway. Consider the 3D effects on the structure's stability.

Structure Geometry:



dimensions in mm

Isometric View:



Load Condition

	Elevation (m)			
	Headwater	**Tailwater**	**Headwater**	**Tailwater**
1. Usual Condition (U1)	1214.0	1211.9	7.0	4.9
2. Unusual Condition 1 (UN1)	1214.0	1211.9	7.0	4.9
3. Unusual Condition 2 (UN2)	1216.5	1213.1	9.5	6.1
4. Unusual Condition 3 (UN3)	1217.0	1213.1	10.0	6.1
5. Extreme Condition 1 (E1-F)	1217.3	1213.8	10.3	6.8
6. Extreme Condition 2 (E2-Q)	1213.5	1211.9	6.5	4.9

User Input

Material Properties:

Unit Weight of Water: $\gamma_w := 9.81 \frac{kN}{m^3}$ (Section 7.2, Design Criteria)

Unit Weight of Concrete: $\gamma_c := \mathbf{23.5} \frac{kN}{m^3}$

Unit Weight of Soil (Moist): $\gamma_m := 20.0 \frac{kN}{m^3}$ (Section 5.3, Design Criteria) assumed moisture content (w) = 5%

Unit Weight Soil (Saturated): $\gamma_{sat} := 22.0 \frac{kN}{m^3}$ (Assuming Specific Gravity = 2.7)

Unit Weight Soil (buoyant): $\gamma_b := \gamma_{sat} - \gamma_w = 12.19 \cdot \frac{kN}{m^3}$

Weight of Soil/Concrete above toe: $\gamma_{toe} := 22.0 \frac{kN}{m^3}$

Unit Weight of Rock: $\gamma_r := 25.6 \frac{kN}{m^3}$ (Section 7.2, Design Criteria)

Unusual Condition 3 (UN3)

Acceptance Parameters

Resultant Location (Overturning and Bearing Pressure):

Unusual (UN1) Resultant located inside middle third (kern) equals 100% base in compression (AT/WCS Guidelines, Section 8.4)

$$B_{\%basecomp.req} := 100\%$$

Allowable rock bearing pressure: $qall := 622 \frac{kN}{m^2}$ (Internal Geotechnical Design Recommendations Rev. Sept 12, 2018, Section 5.3)

FS Sliding:

Unusual (UN2) 1.3 (without cohesion) (CDA Guidelines, Table 6-4, AT/WCS Guidelines, Section 8.3)

Req'd Factor of Safety for Sliding: $FS_{sliding.req} := 1.3$ (Without Cohesion)

FS Floatation:

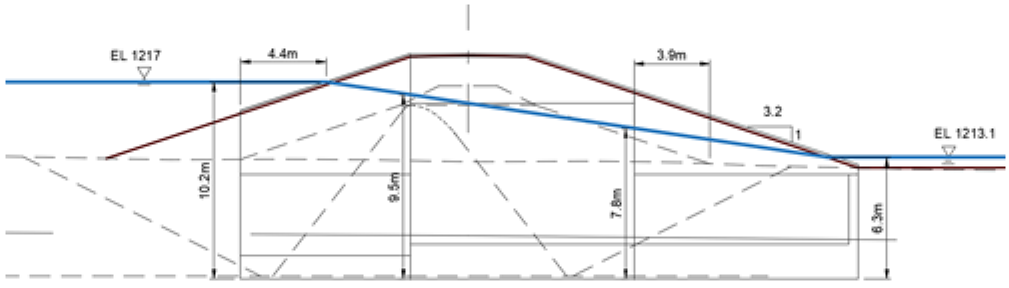
Unusual (UN2) 1.3 (AT/WCS Guidelines, Section 8.5)

Req'd Factor of Safety for Floatation: $FS_{float.req} := 1.3$

Water Surface Elevations

Headwater $H_H := 1217m$

Tailwater $H_T := 1213.1m$



$h_1 := 10.2m$ $h_2 := 9.5m$ $h_3 := 7.8m$ $h_4 := 6.3m$

Interpolated water table heights from retaining wall base.

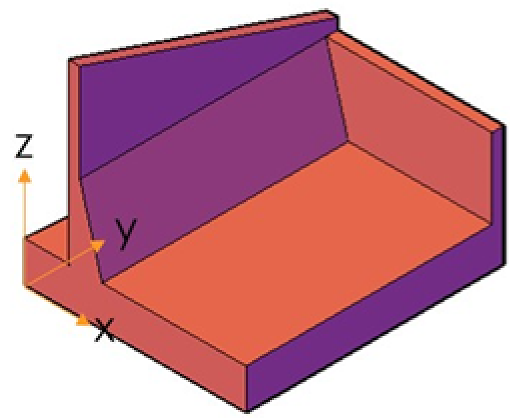
Section 3

Wall Geometry: User Input

Top of Wall Elevation:	$\mathbf{T_w} := 1216.59 \cdot \mathbf{m}$
Top of Footing Elevation:	$\mathbf{Top_{ftg}} := 1208.62 \cdot \mathbf{m}$
Thickness of Footing:	$\mathbf{t_{ftg}} := 1.80\mathbf{m}$
Bottom of Footing Elevation:	$\mathbf{Bot_{ftg}} := \mathbf{Top_{ftg}} - t_{ftg} = 1206.82\ \mathbf{m}$
Overall Height of wall:	$\mathbf{h_w} := \mathbf{T_w} - \mathbf{Bot_{ftg}} = 9.770\ \mathbf{m}$
Thickness of Stem Wall at Top:	$\mathbf{t_{wt}} := 0.5\mathbf{m}$
Slope of Heel Batter:	$\mathbf{S_{batter}} := 0.125$
Thickness of Stem Wall at Base:	$\mathbf{t_{wb}} := 1.5\mathbf{m}$
Length of toe:	$\mathbf{L_{ab}} := 2\mathbf{m}$
Total Length of Footing:	$\mathbf{b} := 10\mathbf{m}$ (max)
Length of heel:	$\mathbf{L_{cd}} := \mathbf{b} - \mathbf{L_{ab}} - \mathbf{t_{wb}} = 6.5\ \mathbf{m}$
Width of Wall:	$\mathbf{B} := 11.6\mathbf{m}$

Retaining Wall

Retaining Wall Volume and Gravity Center (Using AutoCAD 3D: File: 3D Transition Wall Analysis Section 3.dwg)



Isometric View

Volume

$Vol_{RW} := 266.863\ m^3$

$X_{RW} := 4.723m$

$Y_{RW} := 5.905m$

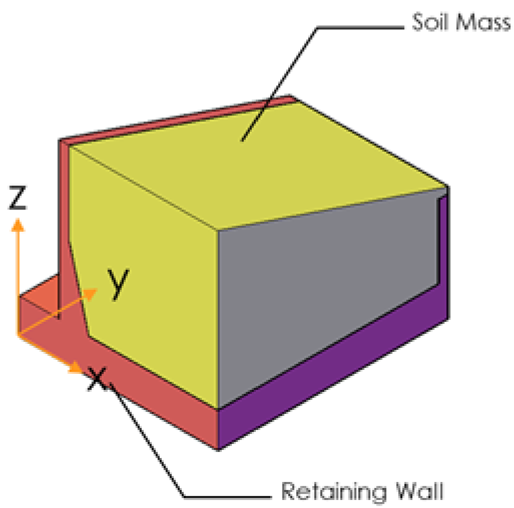
$Z_{RW} := 0m$

Retaining wall total weight $\quad W_{RW} := Vol_{RW} \cdot \gamma_c = 6.27 \cdot MN$

Soil Mass

Retained Soil Volume and Gravity Center (Using AutoCAD 3D: File 3D Transition Wall Analysis.dwg)

Isometric View:



$$\mathbf{Vol_{soil}} := 483.3\ \mathbf{m}^3$$

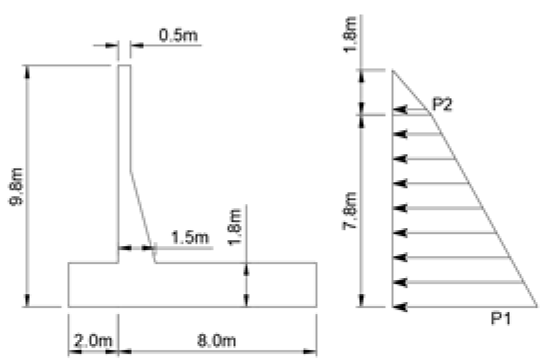
$$\mathbf{X_{soil}} := \mathbf{6.396m}$$

$$\mathbf{Y_{soil}} := \mathbf{4.956m}$$

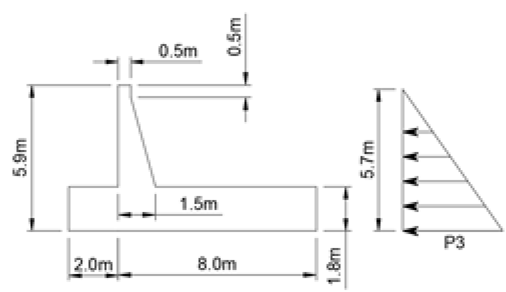
$$\mathbf{Z_{soil}} := 0\mathbf{m}$$

Soil mass total weight $\mathbf{W_{soil}} := \mathbf{Vol_{soil}} \cdot \gamma_{\mathbf{sat}} = 10.63 \cdot \mathbf{MN}$

Soil Pressure



Section1



Section 2

Section 1

depth to water table $\mathbf{dw} := 1.8\mathbf{m}$

saturated soil depth $\mathbf{ds} := 7.8\mathbf{m}$

soil pressure at rest coefficient $\mathbf{Ko} := 0.55$

$$\mathbf{P2} := \gamma_{\mathbf{m}} \cdot \mathbf{dw} \cdot \mathbf{Ko} = 19.8 \cdot \mathbf{kPa}$$

$$\mathbf{P1} := \mathbf{P2} + \gamma_{\mathbf{b}} \cdot \mathbf{ds} \cdot \mathbf{Ko} = 72.095 \cdot \mathbf{kPa}$$

Section 2

depth to water table $\mathbf{dw} := 0$

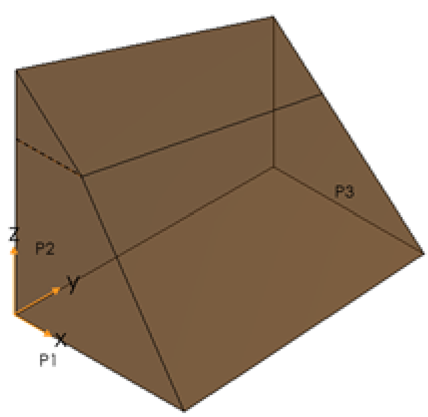
saturated soil depth $\mathbf{ds} := 5.7\mathbf{m}$

soil pressure at rest coefficient $\mathbf{Ko} := 0.55$

$$\mathbf{P4} := \gamma_{\mathbf{m}} \cdot \mathbf{dw} \cdot \mathbf{Ko} = 0 \cdot \mathbf{kPa}$$

$$\mathbf{P3} := \mathbf{P2} + \gamma_{\mathbf{b}} \cdot \mathbf{ds} \cdot \mathbf{Ko} = 58.016 \cdot \mathbf{kPa}$$

Isometric view of the prism representing soil pressures against the retaining wall (Using AutoCAD 3D: File: 3D Transition Wall Analysis Section 3.dwg). The volume of the prism is equal to the equivalent total force.



Isometric View

Total Force

$\mathbf{F_{soil}} := \mathbf{3091.27kN}$

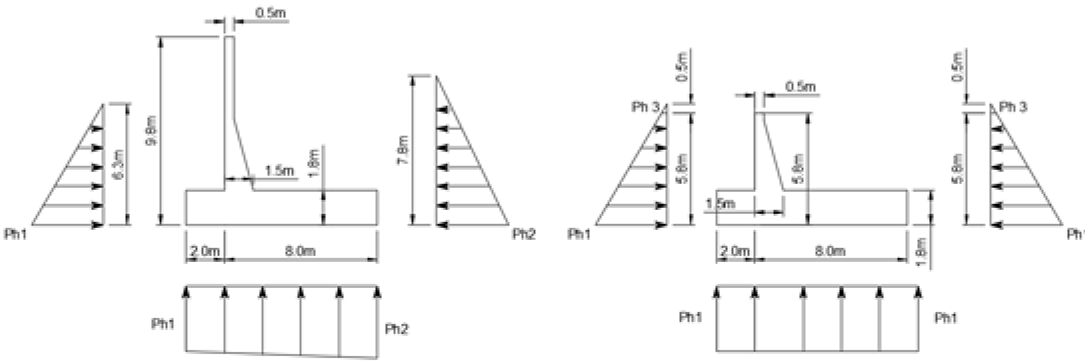
$\mathbf{X_{Fsoil}} := 0\mathbf{m}$

$\mathbf{Y_{Fsoil}} := \mathbf{5.044m}$

$\mathbf{Z_{Fsoil}} := \mathbf{2.761m}$

Hydrostatic Forces

Side View



Section 1 Section 2

Headwater height $\mathbf{h_{Hh}} := 7.5\mathbf{m}$

Tailwater height $\mathbf{h_{Th}} := \mathbf{H_T} - \mathbf{Bot_{ftg}} = 6.28\,\mathbf{m}$

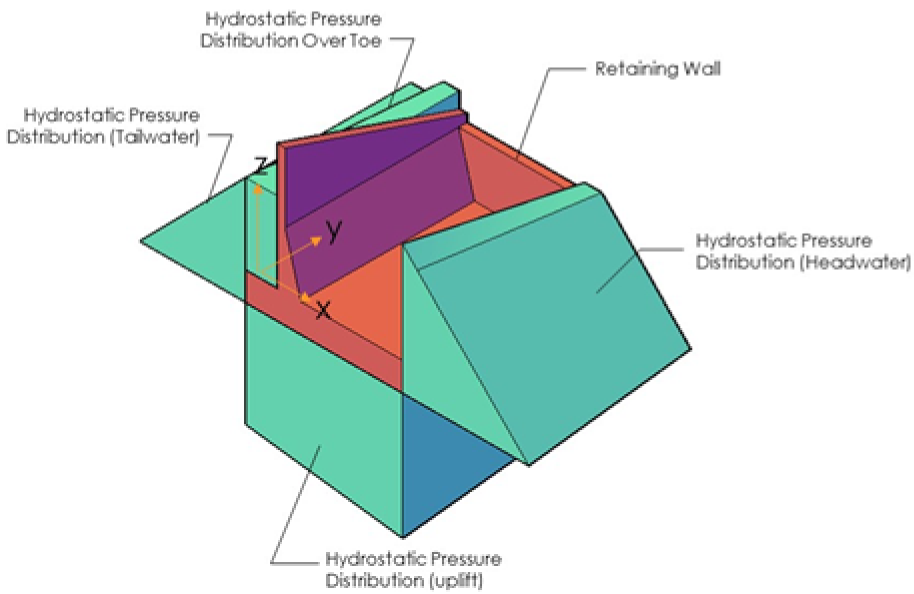
Top of Retaining all to water level Tailwater $\mathbf{d_{Th}} := 6.38\mathbf{m} - 5.8\mathbf{m} = 0.58\,\mathbf{m}$

$$\mathbf{Ph1} := \mathbf{h_{Th}} \cdot \gamma_{\mathbf{w}} = 61.61 \cdot \mathbf{kPa}$$

$$\mathbf{Ph2} := \mathbf{h_{Hh}} \cdot \gamma_{\mathbf{w}} = 73.58 \cdot \mathbf{kPa}$$

$$\mathbf{Ph3} := \mathbf{d_{Th}} \cdot \gamma_{\mathbf{w}} = 5.69 \cdot \mathbf{kPa}$$

Isometric View



Total Hydrostatic Force

Headwater

$H_{Fu} := 2780.79\text{kN}$

$X_{Fu} := 0\text{m}$

$Y_{Fu} := 5.430\text{m}$

$Z_{Fu} := 2.366\text{m}$

Volume and centroid of hydrostatic pressure was determined using AutoCAD 3D: File: 3D Transition Wall Analysis Section 3.dwg

Total Hydrostatic Force

Tailwater

$H_{Ft} := 2311.06\text{kN}$

$X_{Ft} := 0\text{m}$

$Y_{Ft} := 5.789\text{m}$

$Z_{Ft} := 2.115\text{m}$

Volume and centroid of hydrostatic pressure was determined using AutoCAD 3D: File: 3D Transition Wall Analysis Section 3.dwg

Total Water Weight at toe

$\mathbf{Vol_w := 80.040m^3}$

Volume and centroid of hydrostatic pressure was determined using AutoCAD 3D: File: 3D Transition Wall Analysis Section 3.dwg

$\mathbf{W_w := Vol_w \cdot \gamma_w} = 0.79 \cdot \mathbf{MN}$

$\mathbf{X_w := 1.222m}$

$\mathbf{Y_w := 5.156m}$

$\mathbf{Z_w := 0m}$

Uplift

Total Uplift Force

$\mathbf{F_{uplift} := 7205.50kN}$

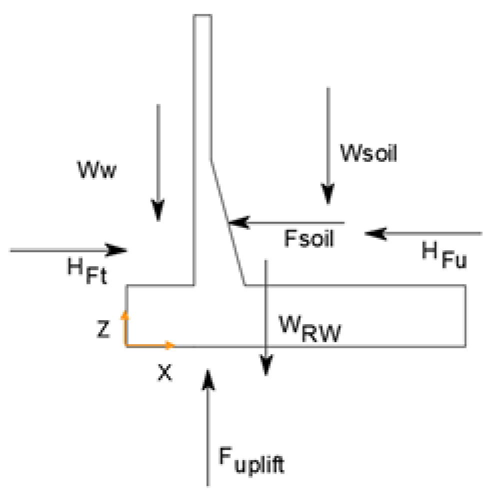
$\mathbf{X_{uplift} := 5.311m}$

$\mathbf{Y_{uplift} := 5.617m}$

$\mathbf{Z_{uplift}} := 0\mathbf{m}$

Volume and centroid of hydrostatic pressure was determined using AutoCAD 3D: File Water Pressure.dwg

Vector Forces Summary



Body diagram, side view

Weight Retaining Wall $\mathbf{W_{RW}} := \left(0 \quad 0 \quad -\mathbf{W_{RW}}\right) = (0 \quad 0 \quad -6.27)\cdot\mathbf{MN}$

Weight Soil $\mathbf{W_{soil}} := \left(0 \quad 0 \quad -\mathbf{W_{soil}}\right) = (0 \quad 0 \quad -10.63)\cdot\mathbf{MN}$

Soil Pressure $\mathbf{F_{soil}} := \left(-\mathbf{F_{soil}} \quad \mathbf{0} \quad 0\right) = (-3.09 \quad 0 \quad 0)\cdot\mathbf{MN}$

Hydrostatic Force Headwater $\mathbf{H_{Fu}} := \left(-\mathbf{H_{Fu}} \quad \mathbf{0} \quad 0\right) = (-2.78 \quad 0 \quad 0)\cdot\mathbf{MN}$

Hydrostatic Force Tailwater $\mathbf{H_{Ft}} := \left(H_{Ft} \quad 0 \quad 0\right) = (2.31 \quad 0 \quad 0)\cdot\mathbf{MN}$

Uplift Force $\mathbf{F_{uplift}} := \left(0 \quad 0 \quad \mathbf{F_{uplift}}\right) = (0 \quad 0 \quad 7.21)\cdot\mathbf{MN}$

Water weight (over toe) $\mathbf{W_w} := \left(0 \quad 0 \quad -\mathbf{W_w}\right) = (0 \quad 0 \quad -0.79)\cdot\mathbf{MN}$

Resultant Total Force

$$\mathbf{F} := \mathbf{W_{RW}} + \mathbf{W_{soil}} + \mathbf{F_{soil}} + \mathbf{H_{Fu}} + \mathbf{H_{Ft}} + \mathbf{F_{uplift}} + \mathbf{W_w}$$

$$\mathbf{F} = (-3.56 \quad 0 \quad -10.48)\cdot\mathbf{MN}$$

Structure Stability

1. Sliding

$236.6\mathbf{m}^3\cdot\gamma_w = 2.32\cdot\mathbf{MN}$

Coefficient of sliding friction $\mu := 0.45$

$$\mathbf{FoS} := \frac{\mathbf{F}_{0,2}\cdot\mu}{\mathbf{F}_{0,0}} = 1.32 \quad > \quad \mathbf{FS_{sliding.req}} = 1.3 \qquad \mathbf{OK}$$

2. Uplift

Summatory of Axial Resistant Forces

$$\mathbf{F_R} := \mathbf{W_{RW}} + \mathbf{W_{soil}} = (0 \quad 0 \quad -16.9)\cdot\mathbf{MN}$$

Uplift Force

$$\mathbf{F_{uplift}} = (0 \quad 0 \quad 7.21)\cdot\mathbf{MN}$$

$$\mathbf{FoS_{uplift}} := \frac{\left|\mathbf{F_R}_{0,2}\right|}{\left|\mathbf{F_{uplift}}_{0,2}\right|} = 2.35 \quad > \quad \mathbf{FS_{float.req}} = 1.3 \qquad \mathbf{OK}$$

3. Overturning

$$\mathbf{r_{RW}} := \left(\mathbf{X_{RW}} \quad Y_{RW} \quad Z_{RW}\right) = (4.72 \quad 5.91 \quad 0)\,\mathbf{m}$$

$$\mathbf{r_{soil}} := \left(X_{soil} \quad Y_{soil} \quad Z_{soil}\right) = (6.4 \quad 4.96 \quad 0)\,\mathbf{m}$$

$$\mathbf{r_{Fsoil}} := \left(X_{Fsoil} \quad Y_{Fsoil} \quad Z_{Fsoil}\right) = (0 \quad 5.04 \quad 2.76)\,\mathbf{m}$$

$$\mathbf{r_{Fu}} := \left(X_{Fu} \quad Y_{Fu} \quad Z_{Fu}\right) = (0 \quad 5.43 \quad 2.37)\,\mathbf{m}$$

$$\mathbf{r_{Ft}} := \left(X_{Ft} \quad Y_{Ft} \quad Z_{Ft}\right) = (0 \quad 5.79 \quad 2.12)\,\mathbf{m}$$

$$\mathbf{r_{uplift}} := \left(X_{uplift} \quad Y_{uplift} \quad Z_{uplift}\right) = (5.31 \quad 5.62 \quad 0)\,\mathbf{m}$$

$$\mathbf{r_{water}} := \left(X_w \quad Y_w \quad Z_w\right) = (1.22 \quad 5.16 \quad 0)\,\mathbf{m}$$

$$\mathbf{M} := \mathbf{W_{RW}}^T \times \mathbf{r_{RW}}^T + \mathbf{W_{soil}}^T \times \mathbf{r_{soil}}^T + \mathbf{F_{soil}}^T \times \mathbf{r_{Fsoil}}^T \cdots$$
$$+ \mathbf{H_{Fu}}^T \times \mathbf{r_{Fu}}^T + \mathbf{H_{Ft}}^T \times \mathbf{r_{Ft}}^T + \mathbf{F_{uplift}}^T \times \mathbf{r_{uplift}}^T + \mathbf{W_w}^T \times \mathbf{r_{water}}^T$$

$$\mathbf{M} = \begin{pmatrix} 53.3 \\ -50.09 \\ -17.31 \end{pmatrix} \cdot \mathbf{MN} \cdot \mathbf{m}$$

$$\mathbf{F} = (-3.56 \quad 0 \quad -10.48) \cdot \mathbf{MN}$$

Location of resultant force:

$$\mathbf{X_R} := \left| \frac{\mathbf{M}_{1,0}}{\mathbf{F}_{0,2}} \right| = 4.78 \cdot \mathbf{m}$$

$$\mathbf{x} := \left| \mathbf{X_R} - \frac{\mathbf{b}}{2} \right| = 0.22\,\mathbf{m} \quad < \quad \frac{\mathbf{b}}{6} = 1.67\,\mathbf{m} \qquad \mathbf{OK}$$

4. **Bearing Capacity**

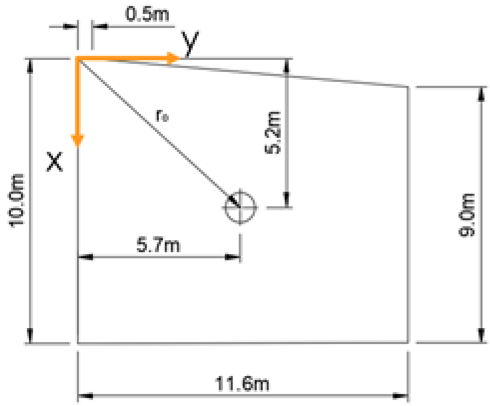
$$\mathbf{q_{all}} := 622\mathbf{kPa}$$

Force and Moment at origin:

$$\mathbf{F} = (-3.56 \quad 0 \quad -10.48) \cdot \mathbf{MN} \qquad \mathbf{M} = \begin{pmatrix} 53.3 \\ -50.09 \\ -17.31 \end{pmatrix} \mathbf{m} \cdot \mathbf{MN}$$

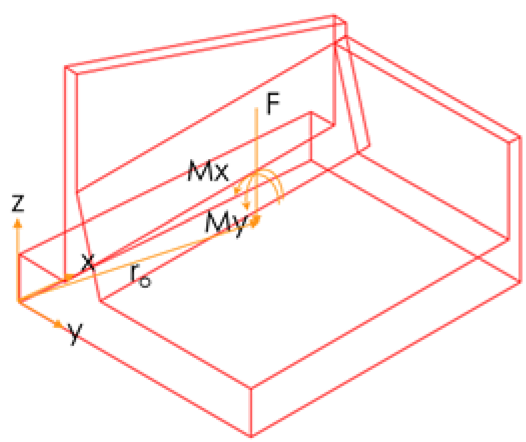
Vector to center of foundation:

$$\mathbf{r_o} := (\mathbf{5.7} \quad \mathbf{5.2} \quad 0)\mathbf{m}$$



Moment at center of Foundation

$$\mathbf{M_o} := \mathbf{M} - \mathbf{F}^{\mathbf{T}} \times \mathbf{r_o}^{\mathbf{T}} = \begin{pmatrix} -1.21 \\ 9.67 \\ 1.2 \end{pmatrix} \mathbf{m} \cdot \mathbf{MN}$$



$$\mathbf{Ix_o} := \mathbf{839.8m^4}$$

$$\mathbf{Iy_o} := \mathbf{1235.5m^4}$$

$$\mathbf{A} := \mathbf{110.43m^2}$$

$$\sigma_{\mathbf{max}} := \left|\frac{\mathbf{F}_{0,2}}{\mathbf{A}}\right| + \left|\frac{\mathbf{M_o}_{0,0}\cdot\mathbf{b}}{2\cdot\mathbf{Ix_o}}\right| + \left|\frac{\mathbf{M_o}_{1,0}\cdot\mathbf{B}}{2\cdot\mathbf{Iy_o}}\right| = 147.53\cdot\mathbf{kPa} \quad < \quad \mathbf{q_{all}} = 622\cdot\mathbf{kPa} \qquad \mathbf{OK}$$

$$\sigma_{\mathbf{min}} := \left|\frac{\mathbf{F}_{0,2}}{\mathbf{A}}\right| - \left|\frac{\mathbf{M_o}_{0,0}\cdot\mathbf{b}}{2\cdot\mathbf{Ix_o}}\right| - \left|\frac{\mathbf{M_o}_{1,0}\cdot\mathbf{B}}{2\cdot\mathbf{Iy_o}}\right| = 42.338\cdot\mathbf{kPa} \quad < \quad \mathbf{q_{all}} = 622\cdot\mathbf{kPa} \qquad \mathbf{OK}$$

TP **Section 3: Extreme Condition (E1)**

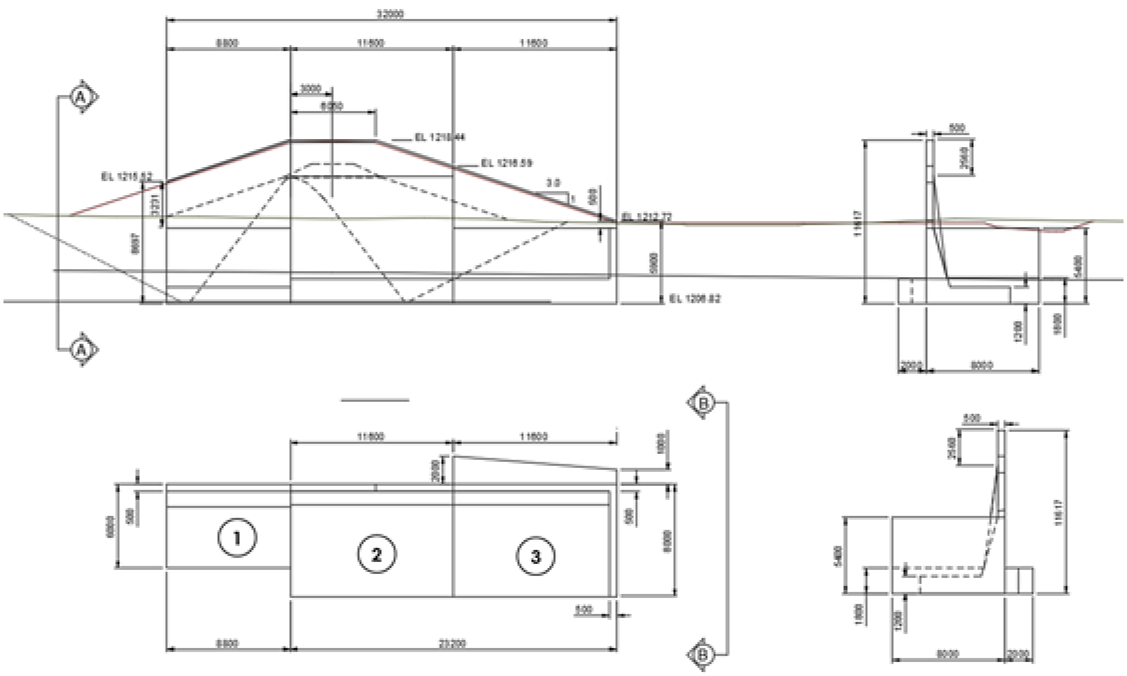
Loading	Horizontal Forces Force (MN)	Horizontal Forces Arm (m)	Vertical Forces Force (MN)	Vertical Forces Arm (m)	Stabilizing Moments (MN-m)	Overturning Moments (MN-m)
Weight of Structure			-6.3	4.7	29.6	
Earthquake Inertia Force						
Soil Mass, front of wall						
Soil Mass, back of wall			-10.6	6.4	68.0	
Soil Pressure, front of wall						
Soil Pressure, back of wall	-3.46	2.78				9.6
Soil Dynamic Pressure, back of wall						
Uplift			7.8	5.3		41.5
Hydrostatic pressure, front of wall	2.67	2.25			6.0	
Hydrostatic pressure, back of wall	-3.21	2.49				8.0
Hydrostatic weight, front of wall			-0.87	1.22	1.1	
SUM	**-4.0**		**-10.0**		**104.7**	**59.1**
					Net Moment	
					45.61	

Stability Calculations
Retaining Wall - Auxiliary Spillway
Right Abutment Transition to Berm

Scope:

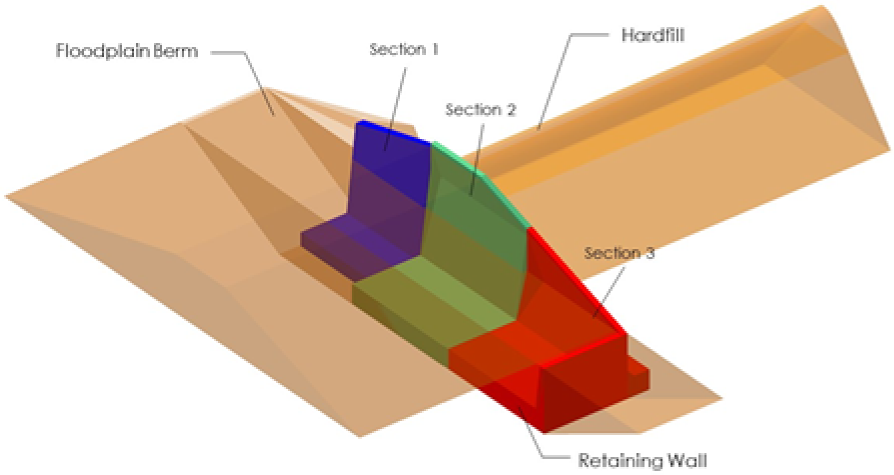
Evaluate the stability of the transition wall of the Auxiliary Spillway. Consider the 3D effects on the structure's stability.

Structure Geometry:



dimensions in mm

Isometric View:



Load Condition

	Elevation (m)			
	Headwater	Tailwater	Headwater	Tailwater
1. Usual Condition (U1)	1214.0	1211.9	7.0	4.9
2. Unusual Condition 1 (UN1)	1214.0	1211.9	7.0	4.9
3. Unusual Condition 2 (UN2)	1216.5	1213.1	9.5	6.1
4. Unusual Condition 3 (UN3)	1217.0	1213.1	10.0	6.1
5. Extreme Condition 1 (E1-F)	1217.3	1213.8	10.3	6.8
6. Extreme Condition 2 (E2-Q)	1213.5	1211.9	6.5	4.9

User Input

Material Properties:

Unit Weight of Water: $\gamma_w := 9.81 \frac{kN}{m^3}$ (Section 7.2, Design Criteria)

Unit Weight of Concrete: $\gamma_c := \mathbf{23.5} \frac{kN}{m^3}$

Unit Weight of Soil (Moist): $\gamma_m := 20.0 \frac{kN}{m^3}$ (Section 5.3, Design Criteria) assumed moisture content (w) = 5%

Unit Weight Soil (Saturated): $\gamma_{sat} := 22.0 \frac{kN}{m^3}$ (Assuming Specific Gravity = 2.7)

Unit Weight Soil (buoyant): $\gamma_b := \gamma_{sat} - \gamma_w = 12.19 \cdot \frac{kN}{m^3}$

Weight of Soil/Concrete above toe: $\gamma_{toe} := 22.0 \frac{kN}{m^3}$

Unit Weight of Rock: $\gamma_r := 25.6 \frac{kN}{m^3}$ (Section 7.2, Design Criteria)

Extreme Condition 1 (E1)

Acceptance Parameters

Resultant Location (Overturning and Bearing Pressure):

Extreme (E1) Resultant located inside middle half (AT/WCS Guidelines, Section 8.4)

Allowable rock bearing pressure: $\mathbf{qall} := 622 \frac{\mathbf{kN}}{\mathbf{m}^2}$ (Internal Geotechnical Design Recommendations Rev. Sept 12, 2018, Section 5.3)

FS Sliding:

Extreme (E1) 1.1 (without cohesion) (CDA Guidelines, Table 6-4, AT/WCS Guidelines, Section 8.3)

Req'd Factor of Safety for Sliding: $\mathbf{FS_{sliding.reqUN}} := 1.1$ (Without Cohesion)

FS Floatation:

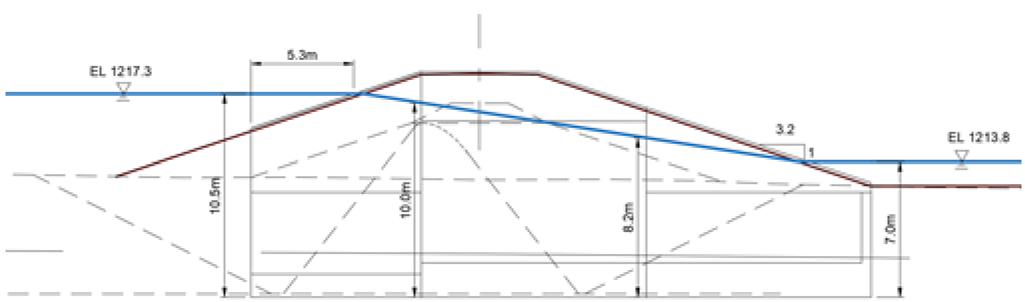
Extreme (E1) 1.1 (AT/WCS Guidelines, Section 8.5)

Req'd Factor of Safety for Floatation: $\mathbf{FS_{float.req.UN}} := 1.1$

Water Surface Elevations

Headwater $\mathbf{H_H} := 1217.4\mathbf{m}$

Tailwater $\mathbf{H_T} := 1213.8\mathbf{m}$



$\mathbf{h_1} := 10.5\mathbf{m}$ $\mathbf{h_2} := 10.\mathbf{m}$ $\mathbf{h_3} := 8.2\mathbf{m}$ $\mathbf{h_4} := 7.0\mathbf{m}$

Interpolated water table heights from retaining wall base.

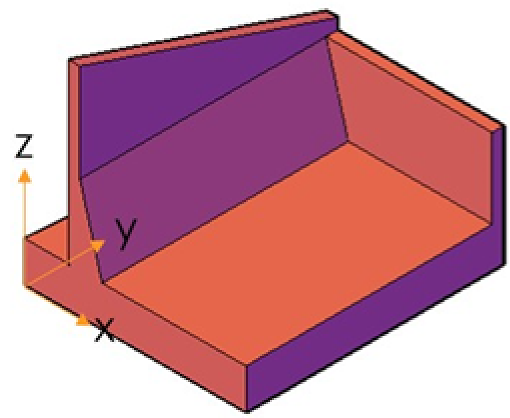
Section 3

Wall Geometry: User Input

Top of Wall Elevation:	$T_w := 1216.59 \cdot m$
Top of Footing Elevation:	$Top_{ftg} := 1208.62 \cdot m$
Thickness of Footing:	$t_{ftg} := 1.80m$
Bottom of Footing Elevation:	$Bot_{ftg} := Top_{ftg} - t_{ftg} = 1206.82\ m$
Overall Height of wall:	$h_w := T_w - Bot_{ftg} = 9.770\ m$
Thickness of Stem Wall at Top:	$t_{wt} := 0.5m$
Slope of Heel Batter:	$S_{batter} := 0.125$
Thickness of Stem Wall at Base:	$t_{wb} := 1.5m$
Length of toe:	$L_{ab} := 2m$
Total Length of Footing:	$b := 10m$ (max)
Length of heel:	$L_{cd} := b - L_{ab} - t_{wb} = 6.5\ m$
Width of Wall:	$B := 11.6m$

Retaining Wall

Retaining Wall Volume and Gravity Center (Using AutoCAD 3D: File: 3D Transition Wall Analysis Section 3.dwg)



Volume

$$Vol_{RW} := 266.863\ m^3$$

$$X_{RW} := 4.723m$$

$$Y_{RW} := 5.905m$$

$$Z_{RW} := 0m$$

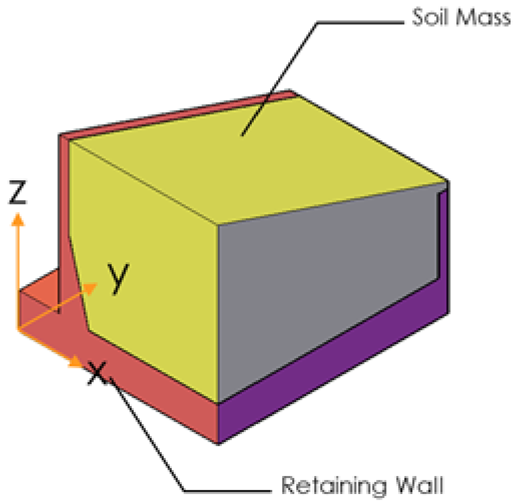
Isometric View

Retaining wall total weight $\quad W_{RW} := Vol_{RW} \cdot \gamma_c = 6.27 \cdot MN$

Soil Mass

Retained Soil Volume and Gravity Center (Using AutoCAD 3D: File: 3D Transition Wall Analysis Section 3.dwg)

Isometric View:



$Vol_{soil} := 483.3\ m^3$

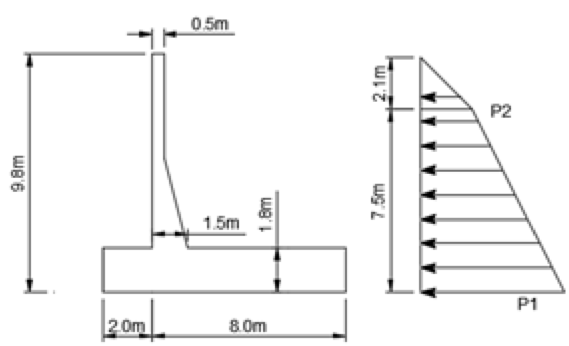
$X_{soil} := 6.396m$

$Y_{soil} := 4.956m$

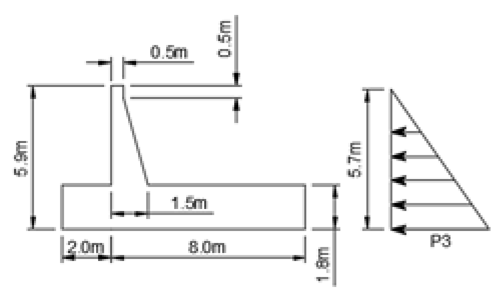
$Z_{soil} := 0m$

Soil mass total weight $W_{soil} := Vol_{soil} \cdot \gamma_{sat} = 10.63 \cdot MN$

Soil Pressure



Section1



Section 2

Section 1

depth to water table $\mathbf{dw} := 2.1\mathbf{m}$

saturated soil depth $\mathbf{ds} := 7.5\mathbf{m}$

soil pressure at rest coefficient $\mathbf{Ko} := 0.55$

$$\mathbf{P2} := \gamma_{\mathbf{m}} \cdot \mathbf{dw} \cdot \mathbf{Ko} = 23.1 \cdot \mathbf{kPa}$$

$$\mathbf{P1} := \mathbf{P2} + \gamma_{\mathbf{b}} \cdot \mathbf{ds} \cdot \mathbf{Ko} = 73.384 \cdot \mathbf{kPa}$$

Section 2

depth to water table $\mathbf{dw} := 0$

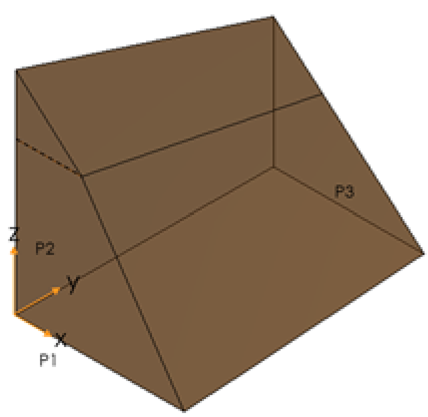
saturated soil depth $\mathbf{ds} := 5.7\mathbf{m}$

soil pressure at rest coefficient $\mathbf{Ko} := 0.55$

$$\mathbf{P4} := \gamma_{\mathbf{m}} \cdot \mathbf{dw} \cdot \mathbf{Ko} = 0 \cdot \mathbf{kPa}$$

$$\mathbf{P3} := \mathbf{P2} + \gamma_{\mathbf{b}} \cdot \mathbf{ds} \cdot \mathbf{Ko} = 61.316 \cdot \mathbf{kPa}$$

Isometric view of the prism representing soil pressures against the retaining wall (Using AutoCAD 3D: File: 3D Transition Wall Analysis Section 3.dwg). The volume of the prism is equal to the equivalent total force.



Isometric View

Total Force

$$\mathbf{F_{soil}} := \mathbf{3459.05kN}$$

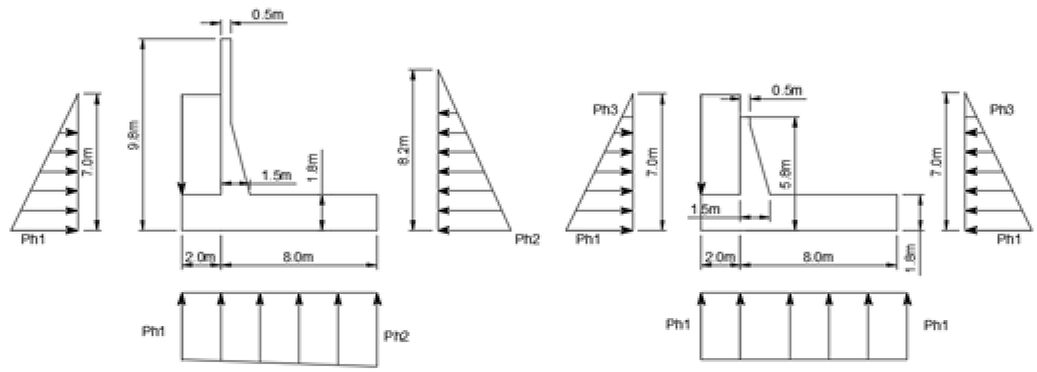
$$\mathbf{X_{Fsoil}} := 0\mathbf{m}$$

$$\mathbf{Y_{Fsoil}} := \mathbf{5.138m}$$

$$\mathbf{Z_{Fsoil}} := \mathbf{2.775m}$$

Hydrostatic Forces

Side View



Section 1 Section 2

Headwater height $\mathbf{h_{Hh}} := 8.2\mathbf{m}$

Tailwater height $\mathbf{h_{Th}} := \mathbf{H_T} - \mathbf{Bot_{ftg}} = 6.98\ \mathbf{m}$

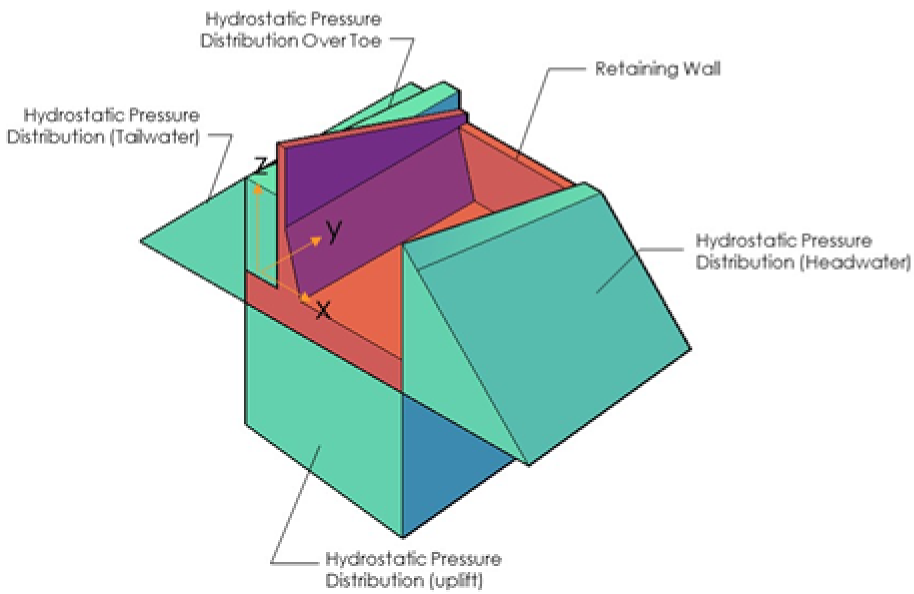
Top of Retaining all to water level Tailwater $\mathbf{d_{Th}} := 6.9\mathbf{m} - 5.8\mathbf{m} = 1.1\ \mathbf{m}$

$$\mathbf{Ph1} := \mathbf{h_{Th}} \cdot \gamma_{\mathbf{w}} = 68.47 \cdot \mathbf{kPa}$$

$$\mathbf{Ph2} := \mathbf{h_{Hh}} \cdot \gamma_{\mathbf{w}} = 80.44 \cdot \mathbf{kPa}$$

$$\mathbf{Ph3} := \mathbf{d_{Th}} \cdot \gamma_{\mathbf{w}} = 10.79 \cdot \mathbf{kPa}$$

Isometric View



Total Hydrostatic Force

Headwater

$H_{Fu} := 3214.66\text{kN}$

$X_{Fu} := 0\text{m}$

$Y_{Fu} := 5.441\text{m}$

$Z_{Fu} := 2.486\text{m}$

Volume and centroid of hydrostatic pressure was determined using AutoCAD 3D: File: 3D Transition Wall Analysis Section 3.dwg

Total Hydrostatic Force

Tailwater

$H_{Ft} := 2669.67\text{kN}$

$X_{Ft} := 0\text{m}$

$Y_{Ft} := 5.775\text{m}$

$Z_{Ft} := 2.253\text{m}$

Volume and centroid of hydrostatic pressure was determined using AutoCAD 3D: File: 3D Transition Wall Analysis Section 3.dwg

Total Water Weight at toe

$\mathbf{Vol_w} := \mathbf{88.740m^3}$

Volume and centroid of hydrostatic pressure was determined using AutoCAD 3D: File Water Pressure.dwg

$\mathbf{W_w} := \mathbf{Vol_w} \cdot \gamma_\mathbf{w} = 0.87 \cdot \mathbf{MN}$

$\mathbf{X_w} := \mathbf{1.222m}$

$\mathbf{Y_w} := \mathbf{5.156m}$

$\mathbf{Z_w} := \mathbf{0m}$

Uplift

Total Uplift Force

$\mathbf{F_{uplift}} := \mathbf{7800.43kN}$

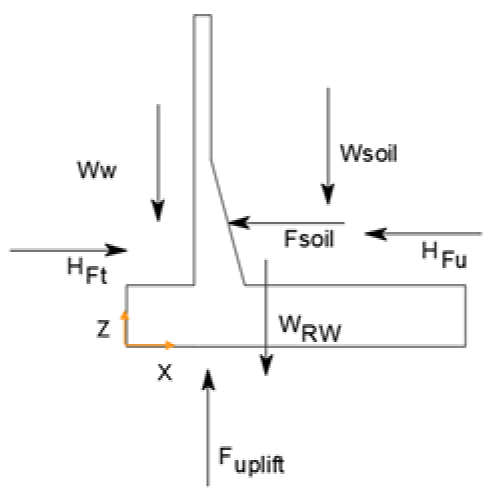
$\mathbf{X_{uplift}} := \mathbf{5.317m}$

$\mathbf{Y_{uplift}} := \mathbf{5.610m}$

$\mathbf{Z_{uplift}} := 0\mathbf{m}$

Volume and centroid of hydrostatic pressure was determined using AutoCAD 3D: File: 3D Transition Wall Analysis Section 3.dwg

Vector Forces Summary



Body diagram, side view

Weight Retaining Wall $\mathbf{W_{RW}} := \begin{pmatrix} 0 & 0 & -\mathbf{W_{RW}} \end{pmatrix} = (0 \quad 0 \quad -6.27)\cdot\mathbf{MN}$

Weight Soil $\mathbf{W_{soil}} := \begin{pmatrix} 0 & 0 & -\mathbf{W_{soil}} \end{pmatrix} = (0 \quad 0 \quad -10.63)\cdot\mathbf{MN}$

Soil Pressure $\mathbf{F_{soil}} := \begin{pmatrix} -\mathbf{F_{soil}} & \mathbf{0} & 0 \end{pmatrix} = (-3.46 \quad 0 \quad 0)\cdot\mathbf{MN}$

Hydrostatic Force Headwater $\mathbf{H_{Fu}} := \begin{pmatrix} -\mathbf{H_{Fu}} & \mathbf{0} & 0 \end{pmatrix} = (-3.21 \quad 0 \quad 0)\cdot\mathbf{MN}$

Hydrostatic Force Tailwater $\mathbf{H_{Ft}} := \begin{pmatrix} H_{Ft} & 0 & 0 \end{pmatrix} = (2.67 \quad 0 \quad 0)\cdot\mathbf{MN}$

Uplift Force $\mathbf{F_{uplift}} := \begin{pmatrix} 0 & 0 & \mathbf{F_{uplift}} \end{pmatrix} = (0 \quad 0 \quad 7.8)\cdot\mathbf{MN}$

Water weight (over toe) $\mathbf{W_w} := \begin{pmatrix} 0 & 0 & -\mathbf{W_w} \end{pmatrix} = (0 \quad 0 \quad -0.87)\cdot\mathbf{MN}$

Resultant Total Force

$$\mathbf{F} := \mathbf{W_{RW}} + \mathbf{W_{soil}} + \mathbf{F_{soil}} + \mathbf{H_{Fu}} + \mathbf{H_{Ft}} + \mathbf{F_{uplift}} + \mathbf{W_w}$$

$$\mathbf{F} = (-4 \quad 0 \quad -9.97)\cdot\mathbf{MN}$$

Structure Stability

1. Sliding

$236.6\mathbf{m}^3 \cdot \gamma_{\mathbf{w}} = 2.32\cdot\mathbf{MN}$

Coefficient of sliding friction $\mu := 0.45$

$$\mathbf{FoS} := \frac{\mathbf{F}_{0,2}\cdot\mu}{\mathbf{F}_{0,0}} = 1.12 \quad > \quad \mathbf{FS_{sliding.reqUN}} = 1.1 \quad \mathbf{OK}$$

2. Uplift

Summatory of Axial Resistant Forces

$$\mathbf{F_R} := \mathbf{W_{RW}} + \mathbf{W_{soil}} = (0 \quad 0 \quad -16.9)\cdot\mathbf{MN}$$

Uplift Force

$$\mathbf{F_{uplift}} = (0 \quad 0 \quad 7.8)\cdot\mathbf{MN}$$

$$\mathbf{FoS_{uplift}} := \frac{\left|\mathbf{F_R}_{0,2}\right|}{\left|\mathbf{F_{uplift}}_{0,2}\right|} = 2.17 \quad > \quad \mathbf{FS_{float.req.UN}} = 1.1 \qquad \mathbf{OK}$$

3. Overturning

$$\mathbf{r_{RW}} := \left(\mathbf{X_{RW}} \quad Y_{RW} \quad Z_{RW}\right) = (4.72 \quad 5.91 \quad 0)\,\mathbf{m}$$

$$\mathbf{r_{soil}} := \left(X_{soil} \quad Y_{soil} \quad Z_{soil}\right) = (6.4 \quad 4.96 \quad 0)\,\mathbf{m}$$

$$\mathbf{r_{Fsoil}} := \left(X_{Fsoil} \quad Y_{Fsoil} \quad Z_{Fsoil}\right) = (0 \quad 5.14 \quad 2.78)\,\mathbf{m}$$

$$\mathbf{r_{Fu}} := \left(X_{Fu} \quad Y_{Fu} \quad Z_{Fu}\right) = (0 \quad 5.44 \quad 2.49)\,\mathbf{m}$$

$$\mathbf{r_{Ft}} := \left(X_{Ft} \quad Y_{Ft} \quad Z_{Ft}\right) = (0 \quad 5.78 \quad 2.25)\,\mathbf{m}$$

$$\mathbf{r_{uplift}} := \left(X_{uplift} \quad Y_{uplift} \quad Z_{uplift}\right) = (5.32 \quad 5.61 \quad 0)\,\mathbf{m}$$

$$\mathbf{r_{water}} := \left(X_w \quad Y_w \quad Z_w\right) = (1.22 \quad 5.16 \quad 0)\,\mathbf{m}$$

$$\mathbf{M} := \mathbf{W_{RW}}^{\mathbf{T}} \times \mathbf{r_{RW}}^{\mathbf{T}} + \mathbf{W_{soil}}^{\mathbf{T}} \times \mathbf{r_{soil}}^{\mathbf{T}} + \mathbf{F_{soil}}^{\mathbf{T}} \times \mathbf{r_{Fsoil}}^{\mathbf{T}} \cdots$$
$$+ \mathbf{H_{Fu}}^{\mathbf{T}} \times \mathbf{r_{Fu}}^{\mathbf{T}} + \mathbf{H_{Ft}}^{\mathbf{T}} \times \mathbf{r_{Ft}}^{\mathbf{T}} + \mathbf{F_{uplift}}^{\mathbf{T}} \times \mathbf{r_{uplift}}^{\mathbf{T}} + \mathbf{W_w}^{\mathbf{T}} \times \mathbf{r_{water}}^{\mathbf{T}}$$

$$\mathbf{M} = \begin{pmatrix} 50.46 \\ -45.64 \\ -19.85 \end{pmatrix} \cdot \mathbf{MN} \cdot \mathbf{m}$$

$$\mathbf{F} = (-4 \quad 0 \quad -9.97) \cdot \mathbf{MN}$$

Location of resultant force:

$$\mathbf{X_R} := \left| \frac{\mathbf{M}_{1,0}}{\mathbf{F}_{0,2}} \right| = 4.58 \cdot \mathbf{m}$$

$$\mathbf{x} := \left| \mathbf{X_R} - \frac{\mathbf{b}}{2} \right| = 0.42\,\mathbf{m} \quad < \quad \frac{\mathbf{b}}{4} = 2.5\,\mathbf{m} \qquad \mathbf{OK}$$

4. **Bearing Capacity**

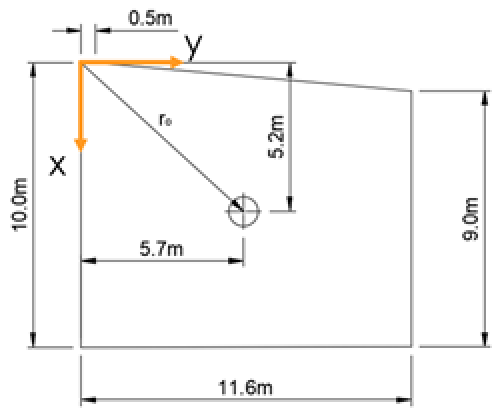
$$\mathbf{q_{all}} := 622\mathbf{kPa}$$

Force and Moment at origin:

$$\mathbf{F} = (-4 \quad 0 \quad -9.97) \cdot \mathbf{MN} \qquad \mathbf{M} = \begin{pmatrix} 50.46 \\ -45.64 \\ -19.85 \end{pmatrix} \mathbf{m} \cdot \mathbf{MN}$$

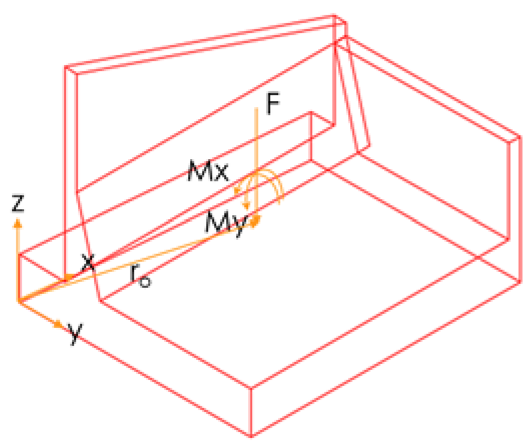
Vector to center of foundation:

$$\mathbf{r_o} := (\mathbf{5.7} \quad \mathbf{5.2} \quad 0)\,\mathbf{m}$$



Moment at center of Foundation

$$\mathbf{M_o} := \mathbf{M} - \mathbf{F}^{\mathbf{T}} \times \mathbf{r_o}^{\mathbf{T}} = \begin{pmatrix} -1.41 \\ 11.21 \\ 0.97 \end{pmatrix} \mathbf{m} \cdot \mathbf{MN}$$



$Ix_o := 839.8m^4$

$Iy_o := 1235.5m^4$

$A := 110.43m^2$

$$\sigma_{max} := \left|\frac{F_{0,2}}{A}\right| + \left|\frac{Mo_{0,0}\cdot b}{2\cdot Ix_o}\right| + \left|\frac{Mo_{1,0}\cdot B}{2\cdot Iy_o}\right| = 151.352\cdot kPa < \quad q_{all} = 622\cdot kPa \quad \text{OK}$$

$$\sigma_{min} := \left|\frac{F_{0,2}}{A}\right| - \left|\frac{Mo_{0,0}\cdot b}{2\cdot Ix_o}\right| - \left|\frac{Mo_{1,0}\cdot B}{2\cdot Iy_o}\right| = 29.287\cdot kPa < \quad q_{all} = 622\cdot kPa \quad \text{OK}$$

TP **Section 3: Extreme Condition (E2)**

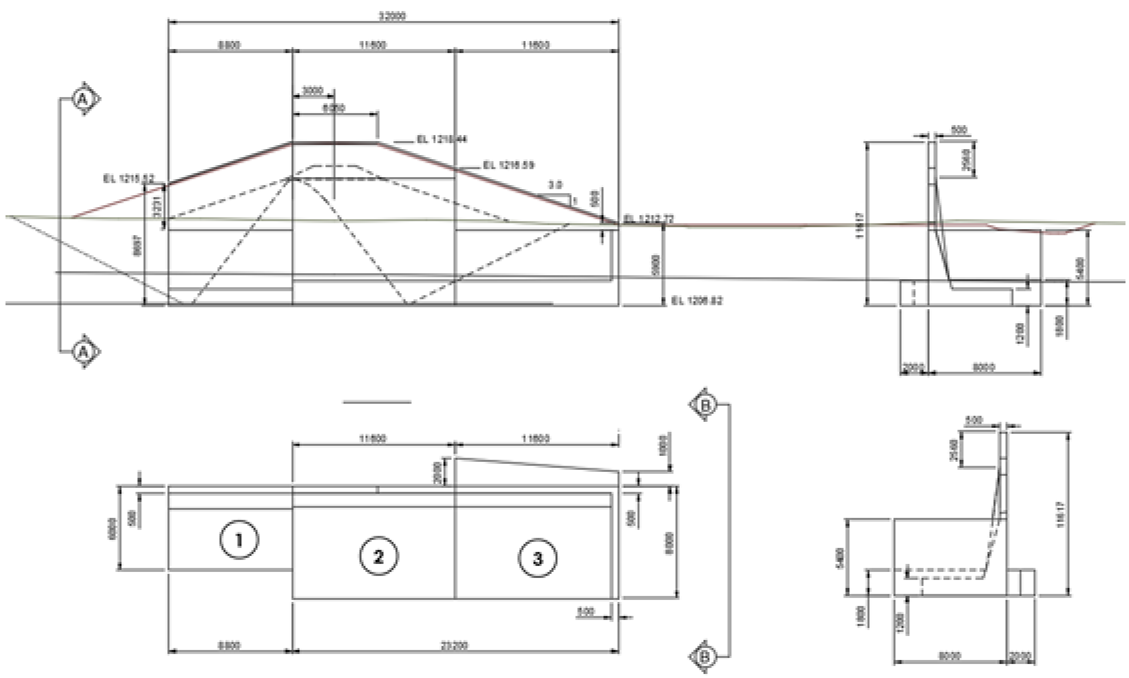
Loading	Horizontal Forces Force (MN)	Horizontal Forces Arm (m)	Vertical Forces Force (MN)	Vertical Forces Arm (m)	Stabilizing Moments (MN-m)	Overturning Moments (MN-m)
Weight of Structure			-6.3	4.7	29.6	
Earthquake Inertia Force	-1.07	1.723				1.84
Soil Mass, front of wall			-1.5	1.2	1.8	
Soil Mass, front of wall, Inertial Force	-0.25	4.85				1.21
Soil Mass, back of wall			-9.7	6.4	61.8	
Soil Mass, back of wall, Inertial Force	-1.64	4.21				6.90
Soil Pressure, front of wall	0.61	2.05				1.25
Soil Pressure, back of wall	-1.13	2.82				3.2
Soil Dynamic Pressure, back of wall	-0.66	5.21				3.5
Uplift			5.7	5.3		30.1
Hydrostatic pressure, front of wall	1.47	1.70				2.5
Hydrostatic pressure, back of wall	-1.69	1.82			3.1	
Hydrostatic weight, front of wall					0.0	
SUM	**-4.4**		**-11.7**		**96.3**	**50.5**
					Net Moment	
					45.81	

Stability Calculations
Retaining Wall - Auxiliary Spillway
Right Abutment Transition to Berm

Scope:

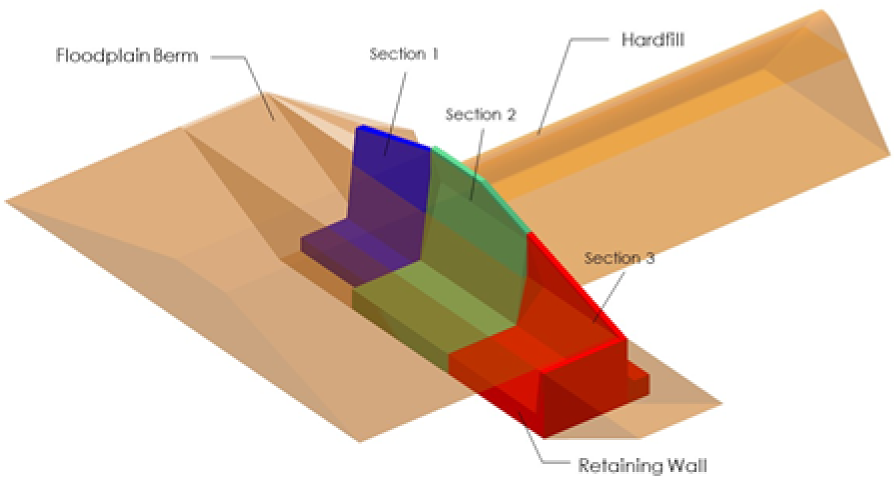
Evaluate the stability of the transition wall of the Auxiliary Spillway. Consider the 3D effects on the structure's stability.

Structure Geometry:



dimensions in mm

Isometric View:



Load Condition

	Elevation (m)			
	Headwater	**Tailwater**	**Headwater**	**Tailwater**
1. Usual Condition (U1)	1214.0	1211.9	7.0	4.9
2. Unusual Condition 1 (UN1)	1214.0	1211.9	7.0	4.9
3. Unusual Condition 2 (UN2)	1216.5	1213.1	9.5	6.1
4. Unusual Condition 3 (UN3)	1217.0	1213.1	10.0	6.1
5. Extreme Condition 1 (E1-F)	1217.3	1213.8	10.3	6.8
6. Extreme Condition 2 (E2-Q)	1213.5	1211.9	6.5	4.9

User Input

Material Properties:

Unit Weight of Water:	$\gamma_w := 9.81\,\frac{kN}{m^3}$	(Section 7.2, Design Criteria)
Unit Weight of Concrete:	$\gamma_c := \mathbf{23.5}\,\frac{kN}{m^3}$	
Unit Weight of Soil (Moist):	$\gamma_m := 20.0\,\frac{kN}{m^3}$	(Section 5.3, Design Criteria) assumed moisture content (w) = 5%
Unit Weight Soil (Saturated):	$\gamma_{sat} := 22.0\,\frac{kN}{m^3}$	(Assuming Specific Gravity = 2.7)
Unit Weight Soil (buoyant):	$\gamma_b := \gamma_{sat} - \gamma_w = 12.19 \cdot \frac{kN}{m^3}$	
Weight of Soil/Concrete above toe:	$\gamma_{toe} := 22.0\,\frac{kN}{m^3}$	
Unit Weight of Rock:	$\gamma_r := 25.6\,\frac{kN}{m^3}$	(Section 7.2, Design Criteria)

Extreme Condition (E2)

Acceptance Parameters

Resultant Location (Overturning and Bearing Pressure):

Extreme (E1) Resultant located inside middle half (AT/WCS Guidelines, Section 8.4)

Allowable rock bearing pressure: $qall := 622 \frac{kN}{m^2}$ (Internal Geotechnical Design Recomendations Rev. Sept 12, 2018, Section 5.3)

FS Sliding:

Extreme (E2) 1.1 (without cohesion) (CDA Guidelines, Table 6-4, AT/WCS Guidelines, Section 8.3)

Req'd Factor of Safety for Sliding: $FS_{sliding.req} := 1.1$ (Without Cohesion)

FS Floatation:

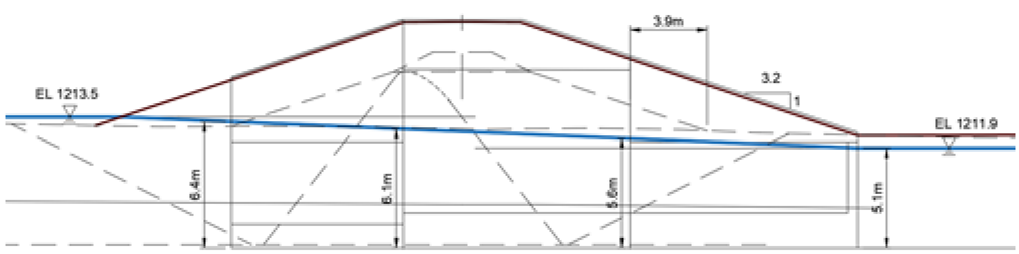
Extreme (E2) 1.1 (AT/WCS Guidelines, Section 8.5)

Req'd Factor of Safety for Floatation: $FS_{float.req} := 1.1$

Water Surface Elevations

Headwater $H_H := 1213.5m$

Tailwater $H_T := 1211.9m$



$h_1 := 6.4m$ $h_2 := 6.1m$ $h_3 := 5.6m$ $h_4 := 5.1m$

Interpolated water table heights from retaining wall base.

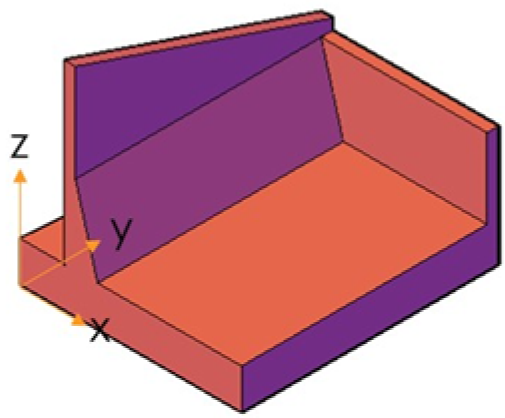
Section 3

Wall Geometry: User Input

Top of Wall Elevation:	$T_w := 1216.59 \cdot m$
Top of Footing Elevation:	$Top_{ftg} := 1208.62 \cdot m$
Thickness of Footing:	$t_{ftg} := 1.80m$
Bottom of Footing Elevation:	$Bot_{ftg} := Top_{ftg} - t_{ftg} = 1206.82\ m$
Overall Height of wall:	$h_w := T_w - Bot_{ftg} = 9.770\ m$
Thickness of Stem Wall at Top:	$t_{wt} := 0.5m$
Slope of Heel Batter:	$S_{batter} := 0.125$
Thickness of Stem Wall at Base:	$t_{wb} := 1.5m$
Length of toe:	$L_{ab} := 4m$
Total Length of Footing:	$b := 10m \quad (max)$
Length of heel:	$L_{cd} := b - L_{ab} - t_{wb} = 4.5\ m$
Width of Wall:	$B := 11.6m$

Retaining Wall

Retaining Wall Volume and Gravity Center (Using AutoCAD 3D: File: 3D Transition Wall Analysis Section 3.dwg)



Isometric View

Volume

$Vol_{RW} := 266.863\ m^3$

$X_{RW} := 4.723m$

$Y_{RW} := 5.905m$

$Z_{RW} := 1.723m$

Retaining wall total weight $W_{RW} := Vol_{RW} \cdot \gamma_c = 6.27 \cdot MN$

Earthquake Inertial Force

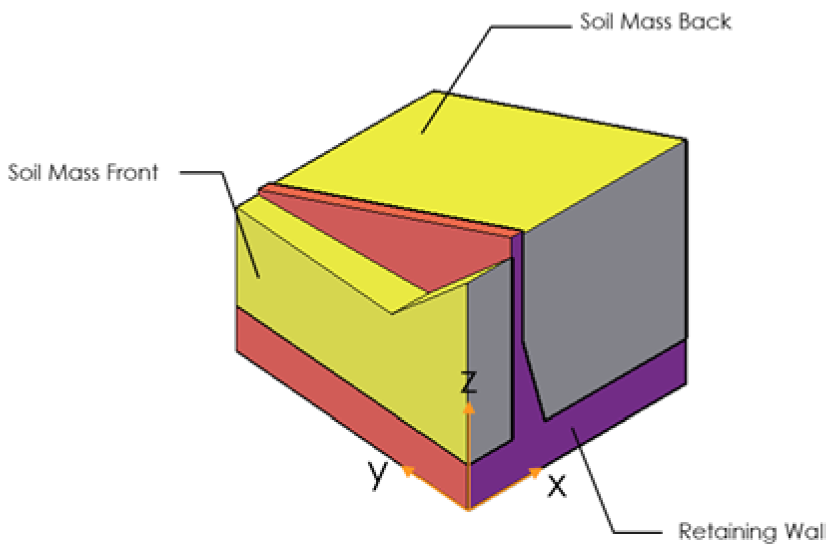
$kh := 0.17$

$F_{RW} := kh \cdot W_{RW} = 1.07 \cdot MN$

Soil Mass

Retained Soil Volume and Gravity Center (Using AutoCAD 3D: File 3D Transition Wall Analysis Section 3.dwg)

Isometric View:



Front of Wal

$\mathbf{Vol_{soilf}} := \mathbf{73.588\ m^3}$

$\mathbf{X_{soilf}} := \mathbf{1.209m}$

$\mathbf{Y_{soilf}} := \mathbf{4.850m}$

$\mathbf{Z_{soilf}} := \mathbf{3.944m}$

Soil mass total weight

$\mathbf{W_{soilf}} := \mathbf{Vol_{soilf}} \cdot \gamma_{\mathbf{m}} = 1.47 \cdot \mathbf{MN}$

Earthquake Inertial Force

$\mathbf{Fsoilb_{AE}} := \mathbf{kh} \cdot \mathbf{W_{soilf}} = 0.25 \cdot \mathbf{MN}$

Back of Wall

$\mathbf{Vol_{soilb}} := 483.3\ \mathbf{m^3}$

$\mathbf{X_{soilb}} := 6.396\mathbf{m}$

$\mathbf{Y_{soilb}} := \mathbf{4.956m}$

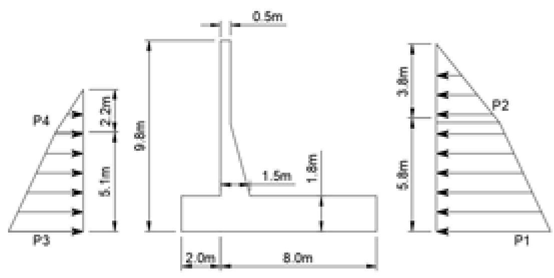
$\mathbf{Z_{soilb}} := 4.995\mathbf{m}$

Soil mass total weight

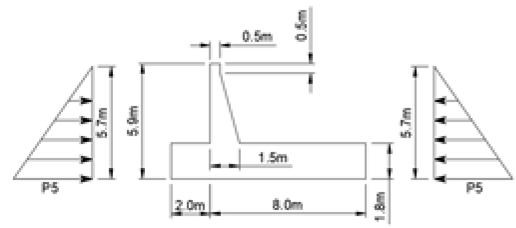
$\mathbf{W_{soilb}} := \mathbf{Vol_{soilb}} \cdot \gamma_{\mathbf{m}} = 9.67 \cdot \mathbf{MN}$

$\mathbf{Fsoilf_{AE}} := \mathbf{kh} \cdot \mathbf{W_{soilb}} = 1.64 \cdot \mathbf{MN}$

Soil Pressure



Section1



Section 2

Section 1

Back of Retaining Wall

depth to water table $\mathbf{dw} := 3.8\mathbf{m}$

saturated soil depth $\mathbf{ds} := 5.8\mathbf{m}$

soil pressure at rest coefficient $\mathbf{Ka} := 0.21$

$$\mathbf{P2} := \gamma_{\mathbf{m}} \cdot \mathbf{dw} \cdot \mathbf{Ka} = 15.96 \cdot \mathbf{kPa}$$

$$\mathbf{P1} := \mathbf{P2} + \gamma_{\mathbf{b}} \cdot \mathbf{ds} \cdot \mathbf{Ka} = 30.807 \cdot \mathbf{kPa}$$

Front of Retaining Wall

depth to water table $\mathbf{dw} := 2.2\mathbf{m}$

saturated soil depth $\mathbf{ds} := 5.1\mathbf{m}$

soil pressure at rest coefficient $\mathbf{Ka} := 0.21$

$$\mathbf{P4} := \gamma_{\mathbf{m}} \cdot \mathbf{dw} \cdot \mathbf{Ka} = 9.24 \cdot \mathbf{kPa}$$

$$\mathbf{P3} := \mathbf{P2} + \gamma_{\mathbf{b}} \cdot \mathbf{ds} \cdot \mathbf{Ka} = 29.015 \cdot \mathbf{kPa}$$

Section 2

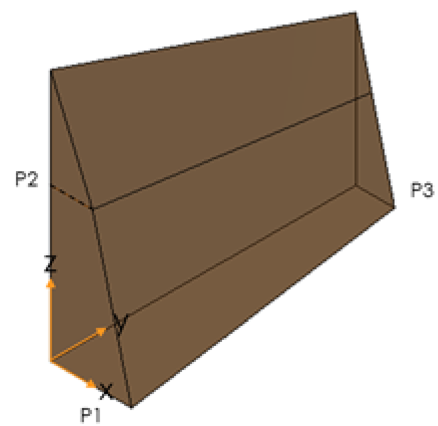
depth to water table $\mathbf{dw} := 0$

saturated soil depth $\mathbf{ds} := 5.8\mathbf{m}$

soil pressure at rest coefficient $\mathbf{Ka} := 0.21$

$$\mathbf{P5} := \gamma_{\mathbf{b}} \cdot \mathbf{ds} \cdot \mathbf{Ka} = 14.847 \cdot \mathbf{kPa}$$

Isometric view of the prism representing soil pressures against the retaining wall (Using AutoCAD 3D: 3D Transition Wall Analysis Section 3.dwg). The volume of the prism is equal to the equivalent total force.



Isometric View

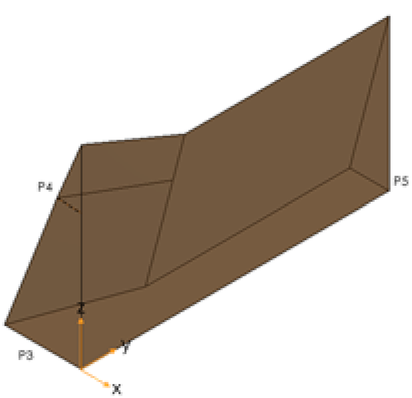
Total Force Back Soil

$\mathbf{F_{soilb}} := \mathbf{1133.18kN}$

$\mathbf{X_{Fsoilb}} := 0\mathbf{m}$

$\mathbf{Y_{Fsoilb}} := \mathbf{4.577m}$

$\mathbf{Z_{Fsoilb}} := \mathbf{2.821m}$



Total Force Front Soil

$\mathbf{F_{soilf}} := \mathbf{610.70kN}$

$\mathbf{X_{Fsoilf}} := 0\mathbf{m}$

$\mathbf{Y_{Fsoilf}} := \mathbf{4.909m}$

$\mathbf{Z_{Fsoilf}} := \mathbf{2.051m}$

Seismic Loading

$\phi_w := 38\mathbf{deg}$ internal friction angle of soil

$\psi := \mathbf{atan}\left(\frac{0.28}{1-0.16}\right) = 18.43 \cdot \mathbf{deg}$ seismic inertia angle

$\beta := 0\mathbf{deg}$ inclination of soil surface

$$K_{AE} := \frac{\cos(\phi_w - \psi)^2}{\cos(\psi)^2 \cdot \left(1 + \sqrt{\frac{\sin(\phi_w)\cdot\sin(\phi_w - \psi - \beta)}{\cos(\beta)\cdot\cos(\psi)}}\right)^2}$$

$K_{AE} = 0.46$

Section 1

Back of Retaining Wall

depth to water table $\mathbf{dw} := 2.2\mathbf{m}$

saturated soil depth $\mathbf{ds} := 5.1\mathbf{m}$

$\Delta\mathbf{P2} := \gamma_m \cdot \mathbf{dw} \cdot K_{AE} - \mathbf{P2} = 4.23 \cdot \mathbf{kPa}$

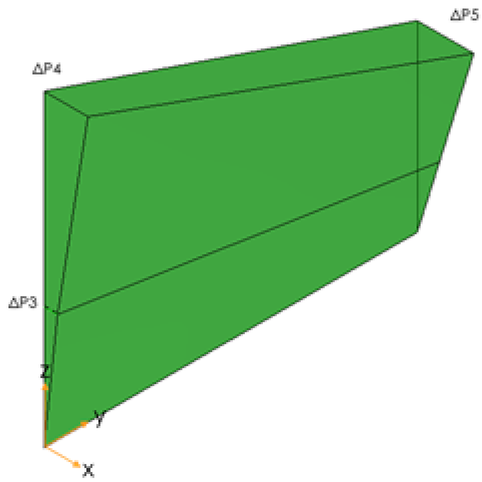
$\Delta\mathbf{P1} := \mathbf{P2} + \Delta\mathbf{P2} + \gamma_b \cdot \mathbf{ds} \cdot K_{AE} - \mathbf{P1} = 17.914 \cdot \mathbf{kPa}$

Section 2

depth to water table $\mathbf{dw} := 0$

saturated soil depth $\mathbf{ds} := 5.8\mathbf{m}$

$\Delta\mathbf{P5} := \gamma_b \cdot \mathbf{ds} \cdot K_{AE} - \mathbf{P5} = 17.598 \cdot \mathbf{kPa}$



Total Force Dynamic Soil Pressure

$$F_{AE} := 661.76\mathbf{kN}$$

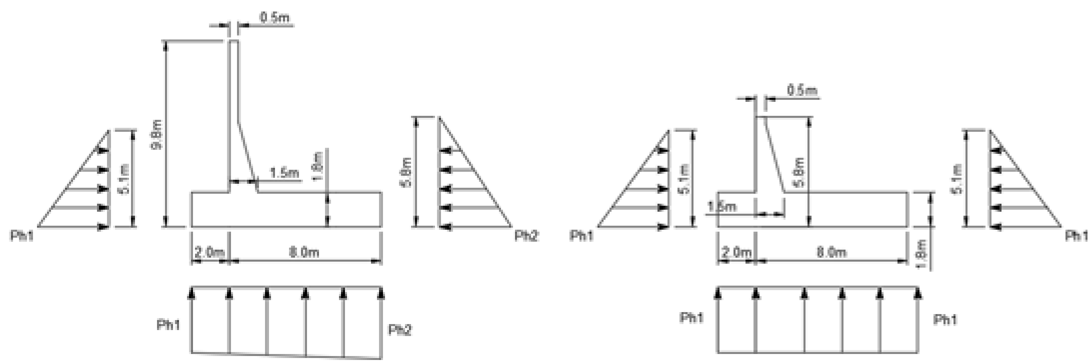
$$X_{AE} := 0\mathbf{m}$$

$$Y_{AE} := 5.643\mathbf{m}$$

$$Z_{AE} := 5.214\mathbf{m}$$

Hydrostatic Forces

Side View



Section 1 Section 2

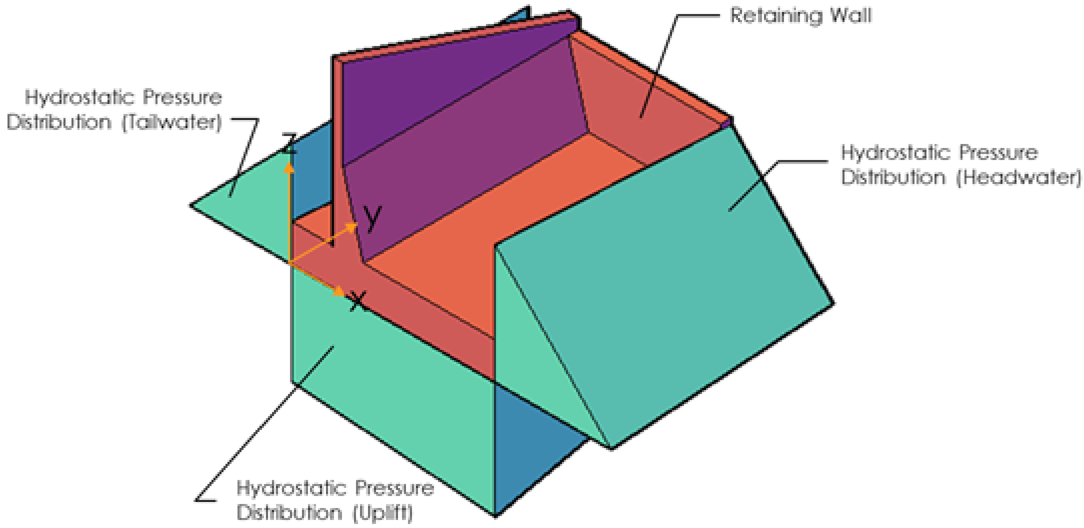
Headwater height $h_{Hh} := 5.8\mathbf{m}$

Tailwater height $h_{Th} := H_T - Bot_{ftg} = 5.08\ \mathbf{m}$

$$\mathbf{Ph1} := h_{Th} \cdot \gamma_w = 49.83 \cdot \mathbf{kPa}$$

$$\mathbf{Ph2} := h_{Hh} \cdot \gamma_w = 56.9 \cdot \mathbf{kPa}$$

Isometric View



Total Hydrostatic Force

Headwater

$H_{Fu} := 1687.87\,kN$

$X_{Fu} := 0\,m$

$Y_{Fu} := 5.546\,m$

$Z_{Fu} := 1.822\,m$

Volume and centroid of hydrostatic pressure was determined using AutoCAD 3D: File 3D Transition Wall Analysis Section 3.dwg

Total Hydrostatic Force

Tailwater

$H_{Ft} := 1471.31\,kN$

$X_{Ft} := 0\,m$

$Y_{Ft} := 5.800\,m$

$Z_{Ft} := 1.700\,m$

Volume and centroid of hydrostatic pressure was determined using AutoCAD 3D: File 3D Transition Wall Analysis Section 3.dwg

Uplift

Total Uplift Force

$F_{uplift} := 5689.46\,kN$

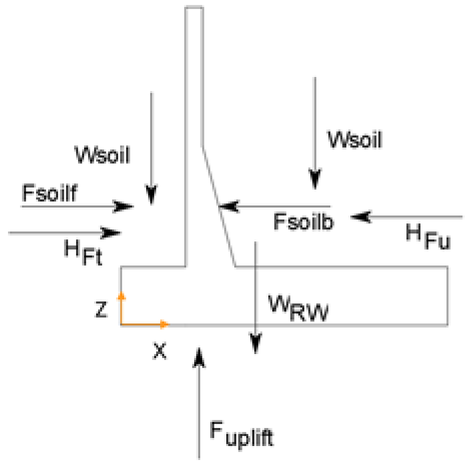
$X_{uplift} := 5.299\,m$

$Y_{uplift} := 5.632\,m$

$Z_{uplift} := 0\,m$

Volume and centroid of hydrostatic pressure was determined using AutoCAD 3D: File 3D Transition Wall Analysis Section 3.dwg

Vector Forces Summary



Body diagram, side view

Weight Retaining Wall	$\mathbf{W_{RW}} := \left(-F_{RW} \quad 0 \quad -\mathbf{W_{RW}}\right) = (-1.07 \quad 0 \quad -6.27)\cdot\mathbf{MN}$
Weight Soil (Back of Wall)	$\mathbf{W_{soilb}} := \left(-Fsoilb_{AE} \quad 0 \quad -\mathbf{W_{soilb}}\right) = (-0.25 \quad 0 \quad -9.67)\cdot\mathbf{MN}$
Weight Soil (Front of Wall)	$\mathbf{W_{soilf}} := \left(-Fsoilf_{AE} \quad 0 \quad -\mathbf{W_{soilf}}\right) = (-1.64 \quad 0 \quad -1.47)\cdot\mathbf{MN}$
Soil Pressure (Back of Wall)	$\mathbf{F_{soilb}} := \left(-\mathbf{F_{soilb}} \quad 0 \quad 0\right) = (-1.13 \quad 0 \quad 0)\cdot\mathbf{MN}$
Soil Pressure (Front of Wall)	$\mathbf{F_{soilf}} := \left(\mathbf{F_{soilf}} \quad 0 \quad 0\right) = (0.61 \quad 0 \quad 0)\cdot\mathbf{MN}$
Hydrostatic Force Headwater	$\mathbf{H_{Fu}} := \left(-\mathbf{H_{Fu}} \quad \mathbf{0} \quad 0\right) = (-1.69 \quad 0 \quad 0)\cdot\mathbf{MN}$
Hydrostatic Force Tailwater	$\mathbf{H_{Ft}} := \left(\mathbf{H_{Ft}} \quad 0 \quad 0\right) = (1.47 \quad 0 \quad 0)\cdot\mathbf{MN}$
Uplift Force	$\mathbf{F_{uplift}} := \left(0 \quad 0 \quad \mathbf{F_{uplift}}\right) = (0 \quad 0 \quad 5.69)\cdot\mathbf{MN}$
Soil Dynamic Pressure	$\mathbf{F_{AE}} := \left(-\mathbf{F_{AE}} \quad 0 \quad 0\right) = (-0.66 \quad 0 \quad 0)\cdot\mathbf{MN}$

Resultant Total Force

$$\mathbf{F} := \mathbf{W_{RW}} + \mathbf{W_{soilb}} + \mathbf{W_{soilf}} + \mathbf{F_{soilb}} + \mathbf{F_{soilf}} + \mathbf{H_{Fu}} + \mathbf{H_{Ft}} + \mathbf{F_{uplift}} + \mathbf{F_{AE}}$$

$$\mathbf{F} = (-4.36 \quad 0 \quad -11.72)\cdot\mathbf{MN}$$

Structure Stability

1. Sliding

$$236.6\mathbf{m}^3\cdot\gamma_\mathbf{w} = 2.32\cdot\mathbf{MN}$$

Coefficient of sliding friction $\mu := 0.45$

$$\mathbf{FoS} := \frac{\mathbf{F}_{0,2}\cdot\mu}{\mathbf{F}_{0,0}} = 1.21 \qquad > \qquad \mathbf{FS_{sliding.req}} = 1.1 \qquad \mathbf{OK}$$

2. Uplift

Summatory of Axial Resistant Forces

$$\mathbf{F_R} := \mathbf{W_{RW}} + \mathbf{W_{soilf}} + \mathbf{W_{soilb}} = (-2.96 \quad 0 \quad -17.41)\cdot\mathbf{MN}$$

Uplift Force

$$\mathbf{F_{uplift}} = (0 \quad 0 \quad 5.69)\cdot\mathbf{MN}$$

$$\mathbf{FoS_{uplift}} := \frac{\left|\mathbf{F_R}_{0,2}\right|}{\left|\mathbf{F_{uplift}}_{0,2}\right|} = 3.06 \qquad > \qquad \mathbf{FS_{float.req}} = 1.1 \qquad \mathbf{OK}$$

3. Overturning

$$\mathbf{r_{RW}} := \left(\mathbf{X_{RW}} \quad Y_{RW} \quad Z_{RW} \right) = (4.72 \quad 5.91 \quad 1.72)\ \mathbf{m}$$

$$\mathbf{r_{soilb}} := \left(X_{soilb} \quad Y_{soilb} \quad Z_{soilb} \right) = (6.4 \quad 4.96 \quad 5)\ \mathbf{m}$$

$$\mathbf{r_{soilf}} := \left(X_{soilf} \quad Y_{soilf} \quad Z_{soilf} \right) = (1.21 \quad 4.85 \quad 3.94)\ \mathbf{m}$$

$$\mathbf{r_{Fsoilb}} := \left(X_{Fsoilb} \quad Y_{Fsoilb} \quad Z_{Fsoilb} \right) = (0 \quad 4.58 \quad 2.82)\ \mathbf{m}$$

$$\mathbf{r_{Fsoilf}} := \left(X_{Fsoilf} \quad Y_{Fsoilf} \quad Z_{Fsoilf} \right) = (0 \quad 4.91 \quad 2.05)\ \mathbf{m}$$

$$\mathbf{r_{Fu}} := \left(X_{Fu} \quad Y_{Fu} \quad Z_{Fu} \right) = (0 \quad 5.55 \quad 1.82)\ \mathbf{m}$$

$$\mathbf{r_{Ft}} := \left(X_{Ft} \quad Y_{Ft} \quad Z_{Ft} \right) = (0 \quad 5.8 \quad 1.7)\ \mathbf{m}$$

$$\mathbf{r_{uplift}} := \left(X_{uplift} \quad Y_{uplift} \quad Z_{uplift} \right) = (5.3 \quad 5.63 \quad 0)\ \mathbf{m}$$

$$\mathbf{r_{AE}} := \left(\mathbf{X_{AE}} \quad \mathbf{Y_{AE}} \quad \mathbf{Z_{AE}} \right) = (0 \quad 5.64 \quad 5.21)\ \mathbf{m}$$

$$\begin{aligned}\mathbf{M} := \ & \mathbf{W_{RW}}^{\mathbf{T}} \times \mathbf{r_{RW}}^{\mathbf{T}} + \mathbf{W_{soilb}}^{\mathbf{T}} \times \mathbf{r_{soilb}}^{\mathbf{T}} + \mathbf{W_{soilf}}^{\mathbf{T}} \times \mathbf{r_{soilf}}^{\mathbf{T}} + \mathbf{F_{soilb}}^{\mathbf{T}} \times \mathbf{r_{Fsoilb}}^{\mathbf{T}} \ldots \\ & + \mathbf{F_{soilf}}^{\mathbf{T}} \times \mathbf{r_{Fsoilf}}^{\mathbf{T}} + \mathbf{H_{Fu}}^{\mathbf{T}} \times \mathbf{r_{Fu}}^{\mathbf{T}} + \mathbf{H_{Ft}}^{\mathbf{T}} \times \mathbf{r_{Ft}}^{\mathbf{T}} + \mathbf{F_{uplift}}^{\mathbf{T}} \times \mathbf{r_{uplift}}^{\mathbf{T}} + \mathbf{F_{AE}}^{\mathbf{T}} \times \mathbf{r_{AE}}^{\mathbf{T}}\end{aligned}$$

$$\mathbf{M} = \begin{pmatrix} 60.03 \\ -47.54 \\ -22.26 \end{pmatrix} \cdot \mathbf{MN} \cdot \mathbf{m}$$

$$\mathbf{F} = (-4.36 \quad 0 \quad -11.72) \cdot \mathbf{MN}$$

Location of resultant force:

$$\mathbf{X_R} := \left| \frac{\mathbf{M}_{1,0}}{\mathbf{F}_{0,2}} \right| = 4.06 \cdot \mathbf{m}$$

$$\mathbf{x} := \left| \mathbf{X_R} - \frac{\mathbf{b}}{2} \right| = 0.94\ \mathbf{m} \quad < \quad \frac{\mathbf{b}}{4} = 2.5\ \mathbf{m} \qquad \mathbf{OK}$$

4. **Bearing Capacity**

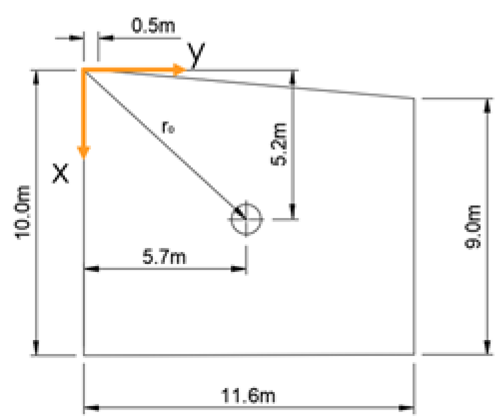
$$\mathbf{q_{all}} := 622\,\mathbf{kPa}$$

Force and Moment at origin:

$$\mathbf{F} = \begin{pmatrix} -4.36 & 0 & -11.72 \end{pmatrix} \cdot \mathbf{MN} \qquad \mathbf{M} = \begin{pmatrix} 60.03 \\ -47.54 \\ -22.26 \end{pmatrix} \mathbf{m} \cdot \mathbf{MN}$$

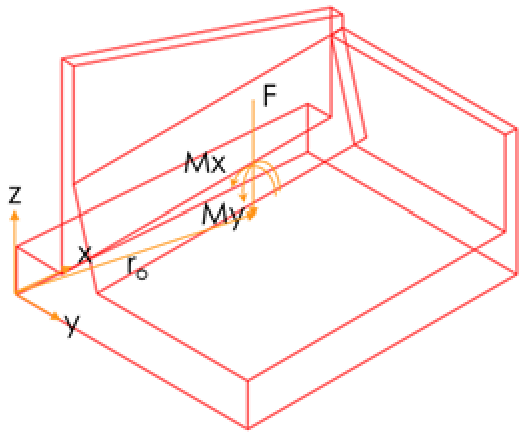
Vector to center of foundation:

$$\mathbf{r_o} := \begin{pmatrix} \mathbf{5.7} & \mathbf{5.2} & 0 \end{pmatrix} \mathbf{m}$$



Moment at center of Foundation

$$\mathbf{M_o} := \mathbf{M} - \mathbf{F}^{\mathbf{T}} \times \mathbf{r_o}^{\mathbf{T}} = \begin{pmatrix} -0.91 \\ 19.26 \\ 0.42 \end{pmatrix} \mathbf{m} \cdot \mathbf{MN}$$



$$\mathbf{Ix_o} := \mathbf{839.8m}^4$$

$$\mathbf{Iy_o} := \mathbf{1235.5m}^4$$

$$\mathbf{A} := \mathbf{110.43m}^2$$

$$\sigma_{\mathbf{max}} := \left|\frac{\mathbf{F}_{0,2}}{\mathbf{A}}\right| + \left|\frac{\mathbf{M_o}_{0,0} \cdot \mathbf{b}}{2 \cdot \mathbf{Ix_o}}\right| + \left|\frac{\mathbf{M_o}_{1,0} \cdot \mathbf{B}}{2 \cdot \mathbf{Iy_o}}\right| = 201.979 \cdot \mathbf{kPa} < \quad \mathbf{q_{all}} = 622 \cdot \mathbf{kPa} \quad \mathbf{OK}$$

$$\sigma_{\mathbf{min}} := \left|\frac{\mathbf{F}_{0,2}}{\mathbf{A}}\right| - \left|\frac{\mathbf{M_o}_{0,0} \cdot \mathbf{b}}{2 \cdot \mathbf{Ix_o}}\right| - \left|\frac{\mathbf{M_o}_{1,0} \cdot \mathbf{B}}{2 \cdot \mathbf{Iy_o}}\right| = 10.274 \cdot \mathbf{kPa} < \quad \mathbf{q_{all}} = 622 \cdot \mathbf{kPa} \quad \mathbf{OK}$$

Appendix E.3-3 AUXILIARY SPILLWAY DRAWINGS

Refer to Preliminary Design Report - Appendix A for drawings.

Springbank Off-Stream Storage Project Structural Design Report

Low-Level Outlet Works

Prepared for:

Alberta Transportation
3rd Floor – Twin Atria Building
4999 – 98 Avenue
Edmonton, AB T6B 2X3

Prepared by:

Stantec Consulting Ltd
Calgary, AB

Project Number 110773396

June 30, 2020

Table of Contents

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

1.0 INTRODUCTION

1.1 PURPOSE

This Structural Design Report (SDR) describes stability assessment, structural analyses and design of the Low-Level Outlet Works (LLOW), which is part of the Springbank Off-stream Storage Project (SR1). The SDR consolidates and documents the design philosophy, relevant criteria, primary design parameters, and reference source of data used for design. The LLOW structures were sized to meet stability requirements and structural members were designed for conformance with structural criteria.

1.2 PROJECT OVERVIEW

SR1 is a flood diversion system comprised of a diversion structure, a diversion channel and off-stream dry storage reservoir (no permanent pool). When in operation, SR1 will divert and temporarily store excess flood water from the Elbow River and release it back into the river system in a controlled manner. SR1 will work in tandem with the downstream Glenmore Reservoir to limit flood flows downstream of Glenmore to less than 170 m^3/s for up to SR1's design event - the 2013 flood or its equivalent.

Elements of the project are:

- Diversion Structure on the Elbow River consisting of, from left to right when looking downstream, gated Diversion Inlet structure leading to a Diversion Channel, gated Service Spillway located on the Elbow River, adjacent Auxiliary Spillway and a Floodplain Berm. A Debris Deflection Barrier is in the headwater of the Diversion Structure to protect the Diversion Inlet from flood debris.

- Diversion Channel leading from the Elbow River at the Diversion Inlet to the Off-stream Storage Reservoir with an Emergency Spillway along the channel and Channel Outlet at end of the channel.

- Off-stream Storage Dam with Low-Level Outlet Works.

1.3 DESIGN OBJECTIVES

Design requirements for the LLOW are described in the Discharge Capacity – Low-Level Outlet Memorandum (June 7, 2016), which is summarized below:

- Provide a LLOW with a maximum capacity of 27 m^3/s to satisfy reservoir evacuation criteria from maximum diversion storage pool, EL 1210.75 m in 40 days.
- Design the LLOW to pass the stream flow from the Off-Stream Storage Dam local watershed without creating a permanent pool, i.e., a dry storage reservoir with minimal dead storage space.

1.4 GENERAL ARRANGEMENT

The selected LLOW arrangement that satisfies the design objectives and criteria is a pressurized drainage structure transitioning to a gated gravity drainage structure located within the existing unnamed stream floodplain and constructed through the embankment dam at Dam station 23+022. Primary elements of the LLOW include:

- Intake structure consisting of a reinforced concrete frame incorporating eight trash rack panels.
- Transition conduit of reinforced concrete that provides the conduit transition from the intake structure gate opening to the pressure conduit.
- Pressure conduit providing drainage with a circular shape reinforced concrete conduit running from the intake structure to the gate structure. The conduit becomes pressurized when diverted flood water is stored in the reservoir.
- Gate structure of reinforced concrete that houses the stainless-steel fabricated slide gates in two wet wells and transitions from pressurized conduit to gravity conduit.
- Gravity conduit providing drainage with a modified basket handle shaped, reinforced concrete conduit running from the gate structure to the CSU rigid basin.
- CSU rigid basin of cast-in-place reinforced concrete located at the downstream end of the gravity conduit. The basin provides an energy dissipating transition from the conduit to the outlet channel.

The general arrangement of the LLOW is depicted on Drawing S-400. Details of each component are shown on the S-400 series Drawings.

Typically, the LLOW acts as an open channel drainage structure through the dam with the regulating gate open. This arrangement provides flow passage for runoff from the off-stream storage dam watershed so as not to create a permanent pool. When diversion is to be initiated, the regulating gate in the LLOW intake is closed to provide detention storage for diverted flows from the Elbow River. Once the flood has passed, the gate is operated to release reservoir storage in a controlled manner downstream into the Elbow River.

1.5 BASIS FOR STRUCTURE LAYOUT

The LLOW layout and sizing is based on hydrotechnical evaluation to establish overall geometry, top of dam elevation, and hydraulic profiles to set crest elevation, stilling basin floor and blocks, and sizing of the gates.

The LLOW location was selected so that the foundation would be on glacial till to provide a uniform foundation, the conduit will be excavated through the existing subgrade materials and not through the embankment, and it would allow separate construction of the LLOW in a dry location until ready for diversion of the unnamed creek.

2.0 CODES AND STANDARDS

In accordance with "terms of reference" for this project, the design complies with current Alberta Transportation (AT) Design Standards and current AT Design and Construction Bulletins. By reference in AT Standards, Canadian Dam Association (CDA) Dam Safety Guidelines and Technical Bulletin Nos. 1 through 9 provided primary guidance for design of the project including the hydraulic structures. Other recognized industry standards referenced in the AT/CDA Guidelines were used to supplement aspects of the design that the AT/CDA Guidelines do not address. Such references include the US Army Corps of Engineers (USACE) Engineering Manuals and US Bureau of Reclamation (USBR) Design Standards. In case of conflicting criteria, AT provisions were used unless a "more stringent" requirement was deemed appropriate based on engineering judgement.

Where referenced by AT and CDA, the National Building Code of Canada (NBCC) and Alberta Building Code (ABC) were used to obtain certain design loads (wind, snow, live, vehicle), and develop load combinations associated with strength and serviceability. NBCC and ABC provisions were used primarily for evaluation of individual elements such as gratings, ladders, and other ancillary structures.

The following codes, guidelines, and standards were identified for use on this project:

2.1 PROJECT STANDARDS

- Alberta Government, Terms of Reference (TOR0015997) for "Flood Mitigation Works, Springbank Off-Stream Storage Project (SR1) (WAC0078983), Addendum No. 2," August 1, 2014.
- AT's "Engineering Consultant Guidelines for Highway Bridge and Water Projects, Volume 1- Design & Tender" - 2011.
- AT's "Engineering Consultant Guidelines for Highway Bridge and Water Projects, Volume 2- Design & Tender" - 2011.
- AT's Civil Works Master Specifications for Construction of Provincial Water Management Projects.

2.2 DAM DESIGN AND SAFETY

- Province of Alberta Water Act – Water (Ministerial) Regulation - Regulation 205/98 (consolidated up to 185/2015).
- AT's "Water Control Structures Selected Design Guidelines" – Nov. 2004

- Canadian Dam Association Dam Safety Guidelines (CDA) 2007 with 2013 Revisions.
- CDA – Technical Bulletins:
    1. Inundation, Consequences, and Classification for Dam Safety, 2007
    2. Surveillance of Dam Facilities, 2007
    3. Flow Control Equipment for Dam Safety, 2007
    4. Retracted & Replaced by "Guidelines for Public Safety Around Dams," 2011
    5. Dam Safety Analysis and Assessment, 2007
    6. Hydrotechnical Considerations for Dam Safety, 2007
    7. Seismic Hazard Considerations for Dam Safety, 2007
    8. Geotechnical Considerations for Dam Safety, 2007
    9. Structural Considerations for Dam Safety, 2007
- USACE – Stability Analysis of Concrete Structures - EM 1110-2-2100, December 2005
- USACE – Earthquake Design and Evaluation of Concrete Hydraulic Structures - EM 1110-2-6053, 1 May 2007
- USACE – Gravity Dam Design - EM 1110-2-2200, June 1995
- USACE – Retaining and Flood Walls – EM 1110-2-2502, 29 September 1989
- USACE – Conduits, Culverts, and Pipes – EM 1110-2-2902, 31 March 1998
- USBR – Design Standards No. 14, Appurtenant Structures for Dams (Spillways and Outlet Works) Design Standards, Chapters 1 to 3, August 2014
- USBR – Design of Small Dams, 3rd Edition, 1987
- FEMA – Best Practices Technical Manuals

2.3 BUILDING CODE & PERSONNEL SAFETY

- Alberta Building Code (ABC) 2014
- National Building Code of Canada (NBCC) 2015
- Alberta Occupational Health and Safety Code (OHS code).

2.4 STRUCTURAL ANALYSIS, DESIGN AND MATERIAL SPECIFICATIONS

- Concrete Materials and Methods of Concrete Construction, CSA A23.1-14 & A23.2 -14
- Design of Concrete Structures, CSA A23.3-14
- Design of Steel Structures, CSA S16-14
- Welded Steel Construction, CSA W59-13
- Canadian Foundation Engineering Manual, Canadian Geotechnical Society – 4th Ed., 2006
- Canadian Highway Bridge Design Code
- Alberta Transportation Bridge Design Criteria
- Reinforcing Steel Institute of Canada, Standards Practice Manual

3.0 PROJECT DATA

3.1 LOCATION

The project is located in the Springbank area of Rocky View County, Alberta, CA, southwest of the City of Calgary in Township 24 (Range 04/03, W5M).

Latitude	51.050504 N
Longitude	114.401436 W
Elevation	1180 to 1220 m

3.2 FOUNDATION PARAMETERS

Site characterization is based on geologic assessment of the project site, exploratory borings, laboratory testing of project samples, and geotechnical engineering judgement. The following soil foundation parameters were obtained from the Preliminary Design Report (PDR), Appendix D - Geotechnical Assessment Report .

- Soil Classifications
  - Soil Layer 1 – Glacial Lacustrine Clay (CH/CL)
    Layer thickness ranges approximately from 3 m to 5 m
  - Soil Layer 2 – Lean Clay Glacial Till with Sand and Gravel (CL)
    Layer thickness ranges approximately from 8 m to 10 m
  - Depths to bedrock range from 11 m to 15 m
- Effective soil angle of repose (Effective Friction Angle, φ)
  - Lean Clay Glacial Till with Sand: $\varphi = 27$ degrees
  - Lean/Fat Lacustrine Clay: $\varphi = 35$ degrees
- Coefficient of Sliding Friction (μ)
  - Lean Clay Glacial Till with Sand: $\mu = 0.51$
  - Lean/Fat Lacustrine Clay: $\mu = 0.42$
- Subgrade Modulus
  - Lean Clay Glacial Till with Sand: 860 kPa
  - Lean/Fat Lacustrine Clay: 690 kPa

- Allowable Bearing Capacity – Continuous Footings (q)
  - $q_{allowable}$ = 150 kPa Long Term (SF = 3.0)
  - $q_{allowable}$ = 200 kPa Short Term (Seismic and Wind Loading)

In accordance with CDA guidelines Technical Bulletin No. 7 (Geotechnical) and Technical Bulletin No. 8 (Structural), cohesion was not included in the sliding stability analysis, and acceptance criteria for sliding will be based on friction only for resistance.

3.3 HYDROTECHNICAL PARAMETERS

Three hydraulic conditions were considered during the preliminary design and stability analysis of the LLOW components. Table 1 provides a summary of the hydrotechnical parameters used in the design and stability analyses of the LLOW structure.

Table 1. Hydrotechnical Parameters

Reservoir Condition	Headwater EL (m)	Conduit Exit EL (m)	Tailwater EL (m)
Maximum Pool	1213.50*	1184.55	1184.22
10-Year Flood	1191.43	1183.85	1183.75
Empty Reservoir	1187.00	1183.12	1182.81

*Top of Dam Elevation

3.4 CLIMATE DATA

3.4.1 Snow

Snow Load data for this project was obtained from Ontario Climate Centre – Environment Canada.

- Ground snow load, snow component (S_s) =1.7 kPa
- Ground snow load, rain component (S_r) =0.1 kPa
- Snow load, Importance factor (I_s) =1.25

3.4.2 Frost Considerations

Frost depth was determined in accordance with ABC and is shown in PDR, Appendix D - Geotechnical Assessment Report.

- Minimum design frost depth of 2.0 m
- Non-frost susceptible backfill - Gravel and clean sands

3.4.3 Temperature Variations

Monthly temperature data for use in the evaluation was obtained from the Calgary International Airport records, which is considered representative of typical temperature ranges at the project site.

3.4.4 Wind

A wind load of 0.48 kPa was determined for use at the site based on the Alberta Building Code.

4.0 CONSTRUCTION MATERIALS

4.1 CONCRETE AND CONCRETE ACCESSORIES

- **Structural Concrete – Class A1**
  30 MPa @ 28 days, (AT Civil Works Specifications)
  General use reinforced concrete where thermal control and volume change are not a concern.

- **Structural Concrete – Class B1**
  30 MPa @ 90 days, (AT Civil Works Specifications)
  General use reinforced concrete where thermal control and volume change need to be considered (typically thickness > 600 mm)

- **Foundation Concrete - Class F**
  15 MPa @ 28 days, (AT Civil Works Specifications)
  For use in foundation preparation such as mud mats and low strength fill.

- **Grout**
  Premixed structural non-shrink grout for equipment bases.

- **Preformed Expansion Joint Filler**
  ASTM D1752, Type I, Closed-cell sponge rubber.

- **Bond Breaker**
  Bituminous paint conforming to CGSB 37.2-88.

- **Waterstops**
  PVC ribbed profile with minimum rated hydrostatic head of 373 KPa based on joint type.

4.2 METALS

- **Reinforcement** - CAN/CSA-G30.18-92 Grade 400 or 400W deformed bars

- **Structural Steel** - CSA-G40.21, Grade 300W or 350W

- **Stainless Steel** - ASTM A276-04

- **Miscellaneous Metals** (gratings, stairs, ladders, handrails) - Galvanized steel

4.3 EARTHWORK MATERIALS

The LLOW will be constructed on a soil foundation as described in Section 3.2 or placed on compacted embankment materials when the subgrade is poor or too low. Soil backfill materials will be various embankment materials as listed below. Refer to PDR, Appendix D - Geotechnical Assessment Report for design values for soil backfill and riprap parameters.

Design values for the bedding, backfill and embankment fill parameters that will surround the LLOW:

- **Saturated Unit Weight (γ_{sat}) -**
  Embankment Soils: 2040 kg/m^3 or 20.0 kN/m^3

- **Moist Unit Weight (γ_{moist}) -**
  Embankment Soils: 2040 kg/m^3 or 20.0 kN/m^3

- **Effective soil angle of repose (Effective Friction Angle, φ_{eff})**
  Embankment Shell: φ = 24 degrees
  Embankment Core: φ = 28 degrees

- **At-Rest Lateral Pressure Coefficient (K_o)**
  Embankment Shell: K_o = 0.59
  Embankment Core: K_o = 0.53

- **Active Lateral Pressure Coefficient (K_a)**
  Embankment Shell: K_a = 0.42
  Embankment Core: K_a = 0.36

- **Passive Lateral Pressure Coefficient (K_p)**
  Embankment Shell: K_p = 2.37
  Embankment Core: K_p = 2.77

5.0 STRUCTURAL ANALYSIS APPROACH

For the purposes of stability assessment, analysis and structural design, the LLOW was divided into individual structures; intake, pressure conduit segments, gate structure, gravity conduit segments, and CSU rigid basin. Each structure was evaluated, as applicable, for global stability, strength, and serviceability. Each component of the LLOW structures was assessed for applicable imposed loads to which they may be subject per the governing Code criteria. Secondary structures such as gate hoists, gate operating mechanisms, ladders, etc., will be designed to work with the supporting structure and to function as required by the applicable Code.

In general, global stability of a structure was assessed using the rigid body analysis method with the application of unfactored loads. This method uses the summation of forces applied to the rigid body to determine resultant location, foundation bearing pressures, sliding resistance along the concrete/soil interface, and structure floatation. MathCAD, Excel spreadsheets, and commercial software using the rigid body method were used to assess stability of the LLOW structures with the exception of the intake and gate structure. Because of the structural complexity of the intake and gate structure, 3-dimensional finite element method (FEM) models consisting of plate and frame elements and spring boundary conditions were created to validate stability calculations. The FEM was supplemented with manual calculations to verify/validate model results.

Strength evaluation of individual concrete elements and members was performed to verify member sizes and reinforcement requirements in accordance with CSA A23.3-14. In general, structural analyses were performed using MathCAD, Excel spreadsheets, or commercial software. For more complex structures, such as the LLOW intake, the FEM previously developed for stability was used to evaluate multiple load combinations, identify stress concentrations, and generate shear and moment values for design of individual elements. Additional elements evaluated as part of strength design will include joint detailing, equipment anchorage, and evaluation of embedded parts.

Serviceability includes limiting deflections, reducing crack potential, providing thermal stress relief, and incorporating measures to mitigate alkali-aggregate reaction (AAR). A combination of MathCAD, Excel spreadsheets, commercial software, or the FEM used for strength evaluation were used to evaluate deflection and thermal effects. Design detailing and material specification will be used to mitigate concrete cracking and AAR potential.

5.1 DESIGN TOOLS AND SOFTWARE

- AutoDesk Robot Structural Analysis - 2019
- Geoslope Geostudio – 2019 – version 10.1.0.18696
- GT STRUDL – 2018 – 37.0.0.0
- ITASCA FLAC – 2019 – version: 8.10
- Microsoft Excel - Office 365 - version: 16.0.11601.20174
- Mathcad 15.0 – 2017 – version: MC15_M050_20171129
- SAP2000 Advanced – 2019 – version: 21.0.2
- StructurePoint spColumn – 2016 – version: 5.50
- Staad.Pro V8i (Select series 4) – 2011 – version: 20.07.07.31
- LPile – 2019 – 2019.11.01

5.2 MODELING APPROACH

Several modeling and analysis approaches were used for the various LLOW structures based on the methodology that is most appropriate for each structure. Sections 5.2.1 through 5.2.5 summarize the different approaches used for each LLOW structure.

5.2.1 Intake Structure

For the Intake Structure, a finite element model (FEM) was developed using SAP2000. This consists of generating a 3D model that includes geometry, material properties, applied loads, and support conditions of the structure to determine its response to various loading conditions. Frame elements were used to model the columns and beams, while the walls were modeled as thick shell elements. Support conditions for this structure are approximated using linear springs that represent the stiffness of the foundation soil. Due to its complex geometry, the seismic response of the intake structure was evaluated using a Response Spectrum Analysis (RSA) in lieu of a pseudo-static approach. The effects of soil-structure interactions such as kinematic and radiation dampening were considered in the response spectrum analysis. Stability and design loads were determined from SAP2000 analysis output.

5.2.2 Intake Structure Wing Walls

The wing walls for the Intake Structure were modeled as rigid bodies. A one-meter strip of wall cross section was analyzed as a two-dimensional rigid body. This is achieved by performing manual calculations accounting for the geometry and the applicable loading conditions. Seismic analysis of this structure was performed using a pseudo-static/coefficient approach outlined in Section 6.9. Mathcad was used to perform and document the stability analyses and structural design calculations. Resultant and reactant forces are compared against stability criteria and design forces are determined for each element.

5.2.3 Gate Structure

The Gate Structure was modeled using a finite element model (FEM) in SAP2000. Support conditions for this structure include both linear and non-linear springs to represent the stiffness of the soil. Linear springs were used at the base of the footing while non-linear springs were used along the embedded length of the tower to capture soil-structure interaction when lateral loads were present. Non-linear springs are composed of p-y curves output from LPile, with different p-y curves used for the saturated and dry soil conditions. Since the Gate Structure is prismatic in geometry, a pseudo-static approach with lumped masses were used for earthquake analysis. Static equivalent seismic forces were applied at the nodes along the height of the tower in the FEM model. Output from SAP2000 was used for the design and stability analysis of the Gate Structure.

5.2.4 CSU Rigid Basin

The CSU rigid basin was analyzed as a three-dimensional rigid body using hand calculations in Mathcad. This included all the geometric features, boundary conditions, and applied loads. The Mathcad calculations were used for the stability analysis of the structure. Seismic analysis consisted of a pseudo-static/coefficient approach as outlined in Section 6.9. A SAP2000 model will be developed later for the structural design.

5.2.5 Concrete Conduits

The LLOW conduit was divided into two sections separated by the Gate Structure The section located upstream of the Gate Structure operates under pressure and the surcharge from the embankment shell, while the section located downstream of the Gate Structure operates under gravity flow and under the highest surcharge from the embankment core. To determine the resultant forces acting on the two concrete conduit structures, finite element models (FEM) were developed to assess the earth's pressure. The FEMs were developed using the module Sigma/W from the computer program GeoStudio (2018). The results from the FE analysis were verified using the Direct Design method.

The Direct Design method is recommended by the City of Calgary for the design of rigid gravity sewer pipes ("Standard Practice for Design and Installation of Rigid Gravity Sewer Pipe in the City of Calgary", Letter: UMA/AECOM to City of Calgary, January 21, 2008). This method was developed as a Standard Practice under ASCE Standard Practice 15, which requires a series of assumptions relative to initial conditions and conduit section properties. The pressure distribution calculations are based on the Heger pressure distribution model.

6.0 LOADS

6.1 DEAD LOADS (D)

Permanent loads on the structure include concrete structure weight and water. Unit weights for principal materials are included in Table 2.

Table 2. Dead Load and Unit Weights

Material	Unit Weight	Source
Water	9.81 kN/m^3	CSA S6-14, Table 3.4
Reinforced Concrete	23.5 kN/m^3	AT WCS Design Guide 4.2
Steel	77.0 kN/m^3	AT WCS Design Guide 4.2

6.2 HYDROSTATIC LOADS (H)

Hydrostatic loads include both horizontal and vertical component of water load based on water surface elevations for the load conditions considered. Upstream and downstream water surface elevations are described in Hydrotechnical Parameters, Section 3.3. The water surface elevations were considered to be hydrostatic pressures without kinematic effects.

6.3 UPLIFT PRESSURE (U)

Uplift pressure and countermeasures for the intake and gate structures were determined per EM 1110-2-2100, Stability Analysis of Concrete Structures. Since the intake and gate structures were within the reservoir, a uniform uplift equivalent to the reservoir hydrostatic head was applied along the base of the structure. Uplift pressures for the upstream pressure conduit were determined per EM 1110-2-2902, Conduits, Culverts, and Pipes. The uplift applied along the base of the upstream pressure conduit was a constant hydrostatic head equivalent to the reservoir pool elevation. Uplift pressures for the CSU rigid basin were determined per EM 1110-2-2100. The basin uplift pressures varied linearly from the conduit exit water elevation to the downstream channel water surface elevation. Refer to Table 1 for a summary of the pool conditions considered during the stability analyses of the LLOW components.

6.4 EARTH PRESSURE (E)

Soil loads include both vertical and horizontal forces due to backfill, sediment and siltation. Vertical forces associated with soil mass above the structure were based on a vertical projection of footing or structure below the soil. Soil mass was based on moist unit weight for material above the waterline and buoyant unit weight for material below the waterline. Vertical force associated with water above the structure was calculated separate from the soil mass.

Horizontal force associated with soil was based on at-rest condition represented by the empirical relationship:

$K_o = 1 - \sin\theta$ where: K_o = At-rest lateral pressure coefficient(*)
θ = Soil friction angle

**In accordance with EM 1110-2-2100 and EM 1110-2-2502 to use At-Rest Coefficient (K_o)*

6.5 LIVE LOADS (L)

The principal live loads on the LLOW include Occupancy Loads (O), such as on the top of the intake structure and within the gate structure, and construction and maintenance Vehicle Loads (V) on the access bridge and over and adjacent to the back face of the intake structure and wing walls, conduit, gate structure, and stilling basin walls. In addition, Hoist/Equipment Loads are associated with gate removal/installation and operation. Live Loads described in this section were considered transitory loads. Transitory loads are used for strength design of individual structure elements, but normally not included in stability analyses. They will be included in strength design for individual components.

Vehicle (vertical and horizontal)	CL-625	
Vehicle (on access bridge)	H5	
Hoist & Equipment	TBD	
Occupancy & Access	3.6 KPa	(2014 Alberta Building Code Table 4.1.5.3)
Heavy Equipment Surcharge	20 kPa	(AT WCS, Section 4.9)

A heavy equipment surcharge of 20 KPa, equivalent to one meter of backfill, was applied to the intake structure, gate structure, and stilling basin retaining wall fills to account for future modifications, long term storage materials and top of wall modifications. This load was not applied simultaneously with vehicle loads.

6.6 HYDRODYNAMIC LOADS (HD)

Hydrodynamic loads include wave action, sub-atmospheric pressure (cavitation), and hydraulic dissipater forces. For the LLOW, these forces were excluded from the analysis since they were considered insignificant or of a localized nature.

- Wave action was not included due to the short-term duration of water storage and relatively short fetch.

- Sub-atmospheric pressure (cavitation) is associated with flow offsets and gates in outlet works. Cavitation is a primary concern at the stainless-steel gates and passages in the gate chamber. Detailing of these areas will minimize effects of sub-atmospheric pressures.

- Hydraulic dissipater forces are localized forces addressed in the hydraulic design of the CSU rigid basin baffles.

6.7 DEBRIS AND IMPACT LOADS

Impact loads associated with debris flows will be developed during final design. For the Preliminary Design, the critical impact load location for stability was identified as the downstream face of the structure at the 10-Year Flood pool elevation.

Impact loading associated with debris flow for structural capacity of the various members of the structure will be determined per FEMA P-55, "Coastal Construction Manual," Volume II, August 2011, Section 8.5.10 - Debris Impact loading.

6.8 ICE LOAD(I)

Three types of ice load to consider for the LLOW hydraulic structures design include Static Ice Load (I_s), Dynamic Ice Loading (I_d), Ice Accretion Load (I_v)

- **Static Ice Load (I_s)** is a result of water surface freezing with application of horizontal load as ice sheet expands and confinement increases. Static ice loading has the potential to occur since the unnamed creek flows through the conduit continuously. Static Ice Load was applied in Usual Load Cases which address winter operating conditions.

- **Dynamic Ice Loading (I_d)** is a result of moving ice floe impacting the structure. Dynamic Ice Load was not be considered as a design load case since there is no permanent pool.

- **Ice Accretion Load (I_v)** occurs when ice bonds to the structure and must be broken as water level rises. Ice Accretion Load associated with water level rise was not considered for the LLOW structures due to small order of magnitude relative to hydrostatic loading and low probability of occurring simultaneously with spring and summer flooding.

Frost Heave. Vertical ice loading associated with "frost heave" is a realistic consideration since the structures are normally in a dewatered or low-water state with freeze/thaw action tending to open concrete/foundation interface and subject the structure to increased uplift potential. To reduce frost heave loading potential and remove this condition from the analysis, foundation interfaces were located below the identified frost depth of 2 m for this site, drainage provided to reduce the formation of ice in the foundation, or insulation placed to form a thermal break between concrete and foundation..

Table 3. Ice Loads

Ice Condition	Load	Source
Static Ice (applied to concrete structures)	150 kN/m @ 0.3 m below WSE	AT WCS Design Guide 4.5.1.1
Static Ice (applied to steel structures)	75 kN/m @ 0.3 m below WSE	AT WCS Design Guide 4.5.1.1
Vertical Ice	N/A – Since foundation interface located below frost depth	N/A

6.9 SEISMIC – EARTHQUAKE LOADS (Q)

The seismic classification for the LLOW is based on Stantec's Seismic Hazard Assessment - Springbank Off-Stream Dam and Reservoir Report dated November 28, 2016. Since the hazard classification is Extreme for the Off-stream Storage Dam, the seismic parameters are based on an Earthquake Design Ground Motion (EDGM) with an Annual Exceedance Probability (AEP) of 1/10,000 resulting in Peak Ground Acceleration (PGA) of 0.28 g for horizontal application and PGA of 0.16 for vertical application.

The seismic loading for the intake structure was performed using a response spectrum analysis. The horizontal and vertical ground motions used in this analysis are presented in Table 4 and the response spectra presented in Figure 1.

Table 4. Horizontal and Vertical Ground Motions

Horizontal Ground Motions (Vs30 = 265 m/s)		Vertical Ground Motions (Vs30 = 265 m/s)	
Period (s)	Horizontal Ground Motions	Ratio of Vertical to Horizontal Ground Motions	Vertical Ground Motions
0.05	0.3300	0.94	0.3102
0.1	0.4700	0.81	0.3807
0.2	0.6400	0.5	0.3200
0.3	0.6900	0.4	0.2760
0.5	0.5200	0.36	0.1872
1	0.2600	0.37	0.0962
2	0.1100	0.43	0.0473
5	0.0340	0.48	0.0163
10	0.0087	0.76	0.0066

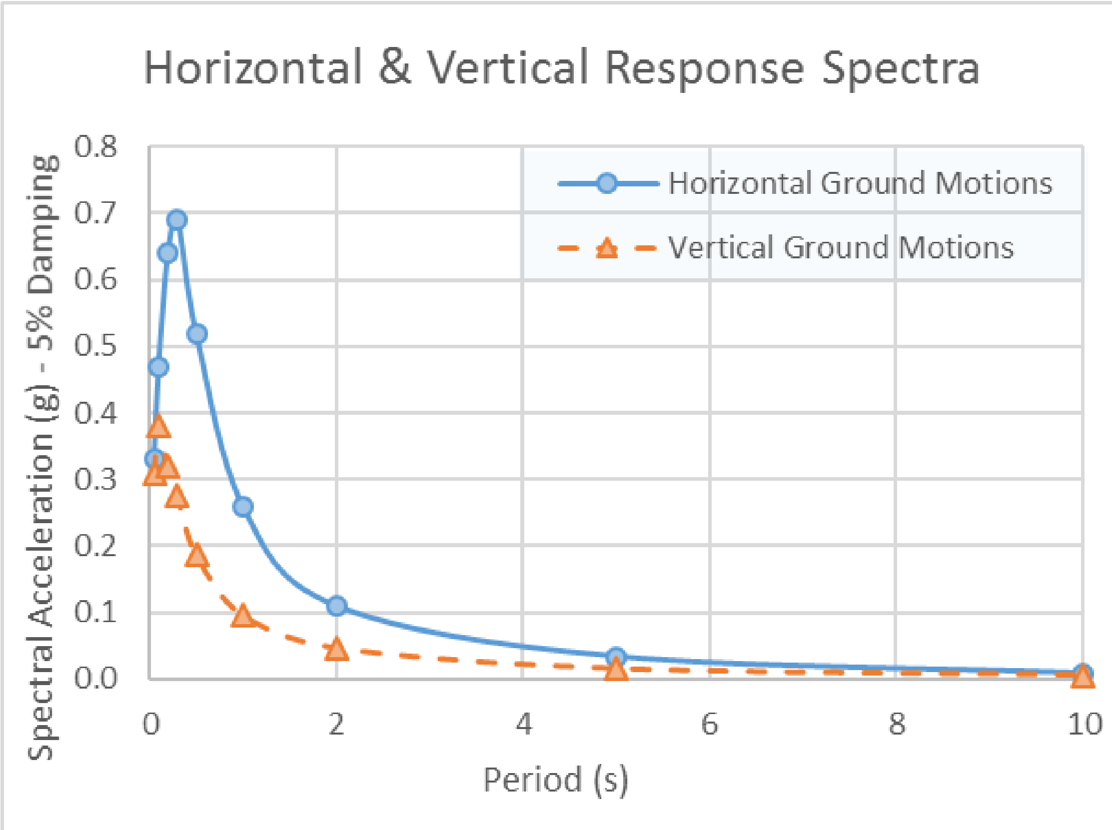


Figure 1. Horizontal and Vertical Ground Motions

This project site is situated in an area of low to moderate seismic activity. Consequently, CDA Guidelines, Section 6.5, allow for the seismic stability analysis of concrete gravity structures to be completed using a pseudo-static approach (coefficient method). This method applies a seismic force to a rigid body with the objective of determining sliding and overturning response of the structure. Since the pseudo-static method does not recognize the oscillatory nature of seismic loads, accepted practice is to perform the stability calculations using sustained acceleration values equivalent to 2/3 of the peak acceleration values.

When performing concrete stress analyses, the objective is to determine the tensile crack length induced by the inertia forces applied to the structure, so peak acceleration is used to calculate seismic coefficients. This approach assumes an instantaneous acceleration spike can induce cracking but is not sustained long enough to develop significant displacement along the crack plane. If no significant displacement occurs, the dynamic stability is maintained.

6.9.1 Seismic Effects on Concrete Mass

The horizontal force required to accelerate the concrete mass is calculated as:

$Q_h = k_h \times W$ where: Q_h = Horizontal seismic load (kN)
k_h = Horizontal seismic coefficient
W = Structure mass (kg)
PGA = Peak ground acceleration= 0.28g

For Stability Analysis (Table 5): k_h = 2/3 x 0.28 = 0.19
For Stress Analysis (Table 6): k_h = 1.0 x 0.28 = 0.28

The vertical force required to accelerate the concrete mass is calculated as:

$Q_v = k_v \times W$ where: Q_v = Vertical seismic load (kN)
k_v = Horizontal seismic coefficient = 0.56*k_h
W = Structure mass (kg)

For Stability Analysis (Table 5): k_v = 2/3 x (0.56*k_h) = 0.10
For Stress Analysis (Table 6): k_v = 1.0 x (0.56*k_h) = 0.15

Since an earthquake produces oscillating forces, the horizontal PGA and vertical PGA cannot occur at the same time. To account for this in the stability calculations, three separate combinations of vertical and horizontal seismic combinations will be considered, but only the maximum value will be reported. The three combinations of vertical and horizontal seismic load are as follows:

Table 5. Stability Analysis – Seismic Coefficients

Seismic Combination	Horizontal	Vertical
100% Horiz., No Vert.	1.0*k_h = 0.19	-
100% Horiz., 30% Vert.	1.0*k_h = 0.19	0.3*k_v = 0.03
30% Horiz., 100% Vert.	0.3*k_h = 0.06	1.0*k_v = 0.10

Table 6. Stress Analysis – Seismic Coefficients

Seismic Combination	Horizontal	Vertical
100% Horiz., No Vert.	1.0*k_h = 0.28	-
100% Horiz., 30% Vert Horiz.	1.0*k_h = 0.28	0.3*k_v = 0.05
30% Horiz., 100% Vert.	0.3*k_h = 0.08	1.0*k_v = 0.16

6.9.2 Seismic Effects on Water (H_E)

No water loads are associated with seismic load cases for the LLOW.

6.9.3 Seismic Effect on Soils

Dynamic soil pressures and associated forces were analyzed assuming non-yielding backfills and an elastic response using Wood's method. As referenced in Section 5-5.a.1, EM 1110-2-2100, this method can be expected to have dynamic soil pressures greater than those predicted by the Mononobe-Okabe method for yielding backfills.

The use of Wood's method is considered reasonable and was used for analysis of the LLOW wing walls and CSU rigid basin that have relatively short backfills (<4 m). The use of Wood's method may be overly conservative for taller retaining walls with height ranging from 4 m to 13 m with backfill consisting of granular fills and/or glacial till materials.

Wood's Method for Non-yielding Backfill: This method applies the effective peak ground acceleration coefficient (k_h) to the soil mass to calculate a lateral seismic force representing dynamic soil pressure effects. The lateral seismic force is assumed to act at a distance of 0.63h above the base of the wall and must be added to the lateral inertial forces, and if water is present, hydrodynamic seismic forces. Calculation of lateral seismic force of soil is as follows:

$$Q_E = y * h^2 * k_h$$

Where: Q_E = Lateral seismic force of soil
Y = unit weight of soil (weighted average of Y_{sat} and y_b)
h^2 = height of backfill
k_h = horizontal seismic coefficient

6.10 CLIMATIC CONDITIONS

6.10.1 Snow Loads (S)

Snow loads were considered insignificant compared to hydrostatic loads and not considered for stability of the LLOW structures. However, Snow Load will be included in load combinations for certain component designs such as the top of the intake and gate structures. Snow load data is listed in Section 3.4.1 above.

6.10.2 .Thermal Loads (T)

Thermal loads for the conduit segments will be evaluated during Final Design.

6.10.3 Wind (W)

Wind loads will be estimated for the Intake and Gate structures in accordance with the Alberta Building Code 2014. The specified wind load and the pertinent parameters to be utilized in the load derivation are summarized below:

Specified Wind Load (p_w) = 0.48 kPa

Importance Factor (I_w) = 1.25

Exposure Factor (C_e) = 0.7

Gust Effect Factor (C_g) = 2.0

7.0 STABILITY ANALYSIS

The intake structure and wing walls, conduit, gate structure, and stilling basin were analyzed for stability for the loading conditions described below, in accordance with AT/CDA Guidelines. Analysis methodology is as follows:

7.1 METHODOLOGY

7.1.1 Overturning and Bearing Stress

The Rigid Body Method (conventional gravity method) was used for the analysis of overturning and bearing stress criteria. Overturning was evaluated as a percentage of base that remains in compression and not a safety factor. This method is outlined in Section 7.2 of CDA Technical Bulletin No. 9 and further described in USACE EM 1110-2-2100. It uses a vector summation of all forces, including uplift, acting on the monolith to determine the vector resultant force (V), resultant force eccentricity (e) within the base, and moment (Ve/S) based on an elastic and homogeneous rectangular beam analogy. Stresses were calculated as indicated below and stability was assured by maintaining the resultant force eccentricity within acceptance criteria limits for various loading conditions.

$$\sigma = \frac{V}{A} \pm \frac{Ve}{S}$$

Where: σ = Applied bearing pressure at each end of base (kN/m^2)
V = Summation of forces normal to base (kN)
A = Base area in compression (m^2)
e = Eccentricity of normal load about centroid of base in compression (m)
S = Section modulus of base area in compression (m^3)

7.1.2 Sliding

The sliding factor of safety was calculated for each load case using the limit equilibrium method as outlined in Section 7.2 of CDA Technical Bulletin No. 9. This method reduces to the equation shown below for a single wedge system with a horizontal sliding plane, along the concrete/rock interface (CRI) or through rock/rock failure plane as identified for each hydraulic structure. For inclined sliding planes projecting from the base of shear key to bottom base slab at the toe, vertical and horizontal forces are resolved into components normal and parallel to the sliding plane. Rock mass between the inclined plane and structure base is included in the dead load summation (EM 1110-2-2100). For this project, cohesion was conservatively assumed to be zero and sliding acceptance criteria for sliding were based only friction angle.

$$SSF = \frac{(Vtan\varphi + c\ A)}{H}$$

Where: SSF = Sliding Safety Factor
V = Summation of vertical loads including uplift (kN)
$tan\ \varphi$ = Coefficient along sliding plane being considered
c = Cohesion at concrete/rock or rock/rock interface (assumed as 0) (kN/m^3)
A = Base area in compression (m^2)
H = Summation of horizontal forces (kN)

7.1.3 Floatation

The floatation factor of safety was determined for components of the project such as stilling basins and apron slabs as outlined in Section 8.5, AT WCS. The factor of safety against floatation is defined as ratio of resisting gravity force to driving uplift force. The possible resistance due to friction between adjacent structures or between structure and backfill were neglected unless shear provisions were provided.

$$FSF = \frac{\Sigma N}{\Sigma U}$$

Where: FSF = Factor of Safety against Floatation
ΣN = Summation of normal forces
ΣU = Summation of uplift forces

7.2 ACCEPTANCE CRITERIA

The following acceptance criteria is based on AT WCS Chapter 8, CDA Table 6-4, and CDA Technical Bulletin No. 8, Section 6.0. The load cases to be evaluated are divided into five categories as listed in Table 7.

Usual Condition: Those conditions under which the structure is intended to serve during normal operations and further defined as a condition that has a high likelihood of occurring within the design life of the structure. Usual load conditions include normal pool and winter conditions. For the LLOW structures, this includes flood events up to the 100-year frequency flood for the Extreme hazard category.

Unusual Condition: Those conditions that occur infrequently and may stress the structure more, under certain aspects, than normal conditions and may occur within the design life of the structure. Unusual load conditions include construction conditions, maintenance conditions, flood events between the 100-year and 1000-year frequency, infrequent earthquake events other than the MDE, and plugged drain conditions for Usual Load Cases.

Extreme – Flood: Extreme Load Conditions have a very remote likelihood of occurring with the design life of the structure. For the SR1 project, it is defined as those floods that occur from the 1000-year frequency event up to the structure's IDF. For the LLOW, the PMF is considered the IDF as it is part of the Storage Dam.

Extreme – Earthquake: For the SR1 project, the Extreme - Earthquake load condition to be assessed is the MDE as it has a very remote likelihood of occurring with the design life of the structure. The MDE is applied to the Usual Condition load cases. The Extreme – Earthquake condition is used to establish Post-Earthquake condition of the hydraulic structure. Thus, there are no stability acceptance criteria for this condition.

Post-Earthquake: The Post-Earthquake condition assesses the stability of the hydraulic structure following the applied seismic event based on earthquake induced cracking at the foundation structural interface and within the structure so that it is still capable of resisting the Usual Loading.

Table 7. Acceptance Criteria for Hydraulic Structures

Loading Combination	Position of Resultant Force (Percent of Base in Compression)[1]	Normal Compression Stress[2]	Sliding Safety Factor (Friction Only)	Floatation Safety Factor
Usual	Middle third of the base: 100% compression	<0.3 x f_c	≥1.5	≥1.5
Unusual	Middle third of the base: 100% compression	<0.5 x f_c	≥1.3	≥1.3
Extreme Flood	Within middle half of the base, and all other acceptance criteria must be met	<0.5 x f_c	≥1.1	≥1.1
Extreme Earthquake	Within the base, except where an instantaneous occurrence of resultant outside the base may be acceptable	<0.9 x f_c	Note [3]	
Post-Earthquake	Within middle half of the base	<0.5 x f_c	≥1.0	≥1.1

[1] Foundation bearing stress is compared to allowable stress determined from Geotechnical Investigation

[2] Where f_c = compressive strength of concrete

[3] The earthquake load case is used to establish post-earthquake condition of the structure

7.3 LOAD CONDITIONS

Load conditions varied for the various structures based on configuration and location of each applied load. The following sections summarize the load conditions for various LLOW structures.

7.3.1 Intake Structure

The loading conditions that were considered in the analysis of the Intake structure are summarized in Table 8.

Table 8. Intake Structure - Load Cases and Stability Acceptance Criteria

Load Case	Description	Loading	Sliding Safety Factor*	Resultant Location*	Bearing Stress**	Flotation Safety Factor***
LC01	Usual: Empty Reservoir	Dead + Earth + Uplift + Wind + Snow	1.5	Middle 1/3	< Allowable	1.5
LC02	Unusual: Construction	Dead + Earth + Uplift + Wind + Surcharge	1.3	Middle 1/3	< Allowable	1.3
LC03	Unusual: 10-Y Flood	Dead + Earth + Hydro + Uplift	1.3	Middle 1/3	< Allowable	1.3
LC04	Extreme: 10-Y Flood + Impact	Dead + Earth + Hydro + Uplift + Impact	1.1	Middle 1/2	< Allowable	1.1
LC05	Unusual: 10-Y Flood (Plugged Trashracks)	Dead + Earth + Hydro + Uplift	1.3	Middle 1/3	< Allowable	1.3
LC06	Extreme: Maximum Pool	Dead + Earth + Hydro + Uplift	1.1	Middle 1/2	< Allowable	1.1
LC07[1]	Extreme: Earthquake	Dead + Earth + Uplift + EQ[1]	n/a			
LC08	Post Earthquake	Dead + Earth + Uplift	1.1	Within Base	< Allowable	1.1
1	Response Spectrum Analysis; EQ=max [24 combinations of EQx, EQy, EQz]					
*	CDA: Dam Safety Guidelines 2007 (Revised 2013), Section 6.7 & Alberta Transportation: Water Control Structures 2004, Section 8.4					
**	Alberta Transportation: Water Control Structures 2004, Section 8.4					
***	Alberta Transportation: Water Control Structures 2004, Section 8.5					

The load cases and acceptance criteria for the intake structure were derived from a combination of several guideline documentations and are described as follows:

Empty Reservoir: The empty reservoir loading condition consists of an empty reservoir with the structure subjected to its self-weight, and other external forces such as wind, snow, and soil loads. The ground water elevation is assumed to be at the top of base elevation. Therefore, a uniform uplift equivalent to the hydrostatic head at the base of the structure is applied against its base.

Construction: After the intake tower is fully constructed, embankment soil will be placed and compacted around it. Construction equipment and soil compaction activities tend to impose additional loads on the structure. This loading condition consists of the structure's self-weight, empty reservoir uplift, fully constructed embankment soil pressures, and an additional one meter of soil surcharge against the downstream face of the intake structure.

10-Year Flood: This condition consists of a reservoir pool elevation of 1191.43 m with the structure subjected to its self-weight, soil loads, hydrostatic loads, and full uniform uplift at the base of the structure.

10-Year Flood with Debris Impact: For this loading, the reservoir pool elevation is at 1191.43 m due to the 10-year flood. The structure is subjected to its self-weight, debris impact, soil loads, hydrostatic loads, and full uniform uplift at the base of the structure. The critical location for the impact load was identified on the downstream face of the structure at the pool elevation. Since the water velocity near that location is unknown and likely very low, a nominal debris impact of 5.0 kN, applied on the downstream face of the structure at the pool elevation, was used in the analysis.

Earthquake: The earthquake loading condition consists of performing response spectrum analyses for the intake structure. The analyses included self-weight, embankment soil loads, empty reservoir uplift loads, and embankment soil added mass. As described in Section 6.9, three major cases of combined vertical and horizontal response spectrum analyses were conducted. Those three cases were then combined in 24 different ways in SAP2000 and the enveloping results of the worse combinations were used for the stability analysis of the intake structure.

7.3.2 Intake Structure Wing Walls

The loading conditions that were considered in the analysis of the Wing Walls are summarized in Table 9. Empty reservoir, construction, and post-earthquake loading conditions are as described for the intake tower. Rapid drawdown consists of fully saturated backfill with no standing water on either side of the wall. The earthquake loading involves the empty reservoir loading conditions combined with additional inertial load due to the design earthquake using a pseudo-static coefficient method of analysis and design. Refer to Table 5 for the seismic coefficients used in the wing wall design.

Table 9. Wing Walls - Load Cases and Stability Acceptance Criteria

Load Case	Description	Loading	Sliding Safety Factor*	Resultant Location*	Bearing Stress**	Flotation Safety Factor***
LC01	Usual: Empty Reservoir	Dead + Earth + Hydrostatic + Uplift	1.5	Middle 1/3	< Allowable	1.5
LC02	Unusual 1: Construction	Dead + Earth + Hydrostatic + Uplift + Surcharge	1.3	Middle 1/3	< Allowable	1.3
LC03	Extreme: Rapid Drawdown	Dead + Earth + Hydrostatic + Uplift	1.1	Middle 1/2	< Allowable	1.1
LC04[1]	Extreme: Earthquake	Dead + Earth + Uplift + EQ[1]	n/a			
LC05	Post Earthquake	Dead + Earth + Hydrostatic + Uplift	1.1	Within Base	< Allowable	1.1

1 Coefficient Method. K_h=0.19, K_v=0.10
* CDA: Dam Safety Guidelines 2007 (Revised 2013), Section 6.7 & Alberta Transportation: Water Control Structures 2004, Section 8.4
** Alberta Transportation: Water Control Structures 2004, Section 8.4
*** Alberta Transportation: Water Control Structures 2004, Section 8.5

7.3.3 Gate Structure

The loading conditions that were considered in the analysis of the Gate Structure are summarized in Table 10.

Table 10. Gate Structure - Load Cases and Stability Acceptance Criteria

Load Case	Description	Loading	Sliding Safety Factor*	Resultant Location*	Bearing Stress**	Flotation Safety Factor***
LC01	Usual: Empty Reservoir	Dead + Live + Earth + Uplift + Wind + Snow	1.5	Middle 1/3	< ALLOWABLE	1.5
LC02	Unusual: 10-Y Flood, Gates Open	Dead + Live + Earth + Uplift + Hydro + Wind	1.3	Middle 1/3	< ALLOWABLE	1.3
LC03	Unusual: 10-Y Flood, Front Gate Closed	Dead + Live + Earth + Uplift + Hydro + Wind	1.3	Middle 1/3	< ALLOWABLE	1.3
LC04	Unusual: Staged Construction	Dead	1.3	Middle 1/3	< ALLOWABLE	1.3
LC05	Extreme: Maximum Pool, Gates Open	Dead + Live + Earth + Uplift + Hydro + Wind	1.1	Middle 1/2	< ALLOWABLE	1.1
LC06	Extreme: Maximum Pool, Front Gate Closed	Dead + Live + Earth + Uplift + Hydro + Wind	1.1	Middle 1/2	< ALLOWABLE	1.1
LC07[1]	Extreme: Earthquake	Dead + Earth + Uplift + EQ[1]	n/a			
LC08	Post-Earthquake	Dead + Earth + Uplift + Wind	1.1	Middle 1/2	< ALLOWABLE	1.1

1 Seismic Analysis; EQ=max [24 combinations of EQx, EQy, EQz]
* CDA: Dam Safety Guidelines 2007 (Revised 2013), Section 6.7 & Alberta Transportation: Water Control Structures 2004, Section 8.4
** Alberta Transportation: Water Control Structures 2004, Section 8.4
*** Alberta Transportation: Water Control Structures 2004, Section 8.5

The load cases and acceptance criteria for the gate structure were derived from a combination of several guideline documentations and as described below:

Empty Reservoir: The empty reservoir loading condition consists of an empty reservoir with the structure subjected to its self-weight, bridge reaction loads, building occupancy loads, and other external forces such as wind, snow, and soil loads. The ground water elevation is assumed to be at the top of the footing, resulting in uniform uplift at the base.

Construction: This load case assumes the tower is partially constructed before the embankment is placed (50%), which results in the lowest bearing capacity (minimum embedment). This is a conservative estimate for the portion of the tower that may be constructed before any embankment is in place. This loading condition consists only of the structure's self-weight.

10-Year Flood: This condition consists of a reservoir pool elevation of 1191.43 m with the structure subjected to its self-weight, soil loads, hydrostatic loads, and full uniform uplift at the base of the structure. There are two cases considered for this scenario: one in which both gates are open, and one that only the front gate is closed. These cases bound any scenarios that exist between the two.

Maximum Pool: This condition is identical to the 10-year flood except for the elevation of the pool. For this case, the pool is taken to be its maximum possible elevation which coincides with the top of the gate structure, Elevation 1213.5 m.

Earthquake: Since the gate structure is prismatic in geometry, a pseudo static approach was appropriate for the assessing the earthquake loading condition. Using an equivalent static procedure allows for the use of non-linear soil springs to be used along the height of the tower embedment to capture the tower's interaction with the soil. The horizontal acceleration used to accelerate the mass is conservatively taken as the PGA (0.28g). The analyses include self-weight, embankment soil added mass, and other miscellaneous dead loads that contribute to the seismic mass of the structure. As described in Section 6.9, three major cases of combined vertical and horizontal seismic loads were conducted. Those three cases are analyzed with 24 different combinations of varying directions in SAP2000 with a stability analysis being performed for each direction.

7.3.4 CSU Rigid Basin

The CSU rigid basin was analyzed for sliding, resultant location, bearing, and floatation. Refer to Figure 2 for the basin load diagram.

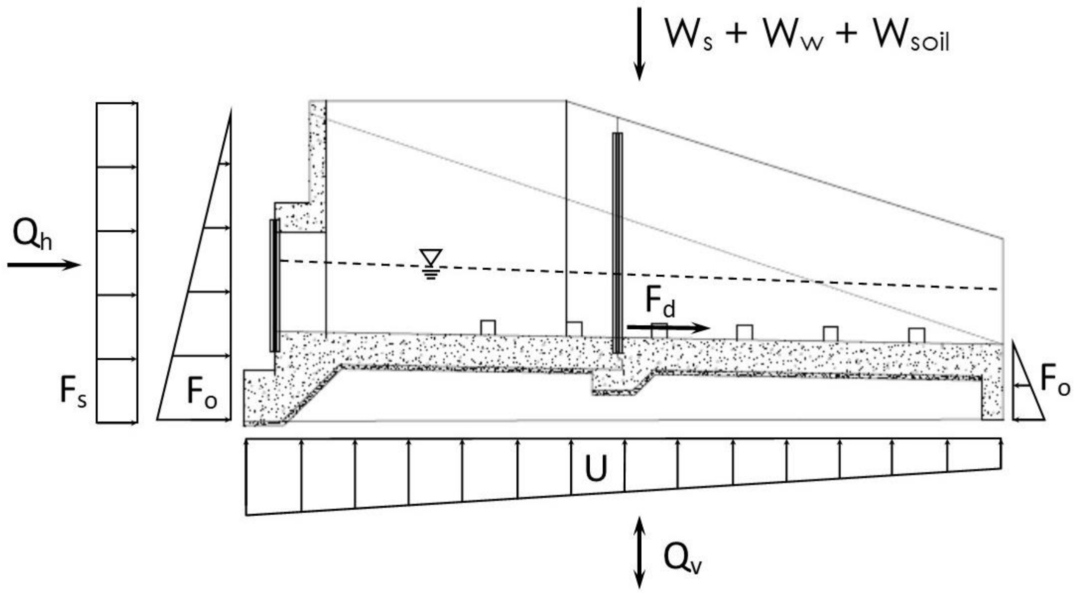


Figure 2. CSU Rigid Basin Load Diagram

Where:

W_s = weight of the structure
W_w = weight of the water in the structure
W_{soil} = weight of soil on the structure
F_o = at-rest soil force
F_s = surcharge force
F_d = dynamic water force on the structure
U = uplift
Q_h = horizontal earthquake load (soil & structure inertia forces)
Q_v = vertical earthquake load

As shown in Table 11, seven loading conditions were considered for the stability analysis of the CSU rigid basin.

Table 11. CSU Rigid Basin - Load Cases and Stability Acceptance Criteria

Load Case	Description	Loading	Sliding Safety Factor*	Resultant Location*	Bearing Stress**	Floatation Safety Factor***
LC01	Usual: Dry Condition	Dead + Earth	1.5	Middle 1/3	< ALLOWABLE	1.5
LC02	Unusual: 10-Year Flood	Dead + Earth + Hydro + Uplift	1.3	Middle 1/3	< ALLOWABLE	1.3
LC03	Unusual: Rapid Gate Closure	Dead + Earth + Uplift	1.3	Middle 1/3	< ALLOWABLE	1.3
LC04	Unusual: Construction/Maintenance	Dead + Earth + Surcharge	1.3	Middle 1/3	< ALLOWABLE	1.3
LC05	Extreme: Maximum Flow	Dead + Earth + Hydro + Uplift	1.1	Middle 1/2	< ALLOWABLE	1.1
LC06[1]	Extreme: Earthquake	Dead + Earth + Uplift + EQ[1]	N/A			
LC07	Post-Earthquake	Dead + Earth	1.1	Middle 1/2	< ALLOWABLE	1.1

* CDA: Dam Safety Guidelines 2007 (Revised 2013), Section 6.7 & Alberta Transportation: Water Control Structures 2004, Section 8.4
** Alberta Transportation: Water Control Structures 2004, Section 8.4
*** Alberta Transportation: Water Control Structures 2004, Section 8.5
[1] Seismic coefficient analysis for three load combination as follows:
Case6a = 1kh +/- 0kv
Case6b = 1kh +/- 0.3kv
Case6c = 0.3kh +/- 1kv

Description of the load conditions in Table 11 for the CSU rigid basin were:

Dry Condition: Dry soil and empty basin

10 Year Flood: Soil saturated and water in basin from tail water depth (= 0.63 m) to headwater depth (= 0.73 m).

Rapid Gate Closure: Soil saturated from tail water depth (= 1.10 m) to headwater depth (= 1.43 m) and empty basin

Construction/Maintenance: Dry soil, empty basin, and surcharge load equivalent to one meter of soil

Maximum Flow: Soil saturated and water in basin from tail water depth (= 1.10 m) to headwater depth (= 1.43 m)

Earthquake : Dry soil, empty basin, and earthquake loads applied. Three earthquake cases were analyzed as indicated in Table 11.

Post-Earthquake: Dry soil and empty basin with base area in contact taken as the position of the structure following the earthquake analysis. If the resultant location for the Earthquake load case is within the middle third, the Post-Earthquake load case passes by inspection.

7.3.5 Concrete Conduits

The Concrete Conduits were designed in accordance with Alberta Transportation: "*Water Control Structures*" in conjunction with guidelines from the US Army Corps of Engineers' EM 1110-2-2902 "*Conduits, Culverts, and Pipes*" and FEMA's "*Technical Manual: Conduits through Embankment Dams*". The pressure conduit was analyzed for floatation considering the load cases as shown in Table 12. Flood water retained in the reservoir was assumed to be of such short duration that development of a phreatic water surface through the embankment would not occur. Therefore, the downstream gravity conduit was not included in the floatation safety factor evaluation.

Table 12. Pressure Conduit - Load Cases and Stability Acceptance Criteria

Load Case	Scenario	Loading	Floatation Safety Factor*
U1	Usual Load Condition 1: Empty Reservoir	Dead	-**
UN1	Unusual Load Condition 1: Construction	Dead + Equipment Surcharge	-**
UN2***	Unusual Load Condition 2: Conduit submerged with water inside of conduit	Dead + Hydro + Uplift	1.3
UN3***	Unusual Load Condition 3: Conduit submerged with no water inside of conduit	Dead + Hydro + Uplift	1.3
E1	Extreme Load Condition 1: Empty Reservoir and earthquake load	Dead + Seismic	-**

*Alberta Transportation: Water Control Structures 2004, Section 8.5
**Groundwater elevation is assumed at bottom of conduit base.
***Only applicable to the pressure conduit section.

7.4 SUMMARY OF STABILITY ANALYSES

Stability analyses for the LLOW structures were performed in accordance with criteria and procedures outlined in the CDA Technical Bulletin No. 9, "Structural Considerations for Dam Safety", and the USACE EM 1110-2-2100 "Stability Analysis of Concrete Structures." Each section or structure was evaluated for Usual, Unusual, Extreme, and Post-Seismic loading conditions representing potential conditions the structure will experience during its design life. Summaries of the stability calculation results are presented in the sections that follow. Refer to Appendices E.5-1 to E.5-4 for stability calculations and results.

7.4.1 Intake Structure

Stability analysis results for the intake structure are summarized in Table 13. As shown in Table 13, the intake structure meets the criteria for sliding, resultant location, floatation, and bearing capacity for the analysis load cases. Refer to Appendix E.5-1 for detailed stability analysis calculations for the Intake Structure.

Table 13. Intake Structure - Stability Analysis Results Summary

Load Case	Reservoir Elevation (m)	Floatation Safety Factor (FSF)		Sliding Safety Factor (SSF)		Foundation Bearing Stress (kPa)		Resultant Location	
		Req.	Calc.	Req.	Calc.	Req.	Calc. (Max)	Req.	Calc.
Usual Load Cases									
LC01- Empty Reservoir (Winter)	1187.00	1.5	8.8	1.5	>10	200	133	100%	100%
LC02 – Empty Reservoir (Summer)	1187.00	1.5	8.7	1.5	>10	200	132	100%	100%
Unusual Load Cases									
LC03 – Construction	1192.00	1.3	9.2	1.3	8.0	200	142	100%	100%
LC04 – 10-Year Flood	1192.00	1.3	2.2	1.3	>10	200	120	100%	100%
Extreme – Flood									
LC05 – 10-Year Flood + Impact	1192.00	1.1	2.2	1.1	7.0	200	131	75%	100%
LC06 – 10-Year Flood + Clogged Trashracks	1192.00	1.1	2.0	1.1	>10	200	102	75%	100%
LC07 – Maximum Pool	1213.50	1.1	1.3	1.1	9.0	200	103	75%	100%
Extreme – Earthquake									
LC08[1] - Earthquake	1187.00	*n/a*	*10.8 – 9.3*	*n/a*	*3.4 – 1.0*	*n/a*	*199-450*	*>0%*	*100% - 51%*
LC09 – Post-Earthquake	1187.00	1.1	8.7	1.1	>10	600[2]	326	100%	100%

1- *No criteria for Earthquake cases. Results are for post-earthquake estimate. A range of results is provided for 24 seismic acceleration configurations.*
2- *Ultimate bearing pressure is used.*

7.4.2 Intake Structure Wing Walls

Stability analysis results for the Wing Walls are summarized in Table 14. The proposed Wing Walls meet the stability criteria described in section for sliding, resultant location, floatation, and bearing capacity for the analysis load cases. Detailed stability calculations for the wing walls are provided in Appendix E.5-1.

Table 14. Intake Structure Wing Walls - Stability Analysis Results Summary

Load Case	Reservoir Elevation (m)	Floatation Safety Factor (FSF)		Sliding Safety Factor (SSF)		Foundation Bearing Stress (kPa)		Resultant Location	
		Req.	Calc.	Req.	Calc.	Req.	Calc. (Max)	Req.	Calc.
Usual Load Cases									
LC01- Empty Reservoir	1187.00	1.5	4.7	1.5	10.9	150	88	100%	100%
Unusual Load Cases									
LC02 – Construction	1187.00	1.3	4.7	1.3	1.7	150	136	100%	100%
LC03 – Rapid Drawdown	1189.75[3]	1.3	2.1	1.3	1.3	150	107	100%	100%
Extreme – Earthquake									
LC04[1] - Earthquake	1187.00	*n/a*	4.6	*n/a*	*2.1*	*n/a*	*196*	*>0%*	*65.7%*
LC05 – Post-Earthquake	1187.00	1.1	4.4	1.1	2.3	450[2]	450	100%	100%

1- No criteria for Earthquake cases. Results are for post-earthquake estimate. Worse case result is provided for 4 seismic acceleration configurations.
2- Ultimate bearing pressure is used.
3- Top of wing wall elevation

7.4.3 Gate Structure

Stability analysis results for the Gate Structure are summarized in Table 15. The intake structure meets the criteria for sliding, resultant location, floatation, and bearing capacity for the analysis load cases considered. Detailed stability calculations for the Gate Structure is provided in Appendix E.5-2.

Table 15. Gate Structure - Stability Analysis Results Summary

Load Case	Reservoir Elevation (m)	Floatation Safety Factor (FSF)		Sliding Safety Factor (SSF)		Foundation Bearing Stress (kPa)			Resultant Location	
							Calc. (Max)			
		Req.	Calc.	Req.	Calc.	Req.	Long Term	Short Term	Req.	Calc.
Usual Load Cases										
LC01- Empty Reservoir	1186.36	1.5	>10	1.5	>10	427	412	424	100%	100%
Unusual Load Cases										
LC02 – 10-Year Flood, Gates Open	1191.43	1.3	6.1	1.3	>10	427	368	384	100%	100%
LC03 – 10-Year Flood, Gate Closed	1191.43	1.3	5.95	1.3	>10	427	353	369	100%	100%
LC04 – Staged Construction	1186.36	1.3	>10	1.3	>10	250	203	n/a	100%	100%
LC05 – Crane Surcharge	1186.36	1.3	>10	1.3	>10	427	n/a	428	100%	100%
Extreme – Flood										
LC05 – Maximum Pool, Gates Open	1213.50	1.1	2.2	1.1	>10	427	350	359	75%	100%
LC06 – Maximum Pool, Gate Closed	1213.50	1.1	2.0	1.1	>10	427	337	345	75%	100%
Extreme – Earthquake										
LC08[1] – Earthquake	1186.36	*n/a*	*>10*	*n/a*	>10	*n/a*	*n/a*	*718*	*>0%*	*100%*
LC09 – Post-Earthquake	1186.36	1.1	>10	1.1	>10	427	n/a	398	100%	100%

1- No criteria for Earthquake cases. Results are for post-earthquake estimate. Worst case result is provided for 24 seismic acceleration configurations.

7.4.4 CSU Rigid Basin

The stability analysis results for the CSU Rigid Basin are summarized in **Error! Reference source not found.**. Refer to Appendix E.5-3 for stability calculations and results.

Table 16. CSU Rigid Basin - Stability Analysis Results Summary

Load Case	Entrance /Exit Water Elevation (m)	Floatation Safety Factor (FSF)		Sliding Safety Factor (SSF)		Foundation Bearing Stress (kPa)		Resultant Location	
		Req.	Calc.	Req.	Calc.	Req.	Calc. (Max)	Req.	Calc.
Usual Load Cases									
LC01- Empty Reservoir	1183.12	1.5	n/a	1.5	2.5	150	94	100%	100%
Unusual Load Cases									
LC02 – 10 Year Flood	1183.85 / 1183.75	1.3	4.3	1.3	1.5	150	75	100%	100%
LC03 – Rapid Gate Closure	1184.55 / 1184.22	1.3	2.8	1.3	1.5	150	65	100%	100%
LC04 – Construction / Maintenance	1183.12	1.3	n/a	1.3	1.9	150	88	100%	100%
Extreme – Earthquake									
LC05 – Maximum Flow	1184.55 / 1184.22	1.1	3.3	1.1	1.4	150	71	100%	100%
LC06[1] - Earthquake	1183.12	*n/a*	*>10*	*n/a*	*1.0 – 1.9*	*200*	*91*	*>0%*	*100%*
LC07 – Post-Earthquake	1183.12	1.1	n/a	1.5	2.5	150	94	100%	100%

1- No criteria for Earthquake cases. Results are for post-earthquake estimate.

7.4.5 Concrete Conduit

The stability analysis results for the Pressure Conduit are summarized in Table 17. Detailed stability calculations for the Concrete Conduit is provided in Appendix E.5-4.

Table 17. Pressure Conduit - Stability Analysis Results Summary

Load Case	Loading Type	Floatation Safety Factor
U1	Usual Load Condition 1: Empty Reservoir	-**
UN1	Unusual Load Condition 1: Construction	-**
UN2	Unusual Load Condition 2: Conduit submerged with water inside of conduit	1.9
UN3	Unusual Load Condition 3: Conduit submerged with no water inside of conduit	1.7
E1	Extreme Load Condition 1: Empty Reservoir and earthquake load	-**

**Groundwater elevation is assumed at bottom of conduit base.

8.0 STRENGTH EVALUATION AND DESIGN

Strength evaluation of individual elements or members of structures and monoliths was used to verify member sizes and steel reinforcement based on application of factored loads as described in the ABC with some adjustment for more severe conditions or loads not included in the ABC.

Reinforced concrete design was performed according to Design of Concrete Structures, CSA A23.3-14 with the additional requirements of the CSA's SEED Document – *Structural Design of Wastewater Treatment Plants-2018* for revisions addressing service load conditions, water tightness, shrinkage and temperature reinforcement, and crack control. The Seed Document contains references to ACI 350M-06 for modifying CSA A23.3-14.

Structural steel design was performed according to Design of Steel Structures, CSA S16-14, and codes for welding, materials, and other pertinent references.

In general, structural analysis and design was performed manually using MathCAD or Excel spreadsheets. For more complex structures, such as the LLOW intake and the Gate Structure, a commercial Three-Dimensional Finite Element Model (FEM) was used to evaluate multiple load combinations, identify stress concentrations, and generate shear and moment values for the design of individual elements. The FEM was supplemented with manual calculations to verify/validate model results and where necessary, refine the analysis of individual elements. Based on model output, a combination of manual calculations and commercial software were used for strength design. Additional elements evaluated as part of strength design included joint detailing, equipment anchorage, and embedded parts.

9.0 SERVICEABILITY

Structural serviceability concerns with the Low-Level Outlet Works relate primarily to concrete durability including limiting deflections, reducing crack potential, providing thermal stress relief, and incorporating measures to mitigate alkali-aggregate reaction (AAR) and other chemical attack. The same manual calculations, commercial software, or 3-D FEM used for strength evaluation were used to evaluate deflection and thermal growth, while design detailing and material specification were used to mitigate cracking and AAR potential.

Shrinkage control and volume changes are addressed primarily with placement sequence, mix design, surface reinforcement, and material specifications. The structure layout and design define concrete placements with balanced aspect ratios. Joint placements allow for proper dissipation of heat of hydration and initial shrinkage before placement of adjacent concrete. Expanded guidance related to placement sequence and joint locations will be addressed as part of constructability review during Final Design.

Tight installation tolerances for gates, hoists and other embedded components are critical for their operation or installation. These tolerances are addressed primarily through second stage concrete placements occurring after initial concrete shrinkage has occurred. Using a second stage concrete placement also allows gate assemblies to be installed, checked and adjusted for operation before components are permanently being embedded in concrete.

10.0 CONSTRUCTION CONSIDERATIONS

Construction specifications and details for the Low-Level Outlet Works will be furthered during Final Design. The following construction considerations are noted:

- The foundation subgrade was located in glacial till to maximize subgrade uniformity and minimize differential settlement and total settlement. Foundation preparation will require special care in preparation of the structure subgrade to meet bearing capacity for the tall structures and conduits. Foundation preparation details will be developed during Final Design.

- Construction sequencing of conduit placements will be required to minimize thermal expansion and contraction due to the concrete's heat of hydration.

- Settlement and conduit elongation are expected to occur. Conduit joint spacing, treatment and type will be developed to address estimated settlement and elongation along the conduits. Total settlement and camber will be used to design appropriate joint spacing in the conduits and to select the types of joint collars to use.

- Joint preparation will require special attention to ensure proper installation of water stops, shear keys, dowels, and reinforcement for joint alignment and water-tight integrity of the conduits.

- Procurement lead-time for the fabricated slide gate components will likely be driven by steel availability and fabrication schedules. An allowance of 3 to 6 months is recommended to account for design, shop drawing review/approval, fabrication, testing, and delivery.; particularly since the LLOW will be the first structure to be constructed since it is needed for diversion of the unnamed creek.

- Fill placement and compaction methods must be reviewed and monitored to ensure conduit monolith and wing wall movement does not occur during construction.

- Gate slots, access bridge, and the control house at the LLOW will require combinations of concrete block outs, anchor bolts, and embedded parts in first and second stage concrete placements. Placement tolerance for some of these items are tighter than typical heavy construction tolerance due to fit and operating clearance requirements.

APPENDIX E.5-1 INTAKE STRUCTURE AND WINGWALLS

Appendix E.5-1 – Intake Structure & Wing Wall Stability Analyses

Springbank Off-Stream Storage/Alberta Transportation

Table of Contents

Intake Structure - Model Input and Calculations

LOAD CALCULATIONS - Snow and Wind Loads
SR1- Low Level Outlet Intake Tower

Source: 1. Alberta Building Code 2014, Volume 1

Objective: Estimate design wind and snow loads for the Intake Structure at SR1.

1.0 Calculated Snow Load

- Importance category:	Post-Disaster	Table 4.1.2.1
- Importance factor for snow load:	$I_s := 1.25$	Table 4.1.6.2
- Basic roof snow load factor:	$C_b := 0.8$	4.1.6.2 (2)
- Wind exposure factor:	$C_w := 1.0$	4.1.6.2 (3)
- Slope factor:	$C_s := 1.0$	4.1.6.2 (5)
- Shape factor:	$C_a := 1.0$	4.1.6.2 (8)
- 1 in 50-year ground snow load factor:	$S_s := 1.1\text{kPa}$	Appendix C, Table C-2
- 1 in 50-year associated rain load:	$S_r := \min\left[0.1\text{kPa}, S_s\cdot\left(C_b\cdot C_w\cdot C_s\cdot C_a\right)\right]$	Appendix C, Table C-2
	$S_r = 0.1\cdot\text{kPa}$	
Specified Snow Load:	$S := I_s\cdot\left[S_s\cdot\left(C_b\cdot C_w\cdot C_s\cdot C_a\right) + S_r\right]$	4.1.6.2
	$\boxed{S = 1.23\cdot\text{kPa}}$	

2.0 Calculated Wind Load

- Height of structure:	$h := 8.7\text{m}$	
- Importance factor:	$I_W := 1.25$ (High)	Table 4.1.7.1
- Exposure factor:	$C_e := \max\left[0.9, \left(\frac{h}{10\text{m}}\right)^{0.2}\right] = 0.97$	4.1.7.1 (5a)
- Gust effect factor:	$C_g := 2.0$	4.1.7.1 (6)
- External Pressure Coefficient:	$C_p := 1.0$	4.1.7.1 (Conservative)
-Reference Velocity Pressure:	$q := 0.48\text{kPa}$	Table C-2 1/50 return
Specified Wind Load:	$\boxed{p := I_W\cdot q\cdot\left(C_e\cdot C_g\cdot C_p\right) = 1.17\cdot\text{kPa}}$	4.1.7.1 (All directions)

INTAKE TRASHRACK WEIGHT

Objective : Approximate the weight of the different Intake tower trashracks. Use Design drawings as reference.

Unit Weight of Steel: $\gamma_s := 77.0 \frac{kN}{m^3}$

Length of Vertical Bars: $l_{v.a} := 2500mm$ $l_{v.b} := 2500mm$ $l_c := 2500mm$

Thickness of Vertical Bars: $t_v := 16mm$

Height of Vertical Bars: $h_v := 50mm$

Number of Vertical Bars: $n_v := 17$

Vertical L Bar Area: $A_L := 19mm(150mm + 131mm) = 5339.00 \cdot mm^2$

Length of Horizontal Bars, Type A & B: $l_h := 2800mm$

Length of Horizontal Bars, Type C: $l_{h.c} := 2800mm$

Thickness of Horizontal Bars: $t_h := 16mm$

Height of Horizontal Bars: $h_h := 200mm$

Number of Horizontal Bars: $n_h := 6$

Corner Trapezoidal Bar Volume: $V_{cb.1} := 10mm \cdot (150mm \cdot 50mm + 0.5 \cdot 100mm \cdot 150mm) = 150000.00 \cdot mm^3$

Corner Bar Volume - top A: $V_{cb.2a} := 50mm \cdot 200mm \cdot 100mm = 1000000.00 \cdot mm^3$

Corner Bar Volume - top B: $V_{cb.2b} := 19mm \cdot 200mm \cdot 100mm = 380000.00 \cdot mm^3$

Corner Bar Volume - bottom: $V_{cb.3} := 19mm \cdot 200mm \cdot 100mm = 380000.00 \cdot mm^3$

Lift Bar Volume: $V_{cb.4} := 25mm \cdot 25mm \cdot 500mm = 312500.00 \cdot mm^3$

BAR VOLUME

Type A Vertical Bars: $V_a := l_{v.a} \cdot \left(n_v \cdot t_v \cdot h_v + 2 \cdot A_L\right) = 60695000.00 \cdot mm^3$

Type B Vertical Bars: $V_b := l_{v.b} \cdot \left(n_v \cdot t_v \cdot h_v + 2 \cdot A_L\right) = 60695000.00 \cdot mm^3$

Type C Vertical Bars: $V_c := l_c \cdot \left(n_v \cdot t_v \cdot h_v + 2 \cdot A_L\right) = 60695000.00 \cdot mm^3$

Horizontal Bars - Type A & B: $V_h := l_h \cdot n_h \cdot t_h \cdot h_h - n_h \cdot t_h \cdot (50mm \cdot 181mm) \cdot 2 = 52022400.00 \cdot mm^3$

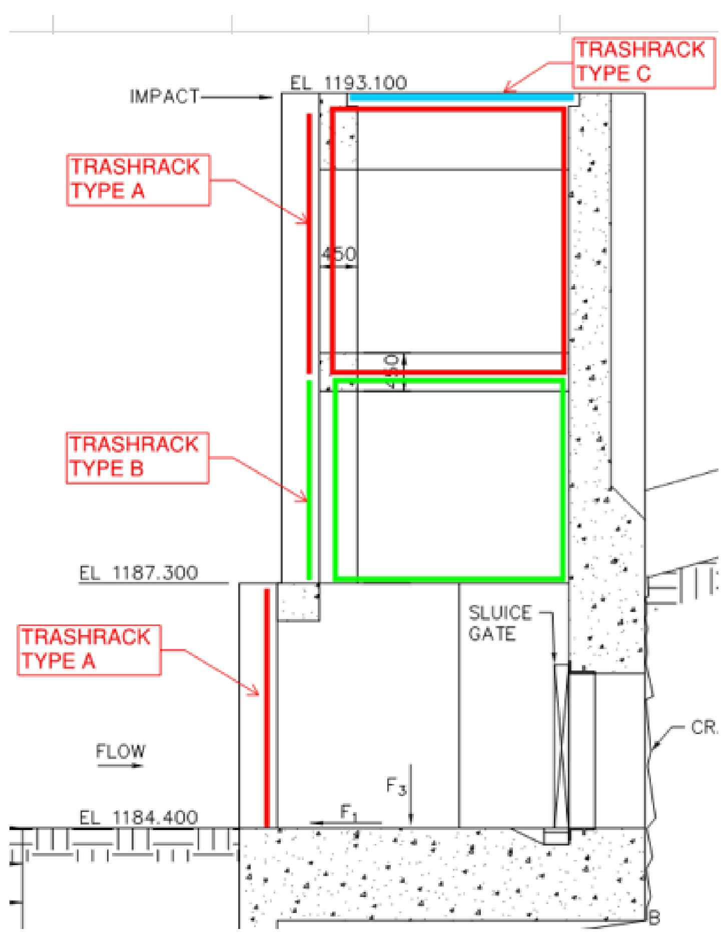
Horizontal Bars - Type C: $V_{h.c} := l_{h.c} \cdot n_h \cdot t_h \cdot h_h - n_h \cdot \left(t_h \cdot 50mm \cdot 181mm\right) \cdot 2 = 52022400.00 \cdot mm^3$

TRASHRACK MASS

Type A: $W_a := \frac{\gamma_s}{g} \cdot \left(V_a + V_h + 4 \cdot V_{cb.1} + 2 \cdot V_{cb.2a} + 2 \cdot V_{cb.3}\right) = 911.4 \cdot kg$

Type B: $W_b := \frac{\gamma_s}{g} \cdot \left(V_b + V_h + 4 \cdot V_{cb.1} + 2 \cdot V_{cb.2b} + 2 \cdot V_{cb.3} + 4 \cdot V_{cb.4}\right) = 911.5 \cdot kg$

Type C: $W_c := \frac{\gamma_s}{g} \cdot \left(V_c + V_{h.c} + 4 \cdot V_{cb.1} + 4 \cdot V_{cb.3}\right) = 901.7 \cdot kg$



Project: Springbank Off-Stream Storage Project - SR1
By: C. Gabriel Date: 8/7/2019
Checked: A. Garland Date: 8/9/2019

SNOW LOADS

Assumptions:
Top Trashracks transfer Snow loads to top side beams
Trashracks are 50% plugged with debris: some snow accumulation

Snow Pressure: 1.23 kPa

			X	Y	Z		
member	**location**	**type**	**Width (mm)**	**Depth (mm)**	**Height (mm)**	**load**	
col	top - front	Point	900	900	varies	1.00	kN
beam	top - front	frame	450	2500	900	0.554	kN/m
beam	top - sides	frame	2500	450	900	1.322	kN/m
Wall	Back - top face (3)	shell	900	5300	5800	1.23	kPa
beam	Mid - front	frame	450	2500	450	0.554	kN/m
beam	Mid - sides	frame	2500	450	450	0.554	kN/m
beam	low - front	frame	950	2500	450	1.17	kN/m
Wall	Sides - top edge	shell	3900	900	2900	1.23	kPa
slab	top - outside	shell	varies	varies	varies	1.23	kPa
slab	top- inside	shell	varies	varies	varies	0.615	kPa

Project: Springbank Off-Stream Storage Project - SR1
By: C. Gabriel   Date: 8/4/2019
Checked: A. Garland   Date: 8/13/2019

WIND LOADS

Assumptions:
Trashracks transfer wind loads to columns
Trashracks are 50% plugged with debris

Wind Pressure: 1.17 kPa

			Z	X	Y	X	Y	
			Tributary					
member	**location**	**type**	**Height (m)**	**Width (mm)**	**Depth (mm)**	**Load**		
col	top	frame	3.175	1525	1525	1.784	1.784	kN/m
col	mid	frame	0.525	1525	1525	1.784	1.784	kN/m
col	Low	frame		1525	1525	1.784	1.784	kN/m
wall	Approach walls	edge frame	2.100	-	1525	1.784	0.000	kN/m
beam	top	frame	0.9	450	2500	1.053	1.053	kN/m
beam	mid + low	frame	0.45	950	2500	0.527	0.527	kN/m
wall	Approach walls	Area	2.9	3900	900	0.000	1.170	kPa
wall	Back Wall	Area	6.025	900	3400	2.340	0	kPa

Load Combinations

	X	y
W1	1	0
W2	0	1
W3	0.75	0.75
W4	-1	0
W5	-0.75	0.75

Project: **Springbank Off-Stream Storage** By:

Title: **Foundation Stiffness Calculations Per FEMA 356** Checked:

Structure: **Low Level Outlet Intake Structure**

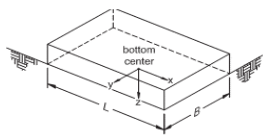
FEMA equations are to be used with U.S. Customary Units, therefore, the inputs are converted from SI for use with the equations and the final values are converted back.

B (m)	L (m)	D (m)	d (m)	h (m)	L/B	D/B	G (MPa)	v
6.30	7.90	2.00	2.0	1.00	1.25	0.32	10	0.45

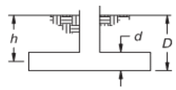
B (ft)	L (ft)	D (ft)	d (ft)	h (ft)	L/B	D/B	G (psf)	v
20.7	25.9	6.6	6.6	3.28	1.25	0.32	208,854	0.45

Chapter 4: Foundations and Geologic Site Hazards

Degree of Freedom	Stiffness of Foundation at Surface	Note
Translation along x-axis	$K_{x,\,sur} = \frac{GB}{2-v}\left[3.4\left(\frac{L}{B}\right)^{0.65} + 1.2\right]$	
Translation along y-axis	$K_{y,\,sur} = \frac{GB}{2-v}\left[3.4\left(\frac{L}{B}\right)^{0.65} + 0.4\frac{L}{B} + 0.8\right]$	
Translation along z-axis	$K_{z,\,sur} = \frac{GB}{1-v}\left[1.55\left(\frac{L}{B}\right)^{0.75} + 0.8\right]$	
Rocking about x-axis	$K_{xx,\,sur} = \frac{GB^3}{1-v}\left[0.4\left(\frac{L}{B}\right) + 0.1\right]$	
Rocking about y-axis	$K_{yy,\,sur} = \frac{GB^3}{1-v}\left[0.47\left(\frac{L}{B}\right)^{2.4} + 0.034\right]$	Orient axes such that $L \geq B$
Torsion about z-axis	$K_{zz,\,sur} = GB^3\left[0.53\left(\frac{L}{B}\right)^{2.45} + 0.51\right]$	



Degree of Freedom	Correction Factor for Embedment	Note
Translation along x-axis	$\beta_x = \left(1 + 0.21\sqrt{\frac{D}{B}}\right)\cdot\left[1 + 1.6\left(\frac{hd(B+L)}{BL^2}\right)^{0.4}\right]$	
Translation along y-axis	$\beta_y = \beta_x$	
Translation along z-axis	$\beta_z = \left[1 + \frac{1}{21}\frac{D}{B}\left(2 + 2.6\frac{B}{L}\right)\right]\cdot\left[1 + 0.32\left(\frac{d(B+L)}{BL}\right)^{2/3}\right]$	d = height of effective sidewall contact (may be less than total foundation height)
Rocking about x-axis	$\beta_{xx} = 1 + 2.5\frac{d}{B}\left[1 + \frac{2d}{B}\left(\frac{d}{D}\right)^{-0.2}\sqrt{\frac{B}{L}}\right]$	h = depth to centroid of effective sidewall contact
Rocking about y-axis	$\beta_{yy} = 1 + 1.4\left(\frac{d}{L}\right)^{0.6}\left[1.5 + 3.7\left(\frac{d}{L}\right)^{1.9}\left(\frac{d}{D}\right)^{-0.6}\right]$	For each degree of freedom, calculate $K_{emb} = \beta K_{sur}$
Torsion about z-axis	$\beta_{zz} = 1 + 2.6\left(1 + \frac{B}{L}\right)\left(\frac{d}{B}\right)^{0.9}$	



FEMA 356, Figure 4-4

Note: When L = B, use x-axis rocking stiffness and embedment correction factor for Y-axis rocking

* Axis Orientation is based on FEMA 356.

	Correction Factors for Embedment*					
	Translational			Rocking		Torsion
Site	β_x	β_y	β_z	β_{xx}	β_{yy}	β_{zz}
Gate Tower	1.74	1.74	1.30	2.24	2.09	2.66

	Stiffness of Foundation at Surface*					
	Translational (lb/ft)			Rocking (lb-ft/rad)		Torsion (lb-ft/rad)
Site	$k_{x,sur}$	$k_{y,sur}$	$k_{z,sur}$	$k_{xx,sur}$	$k_{yy,sur}$	$k_{zz,sur}$
Gate Tower	14,312,687	14,595,629	20,696,365	2,017,528,748	2,827,380,047	2,642,714,287

	Stiffness of Foundation With Embedment Corrections*					
	Translational (kip/ft)			Rocking (kip-ft/rad)		Torsion (kip-ft/rad)
Site	$k_{x,emb}$	$k_{y,emb}$	$k_{z,emb}$	$k_{xx,emb}$	$k_{yy,emb}$	$k_{zz,emb}$
Gate Tower	24,958	25,451	26,808	4,526,616	5,903,709	7,040,209

	Stiffness of Foundation With Embedment Corrections*					
	Translational (kN/m)			Rocking (kN-m/rad)		Torsion (kN-m/rad)
Site	$k_{x,emb}$	$k_{y,emb}$	$k_{z,emb}$	$k_{xx,emb}$	$k_{yy,emb}$	$k_{zz,emb}$
Gate Tower	364,233	371,433	391,231	6,138,091	8,005,429	9,546,523

Project: **Springbank Off-Stream Storage Project - SR1** BY: CG Check: ACG
Site: **Intake Structure** DATE: 9/26/2019 Date: 10/18/2019

Soil-Structure Interaction Effects

Reference: FEMA 440 Chapter 8: Procedures for Including Soil-Structure Interaction Effects
Load Case: Earthquake (MDE)

Conversions	
m to ft	3.2808399
kg to slug	0.0685218

Length of Footing (ft)	25.9	= l_f		Foundation Embedment (ft)	6.56 = e
Width of Footing (ft)	20.7	= w_f		Peak Ground Acceleration (g)	0.2800 = PGA
Effective Foundation Size (ft)	23.15	= b_e		Shear Wave Velocity Reduction	0.66 = n
Area of Footing (ft^2)	535.72	= A_f		Shear Wave Velocity (ft/s)	869 = v_s
Equivalent Foundation Radius (ft)	13.06	= r_x	(EQ. 8-4)	Translational Footing Stiffness (kip/ft)	24,958 = K_h FEMA 356 - Spring Constant Calculation
Poissons Ratio	0.45	= v		Effective Soil Shear Modulus (psf)	208,854 = G
Structure Height (ft)	28.54	= h		Effective Structure Height (ft)	19.98 = h*
Ductility Demand	2.00	= μ		Initial Fixed Base Damping Ratio	5.00 = β_i
Adjustment Factor	1.75	= c_e	(EQ. 8-9c)		

Fixed Base Model

T (sec/cycle)	S_a (g)	RRS_{bsa}	RRS_e	RRS	$\hat{S}_a$ (g)	$(\hat{S}_a)_{\beta\_x}$ (g)	$(\hat{S}_a)_{\beta\_y}$ (g)
0.0818	0.419	0.979	0.936	0.916	0.384	0.368	0.342
0.0703	0.387	0.979	0.936	0.916	0.354	0.339	0.316
0.0384	0.318	0.979	0.936	0.916	0.292	0.279	0.260
0.0283	0.308	0.979	0.936	0.916	0.283	0.270	0.252
0.0250	0.305	0.979	0.936	0.916	0.279	0.268	0.249
0.0198	0.300	0.979	0.936	0.916	0.275	0.263	0.245
0.0184	0.298	0.979	0.936	0.916	0.273	0.262	0.244
0.0168	0.297	0.979	0.936	0.916	0.272	0.260	0.242
0.0152	0.295	0.979	0.936	0.916	0.271	0.259	0.241
0.0144	0.294	0.979	0.936	0.916	0.270	0.258	0.240
0.0140	0.294	0.979	0.936	0.916	0.269	0.258	0.240
0.0124	0.292	0.979	0.936	0.916	0.268	0.256	0.239
0.0122	0.292	0.979	0.936	0.916	0.268	0.256	0.239
0.0113	0.291	0.979	0.997	0.975	0.284	0.272	0.253
0.0101	0.290	0.979	0.936	0.916	0.266	0.254	0.237
0.0097	0.290	0.979	0.936	0.916	0.265	0.254	0.237
0.0092	0.289	0.979	0.936	0.916	0.265	0.254	0.236
0.0089	0.289	0.979	0.936	0.916	0.265	0.253	0.236
0.0086	0.289	0.979	0.936	0.916	0.264	0.253	0.236
0.0080	0.288	0.979	0.936	0.916	0.264	0.253	0.235
0.0079	0.288	0.979	0.936	0.916	0.264	0.253	0.235
0.0078	0.288	0.979	0.936	0.916	0.264	0.252	0.235
0.0076	0.288	0.979	0.936	0.916	0.264	0.252	0.235
0.0076	0.288	0.979	0.936	0.916	0.263	0.252	0.235
0.0068	0.287	0.979	0.936	0.916	0.263	0.252	0.234

Spring Base Model

$\tilde{T}$ (sec/cycle)	S_a (g)	RRS_{bsa}	RRS_e	RRS	$\hat{S}_a$ (g)	$(\hat{S}_a)_{\beta\_x}$ (g)	$(\hat{S}_a)_{\beta\_y}$ (g)
0.2428	0.661	0.983	0.957	0.940	0.622	0.595	0.554
0.1900	0.623	0.979	0.936	0.916	0.571	0.546	0.509
0.1291	0.519	0.979	0.936	0.916	0.476	0.456	0.424
0.0934	0.452	0.979	0.936	0.916	0.414	0.396	0.369
0.0610	0.361	0.979	0.936	0.916	0.331	0.316	0.295
0.0335	0.313	0.979	0.936	0.916	0.287	0.275	0.256
0.0330	0.313	0.979	0.936	0.916	0.287	0.275	0.256
0.0297	0.310	0.979	0.936	0.916	0.284	0.272	0.253
0.0234	0.303	0.979	0.936	0.916	0.278	0.266	0.248
0.0221	0.302	0.979	0.936	0.916	0.277	0.265	0.247

Table 8-1	Shear Wave Velocity Reduction Factor, n			
PGA:	0.10 g	0.15 g	0.20 g	0.30 g
n:	0.90	0.80	0.70	0.65

	Total Masses		
	X	Y	Z
(kg)	393.45	407.85	356.3
(slug)	27.0	27.9	24.4

	Modal Mass Participation Ratio		
	X	Y	Z
Mode 1	0.27	0.00	0.00
Mode 2	0.00	0.14	0.00

	$\check{T}$ (sec/cycle)	M (slug)	K_{fixed} (kip/ft)	K_θ (kip-ft/rad)	r_θ (ft)	$\check{T}_{eff}/T_{eff}$	a_1	a_2	β_f	β_0	B
Mode 1, X-Direction	0.2428	7.31	43,140	2,831,009	14.09	2.21	19.93	-12.74	5.42	5.88	1.04
Mode 2, Y-Direction	0.1900	3.86	30,897	2,432,688	13.39	2.04	17.72	-10.52	7.06	7.65	1.12

S_a : Horizontal Spectra Acceleration @ Structure Period

RRS_{bsa} : Ratio of response spectra for base slab averaging (EQ 8-1)

RRS_e : Ratio of response spectra for embedment (EQ 8-2)

RRS : Ratio of Response Spectra = RRS_{bsa} * RRS_e

$\hat{S}_a$: Horizontal Spectra Acceleration reduced for Kinematic Effects

$(\hat{S}_a)_{\beta\_x}$: X-Direction Horizontal Spectra Acceleration reduced for Kinematic Effects & Foundation Damping (EQ. 6-16)

$(\hat{S}_a)_{\beta\_z}$: Z-Direction Horizontal Spectra Acceleration reduced for Kinematic Effects & Foundation Damping (EQ. 6-16)

T : Fixed Base Model Structural Natural Period

$\check{T}$: Spring Base Model Structural Natural Period

M : Effective Mass for the first mode

K_{fixed} : Effective Structural Stiffness for the Fixed base condition (EQ 8-3)

K_θ : Effective Rotational Stiffness of the Foundation (EQ. 8-6)

r_θ : Equivalent Foundation Radius for Rotation (EQ. 8-7)

$\check{T}_{eff}/T_{eff}$: Effective Period-Lengthening Ratio (EQ. 8-8)

a_1 : Modificaton Factor (EQ. 8-9a)

a_2 : Modificaton Factor (EQ. 8-9b)

β_f : Foundation Damping due to Radiation Damping (EQ. 8-9)

β_0 : Flexible Base Damping Ratio (EQ. 8-10)

B : Spectral Acceleration Reduction Factor for Foundation Damping (EQ. 6-17)

Project: Springbank Off-Stream Storage Project - SR1
By: C. Gabriel Date: 8/4/2019

MODEL VERIFICATION

QTY	DESCRIPTION	X LENGTH (mm)	Y WIDTH (mm)	Z HEIGHT (mm)	Shape Factor	VOLUME (m^3)	DENSITY (kN/m^3)	VERTICAL (kN)
Dead Load of Structure:								
1	base slab	7,900	6,300	900	1.0	44.79	23.56	1,055.5
1	Key	21,100	500	1,100	1.0	11.61	23.56	273.4
2	side wall (approach)	4,800	900	2,900	1.0	12.53	23.56	590.40
2	side wall (ellipse)	900	350	2,900	0.8	0.72	23.56	33.81
2	side wall (transition 1)	1,800	400	1,800	0.5	0.65	23.56	30.54
2	side wall (transition 2)	1,800	850	1,800	1.0	2.75	23.56	129.79
2	side wall (transition 3)	300	850	1,800	1.0	0.46	23.56	21.63
2	top slab (partial allipse)	1,800	650	1,250	0.5	0.73	23.56	34.47
1	top slab (2)	1,800	3,000	1,250	1.0	6.75	23.56	159.09
1	top slap (3)	300	3,000	**850**	1.0	0.77	23.56	18.03
1	top slab (partial ellipse wedge)		2,142		1.0	1.00	23.56	23.61
1	backwall	450	2,500	5,800	1.0	6.53	23.56	153.75
4	column	900	900	5,800	1.0	4.70	23.56	442.80
1	beam (low)	950	2,500	450	1.0	1.07	23.56	25.18
2	beam (sides, mid)	2,500	450	450	1.0	0.51	23.56	23.86
1	beam (front, mid)	450	2,500	450	1.0	0.51	23.56	11.93
2	beam (sides, top)	2,500	450	900	1.0	1.01	23.56	47.72
1	beam (front, top)	450	2,500	900	1.0	1.01	23.56	23.86
4	Trash Rack (Type A)							35.77
3	Trash Rack (Type B)			X				26.83
1	Trash Rack (Type C)							8.94
							Sum Forces =	**3,171**

Model Verification to LC01			
from SAP2000	**Avg**	**Diff**	**%Diff**
3053.0	3111.9	59	1.89

Intake Structure - SAP2000 Report

License #2010*1NRDSQ492PZEHHT

SAP2000 Analysis Report

Prepared by

Stantec Consulting Ltd.

Model Name: 8-INTAKE-hydro.sdb

2 July 2020

Contents

List of Figures

List of Tables

1. Model geometry

This section provides model geometry information, including items such as joint coordinates, joint restraints, and element connectivity.

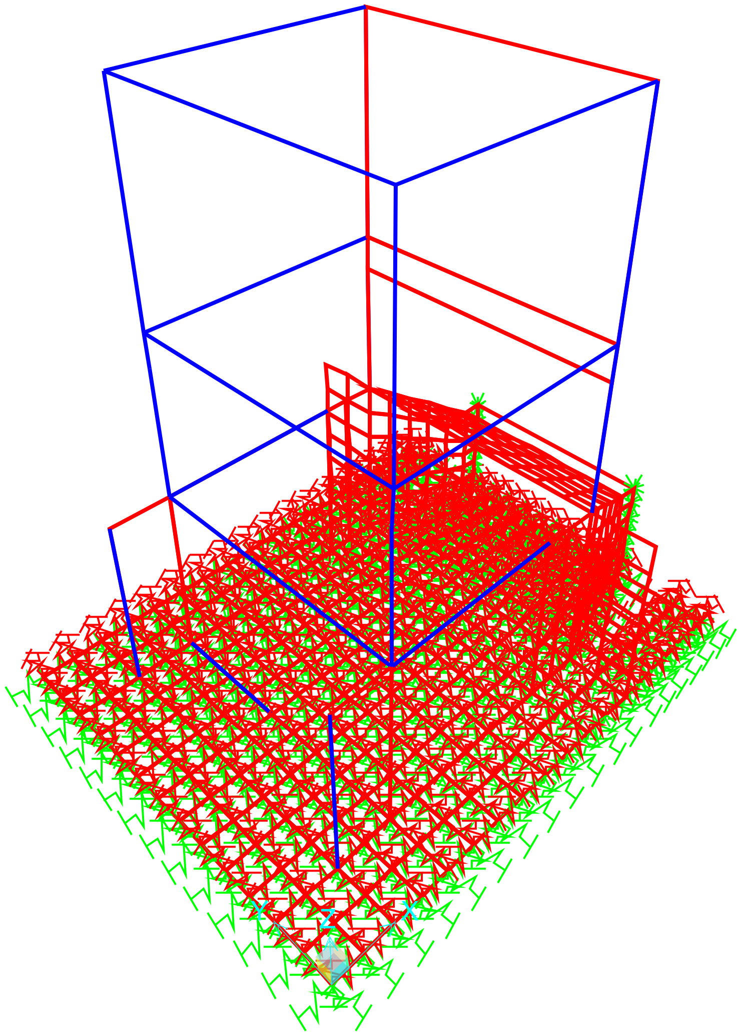


Figure 1: Finite element model

1.1. Joint coordinates

Table 1: Joint Coordinates

Table 1: Joint Coordinates

Joint	CoordSys	CoordType	GlobalX	GlobalY	GlobalZ
			mm	mm	mm
1	GLOBAL	Cartesian	5800.	500.	483.33
2	GLOBAL	Cartesian	0.	0.	0.
3	GLOBAL	Cartesian	500.	0.	0.
4	GLOBAL	Cartesian	1000.	0.	0.

Table 1: Joint Coordinates

Joint	CoordSys	CoordType	GlobalX	GlobalY	GlobalZ
			mm	mm	mm
5	GLOBAL	Cartesian	1950.	0.	0.
6	GLOBAL	Cartesian	5800.	1000.	483.33
7	GLOBAL	Cartesian	4900.	0.	0.
8	GLOBAL	Cartesian	5300.	0.	0.
9	GLOBAL	Cartesian	5800.	0.	0.
10	GLOBAL	Cartesian	7600.	0.	0.
11	GLOBAL	Cartesian	7900.	0.	0.
12	GLOBAL	Cartesian	0.	500.	0.
13	GLOBAL	Cartesian	500.	500.	0.
14	GLOBAL	Cartesian	1000.	500.	0.
15	GLOBAL	Cartesian	1950.	500.	0.
16	GLOBAL	Cartesian	4900.	500.	0.
17	GLOBAL	Cartesian	5300.	500.	0.
18	GLOBAL	Cartesian	5800.	500.	0.
19	GLOBAL	Cartesian	7600.	500.	0.
20	GLOBAL	Cartesian	7900.	500.	0.
21	GLOBAL	Cartesian	0.	1000.	0.
22	GLOBAL	Cartesian	500.	1000.	0.
23	GLOBAL	Cartesian	1000.	1000.	0.
24	GLOBAL	Cartesian	1950.	1000.	0.
25	GLOBAL	Cartesian	4900.	1000.	0.
26	GLOBAL	Cartesian	5300.	1000.	0.
27	GLOBAL	Cartesian	5800.	1000.	0.
28	GLOBAL	Cartesian	5800.	500.	966.67
29	GLOBAL	Cartesian	5800.	1000.	966.67
30	GLOBAL	Cartesian	5800.	500.	1450.
31	GLOBAL	Cartesian	5800.	1000.	1450.
32	GLOBAL	Cartesian	5800.	500.	1933.33
33	GLOBAL	Cartesian	5800.	1000.	1933.33
34	GLOBAL	Cartesian	5800.	500.	2416.67
35	GLOBAL	Cartesian	5800.	1000.	2416.67
36	GLOBAL	Cartesian	5800.	0.	483.33
37	GLOBAL	Cartesian	7600.	1550.	0.
38	GLOBAL	Cartesian	7900.	1550.	0.
39	GLOBAL	Cartesian	5800.	0.	966.67
40	GLOBAL	Cartesian	5800.	0.	1450.
41	GLOBAL	Cartesian	5800.	0.	1933.33
42	GLOBAL	Cartesian	5800.	0.	2416.67
43	GLOBAL	Cartesian	5800.	5800.	483.33
44	GLOBAL	Cartesian	5800.	6300.	483.33
45	GLOBAL	Cartesian	5800.	5800.	966.67
46	GLOBAL	Cartesian	5800.	6300.	966.67
47	GLOBAL	Cartesian	5800.	5800.	1450.
48	GLOBAL	Cartesian	5800.	6300.	1450.
49	GLOBAL	Cartesian	5800.	5800.	1933.33
50	GLOBAL	Cartesian	5800.	6300.	1933.33
51	GLOBAL	Cartesian	5800.	5800.	2416.67
52	GLOBAL	Cartesian	5800.	6300.	2416.67
53	GLOBAL	Cartesian	5800.	5300.	483.33
54	GLOBAL	Cartesian	5800.	5300.	966.67
55	GLOBAL	Cartesian	5800.	5300.	1450.
56	GLOBAL	Cartesian	5800.	5300.	1933.33
57	GLOBAL	Cartesian	5800.	5300.	2416.67
58	GLOBAL	Cartesian	6160.	1110.	0.

Table 1: Joint Coordinates

Joint	CoordSys	CoordType	GlobalX	GlobalY	GlobalZ
			mm	mm	mm
59	GLOBAL	Cartesian	0.	6300.	0.
60	GLOBAL	Cartesian	500.	6300.	0.
61	GLOBAL	Cartesian	1000.	6300.	0.
62	GLOBAL	Cartesian	1950.	6300.	0.
63	GLOBAL	Cartesian	4900.	6300.	0.
64	GLOBAL	Cartesian	5300.	6300.	0.
65	GLOBAL	Cartesian	5800.	6300.	0.
66	GLOBAL	Cartesian	7600.	6300.	0.
67	GLOBAL	Cartesian	7900.	6300.	0.
68	GLOBAL	Cartesian	0.	5800.	0.
69	GLOBAL	Cartesian	500.	5800.	0.
70	GLOBAL	Cartesian	1000.	5800.	0.
71	GLOBAL	Cartesian	1950.	5800.	0.
72	GLOBAL	Cartesian	4900.	5800.	0.
73	GLOBAL	Cartesian	5300.	5800.	0.
74	GLOBAL	Cartesian	5800.	5800.	0.
75	GLOBAL	Cartesian	7600.	5800.	0.
76	GLOBAL	Cartesian	7900.	5800.	0.
77	GLOBAL	Cartesian	0.	5300.	0.
78	GLOBAL	Cartesian	500.	5300.	0.
79	GLOBAL	Cartesian	1000.	5300.	0.
80	GLOBAL	Cartesian	1950.	5300.	0.
81	GLOBAL	Cartesian	4900.	5300.	0.
82	GLOBAL	Cartesian	5300.	5300.	0.
83	GLOBAL	Cartesian	5800.	5300.	0.
84	GLOBAL	Cartesian	6160.	1110.	446.67
85	GLOBAL	Cartesian	6160.	1110.	893.33
86	GLOBAL	Cartesian	7600.	4750.	0.
87	GLOBAL	Cartesian	7900.	4750.	0.
88	GLOBAL	Cartesian	6160.	1110.	1340.
89	GLOBAL	Cartesian	6160.	1110.	1786.67
90	GLOBAL	Cartesian	6160.	1110.	2233.33
91	GLOBAL	Cartesian	6160.	1110.	2680.
92	GLOBAL	Cartesian	6520.	1220.	0.
93	GLOBAL	Cartesian	6520.	1220.	410.
94	GLOBAL	Cartesian	6520.	1220.	820.
95	GLOBAL	Cartesian	6520.	1220.	1230.
96	GLOBAL	Cartesian	6520.	1220.	1640.
97	GLOBAL	Cartesian	6520.	1220.	2050.
98	GLOBAL	Cartesian	6520.	1220.	2460.
99	GLOBAL	Cartesian	6880.	1330.	0.
100	GLOBAL	Cartesian	6880.	1330.	373.33
101	GLOBAL	Cartesian	6880.	1330.	746.67
102	GLOBAL	Cartesian	6880.	1330.	1120.
103	GLOBAL	Cartesian	6880.	1330.	1493.33
104	GLOBAL	Cartesian	6880.	1330.	1866.67
105	GLOBAL	Cartesian	6880.	1330.	2240.
106	GLOBAL	Cartesian	7240.	1440.	0.
107	GLOBAL	Cartesian	7240.	1440.	336.67
108	GLOBAL	Cartesian	7240.	1440.	673.33
109	GLOBAL	Cartesian	7240.	1440.	1010.
110	GLOBAL	Cartesian	7240.	1440.	1346.67
111	GLOBAL	Cartesian	7240.	1440.	1683.33
112	GLOBAL	Cartesian	7240.	1440.	2020.

Table 1: Joint Coordinates

Joint	CoordSys	CoordType	GlobalX	GlobalY	GlobalZ
			mm	mm	mm
113	GLOBAL	Cartesian	7600.	1550.	300.
114	GLOBAL	Cartesian	7600.	1550.	600.
115	GLOBAL	Cartesian	7600.	1550.	900.
116	GLOBAL	Cartesian	7600.	1550.	1200.
117	GLOBAL	Cartesian	7600.	1550.	1500.
118	GLOBAL	Cartesian	7240.	4860.	0.
119	GLOBAL	Cartesian	7240.	4860.	336.67
120	GLOBAL	Cartesian	7600.	4750.	300.
121	GLOBAL	Cartesian	7240.	4860.	673.33
122	GLOBAL	Cartesian	7600.	4750.	600.
123	GLOBAL	Cartesian	7240.	4860.	1010.
124	GLOBAL	Cartesian	7600.	4750.	900.
125	GLOBAL	Cartesian	7240.	4860.	1346.67
126	GLOBAL	Cartesian	7600.	4750.	1200.
127	GLOBAL	Cartesian	7240.	4860.	1683.33
128	GLOBAL	Cartesian	7600.	4750.	1500.
129	GLOBAL	Cartesian	7240.	4860.	2020.
130	GLOBAL	Cartesian	6880.	4970.	0.
131	GLOBAL	Cartesian	6880.	4970.	373.33
132	GLOBAL	Cartesian	6880.	4970.	746.67
133	GLOBAL	Cartesian	6880.	4970.	1120.
134	GLOBAL	Cartesian	6880.	4970.	1493.33
135	GLOBAL	Cartesian	6880.	4970.	1866.67
136	GLOBAL	Cartesian	6880.	4970.	2240.
137	GLOBAL	Cartesian	6520.	5080.	0.
138	GLOBAL	Cartesian	6520.	5080.	410.
139	GLOBAL	Cartesian	6520.	5080.	820.
140	GLOBAL	Cartesian	6520.	5080.	1230.
141	GLOBAL	Cartesian	6520.	5080.	1640.
142	GLOBAL	Cartesian	6520.	5080.	2050.
143	GLOBAL	Cartesian	6520.	5080.	2460.
144	GLOBAL	Cartesian	1000.	1000.	2900.
145	GLOBAL	Cartesian	1950.	1000.	2900.
146	GLOBAL	Cartesian	4900.	1000.	2900.
147	GLOBAL	Cartesian	5300.	1000.	2900.
148	GLOBAL	Cartesian	5800.	1000.	2900.
149	GLOBAL	Cartesian	6160.	5190.	0.
150	GLOBAL	Cartesian	6160.	5190.	446.67
151	GLOBAL	Cartesian	1000.	5300.	2900.
152	GLOBAL	Cartesian	1950.	5300.	2900.
153	GLOBAL	Cartesian	4900.	5300.	2900.
154	GLOBAL	Cartesian	5300.	5300.	2900.
155	GLOBAL	Cartesian	5800.	5300.	2900.
156	GLOBAL	Cartesian	6160.	5190.	893.33
157	GLOBAL	Cartesian	6160.	5190.	1340.
158	GLOBAL	Cartesian	6160.	5190.	1786.67
159	GLOBAL	Cartesian	5800.	0.	2900.
160	GLOBAL	Cartesian	6160.	5190.	2233.33
161	GLOBAL	Cartesian	5800.	500.	2900.
162	GLOBAL	Cartesian	6160.	5190.	2680.
163	GLOBAL	Cartesian	5800.	6300.	2900.
164	GLOBAL	Cartesian	7900.	1550.	300.
165	GLOBAL	Cartesian	5800.	5800.	2900.
166	GLOBAL	Cartesian	7900.	1550.	600.

Table 1: Joint Coordinates

Joint	CoordSys	CoordType	GlobalX	GlobalY	GlobalZ
			mm	mm	mm
167	GLOBAL	Cartesian	7900.	1550.	900.
168	GLOBAL	Cartesian	7900.	1550.	1200.
169	GLOBAL	Cartesian	7900.	1550.	1500.
170	GLOBAL	Cartesian	7900.	4750.	300.
171	GLOBAL	Cartesian	7900.	4750.	600.
172	GLOBAL	Cartesian	7600.	1550.	1800.
173	GLOBAL	Cartesian	7900.	1550.	1800.
174	GLOBAL	Cartesian	7600.	4750.	1800.
175	GLOBAL	Cartesian	7900.	4750.	1800.
176	GLOBAL	Cartesian	1950.	1000.	5000.
177	GLOBAL	Cartesian	5800.	1000.	5000.
178	GLOBAL	Cartesian	1950.	5300.	5000.
179	GLOBAL	Cartesian	5800.	5300.	5000.
180	GLOBAL	Cartesian	1950.	1000.	5525.
181	GLOBAL	Cartesian	5800.	1000.	5525.
182	GLOBAL	Cartesian	1950.	5300.	5525.
183	GLOBAL	Cartesian	5800.	5300.	5525.
184	GLOBAL	Cartesian	1950.	1000.	8700.
185	GLOBAL	Cartesian	5800.	1000.	8700.
186	GLOBAL	Cartesian	1950.	5300.	8700.
187	GLOBAL	Cartesian	5800.	5300.	8700.
188	GLOBAL	Cartesian	7900.	4750.	900.
189	GLOBAL	Cartesian	7900.	4750.	1200.
190	GLOBAL	Cartesian	7900.	4750.	1500.
191	GLOBAL	Cartesian	500.	1477.78	0.
192	GLOBAL	Cartesian	0.	1477.78	0.
193	GLOBAL	Cartesian	500.	1955.56	0.
194	GLOBAL	Cartesian	0.	1955.56	0.
195	GLOBAL	Cartesian	500.	2433.33	0.
196	GLOBAL	Cartesian	0.	2433.33	0.
197	GLOBAL	Cartesian	500.	2911.11	0.
198	GLOBAL	Cartesian	0.	2911.11	0.
199	GLOBAL	Cartesian	500.	3388.89	0.
200	GLOBAL	Cartesian	0.	3388.89	0.
201	GLOBAL	Cartesian	500.	3866.67	0.
202	GLOBAL	Cartesian	0.	3866.67	0.
203	GLOBAL	Cartesian	500.	4344.44	0.
204	GLOBAL	Cartesian	0.	4344.44	0.
205	GLOBAL	Cartesian	500.	4822.22	0.
206	GLOBAL	Cartesian	0.	4822.22	0.
207	GLOBAL	Cartesian	1000.	1477.78	0.
208	GLOBAL	Cartesian	1000.	1955.56	0.
209	GLOBAL	Cartesian	1000.	2433.33	0.
210	GLOBAL	Cartesian	1000.	2911.11	0.
211	GLOBAL	Cartesian	1000.	3388.89	0.
212	GLOBAL	Cartesian	1000.	3866.67	0.
213	GLOBAL	Cartesian	1000.	4344.44	0.
214	GLOBAL	Cartesian	1000.	4822.22	0.
215	GLOBAL	Cartesian	1475.	1000.	0.
216	GLOBAL	Cartesian	1475.	1477.78	0.
217	GLOBAL	Cartesian	1475.	1955.56	0.
218	GLOBAL	Cartesian	1475.	2433.33	0.
219	GLOBAL	Cartesian	1475.	2911.11	0.
220	GLOBAL	Cartesian	1475.	3388.89	0.

Table 1: Joint Coordinates

Joint	CoordSys	CoordType	GlobalX	GlobalY	GlobalZ
			mm	mm	mm
221	GLOBAL	Cartesian	1475.	3866.67	0.
222	GLOBAL	Cartesian	1475.	4344.44	0.
223	GLOBAL	Cartesian	1475.	4822.22	0.
224	GLOBAL	Cartesian	1475.	5300.	0.
225	GLOBAL	Cartesian	1950.	1477.78	0.
226	GLOBAL	Cartesian	1950.	1955.56	0.
227	GLOBAL	Cartesian	1950.	2433.33	0.
228	GLOBAL	Cartesian	1950.	2911.11	0.
229	GLOBAL	Cartesian	1950.	3388.89	0.
230	GLOBAL	Cartesian	1950.	3866.67	0.
231	GLOBAL	Cartesian	1950.	4344.44	0.
232	GLOBAL	Cartesian	1950.	4822.22	0.
233	GLOBAL	Cartesian	1475.	5800.	0.
234	GLOBAL	Cartesian	1475.	6300.	0.
235	GLOBAL	Cartesian	1475.	500.	0.
236	GLOBAL	Cartesian	1475.	0.	0.
237	GLOBAL	Cartesian	2441.67	5800.	0.
238	GLOBAL	Cartesian	2441.67	6300.	0.
239	GLOBAL	Cartesian	2933.33	5800.	0.
240	GLOBAL	Cartesian	2933.33	6300.	0.
241	GLOBAL	Cartesian	3425.	5800.	0.
242	GLOBAL	Cartesian	3425.	6300.	0.
243	GLOBAL	Cartesian	3916.67	5800.	0.
244	GLOBAL	Cartesian	3916.67	6300.	0.
245	GLOBAL	Cartesian	4408.33	5800.	0.
246	GLOBAL	Cartesian	4408.33	6300.	0.
247	GLOBAL	Cartesian	2441.67	5300.	0.
248	GLOBAL	Cartesian	2933.33	5300.	0.
249	GLOBAL	Cartesian	3425.	5300.	0.
250	GLOBAL	Cartesian	3916.67	5300.	0.
251	GLOBAL	Cartesian	4408.33	5300.	0.
262	GLOBAL	Cartesian	2441.67	1000.	0.
263	GLOBAL	Cartesian	2441.67	1477.78	0.
264	GLOBAL	Cartesian	2441.67	1955.56	0.
265	GLOBAL	Cartesian	2441.67	2433.33	0.
266	GLOBAL	Cartesian	2441.67	2911.11	0.
267	GLOBAL	Cartesian	2441.67	3388.89	0.
268	GLOBAL	Cartesian	2441.67	3866.67	0.
269	GLOBAL	Cartesian	2441.67	4344.44	0.
270	GLOBAL	Cartesian	2441.67	4822.22	0.
271	GLOBAL	Cartesian	2933.33	1000.	0.
272	GLOBAL	Cartesian	2933.33	1477.78	0.
273	GLOBAL	Cartesian	2933.33	1955.56	0.
274	GLOBAL	Cartesian	2933.33	2433.33	0.
275	GLOBAL	Cartesian	2933.33	2911.11	0.
276	GLOBAL	Cartesian	2933.33	3388.89	0.
277	GLOBAL	Cartesian	2933.33	3866.67	0.
278	GLOBAL	Cartesian	2933.33	4344.44	0.
279	GLOBAL	Cartesian	2933.33	4822.22	0.
280	GLOBAL	Cartesian	3425.	1000.	0.
281	GLOBAL	Cartesian	3425.	1477.78	0.
282	GLOBAL	Cartesian	3425.	1955.56	0.
283	GLOBAL	Cartesian	3425.	2433.33	0.
284	GLOBAL	Cartesian	3425.	2911.11	0.

Table 1: Joint Coordinates

Joint	CoordSys	CoordType	GlobalX	GlobalY	GlobalZ
			mm	mm	mm
285	GLOBAL	Cartesian	3425.	3388.89	0.
286	GLOBAL	Cartesian	3425.	3866.67	0.
287	GLOBAL	Cartesian	3425.	4344.44	0.
288	GLOBAL	Cartesian	3425.	4822.22	0.
289	GLOBAL	Cartesian	3916.67	1000.	0.
290	GLOBAL	Cartesian	3916.67	1477.78	0.
291	GLOBAL	Cartesian	3916.67	1955.56	0.
292	GLOBAL	Cartesian	3916.67	2433.33	0.
293	GLOBAL	Cartesian	3916.67	2911.11	0.
294	GLOBAL	Cartesian	3916.67	3388.89	0.
295	GLOBAL	Cartesian	3916.67	3866.67	0.
296	GLOBAL	Cartesian	3916.67	4344.44	0.
297	GLOBAL	Cartesian	3916.67	4822.22	0.
298	GLOBAL	Cartesian	4408.33	1000.	0.
299	GLOBAL	Cartesian	4408.33	1477.78	0.
300	GLOBAL	Cartesian	4408.33	1955.56	0.
301	GLOBAL	Cartesian	4408.33	2433.33	0.
302	GLOBAL	Cartesian	4408.33	2911.11	0.
303	GLOBAL	Cartesian	4408.33	3388.89	0.
304	GLOBAL	Cartesian	4408.33	3866.67	0.
305	GLOBAL	Cartesian	4408.33	4344.44	0.
306	GLOBAL	Cartesian	4408.33	4822.22	0.
307	GLOBAL	Cartesian	4900.	1477.78	0.
308	GLOBAL	Cartesian	4900.	1955.56	0.
309	GLOBAL	Cartesian	4900.	2433.33	0.
310	GLOBAL	Cartesian	4900.	2911.11	0.
311	GLOBAL	Cartesian	4900.	3388.89	0.
312	GLOBAL	Cartesian	4900.	3866.67	0.
313	GLOBAL	Cartesian	4900.	4344.44	0.
314	GLOBAL	Cartesian	4900.	4822.22	0.
315	GLOBAL	Cartesian	2441.67	500.	0.
316	GLOBAL	Cartesian	2933.33	500.	0.
317	GLOBAL	Cartesian	3425.	500.	0.
318	GLOBAL	Cartesian	3916.67	500.	0.
319	GLOBAL	Cartesian	4408.33	500.	0.
320	GLOBAL	Cartesian	2441.67	0.	0.
321	GLOBAL	Cartesian	2933.33	0.	0.
322	GLOBAL	Cartesian	3425.	0.	0.
323	GLOBAL	Cartesian	3916.67	0.	0.
324	GLOBAL	Cartesian	4408.33	0.	0.
325	GLOBAL	Cartesian	5300.	1477.78	0.
326	GLOBAL	Cartesian	5300.	1955.56	0.
327	GLOBAL	Cartesian	5300.	2433.33	0.
328	GLOBAL	Cartesian	5300.	2911.11	0.
329	GLOBAL	Cartesian	5300.	3388.89	0.
330	GLOBAL	Cartesian	5300.	3866.67	0.
331	GLOBAL	Cartesian	5300.	4344.44	0.
332	GLOBAL	Cartesian	5300.	4822.22	0.
333	GLOBAL	Cartesian	5800.	1477.78	0.
334	GLOBAL	Cartesian	5800.	1955.56	0.
335	GLOBAL	Cartesian	5800.	2433.33	0.
336	GLOBAL	Cartesian	5800.	2911.11	0.
337	GLOBAL	Cartesian	5800.	3388.89	0.
338	GLOBAL	Cartesian	5800.	3866.67	0.

Table 1: Joint Coordinates

Joint	CoordSys	CoordType	GlobalX	GlobalY	GlobalZ
			mm	mm	mm
339	GLOBAL	Cartesian	5800.	4344.44	0.
340	GLOBAL	Cartesian	5800.	4822.22	0.
341	GLOBAL	Cartesian	6160.	1563.33	0.
342	GLOBAL	Cartesian	6160.	2016.67	0.
343	GLOBAL	Cartesian	6160.	2470.	0.
344	GLOBAL	Cartesian	6160.	2923.33	0.
345	GLOBAL	Cartesian	6160.	3376.67	0.
346	GLOBAL	Cartesian	6160.	3830.	0.
347	GLOBAL	Cartesian	6160.	4283.33	0.
348	GLOBAL	Cartesian	6160.	4736.67	0.
349	GLOBAL	Cartesian	6520.	1648.89	0.
350	GLOBAL	Cartesian	6520.	2077.78	0.
351	GLOBAL	Cartesian	6520.	2506.67	0.
352	GLOBAL	Cartesian	6520.	2935.56	0.
353	GLOBAL	Cartesian	6520.	3364.44	0.
354	GLOBAL	Cartesian	6520.	3793.33	0.
355	GLOBAL	Cartesian	6520.	4222.22	0.
356	GLOBAL	Cartesian	6520.	4651.11	0.
357	GLOBAL	Cartesian	6880.	1734.44	0.
358	GLOBAL	Cartesian	6880.	2138.89	0.
359	GLOBAL	Cartesian	6880.	2543.33	0.
360	GLOBAL	Cartesian	6880.	2947.78	0.
361	GLOBAL	Cartesian	6880.	3352.22	0.
362	GLOBAL	Cartesian	6880.	3756.67	0.
363	GLOBAL	Cartesian	6880.	4161.11	0.
364	GLOBAL	Cartesian	6880.	4565.56	0.
365	GLOBAL	Cartesian	7240.	1820.	0.
366	GLOBAL	Cartesian	7240.	2200.	0.
367	GLOBAL	Cartesian	7240.	2580.	0.
368	GLOBAL	Cartesian	7240.	2960.	0.
369	GLOBAL	Cartesian	7240.	3340.	0.
370	GLOBAL	Cartesian	7240.	3720.	0.
371	GLOBAL	Cartesian	7240.	4100.	0.
372	GLOBAL	Cartesian	7240.	4480.	0.
373	GLOBAL	Cartesian	7600.	1905.56	0.
374	GLOBAL	Cartesian	7600.	2261.11	0.
375	GLOBAL	Cartesian	7600.	2616.67	0.
376	GLOBAL	Cartesian	7600.	2972.22	0.
377	GLOBAL	Cartesian	7600.	3327.78	0.
378	GLOBAL	Cartesian	7600.	3683.33	0.
379	GLOBAL	Cartesian	7600.	4038.89	0.
380	GLOBAL	Cartesian	7600.	4394.44	0.
381	GLOBAL	Cartesian	6160.	5800.	0.
382	GLOBAL	Cartesian	6520.	5800.	0.
383	GLOBAL	Cartesian	6880.	5800.	0.
384	GLOBAL	Cartesian	7240.	5800.	0.
385	GLOBAL	Cartesian	6160.	6300.	0.
386	GLOBAL	Cartesian	6520.	6300.	0.
387	GLOBAL	Cartesian	6880.	6300.	0.
388	GLOBAL	Cartesian	7240.	6300.	0.
389	GLOBAL	Cartesian	7900.	1905.56	0.
390	GLOBAL	Cartesian	7900.	2261.11	0.
391	GLOBAL	Cartesian	7900.	2616.67	0.
392	GLOBAL	Cartesian	7900.	2972.22	0.

Table 1: Joint Coordinates

Joint	CoordSys	CoordType	GlobalX	GlobalY	GlobalZ
			mm	mm	mm
393	GLOBAL	Cartesian	7900.	3327.78	0.
394	GLOBAL	Cartesian	7900.	3683.33	0.
395	GLOBAL	Cartesian	7900.	4038.89	0.
396	GLOBAL	Cartesian	7900.	4394.44	0.
397	GLOBAL	Cartesian	6160.	500.	0.
398	GLOBAL	Cartesian	6520.	500.	0.
399	GLOBAL	Cartesian	6880.	500.	0.
400	GLOBAL	Cartesian	7240.	500.	0.
401	GLOBAL	Cartesian	6160.	0.	0.
402	GLOBAL	Cartesian	6520.	0.	0.
403	GLOBAL	Cartesian	6880.	0.	0.
404	GLOBAL	Cartesian	7240.	0.	0.
451	GLOBAL	Cartesian	7600.	1905.56	1800.
452	GLOBAL	Cartesian	7240.	1820.	2020.
453	GLOBAL	Cartesian	6880.	1734.44	2240.
454	GLOBAL	Cartesian	6520.	1648.89	2460.
455	GLOBAL	Cartesian	6160.	1563.33	2680.
456	GLOBAL	Cartesian	5800.	1477.78	2900.
457	GLOBAL	Cartesian	7600.	2261.11	1800.
458	GLOBAL	Cartesian	7240.	2200.	2020.
459	GLOBAL	Cartesian	6880.	2138.89	2240.
460	GLOBAL	Cartesian	6520.	2077.78	2460.
461	GLOBAL	Cartesian	6160.	2016.67	2680.
462	GLOBAL	Cartesian	5800.	1955.56	2900.
463	GLOBAL	Cartesian	7600.	2616.67	1800.
464	GLOBAL	Cartesian	7240.	2580.	2020.
465	GLOBAL	Cartesian	6880.	2543.33	2240.
466	GLOBAL	Cartesian	6520.	2506.67	2460.
467	GLOBAL	Cartesian	6160.	2470.	2680.
468	GLOBAL	Cartesian	5800.	2433.33	2900.
469	GLOBAL	Cartesian	7600.	2972.22	1800.
470	GLOBAL	Cartesian	7240.	2960.	2020.
471	GLOBAL	Cartesian	6880.	2947.78	2240.
472	GLOBAL	Cartesian	6520.	2935.56	2460.
473	GLOBAL	Cartesian	6160.	2923.33	2680.
474	GLOBAL	Cartesian	5800.	2911.11	2900.
475	GLOBAL	Cartesian	7600.	3327.78	1800.
476	GLOBAL	Cartesian	7240.	3340.	2020.
477	GLOBAL	Cartesian	6880.	3352.22	2240.
478	GLOBAL	Cartesian	6520.	3364.44	2460.
479	GLOBAL	Cartesian	6160.	3376.67	2680.
480	GLOBAL	Cartesian	5800.	3388.89	2900.
481	GLOBAL	Cartesian	7600.	3683.33	1800.
482	GLOBAL	Cartesian	7240.	3720.	2020.
483	GLOBAL	Cartesian	6880.	3756.67	2240.
484	GLOBAL	Cartesian	6520.	3793.33	2460.
485	GLOBAL	Cartesian	6160.	3830.	2680.
486	GLOBAL	Cartesian	5800.	3866.67	2900.
487	GLOBAL	Cartesian	7600.	4038.89	1800.
488	GLOBAL	Cartesian	7240.	4100.	2020.
489	GLOBAL	Cartesian	6880.	4161.11	2240.
490	GLOBAL	Cartesian	6520.	4222.22	2460.
491	GLOBAL	Cartesian	6160.	4283.33	2680.
492	GLOBAL	Cartesian	5800.	4344.44	2900.

Table 1: Joint Coordinates

Joint	CoordSys	CoordType	GlobalX	GlobalY	GlobalZ
			mm	mm	mm
493	GLOBAL	Cartesian	7600.	4394.44	1800.
494	GLOBAL	Cartesian	7240.	4480.	2020.
495	GLOBAL	Cartesian	6880.	4565.56	2240.
496	GLOBAL	Cartesian	6520.	4651.11	2460.
497	GLOBAL	Cartesian	6160.	4736.67	2680.
498	GLOBAL	Cartesian	5800.	4822.22	2900.

1.2. Joint restraints

Table 2: Joint Restraint Assignments

Table 2: Joint Restraint Assignments

Joint	U1	U2	U3	R1	R2	R3
11	Yes	No	No	No	No	No
20	Yes	No	No	No	No	No
38	Yes	No	No	No	No	No
67	Yes	No	No	No	No	No
76	Yes	No	No	No	No	No
87	Yes	No	No	No	No	No
164	Yes	No	No	No	No	No
166	Yes	No	No	No	No	No
167	Yes	No	No	No	No	No
168	Yes	No	No	No	No	No
169	Yes	No	No	No	No	No
170	Yes	No	No	No	No	No
171	Yes	No	No	No	No	No
173	Yes	No	No	No	No	No
175	Yes	No	No	No	No	No
188	Yes	No	No	No	No	No
189	Yes	No	No	No	No	No
190	Yes	No	No	No	No	No
389	Yes	No	No	No	No	No
390	Yes	No	No	No	No	No
391	Yes	No	No	No	No	No
392	Yes	No	No	No	No	No
393	Yes	No	No	No	No	No
394	Yes	No	No	No	No	No
395	Yes	No	No	No	No	No
396	Yes	No	No	No	No	No

1.3. Element connectivity

Table 3: Connectivity - Frame

Table 3: Connectivity - Frame

Frame	JointI	JointJ	Length
			mm
1	145	176	2100.
2	176	180	525.
3	180	184	3175.
4	152	178	2100.
5	178	182	525.
6	182	186	3175.
7	145	152	4300.
8	183	182	3850.
9	182	180	4300.
10	180	181	3850.
11	187	186	3850.
12	186	184	4300.
13	184	185	3850.
14	155	179	2100.
15	145	146	2950.
16	152	153	2950.
17	24	80	4300.
18	179	183	525.
19	183	187	3175.
20	148	177	2100.
21	177	181	525.
22	181	185	3175.
23	23	144	2900.
24	79	151	2900.

Table 4: Frame Section Assignments

Table 4: Frame Section Assignments

Frame	AnalSect	DesignSect	MatProp
1	Column	Column	Default
2	Column	Column	Default
3	Column	Column	Default
4	Column	Column	Default
5	Column	Column	Default
6	Column	Column	Default
7	Lower_Beam	Lower_Beam	Default
8	Mid_Beam	Mid_Beam	Default
9	Mid_Beam	Mid_Beam	Default
10	Mid_Beam	Mid_Beam	Default
11	Top_Beam	Top_Beam	Default
12	Top_Beam	Top_Beam	Default
13	Top_Beam	Top_Beam	Default
14	None		
15	None		
16	None		
17	None		
18	None		
19	None		
20	None		
21	None		

Table 4: Frame Section Assignments

Frame	AnalSect	DesignSect	MatProp
22	None		
23	None		
24	None		

Table 5: Connectivity - Area

Table 5: Connectivity - Area

Area	Joint1	Joint2	Joint3	Joint4
1	27	18	1	6
2	6	1	28	29
3	29	28	30	31
4	31	30	32	33
5	33	32	34	35
6	35	34	161	148
7	18	9	36	1
8	1	36	39	28
9	28	39	40	30
10	30	40	41	32
11	32	41	42	34
12	34	42	159	161
13	65	74	43	44
14	44	43	45	46
15	46	45	47	48
16	48	47	49	50
17	50	49	51	52
18	52	51	165	163
19	74	83	53	43
20	43	53	54	45
21	45	54	55	47
22	47	55	56	49
23	49	56	57	51
24	51	57	155	165
25	27	58	84	6
26	6	84	85	29
27	29	85	88	31
28	31	88	89	33
29	33	89	90	35
30	35	90	91	148
31	58	92	93	84
32	84	93	94	85
33	85	94	95	88
34	88	95	96	89
35	89	96	97	90
36	90	97	98	91
37	92	99	100	93
38	93	100	101	94
39	94	101	102	95
40	95	102	103	96
41	96	103	104	97
42	97	104	105	98
43	99	106	107	100

Table 5: Connectivity - Area

Area	Joint1	Joint2	Joint3	Joint4
44	100	107	108	101
45	101	108	109	102
46	102	109	110	103
47	103	110	111	104
48	104	111	112	105
49	106	37	113	107
50	107	113	114	108
51	108	114	115	109
52	109	115	116	110
53	110	116	117	111
54	111	117	172	112
55	86	118	119	120
56	120	119	121	122
57	122	121	123	124
58	124	123	125	126
59	126	125	127	128
60	128	127	129	174
61	118	130	131	119
62	119	131	132	121
63	121	132	133	123
64	123	133	134	125
65	125	134	135	127
66	127	135	136	129
67	130	137	138	131
68	131	138	139	132
69	132	139	140	133
70	133	140	141	134
71	134	141	142	135
72	135	142	143	136
73	137	149	150	138
74	138	150	156	139
75	139	156	157	140
76	140	157	158	141
77	141	158	160	142
78	142	160	162	143
79	149	83	53	150
80	150	53	54	156
81	156	54	55	157
82	157	55	56	158
83	158	56	57	160
84	160	57	155	162
85	37	38	164	113
86	113	164	166	114
87	114	166	167	115
88	115	167	168	116
89	116	168	169	117
90	117	169	173	172
91	87	86	120	170
92	170	120	122	171
93	171	122	124	188
94	188	124	126	189
95	189	126	128	190
96	190	128	174	175
97	21	22	191	192

Table 5: Connectivity - Area

Area	Joint1	Joint2	Joint3	Joint4
98	192	191	193	194
99	194	193	195	196
100	196	195	197	198
101	198	197	199	200
102	200	199	201	202
103	202	201	203	204
104	204	203	205	206
105	206	205	78	77
106	22	23	207	191
107	191	207	208	193
108	193	208	209	195
109	195	209	210	197
110	197	210	211	199
111	199	211	212	201
112	201	212	213	203
113	203	213	214	205
114	205	214	79	78
115	23	215	216	207
116	207	216	217	208
117	208	217	218	209
118	209	218	219	210
119	210	219	220	211
120	211	220	221	212
121	212	221	222	213
122	213	222	223	214
123	214	223	224	79
124	215	24	225	216
125	216	225	226	217
126	217	226	227	218
127	218	227	228	219
128	219	228	229	220
129	220	229	230	221
130	221	230	231	222
131	222	231	232	223
132	223	232	80	224
133	79	224	233	70
134	224	80	71	233
135	70	233	234	61
136	233	71	62	234
137	14	235	215	23
138	2	3	13	12
139	12	13	22	21
140	235	15	24	215
141	4	236	235	14
142	236	5	15	235
143	77	78	69	68
144	68	69	60	59
145	3	4	14	13
146	13	14	23	22
147	71	237	238	62
148	237	239	240	238
149	239	241	242	240
150	78	79	70	69
151	69	70	61	60

Table 5: Connectivity - Area

Area	Joint1	Joint2	Joint3	Joint4
152	241	243	244	242
153	243	245	246	244
154	245	72	63	246
155	80	247	237	71
156	247	248	239	237
157	248	249	241	239
158	249	250	243	241
161	250	251	245	243
162	251	81	72	245
166	7	8	17	16
167	16	17	26	25
171	81	82	73	72
172	72	73	64	63
173	8	9	18	17
174	17	18	27	26
178	82	83	74	73
179	73	74	65	64
184	24	262	263	225
185	225	263	264	226
187	10	11	20	19
188	226	264	265	227
189	227	265	266	228
191	228	266	267	229
192	229	267	268	230
193	75	76	67	66
194	23	24	145	144
195	24	25	146	145
196	25	26	147	146
197	26	27	148	147
199	19	20	38	37
200	86	87	76	75
202	230	268	269	231
203	231	269	270	232
204	232	270	247	80
205	262	271	272	263
210	263	272	273	264
211	264	273	274	265
212	265	274	275	266
213	266	275	276	267
214	267	276	277	268
215	268	277	278	269
216	269	278	279	270
217	270	279	248	247
218	271	280	281	272
219	272	281	282	273
220	273	282	283	274
221	274	283	284	275
222	83	82	154	155
223	82	81	153	154
224	81	80	152	153
225	80	79	151	152
226	275	284	285	276
227	276	285	286	277
228	148	155	179	177

Table 5: Connectivity - Area

Area	Joint1	Joint2	Joint3	Joint4
229	177	179	183	181
230	181	183	187	185
231	173	175	174	172
233	277	286	287	278
234	278	287	288	279
235	279	288	249	248
236	280	289	290	281
237	281	290	291	282
238	282	291	292	283
239	283	292	293	284
240	284	293	294	285
241	285	294	295	286
242	286	295	296	287
243	287	296	297	288
244	288	297	250	249
245	289	298	299	290
246	290	299	300	291
247	291	300	301	292
248	292	301	302	293
249	293	302	303	294
250	294	303	304	295
251	295	304	305	296
252	296	305	306	297
253	297	306	251	250
254	298	25	307	299
255	299	307	308	300
256	300	308	309	301
257	301	309	310	302
258	302	310	311	303
259	303	311	312	304
260	304	312	313	305
261	305	313	314	306
262	306	314	81	251
263	15	315	262	24
264	315	316	271	262
265	316	317	280	271
266	317	318	289	280
267	318	319	298	289
268	319	16	25	298
269	5	320	315	15
270	320	321	316	315
271	321	322	317	316
272	322	323	318	317
273	323	324	319	318
274	324	7	16	319
275	25	26	325	307
276	307	325	326	308
277	308	326	327	309
278	309	327	328	310
279	310	328	329	311
280	311	329	330	312
281	312	330	331	313
282	313	331	332	314
283	314	332	82	81

Table 5: Connectivity - Area

Area	Joint1	Joint2	Joint3	Joint4
284	26	27	333	325
285	325	333	334	326
286	326	334	335	327
287	327	335	336	328
288	328	336	337	329
289	329	337	338	330
290	330	338	339	331
291	331	339	340	332
292	332	340	83	82
293	27	58	341	333
294	333	341	342	334
295	334	342	343	335
296	335	343	344	336
297	336	344	345	337
298	337	345	346	338
299	338	346	347	339
300	339	347	348	340
301	340	348	149	83
302	58	92	349	341
303	341	349	350	342
304	342	350	351	343
305	343	351	352	344
306	344	352	353	345
307	345	353	354	346
308	346	354	355	347
309	347	355	356	348
310	348	356	137	149
311	92	99	357	349
312	349	357	358	350
313	350	358	359	351
314	351	359	360	352
315	352	360	361	353
316	353	361	362	354
317	354	362	363	355
318	355	363	364	356
319	356	364	130	137
320	99	106	365	357
321	357	365	366	358
322	358	366	367	359
323	359	367	368	360
324	360	368	369	361
325	361	369	370	362
326	362	370	371	363
327	363	371	372	364
328	364	372	118	130
329	106	37	373	365
330	365	373	374	366
331	366	374	375	367
332	367	375	376	368
333	368	376	377	369
334	369	377	378	370
335	370	378	379	371
336	371	379	380	372
337	372	380	86	118

Table 5: Connectivity - Area

Area	Joint1	Joint2	Joint3	Joint4
338	83	149	381	74
339	149	137	382	381
340	137	130	383	382
341	130	118	384	383
342	118	86	75	384
343	74	381	385	65
344	381	382	386	385
345	382	383	387	386
346	383	384	388	387
347	384	75	66	388
348	37	38	389	373
349	373	389	390	374
350	374	390	391	375
351	375	391	392	376
352	376	392	393	377
353	377	393	394	378
354	378	394	395	379
355	379	395	396	380
356	380	396	87	86
357	18	397	58	27
358	397	398	92	58
359	398	399	99	92
360	399	400	106	99
361	400	19	37	106
362	9	401	397	18
363	401	402	398	397
364	402	403	399	398
365	403	404	400	399
366	404	10	19	400
389	172	451	452	112
390	112	452	453	105
391	105	453	454	98
392	98	454	455	91
393	91	455	456	148
394	451	457	458	452
395	452	458	459	453
396	453	459	460	454
397	454	460	461	455
398	455	461	462	456
399	457	463	464	458
400	458	464	465	459
401	459	465	466	460
402	460	466	467	461
403	461	467	468	462
404	463	469	470	464
405	464	470	471	465
406	465	471	472	466
407	466	472	473	467
408	467	473	474	468
409	469	475	476	470
410	470	476	477	471
411	471	477	478	472
412	472	478	479	473
413	473	479	480	474

Table 5: Connectivity - Area

Area	Joint1	Joint2	Joint3	Joint4
414	475	481	482	476
415	476	482	483	477
416	477	483	484	478
417	478	484	485	479
418	479	485	486	480
419	481	487	488	482
420	482	488	489	483
421	483	489	490	484
422	484	490	491	485
423	485	491	492	486
424	487	493	494	488
425	488	494	495	489
426	489	495	496	490
427	490	496	497	491
428	491	497	498	492
429	493	174	129	494
430	494	129	136	495
431	495	136	143	496
432	496	143	162	497
433	497	162	155	498

Table 6: Area Section Assignments

Table 6: Area Section Assignments

Area	Section	MatProp
1	Backwall	Default
2	Backwall	Default
3	Backwall	Default
4	Backwall	Default
5	Backwall	Default
6	Backwall	Default
7	Backwall	Default
8	Backwall	Default
9	Backwall	Default
10	Backwall	Default
11	Backwall	Default
12	Backwall	Default
13	Backwall	Default
14	Backwall	Default
15	Backwall	Default
16	Backwall	Default
17	Backwall	Default
18	Backwall	Default
19	Backwall	Default
20	Backwall	Default
21	Backwall	Default
22	Backwall	Default
23	Backwall	Default
24	Backwall	Default
25	Channel	Default
26	Channel	Default

Table 6: Area Section Assignments

Area	Section	MatProp
27	Channel	Default
28	Channel	Default
29	Channel	Default
30	Channel	Default
31	Channel	Default
32	Channel	Default
33	Channel	Default
34	Channel	Default
35	Channel	Default
36	Channel	Default
37	Channel	Default
38	Channel	Default
39	Channel	Default
40	Channel	Default
41	Channel	Default
42	Channel	Default
43	Channel	Default
44	Channel	Default
45	Channel	Default
46	Channel	Default
47	Channel	Default
48	Channel	Default
49	Channel	Default
50	Channel	Default
51	Channel	Default
52	Channel	Default
53	Channel	Default
54	Channel	Default
55	Channel	Default
56	Channel	Default
57	Channel	Default
58	Channel	Default
59	Channel	Default
60	Channel	Default
61	Channel	Default
62	Channel	Default
63	Channel	Default
64	Channel	Default
65	Channel	Default
66	Channel	Default
67	Channel	Default
68	Channel	Default
69	Channel	Default
70	Channel	Default
71	Channel	Default
72	Channel	Default
73	Channel	Default
74	Channel	Default
75	Channel	Default
76	Channel	Default
77	Channel	Default
78	Channel	Default
79	Channel	Default
80	Channel	Default

Table 6: Area Section Assignments

Area	Section	MatProp
81	Channel	Default
82	Channel	Default
83	Channel	Default
84	Channel	Default
85	Channel	Default
86	Channel	Default
87	Channel	Default
88	Channel	Default
89	Channel	Default
90	Channel	Default
91	Channel	Default
92	Channel	Default
93	Channel	Default
94	Channel	Default
95	Channel	Default
96	Channel	Default
97	Base2	Default
98	Base2	Default
99	Base2	Default
100	Base2	Default
101	Base2	Default
102	Base2	Default
103	Base2	Default
104	Base2	Default
105	Base2	Default
106	Base	Default
107	Base	Default
108	Base	Default
109	Base	Default
110	Base	Default
111	Base	Default
112	Base	Default
113	Base	Default
114	Base	Default
115	Base	Default
116	Base	Default
117	Base	Default
118	Base	Default
119	Base	Default
120	Base	Default
121	Base	Default
122	Base	Default
123	Base	Default
124	Base	Default
125	Base	Default
126	Base	Default
127	Base	Default
128	Base	Default
129	Base	Default
130	Base	Default
131	Base	Default
132	Base	Default
133	Base	Default
134	Base	Default

Table 6: Area Section Assignments

Area	Section	MatProp
135	Base2	Default
136	Base2	Default
137	Base	Default
138	Base2	Default
139	Base2	Default
140	Base	Default
141	Base2	Default
142	Base2	Default
143	Base2	Default
144	Base2	Default
145	Base2	Default
146	Base	Default
147	Base2	Default
148	Base2	Default
149	Base2	Default
150	Base	Default
151	Base2	Default
152	Base2	Default
153	Base2	Default
154	Base2	Default
155	Base	Default
156	Base	Default
157	Base	Default
158	Base	Default
161	Base	Default
162	Base	Default
166	Base2	Default
167	Base	Default
171	Base	Default
172	Base2	Default
173	Base2	Default
174	Base	Default
178	Base	Default
179	Base2	Default
184	Base	Default
185	Base	Default
187	Base2	Default
188	Base	Default
189	Base	Default
191	Base	Default
192	Base	Default
193	Base2	Default
194	Approach_Wall	Default
195	Approach_Wall	Default
196	Approach_Wall	Default
197	Channel	Default
199	Base	Default
200	Base	Default
202	Base	Default
203	Base	Default
204	Base	Default
205	Base	Default
210	Base	Default
211	Base	Default

Table 6: Area Section Assignments

Area	Section	MatProp
212	Base	Default
213	Base	Default
214	Base	Default
215	Base	Default
216	Base	Default
217	Base	Default
218	Base	Default
219	Base	Default
220	Base	Default
221	Base	Default
222	Channel	Default
223	Approach_Wall	Default
224	Approach_Wall	Default
225	Approach_Wall	Default
226	Base	Default
227	Base	Default
228	Backwall	Default
229	Backwall	Default
230	Backwall	Default
231	Channel	Default
233	Base	Default
234	Base	Default
235	Base	Default
236	Base	Default
237	Base	Default
238	Base	Default
239	Base	Default
240	Base	Default
241	Base	Default
242	Base	Default
243	Base	Default
244	Base	Default
245	Base	Default
246	Base	Default
247	Base	Default
248	Base	Default
249	Base	Default
250	Base	Default
251	Base	Default
252	Base	Default
253	Base	Default
254	Base	Default
255	Base	Default
256	Base	Default
257	Base	Default
258	Base	Default
259	Base	Default
260	Base	Default
261	Base	Default
262	Base	Default
263	Base	Default
264	Base	Default
265	Base	Default
266	Base	Default

Table 6: Area Section Assignments

Area	Section	MatProp
267	Base	Default
268	Base	Default
269	Base2	Default
270	Base2	Default
271	Base2	Default
272	Base2	Default
273	Base2	Default
274	Base2	Default
275	Base	Default
276	Base	Default
277	Base	Default
278	Base	Default
279	Base	Default
280	Base	Default
281	Base	Default
282	Base	Default
283	Base	Default
284	Base	Default
285	Base	Default
286	Base	Default
287	Base	Default
288	Base	Default
289	Base	Default
290	Base	Default
291	Base	Default
292	Base	Default
293	Base	Default
294	Base	Default
295	Base	Default
296	Base	Default
297	Base	Default
298	Base	Default
299	Base	Default
300	Base	Default
301	Base	Default
302	Base	Default
303	Base	Default
304	Base	Default
305	Base	Default
306	Base	Default
307	Base	Default
308	Base	Default
309	Base	Default
310	Base	Default
311	Base	Default
312	Base	Default
313	Base	Default
314	Base	Default
315	Base	Default
316	Base	Default
317	Base	Default
318	Base	Default
319	Base	Default
320	Base	Default

Table 6: Area Section Assignments

Area	Section	MatProp
321	Base	Default
322	Base	Default
323	Base	Default
324	Base	Default
325	Base	Default
326	Base	Default
327	Base	Default
328	Base	Default
329	Base	Default
330	Base	Default
331	Base	Default
332	Base	Default
333	Base	Default
334	Base	Default
335	Base	Default
336	Base	Default
337	Base	Default
338	Base	Default
339	Base	Default
340	Base	Default
341	Base	Default
342	Base	Default
343	Base2	Default
344	Base2	Default
345	Base2	Default
346	Base2	Default
347	Base2	Default
348	Base	Default
349	Base	Default
350	Base	Default
351	Base	Default
352	Base	Default
353	Base	Default
354	Base	Default
355	Base	Default
356	Base	Default
357	Base	Default
358	Base	Default
359	Base	Default
360	Base	Default
361	Base	Default
362	Base2	Default
363	Base2	Default
364	Base2	Default
365	Base2	Default
366	Base2	Default
389	Channel	Default
390	Channel	Default
391	Channel	Default
392	Channel	Default
393	Channel	Default
394	Channel	Default
395	Channel	Default
396	Channel	Default

Table 6: Area Section Assignments

Area	Section	MatProp
397	Channel	Default
398	Channel	Default
399	Channel	Default
400	Channel	Default
401	Channel	Default
402	Channel	Default
403	Channel	Default
404	Channel	Default
405	Channel	Default
406	Channel	Default
407	Channel	Default
408	Channel	Default
409	Channel	Default
410	Channel	Default
411	Channel	Default
412	Channel	Default
413	Channel	Default
414	Channel	Default
415	Channel	Default
416	Channel	Default
417	Channel	Default
418	Channel	Default
419	Channel	Default
420	Channel	Default
421	Channel	Default
422	Channel	Default
423	Channel	Default
424	Channel	Default
425	Channel	Default
426	Channel	Default
427	Channel	Default
428	Channel	Default
429	Channel	Default
430	Channel	Default
431	Channel	Default
432	Channel	Default
433	Channel	Default

2. Material properties

This section provides material property information for materials used in the model.

Table 7: Material Properties 02 - Basic Mechanical Properties

Table 7: Material Properties 02 - Basic Mechanical Properties

Material	UnitWeight	UnitMass	E1	G12	U12	A1
	KN/mm3	KN-s2/mm4	KN/mm2	KN/mm2		1/C
4000Psi	2.3563E-08	2.4028E-12	24.85558	10.35649	0.2	9.9000E-06
A416Gr270	7.6973E-08	7.8490E-12	196.5006			1.1700E-05
A992Fy50	7.6973E-08	7.8490E-12	199.94798	76.90307	0.3	1.1700E-05
C30	2.3560E-08	2.4025E-12	33.	13.75	0.2	1.0000E-05
C30/37	2.3560E-08	2.4025E-12	33.	13.75	0.2	1.0000E-05

Table 7: Material Properties 02 - Basic Mechanical Properties

Material	UnitWeight	UnitMass	E1	G12	U12	A1
	KN/mm3	KN-s2/mm4	KN/mm2	KN/mm2		1/C
CSA G30.18	7.6973E-08	7.8490E-12	199.94798			1.1700E-05

Table 8: Material Properties 03a - Steel Data

Table 8: Material Properties 03a - Steel Data

Material	Fy	Fu	FinalSlope
	KN/mm2	KN/mm2	
A992Fy50	0.34474	0.44816	-0.1

Table 9: Material Properties 03b - Concrete Data

Table 9: Material Properties 03b - Concrete Data

Material	Fc	eFc	FinalSlope
	KN/mm2	KN/mm2	
4000Psi	0.02758	0.02758	-0.1
C30	0.03	0.03	-0.1
C30/37	0.03	0.03	-0.1

Table 10: Material Properties 03e - Rebar Data

Table 10: Material Properties 03e - Rebar Data

Material	Fy	Fu	FinalSlope
	KN/mm2	KN/mm2	
CSA G30.18	0.4	0.54	-0.1

Table 11: Material Properties 03f - Tendon Data

Table 11: Material Properties 03f - Tendon Data

Material	Fy	Fu	FinalSlope
	KN/mm2	KN/mm2	
A416Gr270	1.68991	1.86158	-0.1

3. Section properties

This section provides section property information for objects used in the model.

3.1. Frames

Table 12: Frame Section Properties 01 - General, Part 1 of 4

Table 12: Frame Section Properties 01 - General, Part 1 of 4

SectionName	Material	Shape	t3	t2	Area	TorsConst	I33	I22
			mm	mm	mm2	mm4	mm4	mm4
Column	C30	Rectangular	900.	900.	810000.	9.240E+10	5.468E+10	5.468E+10
Lower_Beam	C30	Rectangular	450.	950.	427500.	2.028E+10	7214062500.	3.215E+10
Mid_Beam	C30	Rectangular	450.	450.	202500.	5775046875.	3417187500.	3417187500.
Top_Beam	C30	Rectangular	550.	450.	247500.	8416516293.	6239062500.	4176562500.

Table 12: Frame Section Properties 01 - General, Part 2 of 4

Table 12: Frame Section Properties 01 - General, Part 2 of 4

SectionName	I23	AS2	AS3
	mm4	mm2	mm2
Column	0.	675000.	675000.
Lower_Beam	0.	356250.	356250.
Mid_Beam	0.	168750.	168750.
Top_Beam	0.	206250.	206250.

Table 12: Frame Section Properties 01 - General, Part 3 of 4

Table 12: Frame Section Properties 01 - General, Part 3 of 4

SectionName	S33	S22	Z33	Z22	R33	R22
	mm3	mm3	mm3	mm3	mm	mm
Column	121500000.	121500000.	182250000.	182250000.	259.808	259.808
Lower_Beam	32062500.	67687500.	48093750.	101531250.	129.904	274.241
Mid_Beam	15187500.	15187500.	22781250.	22781250.	129.904	129.904
Top_Beam	22687500.	18562500.	34031250.	27843750.	158.771	129.904

Table 12: Frame Section Properties 01 - General, Part 4 of 4

Table 12: Frame Section Properties 01 - General, Part 4 of 4

SectionName	AMod	A2Mod	A3Mod	JMod	I2Mod	I3Mod	MMod	WMod
Column	1.	1.	1.	1.	1.	1.	1.	1.
Lower_Beam	1.	1.	1.	1.	1.	1.	1.	1.
Mid_Beam	1.	1.	1.	1.	1.	1.	1.	1.
Top_Beam	1.	1.	1.	1.	1.	1.	1.	1.

Table 13: Frame Section Properties 02 - Concrete Column, Part 1 of 2

Table 13: Frame Section Properties 02 - Concrete Column, Part 1 of 2

SectionName	RebarMatL	RebarMatC	ReinfConfig	LatReinf	Cover	NumBars3Dir	NumBars2Dir
					mm		
Column	CSA G30.18	CSA G30.18	Rectangular	Ties	40.	3	3

Table 13: Frame Section Properties 02 - Concrete Column, Part 2 of 2

Table 13: Frame Section Properties 02 - Concrete Column, Part 2 of 2

SectionName	BarSizeL	BarSizeC	SpacingC	NumCBars2	NumCBars3
			mm		
Column	#9	#4	150.	3	3

Table 14: Frame Section Properties 03 - Concrete Beam, Part 1 of 2

Table 14: Frame Section Properties 03 - Concrete Beam, Part 1 of 2

SectionName	RebarMatL	RebarMatC	TopCover	BotCover
			mm	mm
Lower_Beam	CSA G30.18	CSA G30.18	75.	75.
Mid_Beam	CSA G30.18	CSA G30.18	75.	75.
Top_Beam	CSA G30.18	CSA G30.18	75.	75.

Table 14: Frame Section Properties 03 - Concrete Beam, Part 2 of 2

Table 14: Frame Section Properties 03 - Concrete Beam, Part 2 of 2

SectionName	TopLeftArea	TopRghtArea	BotLeftArea	BotRghtArea
	mm2	mm2	mm2	mm2
Lower_Beam	0.	0.	0.	0.
Mid_Beam	0.	0.	0.	0.
Top_Beam	0.	0.	0.	0.

3.2. Areas

Table 15: Area Section Properties, Part 1 of 3

Table 15: Area Section Properties, Part 1 of 3

Section	Material	AreaType	Type	DrillDOF	Thickness	BendThick	F11Mod
					mm	mm	
Approach_Wall	C30	Shell	Shell-Thick	Yes	900.	900.	1.
Backwall	C30	Shell	Shell-Thick	Yes	900.	900.	1.
Base	C30	Shell	Shell-Thick	Yes	900.	900.	1.
Base2	C30	Shell	Shell-Thick	Yes	2000.	2000.	1.
Channel	C30	Shell	Shell-Thick	Yes	850.	850.	1.

Table 15: Area Section Properties, Part 2 of 3

Table 15: Area Section Properties, Part 2 of 3

Section	F22Mod	F12Mod	M11Mod	M22Mod	M12Mod	V13Mod	V23Mod
Approach_Wall	1.	1.	1.	1.	1.	1.	1.
Backwall	1.	1.	1.	1.	1.	1.	1.
Base	1.	1.	1.	1.	1.	1.	1.
Base2	1.	1.	1.	1.	1.	1.	1.
Channel	1.	1.	1.	1.	1.	1.	1.

Table 15: Area Section Properties, Part 3 of 3

Table 15: Area Section Properties, Part 3 of 3

Section	MMod	WMod
Approach_Wall	1.	1.
Backwall	1.	1.
Base	1.	1.
Base2	1.	1.
Channel	1.	1.

3.3. Solids

Table 16: Solid Property Definitions

Table 16: Solid Property Definitions

SolidProp	Material	MatAngleA	MatAngleB	MatAngleC
		Degrees	Degrees	Degrees
Solid1	4000Psi	0.	0.	0.

4. Load patterns

This section provides loading information as applied to the model.

4.1. Definitions

Table 17: Load Pattern Definitions

Table 17: Load Pattern Definitions

LoadPat	DesignType	SelfWtMult	AutoLoad
SELF	Dead	1.	
Wind-X	Wind	0.	USER
Wind-Y	Wind	0.	USER
Snow	Snow	0.	
SOIL	Dead	0.	
Trashrack	Dead	0.	
Surcharge	Dead	0.	
Wind2-X	Wind	0.	USER
Wind2-Y	Wind	0.	USER
Uplift-U	Live	0.	
Uplift-Un	Live	0.	
Uplift-ex	Live	0.	
Hydro-un	Live	0.	
Hydro-ex	Live	0.	

4.2. Auto wind loading

5. Load cases

This section provides load case information.

5.1. Definitions

Table 18: Load Case Definitions, Part 1 of 2

Table 18: Load Case Definitions, Part 1 of 2

Case	Type	InitialCond	ModalCase	BaseCase	MassSource	DesActOpt
SELF	LinStatic	Zero				Prog Det
MODAL	LinModal	Zero				Prog Det
DEAD	LinStatic	Zero				Prog Det
Wind-X	LinStatic	Zero				Prog Det
Wind-Y	LinStatic	Zero				Prog Det
Snow	LinStatic	Zero				Prog Det
Soil	LinStatic	Zero				Prog Det
EQx	LinRespSpec		MODAL			Prog Det
EQy	LinRespSpec		MODAL			Prog Det
EQz	LinRespSpec		MODAL			Prog Det
Trashrack	LinStatic	Zero				Prog Det
Surcharge	LinStatic	Zero				Prog Det
Wind2-X	LinStatic	Zero				Prog Det
Wind2-Y	LinStatic	Zero				Prog Det
Uplift-U	LinStatic	Zero				Prog Det
Uplift-Un	LinStatic	Zero				Prog Det
Uplift-ex	LinStatic	Zero				Prog Det
Hydro-un	LinStatic	Zero				Prog Det
Hydro-ex	LinStatic	Zero				Prog Det

Table 18: Load Case Definitions, Part 2 of 2

Table 18: Load Case Definitions, Part 2 of 2

Case	DesignAct
SELF	Non-Composite
MODAL	Other
DEAD	Non-Composite
Wind-X	Short-Term Composite
Wind-Y	Short-Term Composite
Snow	Short-Term Composite
Soil	Non-Composite
EQx	Short-Term Composite

Table 18: Load Case Definitions, Part 2 of 2

Case	DesignAct
EQy	Short-Term Composite
EQz	Short-Term Composite
Trashrack	Non-Compos ite
Surcharge	Non-Compos ite
Wind2-X	Short-Term Composite
Wind2-Y	Short-Term Composite
Uplift-U	Short-Term Composite
Uplift-Un	Short-Term Composite
Uplift-ex	Short-Term Composite
Hydro-un	Short-Term Composite
Hydro-ex	Short-Term Composite

5.2. Static case load assignments

Table 19: Case - Static 1 - Load Assignments

Table 19: Case - Static 1 - Load Assignments

Case	LoadType	LoadName	LoadSF
SELF	Load pattern	SELF	1.
DEAD	Load pattern	SELF	1.
DEAD	Load pattern	Trashrack	1.
Wind-X	Load pattern	Wind-X	1.
Wind-Y	Load pattern	Wind-Y	1.
Snow	Load pattern	Snow	1.
Soil	Load pattern	SOIL	1.
Trashrack	Load pattern	Trashrack	1.
Surcharge	Load pattern	Surcharge	1.
Wind2-X	Load pattern	Wind2-X	1.
Wind2-Y	Load pattern	Wind2-Y	1.
Uplift-U	Load pattern	Uplift-U	1.
Uplift-Un	Load pattern	Uplift-Un	1.
Uplift-ex	Load pattern	Uplift-ex	1.
Hydro-un	Load pattern	Hydro-un	1.
Hydro-ex	Load pattern	Hydro-ex	1.

5.3. Response spectrum case load assignments

Table 20: Case - Response Spectrum 1 - General, Part 1 of 2

Table 20: Case - Response Spectrum 1 - General, Part 1 of 2

Case	ModalCombo	GMCf1	GMCf2	PerRigid	DirCombo	MotionType	DampingType
		Cyc/sec	Cyc/sec				
EQx	CQC	1.0000E+00	0.0000E+00	SRSS	SRSS	Acceleration	Constant
EQy	CQC	1.0000E+00	0.0000E+00	SRSS	SRSS	Acceleration	Constant
EQz	CQC	1.0000E+00	0.0000E+00	SRSS	SRSS	Acceleration	Constant

Table 20: Case - Response Spectrum 1 - General, Part 2 of 2

Table 20: Case - Response Spectrum 1 - General, Part 2 of 2

Case	ConstDamp
EQx	0.05
EQy	0.05
EQz	0.05

Table 21: Case - Response Spectrum 2 - Load Assignments

Table 21: Case - Response Spectrum 2 - Load Assignments

Case	LoadType	LoadName	CoordSys	Function	Angle	TransAccSF
					Degrees	mm/sec2
EQx	Acceleration	U1	GLOBAL	SR-1_X	0.	9810.
EQy	Acceleration	U2	GLOBAL	SR-1_Y	0.	9810.
EQz	Acceleration	U3	GLOBAL	SR-1_V	0.	9810.

Table 22: Function - Response Spectrum - User

Table 22: Function - Response Spectrum - User

Name	Period	Accel	FuncDamp
	Sec		
SR-1_Y	0.022126	0.247	0.05
SR-1_Y	0.023356	0.248	
SR-1_Y	0.029676	0.253	
SR-1_Y	0.032964	0.256	
SR-1_Y	0.033454	0.256	
SR-1_Y	0.061017	0.295	
SR-1_Y	0.09342	0.369	
SR-1_Y	0.129093	0.424	
SR-1_Y	0.189951	0.509	
SR-1_Y	0.242776	0.554	
SR-1_V	0.05	0.3102	0.05
SR-1_V	0.1	0.3807	
SR-1_V	0.2	0.32	

Table 22: Function - Response Spectrum - User

Name	Period Sec	Accel	FuncDamp
SR-1_V	0.3	0.276	
SR-1_V	0.5	0.1872	
SR-1_V	1.	0.0962	
SR-1_V	2.	0.0473	
SR-1_V	5.	0.0163	
SR-1_V	10.	0.0066	
SR-1_X	0.022126	0.265	0.05
SR-1_X	0.023356	0.266	
SR-1_X	0.029676	0.272	
SR-1_X	0.032964	0.275	
SR-1_X	0.033454	0.275	
SR-1_X	0.061017	0.316	
SR-1_X	0.09342	0.396	
SR-1_X	0.129093	0.456	
SR-1_X	0.189951	0.546	
SR-1_X	0.242776	0.595	

6. Load combinations

This section provides load combination information.

Table 23: Combination Definitions

Table 23: Combination Definitions

ComboName	ComboType	CaseName	ScaleFactor
W4	Linear Add	Wind-X	-1.
W3	Linear Add	Wind-X	0.75
W3		Wind-Y	0.75
W5	Linear Add	Wind-X	-0.75
W5		Wind-Y	0.75
Wind	Envelope	Wind-X	1.
Wind		Wind-Y	1.
Wind		W3	1.
Wind		W4	1.
Wind		W5	1.
E1	SRSS	EQx	0.3
E1		EQy	0.3
E1		EQz	1.
E2	SRSS	EQx	0.3
E2		EQy	-0.3
E2		EQz	1.
E3	Linear Add	EQx	-0.3
E3		EQy	-0.3
E3		EQz	1.
E4	Linear Add	EQx	-0.3
E4		EQy	0.3
E4		EQz	1.
E13	Linear Add	EQx	0.3
E13		EQy	0.3
E13		EQz	-1.
E14	Linear Add	EQx	0.3

Table 23: Combination Definitions

ComboName	ComboType	CaseName	ScaleFactor
E14		EQy	-0.3
E14		EQz	-1.
E15	Linear Add	EQx	-0.3
E15		EQy	-0.3
E15		EQz	-1.
E16	Linear Add	EQx	-0.3
E16		EQy	0.3
E16		EQz	-1.
E5	Linear Add	EQx	1.
E5		EQy	0.3
E5		EQz	0.3
E6	Linear Add	EQx	1.
E6		EQy	-0.3
E6		EQz	0.3
E7	Linear Add	EQx	-1.
E7		EQy	-0.3
E7		EQz	0.3
E8	Linear Add	EQx	-1.
E8		EQy	0.3
E8		EQz	0.3
E17	Linear Add	EQx	1.
E17		EQy	0.3
E17		EQz	-0.3
E18	Linear Add	EQx	1.
E18		EQy	-0.3
E18		EQz	-0.3
E19	Linear Add	EQx	-1.
E19		EQy	-0.3
E19		EQz	-0.3
E20	Linear Add	EQx	-1.
E20		EQy	0.3
E20		EQz	-0.3
E9	Linear Add	EQx	0.3
E9		EQy	1.
E9		EQz	0.3
E10	Linear Add	EQx	0.3
E10		EQy	-1.
E10		EQz	0.3
E11	Linear Add	EQx	-0.3
E11		EQy	-1.
E11		EQz	0.3
E12	Linear Add	EQx	-0.3
E12		EQy	1.
E12		EQz	0.3
E21	Linear Add	EQx	0.3
E21		EQy	1.
E21		EQz	-0.3
E22	Linear Add	EQx	0.3
E22		EQy	-1.
E22		EQz	-0.3
E23	Linear Add	EQx	-0.3
E23		EQy	-1.
E23		EQz	-0.3
E24	Linear Add	EQx	-0.3

Table 23: Combination Definitions

ComboName	ComboType	CaseName	ScaleFactor
E24		EQy	1.
E24		EQz	-0.3
EQ	Envelope	E1	1.
EQ		E2	1.
EQ		E3	1.
EQ		E4	1.
EQ		E5	1.
EQ		E6	1.
EQ		E7	1.
EQ		E8	1.
EQ		E9	1.
EQ		E10	1.
EQ		E11	1.
EQ		E12	1.
EQ		E13	1.
EQ		E14	1.
EQ		E15	1.
EQ		E16	1.
EQ		E17	1.
EQ		E18	1.
EQ		E19	1.
EQ		E20	1.
EQ		E21	1.
EQ		E22	1.
EQ		E23	1.
EQ		E24	1.
W4-2	Linear Add	Wind2-X	-1.
W3-2	Linear Add	Wind2-X	0.75
W3-2		Wind2-Y	0.75
W5-2	Linear Add	Wind2-X	-0.75
W5-2		Wind2-Y	0.75
Wind-2	Envelope	Wind2-X	1.
Wind-2		Wind2-Y	1.
Wind-2		W3-2	1.
Wind-2		W4-2	1.
Wind-2		W5-2	1.
LC1	Linear Add	DEAD	1.4
LC1		Soil	1.5
S1	Linear Add	DEAD	1.
S1		Soil	1.
2-2	Linear Add	DEAD	1.25
2-2		Soil	1.5
2-2		Uplift-U	1.5
2-2		Wind	0.4
2-1	Linear Add	DEAD	1.25
2-1		Soil	1.5
2-1		Uplift-U	1.5
2-1		Snow	1.
2-3	Linear Add	DEAD	0.9
2-3		Soil	1.5
2-3		Uplift-U	1.5
2-3		Snow	1.
2-4	Linear Add	DEAD	0.9
2-4		Soil	1.5

Table 23: Combination Definitions

ComboName	ComboType	CaseName	ScaleFactor
2-4		Uplift-U	1.5
2-4		Wind	0.4
2-5	Linear Add	DEAD	1.25
2-5		Soil	1.5
2-5		Uplift-U	1.5
2-6	Linear Add	DEAD	0.9
2-6		Soil	1.5
2-6		Uplift-U	1.5
LC2A	Envelope	2-1	1.
LC2A		2-2	1.
LC2A		2-3	1.
LC2A		2-4	1.
LC2A		2-5	1.
LC2A		2-6	1.
S2A	Linear Add	DEAD	1.
S2A		Soil	1.
S2A		Uplift-U	1.
S2A		Snow	1.
S2A		Wind	1.
3-1	Linear Add	DEAD	1.25
3-1		Soil	1.5
3-1		Uplift-U	1.
3-1		Snow	1.5
3-2	Linear Add	DEAD	1.25
3-2		Soil	1.5
3-2		Snow	1.5
3-2		Wind	0.4
3-3	Linear Add	DEAD	0.9
3-3		Soil	1.5
3-3		Uplift-U	1.
3-3		Snow	1.5
3-4	Linear Add	DEAD	0.9
3-4		Soil	1.5
3-4		Snow	1.5
3-4		Wind	0.4
3-5	Linear Add	DEAD	1.25
3-5		Soil	1.5
3-5		Snow	1.5
3-6	Linear Add	DEAD	0.9
3-6		Soil	1.5
3-6		Snow	1.5
LC3A	Envelope	3-1	1.
LC3A		3-2	1.
LC3A		3-3	1.
LC3A		3-4	1.
LC3A		3-5	1.
LC3A		3-6	1.
S3A	Linear Add	DEAD	1.
S3A		Soil	1.
S3A		Uplift-U	1.
S3A		Snow	1.
S3A		Wind	1.
4-1	Linear Add	DEAD	1.25
4-1		Soil	1.5

Table 23: Combination Definitions

ComboName	ComboType	CaseName	ScaleFactor
4-1		Uplift-U	1.
4-1		Snow	1.4
4-2	Linear Add	DEAD	1.25
4-2		Soil	1.5
4-2		Snow	0.5
4-2		Wind	1.4
4-3	Linear Add	DEAD	0.9
4-3		Soil	1.5
4-3		Uplift-U	1.
4-3		Wind	1.4
4-4	Linear Add	DEAD	0.9
4-4		Soil	1.5
4-4		Snow	0.5
4-4		Wind	1.4
4-5	Linear Add	DEAD	1.25
4-5		Soil	1.5
4-5		Wind	1.4
4-6	Linear Add	DEAD	0.9
4-6		Soil	1.5
4-6		Wind	1.4
LC4A	Envelope	4-1	1.
LC4A		4-2	1.
LC4A		4-3	1.
LC4A		4-4	1.
LC4A		4-5	1.
LC4A		4-6	1.
S4A	Linear Add	DEAD	1.
S4A		Soil	1.
S4A		Uplift-U	1.
S4A		Snow	1.
S4A		Wind	1.
LC5-1	Linear Add	DEAD	1.
LC5-1		Soil	1.
LC5-1		Uplift-U	1.
LC5-1		Snow	0.25
LC5-1		EQ	1.
LC5-2	Linear Add	DEAD	1.
LC5-2		EQ	1.
LC5-2		Soil	1.
LC5-2		Uplift-U	1.
S5-1	Linear Add	DEAD	1.
S5-1		Soil	1.
S5-1		Uplift-U	1.
S5-1		Snow	1.
S5-1		EQ	1.
2B-1	Linear Add	DEAD	1.25
2B-1		Soil	1.5
2B-1		Hydro-un	1.25
2B-1		Uplift-Un	1.5
2B-1		Snow	1.
2B-2	Linear Add	DEAD	1.25
2B-2		Soil	1.5
2B-2		Hydro-un	1.25
2B-2		Uplift-Un	1.5

Table 23: Combination Definitions

ComboName	ComboType	CaseName	ScaleFactor
2B-2		Wind-2	0.4
2B-3	Linear Add	DEAD	0.9
2B-3		Soil	1.5
2B-3		Hydro-un	1.25
2B-3		Uplift-Un	1.5
2B-3		Snow	1.
2B-4	Linear Add	DEAD	0.9
2B-4		Soil	1.5
2B-4		Hydro-un	1.25
2B-4		Uplift-Un	1.5
2B-4		Wind-2	0.4
2B-5	Linear Add	DEAD	1.25
2B-5		Soil	1.5
2B-5		Hydro-un	1.25
2B-5		Uplift-Un	1.5
2B-6	Linear Add	DEAD	0.9
2B-6		Soil	1.5
2B-6		Hydro-un	1.25
2B-6		Uplift-Un	1.5
LC2B	Envelope	2B-1	1.
LC2B		2B-2	1.
LC2B		2B-3	1.
LC2B		2B-4	1.
LC2B		2B-5	1.
LC2B		2B-6	1.
S2B	Linear Add	DEAD	1.
S2B		Soil	1.
S2B		Hydro-un	1.
S2B		Uplift-Un	1.
S2B		Snow	1.
S2B		Wind-2	1.
3B-1	Linear Add	DEAD	1.25
3B-1		Uplift-Un	1.
3B-1		Snow	1.5
3B-1		Soil	1.5
3B-1		Hydro-un	1.
3B-2	Linear Add	DEAD	1.25
3B-2		Wind-2	0.4
3B-2		Snow	1.5
3B-2		Soil	1.5
3B-3	Linear Add	DEAD	0.9
3B-3		Uplift-Un	1.
3B-3		Snow	1.5
3B-3		Soil	1.5
3B-3		Hydro-un	1.
3B-4	Linear Add	DEAD	0.9
3B-4		Wind-2	0.4
3B-4		Snow	1.5
3B-4		Soil	1.5
3B-5	Linear Add	DEAD	1.25
3B-5		Snow	1.5
3B-5		Soil	1.5
3B-6	Linear Add	DEAD	0.9
3B-6		Snow	1.5

Table 23: Combination Definitions

ComboName	ComboType	CaseName	ScaleFactor
3B-6		Soil	1.5
LC3B	Envelope	3B-1	1.
LC3B		3B-2	1.
LC3B		3B-3	1.
LC3B		3B-4	1.
LC3B		3B-5	1.
LC3B		3B-6	1.
S3B	Linear Add	DEAD	1.
S3B		Soil	1.
S3B		Snow	1.
S3B		Wind-2	1.
S3B		Uplift-Un	1.
S3B		Hydro-un	1.
4B-1	Linear Add	DEAD	1.25
4B-1		Uplift-Un	1.
4B-1		Wind-2	1.4
4B-1		Soil	1.5
4B-1		Hydro-un	1.
4B-2	Linear Add	DEAD	1.25
4B-2		Snow	0.5
4B-2		Wind-2	1.4
4B-2		Soil	1.5
4B-5	Linear Add	DEAD	1.25
4B-5		Wind-2	1.4
4B-5		Soil	1.5
4B-6	Linear Add	DEAD	0.9
4B-6		Wind-2	1.4
4B-6		Soil	0.9
4B-3	Linear Add	DEAD	0.9
4B-3		Uplift-Un	1.
4B-3		Wind-2	1.4
4B-3		Soil	1.5
4B-3		Hydro-un	1.
4B-4	Linear Add	DEAD	0.9
4B-4		Snow	0.5
4B-4		Wind-2	1.4
4B-4		Soil	1.5
LC4B	Envelope	4B-1	1.
LC4B		4B-2	1.
LC4B		4B-3	1.
LC4B		4B-4	1.
LC4B		4B-5	1.
LC4B		4B-6	1.
S4B	Linear Add	DEAD	1.
S4B		Soil	1.
S4B		Snow	1.
S4B		Wind-2	1.
S4B		Uplift-Un	1.
S4B		Hydro-un	1.
2C-1	Linear Add	DEAD	1.25
2C-1		Snow	1.
2C-1		Soil	1.5
2C-1		Uplift-U	1.5
2C-1		Surcharge	1.5

Table 23: Combination Definitions

ComboName	ComboType	CaseName	ScaleFactor
2C-2	Linear Add	DEAD	1.25
2C-2		Wind	0.4
2C-2		Soil	1.5
2C-2		Uplift-U	1.5
2C-2		Surcharge	1.5
2C-3	Linear Add	DEAD	0.9
2C-3		Soil	1.5
2C-3		Uplift-U	1.5
2C-3		Snow	1.
2C-3		Surcharge	1.5
2C-4	Linear Add	DEAD	0.9
2C-4		Wind	0.4
2C-4		Uplift-U	1.5
2C-4		Soil	1.5
2C-4		Surcharge	1.5
2C-5	Linear Add	DEAD	1.25
2C-5		Soil	1.5
2C-5		Uplift-U	1.5
2C-5		Surcharge	1.5
2C-6	Linear Add	DEAD	0.9
2C-6		Soil	1.5
2C-6		Uplift-U	1.5
2C-6		Surcharge	1.5
LC2C	Envelope	2C-1	1.
LC2C		2C-2	1.
LC2C		2C-3	1.
LC2C		2C-4	1.
LC2C		2C-5	1.
LC2C		2C-6	1.
S2C	Linear Add	DEAD	1.
S2C		Soil	1.
S2C		Uplift-U	1.
S2C		Snow	1.
S2C		Wind	1.
S2C		Surcharge	1.
3C-1	Linear Add	DEAD	1.25
3C-1		Uplift-U	1.
3C-1		Snow	1.5
3C-1		Soil	1.5
3C-1		Surcharge	1.
3C-2	Linear Add	DEAD	1.25
3C-2		Wind	0.4
3C-2		Snow	1.5
3C-2		Soil	1.5
3C-3	Linear Add	DEAD	0.9
3C-3		Uplift-U	1.
3C-3		Snow	1.5
3C-3		Soil	1.5
3C-3		Surcharge	1.
3C-4	Linear Add	DEAD	0.9
3C-4		Wind	0.4
3C-4		Snow	1.5
3C-4		Soil	1.5
3C-5	Linear Add	DEAD	1.25

Table 23: Combination Definitions

ComboName	ComboType	CaseName	ScaleFactor
3C-5		Snow	1.5
3C-5		Soil	1.5
3C-6	Linear Add	DEAD	0.9
3C-6		Snow	1.5
3C-6		Soil	1.5
LC3C	Envelope	3C-1	1.
LC3C		3C-2	1.
LC3C		3C-3	1.
LC3C		3C-4	1.
LC3C		3B-5	1.
LC3C		3B-6	1.
S3C	Linear Add	DEAD	1.
S3C		Soil	1.
S3C		Surcharge	1.
S3C		Snow	1.
S3C		Wind	1.
S3C		Uplift-U	1.
4C-1	Linear Add	DEAD	1.25
4C-1		Uplift-U	0.5
4C-1		Wind	1.4
4C-1		Soil	1.5
4C-1		Surcharge	1.
4C-2	Linear Add	DEAD	1.25
4C-2		Snow	0.5
4C-2		Wind	1.4
4C-2		Soil	1.5
4C-3	Linear Add	DEAD	0.9
4C-3		Uplift-U	0.5
4C-3		Wind	1.4
4C-3		Soil	1.5
4C-3		Surcharge	1.
4C-4	Linear Add	DEAD	0.9
4C-4		Snow	0.5
4C-4		Wind	1.4
4C-4		Soil	1.5
4C-5	Linear Add	DEAD	1.25
4C-5		Wind	1.4
4C-5		Soil	1.5
4C-6	Linear Add	DEAD	0.9
4C-6		Wind	1.4
4C-6		Soil	0.9
LC4C	Envelope	4C-1	1.
LC4C		4B-2	1.
LC4C		4B-3	1.
LC4C		4B-4	1.
LC4C		4C-5	1.
LC4C		4C-6	1.
S4C	Linear Add	DEAD	1.
S4C		Soil	1.
S4C		Surcharge	1.
S4C		Snow	1.
S4C		Wind	1.
S4C		Uplift-U	1.
2D-1	Linear Add	DEAD	1.25

Table 23: Combination Definitions

ComboName	ComboType	CaseName	ScaleFactor
2D-1		Soil	1.5
2D-1		Uplift-ex	1.5
2D-1		Hydro-ex	1.05
2D-2	Linear Add	DEAD	1.25
2D-2		Soil	1.5
2D-2		Uplift-ex	1.5
2D-2		Hydro-ex	1.05
2D-3	Linear Add	DEAD	0.9
2D-3		Soil	1.5
2D-3		Uplift-ex	1.5
2D-3		Hydro-ex	1.05
2D-4	Linear Add	DEAD	0.9
2D-4		Uplift-ex	1.5
2D-4		Soil	1.5
2D-4		Hydro-ex	1.05
2D-5	Linear Add	DEAD	1.25
2D-5		Soil	1.5
2D-5		Uplift-ex	1.5
2D-5		Hydro-ex	1.05
2D-6	Linear Add	DEAD	0.9
2D-6		Soil	1.5
2D-6		Uplift-ex	1.5
2D-6		Hydro-ex	1.05
LC2D	Envelope	2D-1	1.
LC2D		2D-2	1.
LC2D		2D-3	1.
LC2D		2D-4	1.
LC2D		2D-5	1.
LC2D		2D-6	1.
S2D	Linear Add	DEAD	1.
S2D		Soil	1.
S2D		Uplift-ex	1.
S2D		Hydro-ex	1.
3D-1	Linear Add	DEAD	1.25
3D-1		Soil	1.5
3D-1		Hydro-ex	1.
3D-1		Uplift-ex	1.
3D-2	Linear Add	DEAD	1.25
3D-2		Soil	1.5
3D-3	Linear Add	DEAD	0.9
3D-3		Uplift-ex	1.
3D-3		Soil	1.5
3D-3		Hydro-ex	1.
3D-4	Linear Add	DEAD	0.9
3D-4		Soil	1.5
3D-5	Linear Add	DEAD	1.25
3D-5		Soil	1.5
3D-6	Linear Add	DEAD	0.9
3D-6		Soil	1.5
LC3D	Envelope	3D-1	1.
LC3D		3D-2	1.
LC3D		3D-3	1.
LC3D		3D-4	1.
LC3D		3D-5	1.

Table 23: Combination Definitions

ComboName	ComboType	CaseName	ScaleFactor
LC3D		3D-6	1.
S3D	Linear Add	DEAD	1.
S3D		Soil	1.
S3D		Uplift-ex	1.
S3D		Hydro-ex	1.
4D-1	Linear Add	DEAD	1.25
4D-1		Uplift-ex	1.
4D-1		Soil	1.5
4D-1		Hydro-ex	1.
4D-2	Linear Add	DEAD	1.25
4D-2		Soil	1.5
4D-3	Linear Add	DEAD	0.9
4D-3		Uplift-ex	1.
4D-3		Soil	1.5
4D-3		Hydro-ex	1.
4D-4	Linear Add	DEAD	0.9
4D-4		Soil	1.5
4D-5	Linear Add	DEAD	1.25
4D-5		Soil	1.5
4D-6	Linear Add	DEAD	0.9
4D-6		Soil	1.5
LC4D	Envelope	4D-1	1.
LC4D		4D-2	1.
LC4D		4D-3	1.
LC4D		4D-4	1.
LC4D		4D-5	1.
LC4D		4D-6	1.
S4D	Linear Add	DEAD	1.
S4D		Soil	1.
S4D		Uplift-ex	1.
S4D		Hydro-ex	1.
S5-2	Linear Add	DEAD	1.
S5-2		Soil	1.
S5-2		Uplift-U	1.
S5-2		EQ	1.

7. Design preferences

This section provides the design preferences for each type of design, which typically include material reduction factors, framing type, stress ratio limit, deflection limits, and other code specific items.

7.1. Steel design

Table 24: Preferences - Steel Design - AISC 360-10, Part 1 of 4

Table 24: Preferences - Steel Design - AISC 360-10, Part 1 of 4

THDesign	FrameType	PatLLF	SRatioLimit	MaxIter	SDC	SeisCode	SeisLoad	ImpFactor
Envelopes	SMF	0.75	0.95	1	D	Yes	Yes	1.

Table 24: Preferences - Steel Design - AISC 360-10, Part 2 of 4

Table 24: Preferences - Steel Design - AISC 360-10, Part 2 of 4

SystemRho	SystemSds	SystemR	SystemCd	Omega0	Provision	AMethod	SOMethod	SRMethod
1.	0.5	8.	5.5	3.	LRFD	Direct Analysis	General 2nd Order	Tau-b Fixed

Table 24: Preferences - Steel Design - AISC 360-10, Part 3 of 4

Table 24: Preferences - Steel Design - AISC 360-10, Part 3 of 4

NLCoeff	PhiB	PhiC	PhiTY	PhiTF	PhiV	PhiVRolledI	PhiVT	PlugWeld
0.002	0.9	0.9	0.9	0.75	0.9	1.	0.9	Yes

Table 24: Preferences - Steel Design - AISC 360-10, Part 4 of 4

Table 24: Preferences - Steel Design - AISC 360-10, Part 4 of 4

HSSWelding	HSSReduceT	CheckDefl	DLRat	SDLAndLLRat	LLRat	TotalRat	NetRat
ERW	No	No	120.	120.	360.	240.	240.

7.2. Concrete design

Table 25: Preferences - Concrete Design - CSA-A233-14

Table 25: Preferences - Concrete Design - CSA-A233-14

THDesign	NumCurves	NumPoints	MinEccen	PatLLF	UFLimit	PhiS	PhiC
Envelopes	24	11	Yes	0.75	0.95	0.85	0.65

7.3. Aluminum design

Table 26: Preferences - Aluminum Design - AA-ASD 2000

Table 26: Preferences - Aluminum Design - AA-ASD 2000

FrameType	SRatioLimit	LatFact	UseLatFact
Moment Frame	1.	1.333333	No

7.4. Cold formed design

Table 27: Preferences - Cold Formed Design - AISI-ASD96

Table 27: Preferences - Cold Formed Design - AISI-ASD96

FrameType	SRatioLimit	OmegaBS	OmegaBUS	OmegaBLTB	OmegaVS	OmegaVNS	OmegaT	OmegaC
Braced Frame	1.	1.67	1.67	1.67	1.67	1.5	1.67	1.8

8. Design overwrites

This section provides the design overwrites for each type of design, which are assigned to individual members of the structure.

8.1. Concrete design

Table 28: Overwrites - Concrete Design - CSA-A233-14, Part 1 of 3

Table 28: Overwrites - Concrete Design - CSA-A233-14, Part 1 of 3

Frame	DesignSect	FrameType	RLLF	XLMajor	XLMinor	XKMajor
1	Program Determined	Program Determined	0.	0.	0.	0.
2	Program Determined	Program Determined	0.	0.	0.	0.
3	Program Determined	Program Determined	0.	0.	0.	0.
4	Program Determined	Program Determined	0.	0.	0.	0.
5	Program Determined	Program Determined	0.	0.	0.	0.
6	Program Determined	Program Determined	0.	0.	0.	0.
7	Program Determined	Program Determined	0.	0.	0.	
8	Program Determined	Program Determined	0.	0.	0.	
9	Program Determined	Program Determined	0.	0.	0.	
10	Program Determined	Program Determined	0.	0.	0.	
11	Program Determined	Program Determined	0.	0.	0.	
12	Program Determined	Program Determined	0.	0.	0.	
13	Program Determined	Program Determined	0.	0.	0.	

Table 28: Overwrites - Concrete Design - CSA-A233-14, Part 2 of 3

Table 28: Overwrites - Concrete Design - CSA-A233-14, Part 2 of 3

Frame	XKMinor	CmMajor	CmMinor	DbMajor	DbMinor	DsMajor	DsMinor
1	0.	0.	0.	0.	0.	0.	0.
2	0.	0.	0.	0.	0.	0.	0.
3	0.	0.	0.	0.	0.	0.	0.
4	0.	0.	0.	0.	0.	0.	0.
5	0.	0.	0.	0.	0.	0.	0.
6	0.	0.	0.	0.	0.	0.	0.
7							
8							
9							
10							
11							
12							
13							

Table 28: Overwrites - Concrete Design - CSA-A233-14, Part 3 of 3

Table 28: Overwrites - Concrete Design - CSA-A233-14, Part 3 of 3

Frame	Rd	Ro	MaxAggSize mm
1	0.	0.	0.
2	0.	0.	0.
3	0.	0.	0.
4	0.	0.	0.
5	0.	0.	0.
6	0.	0.	0.
7			
8			
9			
10			
11			
12			
13			

Intake Structure – Stability Analysis

Project: Springbank Off-Stream Storage Project - SR1
By: C. Gabriel Date: 8/19/2019
Checked: A.Garland Date: 9/30/2019

LOAD SUMMARY FOR STABILITY ANALYSES

Water unit weight (kN/m^3)	9.807
Base slab thickness (m)	0.9
Top of slab Elev. (m)	1187
Base length (m)	7.9
Base width (m)	6.3

1- Water Weights

						NOC		10-Year Flood		Max Pool		Plugged
						1187.00		1192		1213.50		1192
	Area (m^2)	Depth (m)	Arm(m)	Top Elev. (m)	Bot Elev. (m)	Head (m)	Weight (kN)	Head (m)	Weight (kN)	Head (m)	Weight (kN)	Weight (kN)
A1	21.06	varies	3.39	varies	1187.000	0.0	0.0	5.00	1032.7	26.50	5473.2	1032.7
A2	9.81	2.90	2.94	1189.900	1187.000	0.0	0.0	2.90	279.0	2.90	279.0	0.0
A3	5.56	2.04	6.36	1189.037	1187.000	0.0	0.0	2.04	111.1	2.04	111.1	0.0
A4	15.32	2.28	3.06	1192.175	1189.900	0.0	0.0	2.10	315.5	2.28	341.8	0.0
	15.32	2.18	3.06	1194.800	1192.625	0.0	0.0	0.00	0.0	2.18	326.8	0.0
A5	11.95	0.45	3.03	1192.625	1192.175	0.0	0.0	0.00	0.0	0.45	52.7	0.0
	11.95	0.90	3.03	1195.700	1194.800	0.0	0.0	0.00	0.0	0.90	105.4	0.0
A6	8.07	0.993	6.81	1190.64	1189.650	0.0	0.0	0.99	78.6	0.99	78.6	78.6
A7	8.07	varies	6.81	varies	1190.64	0.0	0.0	1.36	107.4	22.86	1809.0	107.4
A8	20.64	varies	3.40	varies	1195.7	0.0	0.0	0.00	0.0	17.80	3603.0	0.0
						Sum (kN)	0.0		1924.3		12180.6	1218.7
						Arm (m)	0		3.77		3.92	3.91

2- Uplift Loads

NOC		10-Year Flood		Max Pool	
Head (m)	Load KN)	Head (m)	Load KN)	Head (m)	Load KN)
1.13	553.1	6.13	2993.6	27.63	13487.6

3-Impact Loads

NOC		10-Year Flood		Max Pool	
Elev. (m)	Load KN)	Elev. (m)	Load KN)	Elev. (m)	Load KN)
1187.00	0.0	1192.00	100.0	1213.50	0.0

4- SAP 2000 Static Reactions

	Fx (kN)	Fy (kN)	Fz (kN)	Mx (kN-m)	My (kN-m)
DEAD	0.0	0.0	3494.5	0.0	-904.5
Wind-X	-87.9	0.0	0.0	0.0	-672.5
Wind-Y	0.0	-78.5	0.0	498.4	0.0
Snow	0.0	0.0	66.5	0.0	64.0
Soil	-29.8	0.0	452.1	-0.4	-1416.1
Surcharge	2.9	0.0	281.2	0.0	-761.6
Wind2-X	-54.4	0.0	0.0	0.0	-483.7
Wind2-Y	0.0	-34.3	0.0	308.5	0.0

5- SAP 2000 Seismic Reactions

	Fx (kN)	Fy (kN)	Fz (kN)	Mx (kN-m)	My (kN-m)
E1	193.3	567.2	1139.2	2928.9	1052.9
E2	193.3	567.2	1139.2	2928.9	1052.9
E3	223.5	567.2	1143.0	2928.9	1437.1
E4	223.5	567.2	1143.0	2928.9	1437.1
E5	644.9	567.2	354.5	2928.9	3202.0
E6	644.9	567.2	354.5	2928.9	3202.0
E7	644.9	567.2	354.5	2928.9	3202.0
E8	644.9	567.2	354.5	2928.9	3202.0
E9	200.5	1890.7	345.6	9763.0	1070.7
E10	200.5	1890.7	345.6	9763.0	1070.7
E11	200.5	1890.7	345.6	9763.0	1070.7
E12	200.5	1890.7	345.6	9763.0	1070.7
E13	223.5	567.2	1143.0	2928.9	1437.1
E14	223.5	567.2	1143.0	2928.9	1437.1
E15	223.5	567.2	1143.0	2928.9	1437.1
E16	223.5	567.2	1143.0	2928.9	1437.1
E17	644.9	567.2	354.5	2928.9	3202.0
E18	644.9	567.2	354.5	2928.9	3202.0
E19	644.9	567.2	354.5	2928.9	3202.0
E20	644.9	567.2	354.5	2928.9	3202.0
E21	200.5	1890.7	345.6	9763.0	1070.7
E22	200.5	1890.7	345.6	9763.0	1070.7
E23	200.5	1890.7	345.6	9763.0	1070.7
E24	200.5	1890.7	345.6	9763.0	1070.7

Load Case	Description	Loading
LC01	Usual - Empty Reservoir, Winter	Dead + Earth + Uplift + Wind + Snow
LC02	Usual - Empty Reservoir, Summer	Dead + Earth + Uplift + Wind
LC03	Unusual - Construction	Dead + Earth + Uplift + Wind + Surcharge
LC04	Unusual - 10-Year Flood	Dead + Earth + Hydro + Uplift + Wind
LC05	Extreme - 10-Year Flood + Impact	Dead + Earth + Hydro + Uplift + Wind + Impact
LC06	Extreme - Maximum Pool	Dead + Earth + Hydro + Uplift
LC07	Extreme - Earthquake	Dead + Earth + Wind + Uplift + EQ[1]
LC08	Post-Earthquake	Dead + Earth + Uplift + Wind

1 Response Spectrum Analysis; EQ=max [24 combinations of EQx, EQy, EQz]

INTAKE TOWER STATIC STABILITY ANALYSIS SUMMARY

Job Name:	Springbank Off-Stream Storage Project	Number:	110773396
Site:	Intake Structure	Originator:	CG 7/2/2020

Results Summary:

SR-1 - Summary of Intake Structure Static Stability Assessment

Load Case	Load Category	Sliding Stability Safety Factor		Base Area in Compression(2)		Bearing Pressures (3) (kPa)		Flotation Safety Factor	
		Required	Calculated	Required	Calculated	Req.	Max Calc.	Required	Calculated
1- Empty Reservoir, Winter	Usual	1.5	**17**	100%	**100%**	200.0	**133.0**	1.5	**8.8**
2- Empty Reservoir, Summer	Usual	1.5	**17**	100%	**100%**	200.0	**132.3**	1.5	**8.7**
3- Construction	Unusual	1.3	**8**	100%	**100%**	200.0	**142.3**	1.3	**9.2**
4- 10-Year Flood	Unusual	1.3	**14**	100%	**100%**	200.0	**120.3**	1.3	**2.2**
5- 10-Year Flood + Impact	Extreme	1.1	**7**	75%	**100%**	200.0	**131.2**	1.1	**2.2**
6- 10-Year Flood + Clogged Trashracks	Unusual	1.3	**12**	100%	**100%**	200.0	**102.0**	1.3	**2.0**
7- Maximum Pool	Extreme	1.1	**9**	75%	**100%**	200.0	**103.0**	1.1	**1.3**

(1)- Direction of wind and wave loads do not apply when the structure is submerged.

(2)- 100% base compression = resultant within the middle 1/3

75% base compression = resultant within the middle 1/2

>0% base compression = resultant within the base

(3)- Bearing pressure limits are based on the allowable bearing capacity of the foundation soils

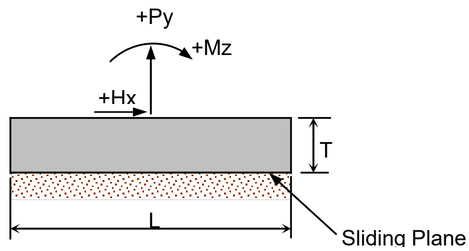
INTAKE TOWER STABILITY ANALYSIS

Job Name:	Springbank Off-Stream Storage Project (SR-1)	Number:	110773396		
Site:	Intake Structure	Originator:	CG 7/2/2020	Checker:	ACG
Load Case:	1 Empty Reservoir, Winter				

Input Data:

Footing Data:

Footing Length, L =	7.90	m
Footing Width, B =	6.30	m
Footing Thickness, T =	0.00	m
Coef. of Base Friction, μ =	0.420	
Allowable Bearing, Pall =	200.0	kPa

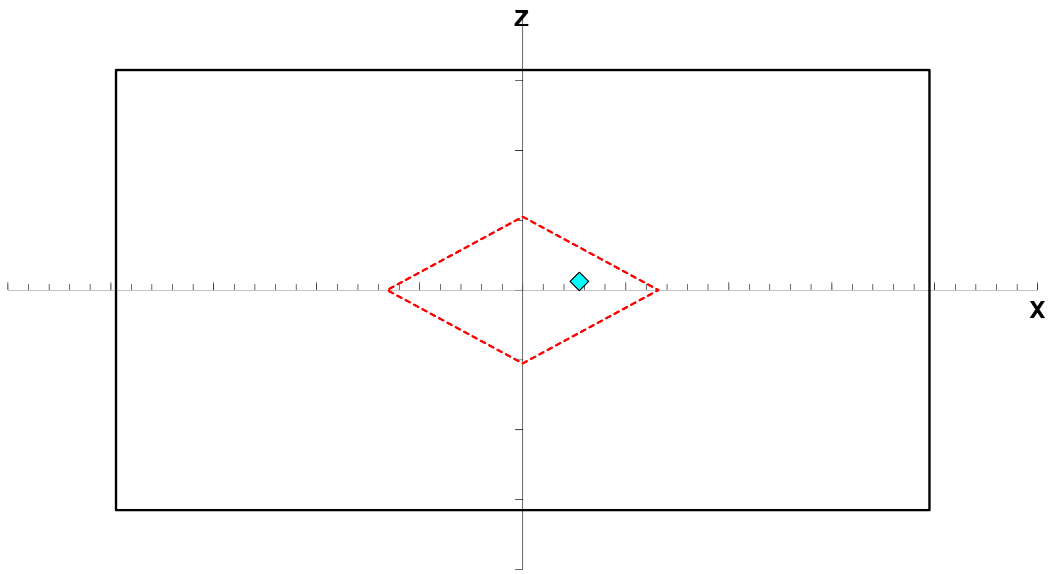


Nomenclature

Loading Data:

Direction of Wind Force: COMBINED

	Uplift	Wind		Snow	Dead	Soil
Xp (m.) =						
Zp (m.) =						
Py (kN) =	553.10			-66.00	-4357.34	-452.10
Hx (kN) =		87.90				-158.40
Hz (kN) =		78.50				0.00
Mx (kN-m) =		-498.40			0.00	0.40
Mz (kN-m) =		672.50		-64.00	904.50	857.80



FOOTING PLAN

Note: Is the "Kern" area of footing (When resultant of loads falls within "Kern", entire footing base is in bearing.)

Results:

Total Resultant Load and Eccentricities:

ΣPy =	-4322.34	kN
ex =	0.55	m (<= L/6)
ez =	0.12	m (<= B/6)
ΣHx =	-70.50	kN
ΣHz =	78.50	kN
H resultant =	105.51	kN
ΣMrx =	15357.64	kN-m
ΣMox =	-2240.27	kN-m
ΣMry =	19257.99	kN-m
ΣMoy =	4555.55	kN-m

Sliding Check:

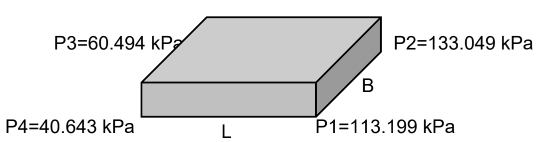
Frict =	1815.38	kN
FS(slid) =	17.206	

% Base Area in Compression:

Dist. x =	N.A.	m
Dist. z =	N.A.	m
Brg. Lx =	7.900	m
Brg. Lz =	6.300	m
%Brg. Area =	100.00	%
Biaxial Case =	N.A.	6*ex/L + 6*ez/B = 0.532

Gross Soil Bearing Corner Pressures:

P1 =	113.199	kPa
P2 =	133.049	kPa
P3 =	60.494	kPa
P4 =	40.643	kPa



CORNER PRESSURES

Summary of Results:

Sliding Check:

FS(slid) =	17.21	> 1.5	OK

Bearing Area Check:

%Brg. Area =	100.00%	< 100%	OK

Bearing Pressure Check:

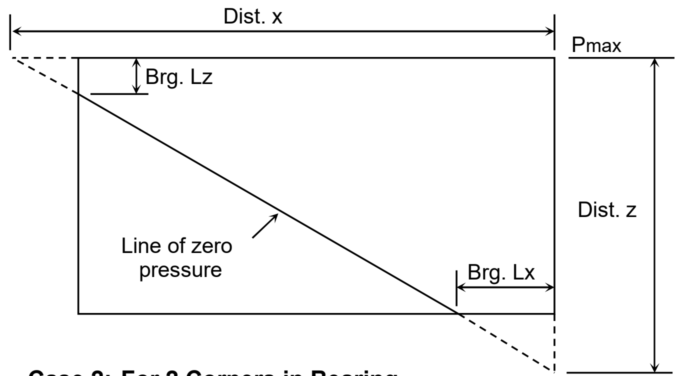
FS(brg) =	1.50	> 1.0	OK

Flotation Check:

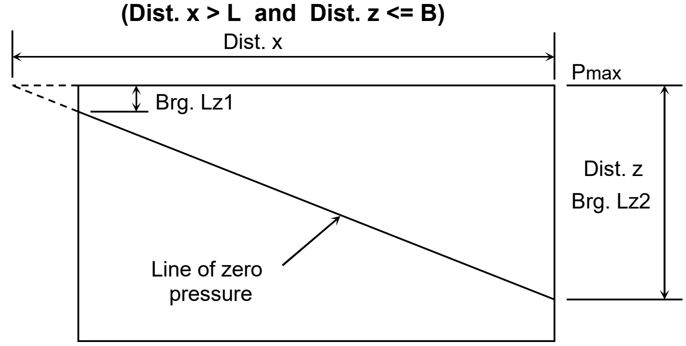
FS (float) =	8.81	> 1.5	OK

Nomenclature for Biaxial Eccentricity:

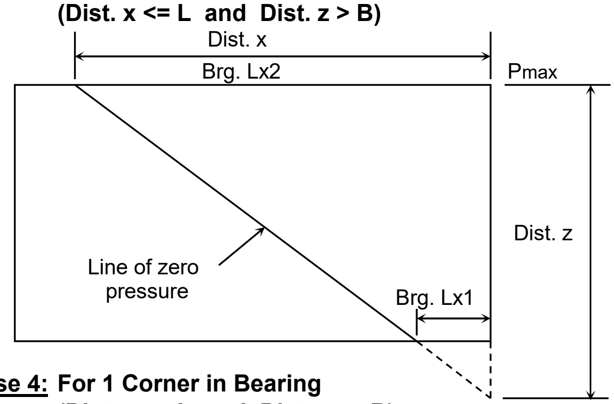
Case 1: For 3 Corners in Bearing
(Dist. x > L and Dist. z > B)



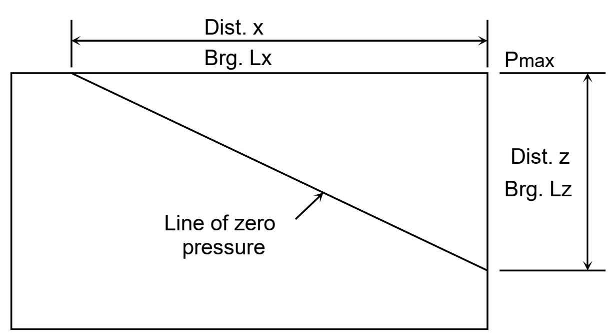
Case 2: For 2 Corners in Bearing
(Dist. x > L and Dist. z <= B)



Case 3: For 2 Corners in Bearing
(Dist. x <= L and Dist. z > B)



Case 4: For 1 Corner in Bearing
(Dist. x <= L and Dist. z <= B)



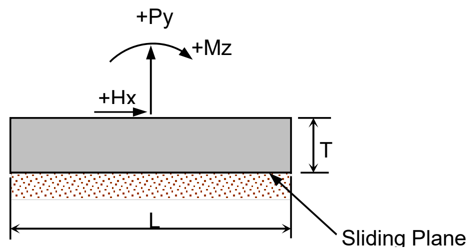
INTAKE TOWER STABILITY ANALYSIS

Job Name:	Springbank Off-Stream Storage Project (SR-1)	Number:	110773396
Site:	Intake Structure	Originator:	CG 7/2/2020 Checker: ACG
Load Case:	2 Empty Reservoir, Summer		

Input Data:

Footing Data:

Footing Length, L =	7.90	m
Footing Width, B =	6.30	m
Footing Thickness, T =	0.00	m
Coef. of Base Friction, μ =	0.42	
Allowable Bearing, Pall =	200.00	kPa

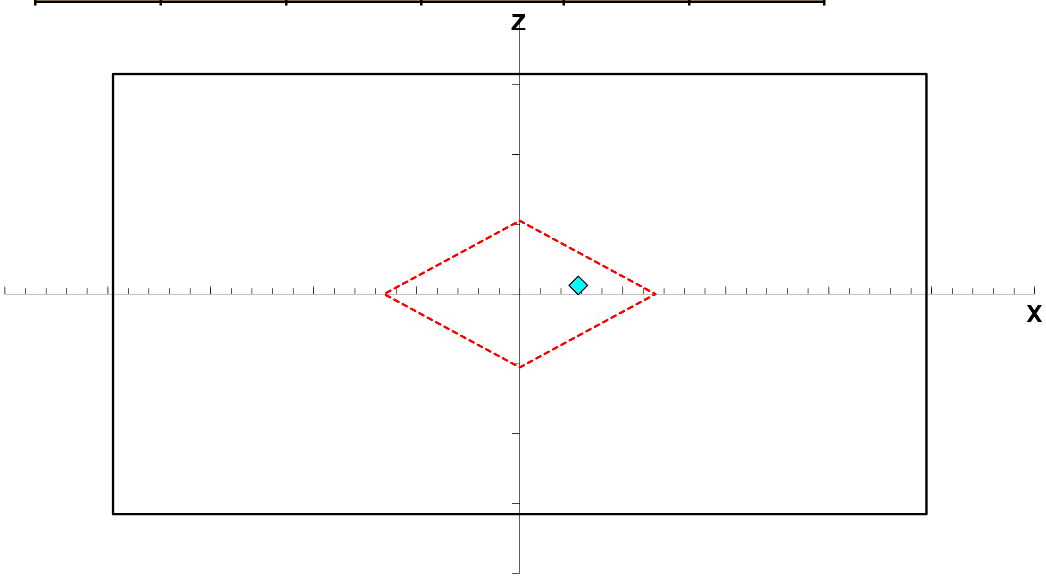


Nomenclature

Loading Data:

Direction of Wind Force: COMBINED

	Uplift	Wind		Snow	Dead	Soil
Xp (m.) =						
Zp (m.) =						
Py (kN) =	553.10	0.00			-4357.34	-452.10
Hx (kN) =		87.90			0.00	-158.40
Hz (kN) =		78.50			0.00	0.00
Mx (kN-m) =		-498.40			0.00	0.40
Mz (kN-m) =		672.50			904.50	857.80



FOOTING PLAN

Note: Is the "Kern" area of footing (When resultant of loads falls within "Kern", entire footing base is in bearing.)

Results:

Total Resultant Load and Eccentricities:

ΣPy =	-4256.34	kN
ex =	0.57	m (<= L/6)
ez =	0.12	m (<= B/6)
ΣHx =	-70.50	kN
ΣHz =	78.50	kN
H resultant =	105.51	kN
ΣMrx =	15149.74	kN-m
ΣMox =	-2240.27	kN-m
ΣMry =	18997.29	kN-m
ΣMoy =	4619.55	kN-m

Sliding Check:

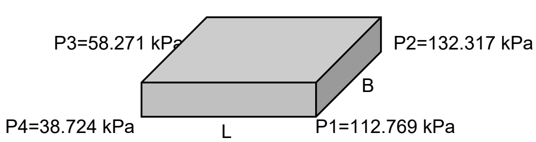
Frict =	1787.66	kN
FS(slid) =	16.943	

% Base Area in Compression:

Dist. x =	N.A.	m
Dist. z =	N.A.	m
Brg. Lx =	7.900	m
Brg. Lz =	6.300	m
%Brg. Area =	100.00	%
Biaxial Case =	N.A.	6*ex/L + 6*ez/B = 0.547

Gross Soil Bearing Corner Pressures:

P_1 =	112.769	kPa
P_2 =	132.317	kPa
P_3 =	58.271	kPa
P_4 =	38.724	kPa



CORNER PRESSURES

Summary of Results:

Sliding Check:

FS(slid) =	16.94	> 1.5	OK

Bearing Area Check:

%Brg. Area =	100.00%	< 100%	OK

Bearing Pressure Check:

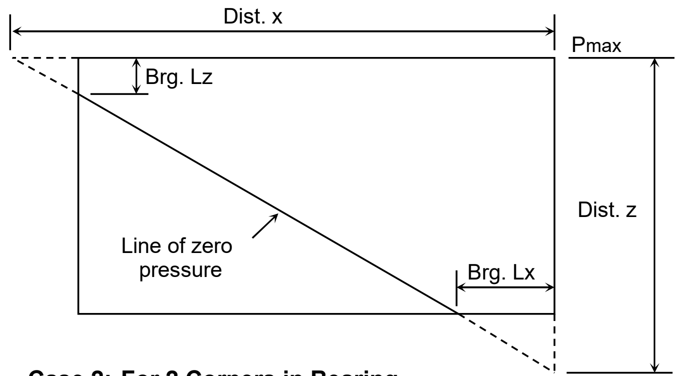
FS(brg) =	1.51	> 1.0	OK

Flotation Check:

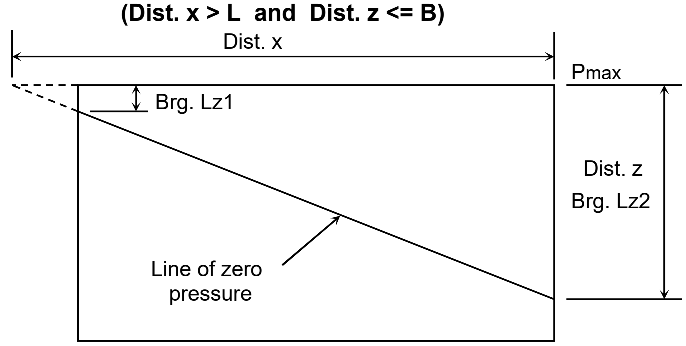
FS (float) =	8.70	> 1.5	OK

Nomenclature for Biaxial Eccentricity:

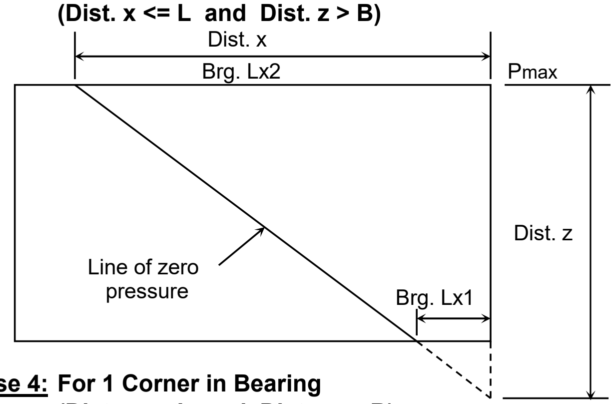
Case 1: For 3 Corners in Bearing (Dist. x > L and Dist. z > B)



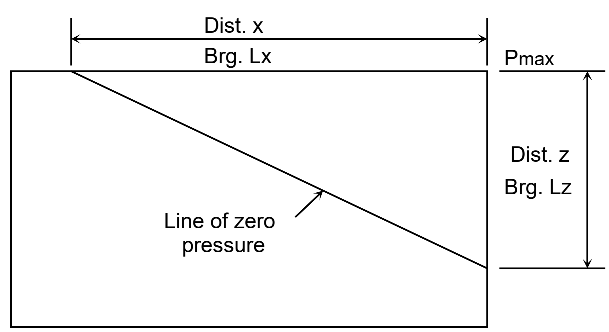
Case 2: For 2 Corners in Bearing (Dist. x > L and Dist. z <= B)



Case 3: For 2 Corners in Bearing (Dist. x <= L and Dist. z > B)



Case 4: For 1 Corner in Bearing (Dist. x <= L and Dist. z <= B)



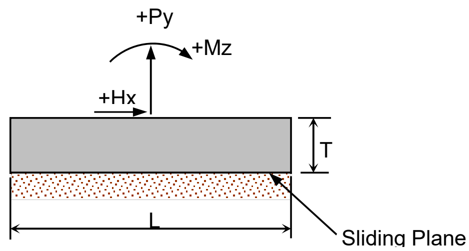
INTAKE TOWER STABILITY ANALYSIS

Job Name:	Springbank Off-Stream Storage Project (SR-1)	Number:	110773396			
Site:	Intake Structure	Originator:	CG	7/2/2020	Checker:	ACG
Load Case:	3 Construction					

Input Data:

Footing Data:

Footing Length, L =	7.90	m
Footing Width, B =	6.30	m
Footing Thickness, T =	0.00	m
Coef. of Base Friction, µ =	0.42	
Allowable Bearing, Pall =	200.00	kPa

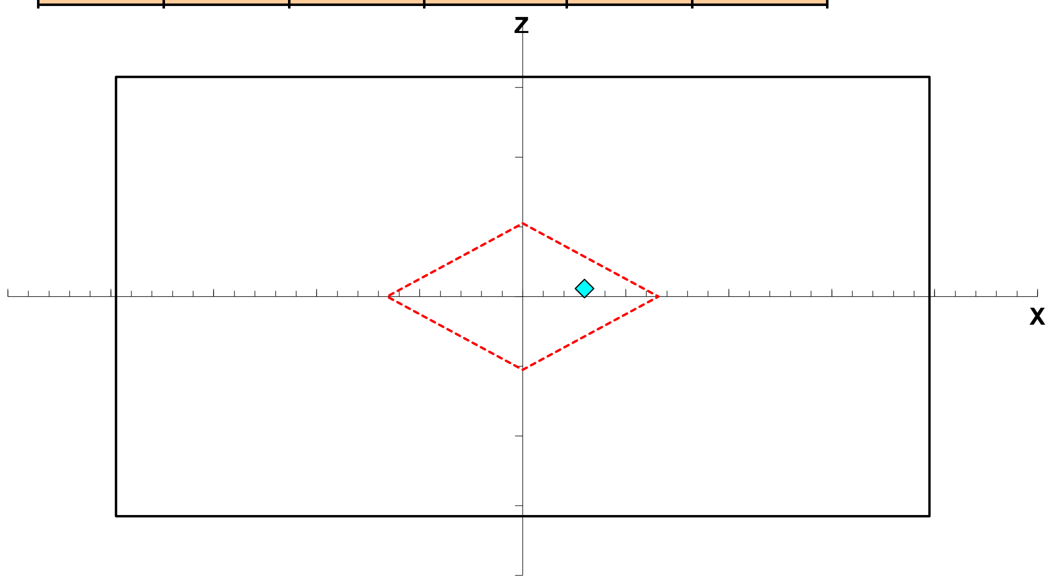


Nomenclature

Loading Data:

Direction of Wind Force: COMBINED

	Uplift	Wind		Surcharge	Dead	Soil
Xp (m.) =						
Zp (m.) =						
Py (kN) =	553.10	0.00		**-281.20**	-4357.34	-452.10
Hx (kN) =		87.90		**-139.80**	0.00	-158.40
Hz (kN) =		78.50		**0.00**	0.00	0.00
Mx (kN-m) =		-498.40		**0.00**	0.00	0.40
Mz (kN-m) =		672.50		**289.40**	904.50	857.80



FOOTING PLAN

Note: Is the "Kern" area of footing (When resultant of loads falls within "Kern", entire footing base is in bearing.)

Results:

Total Resultant Load and Eccentricities:

ΣPy =	-4537.54	kN
ex =	0.60	m (<= L/6)
ez =	0.11	m (<= B/6)
ΣHx =	-210.30	kN
ΣHz =	78.50	kN
H resultant =	224.47	kN
ΣMrx =	16035.52	kN-m
ΣMox =	-2240.27	kN-m
ΣMry =	20108.03	kN-m
ΣMoy =	4908.95	kN-m

Sliding Check:

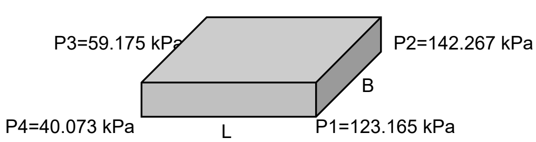
Frict =	1905.77	kN
FS(slid) =	8.490	

% Base Area in Compression:

Dist. x =	N.A.	m
Dist. z =	N.A.	m
Brg. Lx =	7.900	m
Brg. Lz =	6.300	m
%Brg. Area =	100.00	%
Biaxial Case =	N.A.	6*ex/L + 6*ez/B = 0.56

Gross Soil Bearing Corner Pressures:

P_1 =	123.165	kPa
P_2 =	142.267	kPa
P_3 =	59.175	kPa
P_4 =	40.073	kPa



CORNER PRESSURES

Summary of Results:

Sliding Check:

FS(slid) =	8.49	> 1.3	OK

Bearing Area Check:

%Brg. Area =	100.00%	< 100%	OK

Bearing Pressure Check:

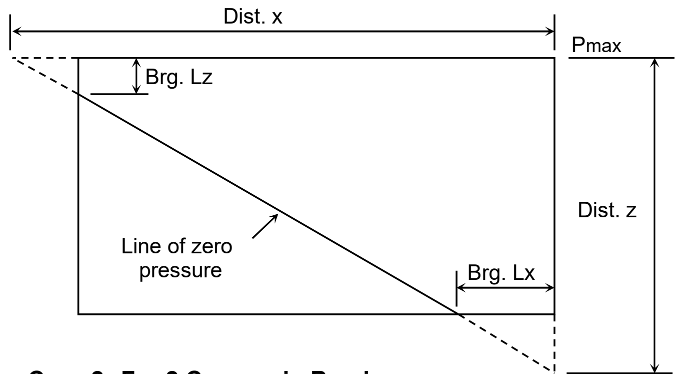
FS(brg) =	1.41	> 1.0	OK

Flotation Check:

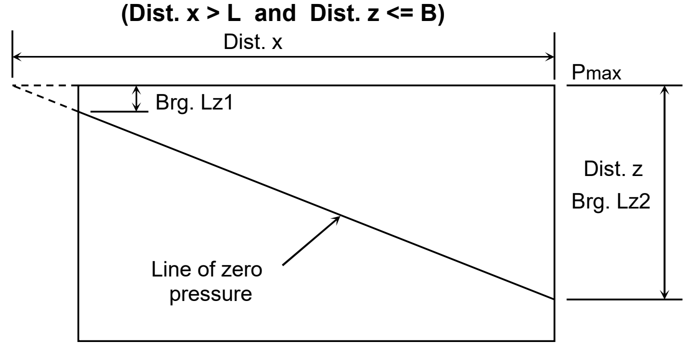
FS (float) =	9.20	> 1.3	OK

Nomenclature for Biaxial Eccentricity:

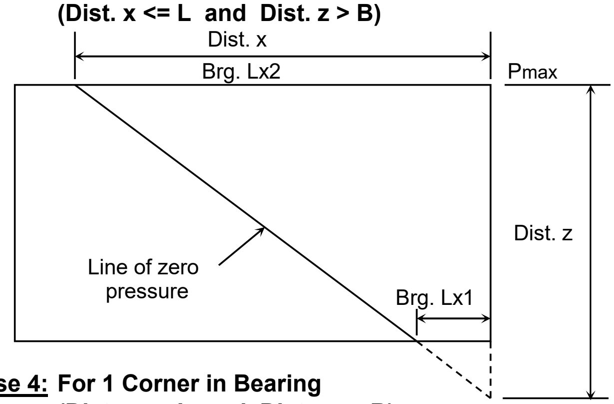
Case 1: For 3 Corners in Bearing
(Dist. x > L and Dist. z > B)



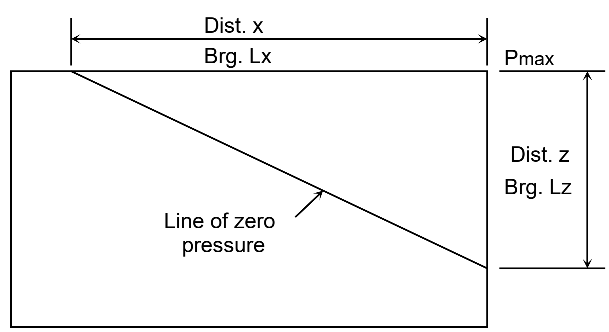
Case 2: For 2 Corners in Bearing
(Dist. x > L and Dist. z <= B)



Case 3: For 2 Corners in Bearing
(Dist. x <= L and Dist. z > B)



Case 4: For 1 Corner in Bearing
(Dist. x <= L and Dist. z <= B)

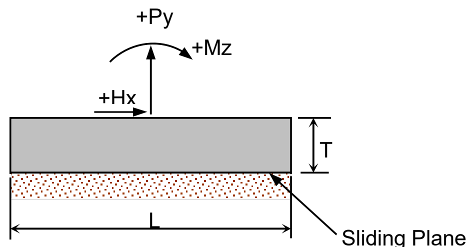


INTAKE TOWER STABILITY ANALYSIS					
Job Name:	Springbank Off-Stream Storage Project (SR-1)	Number:	110773396		
Site:	Intake Structure	Originator:	CG 7/2/2020	Checker:	ACG
Load Case:	4 10-Year Flood				

Input Data:

Footing Data:

Footing Length, L =	7.90	m
Footing Width, B =	6.30	m
Footing Thickness, T =	0.00	m
Coef. of Base Friction, μ =	0.42	
Allowable Bearing, Pall =	200.00	kPa

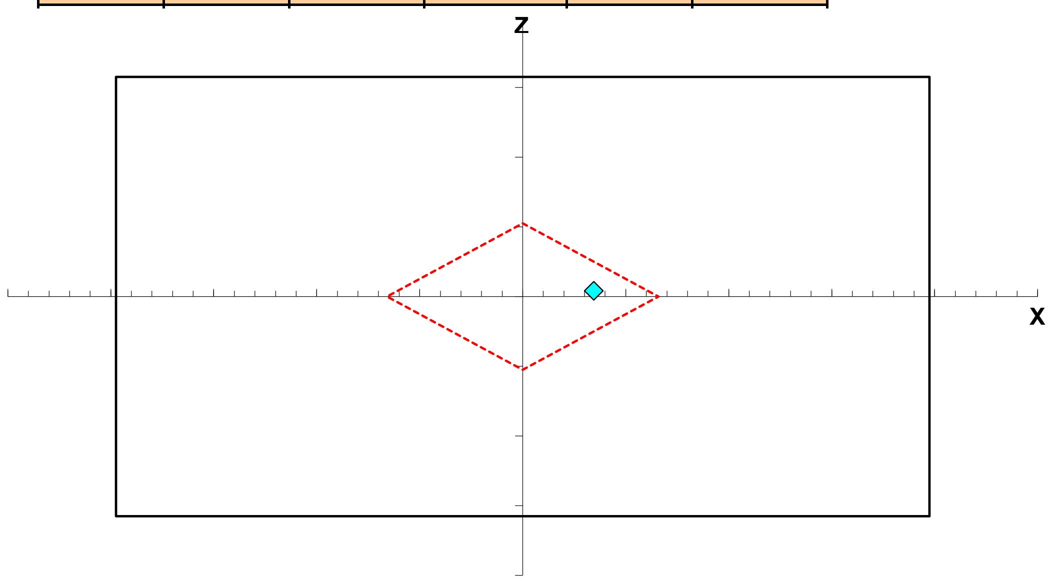


Nomenclature

Loading Data:

Direction of Wind Force: COMBINED

	Uplift	Wind		Water Wt.	Dead	Soil
Xp (m.) =				0.18		
Zp (m.) =						
Py (kN) =	2993.60			-1924.30	-4357.34	-452.10
Hx (kN) =		54.40			0.00	-158.40
Hz (kN) =		34.30			0.00	0.00
Mx (kN-m) =		-308.50			0.00	0.40
Mz (kN-m) =		483.70			904.50	857.80



FOOTING PLAN

Note: Is the "Kern" area of footing (When resultant of loads falls within "Kern", entire footing base is in bearing.)

Results:

Total Resultant Load and Eccentricities:

ΣPy =	-3740.14	kN
ex =	0.69	m (<= L/6)
ez =	0.08	m (<= B/6)
ΣHx =	-104.00	kN
ΣHz =	34.30	kN
H resultant =	109.51	kN
ΣMrx =	21211.28	kN-m
ΣMox =	-9737.94	kN-m
ΣMry =	26251.90	kN-m
ΣMoy =	14070.72	kN-m

Sliding Check:

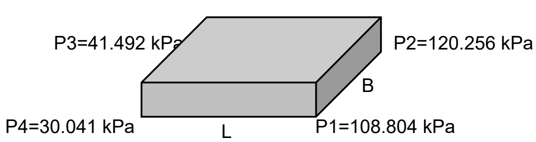
Frict =	1570.86	kN
FS(slid) =	14.344	

% Base Area in Compression:

Dist. x =	N.A.	m
Dist. z =	N.A.	m
Brg. Lx =	7.900	m
Brg. Lz =	6.300	m
%Brg. Area =	100.00	%
Biaxial Case =	N.A.	6*ex/L + 6*ez/B = 0.6

Gross Soil Bearing Corner Pressures:

P_1 =	108.804	kPa
P_2 =	120.256	kPa
P_3 =	41.492	kPa
P_4 =	30.041	kPa



CORNER PRESSURES

Summary of Results:

Sliding Check:

FS(slid) =	14.34	> 1.3	OK

Bearing Area Check:

%Brg. Area =	100.00%	< 100%	OK

Bearing Pressure Check:

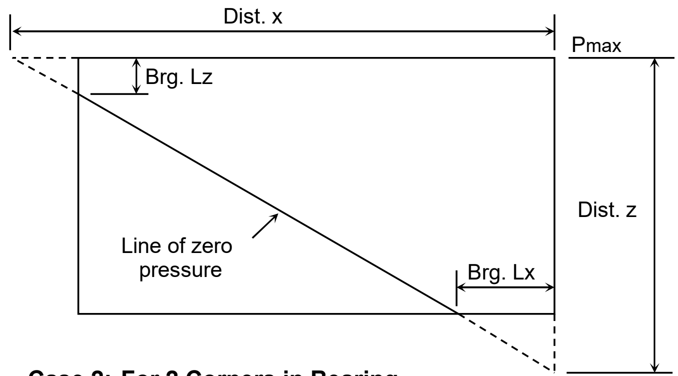
FS(brg) =	1.66	> 1.0	OK

Flotation Check:

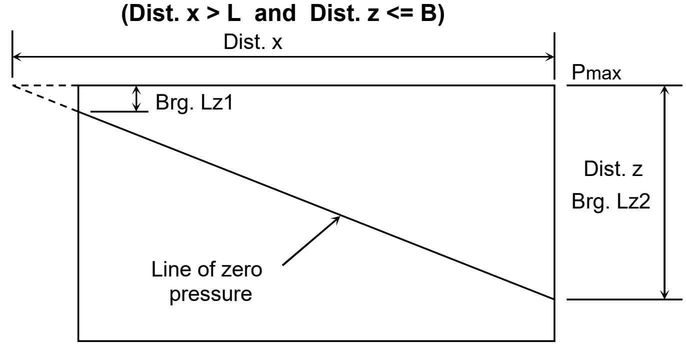
FS (float) =	2.25	> 1.3	OK

Nomenclature for Biaxial Eccentricity:

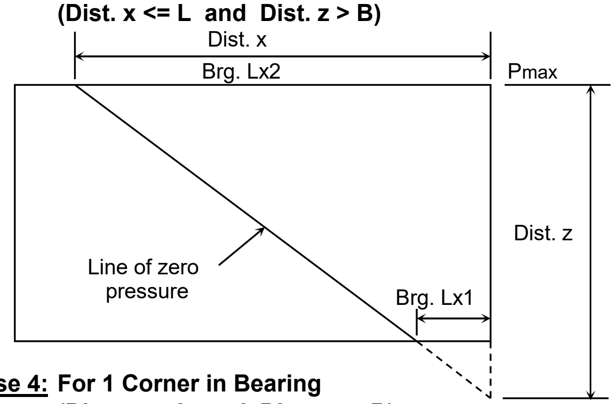
Case 1: For 3 Corners in Bearing (Dist. x > L and Dist. z > B)



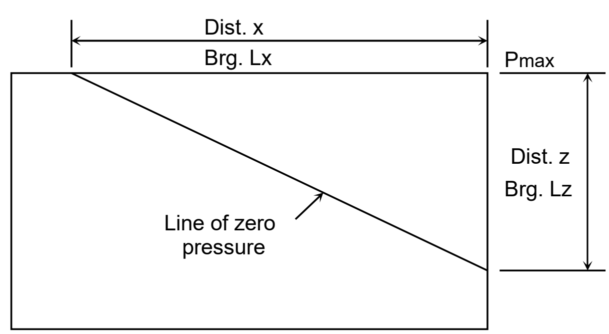
Case 2: For 2 Corners in Bearing (Dist. x > L and Dist. z <= B)



Case 3: For 2 Corners in Bearing (Dist. x <= L and Dist. z > B)



Case 4: For 1 Corner in Bearing (Dist. x <= L and Dist. z <= B)



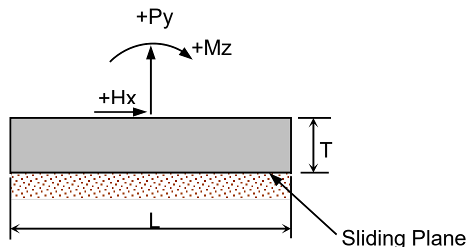
INTAKE TOWER STABILITY ANALYSIS

Job Name:	Springbank Off-Stream Storage Project (SR-1)	Number:	110773396
Site:	Intake Structure	Originator:	CG 7/2/2020 Checker: ACG
Load Case:	5 10-Year Flood + Impact		

Input Data:

Footing Data:

Footing Length, L =	7.90	m
Footing Width, B =	6.30	m
Footing Thickness, T =	0.00	m
Coef. of Base Friction, μ =	0.42	
Allowable Bearing, Pall =	200.00	kPa

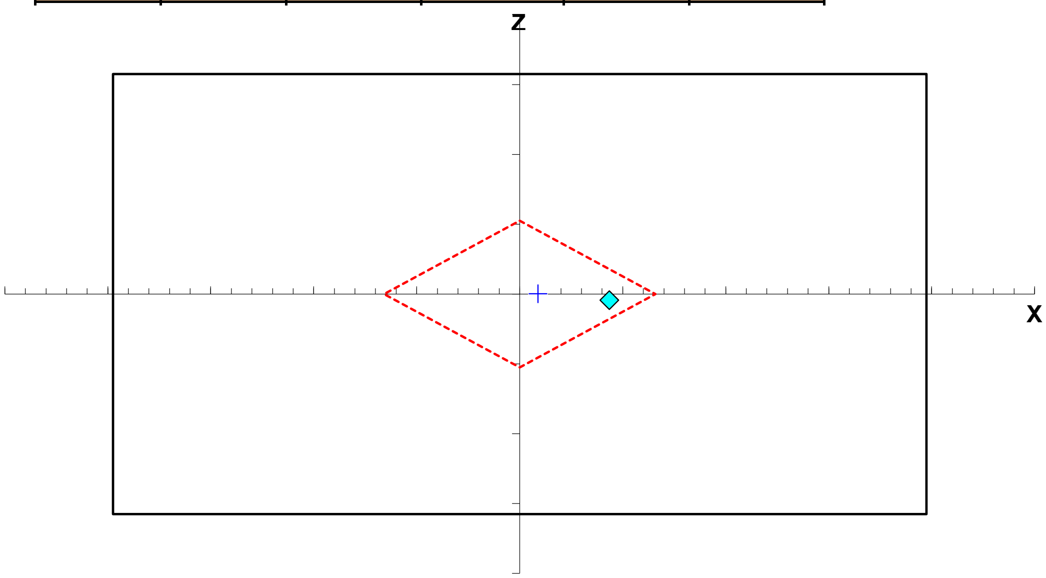


Nomenclature

Loading Data:

Direction of Wind Force: COMBINED

	Uplift	Wind	Impact	Water Wt.	Dead	Soil
Xp (m.) =				0.18		
Zp (m.) =				0.00		
Py (kN) =	2993.60			-1924.30	-4357.34	-452.10
Hx (kN) =		54.40	**-100.00**		0.00	-158.40
Hz (kN) =		34.30	**-100.00**		0.00	0.00
Mx (kN-m) =		-308.50	**643.00**		0.00	0.40
Mz (kN-m) =		483.70	**643.00**		904.50	857.80



FOOTING PLAN

Note: Is the "Kern" area of footing (When resultant of loads falls within "Kern", entire footing base is in bearing.)

Results:

Total Resultant Load and Eccentricities:

ΣPy =	-3740.14	kN
ex =	0.87	m (<= L/6)
ez =	-0.09	m (<= B/6)
ΣHx =	-204.00	kN
ΣHz =	-65.70	kN
H resultant =	214.32	kN
ΣMrx =	21211.28	kN-m
ΣMox =	9764.74	kN-m
ΣMry =	26251.90	kN-m
ΣMoy =	14713.72	kN-m

Sliding Check:

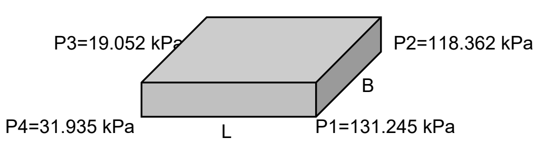
Frict =	1570.86	kN
FS(slid) =	7.330	

% Base Area in Compression:

Dist. x =	N.A.	m
Dist. z =	N.A.	m
Brg. Lx =	7.900	m
Brg. Lz =	6.300	m
%Brg. Area =	100.00	%
Biaxial Case =	N.A.	6*ex/L + 6*ez/B = 0.746

Gross Soil Bearing Corner Pressures:

P1 =	131.245	kPa
P2 =	118.362	kPa
P3 =	19.052	kPa
P4 =	31.935	kPa



CORNER PRESSURES

Summary of Results:

Sliding Check:

FS(slid) =	7.33	> 1.1	OK

Bearing Area Check:

%Brg. Area =	100.00%	> 75%	OK

Bearing Pressure Check:

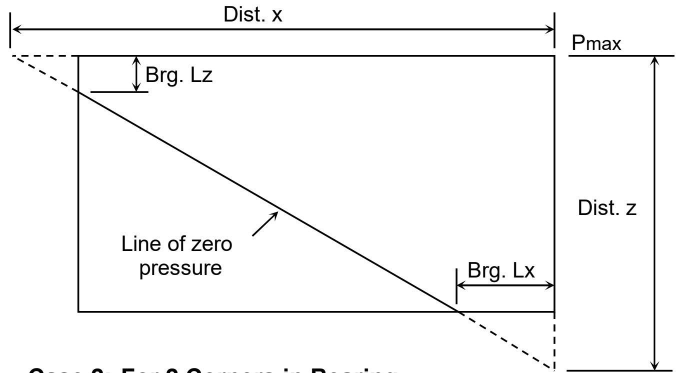
FS(brg) =	1.52	> 1.0	OK

Flotation Check:

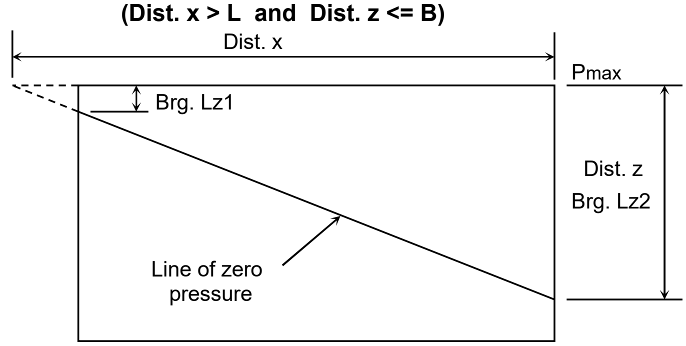
FS (float) =	2.25	> 1.1	OK

Nomenclature for Biaxial Eccentricity:

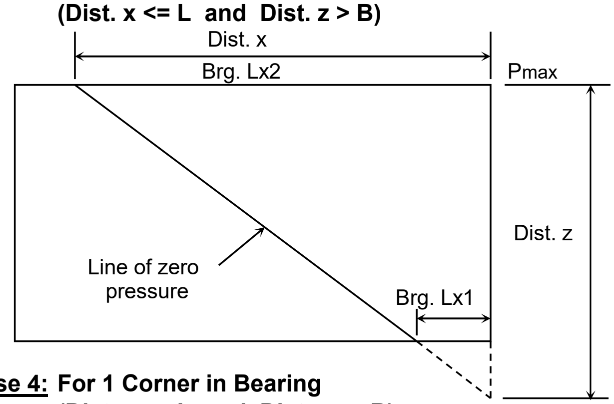
Case 1: **For 3 Corners in Bearing**
(Dist. x > L and Dist. z > B)



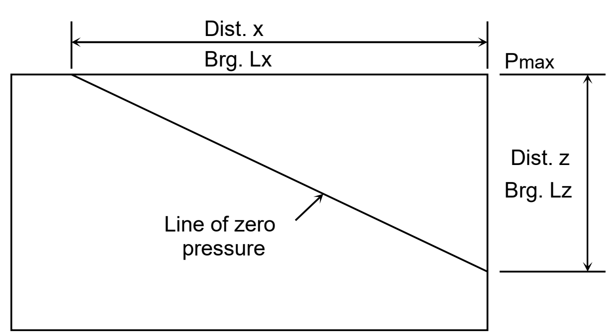
Case 2: **For 2 Corners in Bearing**
(Dist. x > L and Dist. z <= B)



Case 3: **For 2 Corners in Bearing**
(Dist. x <= L and Dist. z > B)



Case 4: **For 1 Corner in Bearing**
(Dist. x <= L and Dist. z <= B)



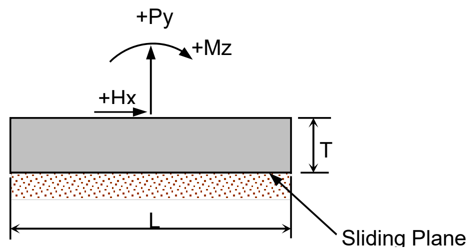
INTAKE TOWER STABILITY ANALYSIS

Job Name:	Springbank Off-Stream Storage Project (SR-1)	Number:	110773396
Site:	Intake Structure	Originator:	CG 7/2/2020 Checker: ACG
Load Case:	6 10-Year Flood + Clogged Trashracks		

Input Data:

Footing Data:

Footing Length, L =	7.90	m
Footing Width, B =	6.30	m
Footing Thickness, T =	0.00	m
Coef. of Base Friction, μ =	0.42	
Allowable Bearing, Pall =	200.00	kPa

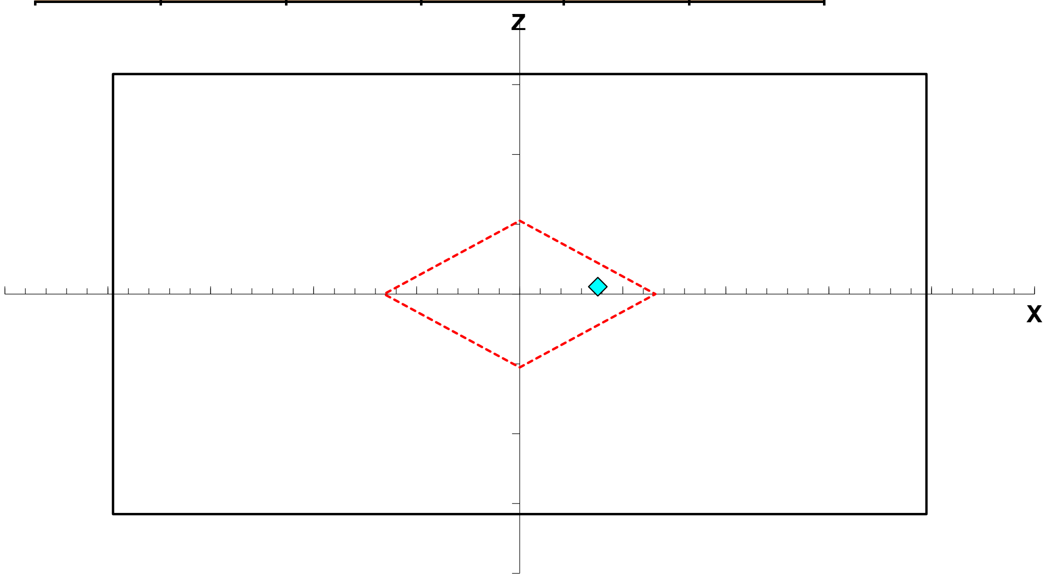


Nomenclature

Loading Data:

Direction of Wind Force: COMBINED

	Uplift	Wind	Impact	Water Wt.	Dead	Soil
Xp (m.) =				**0.04**		
Zp (m.) =						
Py (kN) =	2993.60			**-1218.70**	-4357.34	-452.10
Hx (kN) =		54.40			0.00	-158.40
Hz (kN) =		34.30			0.00	0.00
Mx (kN-m) =		-308.50			0.00	0.40
Mz (kN-m) =		483.70			904.50	857.80



FOOTING PLAN

Note: Is the "Kern" area of footing (When resultant of loads falls within "Kern", entire footing base is in bearing.)

Results:

Total Resultant Load and Eccentricities:

ΣPy =	-3034.54	kN
ex =	0.76	m (<= L/6)
ez =	0.10	m (<= B/6)
ΣHx =	-104.00	kN
ΣHz =	34.30	kN
H resultant =	109.51	kN
ΣMrx =	18988.64	kN-m
ΣMox =	-9737.94	kN-m
ΣMry =	23762.41	kN-m
ΣMoy =	14070.72	kN-m

Sliding Check:

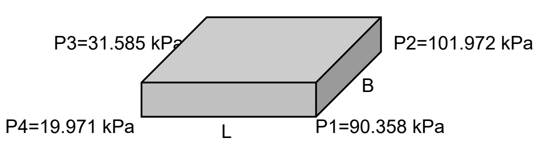
Frict =	1274.51	kN
FS(slid) =	11.638	

% Base Area in Compression:

Dist. x =	N.A.	m
Dist. z =	N.A.	m
Brg. Lx =	7.900	m
Brg. Lz =	6.300	m
%Brg. Area =	100.00	%
Biaxial Case =	N.A.	6*ex/L + 6*ez/B = 0.672

Gross Soil Bearing Corner Pressures:

P_1 =	90.358	kPa
P_2 =	101.972	kPa
P_3 =	31.585	kPa
P_4 =	19.971	kPa



CORNER PRESSURES

Summary of Results:

Sliding Check:

FS(slid) = **11.64** > 1.3 OK

Bearing Area Check:

%Brg. Area = **100.00%** < 100% OK

Bearing Pressure Check:

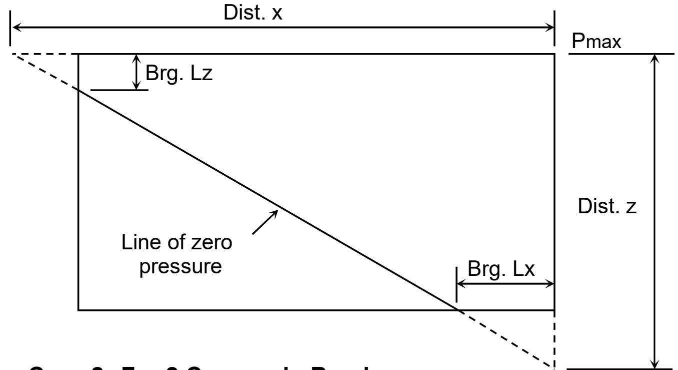
FS(brg) = **1.96** > 1.0 OK

Flotation Check:

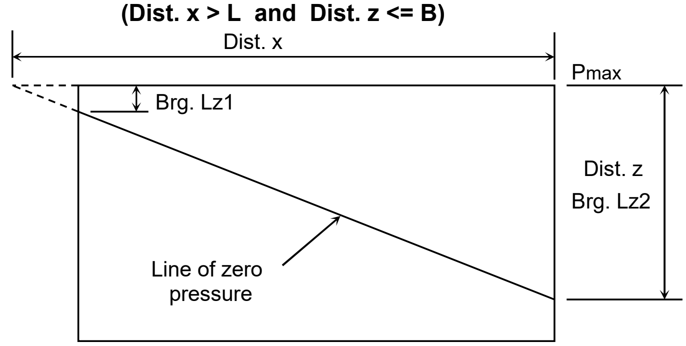
FS (float) = **2.01** > 1.3 OK

Nomenclature for Biaxial Eccentricity:

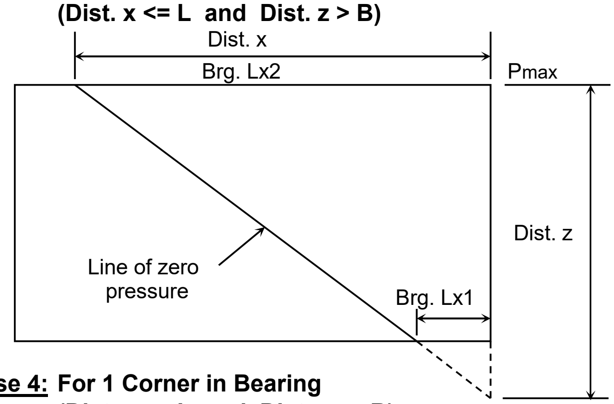
Case 1: For 3 Corners in Bearing (Dist. x > L and Dist. z > B)



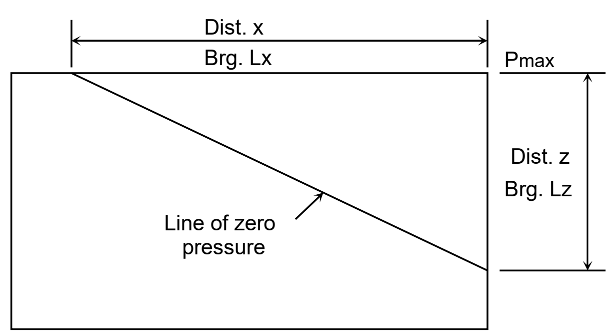
Case 2: For 2 Corners in Bearing (Dist. x > L and Dist. z <= B)



Case 3: For 2 Corners in Bearing (Dist. x <= L and Dist. z > B)



Case 4: For 1 Corner in Bearing (Dist. x <= L and Dist. z <= B)



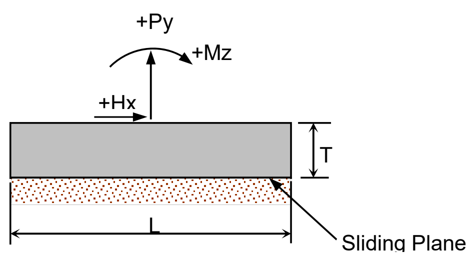
INTAKE TOWER STABILITY ANALYSIS

Job Name:	Springbank Off-Stream Storage Project (SR-1)	Number:	110773396
Site:	Intake Structure	Originator:	CG 7/2/2020 Checker: ACG
Load Case:	7 Maximum Pool		

Input Data:

Footing Data:

Footing Length, L =	7.90	m
Footing Width, B =	6.30	m
Footing Thickness, T =	0.00	m
Coef. of Base Friction, μ =	0.42	
Allowable Bearing, Pall =	200.00	kPa

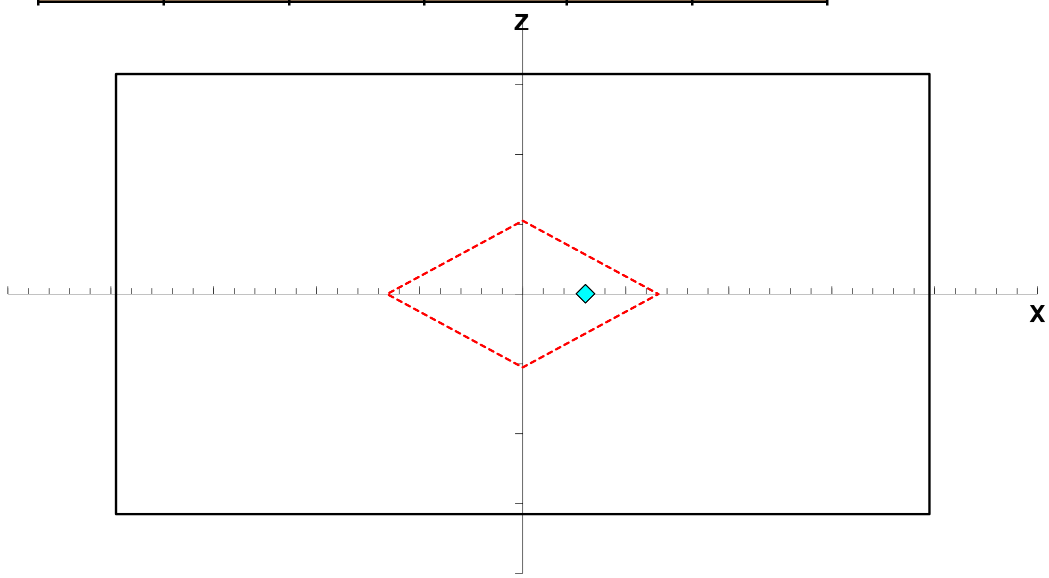


Nomenclature

Loading Data:

Direction of Wind Force: COMBINED

	Uplift	Wind	Impact	Water Wt.	Dead	Soil
Xp (m.) =				0.03		
Zp (m.) =						
Py (kN) =	13487.60			-12180.60	-4357.34	-452.10
Hx (kN) =					0.00	-158.40
Hz (kN) =					0.00	0.00
Mx (kN-m) =					0.00	0.40
Mz (kN-m) =					904.50	857.80



FOOTING PLAN

Note: Is the "Kern" area of footing (When resultant of loads falls within "Kern", entire footing base is in bearing.)

Results:

Total Resultant Load and Eccentricities:

ΣPy =	-3502.44	kN
ex =	0.61	m (<= L/6)
ez =	0.00	
ΣHx =	-158.40	kN
ΣHz =	0.00	kN
H resultant =	158.40	kN
ΣMrx =	N.A.	kN-m
ΣMox =	N.A.	kN-m
ΣMry =	66745.24	kN-m
ΣMoy =	55038.32	kN-m

Sliding Check:

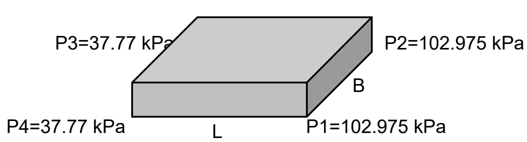
Frict =	1471.02	kN
FS(slid) =	9.287	

% Base Area in Compression:

Dist. x =	N.A.	m
Dist. z =	N.A.	m
Brg. Lx =	7.900	m
Brg. Lz =	6.300	m
%Brg. Area =	100.00	%
Biaxial Case =	N.A.	

Gross Soil Bearing Corner Pressures:

P_1 =	102.975	kPa
P_2 =	102.975	kPa
P_3 =	37.770	kPa
P_4 =	37.770	kPa



CORNER PRESSURES

Summary of Results:

Sliding Check:

FS(slid) =	**9.29**	> 1.1	OK

Bearing Area Check:

%Brg. Area =	**100.00%**	> 75%	OK

Bearing Pressure Check:

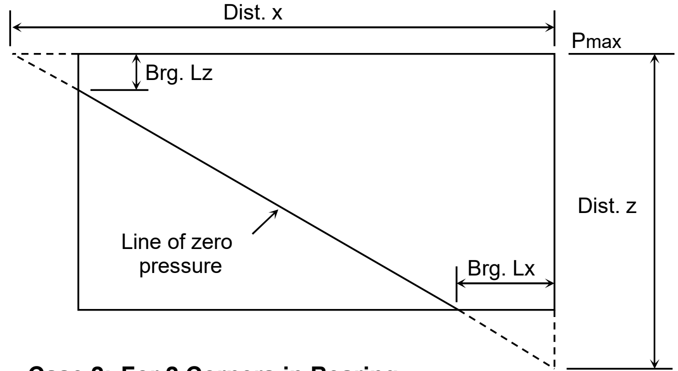
FS(brg) =	**1.94**	> 1.0	OK

Flotation Check:

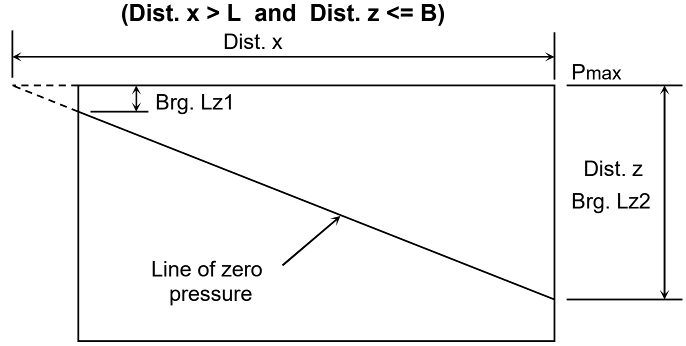
FS (float) =	**1.26**	> 1.1	OK

Nomenclature for Biaxial Eccentricity:

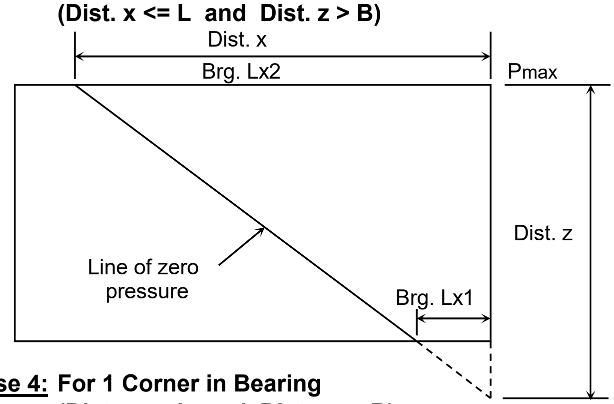
Case 1: For 3 Corners in Bearing (Dist. x > L and Dist. z > B)



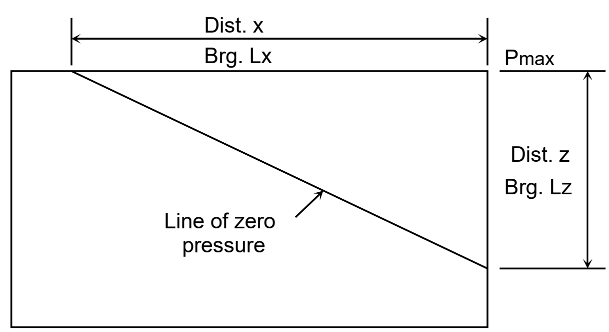
Case 2: For 2 Corners in Bearing (Dist. x > L and Dist. z <= B)



Case 3: For 2 Corners in Bearing (Dist. x <= L and Dist. z > B)



Case 4: For 1 Corner in Bearing (Dist. x <= L and Dist. z <= B)



INTAKE TOWER SEISMIC STABILITY ANALYSIS SUMMARY

Job Name:	Springbank Off-Stream Storage Project	Number:	110773396
Site:	Intake Structure	Originator:	CG 7/2/2020

Results Summary:

SR-1 - Summary of Intake Structure Static Stability Assessment								
Load Case	**Sliding Stability Safety Factor**		**Base Area in Compression(1)**		**Bearing Pressures (kPa)**		**Flotation**	
	Max	**Min**	**Max**	**Min**	**Max Calc.**	**Min Calc.**	**Max**	**Min**
Earthquake	3.4	1.0	100%	51%	450.0	198.7	10.8	9.3
Post-Earthquake (3)	17		100%		326.0		8.7	

(1)- 100% base compression = resultant within the middle 1/3
75% base compression = resultant within the middle 1/2
>0% base compression = resultant within the base
(2)- See Criteria Below for Post-Earthquake Load Case.

Acceptance Criteria				
Load Case	**Sliding Stability Safety Factor**	**Base Area in Compression(1)**	**Bearing Pressures (kPa)**	**Flotation**
Earthquake	N/A			
Post Earthquake	1.1	Within Base	450.0	1.1

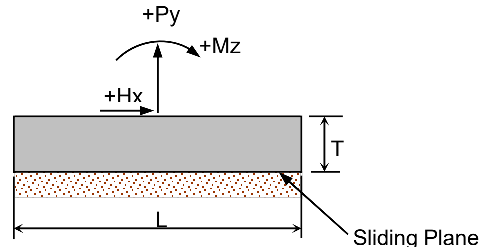
INTAKE TOWER STABILITY ANALYSIS

Job Name:	Springbank Off-Stream Storage Project (SR-1)	Number:	110773396
Site:	Intake Structure	Originator:	CG 7/2/2020 Checker: ACG
Load Case:	E1 Earthquake		

Input Data:

Footing Data:

Footing Length, L =	7.90	m
Footing Width, B =	6.30	m
Footing Thickness, T =	0.00	m
Coef. of Base Friction, μ =	0.420	
Ultimate Bearing, Pall =	450.0	kPa

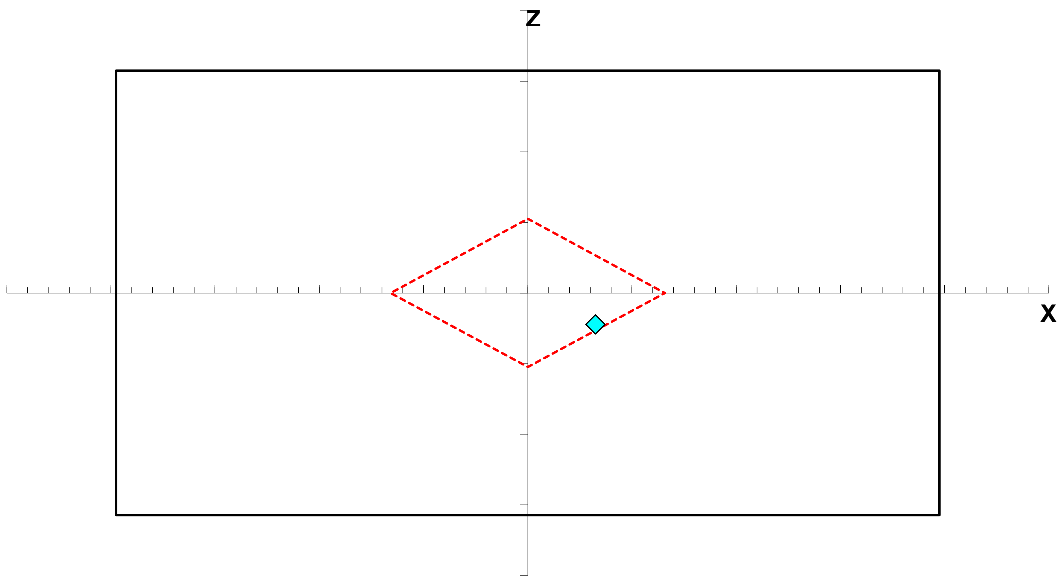


Nomenclature

Loading Data:

Direction of Seismic Force: COMBINED

	Uplift	Wind		EQ	Dead	Soil
Xp (m.) =						
Zp (m.) =						
Py (kN) =	553.10			-1139.19	-4357.34	-452.10
Hx (kN) =		87.90		193.34		-158.40
Hz (kN) =		78.50		567.21		0.00
Mx (kN-m) =		-498.40		2928.89	0.00	0.40
Mz (kN-m) =		672.50		1052.87	904.50	857.80



FOOTING PLAN

Note: Is the "Kern" area of footing (When resultant of loads falls within "Kern", entire footing base is in bearing.)

Results:

Total Resultant Load and Eccentricities:

ΣPy =	-5395.53	kN
ex =	0.65	m (<= L/6)
ez =	-0.45	m (<= B/6)
ΣHx =	122.84	kN
ΣHz =	645.71	kN
H resultant =	657.29	kN
ΣMrx =	18738.19	kN-m
ΣMox =	4173.15	kN-m
ΣMry =	23497.09	kN-m
ΣMoy =	5672.41	kN-m

Sliding Check:

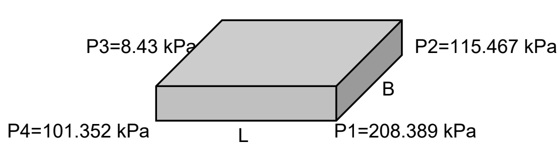
Frict =	2266.12	kN
FS(slid) =	3.448	

% Base Area in Compression:

Dist. x =	N.A.	m
Dist. z =	N.A.	m
Brg. Lx =	7.900	m
Brg. Lz =	6.300	m
%Brg. Area =	100.00	%
Biaxial Case =	N.A.	6*ex/L + 6*ez/B = 0.922

Gross Soil Bearing Corner Pressures:

P_1 =	208.389	kPa
P_2 =	115.467	kPa
P_3 =	8.430	kPa
P_4 =	101.352	kPa



CORNER PRESSURES

Summary of Results:

Sliding Check:

FS(slid) = **3.45** >1 OK

Bearing Area Check:

%Brg. Area = **100.00%** >1% OK

Bearing Pressure Check:

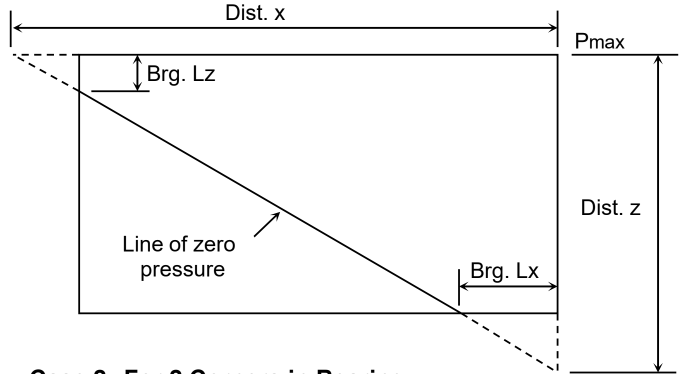
FS(brg) = **2.16** >1 OK

Flotation Check:

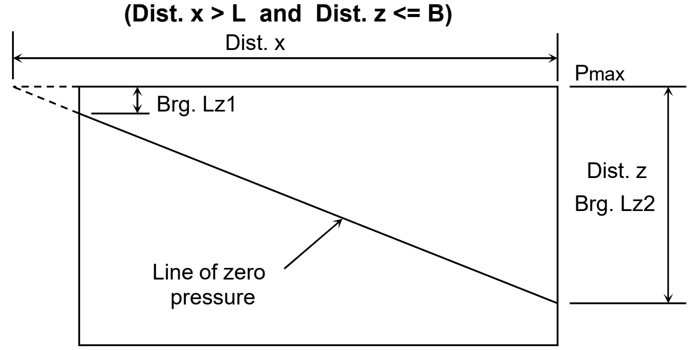
FS (float) = **10.76** >1 OK

Nomenclature for Biaxial Eccentricity:

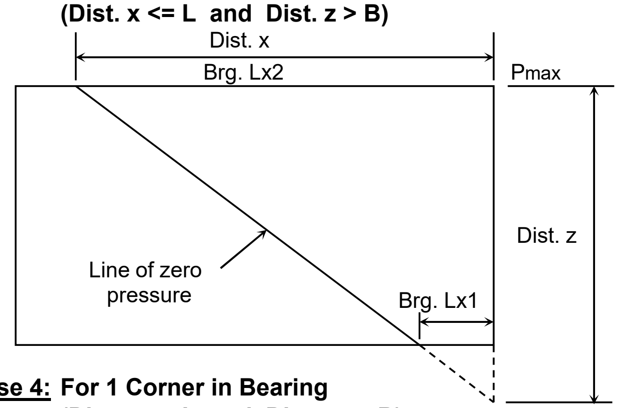
Case 1: For 3 Corners in Bearing
(Dist. x > L and Dist. z > B)



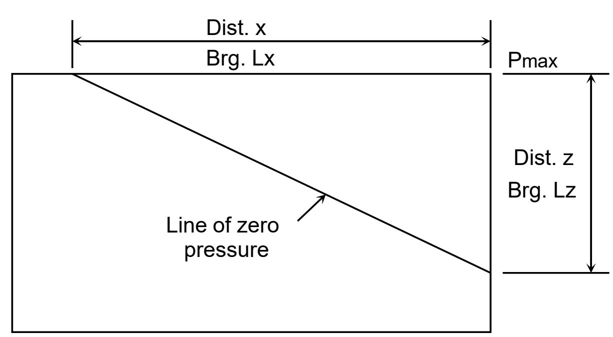
Case 2: For 2 Corners in Bearing
(Dist. x > L and Dist. z <= B)



Case 3: For 2 Corners in Bearing
(Dist. x <= L and Dist. z > B)



Case 4: For 1 Corner in Bearing
(Dist. x <= L and Dist. z <= B)



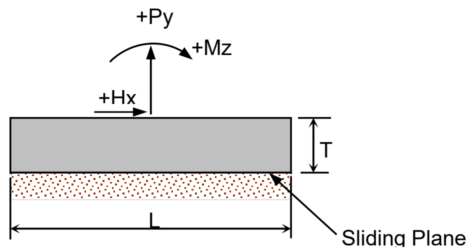
INTAKE TOWER STABILITY ANALYSIS

Job Name:	Springbank Off-Stream Storage Project (SR-1)	Number:	110773396		
Site:	Intake Structure	Originator:	CG	7/2/2020	Checker: ACG
Load Case:	E2 Earthquake				

Input Data:

Footing Data:

Footing Length, L =	7.90	m
Footing Width, B =	6.30	m
Footing Thickness, T =	0.00	m
Coef. of Base Friction, μ =	0.42	
Ultimate Bearing, Pall =	450.00	kPa

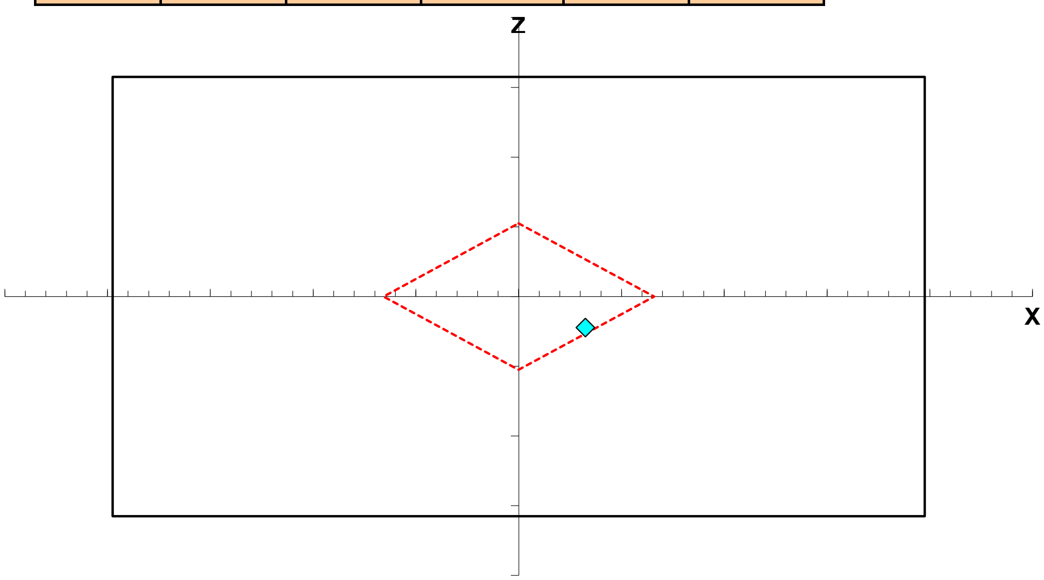


Nomenclature

Loading Data:

Direction of Seismic Force: COMBINED

	Uplift	Wind		EQ	Dead	Soil
Xp (m.) =						
Zp (m.) =						
Py (kN) =	553.10	0.00		-1139.19	-4357.34	-452.10
Hx (kN) =		87.90		193.34	0.00	-158.40
Hz (kN) =		78.50		567.21	0.00	0.00
Mx (kN-m) =		-498.40		2928.89	0.00	0.40
Mz (kN-m) =		672.50		1052.87	904.50	857.80



FOOTING PLAN

Note: Is the "Kern" area of footing (When resultant of loads falls within "Kern", entire footing base is in bearing.)

Results:

Total Resultant Load and Eccentricities:

ΣPy =	-5395.53	kN
ex =	0.65	m (<= L/6)
ez =	-0.45	m (<= B/6)
ΣHx =	122.84	kN
ΣHz =	645.71	kN
H resultant =	657.29	kN
ΣMrx =	18738.19	kN-m
ΣMox =	4173.15	kN-m
ΣMry =	23497.09	kN-m
ΣMoy =	5672.41	kN-m

Sliding Check:

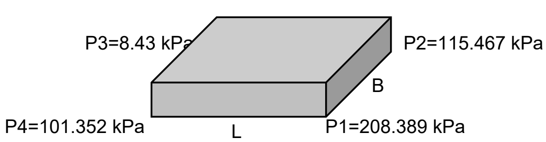
Frict =	2266.12	kN
FS(slid) =	3.448	

% Base Area in Compression:

Dist. x =	N.A.	m
Dist. z =	N.A.	m
Brg. Lx =	7.900	m
Brg. Lz =	6.300	m
%Brg. Area =	100.00	%
Biaxial Case =	N.A.	6*ex/L + 6*ez/B = 0.922

Gross Soil Bearing Corner Pressures:

P1 =	208.389	kPa
P2 =	115.467	kPa
P3 =	8.430	kPa
P4 =	101.352	kPa



CORNER PRESSURES

Summary of Results:

Sliding Check:

FS(slid) =	3.45	>1	OK

Bearing Area Check:

%Brg. Area =	100.00%	>0.001%	OK

Bearing Pressure Check:

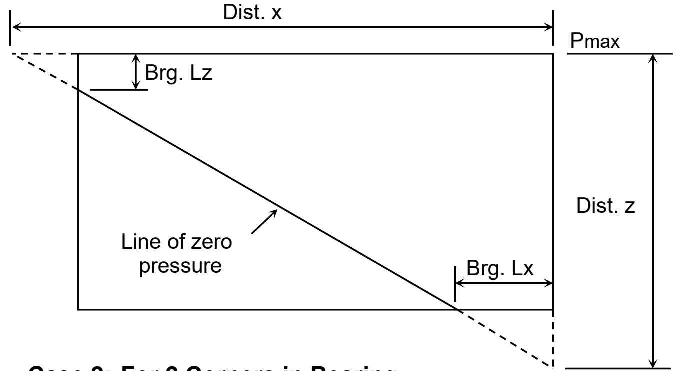
FS(brg) =	2.16	>1	OK

Flotation Check:

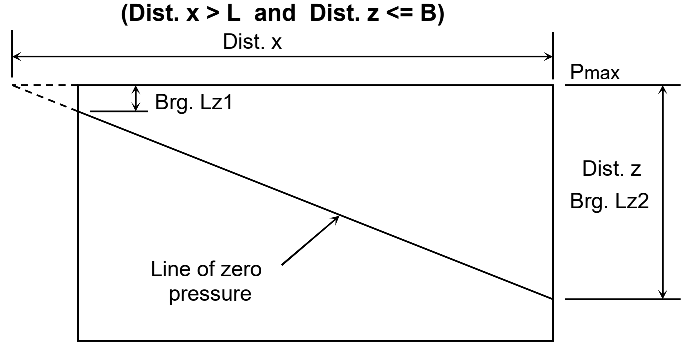
FS (float) =	10.76	>1	OK

Nomenclature for Biaxial Eccentricity:

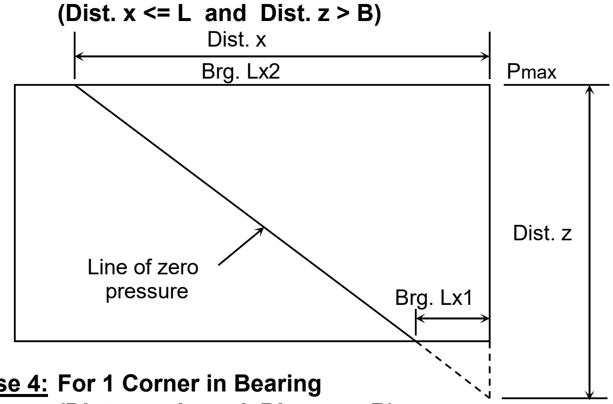
Case 1: For 3 Corners in Bearing
(Dist. x > L and Dist. z > B)



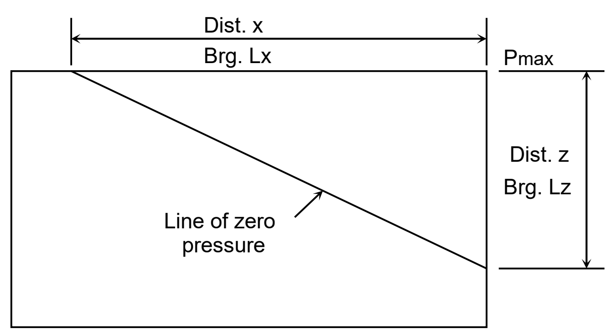
Case 2: For 2 Corners in Bearing
(Dist. x > L and Dist. z <= B)



Case 3: For 2 Corners in Bearing
(Dist. x <= L and Dist. z > B)



Case 4: For 1 Corner in Bearing
(Dist. x <= L and Dist. z <= B)



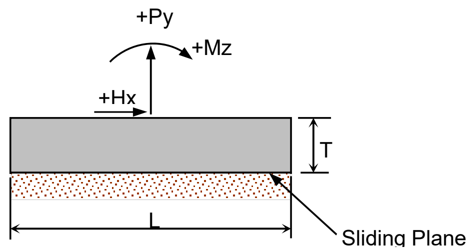
INTAKE TOWER STABILITY ANALYSIS

Job Name:	Springbank Off-Stream Storage Project (SR-1)	Number:	110773396				
Site:	Intake Structure	Originator:	CG	7/2/2020	Checker:	ACG	
Load Case:	E3 Earthquake						

Input Data:

Footing Data:

Footing Length, L =	7.90	m
Footing Width, B =	6.30	m
Footing Thickness, T =	0.00	m
Coef. of Base Friction, μ =	0.42	
Ultimate Bearing, Pall =	450.00	kPa

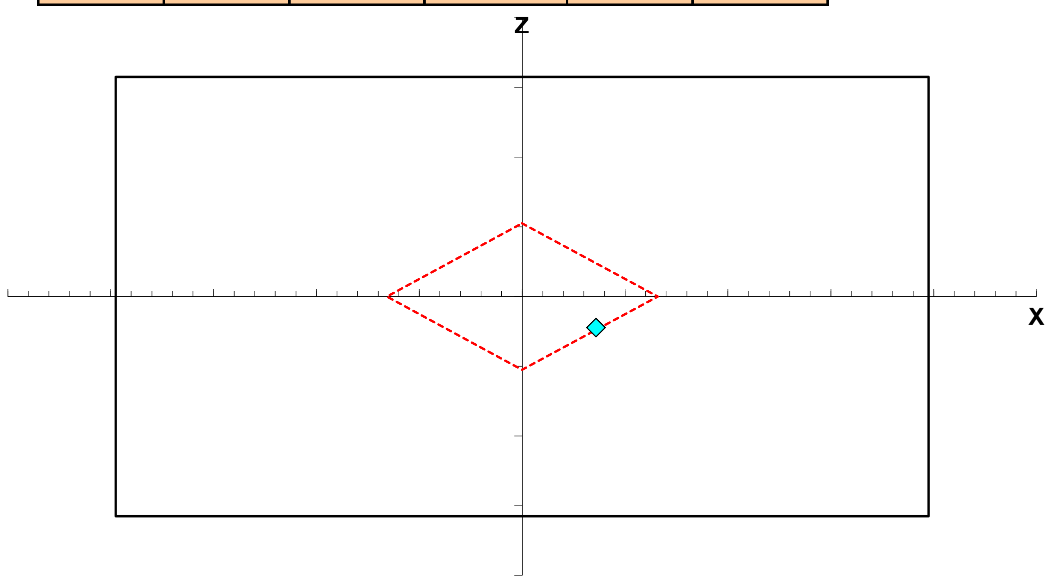


Nomenclature

Loading Data:

Direction of Seismic Force: COMBINED

	Uplift	Wind		EQ	Dead	Soil
Xp (m.) =						
Zp (m.) =						
Py (kN) =	553.10	0.00		-1143.00	-4357.34	-452.10
Hx (kN) =		87.90		223.47	0.00	-158.40
Hz (kN) =		78.50		567.21	0.00	0.00
Mx (kN-m) =		-498.40		2928.89	0.00	0.40
Mz (kN-m) =		672.50		1437.10	904.50	857.80



FOOTING PLAN

Note: Is the "Kern" area of footing (When resultant of loads falls within "Kern", entire footing base is in bearing.)

Results:

Total Resultant Load and Eccentricities:

ΣPy =	-5399.34	kN
ex =	0.72	m (<= L/6)
ez =	-0.45	m (<= B/6)
ΣHx =	152.97	kN
ΣHz =	645.71	kN
H resultant =	663.58	kN
ΣMrx =	18750.17	kN-m
ΣMox =	4173.16	kN-m
ΣMry =	23512.12	kN-m
ΣMoy =	6056.65	kN-m

Sliding Check:

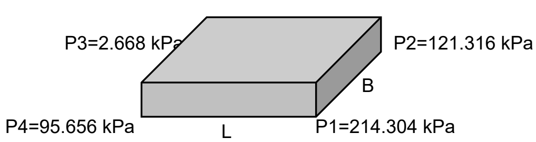
Frict =	2267.72	kN
FS(slid) =	3.417	

% Base Area in Compression:

Dist. x =	N.A.	m
Dist. z =	N.A.	m
Brg. Lx =	7.900	m
Brg. Lz =	6.300	m
%Brg. Area =	100.00	%
Biaxial Case =	N.A.	6*ex/L + 6*ez/B = 0.975

Gross Soil Bearing Corner Pressures:

P_1 =	214.304	kPa
P_2 =	121.316	kPa
P_3 =	2.668	kPa
P_4 =	95.656	kPa



CORNER PRESSURES

Summary of Results:

Sliding Check:

FS(slid) =	3.42	>1	OK

Bearing Area Check:

%Brg. Area =	100.00%	>1%	OK

Bearing Pressure Check:

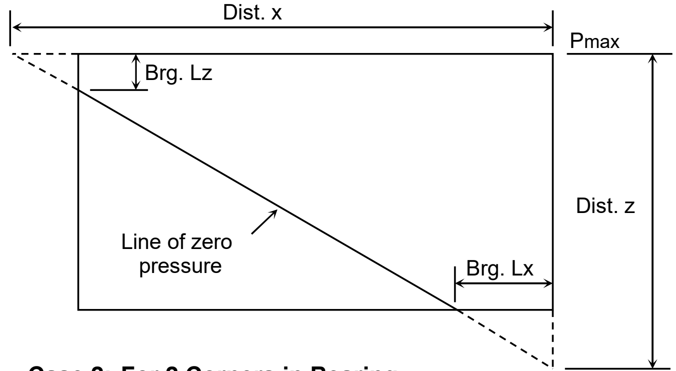
FS(brg) =	2.10	>1	OK

Flotation Check:

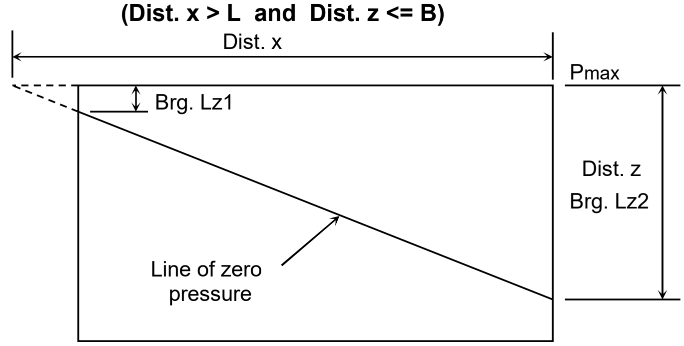
FS (float) =	10.76	>1	OK

Nomenclature for Biaxial Eccentricity:

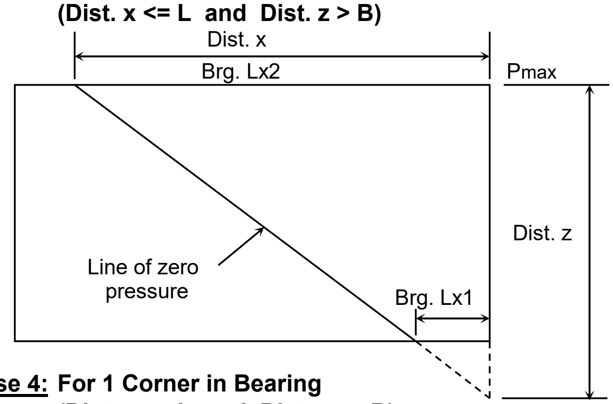
Case 1: For 3 Corners in Bearing (Dist. x > L and Dist. z > B)



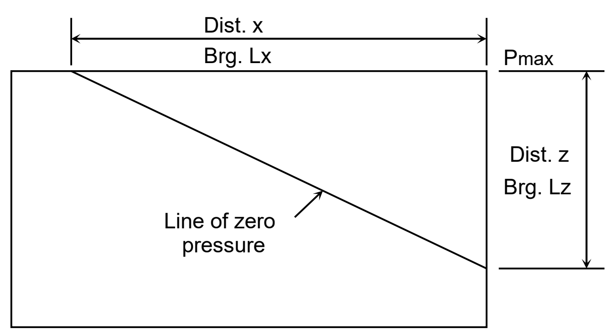
Case 2: For 2 Corners in Bearing (Dist. x > L and Dist. z <= B)



Case 3: For 2 Corners in Bearing (Dist. x <= L and Dist. z > B)



Case 4: For 1 Corner in Bearing (Dist. x <= L and Dist. z <= B)



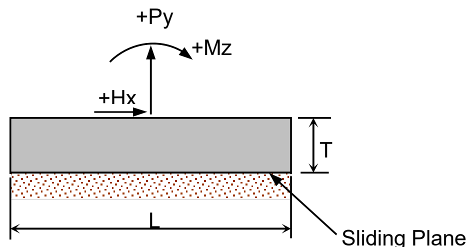
INTAKE TOWER STABILITY ANALYSIS

Job Name:	Springbank Off-Stream Storage Project (SR-1)	Number:	110773396			
Site:	Intake Structure	Originator:	CG	7/2/2020	Checker:	ACG
Load Case:	E4 Earthquake					

Input Data:

Footing Data:

Footing Length, L =	7.90	m
Footing Width, B =	6.30	m
Footing Thickness, T =	0.00	m
Coef. of Base Friction, μ =	0.42	
Ultimate Bearing, Pall =	450.00	kPa

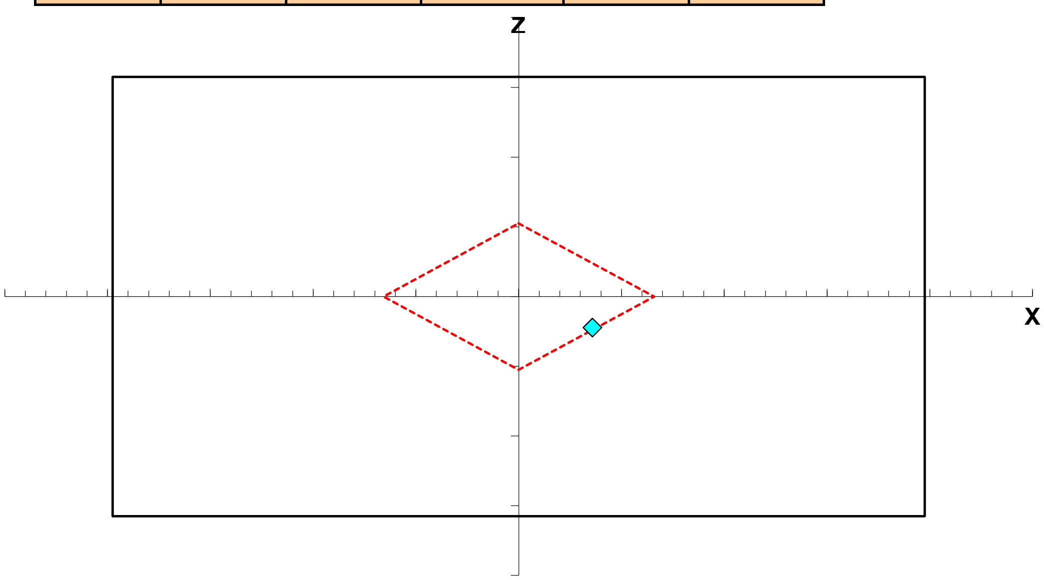


Nomenclature

Loading Data:

Direction of Seismic Force: COMBINED

	Uplift	Wind		EQ	Dead	Soil
Xp (m.) =						
Zp (m.) =						
Py (kN) =	553.10	0.00		-1143.00	-4357.34	-452.10
Hx (kN) =		87.90		223.47	0.00	-158.40
Hz (kN) =		78.50		567.21	0.00	0.00
Mx (kN-m) =		-498.40		2928.89	0.00	0.40
Mz (kN-m) =		672.50		1437.10	904.50	857.80



FOOTING PLAN

Note: Is the "Kern" area of footing (When resultant of loads falls within "Kern", entire footing base is in bearing.)

Results:

Total Resultant Load and Eccentricities:

ΣPy =	-5399.34	kN
ex =	0.72	m (<= L/6)
ez =	-0.45	m (<= B/6)
ΣHx =	152.97	kN
ΣHz =	645.71	kN
H resultant =	663.58	kN
ΣMrx =	18750.17	kN-m
ΣMox =	4173.16	kN-m
ΣMry =	23512.12	kN-m
ΣMoy =	6056.65	kN-m

Sliding Check:

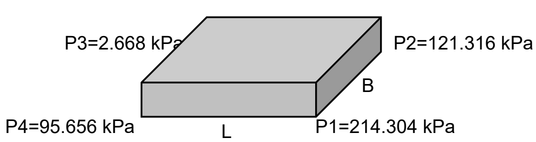
Frict =	2267.72	kN
FS(slid) =	3.417	

% Base Area in Compression:

Dist. x =	N.A.	m
Dist. z =	N.A.	m
Brg. Lx =	7.900	m
Brg. Lz =	6.300	m
%Brg. Area =	100.00	%
Biaxial Case =	N.A.	6*ex/L + 6*ez/B = 0.975

Gross Soil Bearing Corner Pressures:

P_1 =	214.304	kPa
P_2 =	121.316	kPa
P_3 =	2.668	kPa
P_4 =	95.656	kPa



CORNER PRESSURES

Summary of Results:

Sliding Check:

FS(slid) =	3.42	>1	OK

Bearing Area Check:

%Brg. Area =	100.00%	>1%	OK

Bearing Pressure Check:

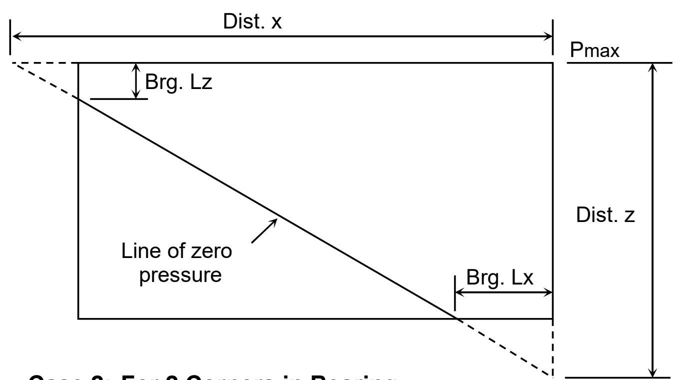
FS(brg) =	2.10	>1	OK

Flotation Check:

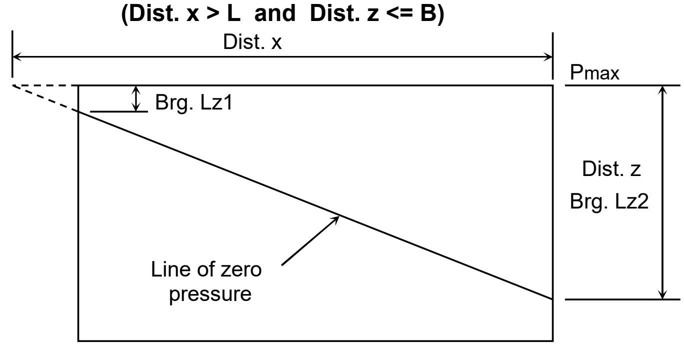
FS (float) =	10.76	>1	OK

Nomenclature for Biaxial Eccentricity:

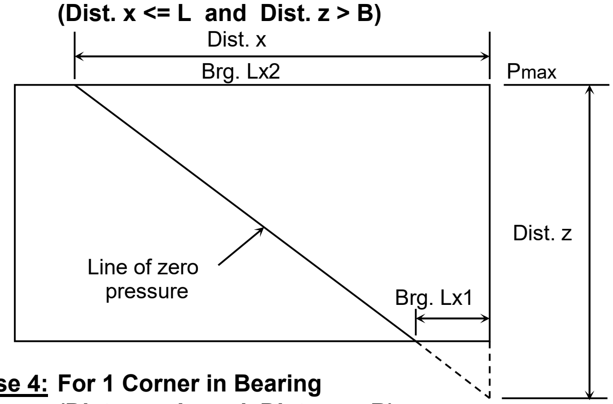
Case 1: For 3 Corners in Bearing
(Dist. x > L and Dist. z > B)



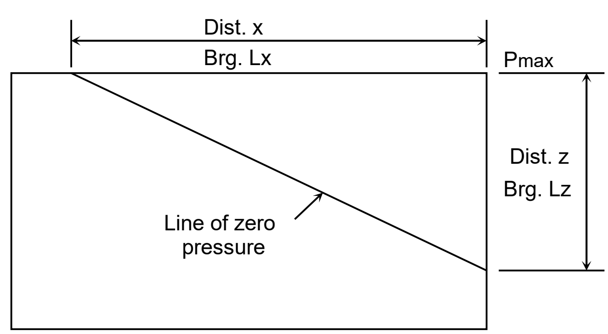
Case 2: For 2 Corners in Bearing
(Dist. x > L and Dist. z <= B)



Case 3: For 2 Corners in Bearing
(Dist. x <= L and Dist. z > B)



Case 4: For 1 Corner in Bearing
(Dist. x <= L and Dist. z <= B)



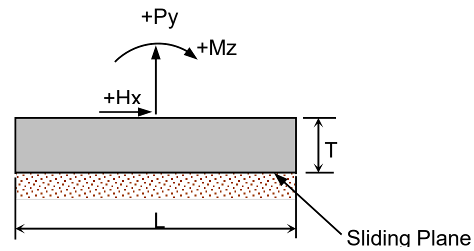
INTAKE TOWER STABILITY ANALYSIS

Job Name:	Springbank Off-Stream Storage Project (SR-1)	Number:	110773396		
Site:	Intake Structure	Originator:	CG 7/2/2020	Checker:	ACG
Load Case:	E5 Earthquake				

Input Data:

Footing Data:

Footing Length, L =	7.90	m
Footing Width, B =	6.30	m
Footing Thickness, T =	0.00	m
Coef. of Base Friction, μ =	0.42	
Ultimate Bearing, Pall =	450.00	kPa

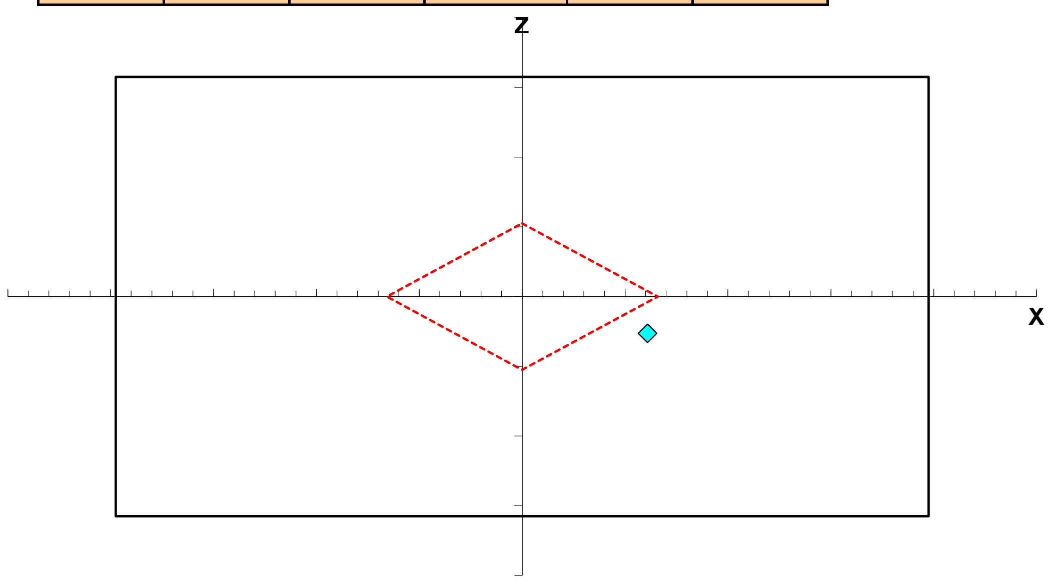


Nomenclature

Loading Data:

Direction of Seismic Force: COMBINED

	Uplift	Wind		EQ	Dead	Soil
Xp (m.) =						
Zp (m.) =						
Py (kN) =	553.10	0.00		**-354.46**	-4357.34	-452.10
Hx (kN) =		87.90		**644.95**	0.00	-158.40
Hz (kN) =		78.50		**567.21**	0.00	0.00
Mx (kN-m) =		-498.40		**2928.91**	0.00	0.40
Mz (kN-m) =		672.50		**3201.96**	904.50	857.80



FOOTING PLAN

Note: Is the "Kern" area of footing (When resultant of loads falls within "Kern", entire footing base is in bearing.)

Results:

Total Resultant Load and Eccentricities:

ΣPy =	-4610.80	kN
ex =	1.22	m (<= L/6)
ez =	-0.53	m (<= B/6)
ΣHx =	574.45	kN
ΣHz =	645.71	kN
H resultant =	864.25	kN
ΣMrx =	16266.29	kN-m
ΣMox =	4173.17	kN-m
ΣMry =	20397.41	kN-m
ΣMoy =	7821.51	kN-m

Sliding Check:

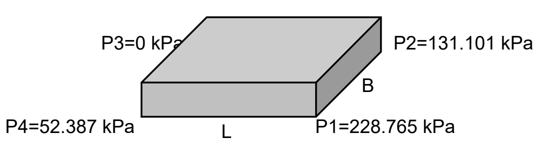
Frict =	1936.54	kN
FS(slid) =	2.24	

% Base Area in Compression:

Dist. x =	10.246	m
Dist. z =	14.757	m
Brg. Lx =	5.872	m
Brg. Lz =	3.379	m
%Brg. Area =	94.05	%
Biaxial Case =	Case 1	6*ex/L + 6*ez/B = 1.431

Gross Soil Bearing Corner Pressures:

P_1 =	228.765	kPa
P_2 =	131.101	kPa
P_3 =	0.000	kPa
P_4 =	52.387	kPa



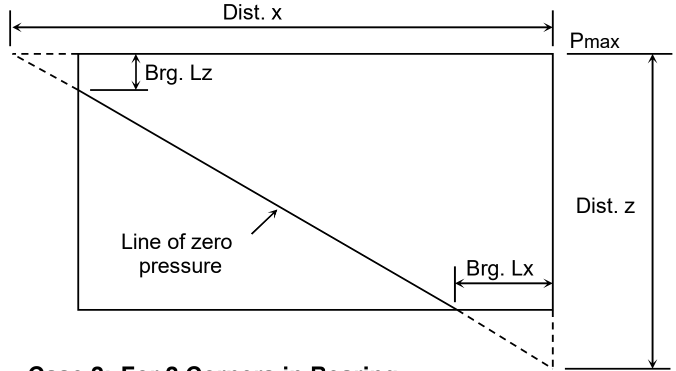
CORNER PRESSURES

Summary of Results:

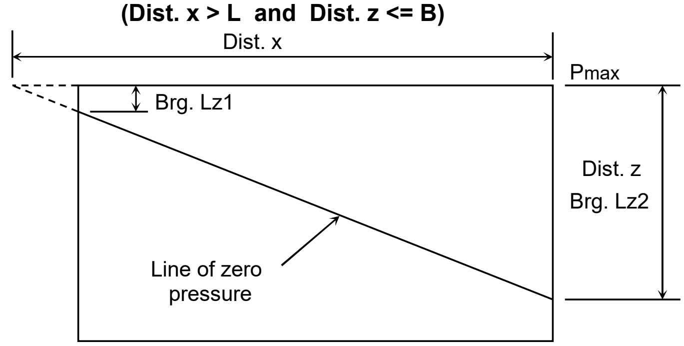
Sliding Check:			
FS(slid) =	2.24	>1	OK
Bearing Area Check:			
%Brg. Area =	94.05%	>1%	OK
Bearing Pressure Check:			
FS(brg) =	1.97	>1	OK
Flotation Check:			
FS (float) =	9.34	>1	OK

Nomenclature for Biaxial Eccentricity:

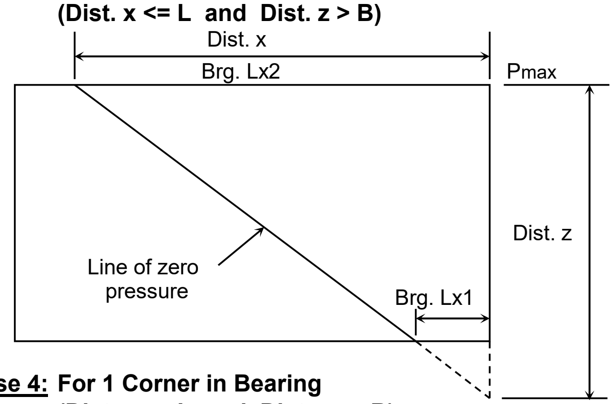
Case 1: **For 3 Corners in Bearing (Dist. x > L and Dist. z > B)**



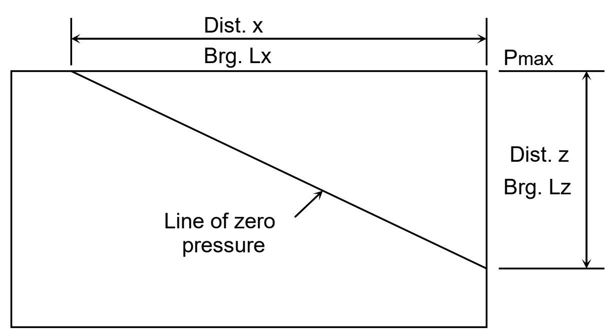
Case 2: **For 2 Corners in Bearing (Dist. x > L and Dist. z <= B)**



Case 3: **For 2 Corners in Bearing (Dist. x <= L and Dist. z > B)**



Case 4: **For 1 Corner in Bearing (Dist. x <= L and Dist. z <= B)**



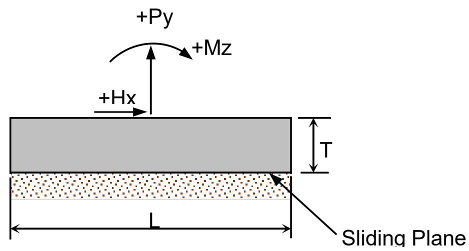
INTAKE TOWER STABILITY ANALYSIS

Job Name:	Springbank Off-Stream Storage Project (SR-1)	Number:	110773396
Site:	Intake Structure	Originator:	CG 7/2/2020 Checker: ACG
Load Case:	E6 Earthquake		

Input Data:

Footing Data:

Footing Length, L =	7.90	m
Footing Width, B =	6.30	m
Footing Thickness, T =	0.00	m
Coef. of Base Friction, μ =	0.42	
Ultimate Bearing, Pall =	450.00	kPa

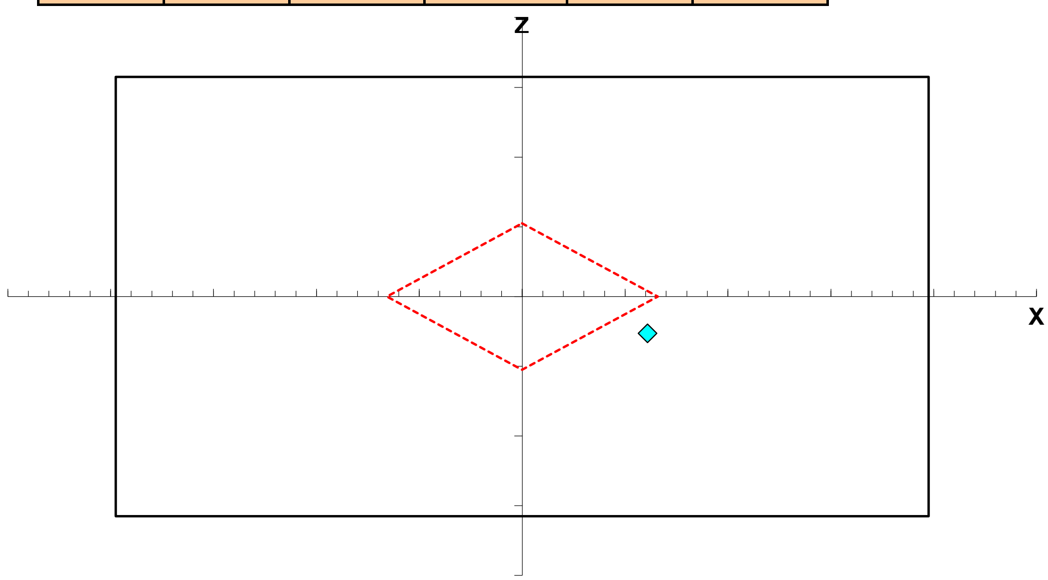


Nomenclature

Loading Data:

Direction of Seismic Force: COMBINED

	Uplift	Wind		EQ	Dead	Soil
Xp (m.) =						
Zp (m.) =						
Py (kN) =	553.10	0.00		-354.46	-4357.34	-452.10
Hx (kN) =		87.90		644.95	0.00	-158.40
Hz (kN) =		78.50		567.21	0.00	0.00
Mx (kN-m) =		-498.40		2928.91	0.00	0.40
Mz (kN-m) =		672.50		3201.96	904.50	857.80



FOOTING PLAN

Note: Is the "Kern" area of footing (When resultant of loads falls within "Kern", entire footing base is in bearing.)

Results:

Total Resultant Load and Eccentricities:

ΣPy =	-4610.80	kN
ex =	1.22	m (<= L/6)
ez =	-0.53	m (<= B/6)
ΣHx =	574.45	kN
ΣHz =	645.71	kN
H resultant =	864.25	kN
ΣMrx =	16266.29	kN-m
ΣMox =	4173.17	kN-m
ΣMry =	20397.41	kN-m
ΣMoy =	7821.51	kN-m

Sliding Check:

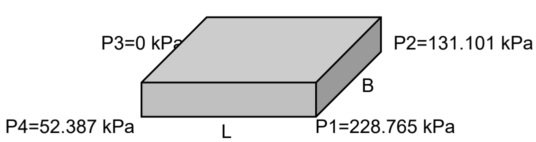
Frict =	1936.54	kN
FS(slid) =	2.24	

% Base Area in Compression:

Dist. x =	10.246	m
Dist. z =	14.757	m
Brg. Lx =	5.872	m
Brg. Lz =	3.379	m
%Brg. Area =	94.05	%
Biaxial Case =	Case 1	6*ex/L + 6*ez/B = 1.431

Gross Soil Bearing Corner Pressures:

P_1 =	228.765	kPa
P_2 =	131.101	kPa
P_3 =	0.000	kPa
P_4 =	52.387	kPa



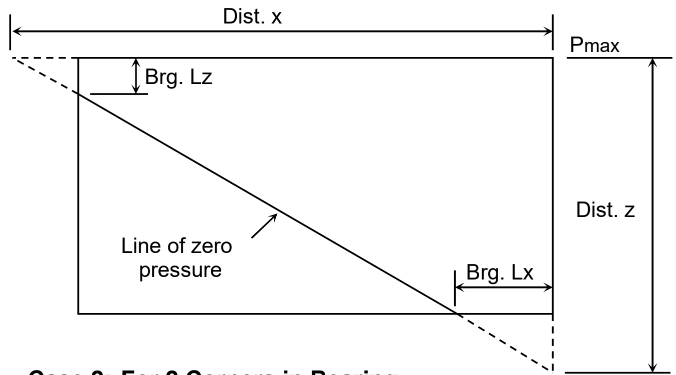
CORNER PRESSURES

Summary of Results:

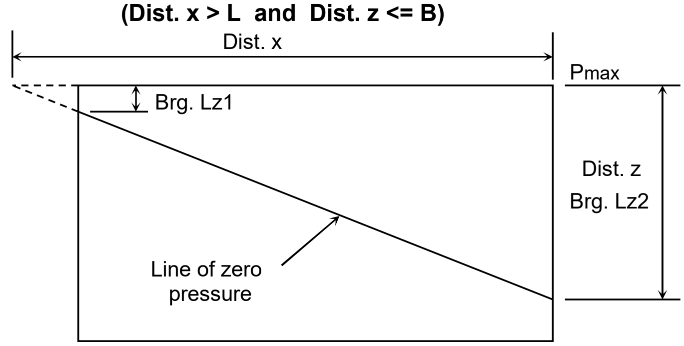
Sliding Check:			
FS(slid) =	2.24	>1	OK
Bearing Area Check:			
%Brg. Area =	94.05%	>1%	OK
Bearing Pressure Check:			
FS(brg) =	1.97	>1	OK
Flotation Check:			
FS (float) =	9.34	>1	OK

Nomenclature for Biaxial Eccentricity:

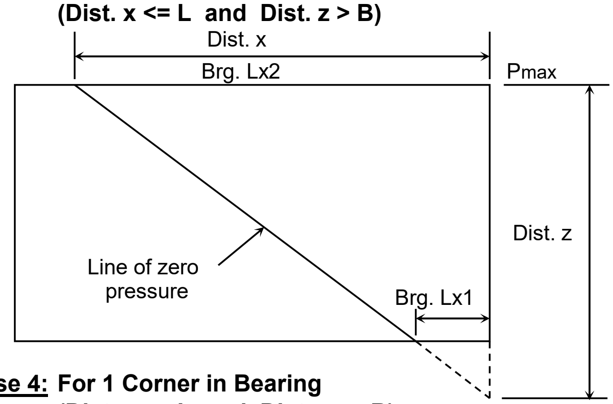
Case 1: For 3 Corners in Bearing
(Dist. x > L and Dist. z > B)



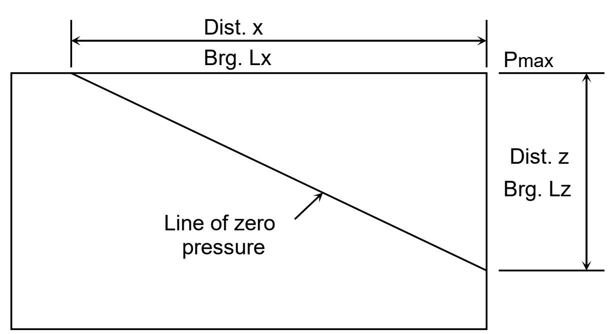
Case 2: For 2 Corners in Bearing
(Dist. x > L and Dist. z <= B)



Case 3: For 2 Corners in Bearing
(Dist. x <= L and Dist. z > B)



Case 4: For 1 Corner in Bearing
(Dist. x <= L and Dist. z <= B)



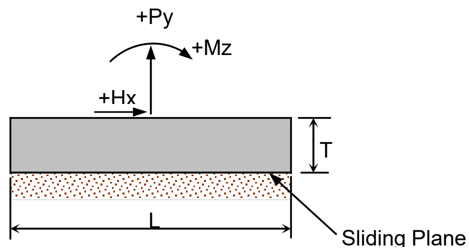
INTAKE TOWER STABILITY ANALYSIS

Job Name:	Springbank Off-Stream Storage Project (SR-1)	Number:	110773396		
Site:	Intake Structure	Originator:	CG 7/2/2020	Checker:	ACG
Load Case:	E7 Earthquake				

Input Data:

Footing Data:

Footing Length, L =	7.90	m
Footing Width, B =	6.30	m
Footing Thickness, T =	0.00	m
Coef. of Base Friction, μ =	0.42	
Ultimate Bearing, Pall =	450.00	kPa

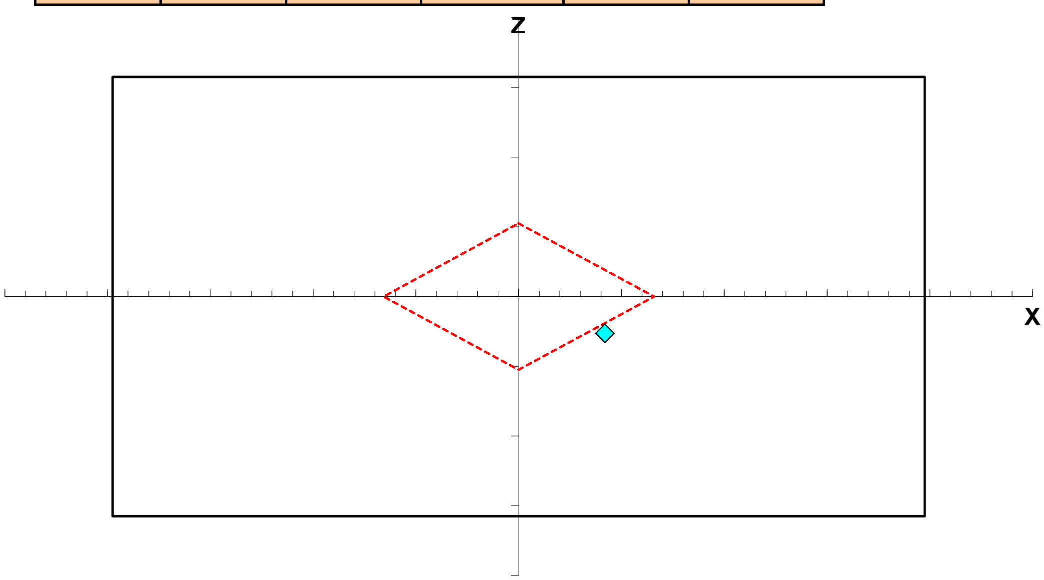


Nomenclature

Loading Data:

Direction of Seismic Force: COMBINED

	Uplift	Wind		EQ	Dead	Soil
Xp (m.) =						
Zp (m.) =						
Py (kN) =	553.10	0.00		**-354.46**	-4357.34	-452.10
Hx (kN) =		87.90		**644.95**		-158.40
Hz (kN) =		78.50		**567.21**		
Mx (kN-m) =		-498.40		**2928.91**		
Mz (kN-m) =		672.50		**3201.96**		



FOOTING PLAN

Note: Is the "Kern" area of footing (When resultant of loads falls within "Kern", entire footing base is in bearing.)

Results:

Total Resultant Load and Eccentricities:

ΣPy =	-4610.80	kN
ex =	0.84	m (<= L/6)
ez =	-0.53	m (<= B/6)
ΣHx =	574.45	kN
ΣHz =	645.71	kN
H resultant =	864.25	kN
ΣMrx =	16266.29	kN-m
ΣMox =	4172.77	kN-m
ΣMry =	20397.41	kN-m
ΣMoy =	6059.21	kN-m

Sliding Check:

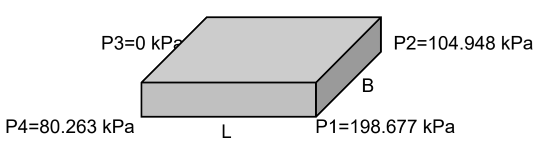
Frict =	1936.54	kN
FS(slid) =	2.24	

% Base Area in Compression:

Dist. x =	13.255	m
Dist. z =	13.354	m
Brg. Lx =	7.002	m
Brg. Lz =	5.395	m
%Brg. Area =	99.18	%
Biaxial Case =	Case 1	6*ex/L + 6*ez/B = 1.143

Gross Soil Bearing Corner Pressures:

P_1 =	198.677	kPa
P_2 =	104.948	kPa
P_3 =	0.000	kPa
P_4 =	80.263	kPa



CORNER PRESSURES

Summary of Results:

Sliding Check:

FS(slid) =	2.24	>1	OK

Bearing Area Check:

%Brg. Area =	99.18%	>1%	OK

Bearing Pressure Check:

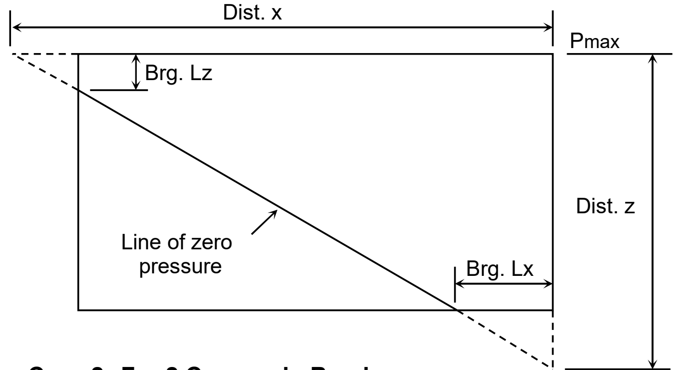
FS(brg) =	2.26	>1	OK

Flotation Check:

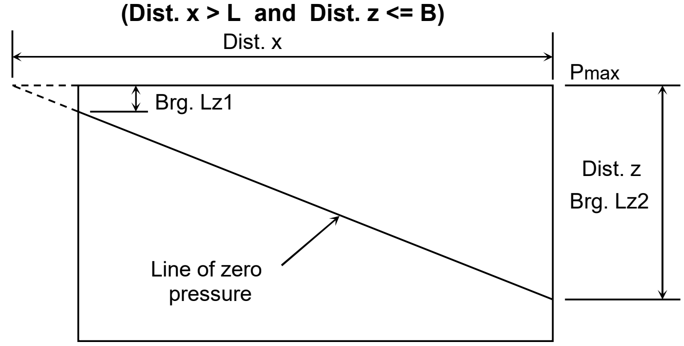
FS (float) =	9.34	>1	OK

Nomenclature for Biaxial Eccentricity:

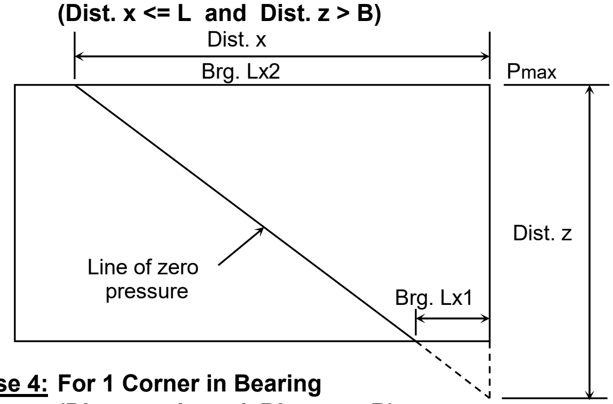
Case 1: For 3 Corners in Bearing
(Dist. x > L and Dist. z > B)



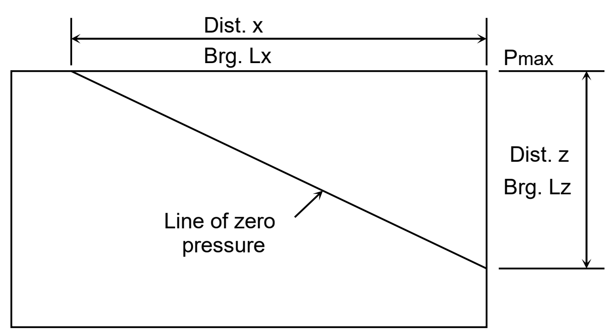
Case 2: For 2 Corners in Bearing
(Dist. x > L and Dist. z <= B)



Case 3: For 2 Corners in Bearing
(Dist. x <= L and Dist. z > B)



Case 4: For 1 Corner in Bearing
(Dist. x <= L and Dist. z <= B)



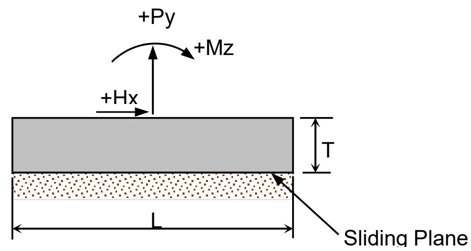
INTAKE TOWER STABILITY ANALYSIS

Job Name:	Springbank Off-Stream Storage Project (SR-1)	Number:	110773396		
Site:	Intake Structure	Originator:	CG 7/2/2020	Checker:	ACG
Load Case:	E8 Earthquake				

Input Data:

Footing Data:

Footing Length, L =	7.90	m
Footing Width, B =	6.30	m
Footing Thickness, T =	0.00	m
Coef. of Base Friction, μ =	0.42	
Ultimate Bearing, Pall =	450.00	kPa

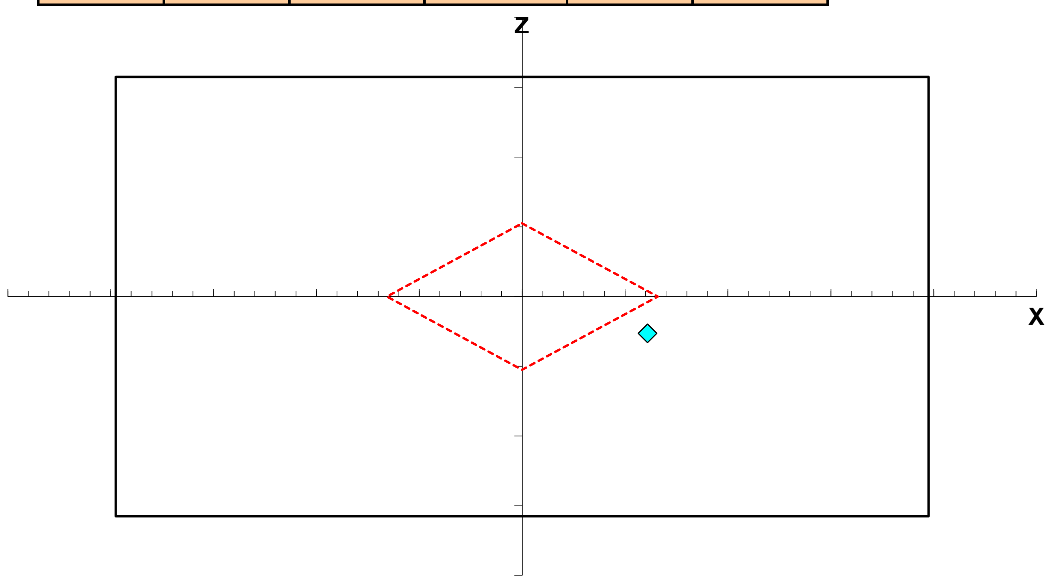


Nomenclature

Loading Data:

Direction of Seismic Force: COMBINED

	Uplift	Wind		EQ	Dead	Soil
Xp (m.) =						
Zp (m.) =						
Py (kN) =	553.10	0.00		-354.46	-4357.34	-452.10
Hx (kN) =		87.90		644.95	0.00	-158.40
Hz (kN) =		78.50		567.21	0.00	0.00
Mx (kN-m) =		-498.40		2928.91	0.00	0.40
Mz (kN-m) =		672.50		3201.96	904.50	857.80



FOOTING PLAN

Note: Is the "Kern" area of footing (When resultant of loads falls within "Kern", entire footing base is in bearing.)

Results:

Total Resultant Load and Eccentricities:

ΣPy =	-4610.80	kN
ex =	1.22	m (<= L/6)
ez =	-0.53	m (<= B/6)
ΣHx =	574.45	kN
ΣHz =	645.71	kN
H resultant =	864.25	kN
ΣMrx =	16266.29	kN-m
ΣMox =	4173.17	kN-m
ΣMry =	20397.41	kN-m
ΣMoy =	7821.51	kN-m

Sliding Check:

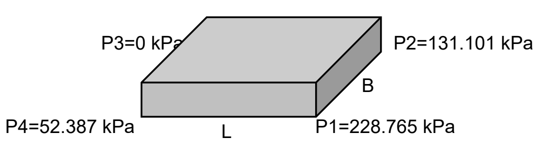
Frict =	1936.54	kN
FS(slid) =	2.241	

% Base Area in Compression:

Dist. x =	10.246	m
Dist. z =	14.757	m
Brg. Lx =	5.872	m
Brg. Lz =	3.379	m
%Brg. Area =	94.05	%
Biaxial Case =	Case 1	6*ex/L + 6*ez/B = 1.431

Gross Soil Bearing Corner Pressures:

P_1 =	228.765	kPa
P_2 =	131.101	kPa
P_3 =	0.000	kPa
P_4 =	52.387	kPa



CORNER PRESSURES

Summary of Results:

Sliding Check:

FS(slid) =	2.24	>1	OK

Bearing Area Check:

%Brg. Area =	94.05%	>1%	OK

Bearing Pressure Check:

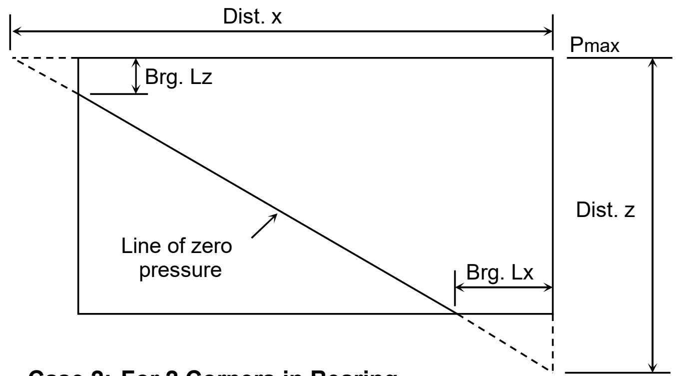
FS(brg) =	1.97	>1	OK

Flotation Check:

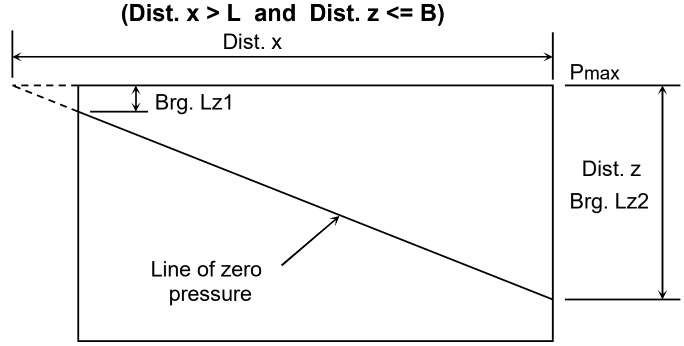
FS (float) =	9.34	>1	OK

Nomenclature for Biaxial Eccentricity:

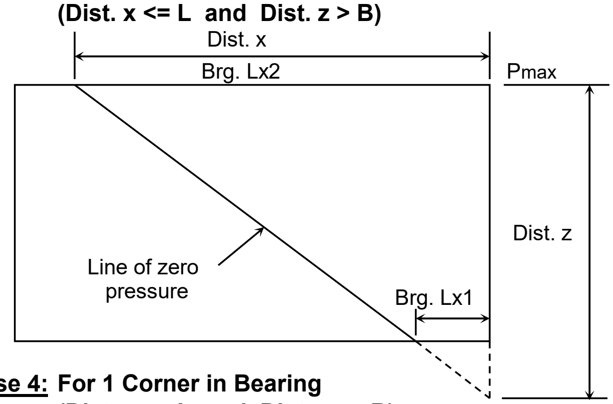
Case 1: For 3 Corners in Bearing (Dist. x > L and Dist. z > B)



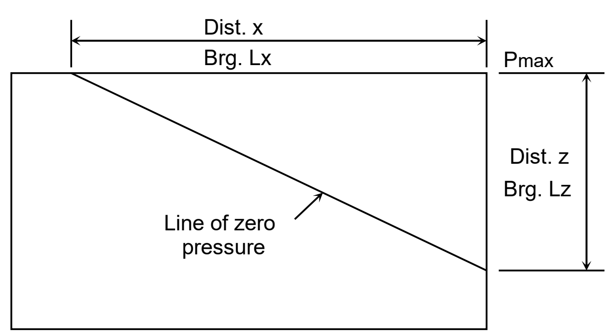
Case 2: For 2 Corners in Bearing (Dist. x > L and Dist. z <= B)



Case 3: For 2 Corners in Bearing (Dist. x <= L and Dist. z > B)



Case 4: For 1 Corner in Bearing (Dist. x <= L and Dist. z <= B)



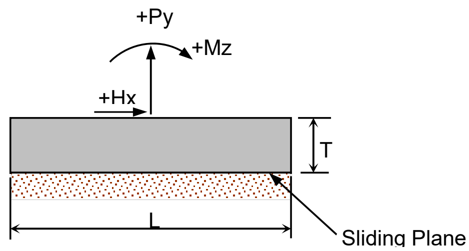
INTAKE TOWER STABILITY ANALYSIS

Job Name:	Springbank Off-Stream Storage Project (SR-1)	Number:	110773396		
Site:	Intake Structure	Originator:	CG 7/2/2020	Checker:	ACG
Load Case:	E9 Earthquake				

Input Data:

Footing Data:

Footing Length, L =	7.90	m
Footing Width, B =	6.30	m
Footing Thickness, T =	0.00	m
Coef. of Base Friction, μ =	0.42	
Ultimate Bearing, Pall =	450.00	kPa

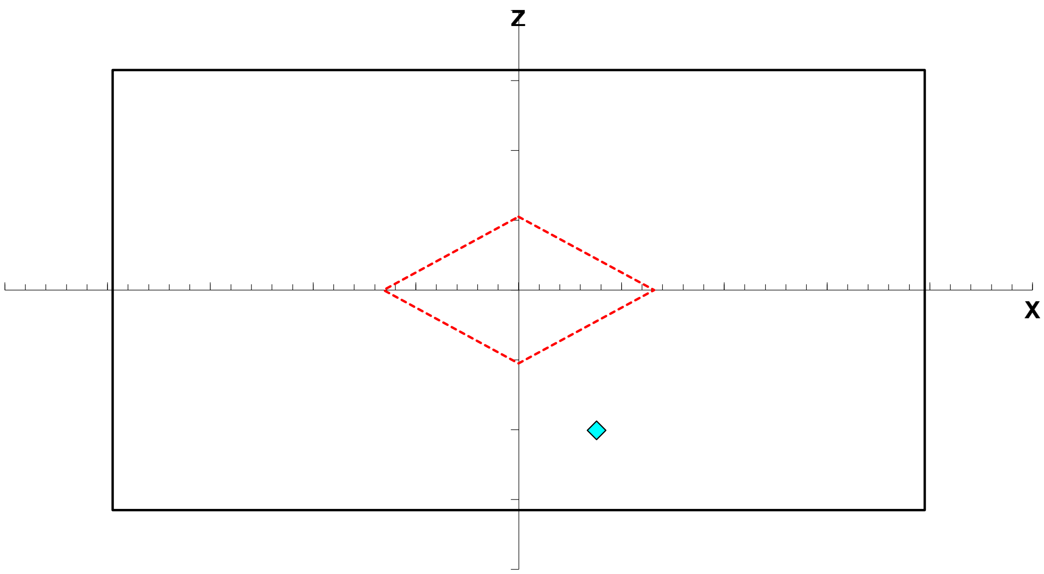


Nomenclature

Loading Data:

Direction of Seismic Force: COMBINED

	Uplift	Wind		EQ	Dead	Soil
Xp (m.) =						
Zp (m.) =						
Py (kN) =	553.10	0.00		-345.57	-4357.34	-452.10
Hx (kN) =		87.90		200.47	0.00	-158.40
Hz (kN) =		78.50		1890.69	0.00	0.00
Mx (kN-m) =		-498.40		9762.96	0.00	0.40
Mz (kN-m) =		672.50		1070.74	904.50	857.80



FOOTING PLAN

Note: Is the "Kern" area of footing (When resultant of loads falls within "Kern", entire footing base is in bearing.)

Results:

Total Resultant Load and Eccentricities:

ΣPy =	-4601.91	kN
ex =	0.76	m (<= L/6)
ez =	-2.01	m (> B/6)
ΣHx =	129.97	kN
ΣHz =	1969.19	kN
H resultant =	1973.48	kN
ΣMrx =	16238.27	kN-m
ΣMox =	11007.22	kN-m
ΣMry =	20362.28	kN-m
ΣMoy =	5690.28	kN-m

Sliding Check:

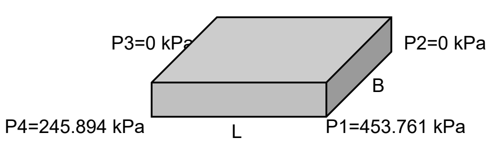
Frict =	1932.80	kN
FS(slid) =	0.979	

% Base Area in Compression:

Dist. x =	17.245	m
Dist. z =	4.196	m
Brg. Lz1 =	2.274	m
Brg. Lz2 =	4.196	m
%Brg. Area =	51.35	%
Biaxial Case =	Case 2	6*ex/L + 6*ez/B = 2.492

Gross Soil Bearing Corner Pressures:

P1 =	453.761	kPa
P2 =	0.000	kPa
P3 =	0.000	kPa
P4 =	245.894	kPa



CORNER PRESSURES

Summary of Results:

Sliding Check:

FS(slid) =	1.00	>1	OK

Bearing Area Check:

%Brg. Area =	51.35%	>1%	OK

Bearing Pressure Check:

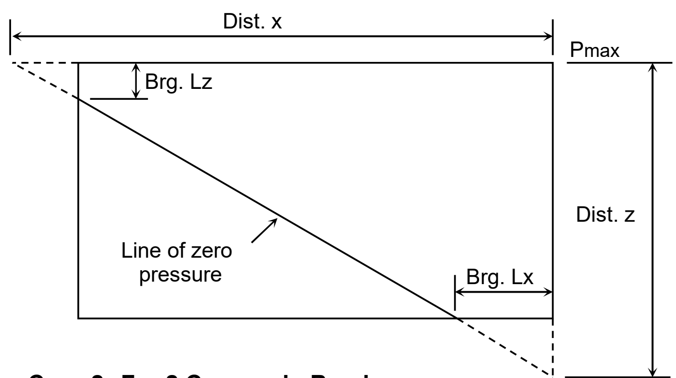
FS(brg) =	0.99	<1	NG

Flotation Check:

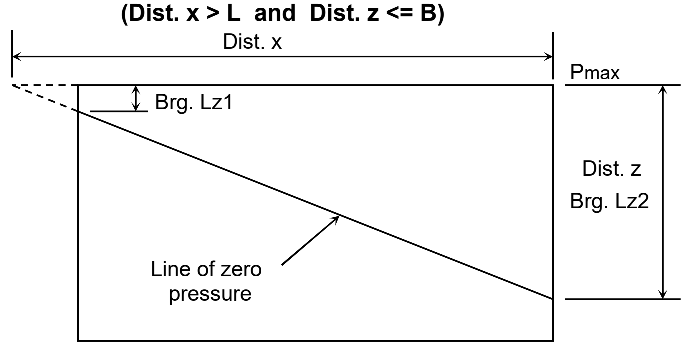
FS (float) =	9.32	>1	OK

Nomenclature for Biaxial Eccentricity:

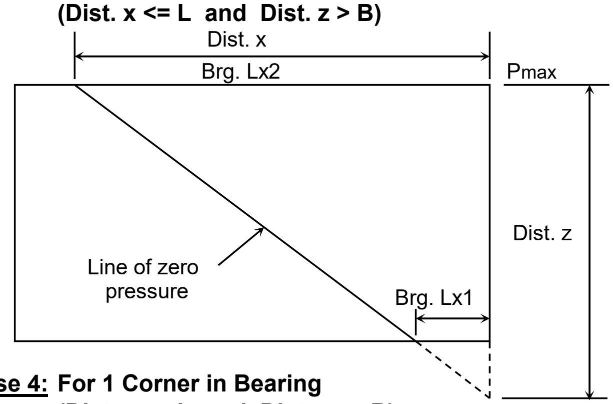
Case 1: For 3 Corners in Bearing (Dist. x > L and Dist. z > B)



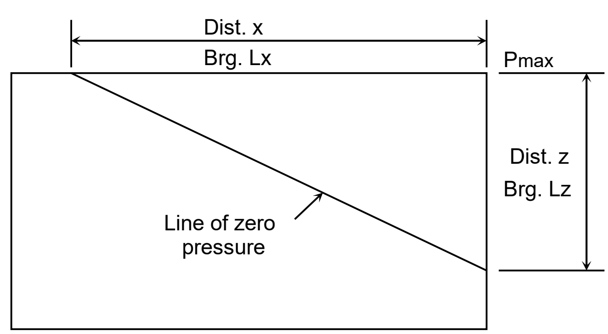
Case 2: For 2 Corners in Bearing (Dist. x > L and Dist. z <= B)



Case 3: For 2 Corners in Bearing (Dist. x <= L and Dist. z > B)



Case 4: For 1 Corner in Bearing (Dist. x <= L and Dist. z <= B)



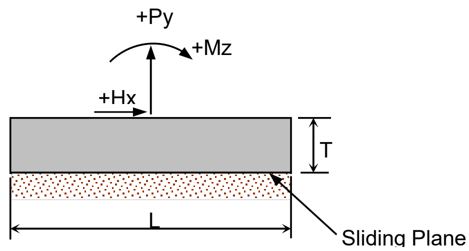
INTAKE TOWER STABILITY ANALYSIS

Job Name:	Springbank Off-Stream Storage Project (SR-1)	Number:	110773396		
Site:	Intake Structure	Originator:	CG 7/2/2020	Checker:	ACG
Load Case:	E10 Earthquake				

Input Data:

Footing Data:

Footing Length, L =	7.90	m
Footing Width, B =	6.30	m
Footing Thickness, T =	0.00	m
Coef. of Base Friction, μ =	0.42	
Ultimate Bearing, Pall =	450.00	kPa

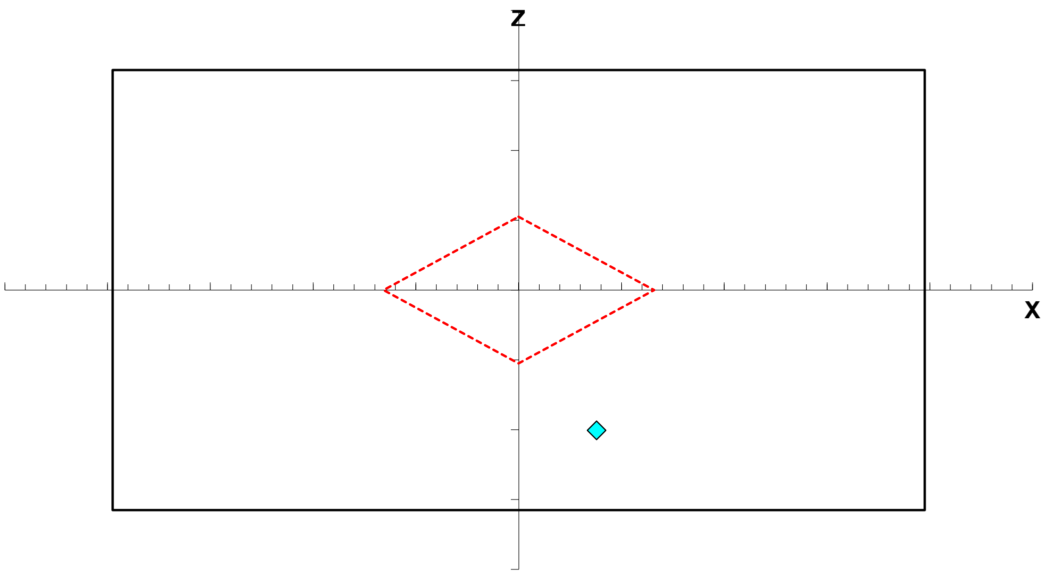


Nomenclature

Loading Data:

Direction of Seismic Force: COMBINED

	Uplift	Wind		EQ	Dead	Soil
Xp (m.) =						
Zp (m.) =						
Py (kN) =	553.10	0.00		**-345.57**	-4357.34	-452.10
Hx (kN) =		87.90		**200.47**	0.00	-158.40
Hz (kN) =		78.50		**1890.69**	0.00	0.00
Mx (kN-m) =		-498.40		**9762.96**	0.00	0.40
Mz (kN-m) =		672.50		**1070.74**	904.50	857.80



FOOTING PLAN

Note: Is the "Kern" area of footing (When resultant of loads falls within "Kern", entire footing base is in bearing.)

Results:

Total Resultant Load and Eccentricities:

ΣPy =	-4601.91	kN
ex =	0.76	m (<= L/6)
ez =	-2.01	m (> B/6)
ΣHx =	129.97	kN
ΣHz =	1969.19	kN
H resultant =	1973.48	kN
ΣMrx =	16238.27	kN-m
ΣMox =	11007.22	kN-m
ΣMry =	20362.28	kN-m
ΣMoy =	5690.28	kN-m

Sliding Check:

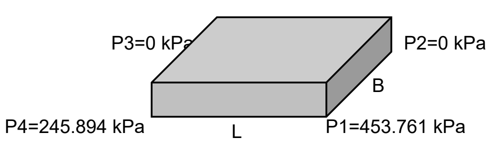
Frict =	1932.80	kN
FS(slid) =	0.979	

% Base Area in Compression:

Dist. x =	17.245	m
Dist. z =	4.196	m
Brg. Lz1 =	2.274	m
Brg. Lz2 =	4.196	m
%Brg. Area =	51.35	%
Biaxial Case =	Case 2	6*ex/L + 6*ez/B = 2.492

Gross Soil Bearing Corner Pressures:

P1 =	453.761	kPa
P2 =	0.000	kPa
P3 =	0.000	kPa
P4 =	245.894	kPa



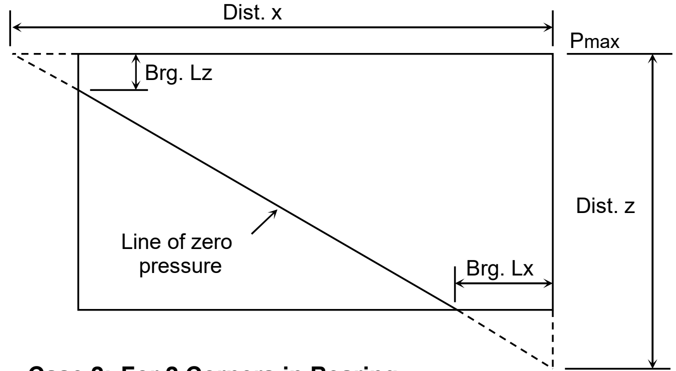
CORNER PRESSURES

Summary of Results:

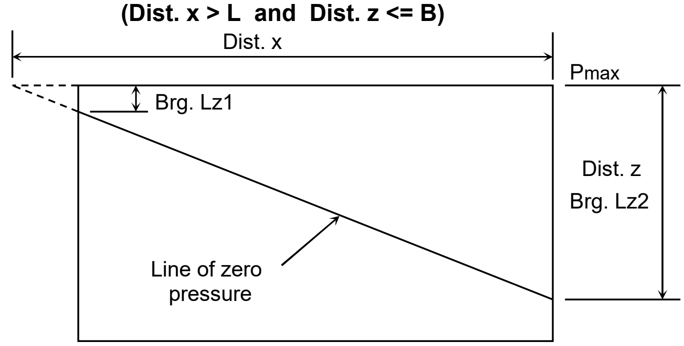
Sliding Check:			
FS(slid) =	1.00	>1	OK
Bearing Area Check:			
%Brg. Area =	51.35%	>1%	OK
Bearing Pressure Check:			
FS(brg) =	0.99	<1	NG
Flotation Check:			
FS (float) =	9.32	>1	OK

Nomenclature for Biaxial Eccentricity:

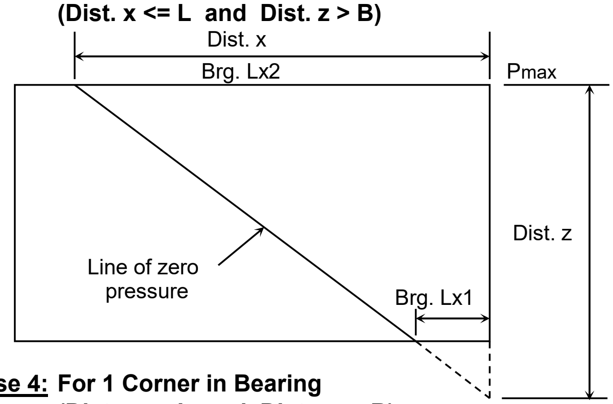
Case 1: For 3 Corners in Bearing (Dist. x > L and Dist. z > B)



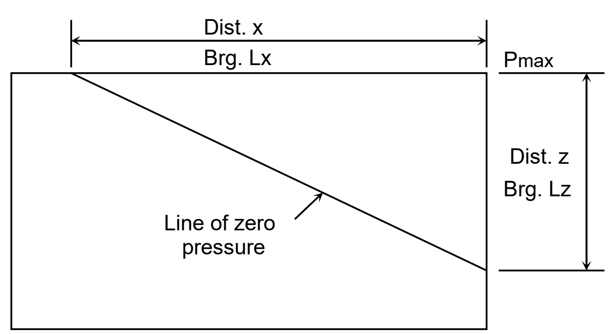
Case 2: For 2 Corners in Bearing (Dist. x > L and Dist. z <= B)



Case 3: For 2 Corners in Bearing (Dist. x <= L and Dist. z > B)



Case 4: For 1 Corner in Bearing (Dist. x <= L and Dist. z <= B)



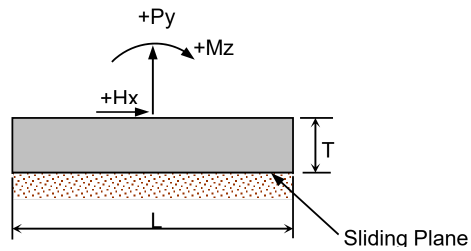
INTAKE TOWER STABILITY ANALYSIS

Job Name:	Springbank Off-Stream Storage Project (SR-1)	Number:	110773396
Site:	Intake Structure	Originator:	CG 7/2/2020 Checker: ACG
Load Case:	E11 Earthquake		

Input Data:

Footing Data:

Footing Length, L =	7.90	m
Footing Width, B =	6.30	m
Footing Thickness, T =	0.00	m
Coef. of Base Friction, μ =	0.42	
Ultimate Bearing, Pall =	450.00	kPa

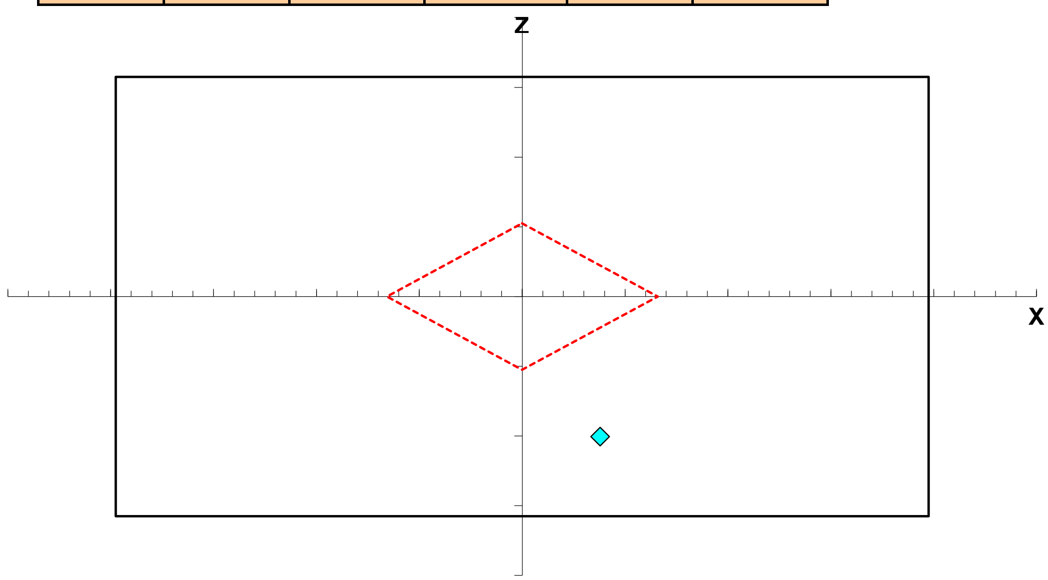


Nomenclature

Loading Data:

Direction of Seismic Force: COMBINED

	Uplift	Wind		EQ	Dead	Soil
Xp (m.) =						
Zp (m.) =						
Py (kN) =	553.10	0.00		**-345.57**	-4357.34	-452.10
Hx (kN) =		87.90		**200.47**	0.00	-158.40
Hz (kN) =		78.50		**1890.69**	0.00	0.00
Mx (kN-m) =		-498.40		**9762.96**	0.00	0.40
Mz (kN-m) =		672.50		**1070.74**	904.50	857.80



FOOTING PLAN

Note: Is the "Kern" area of footing (When resultant of loads falls within "Kern", entire footing base is in bearing.)

Results:

Total Resultant Load and Eccentricities:

ΣPy =	-4601.91	kN
ex =	0.76	m (<= L/6)
ez =	-2.01	m (> B/6)
ΣHx =	129.97	kN
ΣHz =	1969.19	kN
H resultant =	1973.48	kN
ΣMrx =	16238.27	kN-m
ΣMox =	11007.22	kN-m
ΣMry =	20362.28	kN-m
ΣMoy =	5690.28	kN-m

Sliding Check:

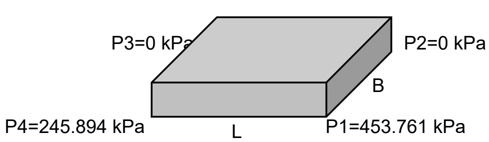
Frict =	1932.80	kN
FS(slid) =	0.979	

% Base Area in Compression:

Dist. x =	17.245	m
Dist. z =	4.196	m
Brg. Lz1 =	2.274	m
Brg. Lz2 =	4.196	m
%Brg. Area =	51.35	%
Biaxial Case =	Case 2	6*ex/L + 6*ez/B = 2.492

Gross Soil Bearing Corner Pressures:

P_1 =	453.761	kPa
P_2 =	0.000	kPa
P_3 =	0.000	kPa
P_4 =	245.894	kPa



CORNER PRESSURES

Summary of Results:

Sliding Check:

FS(slid) =	1.00	>1	OK

Bearing Area Check:

%Brg. Area =	51.35%	>1%	OK

Bearing Pressure Check:

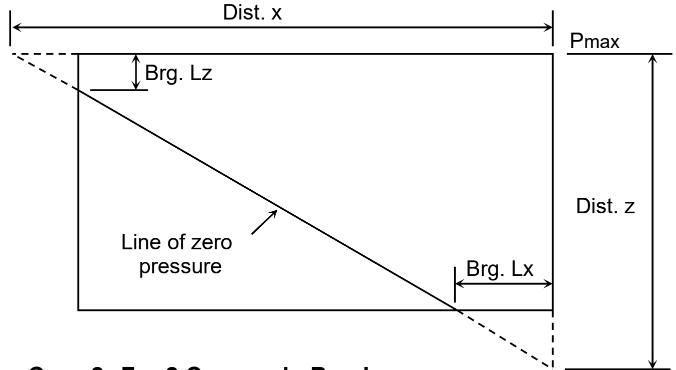
FS(brg) =	0.99	<1	NG

Flotation Check:

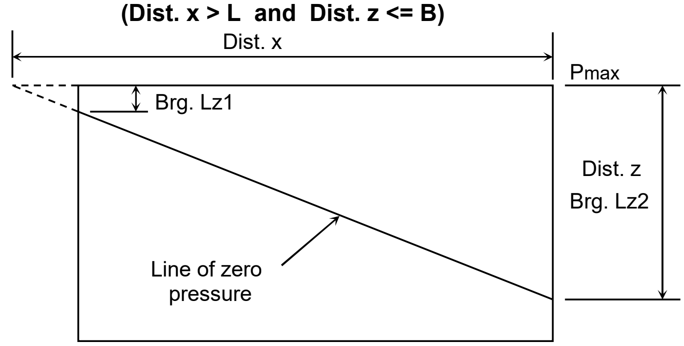
FS (float) =	9.32	>1	OK

Nomenclature for Biaxial Eccentricity:

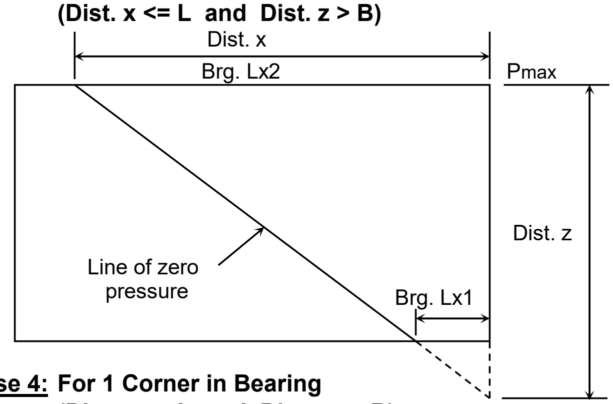
Case 1: For 3 Corners in Bearing
(Dist. x > L and Dist. z > B)



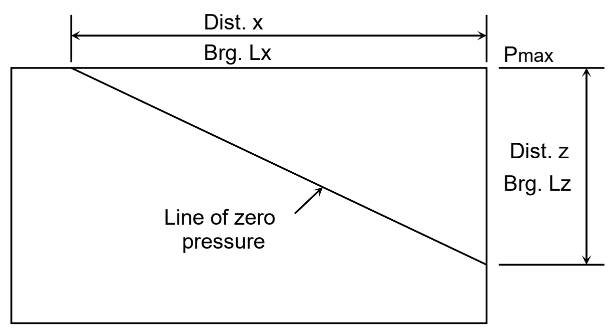
Case 2: For 2 Corners in Bearing
(Dist. x > L and Dist. z <= B)



Case 3: For 2 Corners in Bearing
(Dist. x <= L and Dist. z > B)



Case 4: For 1 Corner in Bearing
(Dist. x <= L and Dist. z <= B)

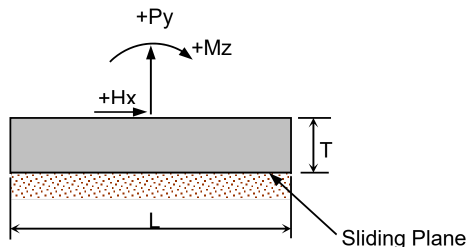


INTAKE TOWER STABILITY ANALYSIS					
Job Name:	Springbank Off-Stream Storage Project (SR-1)	Number:	110773396		
Site:	Intake Structure	Originator:	CG	7/2/2020	Checker: ACG
Load Case:	E12 Earthquake				

Input Data:

Footing Data:

Footing Length, L =	7.90	m
Footing Width, B =	6.30	m
Footing Thickness, T =	0.00	m
Coef. of Base Friction, μ =	0.42	
Ultimate Bearing, Pall =	450.00	kPa

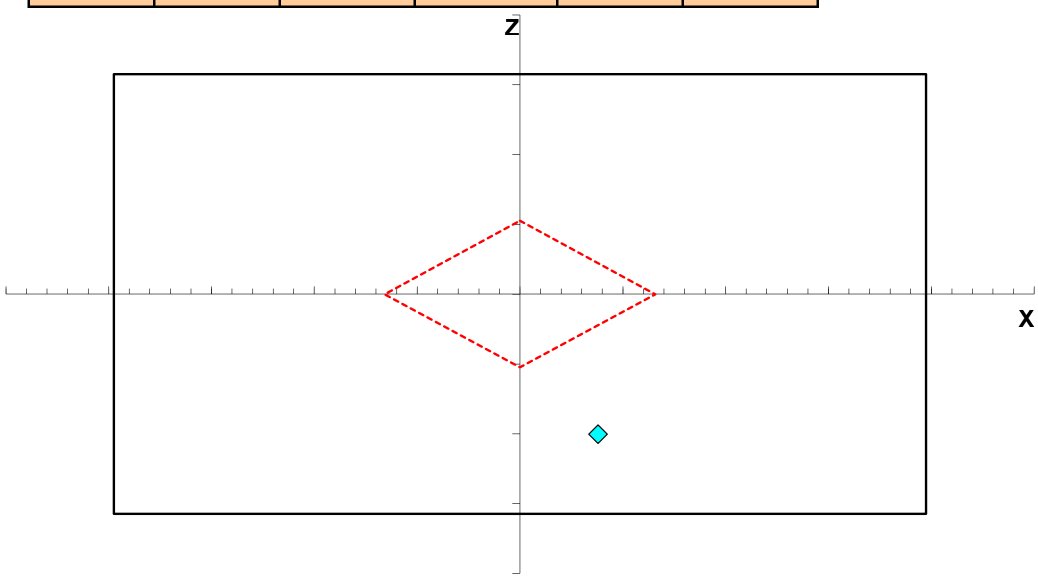


Nomenclature

Loading Data:

Direction of Seismic Force: COMBINED

	Uplift	Wind		EQ	Dead	Soil
Xp (m.) =						
Zp (m.) =						
Py (kN) =	553.10	0.00		**-345.57**	-4357.34	-452.10
Hx (kN) =		87.90		**200.47**	0.00	-158.40
Hz (kN) =		78.50		**1890.69**	0.00	0.00
Mx (kN-m) =		-498.40		**9762.96**	0.00	0.40
Mz (kN-m) =		672.50		**1070.74**	904.50	857.80



FOOTING PLAN

Note: Is the "Kern" area of footing (When resultant of loads falls within "Kern", entire footing base is in bearing.)

Results:

Total Resultant Load and Eccentricities:

ΣPy =	-4601.91	kN
ex =	0.76	m (<= L/6)
ez =	-2.01	m (> B/6)
ΣHx =	129.97	kN
ΣHz =	1969.19	kN
H resultant =	1973.48	kN
ΣMrx =	16238.27	kN-m
ΣMox =	11007.22	kN-m
ΣMry =	20362.28	kN-m
ΣMoy =	5690.28	kN-m

Sliding Check:

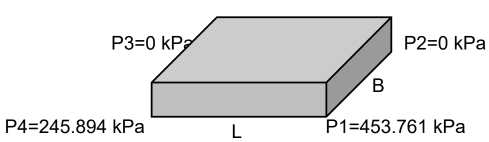
Frict =	1932.80	kN
FS(slid) =	0.979	

% Base Area in Compression:

Dist. x =	17.245	m
Dist. z =	4.196	m
Brg. Lz1 =	2.274	m
Brg. Lz2 =	4.196	m
%Brg. Area =	51.35	%
Biaxial Case =	Case 2	6*ex/L + 6*ez/B = 2.492

Gross Soil Bearing Corner Pressures:

P1 =	453.761	kPa
P2 =	0.000	kPa
P3 =	0.000	kPa
P4 =	245.894	kPa



CORNER PRESSURES

Summary of Results:

Sliding Check:

FS(slid) =	1.00	>1	OK

Bearing Area Check:

%Brg. Area =	51.35%	>1%	OK

Bearing Pressure Check:

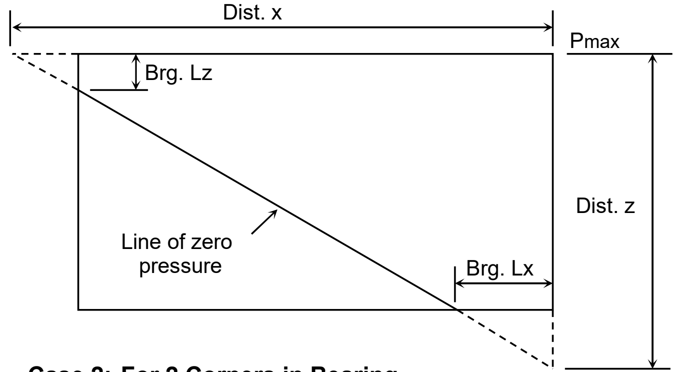
FS(brg) =	0.99	<1	NG

Flotation Check:

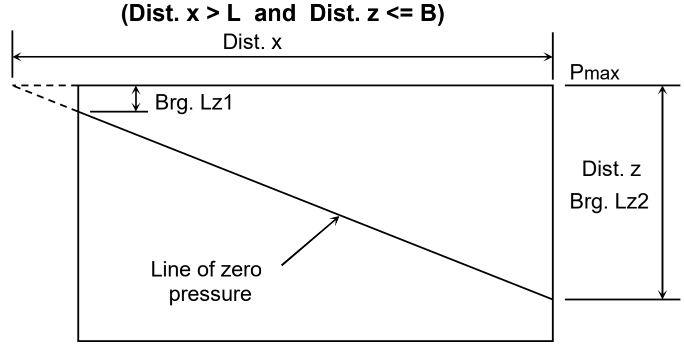
FS (float) =	9.32	>1	OK

Nomenclature for Biaxial Eccentricity:

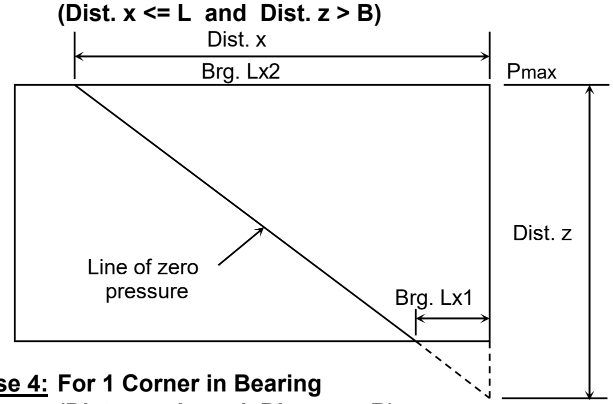
Case 1: For 3 Corners in Bearing
(Dist. x > L and Dist. z > B)



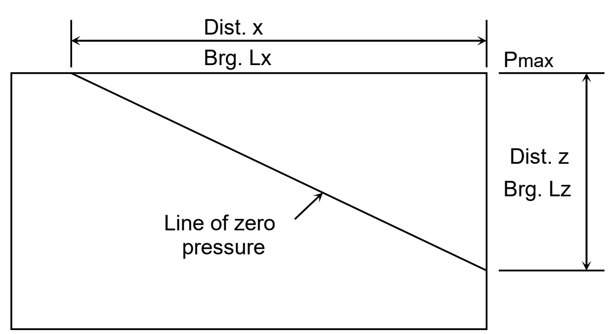
Case 2: For 2 Corners in Bearing
(Dist. x > L and Dist. z <= B)



Case 3: For 2 Corners in Bearing
(Dist. x <= L and Dist. z > B)



Case 4: For 1 Corner in Bearing
(Dist. x <= L and Dist. z <= B)

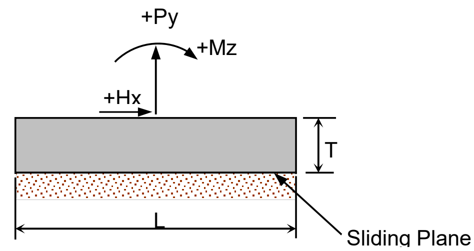


INTAKE TOWER STABILITY ANALYSIS						
Job Name:	Springbank Off-Stream Storage Project (SR-1)	Number:	110773396			
Site:	Intake Structure	Originator:	CG	7/2/2020	Checker:	ACG
Load Case:	E13 Earthquake					

Input Data:

Footing Data:

Footing Length, L =	7.90	m
Footing Width, B =	6.30	m
Footing Thickness, T =	0.00	m
Coef. of Base Friction, μ =	0.42	
Ultimate Bearing, Pall =	450.00	kPa

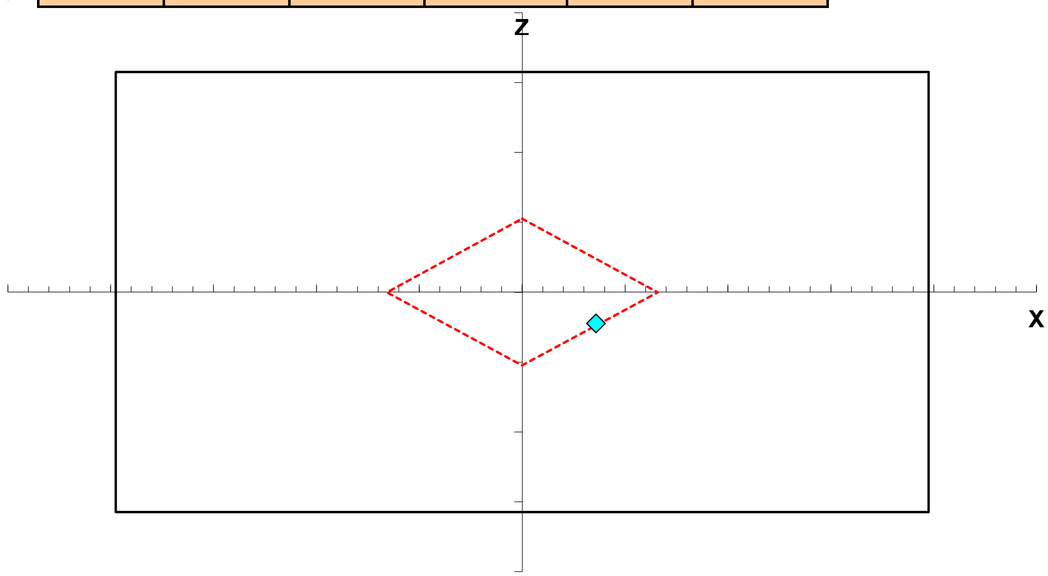


Nomenclature

Loading Data:

Direction of Seismic Force: COMBINED

	Uplift	Wind		EQ	Dead	Soil
Xp (m.) =						
Zp (m.) =						
Py (kN) =	553.10	0.00		-1143.00	-4357.34	-452.10
Hx (kN) =		87.90		223.47	0.00	-158.40
Hz (kN) =		78.50		567.21	0.00	0.00
Mx (kN-m) =		-498.40		2928.89	0.00	0.40
Mz (kN-m) =		672.50		1437.10	904.50	857.80



FOOTING PLAN

Note: Is the "Kern" area of footing (When resultant of loads falls within "Kern", entire footing base is in bearing.)

Results:

Total Resultant Load and Eccentricities:

ΣPy =	-5399.34	kN
ex =	0.72	m (<= L/6)
ez =	-0.45	m (<= B/6)
ΣHx =	152.97	kN
ΣHz =	645.71	kN
H resultant =	663.58	kN
ΣMrx =	18750.17	kN-m
ΣMox =	4173.16	kN-m
ΣMry =	23512.12	kN-m
ΣMoy =	6056.65	kN-m

Sliding Check:

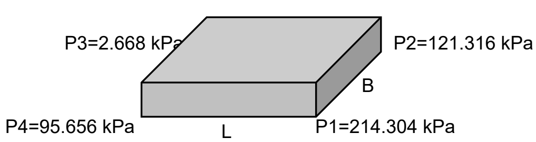
Frict =	2267.72	kN
FS(slid) =	3.417	

% Base Area in Compression:

Dist. x =	N.A.	m
Dist. z =	N.A.	m
Brg. Lx =	7.900	m
Brg. Lz =	6.300	m
%Brg. Area =	100.00	%
Biaxial Case =	N.A.	6*ex/L + 6*ez/B = 0.975

Gross Soil Bearing Corner Pressures:

P_1 =	214.304	kPa
P_2 =	121.316	kPa
P_3 =	2.668	kPa
P_4 =	95.656	kPa



CORNER PRESSURES

Summary of Results:

Sliding Check:

FS(slid) =	3.42	>1	OK

Bearing Area Check:

%Brg. Area =	100.00%	>1%	OK

Bearing Pressure Check:

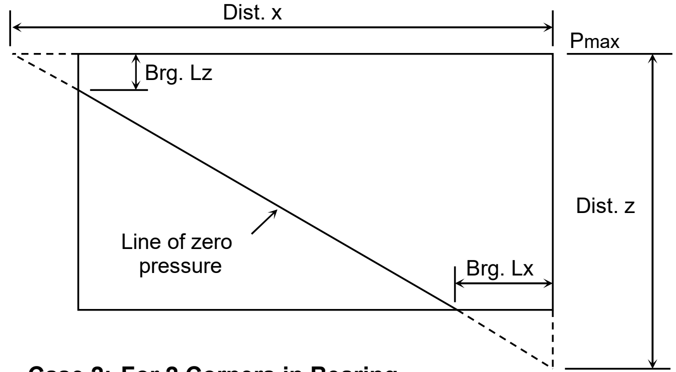
FS(brg) =	2.10	>1	OK

Flotation Check:

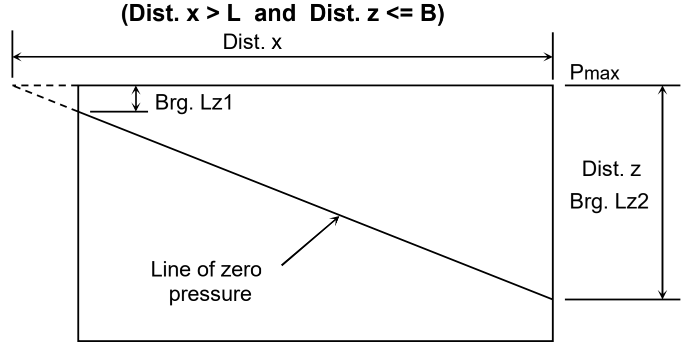
FS (float) =	10.76	>1	OK

Nomenclature for Biaxial Eccentricity:

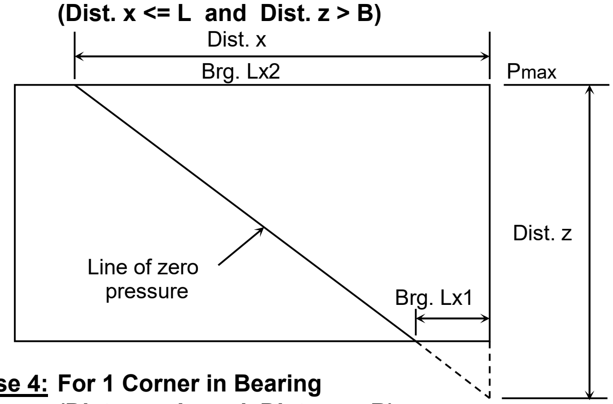
Case 1: For 3 Corners in Bearing
(Dist. x > L and Dist. z > B)



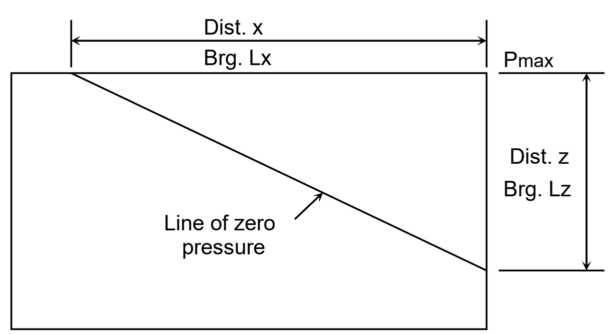
Case 2: For 2 Corners in Bearing
(Dist. x > L and Dist. z <= B)



Case 3: For 2 Corners in Bearing
(Dist. x <= L and Dist. z > B)



Case 4: For 1 Corner in Bearing
(Dist. x <= L and Dist. z <= B)



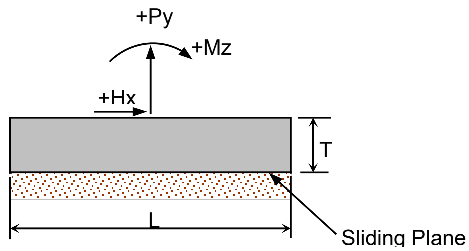
INTAKE TOWER STABILITY ANALYSIS

Job Name:	Springbank Off-Stream Storage Project (SR-1)	Number:	110773396		
Site:	Intake Structure	Originator:	CG 7/2/2020	Checker:	ACG
Load Case:	E14 Earthquake				

Input Data:

Footing Data:

Footing Length, L =	7.90	m
Footing Width, B =	6.30	m
Footing Thickness, T =	0.00	m
Coef. of Base Friction, μ =	0.42	
Ultimate Bearing, Pall =	450.00	kPa

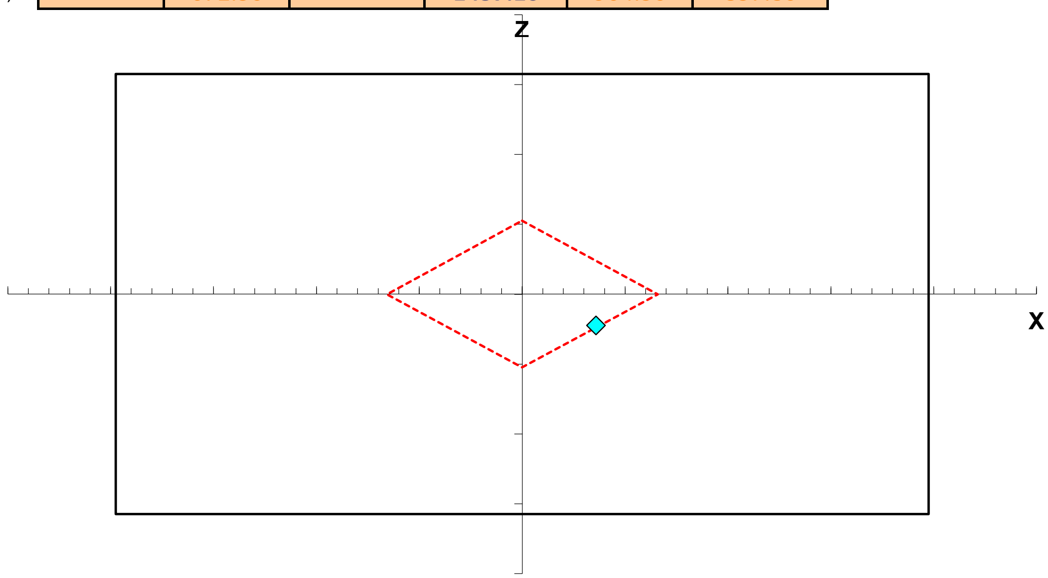


Nomenclature

Loading Data:

Direction of Seismic Force: COMBINED

	Uplift	Wind		EQ	Dead	Soil
Xp (m.) =						
Zp (m.) =						
Py (kN) =	553.10	0.00		-1143.00	-4357.34	-452.10
Hx (kN) =		87.90		223.47	0.00	-158.40
Hz (kN) =		78.50		567.21	0.00	0.00
Mx (kN-m) =		-498.40		2928.89	0.00	0.40
Mz (kN-m) =		672.50		1437.10	904.50	857.80



FOOTING PLAN

Note: Is the "Kern" area of footing (When resultant of loads falls within "Kern", entire footing base is in bearing.)

Results:

Total Resultant Load and Eccentricities:

ΣPy =	-5399.34	kN
ex =	0.72	m (<= L/6)
ez =	-0.45	m (<= B/6)
ΣHx =	152.97	kN
ΣHz =	645.71	kN
H resultant =	663.58	kN
ΣMrx =	18750.17	kN-m
ΣMox =	4173.16	kN-m
ΣMry =	23512.12	kN-m
ΣMoy =	6056.65	kN-m

Sliding Check:

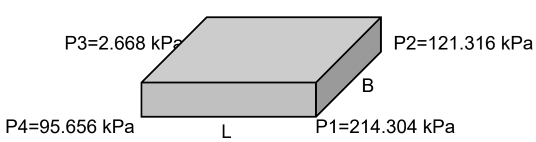
Frict =	2267.72	kN
FS(slid) =	3.417	

% Base Area in Compression:

Dist. x =	N.A.	m
Dist. z =	N.A.	m
Brg. Lx =	7.900	m
Brg. Lz =	6.300	m
%Brg. Area =	100.00	%
Biaxial Case =	N.A.	6*ex/L + 6*ez/B = 0.975

Gross Soil Bearing Corner Pressures:

P_1 =	214.304	kPa
P_2 =	121.316	kPa
P_3 =	2.668	kPa
P_4 =	95.656	kPa



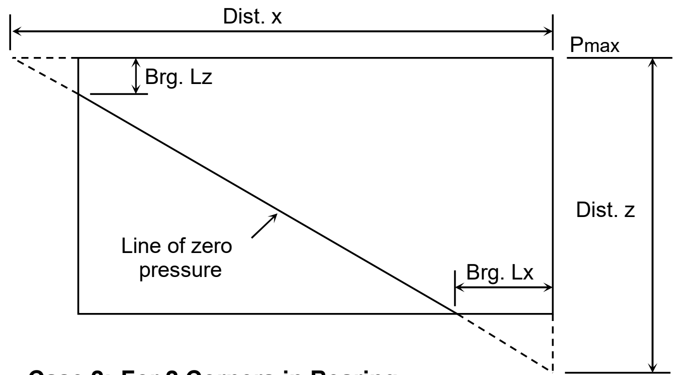
CORNER PRESSURES

Summary of Results:

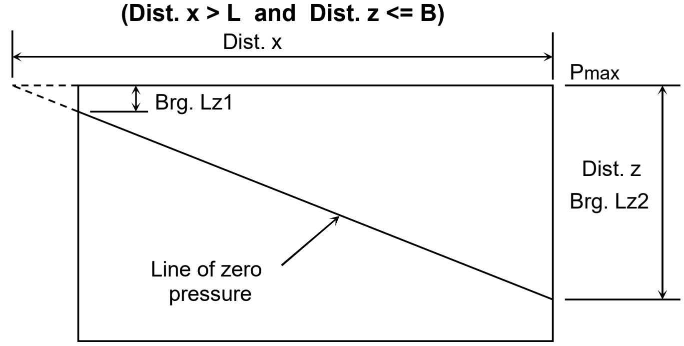
Sliding Check:			
FS(slid) =	3.42	>1	OK
Bearing Area Check:			
%Brg. Area =	100.00%	>1%	OK
Bearing Pressure Check:			
FS(brg) =	2.10	>1	OK
Flotation Check:			
FS (float) =	10.76	>1	OK

Nomenclature for Biaxial Eccentricity:

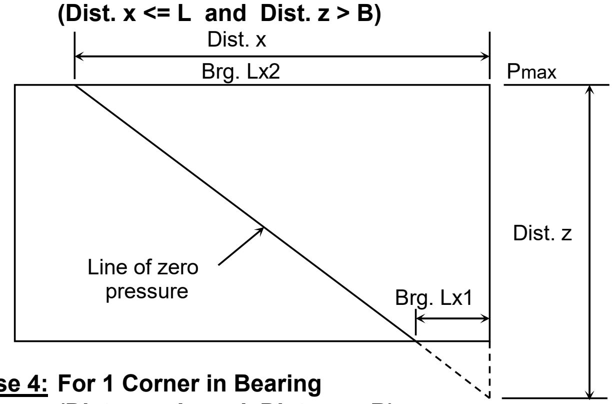
Case 1: For 3 Corners in Bearing
(Dist. x > L and Dist. z > B)



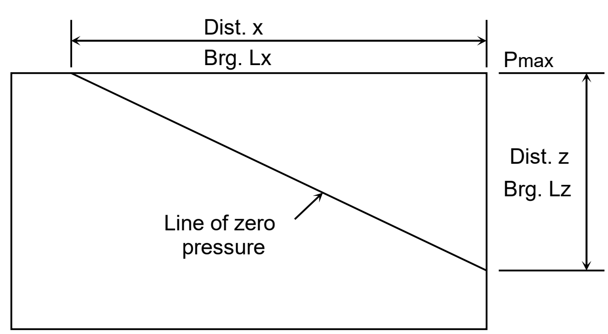
Case 2: For 2 Corners in Bearing
(Dist. x > L and Dist. z <= B)



Case 3: For 2 Corners in Bearing
(Dist. x <= L and Dist. z > B)



Case 4: For 1 Corner in Bearing
(Dist. x <= L and Dist. z <= B)



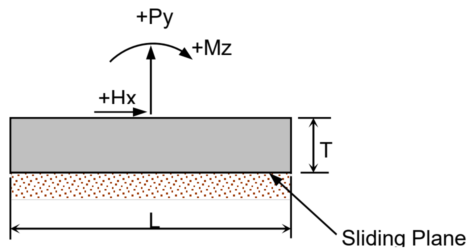
INTAKE TOWER STABILITY ANALYSIS

Job Name:	Springbank Off-Stream Storage Project (SR-1)	Number:	110773396
Site:	Intake Structure	Originator:	CG 7/2/2020 Checker: ACG
Load Case:	E15 Earthquake		

Input Data:

Footing Data:

Footing Length, L =	7.90	m
Footing Width, B =	6.30	m
Footing Thickness, T =	0.00	m
Coef. of Base Friction, μ =	0.42	
Ultimate Bearing, Pall =	450.00	kPa

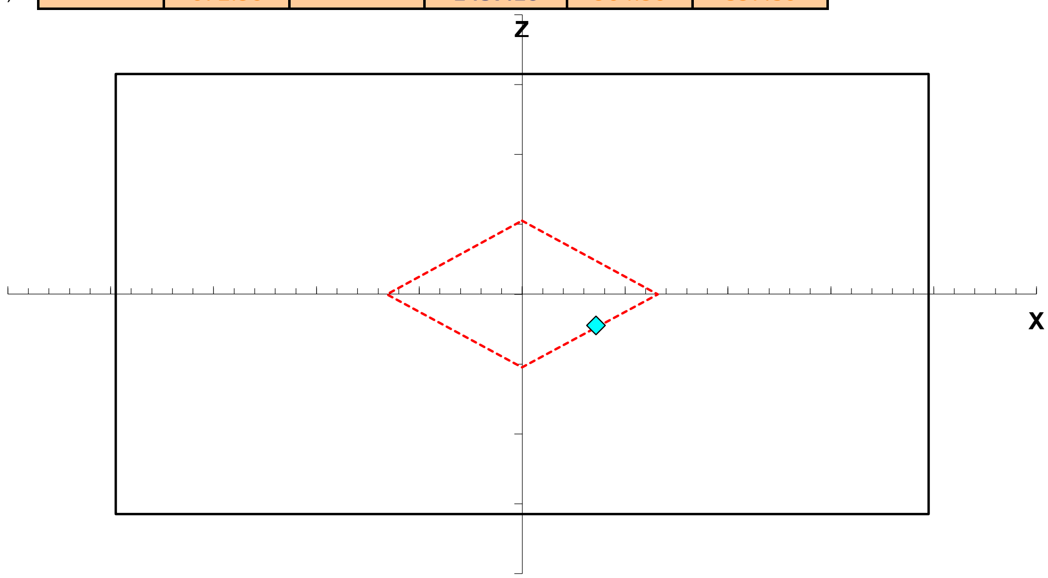


Nomenclature

Loading Data:

Direction of Seismic Force: COMBINED

	Uplift	Wind		EQ	Dead	Soil
Xp (m.) =						
Zp (m.) =						
Py (kN) =	553.10	0.00		-1143.00	-4357.34	-452.10
Hx (kN) =		87.90		223.47	0.00	-158.40
Hz (kN) =		78.50		567.21	0.00	0.00
Mx (kN-m) =		-498.40		2928.89	0.00	0.40
Mz (kN-m) =		672.50		1437.10	904.50	857.80



FOOTING PLAN

Note: Is the "Kern" area of footing (When resultant of loads falls within "Kern", entire footing base is in bearing.)

Results:

Total Resultant Load and Eccentricities:

ΣPy =	-5399.34	kN
ex =	0.72	m (<= L/6)
ez =	-0.45	m (<= B/6)
ΣHx =	152.97	kN
ΣHz =	645.71	kN
H resultant =	663.58	kN
ΣMrx =	18750.17	kN-m
ΣMox =	4173.16	kN-m
ΣMry =	23512.12	kN-m
ΣMoy =	6056.65	kN-m

Sliding Check:

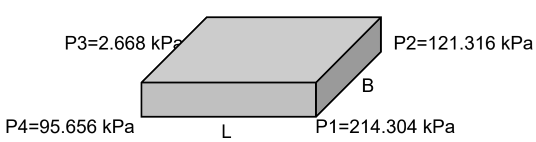
Frict =	2267.72	kN
FS(slid) =	3.417	

% Base Area in Compression:

Dist. x =	N.A.	m
Dist. z =	N.A.	m
Brg. Lx =	7.900	m
Brg. Lz =	6.300	m
%Brg. Area =	100.00	%
Biaxial Case =	N.A.	6*ex/L + 6*ez/B = 0.975

Gross Soil Bearing Corner Pressures:

P_1 =	214.304	kPa
P_2 =	121.316	kPa
P_3 =	2.668	kPa
P_4 =	95.656	kPa



CORNER PRESSURES

Summary of Results:

Sliding Check:

FS(slid) =	3.42	>1	OK

Bearing Area Check:

%Brg. Area =	100.00%	>1%	OK

Bearing Pressure Check:

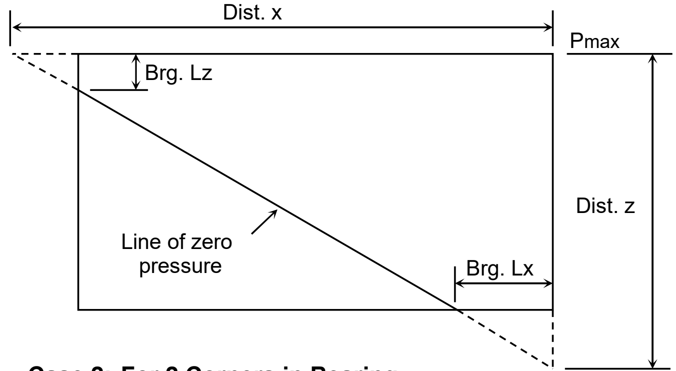
FS(brg) =	2.10	>1	OK

Flotation Check:

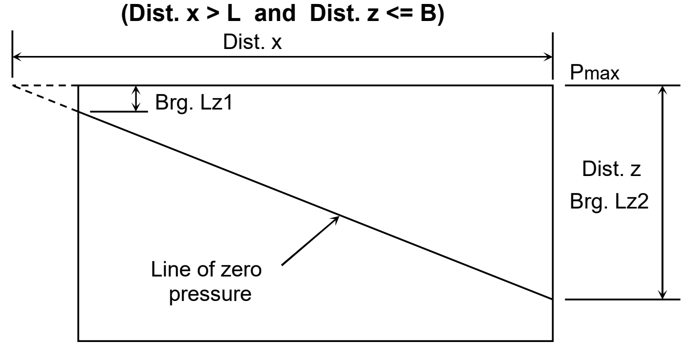
FS (float) =	10.76	>1	OK

Nomenclature for Biaxial Eccentricity:

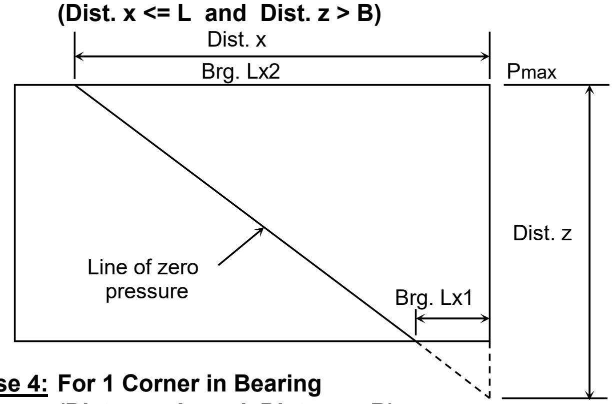
Case 1: For 3 Corners in Bearing
(Dist. x > L and Dist. z > B)



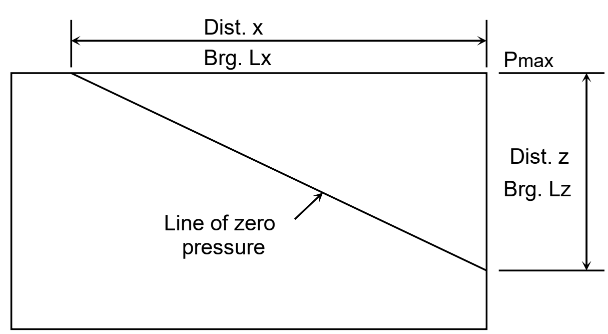
Case 2: For 2 Corners in Bearing
(Dist. x > L and Dist. z <= B)



Case 3: For 2 Corners in Bearing
(Dist. x <= L and Dist. z > B)



Case 4: For 1 Corner in Bearing
(Dist. x <= L and Dist. z <= B)



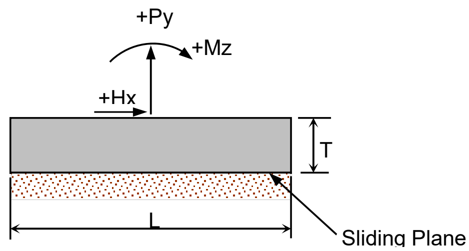
INTAKE TOWER STABILITY ANALYSIS

Job Name:	Springbank Off-Stream Storage Project (SR-1)	Number:	110773396		
Site:	Intake Structure	Originator:	CG 7/2/2020	Checker:	ACG
Load Case:	E16 Earthquake				

Input Data:

Footing Data:

Footing Length, L =	7.90	m
Footing Width, B =	6.30	m
Footing Thickness, T =	0.00	m
Coef. of Base Friction, μ =	0.42	
Ultimate Bearing, Pall =	450.00	kPa

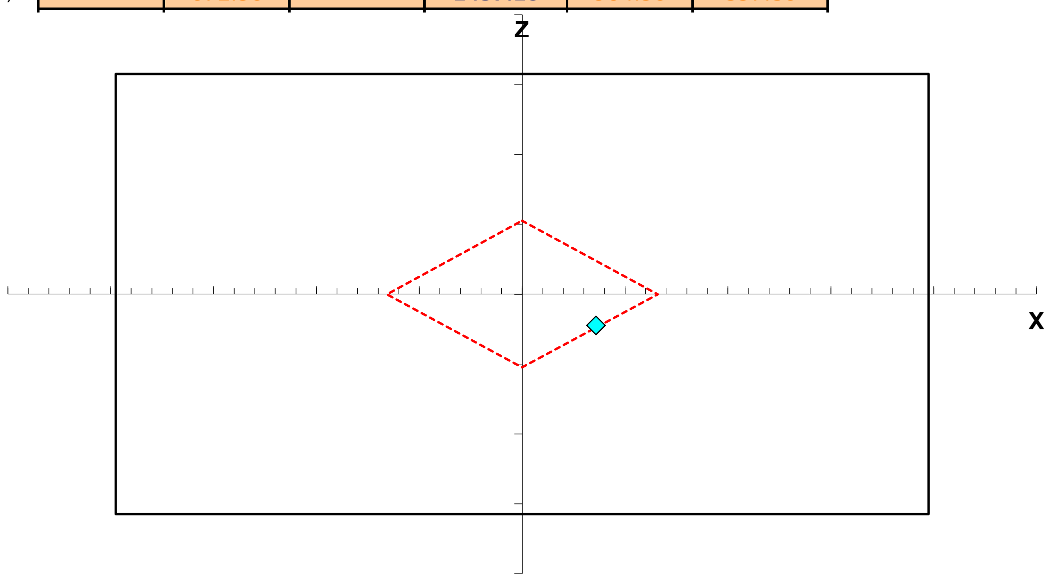


Nomenclature

Loading Data:

Direction of Seismic Force: COMBINED

	Uplift	Wind		EQ	Dead	Soil
Xp (m.) =						
Zp (m.) =						
Py (kN) =	553.10	0.00		**-1143.00**	-4357.34	-452.10
Hx (kN) =		87.90		**223.47**	0.00	-158.40
Hz (kN) =		78.50		**567.21**	0.00	0.00
Mx (kN-m) =		-498.40		**2928.89**	0.00	0.40
Mz (kN-m) =		672.50		**1437.10**	904.50	857.80



FOOTING PLAN

Note: Is the "Kern" area of footing (When resultant of loads falls within "Kern", entire footing base is in bearing.)

Results:

Total Resultant Load and Eccentricities:

ΣPy =	-5399.34	kN
ex =	0.72	m (<= L/6)
ez =	-0.45	m (<= B/6)
ΣHx =	152.97	kN
ΣHz =	645.71	kN
H resultant =	663.58	kN
ΣMrx =	18750.17	kN-m
ΣMox =	4173.16	kN-m
ΣMry =	23512.12	kN-m
ΣMoy =	6056.65	kN-m

Sliding Check:

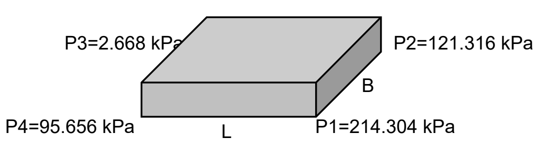
Frict =	2267.72	kN
FS(slid) =	3.417	

% Base Area in Compression:

Dist. x =	N.A.	m
Dist. z =	N.A.	m
Brg. Lx =	7.900	m
Brg. Lz =	6.300	m
%Brg. Area =	100.00	%
Biaxial Case =	N.A.	6*ex/L + 6*ez/B = 0.975

Gross Soil Bearing Corner Pressures:

P_1 =	214.304	kPa
P_2 =	121.316	kPa
P_3 =	2.668	kPa
P_4 =	95.656	kPa



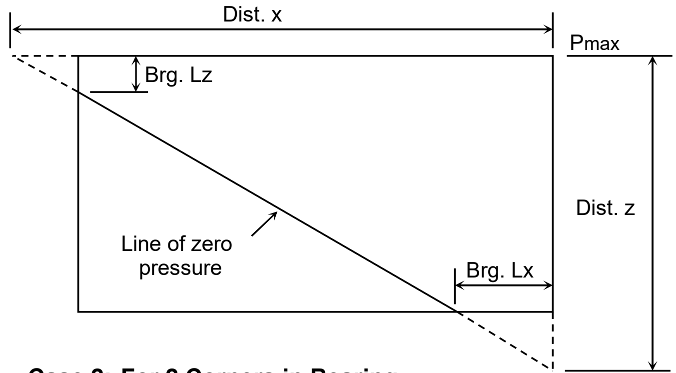
CORNER PRESSURES

Summary of Results:

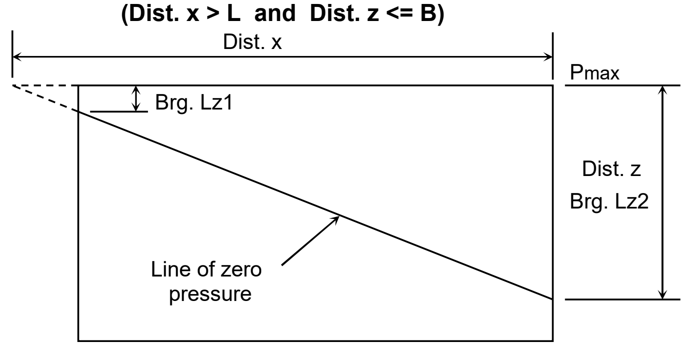
Sliding Check:			
FS(slid) =	3.42	>1	OK
Bearing Area Check:			
%Brg. Area =	100.00%	>1%	OK
Bearing Pressure Check:			
FS(brg) =	2.10	>1	OK
Flotation Check:			
FS (float) =	10.76	>1	OK

Nomenclature for Biaxial Eccentricity:

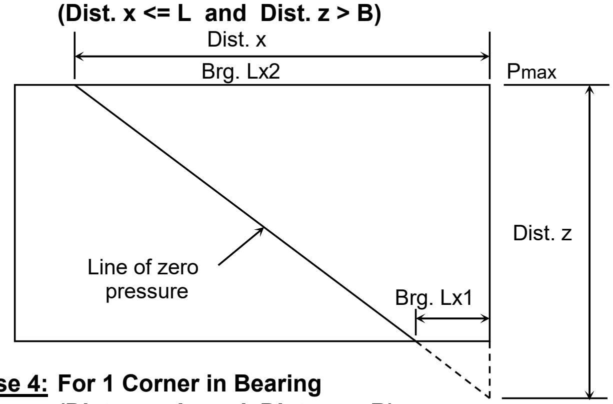
Case 1: For 3 Corners in Bearing
(Dist. x > L and Dist. z > B)



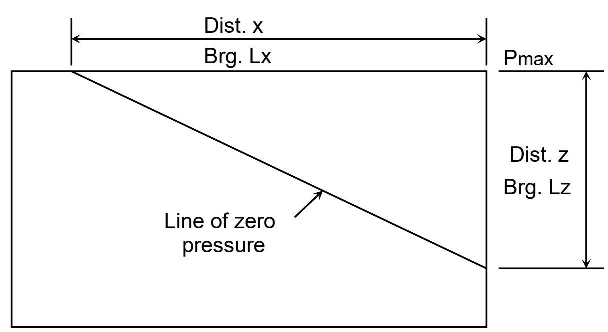
Case 2: For 2 Corners in Bearing
(Dist. x > L and Dist. z <= B)



Case 3: For 2 Corners in Bearing
(Dist. x <= L and Dist. z > B)



Case 4: For 1 Corner in Bearing
(Dist. x <= L and Dist. z <= B)



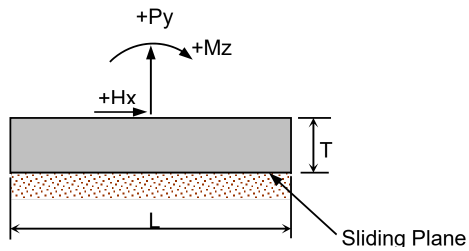
INTAKE TOWER STABILITY ANALYSIS

Job Name:	Springbank Off-Stream Storage Project (SR-1)	Number:	110773396			
Site:	Intake Structure	Originator:	CG	7/2/2020	Checker:	ACG
Load Case:	E17 Earthquake					

Input Data:

Footing Data:

Footing Length, L =	7.90	m
Footing Width, B =	6.30	m
Footing Thickness, T =	0.00	m
Coef. of Base Friction, μ =	0.42	
Ultimate Bearing, Pall =	450.00	kPa

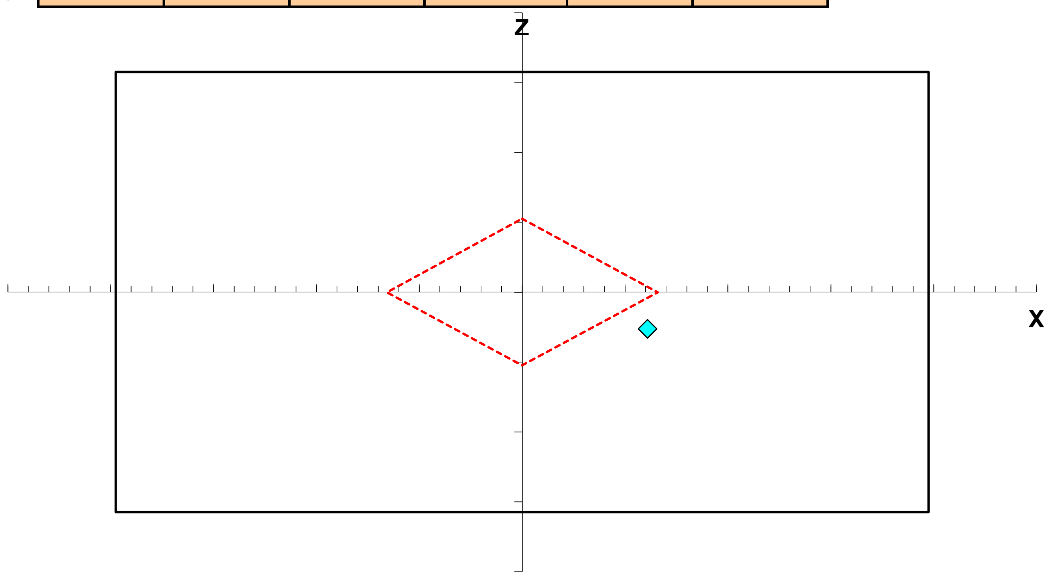


Nomenclature

Loading Data:

Direction of Seismic Force: COMBINED

	Uplift	Wind		EQ	Dead	Soil
Xp (m.) =						
Zp (m.) =						
Py (kN) =	553.10	0.00		**-354.46**	-4357.34	-452.10
Hx (kN) =		87.90		**644.95**	0.00	-158.40
Hz (kN) =		78.50		**567.21**	0.00	0.00
Mx (kN-m) =		-498.40		**2928.91**	0.00	0.40
Mz (kN-m) =		672.50		**3201.96**	904.50	857.80



FOOTING PLAN

Note: Is the "Kern" area of footing (When resultant of loads falls within "Kern", entire footing base is in bearing.)

Results:

Total Resultant Load and Eccentricities:

ΣPy =	-4610.80	kN
ex =	1.22	m (<= L/6)
ez =	-0.53	m (<= B/6)
ΣHx =	574.45	kN
ΣHz =	645.71	kN
H resultant =	864.25	kN
ΣMrx =	16266.29	kN-m
ΣMox =	4173.17	kN-m
ΣMry =	20397.41	kN-m
ΣMoy =	7821.51	kN-m

Sliding Check:

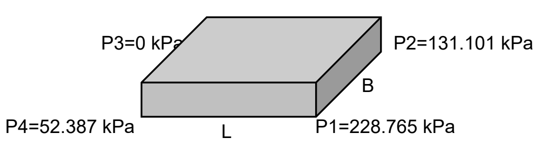
Frict =	1936.54	kN
FS(slid) =	2.24	

% Base Area in Compression:

Dist. x =	10.246	m
Dist. z =	14.757	m
Brg. Lx =	5.872	m
Brg. Lz =	3.379	m
%Brg. Area =	94.05	%
Biaxial Case =	Case 1	6*ex/L + 6*ez/B = 1.431

Gross Soil Bearing Corner Pressures:

P_1 =	228.765	kPa
P_2 =	131.101	kPa
P_3 =	0.000	kPa
P_4 =	52.387	kPa



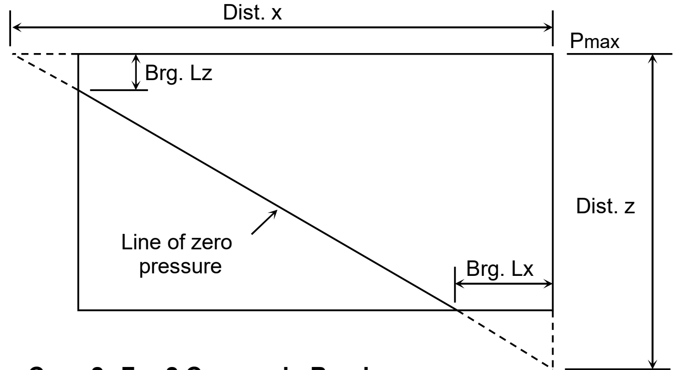
CORNER PRESSURES

Summary of Results:

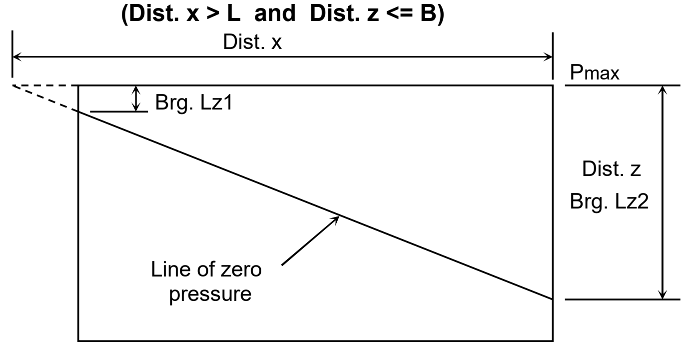
Sliding Check:			
FS(slid) =	2.24	>1	OK
Bearing Area Check:			
%Brg. Area =	94.05%	>1%	OK
Bearing Pressure Check:			
FS(brg) =	1.97	>1	OK
Flotation Check:			
FS (float) =	9.34	>1	OK

Nomenclature for Biaxial Eccentricity:

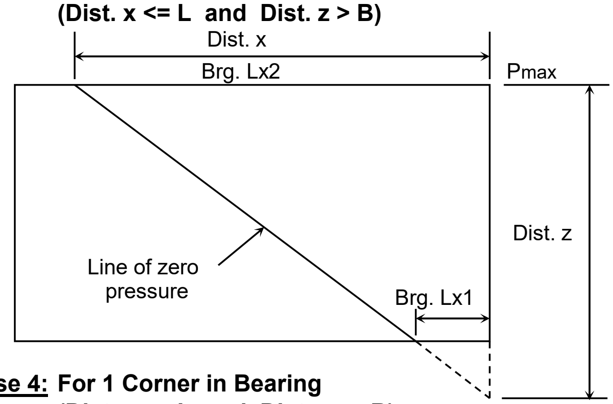
Case 1: For 3 Corners in Bearing (Dist. x > L and Dist. z > B)



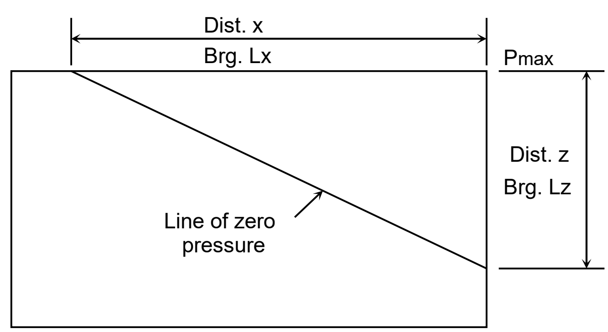
Case 2: For 2 Corners in Bearing (Dist. x > L and Dist. z <= B)



Case 3: For 2 Corners in Bearing (Dist. x <= L and Dist. z > B)



Case 4: For 1 Corner in Bearing (Dist. x <= L and Dist. z <= B)



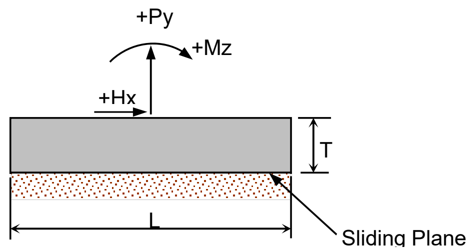
INTAKE TOWER STABILITY ANALYSIS

Job Name:	Springbank Off-Stream Storage Project (SR-1)	Number:	110773396		
Site:	Intake Structure	Originator:	CG 7/2/2020	Checker:	ACG
Load Case:	E18 Earthquake				

Input Data:

Footing Data:

Footing Length, L =	7.90	m
Footing Width, B =	6.30	m
Footing Thickness, T =	0.00	m
Coef. of Base Friction, μ =	0.42	
Ultimate Bearing, Pall =	450.00	kPa

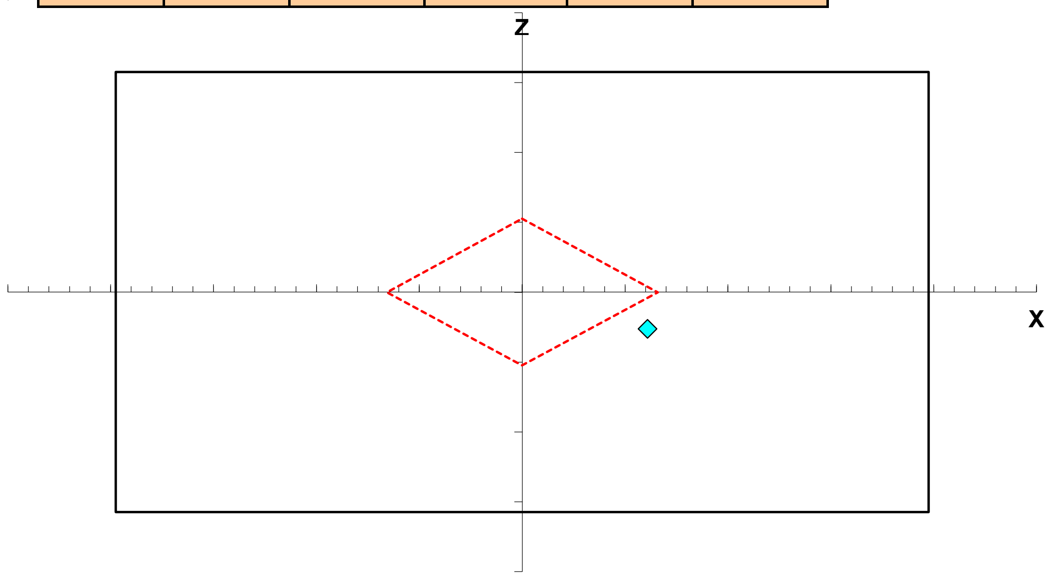


Nomenclature

Loading Data:

Direction of Seismic Force: COMBINED

	Uplift	Wind	Extra Moment	EQ	Dead	Soil
Xp (m.) =						
Zp (m.) =						
Py (kN) =	553.10	0.00		**-354.46**	-4357.34	-452.10
Hx (kN) =		87.90		**644.95**	0.00	-158.40
Hz (kN) =		78.50		**567.21**	0.00	0.00
Mx (kN-m) =		-498.40		**2928.91**	0.00	0.40
Mz (kN-m) =		672.50		**3201.96**	904.50	857.80



FOOTING PLAN

Note: Is the "Kern" area of footing (When resultant of loads falls within "Kern", entire footing base is in bearing.)

Results:

Total Resultant Load and Eccentricities:

ΣPy =	-4610.80	kN
ex =	1.22	m (<= L/6)
ez =	-0.53	m (<= B/6)
ΣHx =	574.45	kN
ΣHz =	645.71	kN
H resultant =	864.25	kN
ΣMrx =	16266.29	kN-m
ΣMox =	4173.17	kN-m
ΣMry =	20397.41	kN-m
ΣMoy =	7821.51	kN-m

Sliding Check:

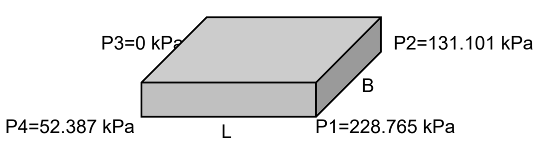
Frict =	1936.54	kN
FS(slid) =	2.24	

% Base Area in Compression:

Dist. x =	10.246	m
Dist. z =	14.757	m
Brg. Lx =	5.872	m
Brg. Lz =	3.379	m
%Brg. Area =	94.05	%
Biaxial Case =	Case 1	6*ex/L + 6*ez/B = 1.431

Gross Soil Bearing Corner Pressures:

P1 =	228.765	kPa
P2 =	131.101	kPa
P3 =	0.000	kPa
P4 =	52.387	kPa



CORNER PRESSURES

Summary of Results:

Sliding Check:

FS(slid) =	2.24	>1	OK

Bearing Area Check:

%Brg. Area =	94.05%	>1%	OK

Bearing Pressure Check:

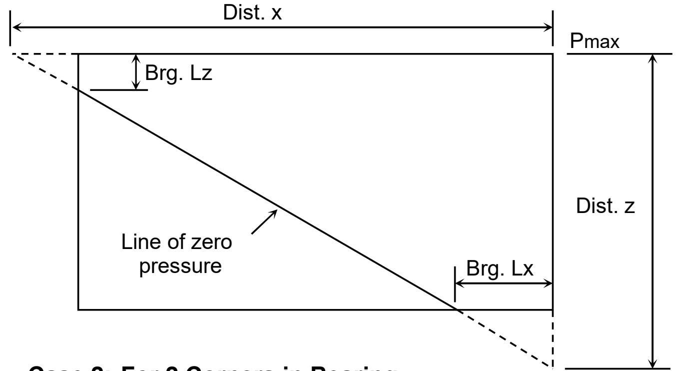
FS(brg) =	1.97	>1	OK

Flotation Check:

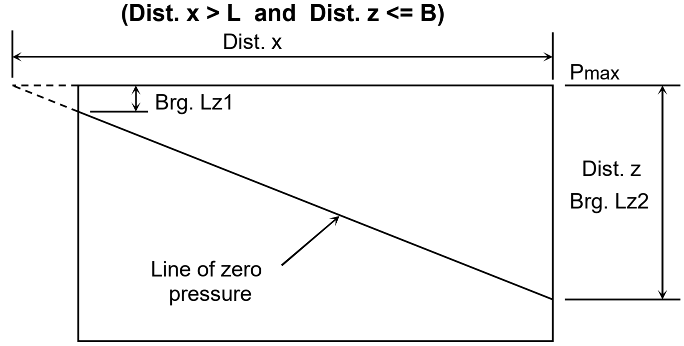
FS (float) =	9.34	>1	OK

Nomenclature for Biaxial Eccentricity:

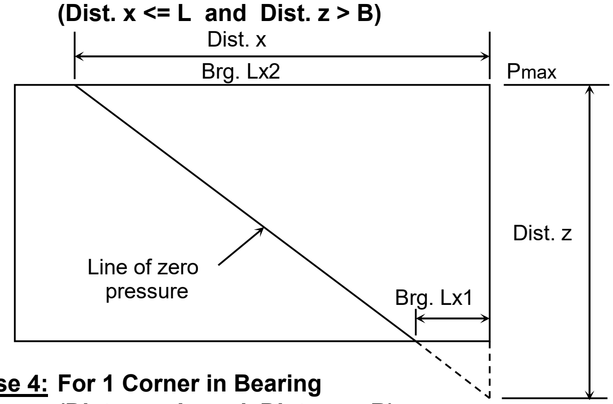
Case 1: For 3 Corners in Bearing
(Dist. x > L and Dist. z > B)



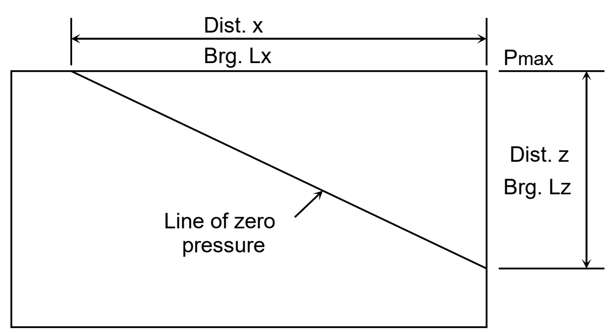
Case 2: For 2 Corners in Bearing
(Dist. x > L and Dist. z <= B)



Case 3: For 2 Corners in Bearing
(Dist. x <= L and Dist. z > B)



Case 4: For 1 Corner in Bearing
(Dist. x <= L and Dist. z <= B)



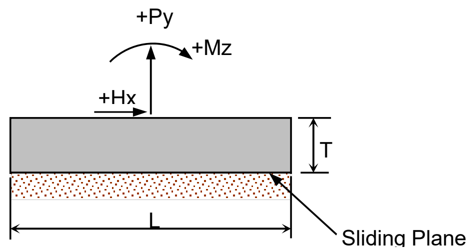
INTAKE TOWER STABILITY ANALYSIS

Job Name:	Springbank Off-Stream Storage Project (SR-1)	Number:	110773396		
Site:	Intake Structure	Originator:	CG 7/2/2020	Checker:	ACG
Load Case:	E19 Earthquake				

Input Data:

Footing Data:

Footing Length, L =	7.90	m
Footing Width, B =	6.30	m
Footing Thickness, T =	0.00	m
Coef. of Base Friction, μ =	0.42	
Ultimate Bearing, Pall =	450.00	kPa

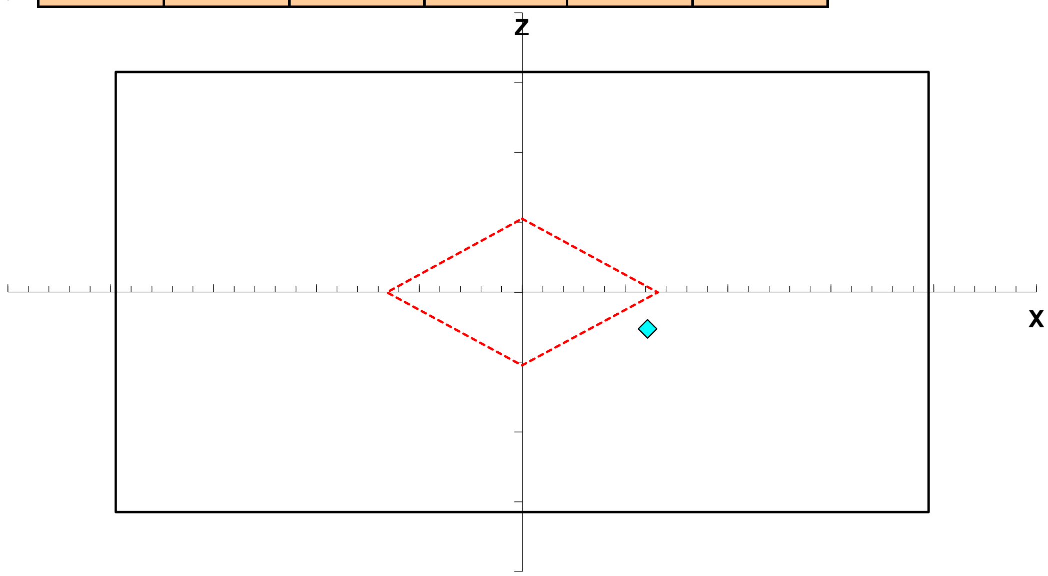


Nomenclature

Loading Data:

Direction of Seismic Force: COMBINED

	Uplift	Wind	Extra Moment	EQ	Dead	Soil
Xp (m.) =						
Zp (m.) =						
Py (kN) =	553.10	0.00		-354.46	-4357.34	-452.10
Hx (kN) =		87.90		644.95	0.00	-158.40
Hz (kN) =		78.50		567.21	0.00	0.00
Mx (kN-m) =		-498.40		2928.91	0.00	0.40
Mz (kN-m) =		672.50		3201.96	904.50	857.80



FOOTING PLAN

Note: Is the "Kern" area of footing (When resultant of loads falls within "Kern", entire footing base is in bearing.)

Results:

Total Resultant Load and Eccentricities:

ΣPy =	-4610.80	kN
ex =	1.22	m (<= L/6)
ez =	-0.53	m (<= B/6)
ΣHx =	574.45	kN
ΣHz =	645.71	kN
H resultant =	864.25	kN
ΣMrx =	16266.29	kN-m
ΣMox =	4173.17	kN-m
ΣMry =	20397.41	kN-m
ΣMoy =	7821.51	kN-m

Sliding Check:

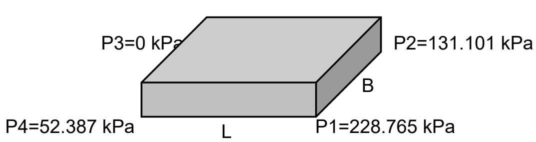
Frict =	1936.54	kN
FS(slid) =	2.24	

% Base Area in Compression:

Dist. x =	10.246	m
Dist. z =	14.757	m
Brg. Lx =	5.872	m
Brg. Lz =	3.379	m
%Brg. Area =	94.05	%
Biaxial Case =	Case 1	6*ex/L + 6*ez/B = 1.431

Gross Soil Bearing Corner Pressures:

P_1 =	228.765	kPa
P_2 =	131.101	kPa
P_3 =	0.000	kPa
P_4 =	52.387	kPa



CORNER PRESSURES

Summary of Results:

Sliding Check:

FS(slid) =	2.24	>1	OK

Bearing Area Check:

%Brg. Area =	94.05%	>1%	OK

Bearing Pressure Check:

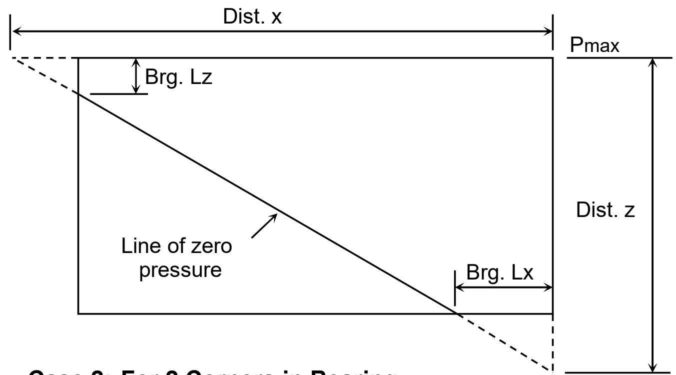
FS(brg) =	1.97	>1	OK

Flotation Check:

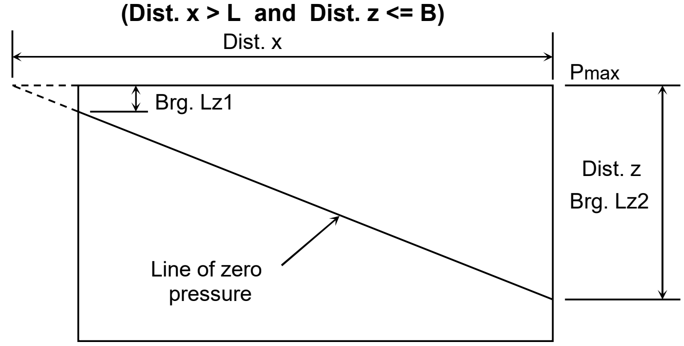
FS (float) =	9.34	>1	OK

Nomenclature for Biaxial Eccentricity:

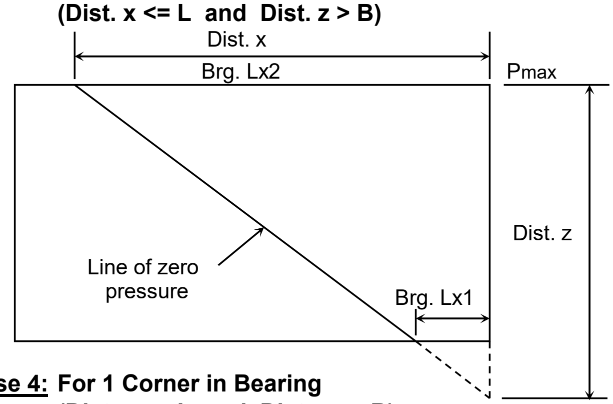
Case 1: For 3 Corners in Bearing (Dist. x > L and Dist. z > B)



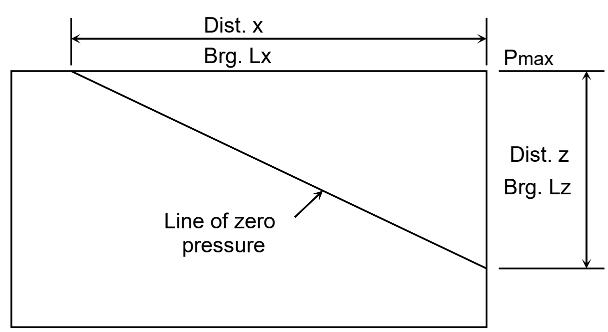
Case 2: For 2 Corners in Bearing (Dist. x > L and Dist. z <= B)



Case 3: For 2 Corners in Bearing (Dist. x <= L and Dist. z > B)



Case 4: For 1 Corner in Bearing (Dist. x <= L and Dist. z <= B)



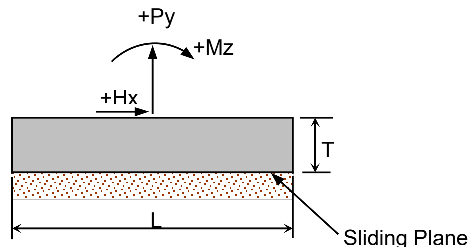
INTAKE TOWER STABILITY ANALYSIS

Job Name:	Springbank Off-Stream Storage Project (SR-1)	Number:	110773396
Site:	Intake Structure	Originator:	CG 7/2/2020 Checker: ACG
Load Case:	E20 Earthquake		

Input Data:

Footing Data:

Footing Length, L =	7.90	m
Footing Width, B =	6.30	m
Footing Thickness, T =	0.00	m
Coef. of Base Friction, μ =	0.42	
Ultimate Bearing, Pall =	450.00	kPa

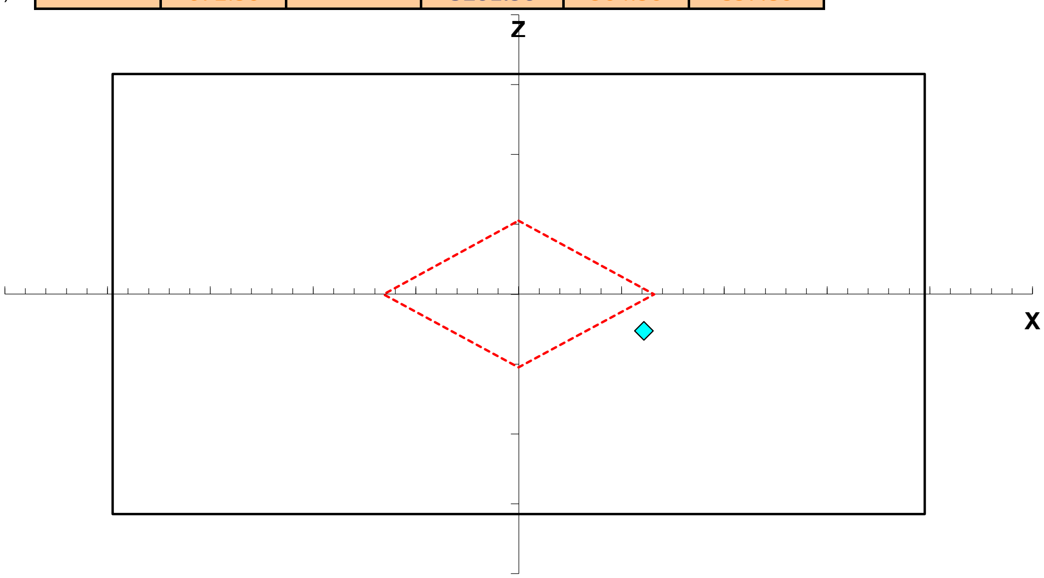


Nomenclature

Loading Data:

Direction of Seismic Force: COMBINED

	Uplift	Wind		EQ	Dead	Soil
Xp (m.) =						
Zp (m.) =						
Py (kN) =	553.10	0.00		-354.46	-4357.34	-452.10
Hx (kN) =		87.90		644.95	0.00	-158.40
Hz (kN) =		78.50		567.21	0.00	0.00
Mx (kN-m) =		-498.40		2928.91	0.00	0.40
Mz (kN-m) =		672.50		3201.96	904.50	857.80



FOOTING PLAN

Note: Is the "Kern" area of footing (When resultant of loads falls within "Kern", entire footing base is in bearing.)

Results:

Total Resultant Load and Eccentricities:

ΣPy =	-4610.80	kN
ex =	1.22	m (<= L/6)
ez =	-0.53	m (<= B/6)
ΣHx =	574.45	kN
ΣHz =	645.71	kN
H resultant =	864.25	kN
ΣMrx =	16266.29	kN-m
ΣMox =	4173.17	kN-m
ΣMry =	20397.41	kN-m
ΣMoy =	7821.51	kN-m

Sliding Check:

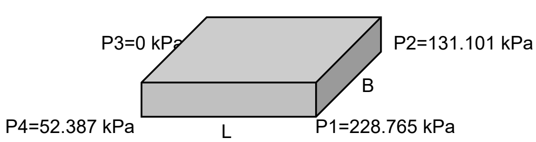
Frict =	1936.54	kN
FS(slid) =	2.24	

% Base Area in Compression:

Dist. x =	10.246	m
Dist. z =	14.757	m
Brg. Lx =	5.872	m
Brg. Lz =	3.379	m
%Brg. Area =	94.05	%
Biaxial Case =	Case 1	6*ex/L + 6*ez/B = 1.431

Gross Soil Bearing Corner Pressures:

P_1 =	228.765	kPa
P_2 =	131.101	kPa
P_3 =	0.000	kPa
P_4 =	52.387	kPa



CORNER PRESSURES

Summary of Results:

Sliding Check:

FS(slid) =	2.24	>1	OK

Bearing Area Check:

%Brg. Area =	94.05%	>1%	OK

Bearing Pressure Check:

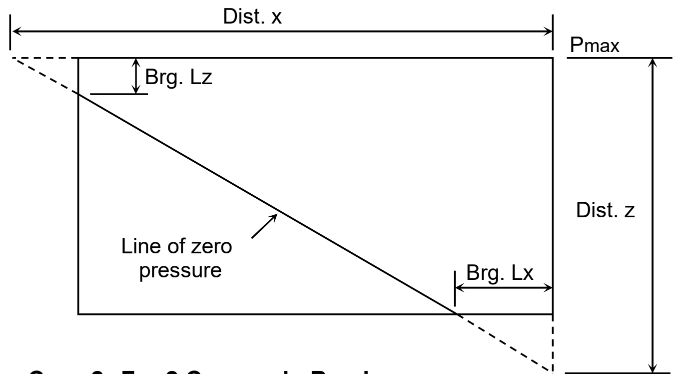
FS(brg) =	1.97	>1	OK

Flotation Check:

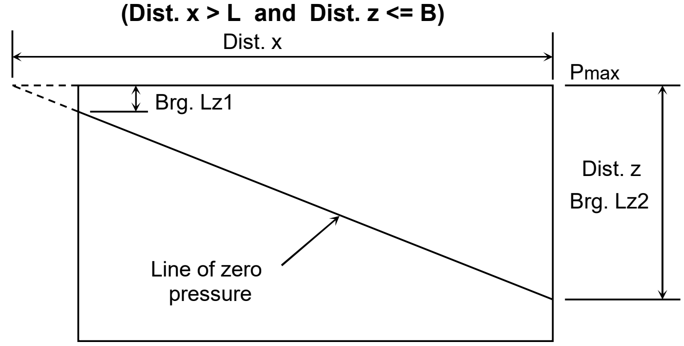
FS (float) =	9.34	>1	OK

Nomenclature for Biaxial Eccentricity:

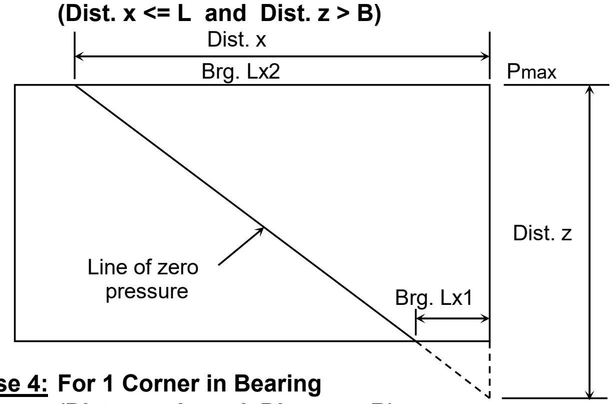
Case 1: For 3 Corners in Bearing (Dist. x > L and Dist. z > B)



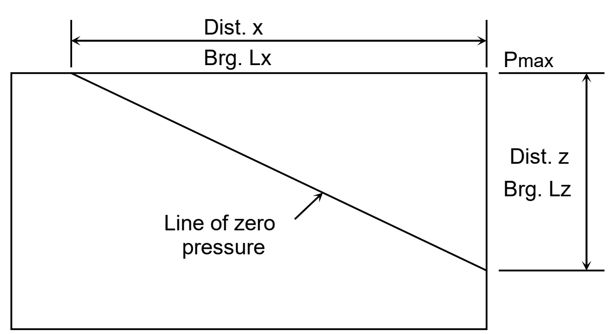
Case 2: For 2 Corners in Bearing (Dist. x > L and Dist. z <= B)



Case 3: For 2 Corners in Bearing (Dist. x <= L and Dist. z > B)



Case 4: For 1 Corner in Bearing (Dist. x <= L and Dist. z <= B)



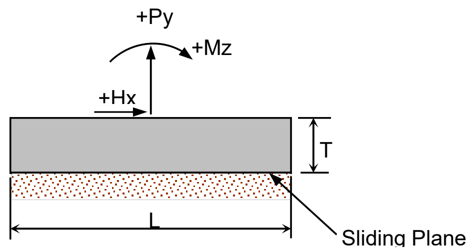
INTAKE TOWER STABILITY ANALYSIS

Job Name:	Springbank Off-Stream Storage Project (SR-1)	Number:	110773396		
Site:	Intake Structure	Originator:	CG 7/2/2020	Checker:	ACG
Load Case:	E21 Earthquake				

Input Data:

Footing Data:

Footing Length, L =	7.90	m
Footing Width, B =	6.30	m
Footing Thickness, T =	0.00	m
Coef. of Base Friction, μ =	0.42	
Ultimate Bearing, Pall =	450.00	kPa

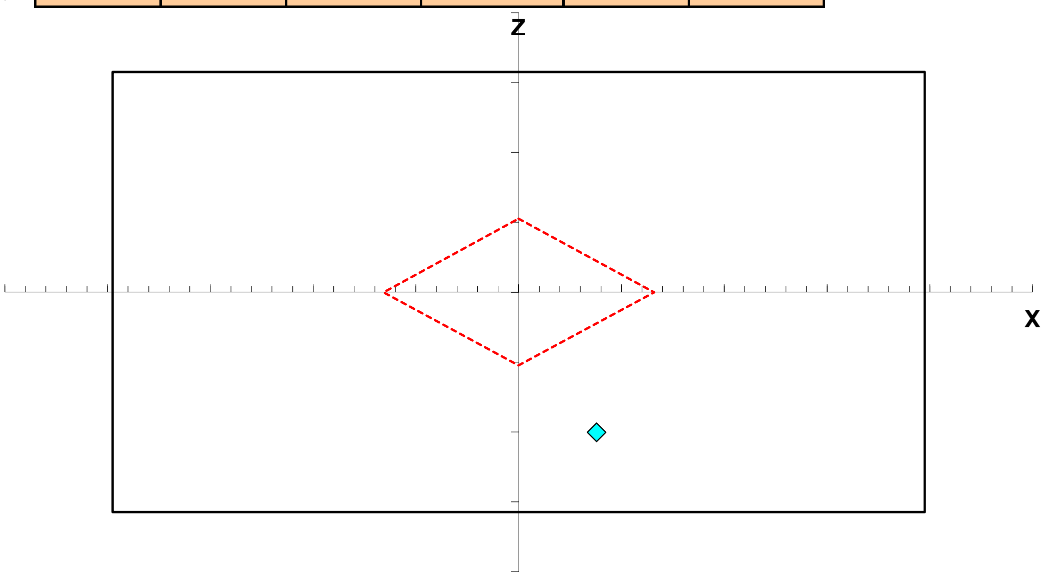


Nomenclature

Loading Data:

Direction of Seismic Force: COMBINED

	Uplift	Wind		EQ	Dead	Soil
Xp (m.) =						
Zp (m.) =						
Py (kN) =	553.10	0.00		-345.57	-4357.34	-452.10
Hx (kN) =		87.90		200.47	0.00	-158.40
Hz (kN) =		78.50		1890.69	0.00	0.00
Mx (kN-m) =		-498.40		9762.96	0.00	0.40
Mz (kN-m) =		672.50		1070.74	904.50	857.80



FOOTING PLAN

Note: Is the "Kern" area of footing (When resultant of loads falls within "Kern", entire footing base is in bearing.)

Results:

Total Resultant Load and Eccentricities:

ΣPy =	-4601.91	kN
ex =	0.76	m (<= L/6)
ez =	-2.01	m (> B/6)
ΣHx =	129.97	kN
ΣHz =	1969.19	kN
H resultant =	1973.48	kN
ΣMrx =	16238.27	kN-m
ΣMox =	11007.22	kN-m
ΣMry =	20362.28	kN-m
ΣMoy =	5690.28	kN-m

Sliding Check:

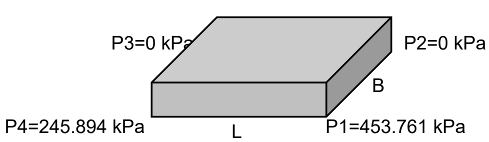
Frict =	1932.80	kN
FS(slid) =	0.979	

% Base Area in Compression:

Dist. x =	17.245	m
Dist. z =	4.196	m
Brg. Lz1 =	2.274	m
Brg. Lz2 =	4.196	m
%Brg. Area =	51.35	%
Biaxial Case =	Case 2	6*ex/L + 6*ez/B = 2.492

Gross Soil Bearing Corner Pressures:

P_1 =	453.761	kPa
P_2 =	0.000	kPa
P_3 =	0.000	kPa
P_4 =	245.894	kPa



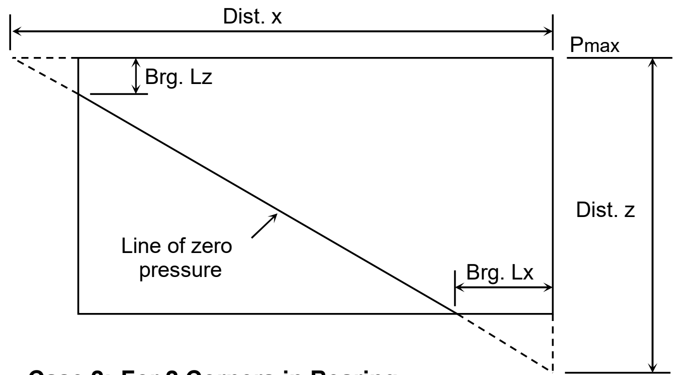
CORNER PRESSURES

Summary of Results:

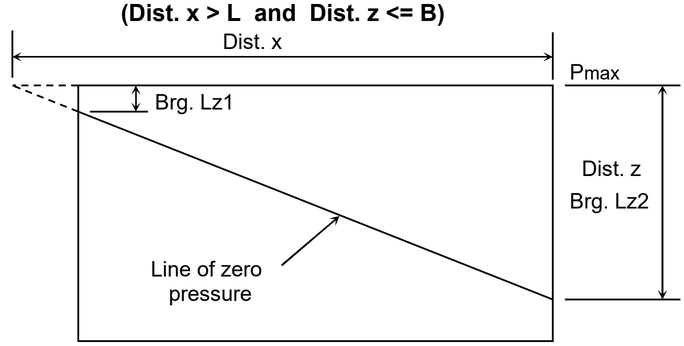
Sliding Check:			
FS(slid) =	1.00	>1	OK
Bearing Area Check:			
%Brg. Area =	51.35%	>1%	OK
Bearing Pressure Check:			
FS(brg) =	0.99	<1	NG
Flotation Check:			
FS (float) =	9.32	>1	OK

Nomenclature for Biaxial Eccentricity:

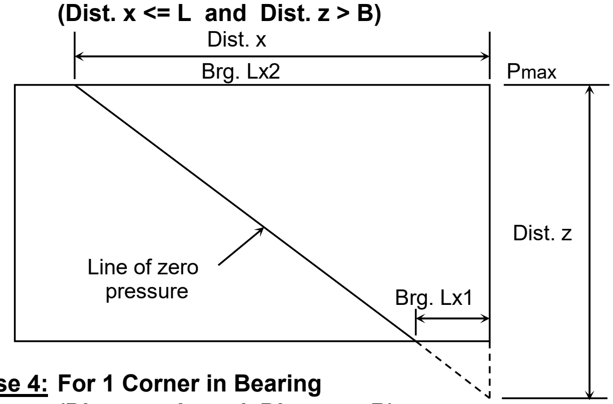
Case 1: For 3 Corners in Bearing
(Dist. x > L and Dist. z > B)



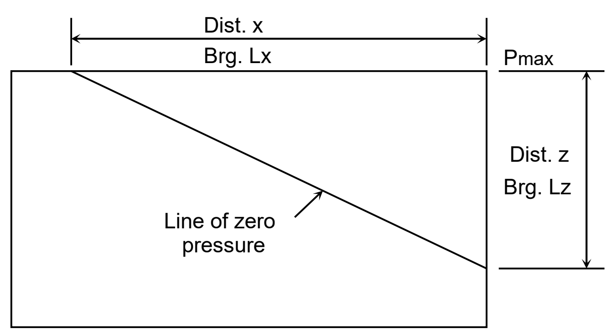
Case 2: For 2 Corners in Bearing
(Dist. x > L and Dist. z <= B)



Case 3: For 2 Corners in Bearing
(Dist. x <= L and Dist. z > B)



Case 4: For 1 Corner in Bearing
(Dist. x <= L and Dist. z <= B)



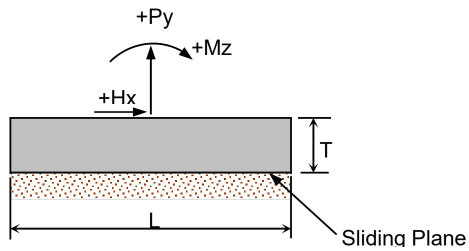
INTAKE TOWER STABILITY ANALYSIS

Job Name:	Springbank Off-Stream Storage Project (SR-1)	Number:	110773396		
Site:	Intake Structure	Originator:	CG 7/2/2020	Checker:	ACG
Load Case:	E22 Earthquake				

Input Data:

Footing Data:

Footing Length, L =	7.90	m
Footing Width, B =	6.30	m
Footing Thickness, T =	0.00	m
Coef. of Base Friction, μ =	0.42	
Ultimate Bearing, Pall =	450.00	kPa

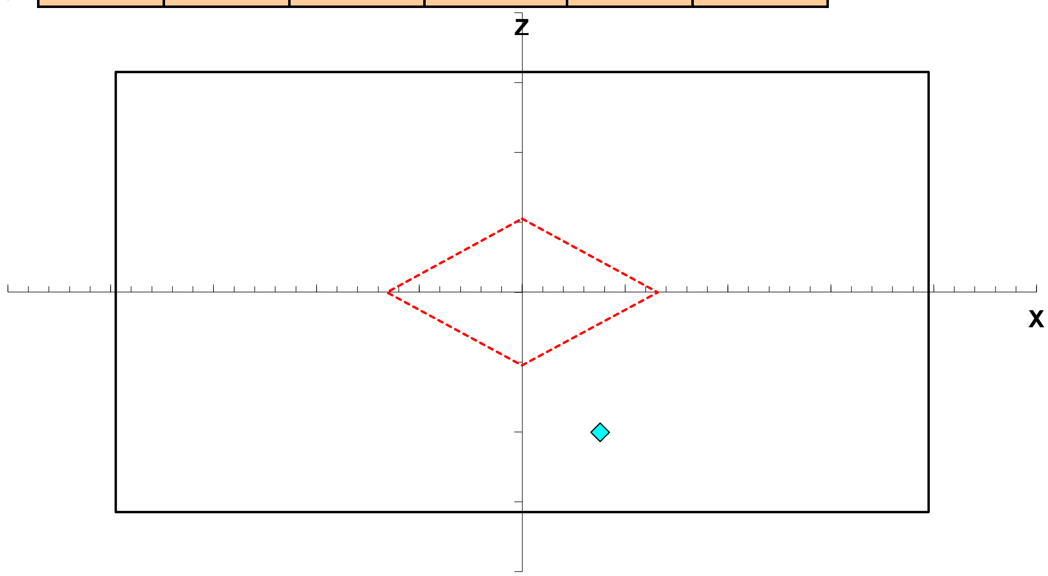


Nomenclature

Loading Data:

Direction of Seismic Force: COMBINED

	Uplift	Wind	Extra Moment	EQ	Dead	Soil
Xp (m.) =						
Zp (m.) =						
Py (kN) =	553.10	0.00		**-345.57**	-4357.34	-452.10
Hx (kN) =	0.00	87.90		**200.47**	0.00	-158.40
Hz (kN) =	0.00	78.50		**1890.69**	0.00	0.00
Mx (kN-m) =	0.00	-498.40		**9762.96**	0.00	0.40
Mz (kN-m) =	0.00	672.50		**1070.74**	904.50	857.80



FOOTING PLAN

Note: Is the "Kern" area of footing (When resultant of loads falls within "Kern", entire footing base is in bearing.)

Results:

Total Resultant Load and Eccentricities:

ΣPy =	-4601.91	kN
ex =	0.76	m (<= L/6)
ez =	-2.01	m (> B/6)
ΣHx =	129.97	kN
ΣHz =	1969.19	kN
H resultant =	1973.48	kN
ΣMrx =	16238.27	kN-m
ΣMox =	11007.22	kN-m
ΣMry =	20362.28	kN-m
ΣMoy =	5690.28	kN-m

Sliding Check:

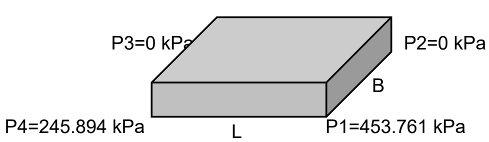
Frict =	1932.80	kN
FS(slid) =	0.979	

% Base Area in Compression:

Dist. x =	17.245	m
Dist. z =	4.196	m
Brg. Lz1 =	2.274	m
Brg. Lz2 =	4.196	m
%Brg. Area =	51.35	%
Biaxial Case =	Case 2	6*ex/L + 6*ez/B = 2.492

Gross Soil Bearing Corner Pressures:

P_1 =	453.761	kPa
P_2 =	0.000	kPa
P_3 =	0.000	kPa
P_4 =	245.894	kPa



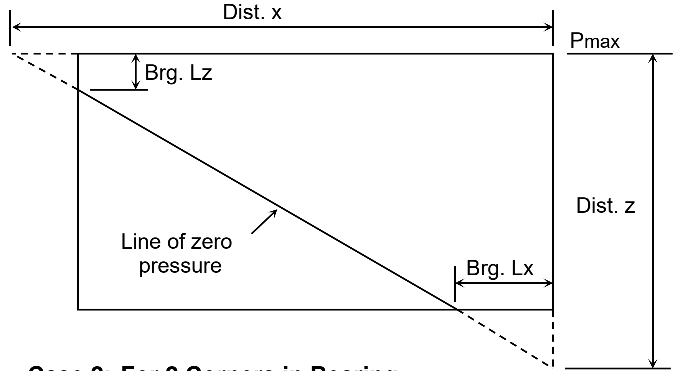
CORNER PRESSURES

Summary of Results:

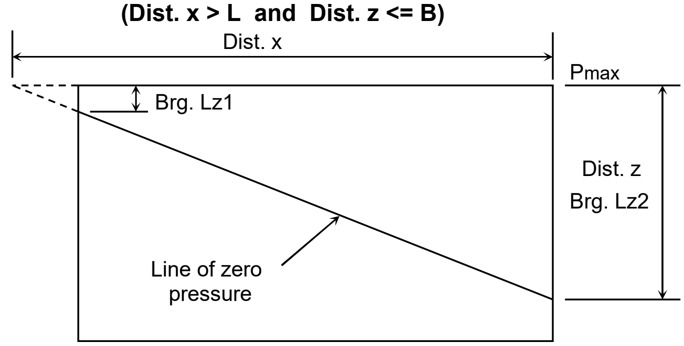
Sliding Check:			
FS(slid) =	1.00	>1	OK
Bearing Area Check:			
%Brg. Area =	51.35%	>1%	OK
Bearing Pressure Check:			
FS(brg) =	0.99	<1	NG
Flotation Check:			
FS (float) =	9.32	>1	OK

Nomenclature for Biaxial Eccentricity:

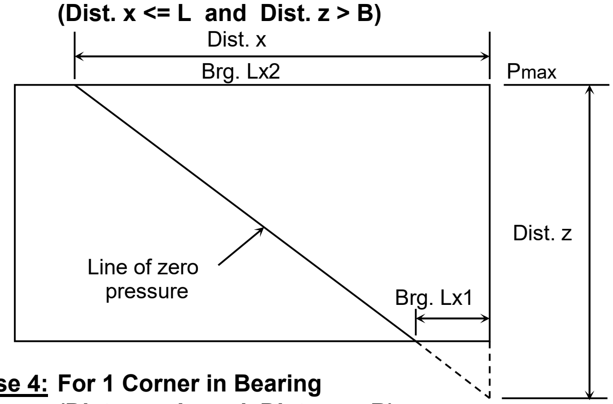
Case 1: For 3 Corners in Bearing
(Dist. x > L and Dist. z > B)



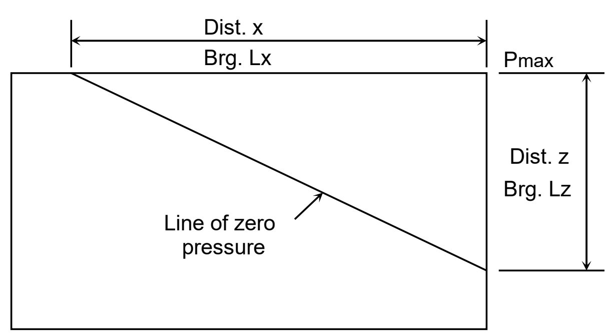
Case 2: For 2 Corners in Bearing
(Dist. x > L and Dist. z <= B)



Case 3: For 2 Corners in Bearing
(Dist. x <= L and Dist. z > B)



Case 4: For 1 Corner in Bearing
(Dist. x <= L and Dist. z <= B)



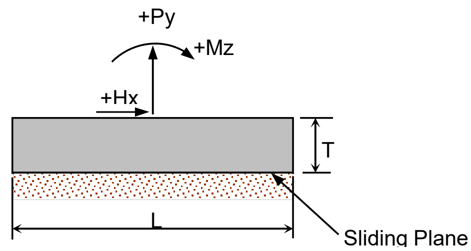
INTAKE TOWER STABILITY ANALYSIS

Job Name:	Springbank Off-Stream Storage Project (SR-1)	Number:	110773396		
Site:	Intake Structure	Originator:	CG 7/2/2020	Checker:	ACG
Load Case:	E23 Earthquake				

Input Data:

Footing Data:

Footing Length, L =	7.90	m
Footing Width, B =	6.30	m
Footing Thickness, T =	0.00	m
Coef. of Base Friction, μ =	0.42	
Ultimate Bearing, Pall =	450.00	kPa

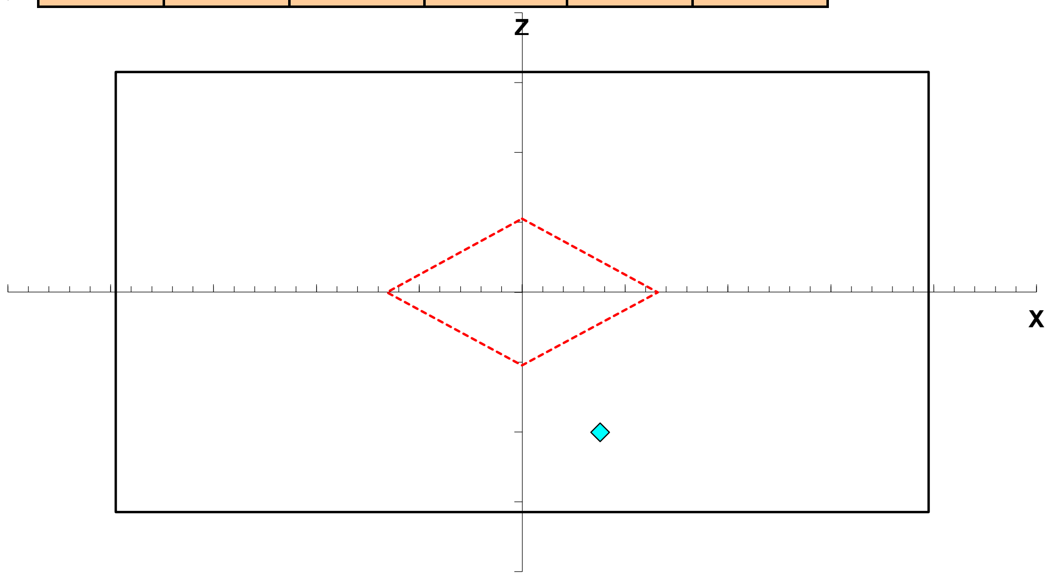


Nomenclature

Loading Data:

Direction of Seismic Force: COMBINED

	Uplift	Wind		EQ	Dead	Soil
Xp (m.) =						
Zp (m.) =						
Py (kN) =	553.10	0.00		**-345.57**	-4357.34	-452.10
Hx (kN) =		87.90		**200.47**	0.00	-158.40
Hz (kN) =		78.50		**1890.69**	0.00	0.00
Mx (kN-m) =		-498.40		**9762.96**	0.00	0.40
Mz (kN-m) =		672.50		**1070.74**	904.50	857.80



FOOTING PLAN

Note: Is the "Kern" area of footing (When resultant of loads falls within "Kern", entire footing base is in bearing.)

Results:

Total Resultant Load and Eccentricities:

ΣPy =	-4601.91	kN
ex =	0.76	m (<= L/6)
ez =	-2.01	m (> B/6)
ΣHx =	129.97	kN
ΣHz =	1969.19	kN
H resultant =	1973.48	kN
ΣMrx =	16238.27	kN-m
ΣMox =	11007.22	kN-m
ΣMry =	20362.28	kN-m
ΣMoy =	5690.28	kN-m

Sliding Check:

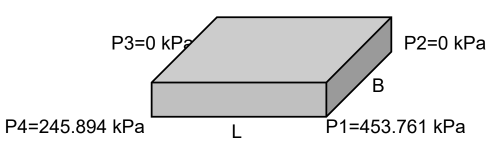
Frict =	1932.80	kN
FS(slid) =	0.979	

% Base Area in Compression:

Dist. x =	17.245	m
Dist. z =	4.196	m
Brg. Lz1 =	2.274	m
Brg. Lz2 =	4.196	m
%Brg. Area =	51.35	%
Biaxial Case =	Case 2	6*ex/L + 6*ez/B = 2.492

Gross Soil Bearing Corner Pressures:

P1 =	453.761	kPa
P2 =	0.000	kPa
P3 =	0.000	kPa
P4 =	245.894	kPa



CORNER PRESSURES

Summary of Results:

Sliding Check:

FS(slid) =	1.00	>1	OK

Bearing Area Check:

%Brg. Area =	51.35%	>1%	OK

Bearing Pressure Check:

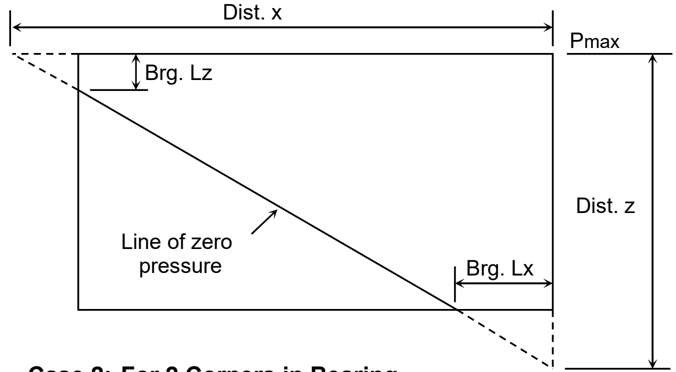
FS(brg) =	0.99	<1	NG

Flotation Check:

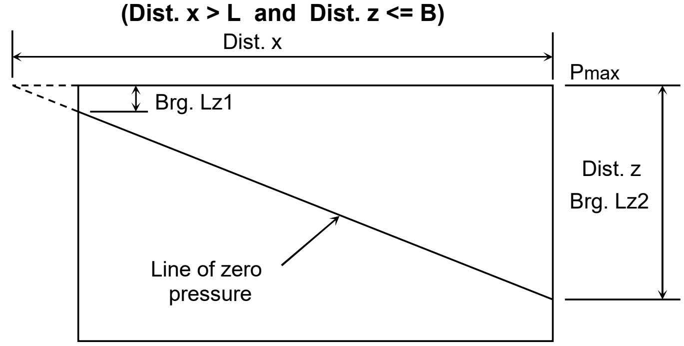
FS (float) =	9.32	>1	OK

Nomenclature for Biaxial Eccentricity:

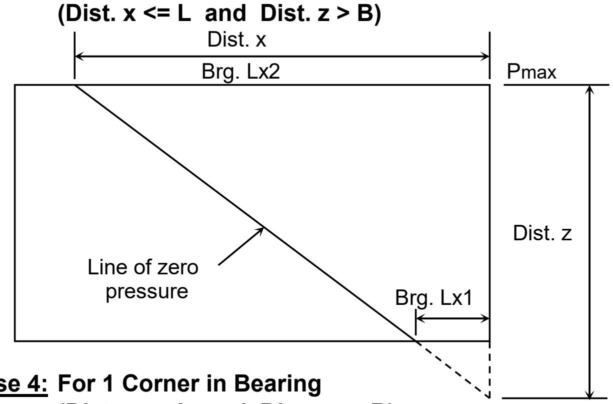
Case 1: For 3 Corners in Bearing (Dist. x > L and Dist. z > B)



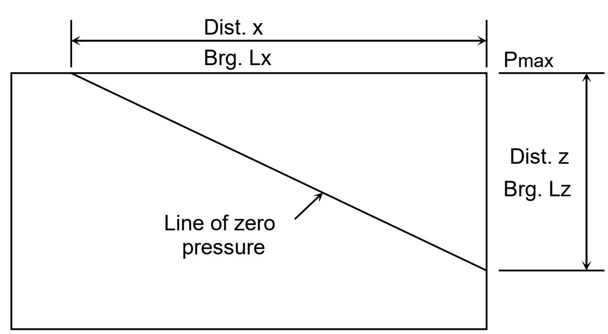
Case 2: For 2 Corners in Bearing (Dist. x > L and Dist. z <= B)



Case 3: For 2 Corners in Bearing (Dist. x <= L and Dist. z > B)



Case 4: For 1 Corner in Bearing (Dist. x <= L and Dist. z <= B)



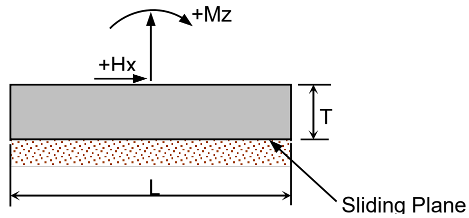
INTAKE TOWER STABILITY ANALYSIS

Job Name:	Springbank Off-Stream Storage Project (SR-1)	Number:	110773396
Site:	Intake Structure	Originator:	CG 7/2/2020 Checker: ACG
Load Case:	E24 Earthquake		

Input Data:

Footing Data:

Footing Length, L =	7.90	m
Footing Width, B =	6.30	m
Footing Thickness, T =	0.00	m
Coef. of Base Friction, μ =	0.42	
Ultimate Bearing, Pall =	450.00	kPa

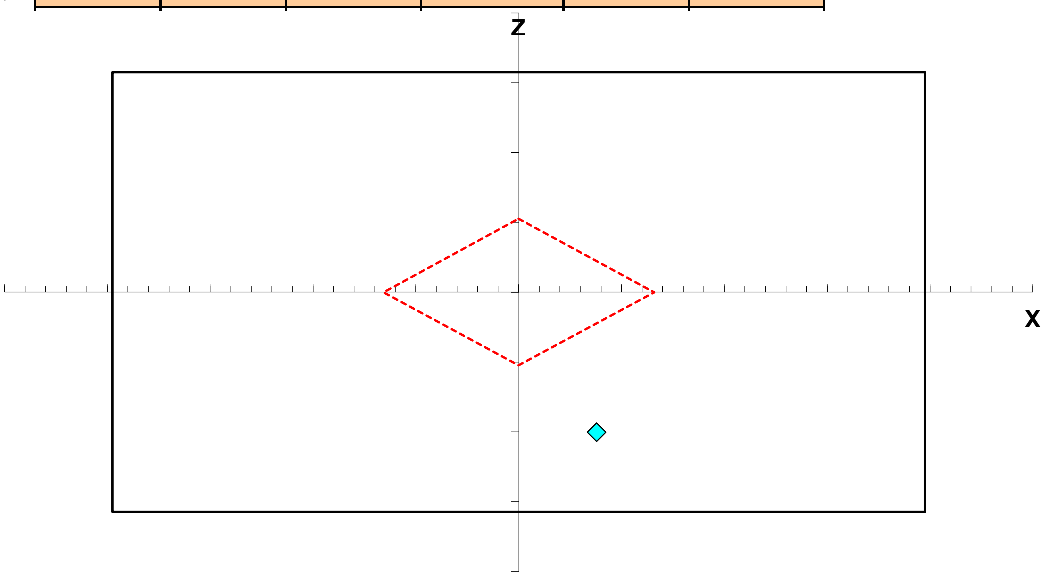


Nomenclature

Loading Data:

Direction of Seismic Force: COMBINED

	Uplift	Wind		EQ	Dead	Soil
Xp (m.) =						
Zp (m.) =						
Py (kN) =	553.10	0.00		-345.57	-4357.34	-452.10
Hx (kN) =		87.90		200.47	0.00	-158.40
Hz (kN) =		78.50		1890.69	0.00	0.00
Mx (kN-m) =		-498.40		9762.96	0.00	0.40
Mz (kN-m) =		672.50		1070.74	904.50	857.80



FOOTING PLAN

Note: Is the "Kern" area of footing (When resultant of loads falls within "Kern", entire footing base is in bearing.)

Results:

Total Resultant Load and Eccentricities:

ΣPy =	-4601.91	kN
ex =	0.76	m (<= L/6)
ez =	-2.01	m (> B/6)
ΣHx =	129.97	kN
ΣHz =	1969.19	kN
H resultant =	1973.48	kN
ΣMrx =	16238.27	kN-m
ΣMox =	11007.22	kN-m
ΣMry =	20362.28	kN-m
ΣMoy =	5690.28	kN-m

Sliding Check:

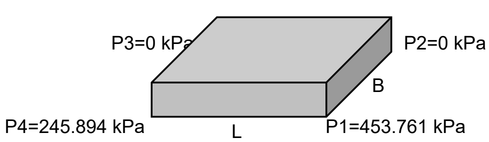
Frict =	1932.80	kN
FS(slid) =	0.979	

% Base Area in Compression:

Dist. x =	17.245	m
Dist. z =	4.196	m
Brg. Lz1 =	2.274	m
Brg. Lz2 =	4.196	m
%Brg. Area =	51.35	%
Biaxial Case =	Case 2	6*ex/L + 6*ez/B = 2.492

Gross Soil Bearing Corner Pressures:

P_1 =	453.761	kPa
P_2 =	0.000	kPa
P_3 =	0.000	kPa
P_4 =	245.894	kPa



CORNER PRESSURES

Summary of Results:

Sliding Check:

FS(slid) =	1.00	>1	OK

Bearing Area Check:

%Brg. Area =	51.35%	>1%	OK

Bearing Pressure Check:

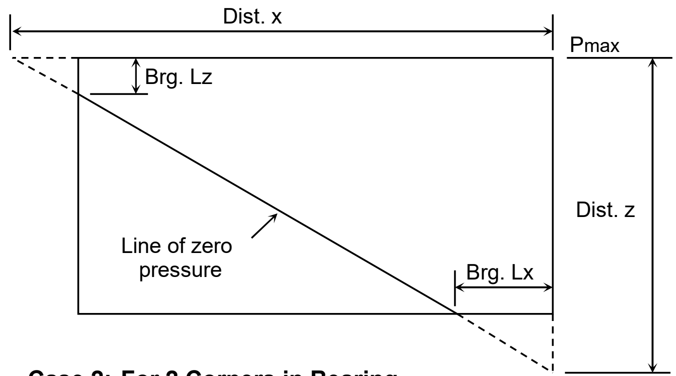
FS(brg) =	0.99	<1	NG

Flotation Check:

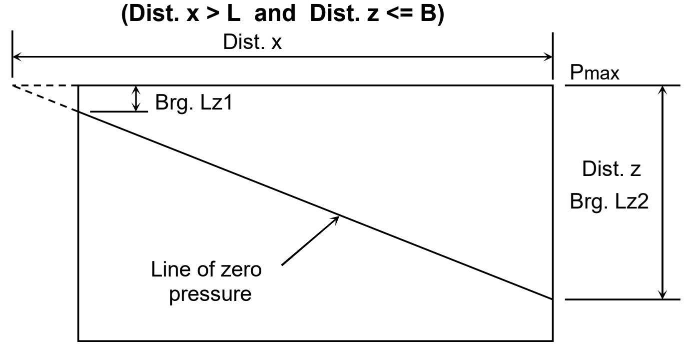
FS (float) =	9.32	>1	OK

Nomenclature for Biaxial Eccentricity:

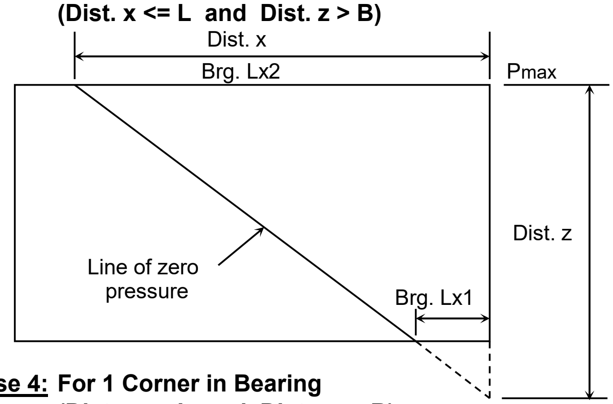
Case 1: For 3 Corners in Bearing (Dist. x > L and Dist. z > B)



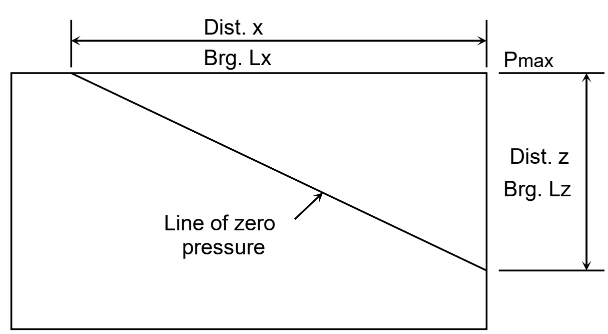
Case 2: For 2 Corners in Bearing (Dist. x > L and Dist. z <= B)



Case 3: For 2 Corners in Bearing (Dist. x <= L and Dist. z > B)



Case 4: For 1 Corner in Bearing (Dist. x <= L and Dist. z <= B)



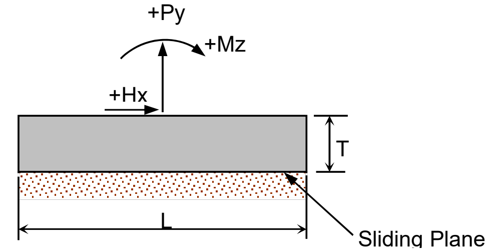
INTAKE TOWER STABILITY ANALYSIS

Job Name:	Springbank Off-Stream Storage Project (SR-1)	Number:	110773396
Site:	Intake Structure	Originator:	CG 7/2/2020 Checker: ACG
Load Case:	8 Post-Earthquake		

Input Data:

Footing Data:

Footing Length, L =	4.06	m
Footing Width, B =	6.30	m
Footing Thickness, T =	0.00	m
Coef. of Base Friction, μ =	0.42	
Allowable Bearing, Pall =	450.00	kPa

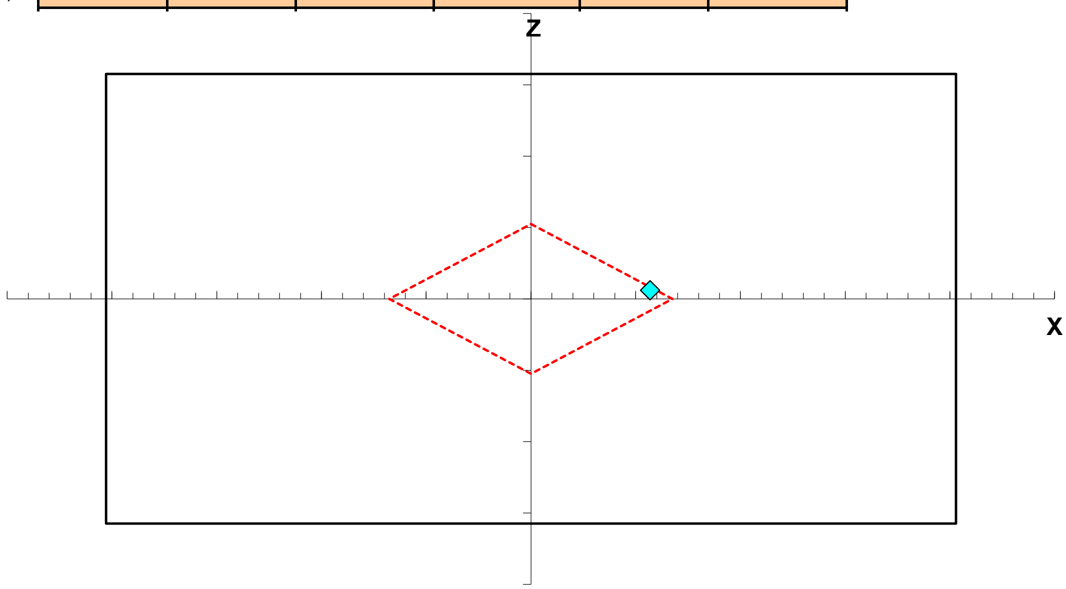


Nomenclature

Loading Data:

Direction of Wave & Wind Force: COMBINED

	Uplift	Wind		EQ	Dead	Soil
Xp (m.) =						
Zp (m.) =						
Py (kN) =	553.10	0.00		0.00	-4357.34	-452.10
Hx (kN) =		87.90		0.00	0.00	-158.40
Hz (kN) =		78.50		0.00	0.00	0.00
Mx (kN-m) =		-498.40		0.00	0.00	0.40
Mz (kN-m) =		672.50		0.00	904.50	857.80



FOOTING PLAN

Note: Is the "Kern" area of footing (When resultant of loads falls within "Kern", entire footing base is in bearing.)

Results:

Total Resultant Load and Eccentricities:

ΣPy =	-4256.34	kN
ex =	0.57	m (<= L/6)
ez =	0.12	m (<= B/6)
ΣHx =	-70.50	kN
ΣHz =	78.50	kN
H resultant =	105.51	kN
ΣMrx =	15149.74	kN-m
ΣMox =	-2240.27	kN-m
ΣMry =	9755.17	kN-m
ΣMoy =	3556.67	kN-m

Sliding Check:

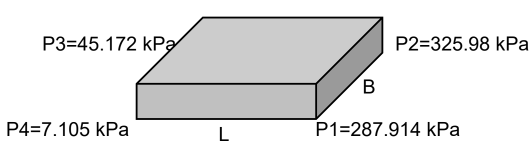
Frict =	1787.66	kN
FS(slid) =	16.943	

% Base Area in Compression:

Dist. x =	N.A.	m
Dist. z =	N.A.	m
Brg. Lx =	4.057	m
Brg. Lz =	6.300	m
%Brg. Area =	100.00	%
Biaxial Case =	N.A.	6*ex/L + 6*ez/B = 0.957

Gross Soil Bearing Corner Pressures:

P1 =	287.914	kPa
P2 =	325.980	kPa
P3 =	45.172	kPa
P4 =	7.105	kPa



CORNER PRESSURES

Summary of Results:

Sliding Check:

FS(slid) =	16.94	>1.1	OK

Bearing Area Check:

%Brg. Area =	100.00%	>1%	OK

Bearing Pressure Check:

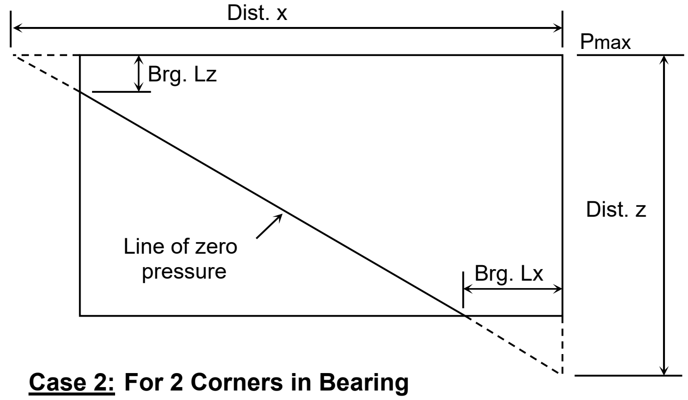
FS(brg) =	1.38	>1	OK

Flotation Check:

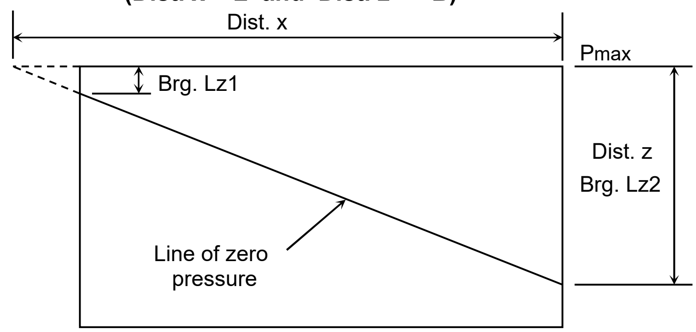
FS (float) =	8.70	>1.1	OK

Nomenclature for Biaxial Eccentricity:

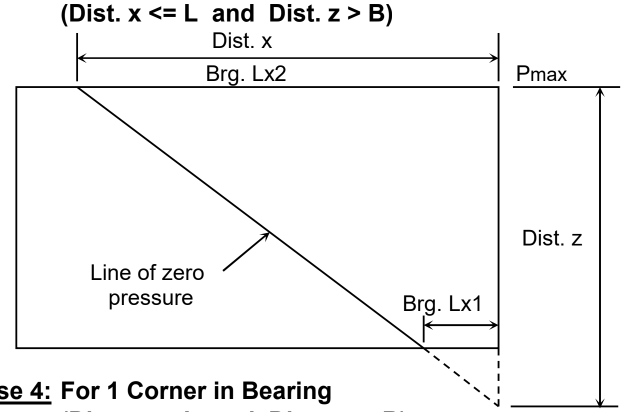
Case 1: For 3 Corners in Bearing
(Dist. x > L and Dist. z > B)



Case 2: For 2 Corners in Bearing
(Dist. x > L and Dist. z <= B)



Case 3: For 2 Corners in Bearing
(Dist. x <= L and Dist. z > B)



Case 4: For 1 Corner in Bearing
(Dist. x <= L and Dist. z <= B)

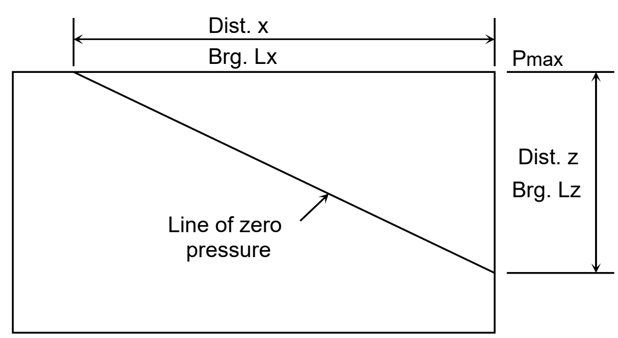


TABLE: Base Reactions					
OutputCase	GlobalFX	GlobalFY	GlobalFZ	GlobalMX	GlobalMY
Text	KN	KN	KN	KN-m	KN-m
E1	193.34	567.21	1139.19	2928.89	1052.87
E2	193.34	567.21	1139.19	2928.89	1052.87
E3	223.47	567.21	1143.00	2928.89	1437.10
E4	223.47	567.21	1143.00	2928.89	1437.10
E5	644.95	567.21	354.46	2928.91	3201.96
E6	644.95	567.21	354.46	2928.91	3201.96
E7	644.95	567.21	354.46	2928.91	3201.96
E8	644.95	567.21	354.46	2928.91	3201.96
E9	200.47	1890.69	345.57	9762.96	1070.74
E10	200.47	1890.69	345.57	9762.96	1070.74
E11	200.47	1890.69	345.57	9762.96	1070.74
E12	200.47	1890.69	345.57	9762.96	1070.74
E13	223.47	567.21	1143.00	2928.89	1437.10
E14	223.47	567.21	1143.00	2928.89	1437.10
E15	223.47	567.21	1143.00	2928.89	1437.10
E16	223.47	567.21	1143.00	2928.89	1437.10
E17	644.95	567.21	354.46	2928.91	3201.96
E18	644.95	567.21	354.46	2928.91	3201.96
E19	644.95	567.21	354.46	2928.91	3201.96
E20	644.95	567.21	354.46	2928.91	3201.96
E21	200.47	1890.69	345.57	9762.96	1070.74
E22	200.47	1890.69	345.57	9762.96	1070.74
E23	200.47	1890.69	345.57	9762.96	1070.74
E24	200.47	1890.69	345.57	9762.96	1070.74

Wing Walls – Stability Analysis

Project: **Springbank Off-Stream Storage Project - SR1**

Summary of Stability Analysis Results For Intake Structure Wing Walls

Load Case	Loading Type	Sliding Safety Factor	Floatation Safety Factor	% Base Compression	Bearing Pressure (kPa)	
					Req.	Calc. (Max)
LC01	Usual 1: Empty Reservoir	10.9	4.7	100%	150.0	88.2
LC02	Unusual 1: Construction	1.7	4.7	100%	150.0	136.4
LC03	Extreme: Rapid Drawdown	1.3	2.1	100%	150.0	107.1
LC04 [1]	*Extreme 2: Earthquake*	*2.1*	*4.6*	65.7%	-	*195.7*
LC05	*Post-Earthquake*	*2.3*	*4.4*	100%	450.0	*450.0*
1	*Seismic load case is reported for information only. There are no acceptance criteria for this load case.*					

STABILITY ANALYSIS FOR CANTILEVER WALL WITH KEY

Project / Client: Springbank Off-Stream Storage (SR1) / Alberta Transportation

Section Location: Intake Structure Wing Wall - Closest to Intake Structure

1.0 OBJECTIVE

For a particular load condition, analyze a reinforced concrete cantilever wall with shear key for overturning, sliding, flotation, and bearing capacity in accordance with criteria described in the listed references.

2.0 BACKGROUND INFORMATION

2.1 DATA SOURCES

1- Soils Report - Recommended Geotechnical Soil Parameters, SR-1 Low Level Outlet (LLO) Structures. July 19, 2019

2- Drawings - Design Drawings

3- Springbank Off-Stream Storage Project - Design Basis Memorandum (DBM) , 2019

2.2 REFERENCES

1. (CDA) Dam Safety Guidelines, 2007 (revised 2013).
2. "Water Control Structures Selected Design Guidelines," Alberta Transportation & Alberta Environment, Calgary Alberta, November 2004.

3.0 DESIGN PARAMETERS AND CRITERIA

3.1 Stability Analysis Criteria (Data source 2)

Load Case	$LC := 1$
Load Case Description	$vlookup(LC, CASES, 1)_0 = $ "Empty Reservoir"
Sliding Minimum Factor of Safety	$FS_{Sliding} := vlookup(LC, CASES, 2)_0 = 1.5$
Overturning Criteria	$Base\_Comp_{Req} := vlookup(LC, CASES, 3)_0 = 100 \cdot \%$
Bearing Capacity Minimum Factor of Safety	$FS_{Bearing} := vlookup(LC, CASES, 4)_0 = 1$
Flotation Minimum Factor of Safety	$FS_{float} := vlookup(LC, CASES, 5)_0 = 1.5$

3.2 Material Properties - Data Source 1 Unless Otherwise Noted

Unit Weight of Water	$\gamma_w := 9.81 \frac{kN}{m^3}$	
Unit Weight of Concrete	$\gamma_c := 23.5 \cdot \frac{kN}{m^3}$	Data Source 3
Unit Weight of Soil (Moist)	$\gamma_{soilm} := 20 \frac{kN}{m^3}$	
Soil Unit Weight Beneath Base (Saturated)	$\gamma_{soilsat} := 20 \frac{kN}{m^3}$	
Soil Cohesion - Drained	$c_{soil} := 0kPa$	
Soil Angle of Internal Friction - Drained	$\phi_{soil} := 24deg$	
Soil Ultimate Bearing Pressure	$Q_b := 150kPa$	
Slope of backfill (Conservative)	$\beta := 0$	
At-rest lateral earth pressure coefficient	$k_o := 1 - \sin(\phi_{soil}) = 0.59$	

4.0 WALL SECTION DESCRIPTION

4.1 Point Locations (Refer to Figure 1 and Drawings)

A - Top of wall	$EL_A := 1189.9m$	$x_A := 3.25m$
B - Top of fill - reservoir side	$EL_B := 1189.75m$	$x_B := x_A = 3.25 \cdot m$
C - Top of Heel	$EL_C := 1187m$	$x_C := x_A = 3.25 \cdot m$
D - Heel side end of footing	$EL_D := EL_C - 500mm = 1186.50\ m$	$x_D := x_A = 3.25 \cdot m$
E - Toe side end of footing	$EL_E := EL_D = 1186.50 \cdot m$	$x_E := 0m$
F - Top of Fill - land side	$EL_F := EL_C + 0.333m = 1187.33 \cdot m$	$x_F := x_E = 0$
G - Heel side face of wall stem	$EL_G := EL_A = 1189.90 \cdot m$	$x_G := 1.25m$
H - Toe side face of wall stem	$EL_H := EL_A = 1189.90 \cdot m$	$x_H := x_G - 0.500m = 0.75 \cdot m$

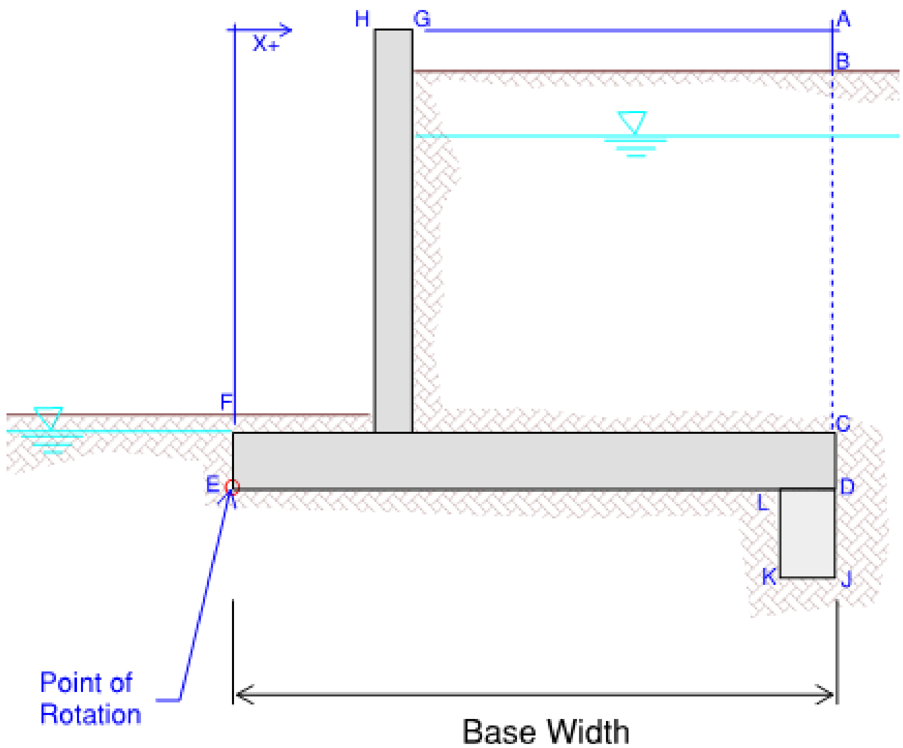


Figure 1. Cantilever Wall Section

J - Bottom of key - heel side	$EL_J := EL_C - 2m = 1185.00 \cdot m$	$x_J := x_D = 3.25\,m$
K - Bottom of key - toe side	$EL_K := EL_J = 1185.00 \cdot m$	$x_K := x_J - 450mm = 2.8 \cdot m$
L - Top of key	$EL_L := EL_D = 1186.50 \cdot m$	$x_L := x_K = 2.8\,m$

Applied Loads Data Source 2

Heel side water elevation

$$EL_{hw} := \begin{cases} EL_B & \text{if } LC = 3 \\ \left(\text{vlookup}(LC, WaterEL, 1)_0 \cdot 1m\right) & \text{otherwise} \end{cases} = 1187$$

Toe side water elevation

$$EL_{tw} := \begin{cases} EL_F & \text{if } LC = 3 \\ \left(\text{vlookup}(LC, WaterEL, 2)_0 \cdot 1m\right) & \text{otherwise} \end{cases} = 1187$$

Equivalent soil surcharge:

$$h_{sur} := \begin{cases} 1.0m & \text{if } LC = 2 \\ 0 & \text{otherwise} \end{cases} = 0 \cdot m$$

4.2 Additional Analysis Dimensions

Analysis Width	$b := 1m$
Length of base	$L_{base} := x_D - x_E = 3.25 \cdot m$
Thickness of base	$t_{base} := EL_C - EL_D = 500 \cdot mm$
Length of stem	$L_{stem} := EL_A - EL_C = 2.9 \cdot m$
Thickness of stem	$t_{stem} := x_G - x_H = 500 \cdot mm$
Length of Heel	$L_{heel} := x_A - x_G = 2000 \cdot mm$
Length of Toe	$L_{toe} := x_H - x_F = 750 \cdot mm$
Thickness of Key	$t_{key} := x_J - x_K = 450 \cdot mm$
Height of Key	$h_{key} := EL_D - EL_J = 1500 \cdot mm$

5.0 UPLIFT & HYDROSTATIC LOADS

5.1 Uplift Pressures for Sliding Stability Analyses

Determine water pressures for designated coordinates using full headwater uplift pressure at the heel and full tailwater uplift pressure at the toe. Uplift distribution is assumed linear from heel to toe.

Hydrostatic pressure at Heel	$u_h := \gamma_w \cdot \left(EL_{hw} - EL_J\right) = 20 \cdot kPa$
Hydrostatic pressure at Toe	$u_t := \gamma_w \cdot \left(EL_{tw} - EL_E\right) = 5 \cdot kPa$
Total uplift loads on base	$P_u := \frac{\left(u_h + u_t\right)}{2} \cdot L_{base} \cdot b = 39.85 \cdot kN$
Uplift resultant location	$x_u := \frac{L_{base}}{2} + \frac{L_{base}}{6} \cdot \frac{\left(u_h - u_t\right)}{u_t + u_h} = 1.95 \cdot m$
Uplift Moment about Toe	$M_u := P_u \cdot x_u = 77.7 \cdot kN \cdot m$

5.2 Headwater Hydrostatic Load - Heel Side

Headwater hydrostatic load $P_{hw} := \frac{1}{2} u_h \cdot (EL_{hw} - EL_J) \cdot b = 19.6 \cdot kN$

Headwater moment arm $y_{hw} := \frac{1}{3}(EL_{hw} - EL_J) - h_{key} = -0.83 \cdot m$

Headwater Moment about Toe $M_{hw} := P_{hw} \cdot y_{hw} = -16.4 \cdot kN \cdot m$

5.3 Tailwater Hydrostatic Load - Toe Side

Tailwater hydrostatic load $P_{tw} := \frac{1}{2} \gamma_w \cdot (EL_{tw} - EL_K)^2 \cdot b = 19.62 \cdot kN$

Tailwater moment arm $y_{tw} := h_{key} - \frac{1}{3}(EL_{tw} - EL_K) = 0.83 \cdot m$

Tailwater Moment about Toe $M_{tw} := P_{tw} \cdot y_{tw} = 16.35 \cdot kN \cdot m$

6.0 LATERAL EARTH PRESSURE

6.1 Lateral Soil Load on Toe Side

Soil pressure at Saturation Level

$$p_{tw} := \begin{cases} k_o \cdot \gamma_{soilm} \cdot (EL_F - EL_{tw}) & \text{if } EL_F > EL_{tw} \\ 0psf & \text{otherwise} \end{cases} = 4.0 \cdot kPa$$

Soil pressure at Toe - base elevation

$$p_E := \begin{cases} p_{tw} + k_o \cdot (\gamma_{soilsat} - \gamma_w) \cdot (EL_{tw} - EL_J) & \text{if } EL_F > EL_{tw} \\ k_o \cdot (\gamma_{soilsat} - \gamma_w) \cdot (EL_F - EL_J) & \text{otherwise} \end{cases}$$

$$p_E = 16.04 \cdot kPa$$

Total soil loads on Wall

$$P_{soil\_t} := \begin{bmatrix} 0.5 \cdot (EL_F - EL_{tw}) \cdot p_{tw} + p_{tw} \cdot (EL_{tw} - EL_J) \ldots \\ + 0.5 \cdot (p_E - p_{tw}) \cdot (EL_{tw} - EL_J) \end{bmatrix} \cdot b = 20.65 \cdot kN$$

Resultant location

$$y_{soil\_t} := \begin{cases} 0 & \text{if } P_{soil\_t} = 0 \\ h_{key} - \dfrac{\begin{bmatrix} 0.5 \cdot (EL_F - EL_{tw}) \cdot p_{tw} \cdot \left[(EL_{tw} - EL_J) + \frac{1}{3}(EL_F - EL_{tw}) \right] + p_{tw} \cdot \frac{1}{2}(EL_{tw} - EL_J)^2 \ldots \\ + 0.5 \cdot (p_E - p_{tw}) \cdot (EL_{tw} - EL_J)^2 \cdot \frac{1}{3} \end{bmatrix} \cdot b}{P_{soil\_t}} & \text{otherwise} \end{cases}$$

$$y_{soil\_t} = 0.66 \cdot m$$

Moment about Toe $M_{soil\_t} := P_{soil\_t} \cdot y_{soil\_t} = 13.62 \cdot kN \cdot m$

6.2 Lateral Soil Load on Heel Side

Soil pressure at Saturation Level

$$p_{hw} := \begin{cases} k_o \cdot \gamma_{soilm} \cdot (EL_B - EL_{hw}) & \text{if } EL_B > EL_{hw} \\ 0psf & \text{otherwise} \end{cases} = 32.6 \cdot kPa$$

Soil pressure at Heel - base elevation

$$p_D := \begin{cases} p_{hw} + k_o \cdot (\gamma_{soilsat} - \gamma_w) \cdot (EL_{hw} - EL_J) & \text{if } EL_B > EL_{hw} \\ k_o \cdot (\gamma_{soilsat} - \gamma_w) \cdot (EL_B - EL_J) & \text{otherwise} \end{cases}$$

$$p_D = 44.72 \cdot kPa$$

Total soil loads on Base

$$P_{soil\_h} := \left[0.5 \cdot (EL_B - EL_{hw}) \cdot p_{hw} + p_{hw} \cdot (EL_{hw} - EL_J) \dots + 0.5 \cdot (p_D - p_{hw}) \cdot (EL_{hw} - EL_J)\right] \cdot b$$

$$P_{soil\_h} = 122.22 \cdot kN$$

Resultant location

$$y_{soil\_h} := \frac{\left[0.5 \cdot (EL_B - EL_{hw}) \cdot p_{hw} \cdot \left[EL_{hw} - EL_J + \frac{1}{3}(EL_B - EL_{hw})\right] + p_{hw} \cdot \frac{1}{2}(EL_{hw} - EL_J)^2 \dots + 0.5 \cdot (p_D - p_{hw}) \cdot (EL_{hw} - EL_J)^2 \cdot \frac{1}{3}\right] \cdot b}{P_{soil\_h}} - h_{key}$$

$$y_{soil\_h} = 0.17 \cdot m$$

Moment about Toe $M_{soil\_h} := P_{soil\_h} \cdot y_{soil\_h} = 20.9 \cdot kN \cdot m$

6.3 Surcharge Soil Load - Heel Side

Surcharge soil pressure $p_{sur} := k_o \cdot \gamma_{soilm} \cdot h_{sur} = 0 \cdot kPa$

Soil load on wall $P_{sur} := p_{sur} \cdot (EL_B - EL_J) \cdot b = 0 \cdot kN$

Resultant location $y_{sur} := \frac{1}{2} \cdot (EL_B - EL_J) - h_{key} = 0.88\ m$

Moment about Toe $M_{sur} := P_{sur} \cdot y_{sur} = 0 \cdot kN \cdot m$

7.0 GRAVITY LOADS

7.1 Weight of Concrete

Weight of Wall footing/base $W_{conc} := \gamma_c \cdot (t_{base} \cdot L_{base} + L_{stem} \cdot t_{stem} + t_{key} \cdot h_{key}) \cdot b = 88.13 \cdot kN$

Resultant location
$$x_{conc} := \frac{\left[\begin{array}{l}\frac{1}{2} t_{base} \cdot L_{base}{}^2 + L_{stem} \cdot t_{stem} \cdot (L_{toe} + 0.5 t_{stem}) \ldots \\ + t_{key} \cdot h_{key} \cdot (L_{base} - 0.5 t_{key})\end{array}\right]}{t_{base} \cdot L_{base} + L_{stem} \cdot t_{stem} + t_{key} \cdot h_{key}} = 1.64\,m$$

Moment about Toe $M_{conc} := W_{conc} \cdot x_{conc} = 144.11 \cdot kN \cdot m$

7.2 Weight of Soil on Heel

Weight of Soil on heel

$$W_{soil\_h} := b \cdot L_{heel} \cdot \left| \begin{array}{ll} (\gamma_{soilsat} - \gamma_w) \cdot (EL_B - EL_C) & \text{if } EL_B < EL_{hw} \\ \gamma_{soilm} \cdot (EL_B - EL_{hw}) + (\gamma_{soilsat} - \gamma_w) \cdot \max[0, (EL_{hw} - EL_C)] & \text{otherwise} \end{array} \right.$$

$W_{soil\_h} = 110 \cdot kN$

Resultant location $x_{soil\_h} := 0.5(x_B - x_G) + x_G = 2.25 \cdot m$

Moment about Toe $M_{soilw\_h} := W_{soil\_h} \cdot x_{soil\_h} = 247.5 \cdot kN \cdot m$

7.3 Weight of Water on Heel

Weight of Water on heel $W_{w\_h} := \gamma_w \cdot \max[0kip, (EL_{hw} - EL_C)] \cdot L_{heel} \cdot b = 0 \cdot kN$

Resultant location $x_{w\_h} := 0.5(x_B - x_G) + x_G = 2.25 \cdot m$

Moment about Toe $M_{w\_h} := W_{w\_h} \cdot x_{w\_h} = 0 \cdot kN \cdot m$

7.4 Weight of Soil on Toe

Weight of Soil on toe Note: Water and soil elevations MUST NOT be below footing elevation

$$W_{soil\_t} := b \cdot L_{toe} \cdot \left| \begin{array}{ll} (\gamma_{soilsat} - \gamma_w) \cdot (\max(0, EL_F - EL_C)) & \text{if } EL_F < EL_{tw} \\ \gamma_{soilm} \cdot \max(0, EL_F - EL_{tw}) + (\gamma_{soilsat} - \gamma_w) \cdot \max(EL_{tw} - EL_C, 0) & \text{otherwise} \end{array} \right.$$

$W_{soil\_t} = 5 \cdot kN$

Resultant location $x_{soil\_t} := 0.5(x_H - x_E) = 0.38 \cdot m$

Moment about Toe $M_{soilw\_t} := W_{soil\_t} \cdot x_{soil\_t} = 1.9 \cdot kN \cdot m$

7.5 Weight of Water on Toe

Weight of Water on toe $W_{w\_t} := \gamma_w \cdot max\left[0kip, \left(EL_{tw} - EL_C\right)\right] \cdot L_{toe} \cdot b = 0 \cdot kN$

Resultant location $x_{w\_t} := 0.5\left(x_H - x_E\right) = 0.38 \cdot m$

Moment about Toe $M_{w\_t} := W_{w\_t} \cdot x_{w\_t} = 0 \cdot kN \cdot m$

7.6 Weight of Soil under Footing and Above Failure Plane EJ

Depth of Soil Wedge Near Key $h_{s\_under} := \left(x_L - x_E\right) \cdot \frac{h_{key}}{L_{base}} = 1.29\,m$

Length of Soil Wedge $L_{s\_under} := x_L - x_E = 2.8\,m$

Weight of Soil Wedge Under Footing $W_{s\_under} := \gamma_{soilsat} \cdot \left(0.5 \cdot h_{s\_under} \cdot L_{s\_under}\right) \cdot b = 36.18 \cdot kN$

Resultant location $x_{s\_under} := \frac{2}{3}\left(x_L - x_E\right) = 1.87 \cdot m$

Moment about Toe $M_{s\_under} := W_{s\_under} \cdot x_{s\_under} = 67.5 \cdot kN \cdot m$

8.0 Overturning Stability Assessment - See Figure 2

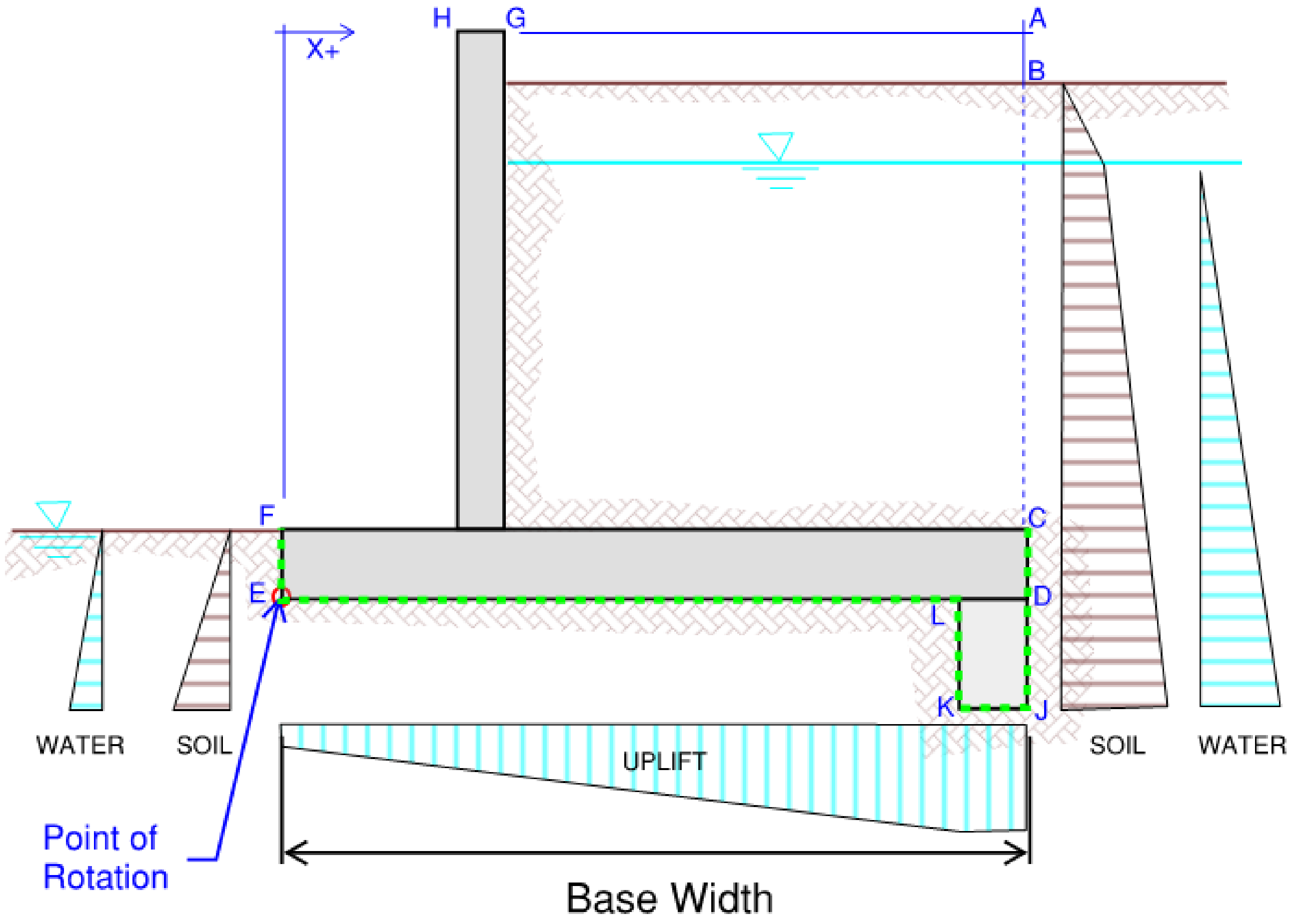


Figure 2. Free Body Diagram for Overturning Analysis

Uplift loads for Overturning

$$P_{u\_ot} := \left[\frac{1}{2}\left(u_h + u_t\right)\cdot\left(x_L - x_E\right) + u_h\cdot t_{key}\right]\cdot b = 43.16\cdot kN$$

Uplift resultant location

$$x_{u\_ot} := \frac{\left[\left[\frac{x_L - x_E}{2} + \frac{x_L - x_E}{6}\cdot\frac{\left(u_h - u_t\right)}{u_t + u_h}\right]\cdot\left[\frac{1}{2}\left(u_h + u_t\right)\cdot\left(x_L - x_E\right)\right] \ldots \\ + \left(L_{base} - 0.5t_{key}\right)\cdot\left(u_h\cdot t_{key}\right)\right]}{\left[\frac{1}{2}\left(u_h + u_t\right)\cdot\left(x_L - x_E\right) + u_h\cdot t_{key}\right]}$$

$$x_{u\_ot} = 1.96\,m$$

Uplift Moment about Toe

$$M_{u\_ot} := P_{u\_ot}\cdot x_{u\_ot} = 84.4\cdot kN\cdot m$$

Total Vertical Forces	$\Sigma V_{ot} := W_{conc} + W_{soil\_h} + W_{soil\_t} + W_{w\_h} + W_{w\_t} - P_{u\_ot} = 160 \cdot kN$
Total Horizontal Forces	$\Sigma H_{ot} := P_{hw} + P_{soil\_h} + P_{sur} - P_{tw} - P_{soil\_t} = 101.56 \cdot kN$
Total Resisting Moments	$\Sigma M_{r\_ot} := M_{conc} + M_{soilw\_h} + M_{w\_h} + M_{soilw\_t} + M_{w\_t} = 393.5 \cdot kN \cdot m$
Total Driving Moments	$\Sigma M_{d\_ot} := M_{hw} + M_{soil\_h} + M_{sur} + M_{u\_ot} + M_{tw} + M_{soil\_t} = 118.9 \cdot kN \cdot m$
Resultant Location from Toe	$x_{r\_ot} := \frac{\Sigma M_{r\_ot} - \Sigma M_{d\_ot}}{\Sigma V_{ot}} = 1.72 \cdot m$
Normalized Resultant Location	$\frac{x_{r\_ot}}{L_{base}} = 0.528$
Eccentricity	$e_{x\_ot} := \frac{L_{base}}{2} - x_{r\_ot} = -0.09 \cdot m$
Approx. Base in Compression	$l_{comp\_ot} := \min\left[L_{base}, \frac{3}{2} \cdot \left(L_{base} - 2 \cdot e_{x\_ot}\right)\right] = 3.25 \cdot m$
Percent Base in Compression	$Base\_Comp := \left(\frac{l_{comp\_ot}}{L_{base}}\right) = 100 \cdot \%$
Resultant Location Check	$check_{res} := if\left(Base\_Comp \geq Base\_Comp_{Req}, "OK", "NG"\right) = "OK"$

9.0 Flotation Stability Assessment - See Figure 2

Calculated Flotation Safety Factor	$FS_f := \frac{W_{conc} + W_{soil\_h} + W_{soil\_t} + W_{w\_h} + W_{w\_t}}{P_{u\_ot}} = 4.7$
Flotation Stability Check	$check_{floatation} := if\left(FS_f \geq FS_{float}, "OK", "NG"\right) = "OK"$

10.0 Sliding Stability Assessment - See Figure 3

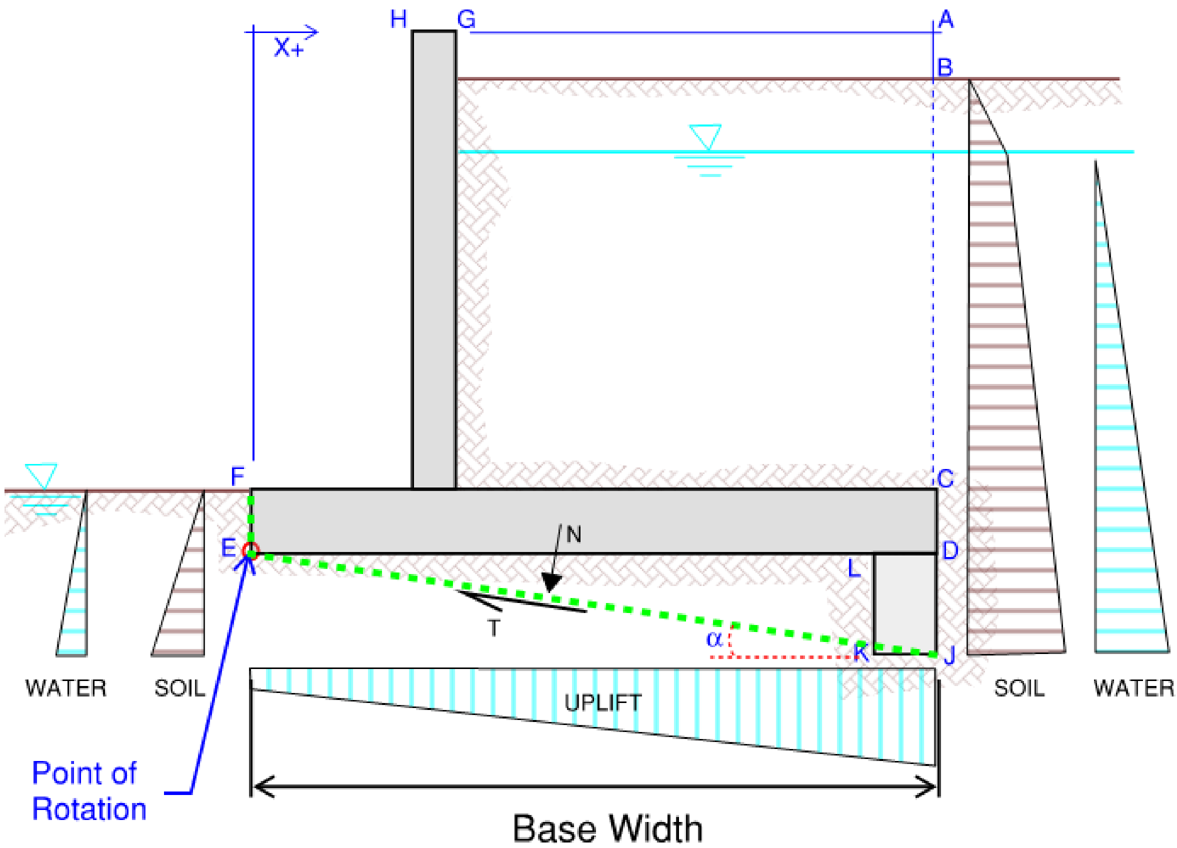


Figure 3. Free Body Diagram for Sliding Analysis

Length of Sliding Failure Plane, EJ

$$L_{fp} := \sqrt{L_{base}^2 + h_{key}^2} = 3.58\,m$$

Angle of Sliding Failure Plane From Horizontal

$$\alpha := atan\left(\frac{h_{key}}{L_{base}}\right) = 24.8 \cdot deg$$

Total Vertical Forces

$$\Sigma V := W_{conc} + W_{soil\_h} + W_{soil\_t} \cdots + W_{w\_h} + W_{s\_under} + W_{w\_t} - P_u = 199.5 \cdot kN$$

Total Horizontal Forces

$$\Sigma H := P_{hw} + P_{soil\_h} + P_{sur} - P_{tw} - P_{soil\_t} = 101.56 \cdot kN$$

Total Resisting Moments

$$\Sigma M_r := M_{conc} + M_{soilw\_h} + M_{w\_h} \cdots + M_{soilw\_t} + M_{w\_t} + M_{s\_under} = 461\ m \cdot kN$$

Total Driving Moments

$$\Sigma M_d := M_{hw} + M_{soil\_h} + M_{sur} + M_u \cdots + M_{tw} + M_{soil\_t} = 112.2 \cdot kN \cdot m$$

Normal Force on Sliding Failure Plane: $N_s := \Sigma H \cdot \sin(\alpha) + \Sigma V \cdot \cos(\alpha) = 223.66 \cdot kN$

Tangential Force on Sliding Failure Plane: $T_s := \Sigma H \cdot \cos(\alpha) - \Sigma V \cdot \sin(\alpha) = 8.63 \cdot kN$

Calculated Sliding Safety Factor $FS_s := \dfrac{\left|N_s \cdot \tan(0.95\phi_{soil})\right|}{\left|T_s\right|} = 10.89$

Sliding Stability Check $check_{sliding} := if(FS_s \geq FS_{Sliding}, "OK", "NG") = "OK"$

11.0 Bearing Capacity Assessment

Resultant Location from Toe $x_r := \dfrac{\Sigma M_r - \Sigma M_d}{N_s} = 1.56 \cdot m$

Eccentricity of N_s from center of base $e_s := \dfrac{L_{fp}}{2} - x_r = 0.23 \cdot m$

Approx. Base in Compression $l_{comp.s} := \min\left[L_{fp}, \dfrac{3}{2} \cdot (L_{fp} - 2 \cdot e_s)\right] = 3.58 \cdot m$

Updated Eccentricity $e_x := \dfrac{l_{comp.s} - L_{fp}}{2} + e_s = 0.23 \cdot m$

Effective base pressure at Toe $q_t := \left(\dfrac{N_s}{l_{comp.s} \cdot b}\right) \cdot \left(1 + \dfrac{6 \cdot e_x}{l_{comp.s}}\right) = 86.57 \cdot kPa$

Effective base pressure at Heel $q_h := \max\left[\left(\dfrac{N_s}{l_{comp.s} \cdot b}\right) \cdot \left(1 - \dfrac{6 \cdot e_x}{l_{comp.s}}\right), 0\right] = 38.39 \cdot kPa$

Calculated Bearing Safety Factor $FS_b := \dfrac{Q_b}{\max(q_t, q_h)} = 1.73$

Bearing Pressure Check $check_{bearing} := if(FS_b \geq FS_{Bearing}, "OK", "NG") = "OK"$

12.0 Summary of Stability Assessments

Base Compression / Resultant Location	$Base\_Comp = 100 \cdot \%$	$check_{res} = "OK"$
Flotation Stability	$FS_f = 4.7$	$check_{floatation} = "OK"$
Sliding Stability	$FS_s = 10.9$	$check_{sliding} = "OK"$
Bearing Pressure	$FS_b = 1.7$	$check_{bearing} = "OK"$

13.0 Structural Loads

13.1 Shear and Moment at Stem Base - See Figure 4

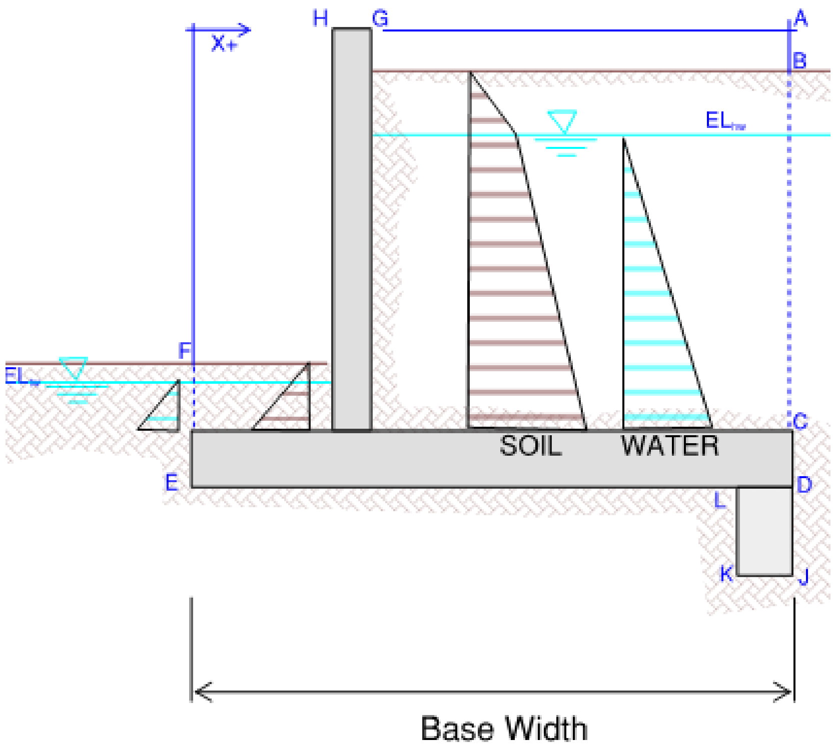


Figure 4 - Loads on Stem

13.1.1 Hydrostatic Load at Stem Base

Heel side hydrostatic load

$$P_{hw\_stem} := \frac{1}{2}\gamma_w \cdot \left(EL_{hw} - EL_C\right)^2 \cdot b = 0.0 \cdot kN$$

Heel side moment at stem base

$$M_{hw\_stem} := P_{hw\_stem} \cdot \left(\frac{EL_{hw} - EL_C}{3}\right) = 0 \cdot kN \cdot m$$

Toe side hydrostatic load

$$P_{tw\_stem} := \frac{1}{2}\gamma_w \cdot \left(EL_{tw} - EL_C\right)^2 \cdot b = 0.0 \cdot kN$$

Toe side moment at stem base

$$M_{tw\_stem} := P_{tw\_stem} \cdot \left(\frac{EL_{tw} - EL_C}{3}\right) = 0 \cdot kN \cdot m$$

13.1.2 Lateral Soil Loads at Stem Base

Soil pressure at saturation level - Toe Side

$$p_t := \begin{cases} k_o \cdot \gamma_{soilm} \cdot (EL_F - EL_{tw}) & \text{if } EL_F > EL_{tw} \\ 0psf & \text{otherwise} \end{cases} = 3.95 \cdot kPa$$

Soil pressure at stem base - Toe Side

$$p_{C.t} := \begin{cases} p_t + k_o \cdot (\gamma_{soilsat} - \gamma_w) \cdot (EL_{tw} - EL_C) & \text{if } EL_F > EL_{tw} \\ k_o \cdot (\gamma_{soilsat} - \gamma_w) \cdot (EL_F - EL_C) & \text{otherwise} \end{cases}$$

$$p_{C.t} = 3.95 \cdot kPa$$

Lateral soil loads at stem base - Toe Side

$$P_{s\_t} := \left[0.5 \cdot (EL_F - EL_{tw}) \cdot p_t + p_t \cdot (EL_{tw} - EL_C) \ldots + 0.5 \cdot (p_{C.t} - p_t) \cdot (EL_{tw} - EL_C)\right] \cdot b = 0.66 \cdot kN$$

Resultant location

$$y_{s\_t} := \begin{cases} 0 & \text{if } P_{s\_t} = 0 \\ \dfrac{\left[0.5 \cdot (EL_F - EL_{tw}) \cdot p_t \cdot \left[(EL_{tw} - EL_C) + \frac{1}{3}(EL_F - EL_{tw})\right] + p_t \cdot \frac{1}{2}(EL_{tw} - EL_C)^2 \ldots + 0.5 \cdot (p_{C.t} - p_t) \cdot (EL_{tw} - EL_C)^2 \cdot \frac{1}{3}\right] \cdot b}{P_{s\_t}} & \text{otherwise} \end{cases}$$

$$y_{s\_t} = 0.11 \cdot m$$

Lateral soil moment at stem base - Toe Side

$$M_{s\_t} := P_{s\_t} \cdot y_{s\_t} = 0.07 \cdot kN \cdot m$$

Soil pressure at saturation level - Heel Side

$$p_h := \begin{cases} k_o \cdot \gamma_{soilm} \cdot (EL_B - EL_{hw}) & \text{if } EL_B > EL_{hw} \\ 0kPa & \text{otherwise} \end{cases} = 32.63 \cdot kPa$$

Soil pressure at stem base - Heel Side

$$p_{C.h} := \begin{cases} p_h + k_o \cdot (\gamma_{soilsat} - \gamma_w) \cdot (EL_{hw} - EL_C) & \text{if } EL_B > EL_{tw} \\ k_o \cdot (\gamma_{soilsat} - \gamma_w) \cdot (EL_B - EL_C) & \text{otherwise} \end{cases}$$

$$p_{C.h} = 32.63 \cdot kPa$$

Lateral soil loads at stem base - Heel Side

$$P_{s\_h} := \left[0.5 \cdot (EL_B - EL_{hw}) \cdot p_h + p_h \cdot (EL_{hw} - EL_C) \ldots + 0.5 \cdot (p_{C.h} - p_h) \cdot (EL_{hw} - EL_C)\right] \cdot b = 44.87 \cdot kN$$

Resultant location

$$y_{s\_h} := \begin{cases} 0 & \text{if } P_{s\_h} = 0 \\ \dfrac{\left[0.5\cdot(EL_B - EL_{hw})\cdot p_h\cdot\left[(EL_{hw} - EL_C) + \frac{1}{3}(EL_B - EL_{hw})\right] + p_h\cdot\frac{1}{2}(EL_{hw} - EL_C)^2 \ldots \\ + 0.5\cdot(p_{C.h} - p_h)\cdot(EL_{hw} - EL_C)^2\cdot\frac{1}{3}\right]\cdot b}{P_{s\_h}} & \text{otherwise} \end{cases}$$

$$y_{s\_h} = 0.92\cdot m$$

Lateral soil moment at stem base - Heel Side $M_{s\_h} := P_{s\_h}\cdot y_{s\_h} = 41.13\cdot kN\cdot m$

13.1.3 Surcharge Loads at Stem Base

Surcharge load at stem base $P_{sur\_stem} := p_{sur}\cdot(EL_B - EL_C)\cdot b = 0\cdot kN$

Surcharge Moment about Toe $M_{sur\_stem} := P_{sur}\cdot\frac{1}{2}(EL_B - EL_C) = 0\cdot kN\cdot m$

13.2 Shear and Moment on Heel - See Figure 5 & Figure 6

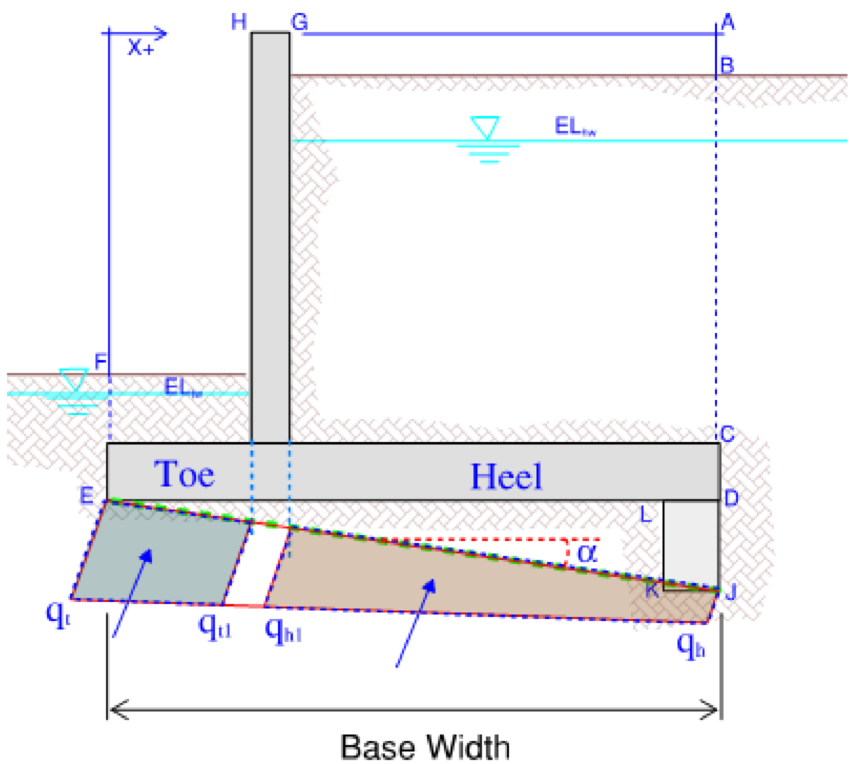


Figure 5 - Base Reaction Loads on Base (Heel & Toe)

13.2.1 Weight of Concrete Heel

Weight of Wall footing/base $W_{c\_heel} := \gamma_c \cdot (t_{base} \cdot L_{heel} + t_{key} \cdot h_{key}) \cdot b = 39.36 \cdot kN$

Resultant location $x_{c\_heel} := \dfrac{\left[\frac{1}{2} t_{base} \cdot L_{heel}{}^2 \ldots + t_{key} \cdot h_{key} \cdot (L_{heel} - 0.5 t_{key})\right]}{t_{base} \cdot L_{heel} + t_{key} \cdot h_{key}} = 1.31\,m$

Moment about stem base $M_{c\_heel} := W_{c\_heel} \cdot x_{c\_heel} = 51.66 \cdot kN \cdot m$

13.2.2 Weight of Soil on Heel

Weight of Soil on heel $W_{s\_heel} := W_{soil\_h} = 110 \cdot kN$

Moment about stem base $M_{s\_heel} := W_{s\_heel} \cdot \left(\frac{1}{2} L_{heel}\right) = 110 \cdot kN \cdot m$

13.2.3 Weight of Water on Heel

Weight of Water on heel $W_{w\_heel} := W_{w\_h} = 0 \cdot kN$

Moment about stem base $M_{w\_heel} := W_{w\_heel} \cdot \left(\frac{1}{2} L_{heel}\right) = 0 \cdot kN \cdot m$

13.2.4 Weight of Concrete Toe

Weight of Wall footing/base $W_{c\_toe} := \gamma_c \cdot t_{base} \cdot L_{toe} \cdot b = 8.81 \cdot kN$

Moment about stem base $M_{c\_toe} := W_{c\_toe} \cdot \left(\frac{1}{2} \cdot L_{toe}\right) = 3.3 \cdot kN \cdot m$

13.2.5 Weight of Soil on Toe

Weight of Soil on Toe $W_{s\_toe} := W_{soil\_t} = 5 \cdot kN$

Moment about stem base $M_{s\_toe} := W_{s\_toe} \cdot \left(\frac{1}{2} L_{toe}\right) = 1.9 \cdot kN \cdot m$

13.2.6 Weight of Water on Toe

Weight of Water on Toe $W_{w\_toe} := W_{w\_t} = 0 \cdot kN$

Moment about stem base $M_{w\_toe} := W_{w\_toe} \cdot \left(\frac{1}{2} L_{toe}\right) = 0 \cdot kN \cdot m$

13.2.7 Bearing Pressures on Footing

Approx. Base in Compression $l_{comp.s} = 3.58\,m$

Effective base pressure at Toe $q_t = 86.57 \cdot kPa$

Effective base pressure at Heel $q_h = 38.39 \cdot kPa$

Compression length under Toe $L_{bearing\_t} := \dfrac{L_{toe}}{\cos(\alpha)} = 0.83\,m$

Compression length under Heel $L_{bearing\_h} := l_{comp.s} - \dfrac{(x_G - x_E)}{\cos(\alpha)} = 2.2\,m$

Bearing pressure under toe side of stem $q_{t1} := L_{bearing\_t} \cdot \left[\dfrac{(q_h - q_t)}{l_{comp.s}}\right] + q_t = 75.45 \cdot kPa$

Bearing pressure under heel side of stem $q_{h1} := \dfrac{(x_G - x_E)}{\cos(\alpha)} \cdot \left[\dfrac{(q_h - q_t)}{l_{comp.s}}\right] + q_t = 68.04 \cdot kPa$

13.2.8 Soil Reaction on Heel

Soil reaction load on Heel $P_{bearing\_h} := \dfrac{1}{2} \cdot (q_h + q_{h1}) \cdot L_{bearing\_h} \cdot b = 117.22 \cdot kN$

Resultant location $x_{bearing\_h} := \dfrac{L_{bearing\_h}}{2} + \dfrac{L_{bearing\_h}}{6} \cdot \dfrac{(q_h - q_{h1})}{q_{h1} + q_h} = 1\,m$

Vertical Component $P_{h\_v} := P_{bearing\_h} \cdot \cos(\alpha) = 106.43 \cdot kN$

Horizontal Component $P_{h\_h} := P_{bearing\_h} \cdot \sin(\alpha) = 49.12 \cdot kN$

Horizontal Moment Arm $x_{h\_h} := x_{bearing\_h} \cdot \cos(\alpha) = 0.91\,m$

Vertical Moment Arm $y_{h\_v} := \left[\dfrac{(x_G - x_E)}{\cos(\alpha)} + x_{bearing\_h}\right] \cdot \sin(\alpha) = 1\,m$

Moment on Heel $M_{bearing\_h} := P_{h\_v} \cdot x_{h\_h} + P_{h\_h} \cdot y_{h\_v} = 145.46 \cdot kN \cdot m$

13.2.9 Soil Reaction on Toe

Soil reaction load on Toe $P_{bearing\_t} := \frac{1}{2} \cdot (q_t + q_{t1}) \cdot L_{bearing\_t} \cdot b = 66.92 \cdot kN$

Resultant location $x_{bearing\_t} := \frac{L_{bearing\_t}}{2} + \frac{L_{bearing\_t}}{6} \cdot \frac{(q_t - q_{t1})}{q_t + q_{t1}} = 0.42\ m$

Vertical Component $P_{t\_v} := P_{bearing\_t} \cdot \cos(\alpha) = 60.76 \cdot kN$

Horizontal Component $P_{t\_h} := P_{bearing\_t} \cdot \sin(\alpha) = 28.04 \cdot kN$

Horizontal Moment Arm $x_{t\_h} := x_{bearing\_t} \cdot \cos(\alpha) = 0.38\ m$

Vertical Moment Arm $y_{t\_v} := (L_{bearing\_t} - x_{bearing\_t}) \cdot \sin(\alpha) = 0.17\ m$

Moment on Toe $M_{bearing\_t} := P_{t\_v} \cdot x_{t\_h} + P_{t\_h} \cdot y_{t\_v} = 28.05 \cdot kN \cdot m$

13.2.10 Uplift Pressure on Footing - Figure 6

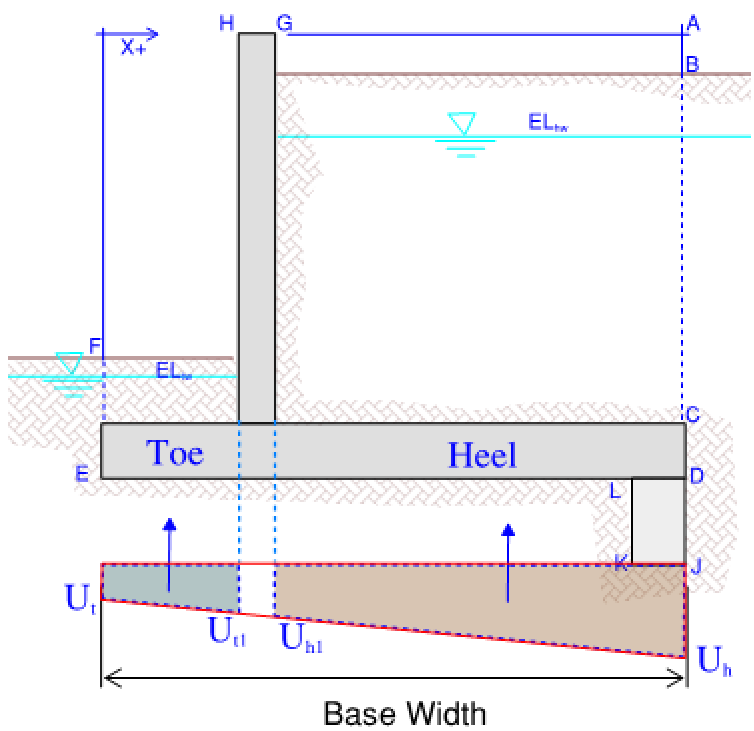


Figure 6 - Uplift Loads on Base (Heel & Toe)

Uplift pressure under toe side of stem $u_{t1} := L_{toe} \cdot \left[\frac{(u_h - u_t)}{L_{base}}\right] + u_t = 8.3 \cdot kPa$

Uplift pressure under heel side of stem $u_{h1} := (x_G - x_E) \cdot \left[\frac{(u_h - u_t)}{L_{base}}\right] + u_t = 10.56 \cdot kPa$

13.2.11 Uplift Loads Heel

Uplift load on Heel $P_{u\_h} := \frac{1}{2} \cdot (u_h + u_{h1}) \cdot L_{heel} \cdot b = 30.18 \cdot kN$

Moment Arm $x_{u\_h} := \frac{L_{heel}}{2} + \frac{L_{heel}}{6} \cdot \frac{(u_h - u_{h1})}{u_{h1} + u_h} = 1.1\,m$

Moment on Heel $M_{u\_h} := P_{u\_h} \cdot x_{u\_h} = 33.2 \cdot kN \cdot m$

13.2.12 Uplift Loads Toe

Uplift load on Toe $P_{u\_t} := \frac{1}{2} \cdot (u_t + u_{t1}) \cdot L_{toe} \cdot b = 4.95 \cdot kN$

Moment Arm $x_{u\_t} := \frac{L_{toe}}{2} + \frac{L_{toe}}{6} \cdot \frac{(u_t - u_{t1})}{u_{t1} + u_t} = 0.34\,m$

Moment on Toe $M_{u\_t} := P_{u\_t} \cdot x_{u\_t} = 1.7 \cdot kN \cdot m$

13.3 Structural Load Summary

Net shear at stem base $V_{stem} := P_{hw\_stem} - P_{tw\_stem} + P_{s\_h} - P_{s\_t} + P_{sur\_stem} = 44.2 \cdot kN$

Net moment at stem base $M_{stem} := M_{hw\_stem} - M_{tw\_stem} + M_{s\_h} - M_{s\_t} + M_{sur\_stem} = 41.1 \cdot kN \cdot m$

Net shear on Toe $V_t := W_{c\_toe} + W_{s\_toe} + W_{w\_toe} - P_{t\_v} - P_{u\_t} = -51.9 \cdot kN$

Net moment on Toe $M_t := M_{c\_toe} + M_{s\_toe} + M_{w\_toe} - M_{bearing\_t} - M_{u\_t} = -24.6 \cdot kN \cdot m$

Net shear on Heel $V_h := W_{c\_heel} + W_{s\_heel} + W_{w\_heel} - P_{h\_v} - P_{u\_h} = 12.7 \cdot kN$

Net moment on Heel $M_h := M_{c\_heel} + M_{s\_heel} + M_{w\_heel} - M_{bearing\_h} - M_{u\_h} = -17 \cdot kN \cdot m$

13.4 Controlling Structural Loads (Unfactored)

Stem cross section

$M_{stem} = 41.1 \cdot kN \cdot m$

$V_{stem} = 44.2 \cdot kN$

Toe cross section

$M_{toe} := M_t = -24.57 \cdot kN \cdot m$

$V_{toe} := V_t = -51.9 \cdot kN$

Heel cross section

$M_{heel} := \min\left(\max\left(M_{stem} - \left|M_{toe}\right|, M_h\right), M_{stem}\right) = 16.5 \cdot kN \cdot m$

$V_{heel} := \max\left(V_{stem}, V_h\right) = 44.2 \cdot kN$

STABILITY ANALYSIS FOR CANTILEVER WALL WITH KEY

Project / Client: Springbank Off-Stream Storage (SR1) / Alberta Transportation

Section Location: Intake Structure Wing Wall - Closest to Intake Structure

1.0 OBJECTIVE

For a particular load condition, analyze a reinforced concrete cantilever wall with shear key for overturning, sliding, flotation, and bearing capacity in accordance with criteria described in the listed references.

2.0 BACKGROUND INFORMATION

2.1 DATA SOURCES

1- Soils Report - Recommended Geotechnical Soil Parameters, SR-1 Low Level Outlet (LLO) Structures. July 19, 2019

2- Drawings - Design Drawings

3- Springbank Off-Stream Storage Project - Design Basis Memorandum (DBM) , 2019

2.2 REFERENCES

1. (CDA) Dam Safety Guidelines, 2007 (revised 2013).
2. "Water Control Structures Selected Design Guidelines," Alberta Transportation & Alberta Environment, Calgary Alberta, November 2004.

3.0 DESIGN PARAMETERS AND CRITERIA

3.1 Stability Analysis Criteria (Data source 2)

Load Case	$LC := 2$
Load Case Description	$\text{vlookup}(LC, CASES, 1)_0 = \text{"Construction"}$
Sliding Minimum Factor of Safety	$FS_{Sliding} := \text{vlookup}(LC, CASES, 2)_0 = 1.3$
Overturning Criteria	$Base\_Comp_{Req} := \text{vlookup}(LC, CASES, 3)_0 = 100 \cdot \%$
Bearing Capacity Minimum Factor of Safety	$FS_{Bearing} := \text{vlookup}(LC, CASES, 4)_0 = 1$
Flotation Minimum Factor of Safety	$FS_{float} := \text{vlookup}(LC, CASES, 5)_0 = 1.3$

3.2 Material Properties - Data Source 1 Unless Otherwise Noted

Unit Weight of Water	$\gamma_w := 9.81 \frac{kN}{m^3}$	
Unit Weight of Concrete	$\gamma_c := 23.5 \cdot \frac{kN}{m^3}$	Data Source 3
Unit Weight of Soil (Moist)	$\gamma_{soilm} := 20 \frac{kN}{m^3}$	
Soil Unit Weight Beneath Base (Saturated)	$\gamma_{soilsat} := 20 \frac{kN}{m^3}$	
Soil Cohesion - Drained	$c_{soil} := 0kPa$	
Soil Angle of Internal Friction - Drained	$\phi_{soil} := 24deg$	
Soil Ultimate Bearing Pressure	$Q_b := 150kPa$	
Slope of backfill (Conservative)	$\beta := 0$	
At-rest lateral earth pressure coefficient	$k_o := 1 - \sin(\phi_{soil}) = 0.59$	

<u>4.0 WALL SECTION DESCRIPTION</u>

4.1 Point Locations (Refer to Figure 1 and Drawings)

A - Top of wall	$EL_A := 1189.9m$	$x_A := 3.25m$
B - Top of fill - reservoir side	$EL_B := 1189.75m$	$x_B := x_A = 3.25 \cdot m$
C - Top of Heel	$EL_C := 1187m$	$x_C := x_A = 3.25 \cdot m$
D - Heel side end of footing	$EL_D := EL_C - 500mm = 1186.50\ m$	$x_D := x_A = 3.25 \cdot m$
E - Toe side end of footing	$EL_E := EL_D = 1186.50 \cdot m$	$x_E := 0m$
F - Top of Fill - land side	$EL_F := EL_C + 0.333m = 1187.33 \cdot m$	$x_F := x_E = 0$
G - Heel side face of wall stem	$EL_G := EL_A = 1189.90 \cdot m$	$x_G := 1.25m$
H - Toe side face of wall stem	$EL_H := EL_A = 1189.90 \cdot m$	$x_H := x_G - 0.500m = 0.75 \cdot m$

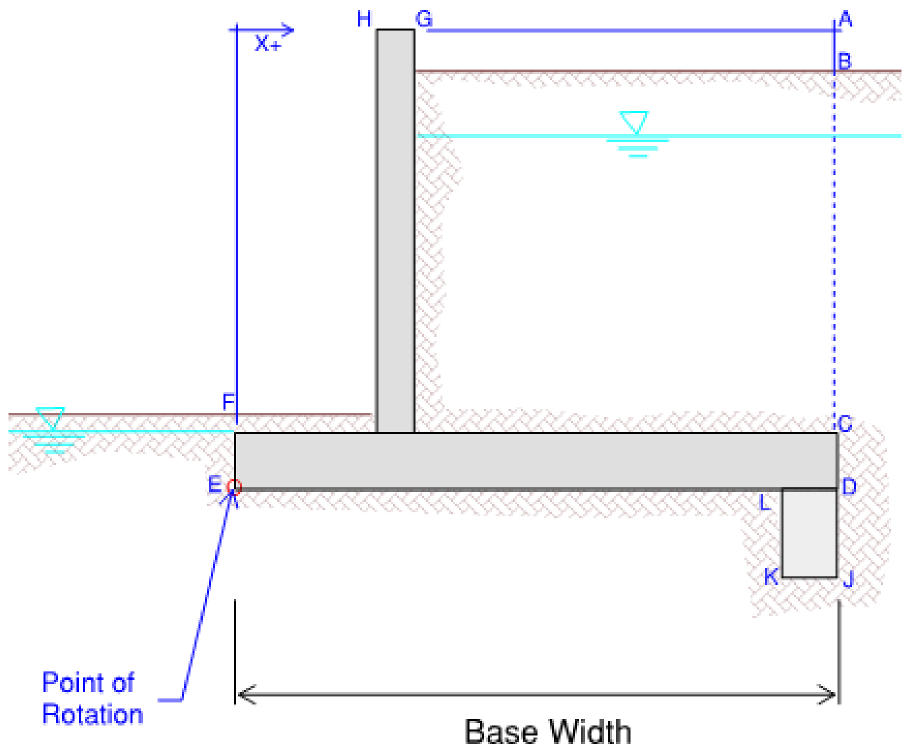


Figure 1. Cantilever Wall Section

J - Bottom of key - heel side	$EL_J := EL_C - 2m = 1185.00 \cdot m$	$x_J := x_D = 3.25\,m$
K - Bottom of key - toe side	$EL_K := EL_J = 1185.00 \cdot m$	$x_K := x_J - 450mm = 2.8 \cdot m$
L - Top of key	$EL_L := EL_D = 1186.50 \cdot m$	$x_L := x_K = 2.8\,m$

Applied Loads Data Source 2

Heel side water elevation

$$EL_{hw} := \begin{array}{|l} EL_B \ \text{if } LC = 3 \\ \left(\text{vlookup}(LC, WaterEL, 1)_0 \cdot 1m\right) \ \text{otherwise} \end{array} = 1187$$

Toe side water elevation

$$EL_{tw} := \begin{array}{|l} EL_F \ \text{if } LC = 3 \\ \left(\text{vlookup}(LC, WaterEL, 2)_0 \cdot 1m\right) \ \text{otherwise} \end{array} = 1187$$

Equivalent soil surcharge:

$$h_{sur} := \begin{array}{|l} 1.0m \ \text{if } LC = 2 \\ 0 \ \text{otherwise} \end{array} = 1 \cdot m$$

4.2 Additional Analysis Dimensions

Analysis Width $b := 1m$

Length of base $L_{base} := x_D - x_E = 3.25 \cdot m$

Thickness of base $t_{base} := EL_C - EL_D = 500 \cdot mm$

Length of stem $L_{stem} := EL_A - EL_C = 2.9 \cdot m$

Thickness of stem $t_{stem} := x_G - x_H = 500 \cdot mm$

Length of Heel $L_{heel} := x_A - x_G = 2000 \cdot mm$

Length of Toe $L_{toe} := x_H - x_F = 750 \cdot mm$

Thickness of Key $t_{key} := x_J - x_K = 450 \cdot mm$

Height of Key $h_{key} := EL_D - EL_J = 1500 \cdot mm$

5.0 UPLIFT & HYDROSTATIC LOADS

5.1 Uplift Pressures for Stability Analyses

Determine water pressures for designated coordinates using full headwater uplift pressure at the heel and full tailwater uplift pressure at the toe. Uplift distribution is assumed linear from heel to toe.

Hydrostatic pressure at Heel $u_h := \gamma_w \cdot (EL_{hw} - EL_J) = 20 \cdot kPa$

Hydrostatic pressure at Toe $u_t := \gamma_w \cdot (EL_{tw} - EL_E) = 5 \cdot kPa$

Total uplift loads on base $P_u := \frac{(u_h + u_t)}{2} \cdot L_{base} \cdot b = 39.85 \cdot kN$

Uplift resultant location $x_u := \frac{L_{base}}{2} + \frac{L_{base}}{6} \cdot \frac{(u_h - u_t)}{u_t + u_h} = 1.95 \cdot m$

Uplift Moment about Toe $M_u := P_u \cdot x_u = 77.7 \cdot kN \cdot m$

5.2 Headwater Hydrostatic Load - Heel Side

Headwater hydrostatic load $P_{hw} := \frac{1}{2} u_h \cdot (EL_{hw} - EL_J) \cdot b = 19.6 \cdot kN$

Headwater moment arm $y_{hw} := \frac{1}{3}(EL_{hw} - EL_J) - h_{key} = -0.83 \cdot m$

Headwater Moment about Toe $M_{hw} := P_{hw} \cdot y_{hw} = -16.4 \cdot kN \cdot m$

5.3 Tailwater Hydrostatic Load - Toe Side

Tailwater hydrostatic load $P_{tw} := \frac{1}{2} \gamma_w \cdot (EL_{tw} - EL_K)^2 \cdot b = 19.62 \cdot kN$

Tailwater moment arm $y_{tw} := h_{key} - \frac{1}{3}(EL_{tw} - EL_K) = 0.83 \cdot m$

Tailwater Moment about Toe $M_{tw} := P_{tw} \cdot y_{tw} = 16.35 \cdot kN \cdot m$

6.0 LATERAL EARTH PRESSURE

6.1 Lateral Soil Load on Toe Side

Soil pressure at Saturation Level

$$p_{tw} := \begin{cases} k_o \cdot \gamma_{soilm} \cdot (EL_F - EL_{tw}) & \text{if } EL_F > EL_{tw} \\ 0psf & \text{otherwise} \end{cases} = 4.0 \cdot kPa$$

Soil pressure at Toe - base elevation

$$p_E := \begin{cases} p_{tw} + k_o \cdot (\gamma_{soilsat} - \gamma_w) \cdot (EL_{tw} - EL_J) & \text{if } EL_F > EL_{tw} \\ k_o \cdot (\gamma_{soilsat} - \gamma_w) \cdot (EL_F - EL_J) & \text{otherwise} \end{cases}$$

$p_E = 16.04 \cdot kPa$

Total soil loads on Wall

$$P_{soil\_t} := \begin{bmatrix} 0.5 \cdot (EL_F - EL_{tw}) \cdot p_{tw} + p_{tw} \cdot (EL_{tw} - EL_J) \ldots \\ + 0.5 \cdot (p_E - p_{tw}) \cdot (EL_{tw} - EL_J) \end{bmatrix} \cdot b = 20.65 \cdot kN$$

Resultant location

$$y_{soil\_t} := \begin{cases} 0 & \text{if } P_{soil\_t} = 0 \\ h_{key} - \dfrac{\begin{bmatrix} 0.5 \cdot (EL_F - EL_{tw}) \cdot p_{tw} \cdot \left[(EL_{tw} - EL_J) + \frac{1}{3}(EL_F - EL_{tw})\right] + p_{tw} \cdot \frac{1}{2}(EL_{tw} - EL_J)^2 \ldots \\ + 0.5 \cdot (p_E - p_{tw}) \cdot (EL_{tw} - EL_J)^2 \cdot \frac{1}{3} \end{bmatrix} \cdot b}{P_{soil\_t}} & \text{otherwise} \end{cases}$$

$y_{soil\_t} = 0.66 \cdot m$

Moment about Toe $M_{soil\_t} := P_{soil\_t} \cdot y_{soil\_t} = 13.62 \cdot kN \cdot m$

6.2 Lateral Soil Load on Heel Side

Soil pressure at Saturation Level

$$p_{hw} := \begin{cases} k_o \cdot \gamma_{soilm} \cdot (EL_B - EL_{hw}) & \text{if } EL_B > EL_{hw} \\ 0psf & \text{otherwise} \end{cases} = 32.6 \cdot kPa$$

Soil pressure at Heel - base elevation

$$p_D := \begin{cases} p_{hw} + k_o \cdot (\gamma_{soilsat} - \gamma_w) \cdot (EL_{hw} - EL_J) & \text{if } EL_B > EL_{hw} \\ k_o \cdot (\gamma_{soilsat} - \gamma_w) \cdot (EL_B - EL_J) & \text{otherwise} \end{cases}$$

$$p_D = 44.72 \cdot kPa$$

Total soil loads on Base

$$P_{soil\_h} := \left[0.5 \cdot (EL_B - EL_{hw}) \cdot p_{hw} + p_{hw} \cdot (EL_{hw} - EL_J) \ldots + 0.5 \cdot (p_D - p_{hw}) \cdot (EL_{hw} - EL_J) \right] \cdot b$$

$$P_{soil\_h} = 122.22 \cdot kN$$

Resultant location

$$y_{soil\_h} := \frac{\left[0.5 \cdot (EL_B - EL_{hw}) \cdot p_{hw} \cdot \left[EL_{hw} - EL_J + \frac{1}{3} (EL_B - EL_{hw}) \right] + p_{hw} \cdot \frac{1}{2} (EL_{hw} - EL_J)^2 \ldots + 0.5 \cdot (p_D - p_{hw}) \cdot (EL_{hw} - EL_J)^2 \cdot \frac{1}{3} \right] \cdot b}{P_{soil\_h}} - h_{key}$$

$$y_{soil\_h} = 0.17 \cdot m$$

Moment about Toe $M_{soil\_h} := P_{soil\_h} \cdot y_{soil\_h} = 20.9 \cdot kN \cdot m$

6.3 Surcharge Soil Load - Heel Side

Surcharge soil pressure $p_{sur} := k_o \cdot \gamma_{soilm} \cdot h_{sur} = 12 \cdot kPa$

Soil load on wall $P_{sur} := p_{sur} \cdot (EL_B - EL_J) \cdot b = 56.36 \cdot kN$

Resultant location $y_{sur} := \frac{1}{2} \cdot (EL_B - EL_J) - h_{key} = 0.88\,m$

Moment about Toe $M_{sur} := P_{sur} \cdot y_{sur} = 49.32 \cdot kN \cdot m$

7.0 GRAVITY LOADS

7.1 Weight of Concrete

Weight of Wall footing/base $W_{conc} := \gamma_c \cdot (t_{base} \cdot L_{base} + L_{stem} \cdot t_{stem} + t_{key} \cdot h_{key}) \cdot b = 88.13 \cdot kN$

Resultant location
$$x_{conc} := \frac{\left[\frac{1}{2} t_{base} \cdot L_{base}^2 + L_{stem} \cdot t_{stem} \cdot (L_{toe} + 0.5 t_{stem}) \dots + t_{key} \cdot h_{key} \cdot (L_{base} - 0.5 t_{key})\right]}{t_{base} \cdot L_{base} + L_{stem} \cdot t_{stem} + t_{key} \cdot h_{key}} = 1.64\,m$$

Moment about Toe $M_{conc} := W_{conc} \cdot x_{conc} = 144.11 \cdot kN \cdot m$

7.2 Weight of Soil on Heel

Weight of Soil on heel

$$W_{soil\_h} := b \cdot L_{heel} \cdot \left| \begin{array}{ll} (\gamma_{soilsat} - \gamma_w) \cdot (EL_B - EL_C) & \text{if } EL_B < EL_{hw} \\ \gamma_{soilm} \cdot (EL_B - EL_{hw}) + (\gamma_{soilsat} - \gamma_w) \cdot \max[0, (EL_{hw} - EL_C)] & \text{otherwise} \end{array} \right.$$

$W_{soil\_h} = 110 \cdot kN$

Resultant location $x_{soil\_h} := 0.5(x_B - x_G) + x_G = 2.25 \cdot m$

Moment about Toe $M_{soilw\_h} := W_{soil\_h} \cdot x_{soil\_h} = 247.5 \cdot kN \cdot m$

7.3 Weight of Water on Heel

Weight of Water on heel $W_{w\_h} := \gamma_w \cdot \max[0kip, (EL_{hw} - EL_C)] \cdot L_{heel} \cdot b = 0 \cdot kN$

Resultant location $x_{w\_h} := 0.5(x_B - x_G) + x_G = 2.25 \cdot m$

Moment about Toe $M_{w\_h} := W_{w\_h} \cdot x_{w\_h} = 0 \cdot kN \cdot m$

7.4 Weight of Soil on Toe

Weight of Soil on toe Note: Water and soil elevations MUST NOT be below footing elevation

$$W_{soil\_t} := b \cdot L_{toe} \cdot \left| \begin{array}{ll} (\gamma_{soilsat} - \gamma_w) \cdot (\max(0, EL_F - EL_C)) & \text{if } EL_F < EL_{tw} \\ \gamma_{soilm} \cdot \max(0, EL_F - EL_{tw}) + (\gamma_{soilsat} - \gamma_w) \cdot \max(EL_{tw} - EL_C, 0) & \text{otherwise} \end{array} \right.$$

$W_{soil\_t} = 5 \cdot kN$

Resultant location $x_{soil\_t} := 0.5(x_H - x_E) = 0.38 \cdot m$

Moment about Toe $M_{soilw\_t} := W_{soil\_t} \cdot x_{soil\_t} = 1.9 \cdot kN \cdot m$

7.5 Weight of Water on Toe

Weight of Water on toe $W_{w\_t} := \gamma_w \cdot \max\left[0kip, \left(EL_{tw} - EL_C\right)\right] \cdot L_{toe} \cdot b = 0 \cdot kN$

Resultant location $x_{w\_t} := 0.5\left(x_H - x_E\right) = 0.38 \cdot m$

Moment about Toe $M_{w\_t} := W_{w\_t} \cdot x_{w\_t} = 0 \cdot kN \cdot m$

7.6 Weight of Soil under Footing and Above Failure Plane EJ

Depth of Soil Wedge Near Key $h_{s\_under} := \left(x_L - x_E\right) \cdot \dfrac{h_{key}}{L_{base}} = 1.29\,m$

Length of Soil Wedge $L_{s\_under} := x_L - x_E = 2.8\,m$

Weight of Soil Wedge Under Footing $W_{s\_under} := \gamma_{soilsat} \cdot \left(0.5 \cdot h_{s\_under} \cdot L_{s\_under}\right) \cdot b = 36.18 \cdot kN$

Resultant location $x_{s\_under} := \dfrac{2}{3}\left(x_L - x_E\right) = 1.87 \cdot m$

Moment about Toe $M_{s\_under} := W_{s\_under} \cdot x_{s\_under} = 67.5 \cdot kN \cdot m$

8.0 Overturning Stability Assessment - See Figure 2

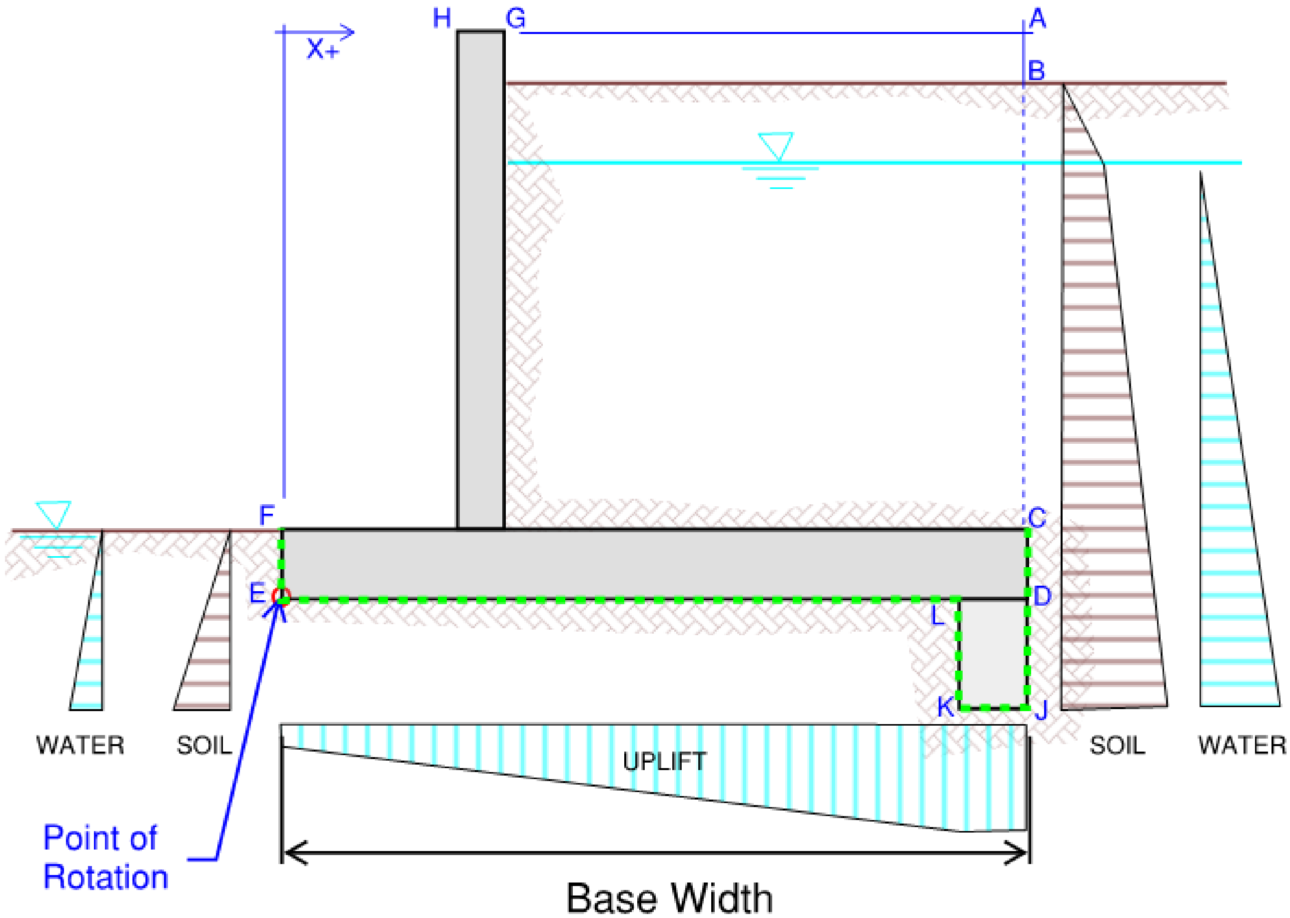


Figure 2. Free Body Diagram for Overturning Analysis

Uplift loads for Overturning

$$P_{u\_ot} := \left[\frac{1}{2}\left(u_h + u_t\right)\cdot\left(x_L - x_E\right) + u_h\cdot t_{key}\right]\cdot b = 43.16\cdot kN$$

Uplift resultant location

$$x_{u\_ot} := \frac{\left[\left[\frac{x_L - x_E}{2} + \frac{x_L - x_E}{6}\cdot\frac{\left(u_h - u_t\right)}{u_t + u_h}\right]\cdot\left[\frac{1}{2}\left(u_h + u_t\right)\cdot\left(x_L - x_E\right)\right] \ldots \\ + \left(L_{base} - 0.5t_{key}\right)\cdot\left(u_h\cdot t_{key}\right)\right]}{\left[\frac{1}{2}\left(u_h + u_t\right)\cdot\left(x_L - x_E\right) + u_h\cdot t_{key}\right]}$$

$$x_{u\_ot} = 1.96\,m$$

Uplift Moment about Toe

$$M_{u\_ot} := P_{u\_ot}\cdot x_{u\_ot} = 84.4\cdot kN\cdot m$$

Total Vertical Forces

$$\Sigma V_{ot} := W_{conc} + W_{soil\_h} + W_{soil\_t} \cdots + W_{w\_h} + W_{w\_t} - P_{u\_ot} = 160 \cdot kN$$

Total Horizontal Forces

$$\Sigma H_{ot} := P_{hw} + P_{soil\_h} + P_{sur} - P_{tw} - P_{soil\_t} = 157.92 \cdot kN$$

Total Resisting Moments

$$\Sigma M_{r\_ot} := M_{conc} + M_{soilw\_h} + M_{w\_h} \cdots + M_{soilw\_t} + M_{w\_t} = 393.5 \cdot kN \cdot m$$

Total Driving Moments

$$\Sigma M_{d\_ot} := M_{hw} + M_{soil\_h} + M_{sur} + M_{u\_ot} \cdots + M_{tw} + M_{soil\_t} = 168.2 \cdot kN \cdot m$$

Resultant Location from Toe

$$x_{r\_ot} := \frac{\Sigma M_{r\_ot} - \Sigma M_{d\_ot}}{\Sigma V_{ot}} = 1.41 \cdot m$$

Normalized Resultant Location

$$\frac{x_{r\_ot}}{L_{base}} = 0.433$$

Eccentricity

$$e_{x\_ot} := \frac{L_{base}}{2} - x_{r\_ot} = 0.22 \cdot m$$

Approx. Base in Compression

$$l_{comp\_ot} := \min\left[L_{base}, \frac{3}{2} \cdot \left(L_{base} - 2 \cdot e_{x\_ot}\right)\right] = 3.25 \cdot m$$

Percent Base in Compression

$$Base\_Comp := \left(\frac{l_{comp\_ot}}{L_{base}}\right) = 100 \cdot \%$$

Resultant Location Check

$$check_{res} := \text{if}\left(Base\_Comp \ge Base\_Comp_{Req}, \text{"OK"}, \text{"NG"}\right) = \text{"OK"}$$

9.0 Flotation Stability Assessment - See Figure 2

Calculated Flotation Safety Factor

$$FS_f := \frac{W_{conc} + W_{soil\_h} + W_{soil\_t} \cdots + W_{w\_h} + W_{w\_t}}{P_{u\_ot}} = 4.7$$

Flotation Stability Check

$$check_{floatation} := \text{if}\left(FS_f \ge FS_{float}, \text{"OK"}, \text{"NG"}\right) = \text{"OK"}$$

10.0 Sliding Stability Assessment - See Figure 3

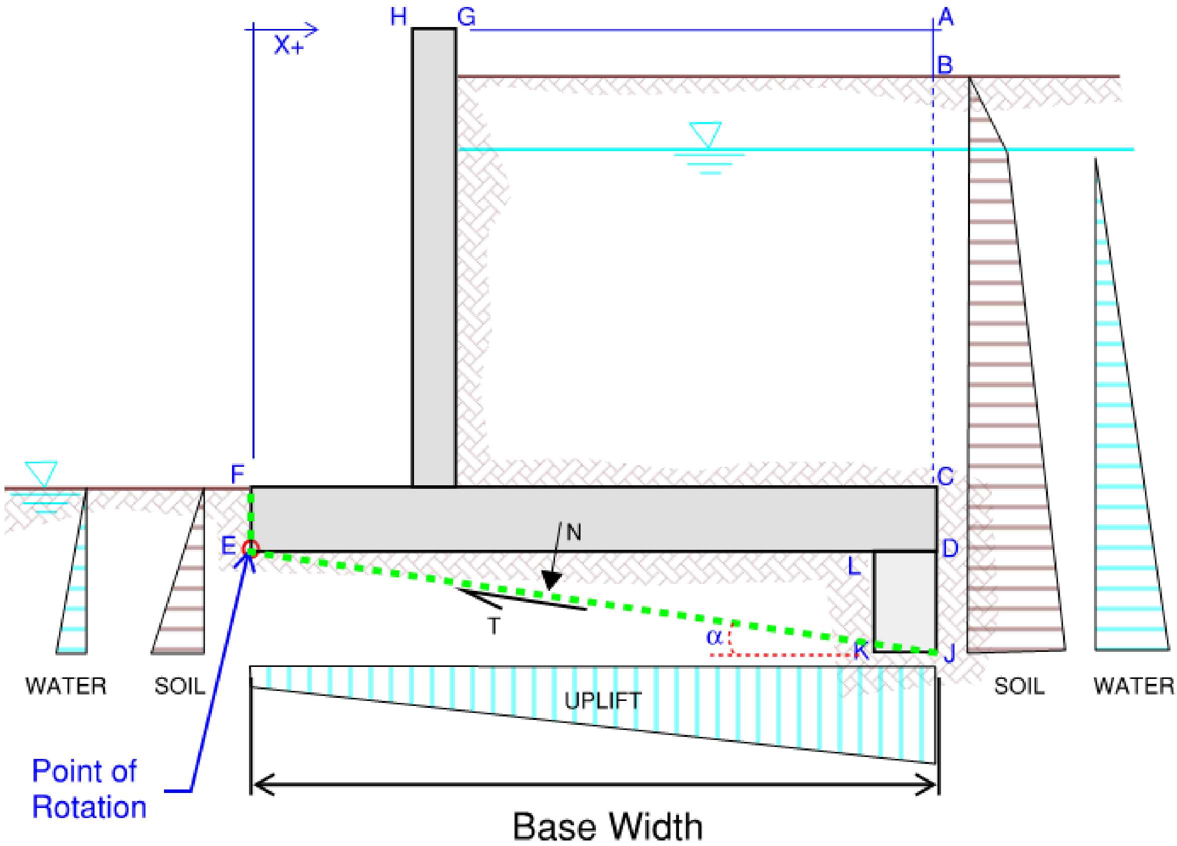


Figure 3. Free Body Diagram for Sliding Analysis

Length of Sliding Failure Plane, EJ

$$L_{fp} := \sqrt{L_{base}^{\ 2} + h_{key}^{\ 2}} = 3.58\ m$$

Angle of Sliding Failure Plane From Horizontal

$$\alpha := \operatorname{atan}\left(\frac{h_{key}}{L_{base}}\right) = 24.8 \cdot deg$$

Total Vertical Forces

$$\Sigma V := W_{conc} + W_{soil\_h} + W_{soil\_t} \cdots + W_{w\_h} + W_{s\_under} + W_{w\_t} - P_u = 199.5 \cdot kN$$

Total Horizontal Forces

$$\Sigma H := P_{hw} + P_{soil\_h} + P_{sur} - P_{tw} - P_{soil\_t} = 157.92 \cdot kN$$

Total Resisting Moments

$$\Sigma M_r := M_{conc} + M_{soilw\_h} + M_{w\_h} \cdots + M_{soilw\_t} + M_{w\_t} + M_{s\_under} = 461\ m \cdot kN$$

Total Driving Moments

$$\Sigma M_d := M_{hw} + M_{soil\_h} + M_{sur} + M_u \cdots + M_{tw} + M_{soil\_t} = 161.5 \cdot kN \cdot m$$

Normal Force on Sliding Failure Plane: $N_s := \Sigma H \cdot \sin(\alpha) + \Sigma V \cdot \cos(\alpha) = 247.27 \cdot kN$

Tangential Force on Sliding Failure Plane: $T_s := \Sigma H \cdot \cos(\alpha) - \Sigma V \cdot \sin(\alpha) = 59.81 \cdot kN$

Calculated Sliding Safety Factor $$FS_s := \frac{\left|N_s \cdot \tan\left(0.95\phi_{soil}\right)\right|}{\left|T_s\right|} = 1.74$$

Sliding Stability Check $check_{sliding} := if\left(FS_s \ge FS_{Sliding}, "OK", "NG"\right) = "OK"$

11.0 Bearing Capacity Assessment

Resultant Location from Toe $$x_r := \frac{\Sigma M_r - \Sigma M_d}{N_s} = 1.21 \cdot m$$

Eccentricity of N_s from center of base $$e_s := \frac{L_{fp}}{2} - x_r = 0.58 \cdot m$$

Approx. Base in Compression $$l_{comp.s} := \min\left[L_{fp}, \frac{3}{2} \cdot \left(L_{fp} - 2 \cdot e_s\right)\right] = 3.58 \cdot m$$

Updated Eccentricity $$e_x := \frac{l_{comp.s} - L_{fp}}{2} + e_s = 0.58 \cdot m$$

Effective base pressure at Toe $$q_t := \left(\frac{N_s}{l_{comp.s} \cdot b}\right) \cdot \left(1 + \frac{6 \cdot e_x}{l_{comp.s}}\right) = 136.06 \cdot kPa$$

Effective base pressure at Heel $$q_h := \max\left[\left(\frac{N_s}{l_{comp.s} \cdot b}\right) \cdot \left(1 - \frac{6 \cdot e_x}{l_{comp.s}}\right), 0\right] = 2.10 \cdot kPa$$

Calculated Bearing Safety Factor $$FS_b := \frac{Q_b}{\max\left(q_t, q_h\right)} = 1.10$$

Bearing Pressure Check $check_{bearing} := if\left(FS_b \ge FS_{Bearing}, "OK", "NG"\right) = "OK"$

12.0 Summary of Stability Assessments

Base Compression / Resultant Location	$Base\_Comp = 100 \cdot \%$	$check_{res} = "OK"$
Flotation Stability	$FS_f = 4.7$	$check_{floatation} = "OK"$
Sliding Stability	$FS_s = 1.7$	$check_{sliding} = "OK"$
Bearing Pressure	$FS_b = 1.1$	$check_{bearing} = "OK"$

13.0 Structural Loads

13.1 Shear and Moment at Stem Base - See Figure 4

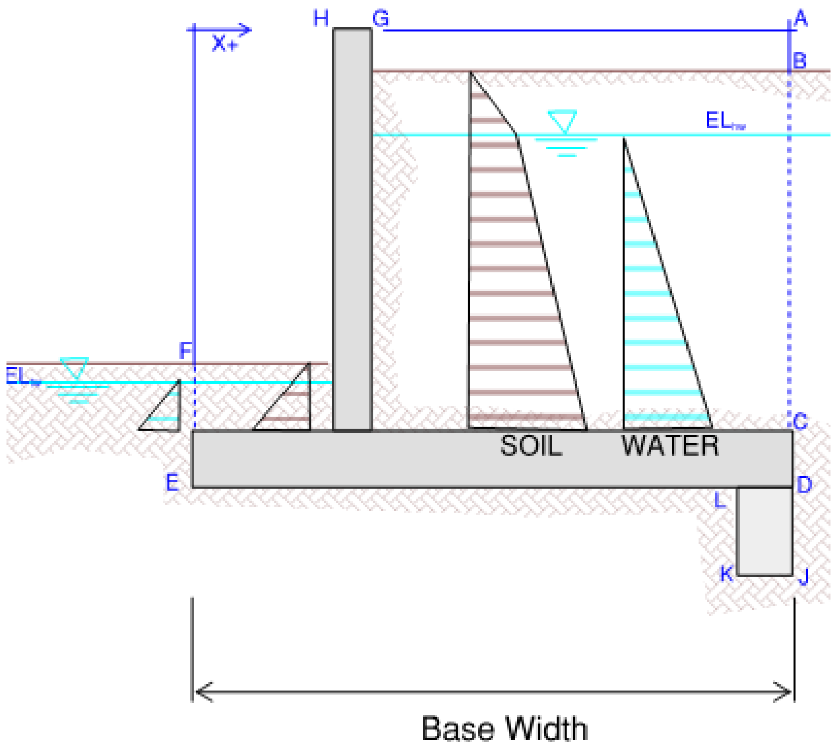


Figure 4 - Loads on Stem

13.1.1 Hydrostatic Load at Stem Base

Heel side hydrostatic load $P_{hw\_stem} := \frac{1}{2}\gamma_w \cdot (EL_{hw} - EL_C)^2 \cdot b = 0.0 \cdot kN$

Heel side moment at stem base $M_{hw\_stem} := P_{hw\_stem} \cdot \left(\frac{EL_{hw} - EL_C}{3}\right) = 0 \cdot kN \cdot m$

Toe side hydrostatic load $P_{tw\_stem} := \frac{1}{2}\gamma_w \cdot (EL_{tw} - EL_C)^2 \cdot b = 0.0 \cdot kN$

Toe side moment at stem base $M_{tw\_stem} := P_{tw\_stem} \cdot \left(\frac{EL_{tw} - EL_C}{3}\right) = 0 \cdot kN \cdot m$

13.1.2 Lateral Soil Loads at Stem Base

Soil pressure at saturation level - Toe Side

$$p_t := \begin{cases} k_o \cdot \gamma_{soilm} \cdot (EL_F - EL_{tw}) & \text{if } EL_F > EL_{tw} \\ 0psf & \text{otherwise} \end{cases} = 3.95 \cdot kPa$$

Soil pressure at stem base - Toe Side

$$p_{C.t} := \begin{cases} p_t + k_o \cdot (\gamma_{soilsat} - \gamma_w) \cdot (EL_{tw} - EL_C) & \text{if } EL_F > EL_{tw} \\ k_o \cdot (\gamma_{soilsat} - \gamma_w) \cdot (EL_F - EL_C) & \text{otherwise} \end{cases}$$

$$p_{C.t} = 3.95 \cdot kPa$$

Lateral soil loads at stem base - Toe Side

$$P_{s\_t} := \left[0.5 \cdot (EL_F - EL_{tw}) \cdot p_t + p_t \cdot (EL_{tw} - EL_C) \ldots + 0.5 \cdot (p_{C.t} - p_t) \cdot (EL_{tw} - EL_C)\right] \cdot b = 0.66 \cdot kN$$

Resultant location

$$y_{s\_t} := \begin{cases} 0 & \text{if } P_{s\_t} = 0 \\ \dfrac{\left[0.5 \cdot (EL_F - EL_{tw}) \cdot p_t \cdot \left[(EL_{tw} - EL_C) + \frac{1}{3}(EL_F - EL_{tw})\right] + p_t \cdot \frac{1}{2}(EL_{tw} - EL_C)^2 \ldots + 0.5 \cdot (p_{C.t} - p_t) \cdot (EL_{tw} - EL_C)^2 \cdot \frac{1}{3}\right] \cdot b}{P_{s\_t}} & \text{otherwise} \end{cases}$$

$$y_{s\_t} = 0.11 \cdot m$$

Lateral soil moment at stem base - Toe Side

$$M_{s\_t} := P_{s\_t} \cdot y_{s\_t} = 0.07 \cdot kN \cdot m$$

Soil pressure at saturation level - Heel Side

$$p_h := \begin{cases} k_o \cdot \gamma_{soilm} \cdot (EL_B - EL_{hw}) & \text{if } EL_B > EL_{hw} \\ 0kPa & \text{otherwise} \end{cases} = 32.63 \cdot kPa$$

Soil pressure at stem base - Heel Side

$$p_{C.h} := \begin{cases} p_h + k_o \cdot (\gamma_{soilsat} - \gamma_w) \cdot (EL_{hw} - EL_C) & \text{if } EL_B > EL_{tw} \\ k_o \cdot (\gamma_{soilsat} - \gamma_w) \cdot (EL_B - EL_C) & \text{otherwise} \end{cases}$$

$$p_{C.h} = 32.63 \cdot kPa$$

Lateral soil loads at stem base - Heel Side

$$P_{s\_h} := \left[0.5 \cdot (EL_B - EL_{hw}) \cdot p_h + p_h \cdot (EL_{hw} - EL_C) \ldots + 0.5 \cdot (p_{C.h} - p_h) \cdot (EL_{hw} - EL_C)\right] \cdot b = 44.87 \cdot kN$$

Resultant location

$$y_{s\_h} := \begin{cases} 0 & \text{if } P_{s\_h} = 0 \\ \dfrac{\left[0.5\cdot(EL_B - EL_{hw})\cdot p_h\cdot\left[(EL_{hw} - EL_C) + \frac{1}{3}(EL_B - EL_{hw})\right] + p_h\cdot\frac{1}{2}(EL_{hw} - EL_C)^2 \ldots \\ + 0.5\cdot(p_{C.h} - p_h)\cdot(EL_{hw} - EL_C)^2\cdot\frac{1}{3}\right]\cdot b}{P_{s\_h}} & \text{otherwise} \end{cases}$$

$$y_{s\_h} = 0.92\cdot m$$

Lateral soil moment at stem base - Heel Side $\quad M_{s\_h} := P_{s\_h}\cdot y_{s\_h} = 41.13\cdot kN\cdot m$

13.1.3 Surcharge Loads at Stem Base

Surcharge load at stem base $\quad P_{sur\_stem} := p_{sur}\cdot(EL_B - EL_C)\cdot b = 32.63\cdot kN$

Surcharge Moment about Toe $\quad M_{sur\_stem} := P_{sur}\cdot\frac{1}{2}(EL_B - EL_C) = 77.5\cdot kN\cdot m$

13.2 Shear and Moment on Heel - See Figure 5

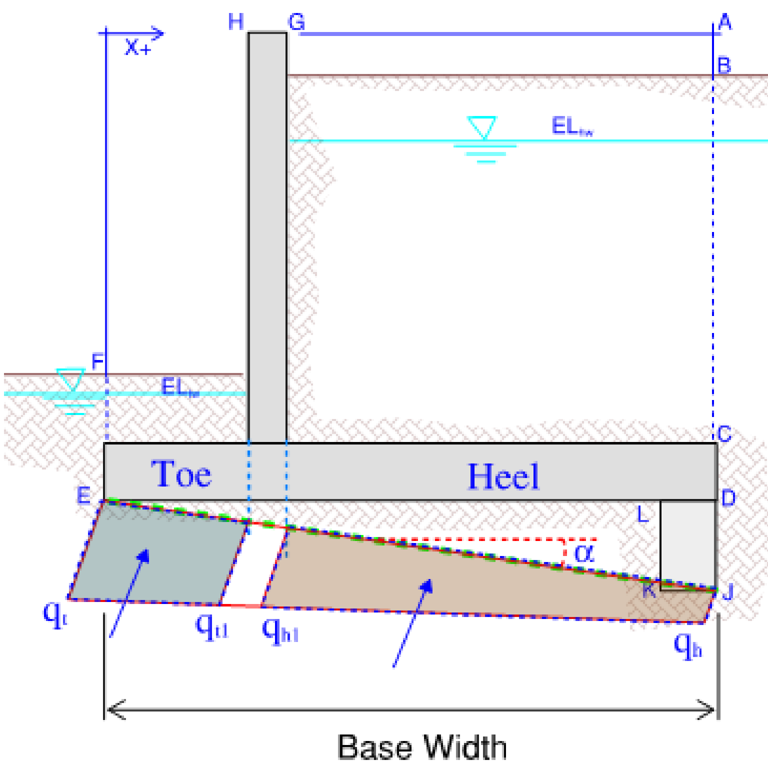


Figure 5 - Loads on Base (Heel & Toe)

13.2.1 Weight of Concrete Heel

Weight of Wall footing/base $W_{c\_heel} := \gamma_c \cdot (t_{base} \cdot L_{heel} + t_{key} \cdot h_{key}) \cdot b = 39.36 \cdot kN$

Resultant location $x_{c\_heel} := \dfrac{\left[\dfrac{1}{2} t_{base} \cdot L_{heel}{}^2 \ldots \\ + t_{key} \cdot h_{key} \cdot (L_{heel} - 0.5 t_{key})\right]}{t_{base} \cdot L_{heel} + t_{key} \cdot h_{key}} = 1.31\ m$

Moment about stem base $M_{c\_heel} := W_{c\_heel} \cdot x_{c\_heel} = 51.66 \cdot kN \cdot m$

13.2.2 Weight of Soil on Heel

Weight of Soil on heel $W_{s\_heel} := W_{soil\_h} = 110 \cdot kN$

Moment about stem base $M_{s\_heel} := W_{s\_heel} \cdot \left(\dfrac{1}{2} L_{heel}\right) = 110 \cdot kN \cdot m$

13.2.3 Weight of Water on Heel

Weight of Water on heel $W_{w\_heel} := W_{w\_h} = 0 \cdot kN$

Moment about stem base $M_{w\_heel} := W_{w\_heel} \cdot \left(\dfrac{1}{2} L_{heel}\right) = 0 \cdot kN \cdot m$

13.2.4 Weight of Concrete Toe

Weight of Wall footing/base $W_{c\_toe} := \gamma_c \cdot t_{base} \cdot L_{toe} \cdot b = 8.81 \cdot kN$

Moment about stem base $M_{c\_toe} := W_{c\_toe} \cdot \left(\dfrac{1}{2} \cdot L_{toe}\right) = 3.3 \cdot kN \cdot m$

13.2.5 Weight of Soil on Toe

Weight of Soil on Toe $W_{s\_toe} := W_{soil\_t} = 5 \cdot kN$

Moment about stem base $M_{s\_toe} := W_{s\_toe} \cdot \left(\dfrac{1}{2} L_{toe}\right) = 1.9 \cdot kN \cdot m$

13.2.6 Weight of Water on Toe

Weight of Water on Toe $W_{w\_toe} := W_{w\_t} = 0 \cdot kN$

Moment about stem base $M_{w\_toe} := W_{w\_toe} \cdot \left(\dfrac{1}{2} L_{toe}\right) = 0 \cdot kN \cdot m$

13.2.7 Bearing Pressures on Footing

Approx. Base in Compression	$l_{comp.s} = 3.58\,m$
Effective base pressure at Toe	$q_t = 136.06 \cdot kPa$
Effective base pressure at Heel	$q_h = 2.10 \cdot kPa$
Compression length under Toe	$L_{bearing\_t} := \dfrac{L_{toe}}{\cos(\alpha)} = 0.83\,m$
Compression length under Heel	$L_{bearing\_h} := l_{comp.s} - \dfrac{(x_G - x_E)}{\cos(\alpha)} = 2.2\,m$
Bearing pressure under toe side of stem	$q_{t1} := L_{bearing\_t} \cdot \left[\dfrac{(q_h - q_t)}{l_{comp.s}}\right] + q_t = 105.15 \cdot kPa$
Bearing pressure under heel side of stem	$q_{h1} := \dfrac{(x_G - x_E)}{\cos(\alpha)} \cdot \left[\dfrac{(q_h - q_t)}{l_{comp.s}}\right] + q_t = 84.54 \cdot kPa$

13.2.8 Soil Reaction on Heel

Soil reaction load on Heel	$P_{bearing\_h} := \dfrac{1}{2} \cdot (q_h + q_{h1}) \cdot L_{bearing\_h} \cdot b = 95.42 \cdot kN$
Resultant location	$x_{bearing\_h} := \dfrac{L_{bearing\_h}}{2} + \dfrac{L_{bearing\_h}}{6} \cdot \dfrac{(q_h - q_{h1})}{q_{h1} + q_h} = 0.75\,m$
Vertical Component	$P_{h\_v} := P_{bearing\_h} \cdot \cos(\alpha) = 86.64 \cdot kN$
Horizontal Component	$P_{h\_h} := P_{bearing\_h} \cdot \sin(\alpha) = 39.99 \cdot kN$
Horizontal Moment Arm	$x_{h\_h} := x_{bearing\_h} \cdot \cos(\alpha) = 0.68\,m$
Vertical Moment Arm	$y_{h\_v} := \left[\dfrac{(x_G - x_E)}{\cos(\alpha)} + x_{bearing\_h}\right] \cdot \sin(\alpha) = 0.89\,m$
Moment on Heel	$M_{bearing\_h} := P_{h\_v} \cdot x_{h\_h} + P_{h\_h} \cdot y_{h\_v} = 94.83 \cdot kN \cdot m$

13.2.9 Soil Reaction on Toe

Soil reaction load on Toe $P_{bearing\_t} := \frac{1}{2} \cdot (q_t + q_{t1}) \cdot L_{bearing\_t} \cdot b = 99.62 \cdot kN$

Resultant location $x_{bearing\_t} := \frac{L_{bearing\_t}}{2} + \frac{L_{bearing\_t}}{6} \cdot \frac{(q_t - q_{t1})}{q_t + q_{t1}} = 0.43\ m$

Vertical Component $P_{t\_v} := P_{bearing\_t} \cdot \cos(\alpha) = 90.45 \cdot kN$

Horizontal Component $P_{t\_h} := P_{bearing\_t} \cdot \sin(\alpha) = 41.75 \cdot kN$

Horizontal Moment Arm $x_{t\_h} := x_{bearing\_t} \cdot \cos(\alpha) = 0.39\ m$

Vertical Moment Arm $y_{t\_v} := (L_{bearing\_t} - x_{bearing\_t}) \cdot \sin(\alpha) = 0.17\ m$

Moment on Toe $M_{bearing\_t} := P_{t\_v} \cdot x_{t\_h} + P_{t\_h} \cdot y_{t\_v} = 42.29 \cdot kN \cdot m$

13.2.10 Uplift Pressure on Footing - Figure 6

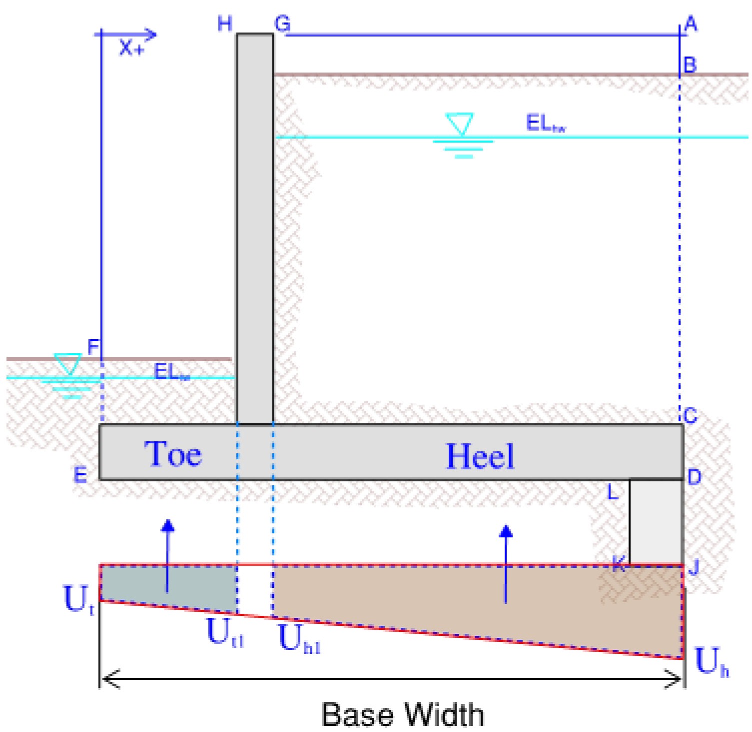


Figure 6 - Uplift Loads on Base (Heel & Toe)

Uplift pressure under toe side of stem $u_{t1} := L_{toe} \cdot \left[\frac{(u_h - u_t)}{L_{base}} \right] + u_t = 8.3 \cdot kPa$

Uplift pressure under heel side of stem $u_{h1} := (x_G - x_E) \cdot \left[\frac{(u_h - u_t)}{L_{base}} \right] + u_t = 10.56 \cdot kPa$

13.2.11 Uplift Loads Heel

Uplift load on Heel $P_{u\_h} := \frac{1}{2} \cdot (u_h + u_{h1}) \cdot L_{heel} \cdot b = 30.18 \cdot kN$

Moment Arm $x_{u\_h} := \frac{L_{heel}}{2} + \frac{L_{heel}}{6} \cdot \frac{(u_h - u_{h1})}{u_{h1} + u_h} = 1.1\, m$

Moment on Heel $M_{u\_h} := P_{u\_h} \cdot x_{u\_h} = 33.2 \cdot kN \cdot m$

13.2.12 Uplift Loads Toe

Uplift load on Toe $P_{u\_t} := \frac{1}{2} \cdot (u_t + u_{t1}) \cdot L_{toe} \cdot b = 4.95 \cdot kN$

Moment Arm $x_{u\_t} := \frac{L_{toe}}{2} + \frac{L_{toe}}{6} \cdot \frac{(u_t - u_{t1})}{u_{t1} + u_t} = 0.34\, m$

Moment on Toe $M_{u\_t} := P_{u\_t} \cdot x_{u\_t} = 1.7 \cdot kN \cdot m$

13.3 Structural Load Summary

Net shear at stem base $V_{stem} := P_{hw\_stem} - P_{tw\_stem} + P_{s\_h} - P_{s\_t} + P_{sur\_stem} = 76.8 \cdot kN$

Net moment at stem base $M_{stem} := M_{hw\_stem} - M_{tw\_stem} + M_{s\_h} - M_{s\_t} + M_{sur\_stem} = 118.5 \cdot kN \cdot m$

Net shear on Toe $V_t := W_{c\_toe} + W_{s\_toe} + W_{w\_toe} - P_{t\_v} - P_{u\_t} = -81.6 \cdot kN$

Net moment on Toe $M_t := M_{c\_toe} + M_{s\_toe} + M_{w\_toe} - M_{bearing\_t} - M_{u\_t} = -38.8 \cdot kN \cdot m$

Net shear on Heel $V_h := W_{c\_heel} + W_{s\_heel} + W_{w\_heel} - P_{h\_v} - P_{u\_h} = 32.5 \cdot kN$

Net moment on Heel $M_h := M_{c\_heel} + M_{s\_heel} + M_{w\_heel} - M_{bearing\_h} - M_{u\_h} = 33.6 \cdot kN \cdot m$

13.4 Controlling Structural Loads (Unfactored)

Stem cross section

$M_{stem} = 118.5 \cdot kN \cdot m$

$V_{stem} = 76.8 \cdot kN$

Toe cross section

$M_{toe} := M_t = -38.81 \cdot kN \cdot m$

$V_{toe} := V_t = -81.6 \cdot kN$

Heel cross section

$M_{heel} := \min\left(\max\left(M_{stem} - \left|M_{toe}\right|, M_h\right), M_{stem}\right) = 79.7 \cdot kN \cdot m$

STABILITY ANALYSIS FOR CANTILEVER WALL WITH KEY

Project / Client: Springbank Off-Stream Storage (SR1) / Alberta Transportation

Section Location: Intake Structure Wing Wall - Closest to Intake Structure

1.0 OBJECTIVE

For a particular load condition, analyze a reinforced concrete cantilever wall with shear key for overturning, sliding, flotation, and bearing capacity in accordance with criteria described in the listed references.

2.0 BACKGROUND INFORMATION

2.1 DATA SOURCES

1- Soils Report - Recommended Geotechnical Soil Parameters, SR-1 Low Level Outlet (LLO) Structures. July 19, 2019

2- Drawings - Design Drawings

3- Springbank Off-Stream Storage Project - Design Basis Memorandum (DBM) , 2019

2.2 REFERENCES

1. (CDA) Dam Safety Guidelines, 2007 (revised 2013).

2. "Water Control Structures Selected Design Guidelines," Alberta Transportation & Alberta Environment, Calgary Alberta, November 2004.

3.0 DESIGN PARAMETERS AND CRITERIA

3.1 Stability Analysis Criteria (Data source 2)

Load Case	$LC := 3$
Load Case Description	$vlookup(LC, CASES, 1)_0 =$ "Rapid Drawdown"
Sliding Minimum Factor of Safety	$FS_{Sliding} := vlookup(LC, CASES, 2)_0 = 1.1$
Overturning Criteria	$Base\_Comp_{Req} := vlookup(LC, CASES, 3)_0 = 75 \cdot \%$
Bearing Capacity Minimum Factor of Safety	$FS_{Bearing} := vlookup(LC, CASES, 4)_0 = 1$
Flotation Minimum Factor of Safety	$FS_{float} := vlookup(LC, CASES, 5)_0 = 1.1$

3.2 Material Properties - Data Source 1 Unless Otherwise Noted

Unit Weight of Water	$\gamma_w := 9.81\,\frac{kN}{m^3}$	
Unit Weight of Concrete	$\gamma_c := 23.5\cdot\frac{kN}{m^3}$	Data Source 3
Unit Weight of Soil (Moist)	$\gamma_{soilm} := 20\,\frac{kN}{m^3}$	
Soil Unit Weight Beneath Base (Saturated)	$\gamma_{soilsat} := 20\,\frac{kN}{m^3}$	
Soil Cohesion - Drained	$c_{soil} := 0kPa$	
Soil Angle of Internal Friction - Drained	$\phi_{soil} := 24deg$	
Soil Ultimate Bearing Pressure	$Q_b := 150kPa$	
Slope of backfill (Conservative)	$\beta := 0$	
At-rest lateral earth pressure coefficient	$k_o := 1 - \sin(\phi_{soil}) = 0.59$	

4.0 WALL SECTION DESCRIPTION

4.1 Point Locations (Refer to Figure 1 and Drawings)

A - Top of wall	$EL_A := 1189.9m$	$x_A := 3.25m$
B - Top of fill - reservoir side	$EL_B := 1189.75m$	$x_B := x_A = 3.25\cdot m$
C - Top of Heel	$EL_C := 1187m$	$x_C := x_A = 3.25\cdot m$
D - Heel side end of footing	$EL_D := EL_C - 500mm = 1186.50\,m$	$x_D := x_A = 3.25\cdot m$
E - Toe side end of footing	$EL_E := EL_D = 1186.50\cdot m$	$x_E := 0m$
F - Top of Fill - land side	$EL_F := EL_C + 0.333m = 1187.33\cdot m$	$x_F := x_E = 0$
G - Heel side face of wall stem	$EL_G := EL_A = 1189.90\cdot m$	$x_G := 1.25m$
H - Toe side face of wall stem	$EL_H := EL_A = 1189.90\cdot m$	$x_H := x_G - 0.500m = 0.75\cdot m$

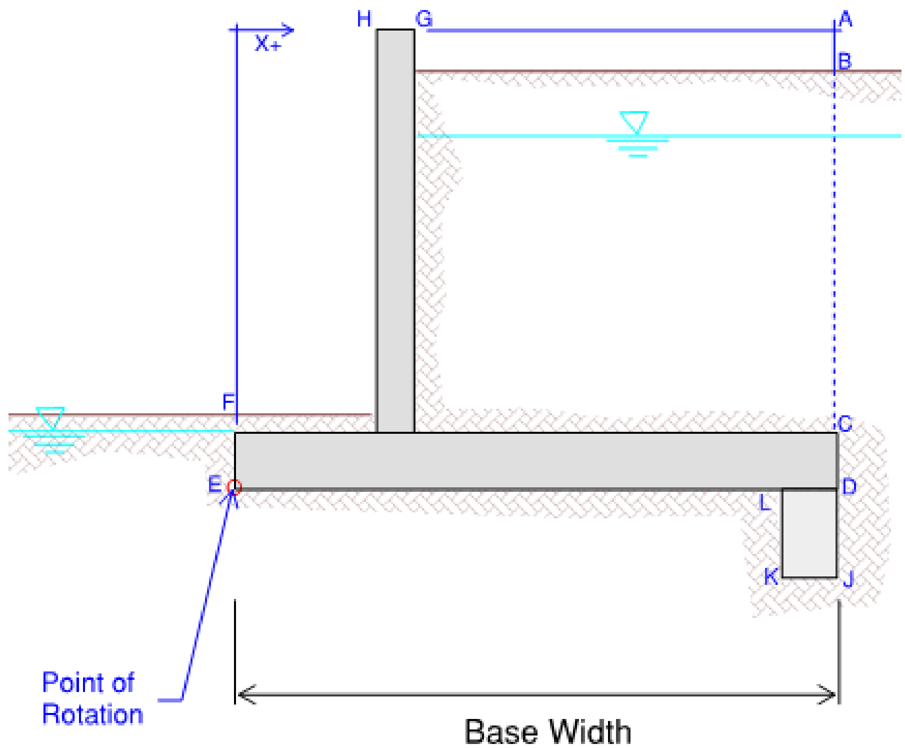


Figure 1. Cantilever Wall Section

J - Bottom of key - heel side	$EL_J := EL_C - 2m = 1185.00 \cdot m$	$x_J := x_D = 3.25\,m$
K - Bottom of key - toe side	$EL_K := EL_J = 1185.00 \cdot m$	$x_K := x_J - 450mm = 2.8 \cdot m$
L - Top of key	$EL_L := EL_D = 1186.50 \cdot m$	$x_L := x_K = 2.8\,m$

Applied Loads Data Source 2

Heel side water elevation

$$EL_{hw} := \begin{cases} EL_B & \text{if } LC = 3 \\ \left(\text{vlookup}(LC, WaterEL, 1)_0 \cdot 1m\right) & \text{otherwise} \end{cases} = 1189.75$$

Toe side water elevation

$$EL_{tw} := \begin{cases} EL_F & \text{if } LC = 3 \\ \left(\text{vlookup}(LC, WaterEL, 2)_0 \cdot 1m\right) & \text{otherwise} \end{cases} = 1187.33$$

Equivalent soil surcharge:

$$h_{sur} := \begin{cases} 1.0m & \text{if } LC = 2 \\ 0 & \text{otherwise} \end{cases} = 0 \cdot m$$

4.2 Additional Analysis Dimensions

Analysis Width $b := 1m$

Length of base $L_{base} := x_D - x_E = 3.25 \cdot m$

Thickness of base $t_{base} := EL_C - EL_D = 500 \cdot mm$

Length of stem $L_{stem} := EL_A - EL_C = 2.9 \cdot m$

Thickness of stem $t_{stem} := x_G - x_H = 500 \cdot mm$

Length of Heel $L_{heel} := x_A - x_G = 2000 \cdot mm$

Length of Toe $L_{toe} := x_H - x_F = 750 \cdot mm$

Thickness of Key $t_{key} := x_J - x_K = 450 \cdot mm$

Height of Key $h_{key} := EL_D - EL_J = 1500 \cdot mm$

5.0 UPLIFT & HYDROSTATIC LOADS

5.1 Uplift Pressures for Stability Analyses

Determine water pressures for designated coordinates using full headwater uplift pressure at the heel and full tailwater uplift pressure at the toe. Uplift distribution is assumed linear from heel to toe.

Hydrostatic pressure at Heel $u_h := \gamma_w \cdot \left(EL_{hw} - EL_J\right) = 47 \cdot kPa$

Hydrostatic pressure at Toe $u_t := \gamma_w \cdot \left(EL_{tw} - EL_E\right) = 8 \cdot kPa$

Total uplift loads on base $P_u := \frac{\left(u_h + u_t\right)}{2} \cdot L_{base} \cdot b = 89 \cdot kN$

Uplift resultant location $x_u := \frac{L_{base}}{2} + \frac{L_{base}}{6} \cdot \frac{\left(u_h - u_t\right)}{u_t + u_h} = 2.01 \cdot m$

Uplift Moment about Toe $M_u := P_u \cdot x_u = 178.4 \cdot kN \cdot m$

5.2 Headwater Hydrostatic Load - Heel Side

Headwater hydrostatic load
$$P_{hw} := \frac{1}{2} u_h \cdot (EL_{hw} - EL_J) \cdot b = 110.7 \cdot kN$$

Headwater moment arm
$$y_{hw} := \frac{1}{3}(EL_{hw} - EL_J) - h_{key} = 0.08 \cdot m$$

Headwater Moment about Toe
$$M_{hw} := P_{hw} \cdot y_{hw} = 9.2 \cdot kN \cdot m$$

5.3 Tailwater Hydrostatic Load - Toe Side

Tailwater hydrostatic load
$$P_{tw} := \frac{1}{2} \gamma_w \cdot (EL_{tw} - EL_K)^2 \cdot b = 26.70 \cdot kN$$

Tailwater moment arm
$$y_{tw} := h_{key} - \frac{1}{3}(EL_{tw} - EL_K) = 0.72 \cdot m$$

Tailwater Moment about Toe
$$M_{tw} := P_{tw} \cdot y_{tw} = 19.28 \cdot kN \cdot m$$

6.0 LATERAL EARTH PRESSURE

6.1 Lateral Soil Load on Toe Side

Soil pressure at Saturation Level
$$p_{tw} := \begin{cases} k_o \cdot \gamma_{soilm} \cdot (EL_F - EL_{tw}) & \text{if } EL_F > EL_{tw} \\ 0psf & \text{otherwise} \end{cases} = 0.0 \cdot kPa$$

Soil pressure at Toe - base elevation
$$p_E := \begin{cases} p_{tw} + k_o \cdot (\gamma_{soilsat} - \gamma_w) \cdot (EL_{tw} - EL_J) & \text{if } EL_F > EL_{tw} \\ k_o \cdot (\gamma_{soilsat} - \gamma_w) \cdot (EL_F - EL_J) & \text{otherwise} \end{cases}$$

$$p_E = 14.1 \cdot kPa$$

Total soil loads on Wall
$$P_{soil\_t} := \begin{bmatrix} 0.5 \cdot (EL_F - EL_{tw}) \cdot p_{tw} + p_{tw} \cdot (EL_{tw} - EL_J) \ldots \\ + 0.5 \cdot (p_E - p_{tw}) \cdot (EL_{tw} - EL_J) \end{bmatrix} \cdot b = 16.45 \cdot kN$$

Resultant location

$$y_{soil\_t} := \begin{cases} 0 & \text{if } P_{soil\_t} = 0 \\ h_{key} - \dfrac{\begin{bmatrix} 0.5 \cdot (EL_F - EL_{tw}) \cdot p_{tw} \cdot \left[(EL_{tw} - EL_J) + \frac{1}{3}(EL_F - EL_{tw}) \right] + p_{tw} \cdot \frac{1}{2} (EL_{tw} - EL_J)^2 \ldots \\ + 0.5 \cdot (p_E - p_{tw}) \cdot (EL_{tw} - EL_J)^2 \cdot \frac{1}{3} \end{bmatrix} \cdot b}{P_{soil\_t}} & \text{otherwise} \end{cases}$$

$$y_{soil\_t} = 0.72 \cdot m$$

Moment about Toe $M_{soil\_t} := P_{soil\_t} \cdot y_{soil\_t} = 11.88 \cdot kN \cdot m$

6.2 Lateral Soil Load on Heel Side

Soil pressure at Saturation Level

$$p_{hw} := \begin{cases} k_o \cdot \gamma_{soilm} \cdot (EL_B - EL_{hw}) & \text{if } EL_B > EL_{hw} \\ 0psf & \text{otherwise} \end{cases} = 0.0 \cdot kPa$$

Soil pressure at Heel - base elevation

$$p_D := \begin{cases} p_{hw} + k_o \cdot (\gamma_{soilsat} - \gamma_w) \cdot (EL_{hw} - EL_J) & \text{if } EL_B > EL_{hw} \\ k_o \cdot (\gamma_{soilsat} - \gamma_w) \cdot (EL_B - EL_J) & \text{otherwise} \end{cases}$$

$$p_D = 28.72 \cdot kPa$$

Total soil loads on Base

$$P_{soil\_h} := \left[0.5 \cdot (EL_B - EL_{hw}) \cdot p_{hw} + p_{hw} \cdot (EL_{hw} - EL_J) \ldots + 0.5 \cdot (p_D - p_{hw}) \cdot (EL_{hw} - EL_J)\right] \cdot b$$

$$P_{soil\_h} = 68.2 \cdot kN$$

Resultant location

$$y_{soil\_h} := \frac{\left[0.5 \cdot (EL_B - EL_{hw}) \cdot p_{hw} \cdot \left[EL_{hw} - EL_J + \frac{1}{3}(EL_B - EL_{hw})\right] + p_{hw} \cdot \frac{1}{2}(EL_{hw} - EL_J)^2 \ldots + 0.5 \cdot (p_D - p_{hw}) \cdot (EL_{hw} - EL_J)^2 \cdot \frac{1}{3}\right] \cdot b}{P_{soil\_h}} - h_{key}$$

$$y_{soil\_h} = 0.08 \cdot m$$

Moment about Toe $M_{soil\_h} := P_{soil\_h} \cdot y_{soil\_h} = 5.7 \cdot kN \cdot m$

6.3 Surcharge Soil Load - Heel Side

Surcharge soil pressure $p_{sur} := k_o \cdot \gamma_{soilm} \cdot h_{sur} = 0 \cdot kPa$

Soil load on wall $P_{sur} := p_{sur} \cdot (EL_B - EL_J) \cdot b = 0 \cdot kN$

Resultant location $y_{sur} := \frac{1}{2} \cdot (EL_B - EL_J) - h_{key} = 0.88\, m$

Moment about Toe $M_{sur} := P_{sur} \cdot y_{sur} = 0 \cdot kN \cdot m$

7.0 GRAVITY LOADS

7.1 Weight of Concrete

Weight of Wall footing/base $W_{conc} := \gamma_c \cdot (t_{base} \cdot L_{base} + L_{stem} \cdot t_{stem} + t_{key} \cdot h_{key}) \cdot b = 88.13 \cdot kN$

Resultant location

$$x_{conc} := \frac{\left[\frac{1}{2} t_{base} \cdot L_{base}^2 + L_{stem} \cdot t_{stem} \cdot (L_{toe} + 0.5 t_{stem}) \ldots + t_{key} \cdot h_{key} \cdot (L_{base} - 0.5 t_{key})\right]}{t_{base} \cdot L_{base} + L_{stem} \cdot t_{stem} + t_{key} \cdot h_{key}} = 1.64\,m$$

Moment about Toe $M_{conc} := W_{conc} \cdot x_{conc} = 144.11 \cdot kN \cdot m$

7.2 Weight of Soil on Heel

Weight of Soil on heel

$$W_{soil\_h} := b \cdot L_{heel} \cdot \begin{cases} (\gamma_{soilsat} - \gamma_w) \cdot (EL_B - EL_C) & \text{if } EL_B < EL_{hw} \\ \gamma_{soilm} \cdot (EL_B - EL_{hw}) + (\gamma_{soilsat} - \gamma_w) \cdot \max[0, (EL_{hw} - EL_C)] & \text{otherwise} \end{cases}$$

$W_{soil\_h} = 56.05 \cdot kN$

Resultant location $x_{soil\_h} := 0.5(x_B - x_G) + x_G = 2.25 \cdot m$

Moment about Toe $M_{soilw\_h} := W_{soil\_h} \cdot x_{soil\_h} = 126.1 \cdot kN \cdot m$

7.3 Weight of Water on Heel

Weight of Water on heel $W_{w\_h} := \gamma_w \cdot \max[0kip, (EL_{hw} - EL_C)] \cdot L_{heel} \cdot b = 53.95 \cdot kN$

Resultant location $x_{w\_h} := 0.5(x_B - x_G) + x_G = 2.25 \cdot m$

Moment about Toe $M_{w\_h} := W_{w\_h} \cdot x_{w\_h} = 121.4 \cdot kN \cdot m$

7.4 Weight of Soil on Toe

Weight of Soil on toe Note: Water and soil elevations MUST NOT be below footing elevation

$$W_{soil\_t} := b \cdot L_{toe} \cdot \begin{cases} (\gamma_{soilsat} - \gamma_w) \cdot (\max(0, EL_F - EL_C)) & \text{if } EL_F < EL_{tw} \\ \gamma_{soilm} \cdot \max(0, EL_F - EL_{tw}) + (\gamma_{soilsat} - \gamma_w) \cdot \max(EL_{tw} - EL_C, 0) & \text{otherwise} \end{cases}$$

$W_{soil\_t} = 2.54 \cdot kN$

Resultant location $x_{soil\_t} := 0.5(x_H - x_E) = 0.38 \cdot m$

Moment about Toe $M_{soilw\_t} := W_{soil\_t} \cdot x_{soil\_t} = 1 \cdot kN \cdot m$

7.5 Weight of Water on Toe

Weight of Water on toe $W_{w\_t} := \gamma_w \cdot \max\left[0kip, \left(EL_{tw} - EL_C\right)\right] \cdot L_{toe} \cdot b = 2.45 \cdot kN$

Resultant location $x_{w\_t} := 0.5\left(x_H - x_E\right) = 0.38 \cdot m$

Moment about Toe $M_{w\_t} := W_{w\_t} \cdot x_{w\_t} = 0.9 \cdot kN \cdot m$

7.6 Weight of Soil under Footing and Above Failure Plane EJ

Depth of Soil Wedge Near Key $h_{s\_under} := \left(x_L - x_E\right) \cdot \frac{h_{key}}{L_{base}} = 1.29\,m$

Length of Soil Wedge $L_{s\_under} := x_L - x_E = 2.8\,m$

Weight of Soil Wedge Under Footing $W_{s\_under} := \gamma_{soilsat} \cdot \left(0.5 \cdot h_{s\_under} \cdot L_{s\_under}\right) \cdot b = 36.18 \cdot kN$

Resultant location $x_{s\_under} := \frac{2}{3}\left(x_L - x_E\right) = 1.87 \cdot m$

Moment about Toe $M_{s\_under} := W_{s\_under} \cdot x_{s\_under} = 67.5 \cdot kN \cdot m$

8.0 Overturning Stability Assessment - See Figure 2

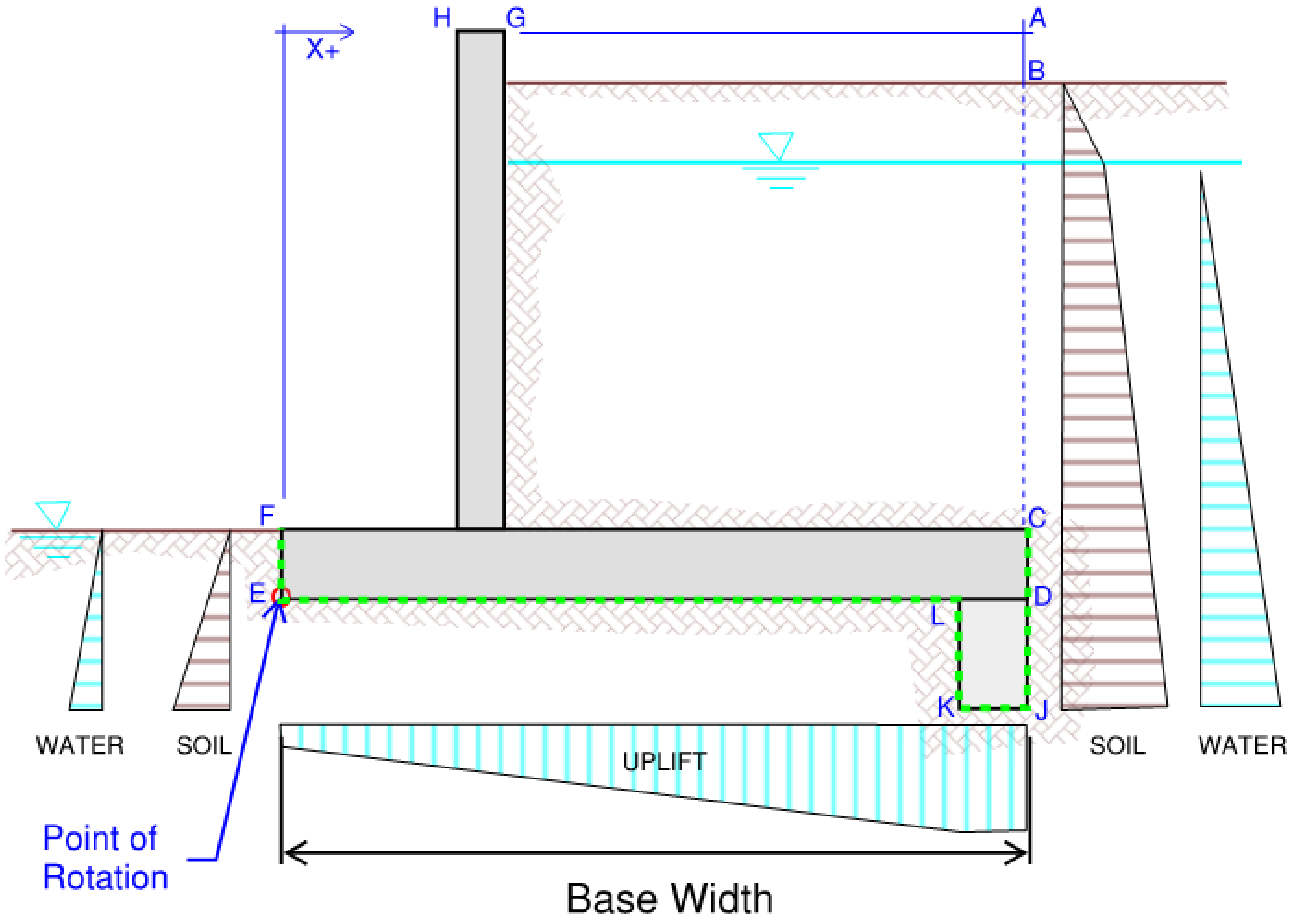


Figure 2. Free Body Diagram for Overturning Analysis

Uplift loads for Overturning

$$P_{u\_ot} := \left[\frac{1}{2}(u_h + u_t)\cdot(x_L - x_E) + u_h\cdot t_{key}\right]\cdot b = 97.65\cdot kN$$

Uplift resultant location

$$x_{u\_ot} := \frac{\left[\left[\frac{x_L - x_E}{2} + \frac{x_L - x_E}{6}\cdot\frac{(u_h - u_t)}{u_t + u_h}\right]\cdot\left[\frac{1}{2}(u_h + u_t)\cdot(x_L - x_E)\right] \ldots \atop + (L_{base} - 0.5t_{key})\cdot(u_h\cdot t_{key})\right]}{\left[\frac{1}{2}(u_h + u_t)\cdot(x_L - x_E) + u_h\cdot t_{key}\right]}$$

$$x_{u\_ot} = 2.01\ m$$

Uplift Moment about Toe

$$M_{u\_ot} := P_{u\_ot}\cdot x_{u\_ot} = 195.9\cdot kN\cdot m$$

Total Vertical Forces $\Sigma V_{ot} := W_{conc} + W_{soil\_h} + W_{soil\_t} \cdots + W_{w\_h} + W_{w\_t} - P_{u\_ot} = 105.5 \cdot kN$

Total Horizontal Forces $\Sigma H_{ot} := P_{hw} + P_{soil\_h} + P_{sur} - P_{tw} - P_{soil\_t} = 135.72 \cdot kN$

Total Resisting Moments $\Sigma M_{r\_ot} := M_{conc} + M_{soilw\_h} + M_{w\_h} \cdots + M_{soilw\_t} + M_{w\_t} = 393.5 \cdot kN \cdot m$

Total Driving Moments $\Sigma M_{d\_ot} := M_{hw} + M_{soil\_h} + M_{sur} + M_{u\_ot} \cdots + M_{tw} + M_{soil\_t} = 242 \cdot kN \cdot m$

Resultant Location from Toe $x_{r\_ot} := \dfrac{\Sigma M_{r\_ot} - \Sigma M_{d\_ot}}{\Sigma V_{ot}} = 1.44 \cdot m$

Normalized Resultant Location $\dfrac{x_{r\_ot}}{L_{base}} = 0.442$

Eccentricity $e_{x\_ot} := \dfrac{L_{base}}{2} - x_{r\_ot} = 0.19 \cdot m$

Approx. Base in Compression $l_{comp\_ot} := \min\left[L_{base}, \dfrac{3}{2} \cdot \left(L_{base} - 2 \cdot e_{x\_ot}\right)\right] = 3.25 \cdot m$

Percent Base in Compression $\boxed{Base\_Comp := \left(\dfrac{l_{comp\_ot}}{L_{base}}\right) = 100 \cdot \%}$

Resultant Location Check $check_{res} := if\left(Base\_Comp \geq Base\_Comp_{Req}, \text{"OK"}, \text{"NG"}\right) = \text{"OK"}$

9.0 Flotation Stability Assessment - See Figure 2

Calculated Flotation Safety Factor $\boxed{FS_f := \dfrac{W_{conc} + W_{soil\_h} + W_{soil\_t} \cdots + W_{w\_h} + W_{w\_t}}{P_{u\_ot}} = 2.1}$

Flotation Stability Check $check_{floatation} := if\left(FS_f \geq FS_{float}, \text{"OK"}, \text{"NG"}\right) = \text{"OK"}$

10.0 Sliding Stability Assessment - See Figure 3

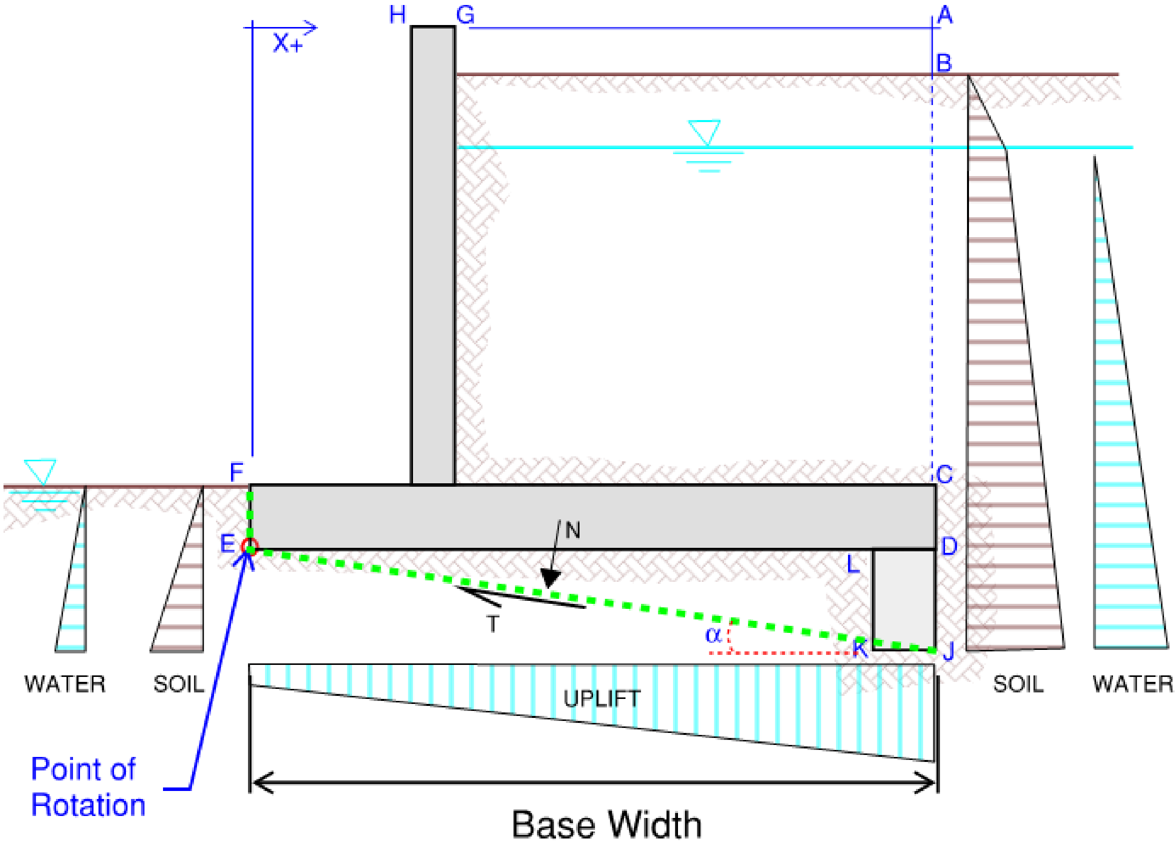


Figure 3. Free Body Diagram for Sliding Analysis

Length of Sliding Failure Plane, EJ $\quad L_{fp} := \sqrt{L_{base}^{\;2} + h_{key}^{\;2}} = 3.58\,m$

Angle of Sliding Failure Plane From Horizontal $\quad \alpha := \operatorname{atan}\left(\dfrac{h_{key}}{L_{base}}\right) = 24.8 \cdot deg$

Total Vertical Forces $\quad \Sigma V := W_{conc} + W_{soil\_h} + W_{soil\_t} \cdots + W_{w\_h} + W_{s\_under} + W_{w\_t} - P_u = 150.3 \cdot kN$

Total Horizontal Forces $\quad \Sigma H := P_{hw} + P_{soil\_h} + P_{sur} - P_{tw} - P_{soil\_t} = 135.72 \cdot kN$

Total Resisting Moments $\quad \Sigma M_r := M_{conc} + M_{soilw\_h} + M_{w\_h} \cdots + M_{soilw\_t} + M_{w\_t} + M_{s\_under} = 461\ m \cdot kN$

Total Driving Moments $\quad \Sigma M_d := M_{hw} + M_{soil\_h} + M_{sur} + M_u \cdots + M_{tw} + M_{soil\_t} = 224.5 \cdot kN \cdot m$

Normal Force on Sliding Failure Plane: $N_s := \Sigma H \cdot \sin(\alpha) + \Sigma V \cdot \cos(\alpha) = 193.34 \cdot kN$

Tangential Force on Sliding Failure Plane: $T_s := \Sigma H \cdot \cos(\alpha) - \Sigma V \cdot \sin(\alpha) = 60.24 \cdot kN$

Calculated Sliding Safety Factor $\boxed{FS_s := \frac{\left|N_s \cdot \tan(0.95\phi_{soil})\right|}{\left|T_s\right|} = 1.35}$

Sliding Stability Check $check_{sliding} := if\left(FS_s \geq FS_{Sliding}, "OK", "NG"\right) = "OK"$

11.0 Bearing Capacity Assessment

Resultant Location from Toe $x_r := \frac{\Sigma M_r - \Sigma M_d}{N_s} = 1.22 \cdot m$

Eccentricity of N_s from center of base $e_s := \frac{L_{fp}}{2} - x_r = 0.57 \cdot m$

Approx. Base in Compression $l_{comp.s} := \min\left[L_{fp}, \frac{3}{2} \cdot \left(L_{fp} - 2 \cdot e_s\right)\right] = 3.58 \cdot m$

Updated Eccentricity $e_x := \frac{l_{comp.s} - L_{fp}}{2} + e_s = 0.57 \cdot m$

Effective base pressure at Toe $q_t := \left(\frac{N_s}{l_{comp.s} \cdot b}\right) \cdot \left(1 + \frac{6 \cdot e_x}{l_{comp.s}}\right) = 105.30 \cdot kPa$

Effective base pressure at Heel $q_h := \max\left[\left(\frac{N_s}{l_{comp.s} \cdot b}\right) \cdot \left(1 - \frac{6 \cdot e_x}{l_{comp.s}}\right), 0\right] = 2.73 \cdot kPa$

Calculated Bearing Safety Factor $\boxed{FS_b := \frac{Q_b}{\max\left(q_t, q_h\right)} = 1.42}$

Bearing Pressure Check $check_{bearing} := if\left(FS_b \geq FS_{Bearing}, "OK", "NG"\right) = "OK"$

12.0 Summary of Stability Assessments

Base Compression / Resultant Location	$Base\_Comp = 100 \cdot \%$	$check_{res} = "OK"$
Flotation Stability	$FS_f = 2.1$	$check_{floatation} = "OK"$
Sliding Stability	$FS_s = 1.3$	$check_{sliding} = "OK"$
Bearing Pressure	$FS_b = 1.4$	$check_{bearing} = "OK"$

13.0 Structural Loads

13.1 Shear and Moment at Stem Base - See Figure 4

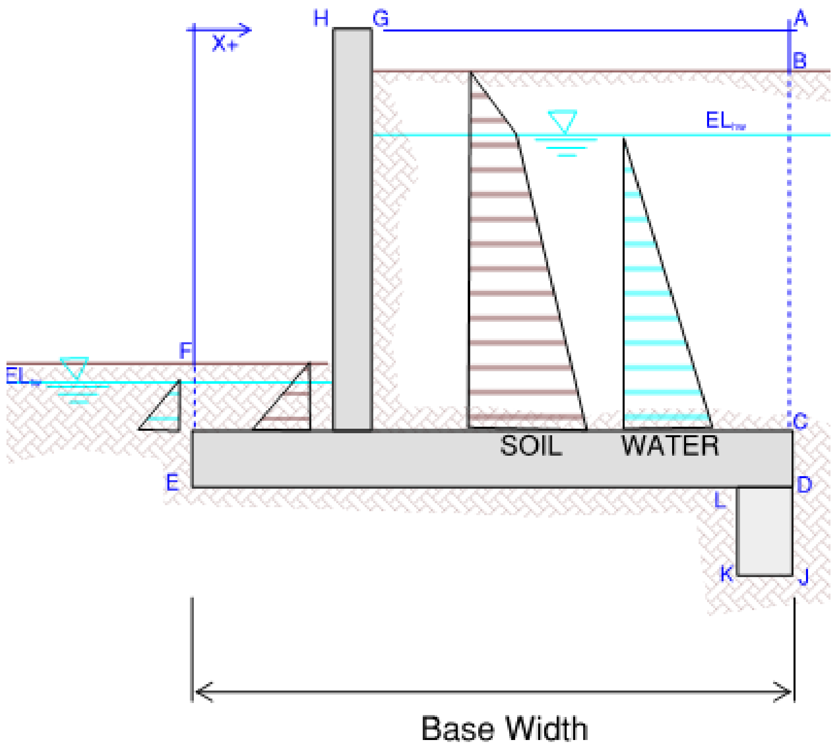


Figure 4 - Loads on Stem

13.1.1 Hydrostatic Load at Stem Base

Heel side hydrostatic load $P_{hw\_stem} := \frac{1}{2}\gamma_w \cdot (EL_{hw} - EL_C)^2 \cdot b = 37.1 \cdot kN$

Heel side moment at stem base $M_{hw\_stem} := P_{hw\_stem} \cdot \left(\frac{EL_{hw} - EL_C}{3}\right) = 34 \cdot kN \cdot m$

Toe side hydrostatic load $P_{tw\_stem} := \frac{1}{2}\gamma_w \cdot (EL_{tw} - EL_C)^2 \cdot b = 0.5 \cdot kN$

Toe side moment at stem base $M_{tw\_stem} := P_{tw\_stem} \cdot \left(\frac{EL_{tw} - EL_C}{3}\right) = 0.1 \cdot kN \cdot m$

13.1.2 Lateral Soil Loads at Stem Base

Soil pressure at saturation level - Toe Side

$$p_t := \begin{cases} k_o \cdot \gamma_{soilm} \cdot (EL_F - EL_{tw}) & \text{if } EL_F > EL_{tw} \\ 0psf & \text{otherwise} \end{cases} = 0.00 \cdot kPa$$

Soil pressure at stem base - Toe Side

$$p_{C.t} := \begin{cases} p_t + k_o \cdot (\gamma_{soilsat} - \gamma_w) \cdot (EL_{tw} - EL_C) & \text{if } EL_F > EL_{tw} \\ k_o \cdot (\gamma_{soilsat} - \gamma_w) \cdot (EL_F - EL_C) & \text{otherwise} \end{cases}$$

$$p_{C.t} = 2.01 \cdot kPa$$

Lateral soil loads at stem base - Toe Side

$$P_{s\_t} := \left[0.5 \cdot (EL_F - EL_{tw}) \cdot p_t + p_t \cdot (EL_{tw} - EL_C) + 0.5 \cdot (p_{C.t} - p_t) \cdot (EL_{tw} - EL_C)\right] \cdot b = 0.34 \cdot kN$$

Resultant location

$$y_{s\_t} := \begin{cases} 0 & \text{if } P_{s\_t} = 0 \\ \dfrac{\left[0.5 \cdot (EL_F - EL_{tw}) \cdot p_t \cdot \left[(EL_{tw} - EL_C) + \frac{1}{3}(EL_F - EL_{tw})\right] + p_t \cdot \frac{1}{2}(EL_{tw} - EL_C)^2 + 0.5 \cdot (p_{C.t} - p_t) \cdot (EL_{tw} - EL_C)^2 \cdot \frac{1}{3}\right] \cdot b}{P_{s\_t}} & \text{otherwise} \end{cases}$$

$$y_{s\_t} = 0.11 \cdot m$$

Lateral soil moment at stem base - Toe Side

$$M_{s\_t} := P_{s\_t} \cdot y_{s\_t} = 0.04 \cdot kN \cdot m$$

Soil pressure at saturation level - Heel Side

$$p_h := \begin{cases} k_o \cdot \gamma_{soilm} \cdot (EL_B - EL_{hw}) & \text{if } EL_B > EL_{hw} \\ 0kPa & \text{otherwise} \end{cases} = 0.00 \cdot kPa$$

Soil pressure at stem base - Heel Side

$$p_{C.h} := \begin{cases} p_h + k_o \cdot (\gamma_{soilsat} - \gamma_w) \cdot (EL_{hw} - EL_C) & \text{if } EL_B > EL_{tw} \\ k_o \cdot (\gamma_{soilsat} - \gamma_w) \cdot (EL_B - EL_C) & \text{otherwise} \end{cases}$$

$$p_{C.h} = 16.62 \cdot kPa$$

Lateral soil loads at stem base - Heel Side

$$P_{s\_h} := \left[0.5 \cdot (EL_B - EL_{hw}) \cdot p_h + p_h \cdot (EL_{hw} - EL_C) + 0.5 \cdot (p_{C.h} - p_h) \cdot (EL_{hw} - EL_C)\right] \cdot b = 22.86 \cdot kN$$

Resultant location

$$y_{s\_h} := \begin{cases} 0 & \text{if } P_{s\_h} = 0 \\ \dfrac{\left[\begin{array}{l} 0.5\cdot(EL_B - EL_{hw})\cdot p_h\cdot\left[(EL_{hw} - EL_C) + \frac{1}{3}(EL_B - EL_{hw})\right] + p_h\cdot\frac{1}{2}(EL_{hw} - EL_C)^2 \;... \\ + 0.5\cdot(p_{C.h} - p_h)\cdot(EL_{hw} - EL_C)^2\cdot\frac{1}{3} \end{array}\right]\cdot b}{P_{s\_h}} & \text{otherwise} \end{cases}$$

$$y_{s\_h} = 0.92\cdot m$$

Lateral soil moment at stem base - Heel Side $M_{s\_h} := P_{s\_h}\cdot y_{s\_h} = 20.95\cdot kN\cdot m$

13.1.3 Surcharge Loads at Stem Base

Surcharge load at stem base $P_{sur\_stem} := p_{sur}\cdot(EL_B - EL_C)\cdot b = 0\cdot kN$

Surcharge Moment about Toe $M_{sur\_stem} := P_{sur}\cdot\frac{1}{2}(EL_B - EL_C) = 0\cdot kN\cdot m$

13.2 Shear and Moment on Heel - See Figure 5

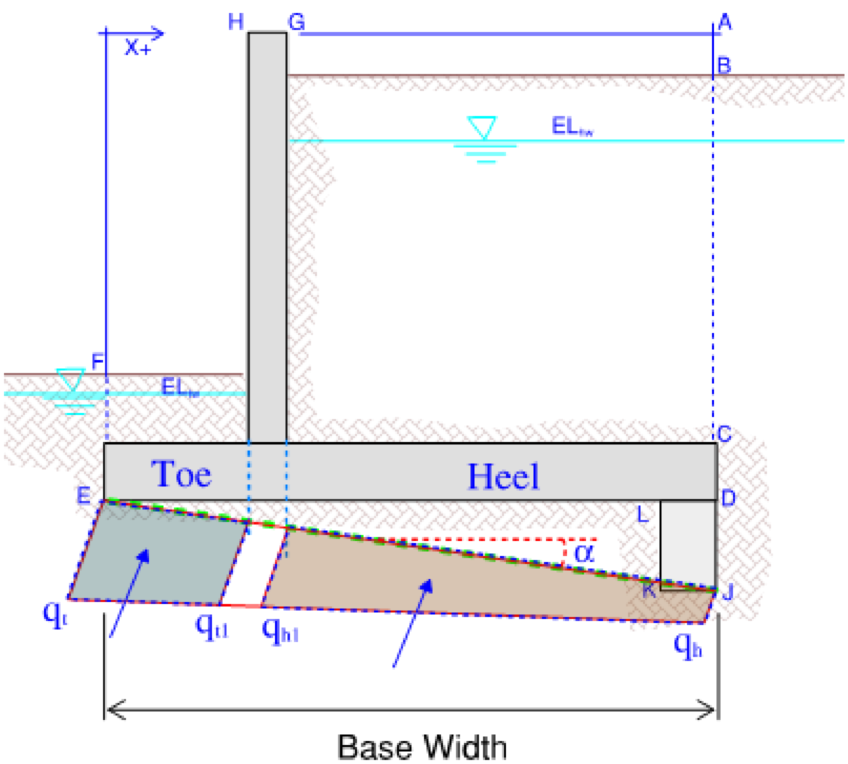


Figure 5 - Loads on Base (Heel & Toe)

13.2.1 Weight of Concrete Heel

Weight of Wall footing/base

$$W_{c\_heel} := \gamma_c \cdot \left(t_{base} \cdot L_{heel} + t_{key} \cdot h_{key}\right) \cdot b = 39.36 \cdot kN$$

Resultant location

$$x_{c\_heel} := \frac{\begin{bmatrix} \frac{1}{2} t_{base} \cdot L_{heel}^{\ 2} \ldots \\ + t_{key} \cdot h_{key} \cdot \left(L_{heel} - 0.5 t_{key}\right) \end{bmatrix}}{t_{base} \cdot L_{heel} + t_{key} \cdot h_{key}} = 1.31\,m$$

Moment about stem base

$$M_{c\_heel} := W_{c\_heel} \cdot x_{c\_heel} = 51.66 \cdot kN \cdot m$$

13.2.2 Weight of Soil on Heel

Weight of Soil on heel

$$W_{s\_heel} := W_{soil\_h} = 56.05 \cdot kN$$

Moment about stem base

$$M_{s\_heel} := W_{s\_heel} \cdot \left(\frac{1}{2} L_{heel}\right) = 56 \cdot kN \cdot m$$

13.2.3 Weight of Water on Heel

Weight of Water on heel

$$W_{w\_heel} := W_{w\_h} = 53.95 \cdot kN$$

Moment about stem base

$$M_{w\_heel} := W_{w\_heel} \cdot \left(\frac{1}{2} L_{heel}\right) = 54 \cdot kN \cdot m$$

13.2.4 Weight of Concrete Toe

Weight of Wall footing/base

$$W_{c\_toe} := \gamma_c \cdot t_{base} \cdot L_{toe} \cdot b = 8.81 \cdot kN$$

Moment about stem base

$$M_{c\_toe} := W_{c\_toe} \cdot \left(\frac{1}{2} \cdot L_{toe}\right) = 3.3 \cdot kN \cdot m$$

13.2.5 Weight of Soil on Toe

Weight of Soil on Toe

$$W_{s\_toe} := W_{soil\_t} = 2.54 \cdot kN$$

Moment about stem base

$$M_{s\_toe} := W_{s\_toe} \cdot \left(\frac{1}{2} L_{toe}\right) = 1 \cdot kN \cdot m$$

13.2.6 Weight of Water on Toe

Weight of Water on Toe

$$W_{w\_toe} := W_{w\_t} = 2.45 \cdot kN$$

Moment about stem base

$$M_{w\_toe} := W_{w\_toe} \cdot \left(\frac{1}{2} L_{toe}\right) = 0.9 \cdot kN \cdot m$$

13.2.7 Bearing Pressures on Footing

Approx. Base in Compression $l_{comp.s} = 3.58\,m$

Effective base pressure at Toe $q_t = 105.30 \cdot kPa$

Effective base pressure at Heel $q_h = 2.73 \cdot kPa$

Compression length under Toe $L_{bearing\_t} := \dfrac{L_{toe}}{\cos(\alpha)} = 0.83\,m$

Compression length under Heel $L_{bearing\_h} := l_{comp.s} - \dfrac{(x_G - x_E)}{\cos(\alpha)} = 2.2\,m$

Bearing pressure under toe side of stem $q_{t1} := L_{bearing\_t} \cdot \left[\dfrac{(q_h - q_t)}{l_{comp.s}}\right] + q_t = 81.63 \cdot kPa$

Bearing pressure under heel side of stem $q_{h1} := \dfrac{(x_G - x_E)}{\cos(\alpha)} \cdot \left[\dfrac{(q_h - q_t)}{l_{comp.s}}\right] + q_t = 65.85 \cdot kPa$

13.2.8 Soil Reaction on Heel

Soil reaction load on Heel $P_{bearing\_h} := \dfrac{1}{2} \cdot (q_h + q_{h1}) \cdot L_{bearing\_h} \cdot b = 75.53 \cdot kN$

Resultant location $x_{bearing\_h} := \dfrac{L_{bearing\_h}}{2} + \dfrac{L_{bearing\_h}}{6} \cdot \dfrac{(q_h - q_{h1})}{q_{h1} + q_h} = 0.76\,m$

Vertical Component $P_{h\_v} := P_{bearing\_h} \cdot \cos(\alpha) = 68.58 \cdot kN$

Horizontal Component $P_{h\_h} := P_{bearing\_h} \cdot \sin(\alpha) = 31.65 \cdot kN$

Horizontal Moment Arm $x_{h\_h} := x_{bearing\_h} \cdot \cos(\alpha) = 0.69\,m$

Vertical Moment Arm $y_{h\_v} := \left[\dfrac{(x_G - x_E)}{\cos(\alpha)} + x_{bearing\_h}\right] \cdot \sin(\alpha) = 0.9\,m$

Moment on Heel $M_{bearing\_h} := P_{h\_v} \cdot x_{h\_h} + P_{h\_h} \cdot y_{h\_v} = 75.92 \cdot kN \cdot m$

13.2.9 Soil Reaction on Toe

Soil reaction load on Toe $P_{bearing\_t} := \frac{1}{2} \cdot (q_t + q_{t1}) \cdot L_{bearing\_t} \cdot b = 77.21 \cdot kN$

Resultant location $x_{bearing\_t} := \frac{L_{bearing\_t}}{2} + \frac{L_{bearing\_t}}{6} \cdot \frac{(q_t - q_{t1})}{q_t + q_{t1}} = 0.43\,m$

Vertical Component $P_{t\_v} := P_{bearing\_t} \cdot \cos(\alpha) = 70.1 \cdot kN$

Horizontal Component $P_{t\_h} := P_{bearing\_t} \cdot \sin(\alpha) = 32.35 \cdot kN$

Horizontal Moment Arm $x_{t\_h} := x_{bearing\_t} \cdot \cos(\alpha) = 0.39\,m$

Vertical Moment Arm $y_{t\_v} := (L_{bearing\_t} - x_{bearing\_t}) \cdot \sin(\alpha) = 0.17\,m$

Moment on Toe $M_{bearing\_t} := P_{t\_v} \cdot x_{t\_h} + P_{t\_h} \cdot y_{t\_v} = 32.76 \cdot kN \cdot m$

13.2.10 Uplift Pressure on Footing - Figure 6

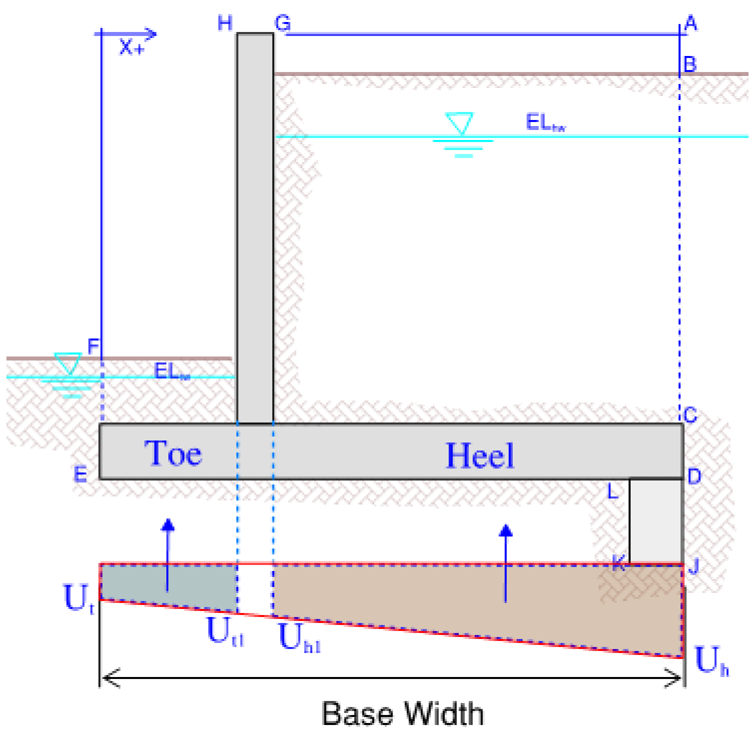


Figure 6 - Uplift Loads on Base (Heel & Toe)

Uplift pressure under toe side of stem $u_{t1} := L_{toe} \cdot \left[\frac{(u_h - u_t)}{L_{base}}\right] + u_t = 17.04 \cdot kPa$

Uplift pressure under heel side of stem $u_{h1} := (x_G - x_E) \cdot \left[\frac{(u_h - u_t)}{L_{base}}\right] + u_t = 22.95 \cdot kPa$

13.2.11 Uplift Loads Heel

Uplift load on Heel $P_{u\_h} := \frac{1}{2} \cdot (u_h + u_{h1}) \cdot L_{heel} \cdot b = 69.55 \cdot kN$

Moment Arm $x_{u\_h} := \frac{L_{heel}}{2} + \frac{L_{heel}}{6} \cdot \frac{(u_h - u_{h1})}{u_{h1} + u_h} = 1.11\ m$

Moment on Heel $M_{u\_h} := P_{u\_h} \cdot x_{u\_h} = 77.43 \cdot kN \cdot m$

13.2.12 Uplift Loads Toe

Uplift load on Toe $P_{u\_t} := \frac{1}{2} \cdot (u_t + u_{t1}) \cdot L_{toe} \cdot b = 9.45 \cdot kN$

Moment Arm $x_{u\_t} := \frac{L_{toe}}{2} + \frac{L_{toe}}{6} \cdot \frac{(u_t - u_{t1})}{u_{t1} + u_t} = 0.33\ m$

Moment on Toe $M_{u\_t} := P_{u\_t} \cdot x_{u\_t} = 3.13 \cdot kN \cdot m$

13.3 Structural Load Summary

Net shear at stem base $V_{stem} := P_{hw\_stem} - P_{tw\_stem} + P_{s\_h} - P_{s\_t} + P_{sur\_stem} = 59.1 \cdot kN$

Net moment at stem base $M_{stem} := M_{hw\_stem} - M_{tw\_stem} + M_{s\_h} - M_{s\_t} + M_{sur\_stem} = 54.9 \cdot kN \cdot m$

Net shear on Toe $V_t := W_{c\_toe} + W_{s\_toe} + W_{w\_toe} - P_{t\_v} - P_{u\_t} = -65.7 \cdot kN$

Net moment on Toe $M_t := M_{c\_toe} + M_{s\_toe} + M_{w\_toe} - M_{bearing\_t} - M_{u\_t} = -30.7 \cdot kN \cdot m$

Net shear on Heel $V_h := W_{c\_heel} + W_{s\_heel} + W_{w\_heel} - P_{h\_v} - P_{u\_h} = 11.2 \cdot kN$

Net moment on Heel $M_h := M_{c\_heel} + M_{s\_heel} + M_{w\_heel} - M_{bearing\_h} - M_{u\_h} = 8.3 \cdot kN \cdot m$

13.4 Controlling Structural Loads (Unfactored)

Stem cross section

$M_{stem} = 54.9 \cdot kN \cdot m$

$V_{stem} = 59.1 \cdot kN$

Toe cross section

$M_{toe} := M_t = -30.71 \cdot kN \cdot m$

$V_{toe} := V_t = -65.7 \cdot kN$

Heel cross section

$M_{heel} := \min\left(\max\left(M_{stem} - \left|M_{toe}\right|, M_h\right), M_{stem}\right) = 24.1 \cdot kN \cdot m$

STABILITY ANALYSIS FOR CANTILEVER WALL WITH KEY

Project / Client: Springbank Off-Stream Storage (SR1) / Alberta Transportation

Section Location: Intake Structure Wing Wall - End of Wingwall

1.0 OBJECTIVE

For a particular load condition, analyze a reinforced concrete cantilever wall with shear key for overturning, sliding, flotation, and bearing capacity in accordance with criteria described in the listed references.

2.0 BACKGROUND INFORMATION

2.1 DATA SOURCES

1- Soils Report - Recommended Geotechnical Soil Parameters, SR-1 Low Level Outlet (LLO) Structures. July 19, 2019

2- Drawings - Design Drawings

3- Springbank Off-Stream Storage Project - Design Basis Memorandum (DBM) , 2019

2.2 REFERENCES

1. (CDA) Dam Safety Guidelines, 2007 (revised 2013).
2. "Water Control Structures Selected Design Guidelines," Alberta Transportation & Alberta Environment, Calgary Alberta, November 2004.

3.0 DESIGN PARAMETERS AND CRITERIA

3.1 Stability Analysis Criteria (Data source 2)

Load Case	$LC := 3$
Load Case Description	$\text{vlookup}(LC, CASES, 1)_0 = \text{"Rapid Drawdown"}$
Sliding Minimum Factor of Safety	$FS_{Sliding} := \text{vlookup}(LC, CASES, 2)_0 = 1.1$
Overturning Criteria	$Base\_Comp_{Req} := \text{vlookup}(LC, CASES, 3)_0 = 75 \cdot \%$
Bearing Capacity Minimum Factor of Safety	$FS_{Bearing} := \text{vlookup}(LC, CASES, 4)_0 = 1$
Flotation Minimum Factor of Safety	$FS_{float} := \text{vlookup}(LC, CASES, 5)_0 = 1.1$

3.2 Material Properties - Data Source 1 Unless Otherwise Noted

Unit Weight of Water	$\gamma_w := 9.81 \frac{kN}{m^3}$	
Unit Weight of Concrete	$\gamma_c := 23.5 \cdot \frac{kN}{m^3}$	Data Source 3
Unit Weight of Soil (Moist)	$\gamma_{soilm} := 20 \frac{kN}{m^3}$	
Soil Unit Weight Beneath Base (Saturated)	$\gamma_{soilsat} := 20 \frac{kN}{m^3}$	
Soil Cohesion - Drained	$c_{soil} := 0kPa$	
Soil Angle of Internal Friction - Drained	$\phi_{soil} := 24deg$	
Soil Ultimate Bearing Pressure	$Q_b := 150kPa$	
Slope of backfill (Conservative)	$\beta := 0$	
At-rest lateral earth pressure coefficient	$k_o := 1 - \sin(\phi_{soil}) = 0.59$	

4.0 WALL SECTION DESCRIPTION

4.1 Point Locations (Refer to Figure 1 and Drawings)

A - Top of wall	$EL_A := 1189.9m$	$x_A := 3.25m$
B - Top of fill - reservoir side	$EL_B := 1189.75m$	$x_B := x_A = 3.25 \cdot m$
C - Top of Heel	$EL_C := 1187m$	$x_C := x_A = 3.25 \cdot m$
D - Heel side end of footing	$EL_D := EL_C - 500mm = 1186.50\ m$	$x_D := x_A = 3.25 \cdot m$
E - Toe side end of footing	$EL_E := EL_D = 1186.50 \cdot m$	$x_E := 0m$
F - Top of Fill - land side	$EL_F := EL_C + 2.417m = 1189.42 \cdot m$	$x_F := x_E = 0$
G - Heel side face of wall stem	$EL_G := EL_A = 1189.90 \cdot m$	$x_G := 1.25m$
H - Toe side face of wall stem	$EL_H := EL_A = 1189.90 \cdot m$	$x_H := x_G - 0.500m = 0.75 \cdot m$

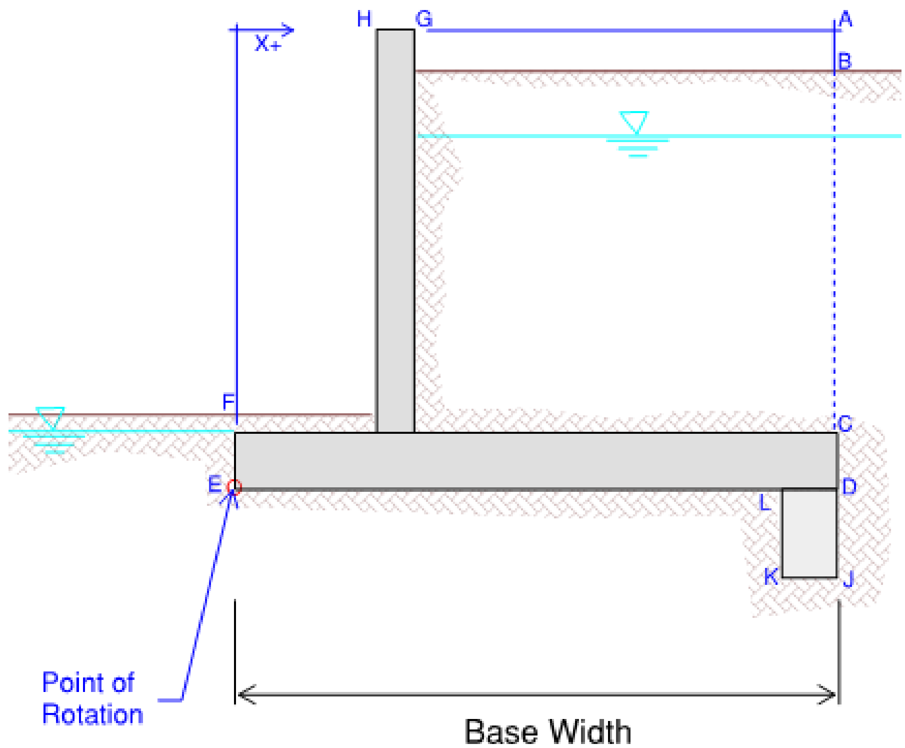


Figure 1. Cantilever Wall Section

J - Bottom of key - heel side	$EL_J := EL_C - 0.95m = 1186.05 \cdot m$	$x_J := x_D = 3.25\ m$
K - Bottom of key - toe side	$EL_K := EL_J = 1186.05 \cdot m$	$x_K := x_J - 450mm = 2.8 \cdot m$
L - Top of key	$EL_L := EL_D = 1186.50 \cdot m$	$x_L := x_K = 2.8\ m$

Applied Loads Data Source 2

Heel side water elevation

$$EL_{hw} := \begin{cases} EL_B & \text{if } LC = 3 \\ \left(\text{vlookup}(LC, WaterEL, 1)_0 \cdot 1m\right) & \text{otherwise} \end{cases} = 1189.75$$

Toe side water elevation

$$EL_{tw} := \begin{cases} EL_F & \text{if } LC = 3 \\ \left(\text{vlookup}(LC, WaterEL, 2)_0 \cdot 1m\right) & \text{otherwise} \end{cases} = 1189.42$$

Equivalent soil surcharge:

$$h_{sur} := \begin{cases} 1.0m & \text{if } LC = 2 \\ 0 & \text{otherwise} \end{cases} = 0 \cdot m$$

4.2 Additional Analysis Dimensions

Analysis Width $b := 1m$

Length of base $L_{base} := x_D - x_E = 3.25 \cdot m$

Thickness of base $t_{base} := EL_C - EL_D = 500 \cdot mm$

Length of stem $L_{stem} := EL_A - EL_C = 2.9 \cdot m$

Thickness of stem $t_{stem} := x_G - x_H = 500 \cdot mm$

Length of Heel $L_{heel} := x_A - x_G = 2000 \cdot mm$

Length of Toe $L_{toe} := x_H - x_F = 750 \cdot mm$

Thickness of Key $t_{key} := x_J - x_K = 450 \cdot mm$

Height of Key $h_{key} := EL_D - EL_J = 450 \cdot mm$

5.0 UPLIFT & HYDROSTATIC LOADS

5.1 Uplift Pressures for Stability Analyses

Determine water pressures for designated coordinates using full headwater uplift pressure at the heel and full tailwater uplift pressure at the toe. Uplift distribution is assumed linear from heel to toe.

Hydrostatic pressure at Heel $u_h := \gamma_w \cdot \left(EL_{hw} - EL_J\right) = 36 \cdot kPa$

Hydrostatic pressure at Toe $u_t := \gamma_w \cdot \left(EL_{tw} - EL_E\right) = 29 \cdot kPa$

Total uplift loads on base $P_u := \frac{\left(u_h + u_t\right)}{2} \cdot L_{base} \cdot b = 105.48 \cdot kN$

Uplift resultant location $x_u := \frac{L_{base}}{2} + \frac{L_{base}}{6} \cdot \frac{\left(u_h - u_t\right)}{u_t + u_h} = 1.69 \cdot m$

Uplift Moment about Toe $M_u := P_u \cdot x_u = 178.2 \cdot kN \cdot m$

5.2 Headwater Hydrostatic Load - Heel Side

Headwater hydrostatic load $P_{hw} := \frac{1}{2} u_h \cdot (EL_{hw} - EL_J) \cdot b = 67.1 \cdot kN$

Headwater moment arm $y_{hw} := \frac{1}{3}(EL_{hw} - EL_J) - h_{key} = 0.78 \cdot m$

Headwater Moment about Toe $M_{hw} := P_{hw} \cdot y_{hw} = 52.6 \cdot kN \cdot m$

5.3 Tailwater Hydrostatic Load - Toe Side

Tailwater hydrostatic load $P_{tw} := \frac{1}{2} \gamma_w \cdot (EL_{tw} - EL_K)^2 \cdot b = 55.61 \cdot kN$

Tailwater moment arm $y_{tw} := h_{key} - \frac{1}{3}(EL_{tw} - EL_K) = -0.67 \cdot m$

Tailwater Moment about Toe $M_{tw} := P_{tw} \cdot y_{tw} = -37.39 \cdot kN \cdot m$

6.0 LATERAL EARTH PRESSURE

6.1 Lateral Soil Load on Toe Side

Soil pressure at Saturation Level

$$p_{tw} := \left| \begin{array}{l} k_o \cdot \gamma_{soilm} \cdot (EL_F - EL_{tw}) \ \text{ if } EL_F > EL_{tw} \\ 0psf \ \text{ otherwise} \end{array} \right. = 0.0 \cdot kPa$$

Soil pressure at Toe - base elevation

$$p_E := \left| \begin{array}{l} p_{tw} + k_o \cdot (\gamma_{soilsat} - \gamma_w) \cdot (EL_{tw} - EL_J) \ \text{ if } EL_F > EL_{tw} \\ k_o \cdot (\gamma_{soilsat} - \gamma_w) \cdot (EL_F - EL_J) \ \text{ otherwise} \end{array} \right.$$

$p_E = 20.35 \cdot kPa$

Total soil loads on Wall

$$P_{soil\_t} := \begin{bmatrix} 0.5 \cdot (EL_F - EL_{tw}) \cdot p_{tw} + p_{tw} \cdot (EL_{tw} - EL_J) \ ... \\ + 0.5 \cdot (p_E - p_{tw}) \cdot (EL_{tw} - EL_J) \end{bmatrix} \cdot b = 34.27 \cdot kN$$

Resultant location

$$y_{soil\_t} := \left| \begin{array}{l} 0 \ \text{ if } P_{soil\_t} = 0 \\ h_{key} - \dfrac{\begin{bmatrix} 0.5 \cdot (EL_F - EL_{tw}) \cdot p_{tw} \left[(EL_{tw} - EL_J) + \frac{1}{3}(EL_F - EL_{tw}) \right] + p_{tw} \cdot \frac{1}{2}(EL_{tw} - EL_J)^2 \ ... \\ + 0.5 \cdot (p_E - p_{tw}) \cdot (EL_{tw} - EL_J)^2 \cdot \frac{1}{3} \end{bmatrix} \cdot b}{P_{soil\_t}} \ \text{ otherwise} \end{array} \right.$$

$y_{soil\_t} = -0.67 \cdot m$

Moment about Toe $M_{soil\_t} := P_{soil\_t} \cdot y_{soil\_t} = -23.04 \cdot kN \cdot m$

6.2 Lateral Soil Load on Heel Side

Soil pressure at Saturation Level

$$p_{hw} := \begin{vmatrix} k_o \cdot \gamma_{soilm} \cdot (EL_B - EL_{hw}) \text{ if } EL_B > EL_{hw} \\ 0psf \text{ otherwise} \end{vmatrix} = 0.0 \cdot kPa$$

Soil pressure at Heel - base elevation

$$p_D := \begin{vmatrix} p_{hw} + k_o \cdot (\gamma_{soilsat} - \gamma_w) \cdot (EL_{hw} - EL_J) \text{ if } EL_B > EL_{hw} \\ k_o \cdot (\gamma_{soilsat} - \gamma_w) \cdot (EL_B - EL_J) \text{ otherwise} \end{vmatrix}$$

$$p_D = 22.37 \cdot kPa$$

Total soil loads on Base

$$P_{soil\_h} := \left[0.5 \cdot (EL_B - EL_{hw}) \cdot p_{hw} + p_{hw} \cdot (EL_{hw} - EL_J) \ldots + 0.5 \cdot (p_D - p_{hw}) \cdot (EL_{hw} - EL_J)\right] \cdot b$$

$$P_{soil\_h} = 41.38 \cdot kN$$

Resultant location

$$y_{soil\_h} := \frac{\left[0.5 \cdot (EL_B - EL_{hw}) \cdot p_{hw} \cdot \left[EL_{hw} - EL_J + \frac{1}{3}(EL_B - EL_{hw})\right] + p_{hw} \cdot \frac{1}{2}(EL_{hw} - EL_J)^2 \ldots + 0.5 \cdot (p_D - p_{hw}) \cdot (EL_{hw} - EL_J)^2 \cdot \frac{1}{3}\right] \cdot b}{P_{soil\_h}} - h_{key}$$

$$y_{soil\_h} = 0.78 \cdot m$$

Moment about Toe $M_{soil\_h} := P_{soil\_h} \cdot y_{soil\_h} = 32.4 \cdot kN \cdot m$

6.3 Surcharge Soil Load - Heel Side

Surcharge soil pressure $p_{sur} := k_o \cdot \gamma_{soilm} \cdot h_{sur} = 0 \cdot kPa$

Soil load on wall $P_{sur} := p_{sur} \cdot (EL_B - EL_J) \cdot b = 0 \cdot kN$

Resultant location $y_{sur} := \frac{1}{2} \cdot (EL_B - EL_J) - h_{key} = 1.4\,m$

Moment about Toe $M_{sur} := P_{sur} \cdot y_{sur} = 0 \cdot kN \cdot m$

7.0 GRAVITY LOADS

7.1 Weight of Concrete

Weight of Wall footing/base $W_{conc} := \gamma_c \cdot (t_{base} \cdot L_{base} + L_{stem} \cdot t_{stem} + t_{key} \cdot h_{key}) \cdot b = 77.02 \cdot kN$

Resultant location
$$x_{conc} := \frac{\left[\frac{1}{2} t_{base} \cdot L_{base}^{\ 2} + L_{stem} \cdot t_{stem} \cdot (L_{toe} + 0.5 t_{stem}) \ldots \atop + t_{key} \cdot h_{key} \cdot (L_{base} - 0.5 t_{key})\right]}{t_{base} \cdot L_{base} + L_{stem} \cdot t_{stem} + t_{key} \cdot h_{key}} = 1.43\ m$$

Moment about Toe $M_{conc} := W_{conc} \cdot x_{conc} = 110.52 \cdot kN \cdot m$

7.2 Weight of Soil on Heel

Weight of Soil on heel

$$W_{soil\_h} := b \cdot L_{heel} \cdot \left| \begin{array}{ll} (\gamma_{soilsat} - \gamma_w) \cdot (EL_B - EL_C) & \text{if } EL_B < EL_{hw} \\ \gamma_{soilm} \cdot (EL_B - EL_{hw}) + (\gamma_{soilsat} - \gamma_w) \cdot \max[0, (EL_{hw} - EL_C)] & \text{otherwise} \end{array} \right.$$

$W_{soil\_h} = 56.05 \cdot kN$

Resultant location $x_{soil\_h} := 0.5(x_B - x_G) + x_G = 2.25 \cdot m$

Moment about Toe $M_{soilw\_h} := W_{soil\_h} \cdot x_{soil\_h} = 126.1 \cdot kN \cdot m$

7.3 Weight of Water on Heel

Weight of Water on heel $W_{w\_h} := \gamma_w \cdot \max[0kip, (EL_{hw} - EL_C)] \cdot L_{heel} \cdot b = 53.95 \cdot kN$

Resultant location $x_{w\_h} := 0.5(x_B - x_G) + x_G = 2.25 \cdot m$

Moment about Toe $M_{w\_h} := W_{w\_h} \cdot x_{w\_h} = 121.4 \cdot kN \cdot m$

7.4 Weight of Soil on Toe

Weight of Soil on toe Note: Water and soil elevations MUST NOT be below footing elevation

$$W_{soil\_t} := b \cdot L_{toe} \cdot \left| \begin{array}{ll} (\gamma_{soilsat} - \gamma_w) \cdot (\max(0, EL_F - EL_C)) & \text{if } EL_F < EL_{tw} \\ \gamma_{soilm} \cdot \max(0, EL_F - EL_{tw}) + (\gamma_{soilsat} - \gamma_w) \cdot \max(EL_{tw} - EL_C, 0) & \text{otherwise} \end{array} \right.$$

$W_{soil\_t} = 18.47 \cdot kN$

Resultant location $x_{soil\_t} := 0.5(x_H - x_E) = 0.38 \cdot m$

Moment about Toe $M_{soilw\_t} := W_{soil\_t} \cdot x_{soil\_t} = 6.9 \cdot kN \cdot m$

7.5 Weight of Water on Toe

Weight of Water on toe $W_{w\_t} := \gamma_w \cdot \max\left[0kip, \left(EL_{tw} - EL_C\right)\right] \cdot L_{toe} \cdot b = 17.78 \cdot kN$

Resultant location $x_{w\_t} := 0.5\left(x_H - x_E\right) = 0.38 \cdot m$

Moment about Toe $M_{w\_t} := W_{w\_t} \cdot x_{w\_t} = 6.7 \cdot kN \cdot m$

7.6 Weight of Soil under Footing and Above Failure Plane EJ

Depth of Soil Wedge Near Key $h_{s\_under} := \left(x_L - x_E\right) \cdot \frac{h_{key}}{L_{base}} = 0.39\,m$

Length of Soil Wedge $L_{s\_under} := x_L - x_E = 2.8\,m$

Weight of Soil Wedge Under Footing $W_{s\_under} := \gamma_{soilsat} \cdot \left(0.5 \cdot h_{s\_under} \cdot L_{s\_under}\right) \cdot b = 10.86 \cdot kN$

Resultant location $x_{s\_under} := \frac{2}{3}\left(x_L - x_E\right) = 1.87 \cdot m$

Moment about Toe $M_{s\_under} := W_{s\_under} \cdot x_{s\_under} = 20.3 \cdot kN \cdot m$

8.0 Overturning Stability Assessment - See Figure 2

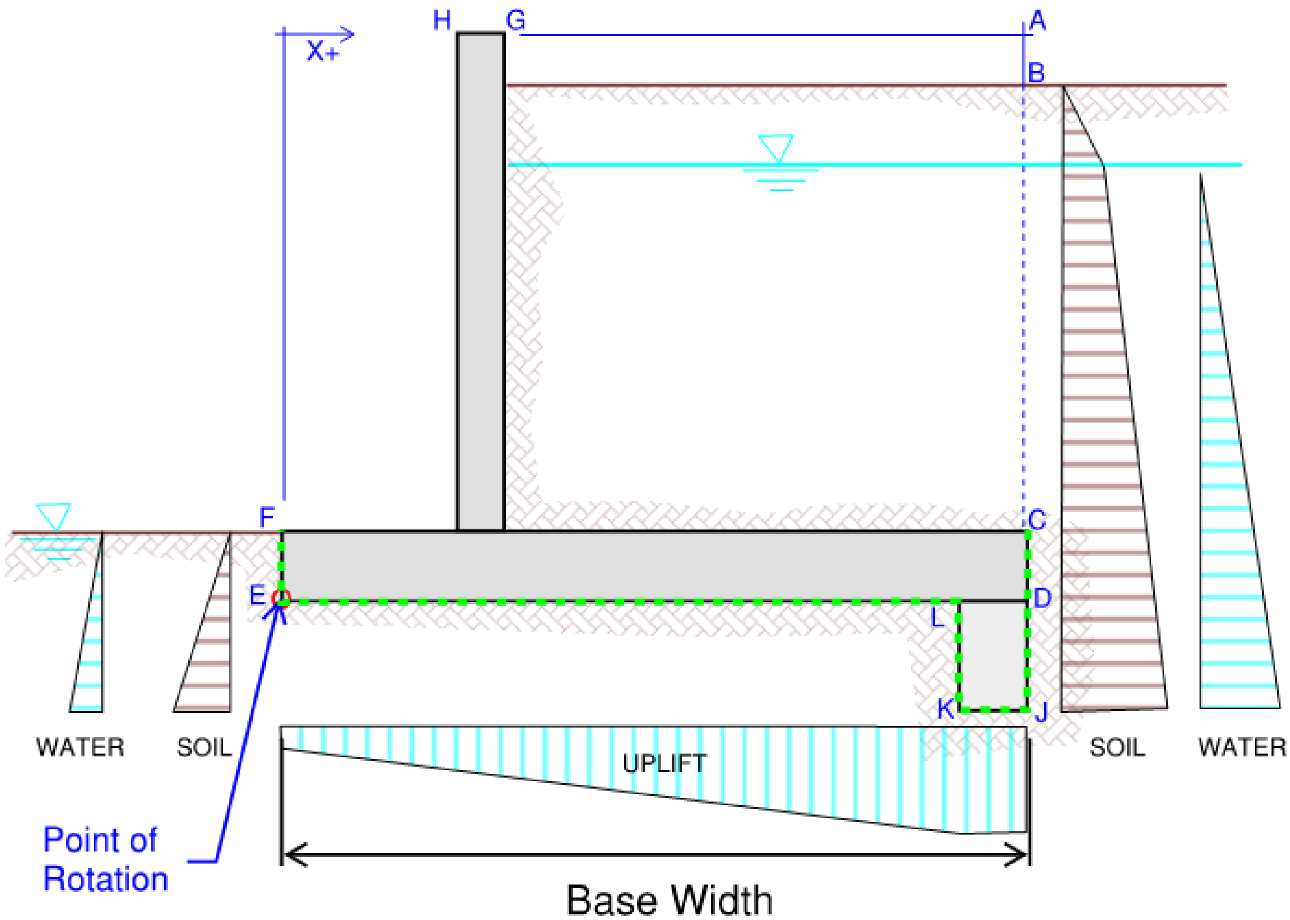


Figure 2. Free Body Diagram for Overturning Analysis

Uplift loads for Overturning

$$P_{u\_ot} := \left[\frac{1}{2}\left(u_h + u_t\right)\cdot\left(x_L - x_E\right) + u_h\cdot t_{key}\right]\cdot b = 107.21\cdot kN$$

Uplift resultant location

$$x_{u\_ot} := \frac{\left[\left[\frac{x_L - x_E}{2} + \frac{x_L - x_E}{6}\cdot\frac{\left(u_h - u_t\right)}{u_t + u_h}\right]\cdot\left[\frac{1}{2}\left(u_h + u_t\right)\cdot\left(x_L - x_E\right)\right] \ldots + \left(L_{base} - 0.5t_{key}\right)\cdot\left(u_h\cdot t_{key}\right)\right]}{\left[\frac{1}{2}\left(u_h + u_t\right)\cdot\left(x_L - x_E\right) + u_h\cdot t_{key}\right]}$$

$$x_{u\_ot} = 1.69\,m$$

Uplift Moment about Toe

$$M_{u\_ot} := P_{u\_ot}\cdot x_{u\_ot} = 181.7\cdot kN\cdot m$$

Total Vertical Forces
$$\Sigma V_{ot} := W_{conc} + W_{soil\_h} + W_{soil\_t} \cdots + W_{w\_h} + W_{w\_t} - P_{u\_ot} = 116.1 \cdot kN$$

Total Horizontal Forces
$$\Sigma H_{ot} := P_{hw} + P_{soil\_h} + P_{sur} - P_{tw} - P_{soil\_t} = 18.66 \cdot kN$$

Total Resisting Moments
$$\Sigma M_{r\_ot} := M_{conc} + M_{soilw\_h} + M_{w\_h} \cdots + M_{soilw\_t} + M_{w\_t} = 371.6 \cdot kN \cdot m$$

Total Driving Moments
$$\Sigma M_{d\_ot} := M_{hw} + M_{soil\_h} + M_{sur} + M_{u\_ot} \cdots + M_{tw} + M_{soil\_t} = 206.2 \cdot kN \cdot m$$

Resultant Location from Toe
$$x_{r\_ot} := \frac{\Sigma M_{r\_ot} - \Sigma M_{d\_ot}}{\Sigma V_{ot}} = 1.42 \cdot m$$

Normalized Resultant Location
$$\frac{x_{r\_ot}}{L_{base}} = 0.438$$

Eccentricity
$$e_{x\_ot} := \frac{L_{base}}{2} - x_{r\_ot} = 0.2 \cdot m$$

Approx. Base in Compression
$$l_{comp\_ot} := \min\left[L_{base}, \frac{3}{2} \cdot \left(L_{base} - 2 \cdot e_{x\_ot}\right)\right] = 3.25 \cdot m$$

Percent Base in Compression
$$\boxed{Base\_Comp := \left(\frac{l_{comp\_ot}}{L_{base}}\right) = 100 \cdot \%}$$

Resultant Location Check
$$check_{res} := if\left(Base\_Comp \geq Base\_Comp_{Req}, \text{"OK"}, \text{"NG"}\right) = \text{"OK"}$$

9.0 Flotation Stability Assessment - See Figure 2

Calculated Flotation Safety Factor
$$\boxed{FS_f := \frac{W_{conc} + W_{soil\_h} + W_{soil\_t} \cdots + W_{w\_h} + W_{w\_t}}{P_{u\_ot}} = 2.1}$$

Flotation Stability Check
$$check_{floatation} := if\left(FS_f \geq FS_{float}, \text{"OK"}, \text{"NG"}\right) = \text{"OK"}$$

10.0 Sliding Stability Assessment - See Figure 3

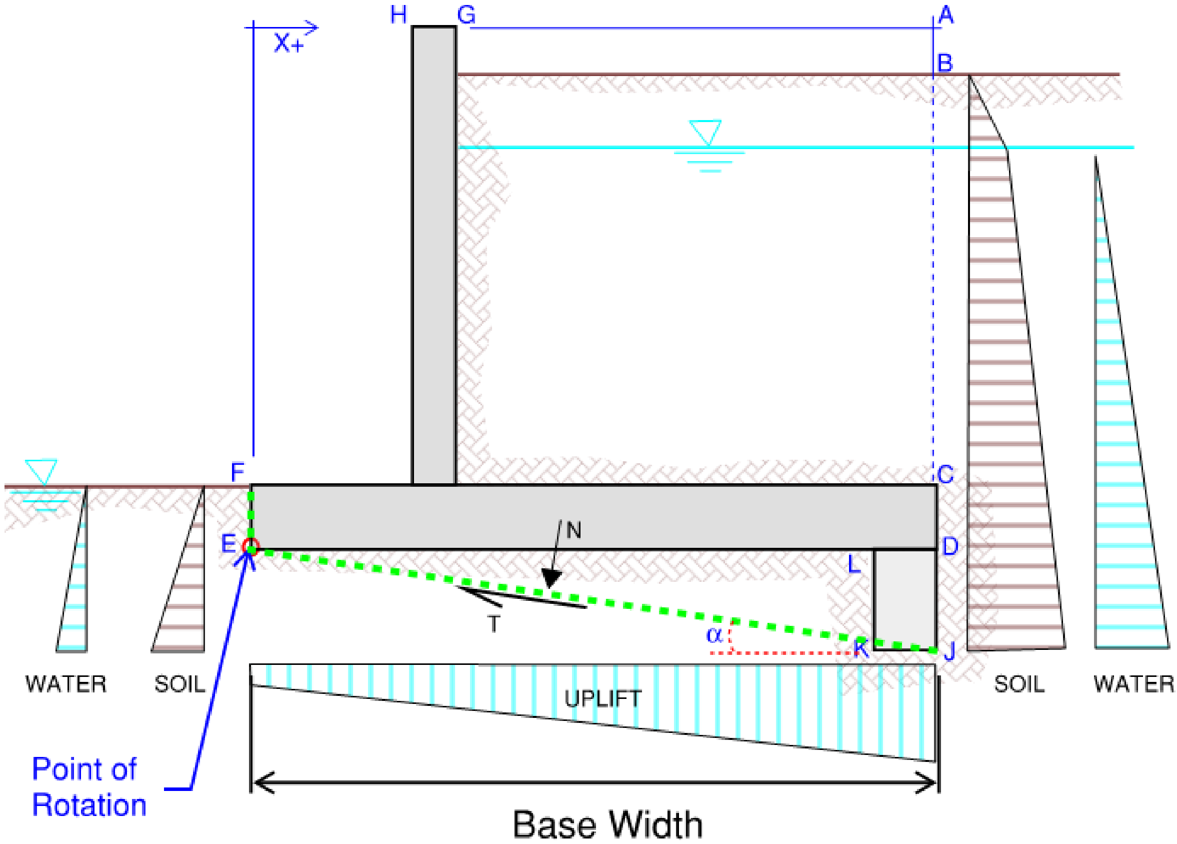


Figure 3. Free Body Diagram for Sliding Analysis

Length of Sliding Failure Plane, EJ

$$L_{fp} := \sqrt{L_{base}^{2} + h_{key}^{2}} = 3.28\,m$$

Angle of Sliding Failure Plane From Horizontal

$$\alpha := \operatorname{atan}\left(\frac{h_{key}}{L_{base}}\right) = 7.9 \cdot deg$$

Total Vertical Forces

$$\Sigma V := W_{conc} + W_{soil\_h} + W_{soil\_t} \cdots + W_{w\_h} + W_{s\_under} + W_{w\_t} - P_u = 128.6 \cdot kN$$

Total Horizontal Forces

$$\Sigma H := P_{hw} + P_{soil\_h} + P_{sur} - P_{tw} - P_{soil\_t} = 18.66 \cdot kN$$

Total Resisting Moments

$$\Sigma M_r := M_{conc} + M_{soilw\_h} + M_{w\_h} \cdots + M_{soilw\_t} + M_{w\_t} + M_{s\_under} = 391.9\,m \cdot kN$$

Total Driving Moments

$$\Sigma M_d := M_{hw} + M_{soil\_h} + M_{sur} + M_u \cdots + M_{tw} + M_{soil\_t} = 202.8 \cdot kN \cdot m$$

Normal Force on Sliding Failure Plane: $N_s := \Sigma H \cdot \sin(\alpha) + \Sigma V \cdot \cos(\alpha) = 129.99 \cdot kN$

Tangential Force on Sliding Failure Plane: $T_s := \Sigma H \cdot \cos(\alpha) - \Sigma V \cdot \sin(\alpha) = 0.84 \cdot kN$

Calculated Sliding Safety Factor $\boxed{FS_s := \frac{\left|N_s \cdot \tan\left(0.95\phi_{soil}\right)\right|}{\left|T_s\right|} = 65.40}$

Sliding Stability Check $check_{sliding} := if\left(FS_s \geq FS_{Sliding}, "OK", "NG"\right) = "OK"$

11.0 Bearing Capacity Assessment

Resultant Location from Toe $x_r := \frac{\Sigma M_r - \Sigma M_d}{N_s} = 1.45 \cdot m$

Eccentricity of N_s from center of base $e_s := \frac{L_{fp}}{2} - x_r = 0.19 \cdot m$

Approx. Base in Compression $l_{comp.s} := \min\left[L_{fp}, \frac{3}{2} \cdot \left(L_{fp} - 2 \cdot e_s\right)\right] = 3.28 \cdot m$

Updated Eccentricity $e_x := \frac{l_{comp.s} - L_{fp}}{2} + e_s = 0.19 \cdot m$

Effective base pressure at Toe $q_t := \left(\frac{N_s}{l_{comp.s} \cdot b}\right) \cdot \left(1 + \frac{6 \cdot e_x}{l_{comp.s}}\right) = 53.07 \cdot kPa$

Effective base pressure at Heel $q_h := \max\left[\left(\frac{N_s}{l_{comp.s} \cdot b}\right) \cdot \left(1 - \frac{6 \cdot e_x}{l_{comp.s}}\right), 0\right] = 26.17 \cdot kPa$

Calculated Bearing Safety Factor $\boxed{FS_b := \frac{Q_b}{\max\left(q_t, q_h\right)} = 2.83}$

Bearing Pressure Check $check_{bearing} := if\left(FS_b \geq FS_{Bearing}, "OK", "NG"\right) = "OK"$

12.0 Summary of Stability Assessments

Base Compression / Resultant Location	$Base\_Comp = 100 \cdot \%$	$check_{res} = "OK"$
Flotation Stability	$FS_f = 2.1$	$check_{floatation} = "OK"$
Sliding Stability	$FS_s = 65.4$	$check_{sliding} = "OK"$
Bearing Pressure	$FS_b = 2.8$	$check_{bearing} = "OK"$

13.0 Structural Loads

13.1 Shear and Moment at Stem Base - See Figure 4

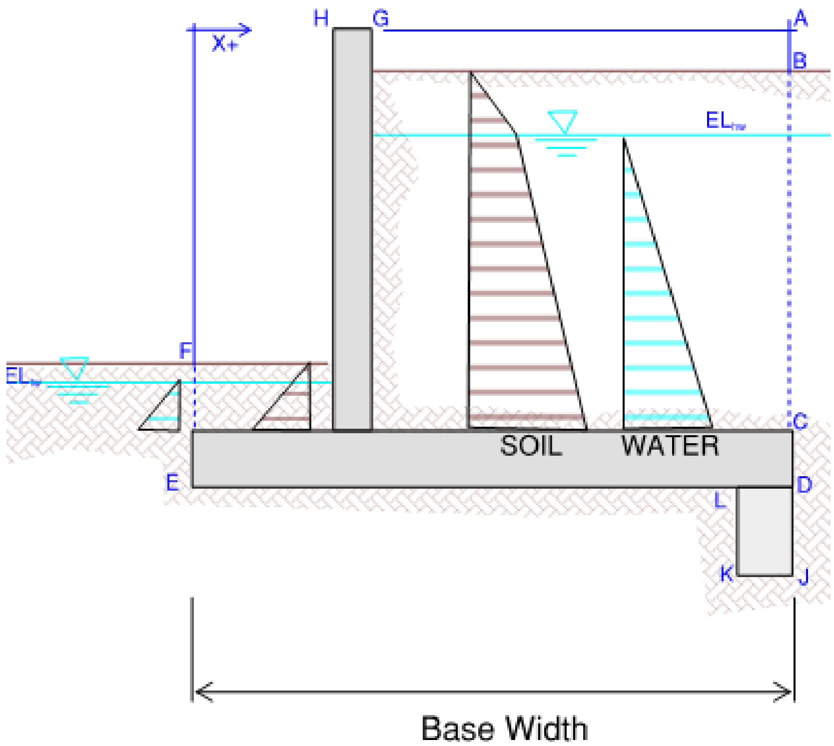


Figure 4 - Loads on Stem

13.1.1 Hydrostatic Load at Stem Base

Heel side hydrostatic load $$P_{hw\_stem} := \frac{1}{2}\gamma_w \cdot \left(EL_{hw} - EL_C\right)^2 \cdot b = 37.1 \cdot kN$$

Heel side moment at stem base $$M_{hw\_stem} := P_{hw\_stem} \cdot \left(\frac{EL_{hw} - EL_C}{3}\right) = 34 \cdot kN \cdot m$$

Toe side hydrostatic load $$P_{tw\_stem} := \frac{1}{2}\gamma_w \cdot \left(EL_{tw} - EL_C\right)^2 \cdot b = 28.7 \cdot kN$$

Toe side moment at stem base $$M_{tw\_stem} := P_{tw\_stem} \cdot \left(\frac{EL_{tw} - EL_C}{3}\right) = 23.1 \cdot kN \cdot m$$

13.1.2 Lateral Soil Loads at Stem Base

Soil pressure at saturation level - Toe Side

$$p_t := \begin{cases} k_o \cdot \gamma_{soilm} \cdot (EL_F - EL_{tw}) & \text{if } EL_F > EL_{tw} \\ 0psf & \text{otherwise} \end{cases} = 0.00 \cdot kPa$$

Soil pressure at stem base - Toe Side

$$p_{C.t} := \begin{cases} p_t + k_o \cdot (\gamma_{soilsat} - \gamma_w) \cdot (EL_{tw} - EL_C) & \text{if } EL_F > EL_{tw} \\ k_o \cdot (\gamma_{soilsat} - \gamma_w) \cdot (EL_F - EL_C) & \text{otherwise} \end{cases}$$

$$p_{C.t} = 14.61 \cdot kPa$$

Lateral soil loads at stem base - Toe Side

$$P_{s\_t} := \left[0.5 \cdot (EL_F - EL_{tw}) \cdot p_t + p_t \cdot (EL_{tw} - EL_C) \ldots + 0.5 \cdot (p_{C.t} - p_t) \cdot (EL_{tw} - EL_C)\right] \cdot b = 17.66 \cdot kN$$

Resultant location

$$y_{s\_t} := \begin{cases} 0 & \text{if } P_{s\_t} = 0 \\ \dfrac{\left[0.5 \cdot (EL_F - EL_{tw}) \cdot p_t \cdot \left[(EL_{tw} - EL_C) + \frac{1}{3}(EL_F - EL_{tw})\right] + p_t \cdot \frac{1}{2}(EL_{tw} - EL_C)^2 \ldots + 0.5 \cdot (p_{C.t} - p_t) \cdot (EL_{tw} - EL_C)^2 \cdot \frac{1}{3}\right] \cdot b}{P_{s\_t}} & \text{otherwise} \end{cases}$$

$$y_{s\_t} = 0.81 \cdot m$$

Lateral soil moment at stem base - Toe Side

$$M_{s\_t} := P_{s\_t} \cdot y_{s\_t} = 14.23 \cdot kN \cdot m$$

Soil pressure at saturation level - Heel Side

$$p_h := \begin{cases} k_o \cdot \gamma_{soilm} \cdot (EL_B - EL_{hw}) & \text{if } EL_B > EL_{hw} \\ 0kPa & \text{otherwise} \end{cases} = 0.00 \cdot kPa$$

Soil pressure at stem base - Heel Side

$$p_{C.h} := \begin{cases} p_h + k_o \cdot (\gamma_{soilsat} - \gamma_w) \cdot (EL_{hw} - EL_C) & \text{if } EL_B > EL_{tw} \\ k_o \cdot (\gamma_{soilsat} - \gamma_w) \cdot (EL_B - EL_C) & \text{otherwise} \end{cases}$$

$$p_{C.h} = 16.62 \cdot kPa$$

Lateral soil loads at stem base - Heel Side

$$P_{s\_h} := \left[0.5 \cdot (EL_B - EL_{hw}) \cdot p_h + p_h \cdot (EL_{hw} - EL_C) \ldots + 0.5 \cdot (p_{C.h} - p_h) \cdot (EL_{hw} - EL_C)\right] \cdot b = 22.86 \cdot kN$$

Resultant location

$$y_{s\_h} := \begin{cases} 0 & \text{if } P_{s\_h} = 0 \\ \dfrac{\left[0.5\cdot(EL_B - EL_{hw})\cdot p_h\cdot\left[(EL_{hw} - EL_C) + \frac{1}{3}(EL_B - EL_{hw})\right] + p_h\cdot\frac{1}{2}(EL_{hw} - EL_C)^2 \ldots + 0.5\cdot(p_{C.h} - p_h)\cdot(EL_{hw} - EL_C)^2\cdot\frac{1}{3}\right]\cdot b}{P_{s\_h}} & \text{otherwise} \end{cases}$$

$$y_{s\_h} = 0.92\cdot m$$

Lateral soil moment at stem base - Heel Side $\qquad M_{s\_h} := P_{s\_h}\cdot y_{s\_h} = 20.95\cdot kN\cdot m$

13.1.3 Surcharge Loads at Stem Base

Surcharge load at stem base $\qquad P_{sur\_stem} := p_{sur}\cdot(EL_B - EL_C)\cdot b = 0\cdot kN$

Surcharge Moment about Toe $\qquad M_{sur\_stem} := P_{sur}\cdot\frac{1}{2}(EL_B - EL_C) = 0\cdot kN\cdot m$

13.2 Shear and Moment on Heel - See Figure 5

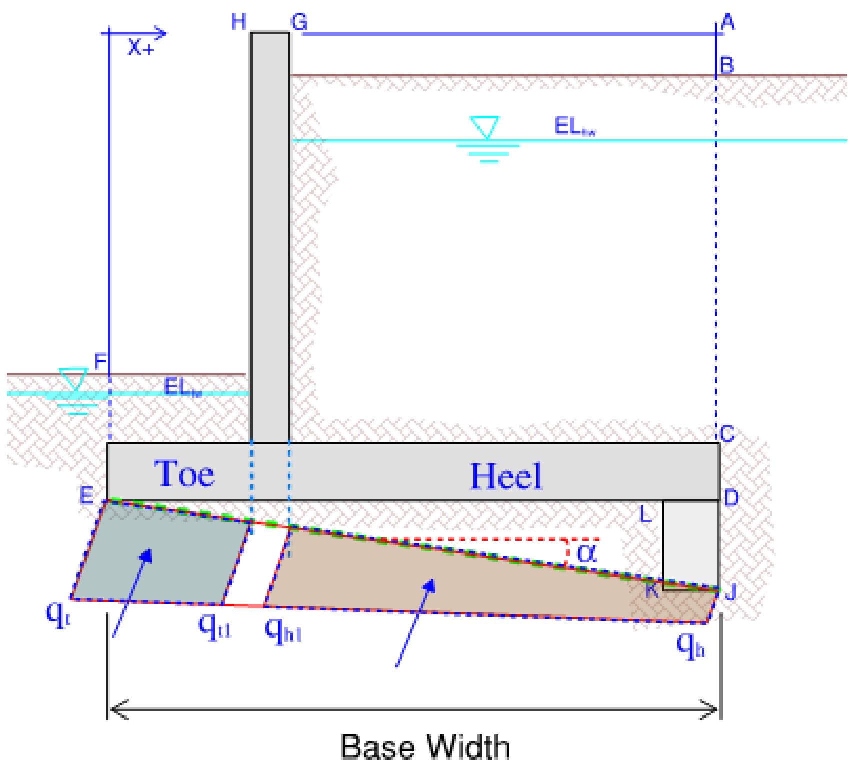


Figure 5 - Loads on Base (Heel & Toe)

13.2.1 Weight of Concrete Heel

Weight of Wall footing/base

$$W_{c\_heel} := \gamma_c \cdot (t_{base} \cdot L_{heel} + t_{key} \cdot h_{key}) \cdot b = 28.26 \cdot kN$$

Resultant location

$$x_{c\_heel} := \frac{\left[\frac{1}{2} t_{base} \cdot L_{heel}^{2} \ldots + t_{key} \cdot h_{key} \cdot (L_{heel} - 0.5 t_{key})\right]}{t_{base} \cdot L_{heel} + t_{key} \cdot h_{key}} = 1.13\ m$$

Moment about stem base

$$M_{c\_heel} := W_{c\_heel} \cdot x_{c\_heel} = 31.95 \cdot kN \cdot m$$

13.2.2 Weight of Soil on Heel

Weight of Soil on heel

$$W_{s\_heel} := W_{soil\_h} = 56.05 \cdot kN$$

Moment about stem base

$$M_{s\_heel} := W_{s\_heel} \cdot \left(\frac{1}{2} L_{heel}\right) = 56 \cdot kN \cdot m$$

13.2.3 Weight of Water on Heel

Weight of Water on heel

$$W_{w\_heel} := W_{w\_h} = 53.95 \cdot kN$$

Moment about stem base

$$M_{w\_heel} := W_{w\_heel} \cdot \left(\frac{1}{2} L_{heel}\right) = 54 \cdot kN \cdot m$$

13.2.4 Weight of Concrete Toe

Weight of Wall footing/base

$$W_{c\_toe} := \gamma_c \cdot t_{base} \cdot L_{toe} \cdot b = 8.81 \cdot kN$$

Moment about stem base

$$M_{c\_toe} := W_{c\_toe} \cdot \left(\frac{1}{2} \cdot L_{toe}\right) = 3.3 \cdot kN \cdot m$$

13.2.5 Weight of Soil on Toe

Weight of Soil on Toe

$$W_{s\_toe} := W_{soil\_t} = 18.47 \cdot kN$$

Moment about stem base

$$M_{s\_toe} := W_{s\_toe} \cdot \left(\frac{1}{2} L_{toe}\right) = 6.9 \cdot kN \cdot m$$

13.2.6 Weight of Water on Toe

Weight of Water on Toe

$$W_{w\_toe} := W_{w\_t} = 17.78 \cdot kN$$

Moment about stem base

$$M_{w\_toe} := W_{w\_toe} \cdot \left(\frac{1}{2} L_{toe}\right) = 6.7 \cdot kN \cdot m$$

13.2.7 Bearing Pressures on Footing

Approx. Base in Compression $l_{comp.s} = 3.28\,m$

Effective base pressure at Toe $q_t = 53.07 \cdot kPa$

Effective base pressure at Heel $q_h = 26.17 \cdot kPa$

Compression length under Toe $L_{bearing\_t} := \dfrac{L_{toe}}{\cos(\alpha)} = 0.76\,m$

Compression length under Heel $L_{bearing\_h} := l_{comp.s} - \dfrac{(x_G - x_E)}{\cos(\alpha)} = 2.02\,m$

Bearing pressure under toe side of stem $q_{t1} := L_{bearing\_t} \cdot \left[\dfrac{(q_h - q_t)}{l_{comp.s}}\right] + q_t = 46.86 \cdot kPa$

Bearing pressure under heel side of stem $q_{h1} := \dfrac{(x_G - x_E)}{\cos(\alpha)} \cdot \left[\dfrac{(q_h - q_t)}{l_{comp.s}}\right] + q_t = 42.72 \cdot kPa$

13.2.8 Soil Reaction on Heel

Soil reaction load on Heel $P_{bearing\_h} := \dfrac{1}{2} \cdot (q_h + q_{h1}) \cdot L_{bearing\_h} \cdot b = 69.55 \cdot kN$

Resultant location $x_{bearing\_h} := \dfrac{L_{bearing\_h}}{2} + \dfrac{L_{bearing\_h}}{6} \cdot \dfrac{(q_h - q_{h1})}{q_{h1} + q_h} = 0.93\,m$

Vertical Component $P_{h\_v} := P_{bearing\_h} \cdot \cos(\alpha) = 68.89 \cdot kN$

Horizontal Component $P_{h\_h} := P_{bearing\_h} \cdot \sin(\alpha) = 9.54 \cdot kN$

Horizontal Moment Arm $x_{h\_h} := x_{bearing\_h} \cdot \cos(\alpha) = 0.92\,m$

Vertical Moment Arm $y_{h\_v} := \left[\dfrac{(x_G - x_E)}{\cos(\alpha)} + x_{bearing\_h}\right] \cdot \sin(\alpha) = 0.3\,m$

Moment on Heel $M_{bearing\_h} := P_{h\_v} \cdot x_{h\_h} + P_{h\_h} \cdot y_{h\_v} = 66.24 \cdot kN \cdot m$

13.2.9 Soil Reaction on Toe

Soil reaction load on Toe $P_{bearing\_t} := \frac{1}{2} \cdot (q_t + q_{t1}) \cdot L_{bearing\_t} \cdot b = 37.83 \cdot kN$

Resultant location $x_{bearing\_t} := \frac{L_{bearing\_t}}{2} + \frac{L_{bearing\_t}}{6} \cdot \frac{(q_t - q_{t1})}{q_t + q_{t1}} = 0.39\,m$

Vertical Component $P_{t\_v} := P_{bearing\_t} \cdot \cos(\alpha) = 37.47 \cdot kN$

Horizontal Component $P_{t\_h} := P_{bearing\_t} \cdot \sin(\alpha) = 5.19 \cdot kN$

Horizontal Moment Arm $x_{t\_h} := x_{bearing\_t} \cdot \cos(\alpha) = 0.38\,m$

Vertical Moment Arm $y_{t\_v} := (L_{bearing\_t} - x_{bearing\_t}) \cdot \sin(\alpha) = 0.05\,m$

Moment on Toe $M_{bearing\_t} := P_{t\_v} \cdot x_{t\_h} + P_{t\_h} \cdot y_{t\_v} = 14.61 \cdot kN \cdot m$

13.2.10 Uplift Pressure on Footing - Figure 6

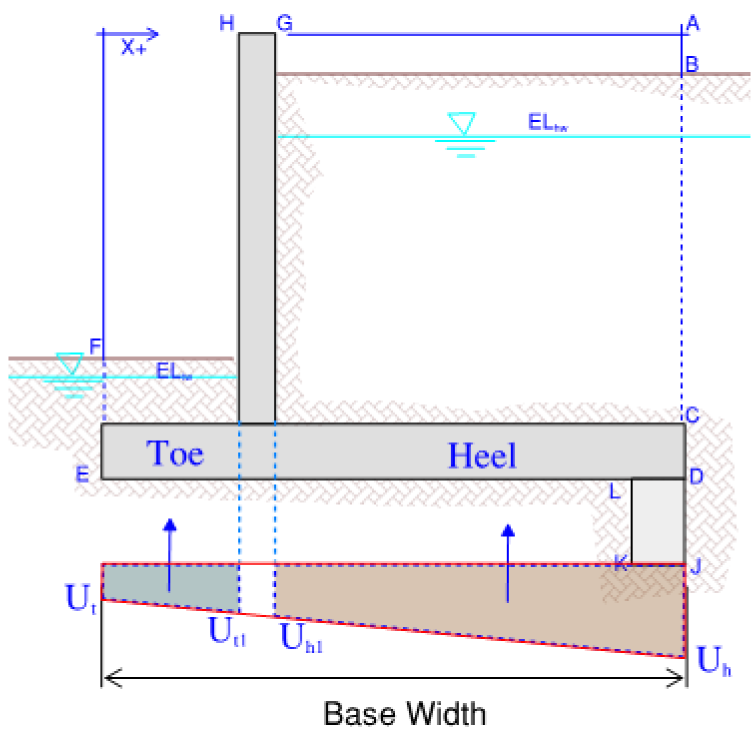


Figure 6 - Uplift Loads on Base (Heel & Toe)

Uplift pressure under toe side of stem $u_{t1} := L_{toe} \cdot \left[\frac{(u_h - u_t)}{L_{base}}\right] + u_t = 30.39 \cdot kPa$

Uplift pressure under heel side of stem $u_{h1} := (x_G - x_E) \cdot \left[\frac{(u_h - u_t)}{L_{base}}\right] + u_t = 31.57 \cdot kPa$

13.2.11 Uplift Loads Heel

Uplift load on Heel $P_{u\_h} := \frac{1}{2} \cdot (u_h + u_{h1}) \cdot L_{heel} \cdot b = 67.87 \cdot kN$

Moment Arm $x_{u\_h} := \frac{L_{heel}}{2} + \frac{L_{heel}}{6} \cdot \frac{(u_h - u_{h1})}{u_{h1} + u_h} = 1.02\ m$

Moment on Heel $M_{u\_h} := P_{u\_h} \cdot x_{u\_h} = 69.44 \cdot kN \cdot m$

13.2.12 Uplift Loads Toe

Uplift load on Toe $P_{u\_t} := \frac{1}{2} \cdot (u_t + u_{t1}) \cdot L_{toe} \cdot b = 22.13 \cdot kN$

Moment Arm $x_{u\_t} := \frac{L_{toe}}{2} + \frac{L_{toe}}{6} \cdot \frac{(u_t - u_{t1})}{u_{t1} + u_t} = 0.37\ m$

Moment on Toe $M_{u\_t} := P_{u\_t} \cdot x_{u\_t} = 8.21 \cdot kN \cdot m$

13.3 Structural Load Summary

Net shear at stem base $V_{stem} := P_{hw\_stem} - P_{tw\_stem} + P_{s\_h} - P_{s\_t} + P_{sur\_stem} = 13.6 \cdot kN$

Net moment at stem base $M_{stem} := M_{hw\_stem} - M_{tw\_stem} + M_{s\_h} - M_{s\_t} + M_{sur\_stem} = 17.6 \cdot kN \cdot m$

Net shear on Toe $V_t := W_{c\_toe} + W_{s\_toe} + W_{w\_toe} - P_{t\_v} - P_{u\_t} = -14.5 \cdot kN$

Net moment on Toe $M_t := M_{c\_toe} + M_{s\_toe} + M_{w\_toe} - M_{bearing\_t} - M_{u\_t} = -5.9 \cdot kN \cdot m$

Net shear on Heel $V_h := W_{c\_heel} + W_{s\_heel} + W_{w\_heel} - P_{h\_v} - P_{u\_h} = 1.5 \cdot kN$

Net moment on Heel $M_h := M_{c\_heel} + M_{s\_heel} + M_{w\_heel} - M_{bearing\_h} - M_{u\_h} = 6.3 \cdot kN \cdot m$

13.4 Controlling Structural Loads (Unfactored)

Stem cross section

$M_{stem} = 17.6 \cdot kN \cdot m$

$V_{stem} = 13.6 \cdot kN$

Toe cross section

$M_{toe} := M_t = -5.92 \cdot kN \cdot m$

$V_{toe} := V_t = -14.5 \cdot kN$

Heel cross section

$M_{heel} := \min\left(\max\left(M_{stem} - \left|M_{toe}\right|, M_h\right), M_{stem}\right) = 11.7 \cdot kN \cdot m$

STABILITY ANALYSIS FOR CANTILEVER WALL WITH KEY

Project / Client: Springbank Off-Stream Storage (SR1) / Alberta Transportation

Section Location: Intake Structure Wing Wall - Closest to Intake Structure

1.0 OBJECTIVE

For a particular load condition, analyze a reinforced concrete cantilever wall with shear key for overturning, sliding, flotation, and bearing capacity in accordance with criteria described in the listed references.

2.0 BACKGROUND INFORMATION

2.1 DATA SOURCES

1- Soils Report - Recommended Geotechnical Soil Parameters, SR-1 Low Level Outlet (LLO) Structures. July 19, 2019

2- Drawings - Design Drawings

3- Springbank Off-Stream Storage Project - Design Basis Memorandum (DBM) , 2019

2.2 REFERENCES

1. (CDA) Dam Safety Guidelines, 2007 (revised 2013).

2. "Water Control Structures Selected Design Guidelines," Alberta Transportation & Alberta Environment, Calgary Alberta, November 2004.

3.0 DESIGN PARAMETERS AND CRITERIA

3.1 Stability Analysis Criteria (Data source 2)

Load Case	$LC := 4$ $\quad$ $EQ := 3$
Load Case Description	$\text{vlookup}(LC, CASES, 1)_0 = \text{"Earthquake"}$
Sliding Minimum Factor of Safety	$FS_{Sliding} := \text{vlookup}(LC, CASES, 2)_0 = 1$
Overturning Criteria	$Base\_Comp_{Req} := \text{vlookup}(LC, CASES, 3)_0 = 0.1 \cdot \%$
Bearing Capacity Minimum Factor of Safety	$FS_{Bearing} := \text{vlookup}(LC, CASES, 4)_0 = 1$
Flotation Minimum Factor of Safety	$FS_{float} := \text{vlookup}(LC, CASES, 5)_0 = 1$

3.2 Applied Loads

Heel side water elevation $EL_{hw} := \text{vlookup}(LC, WaterEL, 1)_0 \cdot 1m = 1187\,m$ Data Source 2

Toe side water elevation $EL_{tw} := \text{vlookup}(LC, WaterEL, 2)_0 \cdot 1m = 1187\,m$

Equivalent soil surcharge $h_{sur} := \begin{cases} 1.0m & \text{if } LC = 2 \\ 0 & \text{otherwise} \end{cases} = 0 \cdot m$

Horizontal Seismic Coefficient $k_h := \begin{cases} \text{vlookup}(EQ, CASES_{eq}, 1)_0 & \text{if } LC = 4 \\ 0 & \text{otherwise} \end{cases} = 0.19$

Vertical Seismic Coefficient $k_v := \begin{cases} \text{vlookup}(EQ, CASES_{eq}, 2)_0 & \text{if } LC = 4 \\ 0 & \text{otherwise} \end{cases} = -0.03$

3.3 Material Properties - Data Source 1 Unless Otherwise Noted

Unit Weight of Water $\gamma_w := 9.81 \dfrac{kN}{m^3}$

Unit Weight of Concrete $\gamma_c := 23.5 \cdot \dfrac{kN}{m^3}$ Data Source 3

Unit Weight of Soil (Moist) $\gamma_{soilm} := 20 \dfrac{kN}{m^3}$

Soil Unit Weight Beneath Base (Saturated) $\gamma_{soilsat} := 20 \dfrac{kN}{m^3}$

Soil Cohesion - Drained $c_{soil} := 0kPa$

Soil Angle of Internal Friction - Drained $\phi_{soil} := 24deg$

Soil Ultimate Bearing Pressure $Q_b := 450kPa$

Slope of backfill (Conservative) $\beta := 0$

At-rest lateral earth pressure coefficient $k_o := 1 - \sin(\phi_{soil}) = 0.59$

4.0 WALL SECTION DESCRIPTION

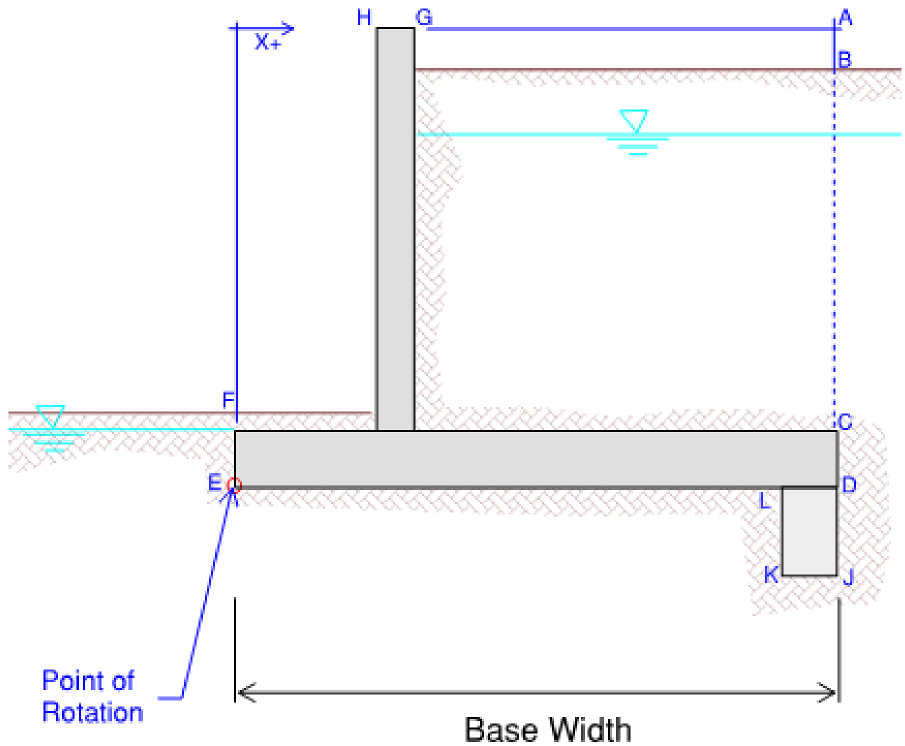


Figure 1. Cantilever Wall Section

4.1 Point Locations (Refer to Figure 1 and Drawings)

A - Top of wall	$EL_A := 1189.9m$	$x_A := 3.25m$
B - Top of fill - reservoir side	$EL_B := 1189.75m$	$x_B := x_A = 3.25 \cdot m$
C - Top of Heel	$EL_C := 1187m$	$x_C := x_A = 3.25 \cdot m$
D - Heel side end of footing	$EL_D := EL_C - 500mm = 1186.50\ m$	$x_D := x_A = 3.25 \cdot m$
E - Toe side end of footing	$EL_E := EL_D = 1186.50 \cdot m$	$x_E := 0m$
F - Top of Fill - land side	$EL_F := EL_C + 333mm = 1187.33 \cdot m$	$x_F := x_E = 0$
G - Heel side face of wall stem	$EL_G := EL_A = 1189.90 \cdot m$	$x_G := 1.25m$
H - Toe side face of wall stem	$EL_H := EL_A = 1189.90 \cdot m$	$x_H := x_G - 0.500m = 0.75 \cdot m$

J - Bottom of key - heel side	$EL_J := EL_C - 2m = 1185.00 \cdot m$	$x_J := x_D = 3.25\ m$
K - Bottom of key - toe side	$EL_K := EL_J = 1185.00 \cdot m$	$x_K := x_J - 450mm = 2.8 \cdot m$
L - Top of key	$EL_L := EL_D = 1186.50 \cdot m$	$x_L := x_K = 2.8\ m$

4.2 Additional Analysis Dimensions

Analysis Width	$b := 1m$
Length of base	$L_{base} := x_D - x_E = 3.25 \cdot m$
Thickness of base	$t_{base} := EL_C - EL_D = 500 \cdot mm$
Length of stem	$L_{stem} := EL_A - EL_C = 2900 \cdot mm$
Thickness of stem	$t_{stem} := x_G - x_H = 500 \cdot mm$
Length of Heel	$L_{heel} := x_A - x_G = 2000 \cdot mm$
Length of Toe	$L_{toe} := x_H - x_F = 750 \cdot mm$
Thickness of Key	$t_{key} := x_J - x_K = 450 \cdot mm$
Height of Key	$h_{key} := EL_D - EL_J = 1500 \cdot mm$

5.0 UPLIFT & HYDROSTATIC LOADS

5.1 Uplift Pressures for Stability Analyses

Determine water pressures for designated coordinates using full headwater uplift pressure at the heel and full tailwater uplift pressure at the toe. Uplift distribution is assumed linear from heel to toe.

Hydrostatic pressure at Heel $\quad u_h := \gamma_w \cdot \left(EL_{hw} - EL_J\right) = 20 \cdot kPa$

Hydrostatic pressure at Toe $\quad u_t := \gamma_w \cdot \left(EL_{tw} - EL_E\right) = 5 \cdot kPa$

Total uplift loads on base $\quad P_u := \frac{\left(u_h + u_t\right)}{2} \cdot L_{base} \cdot b = 39.85 \cdot kN$

Uplift resultant location $\quad x_u := \frac{L_{base}}{2} + \frac{L_{base}}{6} \cdot \frac{\left(u_h - u_t\right)}{u_t + u_h} = 1.95 \cdot m$

Uplift Moment about Toe $\quad M_u := P_u \cdot x_u = 77.7 \cdot kN \cdot m$

5.2 Headwater Hydrostatic Load - Heel Side

Headwater hydrostatic load $P_{hw} := \frac{1}{2} u_h \cdot (EL_{hw} - EL_J) \cdot b = 19.6 \cdot kN$

Headwater moment arm $y_{hw} := \frac{1}{3}(EL_{hw} - EL_J) - h_{key} = -0.83 \cdot m$

Headwater Moment about Toe $M_{hw} := P_{hw} \cdot y_{hw} = -16.4 \cdot kN \cdot m$

5.3 Tailwater Hydrostatic Load - Toe Side

Tailwater hydrostatic load $P_{tw} := \frac{1}{2} \gamma_w \cdot (EL_{tw} - EL_K)^2 \cdot b = 19.62 \cdot kN$

Tailwater moment arm $y_{tw} := h_{key} - \frac{1}{3}(EL_{tw} - EL_K) = 0.83 \cdot m$

Tailwater Moment about Toe $M_{tw} := P_{tw} \cdot y_{tw} = 16.35 \cdot kN \cdot m$

<u>6.0 LATERAL EARTH PRESSURE</u>

6.1 Lateral Soil Load on Toe Side

Soil pressure at Saturation Level

$$p_{tw} := \begin{cases} k_o \cdot \gamma_{soilm} \cdot (EL_F - EL_{tw}) & \text{if } EL_F > EL_{tw} \\ 0psf & \text{otherwise} \end{cases} = 4.0 \cdot kPa$$

Soil pressure at Toe - base elevation

$$p_E := \begin{cases} p_{tw} + k_o \cdot (\gamma_{soilsat} - \gamma_w) \cdot (EL_{tw} - EL_J) & \text{if } EL_F > EL_{tw} \\ k_o \cdot (\gamma_{soilsat} - \gamma_w) \cdot (EL_F - EL_J) & \text{otherwise} \end{cases}$$

$p_E = 16.04 \cdot kPa$

Total soil loads on Wall

$$P_{soil\_t} := \left[0.5 \cdot (EL_F - EL_{tw}) \cdot p_{tw} + p_{tw} \cdot (EL_{tw} - EL_J) \ldots + 0.5 \cdot (p_E - p_{tw}) \cdot (EL_{tw} - EL_J)\right] \cdot b = 20.65 \cdot kN$$

Resultant location

$$y_{soil\_t} := \begin{cases} 0 & \text{if } P_{soil\_t} = 0 \\ h_{key} - \dfrac{\left[0.5 \cdot (EL_F - EL_{tw}) \cdot p_{tw} \cdot \left[(EL_{tw} - EL_J) + \frac{1}{3}(EL_F - EL_{tw})\right] + p_{tw} \cdot \frac{1}{2}(EL_{tw} - EL_J)^2 \ldots + 0.5 \cdot (p_E - p_{tw}) \cdot (EL_{tw} - EL_J)^2 \cdot \frac{1}{3}\right] \cdot b}{P_{soil\_t}} & \text{otherwise} \end{cases}$$

$y_{soil\_t} = 0.66 \cdot m$

Moment about Toe $M_{soil\_t} := P_{soil\_t} \cdot y_{soil\_t} = 13.62 \cdot kN \cdot m$

6.2 Lateral Soil Load on Heel Side

Soil pressure at Saturation Level

$$p_{hw} := \begin{cases} k_o \cdot \gamma_{soilm} \cdot (EL_B - EL_{hw}) & \text{if } EL_B > EL_{hw} \\ 0psf & \text{otherwise} \end{cases} = 32.6 \cdot kPa$$

Soil pressure at Heel - base elevation

$$p_D := \begin{cases} p_{hw} + k_o \cdot (\gamma_{soilsat} - \gamma_w) \cdot (EL_{hw} - EL_J) & \text{if } EL_B > EL_{hw} \\ k_o \cdot (\gamma_{soilsat} - \gamma_w) \cdot (EL_B - EL_J) & \text{otherwise} \end{cases}$$

$$p_D = 44.72 \cdot kPa$$

Total soil loads on Base

$$P_{soil\_h} := \left[0.5 \cdot (EL_B - EL_{hw}) \cdot p_{hw} + p_{hw} \cdot (EL_{hw} - EL_J) \ldots \atop + 0.5 \cdot (p_D - p_{hw}) \cdot (EL_{hw} - EL_J)\right] \cdot b$$

$$P_{soil\_h} = 122.22 \cdot kN$$

Resultant location

$$y_{soil\_h} := \frac{\left[0.5 \cdot (EL_B - EL_{hw}) \cdot p_{hw} \cdot \left[EL_{hw} - EL_J + \frac{1}{3}(EL_B - EL_{hw})\right] + p_{hw} \cdot \frac{1}{2}(EL_{hw} - EL_J)^2 \ldots \atop + 0.5 \cdot (p_D - p_{hw}) \cdot (EL_{hw} - EL_J)^2 \cdot \frac{1}{3}\right] \cdot b}{P_{soil\_h}} - h_{key}$$

$$y_{soil\_h} = 0.17 \cdot m$$

Moment about Toe

$$M_{soil\_h} := P_{soil\_h} \cdot y_{soil\_h} = 20.9 \cdot kN \cdot m$$

6.3 Surcharge Soil Load - Heel Side

Surcharge soil pressure

$$p_{sur} := k_o \cdot \gamma_{soilm} \cdot h_{sur} = 0 \cdot kPa$$

Soil load on wall

$$P_{sur} := p_{sur} \cdot (EL_B - EL_J) \cdot b = 0 \cdot kN$$

Resultant location

$$y_{sur} := \frac{1}{2} \cdot (EL_B - EL_J) - h_{key} = 0.88\, m$$

Moment about Toe

$$M_{sur} := P_{sur} \cdot y_{sur} = 0 \cdot kN \cdot m$$

6.4 Seismic Lateral Soil Load on Toe Side - Woods Method (Data Source 3)

Weighted Average of unit weights

$$\gamma_{EQ\_t} := \frac{\left[\gamma_{soilsat}\cdot\left(EL_F - EL_{tw}\right) + \left(\gamma_{soilsat} - \gamma_w\right)\cdot\left(EL_{tw} - EL_J\right)\right]}{\left(EL_F - EL_J\right)}$$

$$\gamma_{EQ\_t} = 11.59\cdot\frac{kN}{m^3}$$

Seismic Lat. soil load on Wall

$$P_{E\_soil\_t} := \gamma_{EQ\_t}\cdot\left(EL_F - EL_J\right)^2\cdot b\cdot k_h = 11.99\cdot kN$$

Resultant location

$$y_{E\_soil\_t} := h_{key} - 0.63\left(EL_F - EL_J\right) = 0.03\ m$$

Moment about Toe

$$M_{E\_soil\_t} := P_{E\_soil\_t}\cdot y_{E\_soil\_t} = 0.36\cdot kN\cdot m$$

6.5 Seismic Lateral Soil Load on Heel Side - Woods Method (Data Source 3)

Weighted Average of unit weights

$$\gamma_{EQ\_h} := \frac{\left[\gamma_{soilsat}\cdot\left(EL_B - EL_{hw}\right) + \left(\gamma_{soilsat} - \gamma_w\right)\cdot\left(EL_{hw} - EL_J\right)\right]}{\left(EL_B - EL_J\right)}$$

$$\gamma_{EQ\_h} = 15.87\cdot\frac{kN}{m^3}$$

Seismic Lat. soil loads on Wal

$$P_{E\_soil\_h} := \gamma_{EQ\_h}\cdot\left(EL_B - EL_J\right)^2\cdot b\cdot k_h = 68.03\cdot kN$$

Resultant location

$$y_{E\_soil\_h} := 0.63\left(EL_B - EL_J\right) - h_{key} = 1.49\ m$$

Moment about Toe

$$M_{E\_soil\_h} := P_{E\_soil\_h}\cdot y_{E\_soil\_h} = 101.54\cdot kN\cdot m$$

7.0 GRAVITY LOADS

7.1 Weight of Concrete

Weight of Wall footing/base

$$W_{conc} := \gamma_c\cdot\left(t_{base}\cdot L_{base} + L_{stem}\cdot t_{stem} + t_{key}\cdot h_{key}\right)\cdot b = 88.13\cdot kN$$

Resultant location

$$x_{conc} := \frac{\left[\frac{1}{2}t_{base}\cdot L_{base}{}^2 + L_{stem}\cdot t_{stem}\cdot\left(L_{toe} + 0.5t_{stem}\right) \ldots \atop + t_{key}\cdot h_{key}\cdot\left(L_{base} - 0.5t_{key}\right)\right]}{t_{base}\cdot L_{base} + L_{stem}\cdot t_{stem} + t_{key}\cdot h_{key}} = 1.64\ m$$

$$y_{conc} := \frac{\left[\frac{1}{2} t_{base}{}^{2} \cdot L_{base} + L_{stem} \cdot t_{stem} \cdot \left(\frac{1}{2} L_{stem} + t_{base}\right) \cdots \\ + t_{key} \cdot h_{key} \cdot \left(-0.5 t_{key}\right)\right]}{t_{base} \cdot L_{base} + L_{stem} \cdot t_{stem} + t_{key} \cdot h_{key}} = 0.82\,\mathrm{m}$$

Moment about Toe $M_{conc} := W_{conc} \cdot x_{conc} = 144.11 \cdot kN \cdot m$

7.2 Weight of Soil on Heel

Weight of Soil on heel

$$W_{soil\_h} := b \cdot L_{heel} \cdot \begin{cases} (\gamma_{soilsat} - \gamma_w) \cdot (EL_B - EL_C) & \text{if } EL_B < EL_{hw} \\ \gamma_{soilm} \cdot (EL_B - EL_{hw}) + (\gamma_{soilsat} - \gamma_w) \cdot \max[0, (EL_{hw} - EL_C)] & \text{otherwise} \end{cases}$$

$$W_{soil\_h} = 110 \cdot kN$$

Resultant location $x_{s\_h} := 0.5(x_B - x_G) + x_G = 2.25 \cdot m$

$y_{s\_h} := 0.5(EL_B - EL_C) + t_{base} = 1.88 \cdot m$

Moment about Toe $M_{soilw\_h} := W_{soil\_h} \cdot x_{s\_h} = 247.5 \cdot kN \cdot m$

7.3 Weight of Water on Heel

Weight of Water on heel $W_{w\_h} := \gamma_w \cdot \max[0kip, (EL_{hw} - EL_C)] \cdot L_{heel} \cdot b = 0 \cdot kN$

Resultant location $x_{w\_h} := 0.5(x_B - x_G) + x_G = 2.25 \cdot m$

$y_{w\_h} := 0.5(EL_{hw} - EL_C) + t_{base} = 0.5 \cdot m$

Moment about Toe $M_{w\_h} := W_{w\_h} \cdot x_{w\_h} = 0 \cdot kN \cdot m$

7.4 Weight of Soil on Toe

Weight of Soil on toe Note: Water and soil elevations MUST NOT be below footing elevation

$$W_{soil\_t} := b \cdot L_{toe} \cdot \begin{cases} (\gamma_{soilsat} - \gamma_w) \cdot (\max(0, EL_F - EL_C)) & \text{if } EL_F < EL_{tw} \\ \gamma_{soilm} \cdot \max(0, EL_F - EL_{tw}) + (\gamma_{soilsat} - \gamma_w) \cdot \max(EL_{tw} - EL_C, 0) & \text{otherwise} \end{cases}$$

$$W_{soil\_t} = 5 \cdot kN$$

Resultant location $x_{s\_t} := 0.5(x_H - x_E) = 0.38 \cdot m$

$y_{s\_t} := 0.5(EL_F - EL_C) + t_{base} = 0.67 \cdot m$

Moment about Toe $M_{soilw\_t} := W_{soil\_t} \cdot x_{s\_t} = 1.9 \cdot kN \cdot m$

7.5 Weight of Water on Toe

Weight of Water on toe $W_{w\_t} := \gamma_w \cdot \max[0kip, (EL_{tw} - EL_C)] \cdot L_{toe} \cdot b = 0 \cdot kN$

Resultant location $x_{w\_t} := 0.5(x_H - x_E) = 0.38 \cdot m$

$y_{w\_t} := 0.5(EL_{tw} - EL_C) + t_{base} = 0.5 \cdot m$

Moment about Toe $M_{w\_t} := W_{w\_t} \cdot x_{w\_t} = 0 \cdot kN \cdot m$

7.6 Weight of Soil under Footing and Above Failure Plane EJ

Depth of Soil Wedge Near Key $h_{s\_under} := (x_L - x_E)\cdot\frac{h_{key}}{L_{base}} = 1.29\,m$

Length of Soil Wedge $L_{s\_under} := x_L - x_E = 2.8\,m$

Weight of Soil Wedge Under Footing $W_{s\_under} := \gamma_{soilsat}\cdot(0.5\cdot h_{s\_under}\cdot L_{s\_under})\cdot b = 36.18\cdot kN$

Resultant location $x_{s\_under} := \frac{2}{3}(x_L - x_E) = 1.87\cdot m$

$y_{s\_under} := \frac{1}{3}h_{key} = 0.5\cdot m$

Moment about Toe $M_{s\_under} := W_{s\_under}\cdot x_{s\_under} = 67.5\cdot kN\cdot m$

7.7 Seismic Inertial Moments from Gravity Loads

Concrete

Due to vertical component $M_{Ev\_conc} := k_v\cdot W_{conc}\cdot x_{conc} = -4.32\cdot kN\cdot m$

Due to horizontal component $M_{Eh\_conc} := k_h\cdot W_{conc}\cdot y_{conc} = 13.76\cdot kN\cdot m$

Soils on Heel

Due to vertical component $M_{Ev\_soilw\_h} := k_v\cdot W_{soil\_h}\cdot x_{s\_h} = -7.42\cdot kN\cdot m$

Due to horizontal component $M_{Eh\_soilw\_h} := k_h\cdot W_{soil\_h}\cdot y_{s\_h} = 39.19\cdot kN\cdot m$

Soils on Toe

Due to vertical component $M_{Ev\_soilw\_t} := k_v\cdot W_{soil\_t}\cdot x_{s\_t} = -0.06\cdot kN\cdot m$

Due to horizontal component $M_{Eh\_soilw\_t} := k_h\cdot W_{soil\_t}\cdot y_{s\_t} = 0.63\cdot kN\cdot m$

Soil Under Base

Due to vertical component $M_{Ev\_s\_under} := k_v\cdot W_{s\_under}\cdot x_{s\_under} = -2.03\cdot kN\cdot m$

Due to horizontal component $M_{Eh\_s\_under} := k_h\cdot W_{s\_under}\cdot(-y_{s\_under}) = -3.44\cdot kN\cdot m$

Water on Heel

Due to vertical component $M_{Ev\_w\_h} := k_v\cdot W_{w\_h}\cdot x_{w\_h} = 0\cdot kN\cdot m$

Due to horizontal component $M_{Eh\_w\_h} := k_h\cdot W_{w\_h}\cdot y_{w\_h} = 0\cdot kN\cdot m$

Water on Toe

Due to vertical component $M_{Ev\_w\_t} := k_v \cdot W_{w\_t} \cdot x_{w\_t} = 0 \cdot kN \cdot m$

Due to horizontal component $M_{Eh\_w\_t} := k_h \cdot W_{w\_t} \cdot y_{w\_t} = 0 \cdot kN \cdot m$

Total Moment due to Horizontal Seismic Coefficient:

$$M_{EQ\_h} := M_{Eh\_conc} + M_{Eh\_soilw\_h} + M_{Eh\_soilw\_t} + M_{Eh\_s\_under} + M_{Eh\_w\_h} + M_{Eh\_w\_t} = 50.14 \cdot kN \cdot m$$

Total Moment due to Vertical Seismic Coefficient:

$$M_{EQ\_v} := M_{Ev\_conc} + M_{Ev\_soilw\_h} + M_{Ev\_soilw\_t} + M_{Ev\_s\_under} + M_{Ev\_w\_h} + M_{Ev\_w\_t} = -13.83 \cdot kN \cdot m$$

Net Seismic Moment $M_{EQ} := M_{EQ\_v} - M_{EQ\_h} - M_{E\_soil\_h} + M_{E\_soil\_t} = -165.15 \cdot kN \cdot m$

8.0 Overturning Stability Assessment - See Figure 2

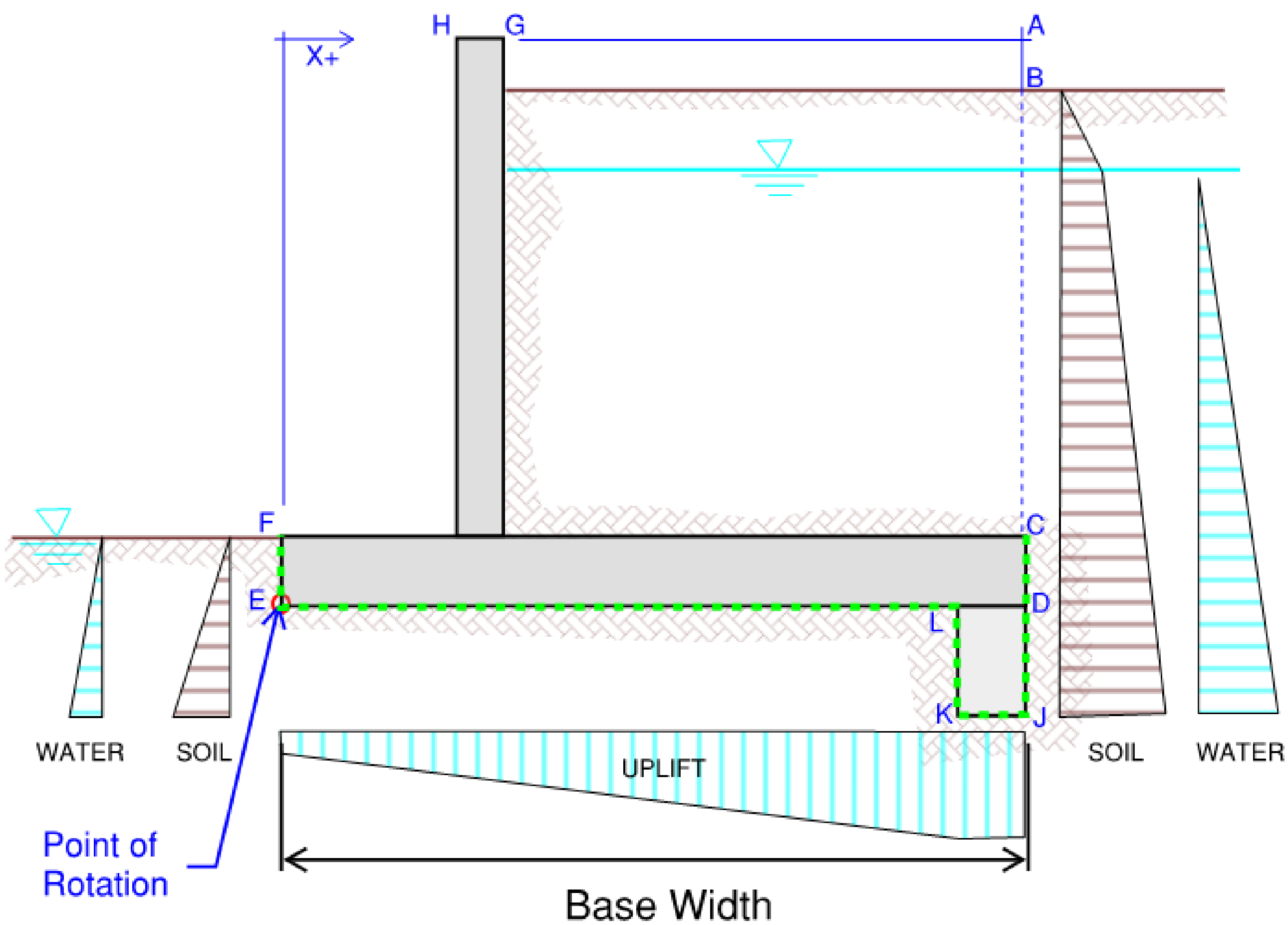


Figure 2. Free Body Diagram for Overturning Analysis

Uplift loads for Overturning

$$P_{u\_ot} := \left[\frac{1}{2}\left(u_h + u_t\right)\cdot\left(x_L - x_E\right) + u_h\cdot t_{key}\right]\cdot b = 43.16\cdot kN$$

Uplift resultant location

$$x_{u\_ot} := \frac{\left[\left[\frac{x_L - x_E}{2} + \frac{x_L - x_E}{6}\cdot\frac{\left(u_h - u_t\right)}{u_t + u_h}\right]\cdot\left[\frac{1}{2}\left(u_h + u_t\right)\cdot\left(x_L - x_E\right)\right] \cdots + \left(L_{base} - 0.5t_{key}\right)\cdot\left(u_h\cdot t_{key}\right)\right]}{\left[\frac{1}{2}\left(u_h + u_t\right)\cdot\left(x_L - x_E\right) + u_h\cdot t_{key}\right]}$$

$$x_{u\_ot} = 1.96\,m$$

Uplift Moment about Toe

$$M_{u\_ot} := P_{u\_ot}\cdot x_{u\_ot} = 84.4\cdot kN\cdot m$$

Vertical Seismic Loads

$$EQ_v := k_v\cdot\left(W_{conc} + W_{soil\_h} + W_{soil\_t} \cdots + W_{w\_h} + W_{w\_t}\right) = -6.09\cdot kN$$

Horizontal Seismic Loads

$$EQ_h := k_h\cdot\left(W_{conc} + W_{soil\_h} + W_{soil\_t} \cdots + W_{w\_h} + W_{w\_t}\right) = 38.59\cdot kN$$

Total Vertical Forces

$$\Sigma V_{ot} := W_{conc} + W_{soil\_h} + W_{soil\_t} \cdots + W_{w\_h} + W_{w\_t} - P_{u\_ot} + EQ_v = 153.9\cdot kN$$

Total Horizontal Forces

$$\Sigma H_{ot} := P_{hw} + P_{soil\_h} + P_{sur} - P_{tw} - P_{soil\_t} \cdots + P_{E\_soil\_t} + P_{E\_soil\_h} + EQ_h = 220.17\cdot kN$$

Total Resisting Moments - Static

$$\Sigma M_{r\_ot} := M_{conc} + M_{soilw\_h} + M_{w\_h} \cdots + M_{soilw\_t} + M_{w\_t} = 393.5\cdot kN\cdot m$$

Total Driving Moments - Static

$$\Sigma M_{d\_ot} := M_{hw} + M_{soil\_h} + M_{sur} + M_{u\_ot} \cdots + M_{tw} + M_{soil\_t} = 118.9\cdot kN\cdot m$$

Resultant Location from Toe

$$x_{r\_ot} := \frac{\Sigma M_{r\_ot} - \Sigma M_{d\_ot} + M_{EQ}}{\Sigma V_{ot}} = 0.71\cdot m$$

Normalized Resultant Location

$$\frac{x_{r\_ot}}{L_{base}} = 0.219$$

Eccentricity

$$e_{x\_ot} := \frac{L_{base}}{2} - x_{r\_ot} = 0.91\cdot m$$

Approx. Base in Compression $l_{comp\_ot} := \min\left[L_{base}, \frac{3}{2}\cdot\left(L_{base} - 2\cdot e_{x\_ot}\right)\right] = 2.13\cdot m$

Percent Base in Compression $Base\_Comp := \left(\frac{l_{comp\_ot}}{L_{base}}\right) = 65.7\cdot\%$

Resultant Location Check $check_{res} := if\left(Base\_Comp \geq Base\_Comp_{Req}, \text{"OK"}, \text{"NG"}\right) = \text{"OK"}$

9.0 Flotation Stability Assessment - See Figure 2

Calculated Flotation Safety Factor $FS_f := \frac{W_{conc} + W_{soil\_h} + W_{soil\_t} + W_{w\_h} + W_{w\_t} + EQ_v}{P_{u\_ot}} = 4.6$

Flotation Stability Check $check_{floatation} := if\left(FS_f \geq FS_{float}, \text{"OK"}, \text{"NG"}\right) = \text{"OK"}$

10.0 Sliding Stability Assessment - See Figure 3

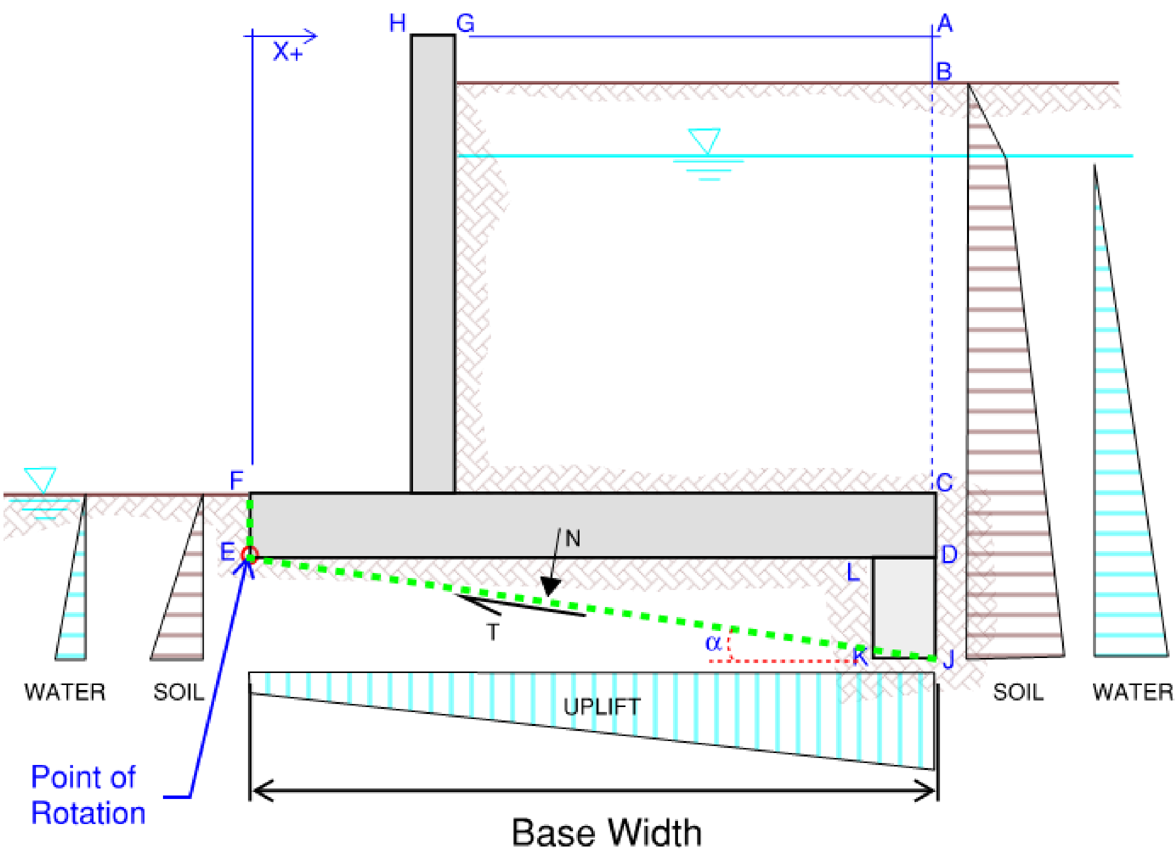


Figure 3. Free Body Diagram for Sliding Analysis

Length of Sliding Failure Plane, EJ $L_{fp} := \sqrt{{L_{base}}^2 + {h_{key}}^2} = 3.58\,m$

Angle of Sliding Failure Plane From Horizontal $\alpha := \operatorname{atan}\left(\frac{h_{key}}{L_{base}}\right) = 24.8 \cdot deg$

Total Vertical Forces $\Sigma V := W_{conc} + W_{soil\_h} + W_{soil\_t} \cdots + W_{w\_h} + W_{s\_under} + W_{w\_t} - P_u + EQ_v = 193.4 \cdot kN$

Total Horizontal Forces $\Sigma H := P_{hw} + P_{soil\_h} + P_{sur} - P_{tw} - P_{soil\_t} + EQ_h = 140.16 \cdot kN$

Total Resisting Moments - Static $\Sigma M_r := M_{conc} + M_{soilw\_h} + M_{w\_h} \cdots + M_{soilw\_t} + M_{w\_t} + M_{s\_under} = 461\ m \cdot kN$

Total Driving Moments - Static $\Sigma M_d := M_{hw} + M_{soil\_h} + M_{sur} + M_u \cdots + M_{tw} + M_{soil\_t} = 112.2 \cdot kN \cdot m$

Normal Force on Sliding Failure Plane: $N_s := \Sigma H \cdot \sin(\alpha) + \Sigma V \cdot \cos(\alpha) = 234.3 \cdot kN$

Tangential Force on Sliding Failure Plane: $T_s := \Sigma H \cdot \cos(\alpha) - \Sigma V \cdot \sin(\alpha) = 46.23 \cdot kN$

Calculated Sliding Safety Factor $\boxed{FS_s := \frac{N_s \cdot \tan(0.95\phi_{soil})}{T_s} = 2.13}$

Sliding Stability Check $check_{sliding} := \text{if}\left(FS_s \geq FS_{Sliding}, \text{"OK"}, \text{"NG"}\right) = \text{"OK"}$

11.0 Bearing Capacity Assessment

Resultant Location from Toe $x_r := \frac{\Sigma M_r - \Sigma M_d + M_{EQ}}{N_s} = 0.78 \cdot m$

Eccentricity of N_s from center of base $e_s := \frac{L_{fp}}{2} - x_r = 1.01 \cdot m$

Approx. Base in Compression $l_{comp.s} := \min\left[L_{fp}, \frac{3}{2} \cdot \left(L_{fp} - 2 \cdot e_s\right)\right] = 2.35 \cdot m$

Updated Eccentricity $e_x := \frac{l_{comp.s} - L_{fp}}{2} + e_s = 0.39 \cdot m$

Effective base pressure at Toe $q_t := \left(\frac{N_s}{l_{comp.s} \cdot b}\right) \cdot \left(1 + \frac{6 \cdot e_x}{l_{comp.s}}\right) = 199.23 \cdot kPa$

Effective base pressure at Heel $q_h := \max\left[\left(\frac{N_s}{l_{comp.s} \cdot b}\right) \cdot \left(1 - \frac{6 \cdot e_x}{l_{comp.s}}\right), 0\right] = 0.00 \cdot kPa$

Calculated Bearing Safety Factor $FS_b := \frac{Q_b}{\max(q_t, q_h)} = 2.26$

Bearing Pressure Check $check_{bearing} := if(FS_b \geq FS_{Bearing}, "OK", "NG") = "OK"$

12.0 Summary of Stability Assessments

Base Compression / Resultant Location $Base\_Comp = 65.7 \cdot \%$

Flotation Stability $FS_f = 4.6$

Sliding Stability $FS_s = 2.1$

Bearing Pressure $FS_b = 2.3$

STABILITY ANALYSIS FOR CANTILEVER WALL WITH KEY

Project / Client: Springbank Off-Stream Storage (SR1) / Alberta Transportation

Section Location: Intake Structure Wing Wall - Closest to Intake Structure

1.0 OBJECTIVE

For a particular load condition, analyze a reinforced concrete cantilever wall with shear key for overturning, sliding, flotation, and bearing capacity in accordance with criteria described in the listed references.

2.0 BACKGROUND INFORMATION

2.1 DATA SOURCES

1- Soils Report - Recommended Geotechnical Soil Parameters, SR-1 Low Level Outlet (LLO) Structures. July 19, 2019

2- Drawings - Design Drawings

3- Springbank Off-Stream Storage Project - Design Basis Memorandum (DBM) , 2019

2.2 REFERENCES

1. (CDA) Dam Safety Guidelines, 2007 (revised 2013).

2. "Water Control Structures Selected Design Guidelines," Alberta Transportation & Alberta Environment, Calgary Alberta, November 2004.

3.0 DESIGN PARAMETERS AND CRITERIA

3.1 Stability Analysis Criteria (Data source 2)

Load Case	$LC := 4$ $EQ := 3$
Load Case Description	$vlookup(LC, CASES, 1)_0 = $ "Earthquake"
Sliding Minimum Factor of Safety	$FS_{Sliding} := vlookup(LC, CASES, 2)_0 = 1$
Overturning Criteria	$Base\_Comp_{Req} := vlookup(LC, CASES, 3)_0 = 0.1 \cdot \%$
Bearing Capacity Minimum Factor of Safety	$FS_{Bearing} := vlookup(LC, CASES, 4)_0 = 1$
Flotation Minimum Factor of Safety	$FS_{float} := vlookup(LC, CASES, 5)_0 = 1$

3.2 Applied Loads

Heel side water elevation $EL_{hw} := \text{vlookup}(LC, WaterEL, 1)_0 \cdot 1m = 1187\,m$ Data Source 2

Toe side water elevation $EL_{tw} := \text{vlookup}(LC, WaterEL, 2)_0 \cdot 1m = 1187\,m$

Equivalent soil surcharge $h_{sur} := \begin{cases} 1.0m & \text{if } LC = 2 \\ 0 & \text{otherwise} \end{cases} = 0 \cdot m$

Horizontal Seismic Coefficient $k_h := \begin{cases} \text{vlookup}(EQ, CASES_{eq}, 1)_0 & \text{if } LC = 4 \\ 0 & \text{otherwise} \end{cases} = 0.19$

Vertical Seismic Coefficient $k_v := \begin{cases} \text{vlookup}(EQ, CASES_{eq}, 2)_0 & \text{if } LC = 4 \\ 0 & \text{otherwise} \end{cases} = -0.03$

3.3 Material Properties - Data Source 1 Unless Otherwise Noted

Unit Weight of Water $\gamma_w := 9.81 \frac{kN}{m^3}$

Unit Weight of Concrete $\gamma_c := 23.5 \cdot \frac{kN}{m^3}$ Data Source 3

Unit Weight of Soil (Moist) $\gamma_{soilm} := 20 \frac{kN}{m^3}$

Soil Unit Weight Beneath Base (Saturated) $\gamma_{soilsat} := 20 \frac{kN}{m^3}$

Soil Cohesion - Drained $c_{soil} := 0kPa$

Soil Angle of Internal Friction - Drained $\phi_{soil} := 24deg$

Soil Ultimate Bearing Pressure $Q_b := 450kPa$

Slope of backfill (Conservative) $\beta := 0$

At-rest lateral earth pressure coefficient $k_o := 1 - \sin(\phi_{soil}) = 0.59$

4.0 WALL SECTION DESCRIPTION

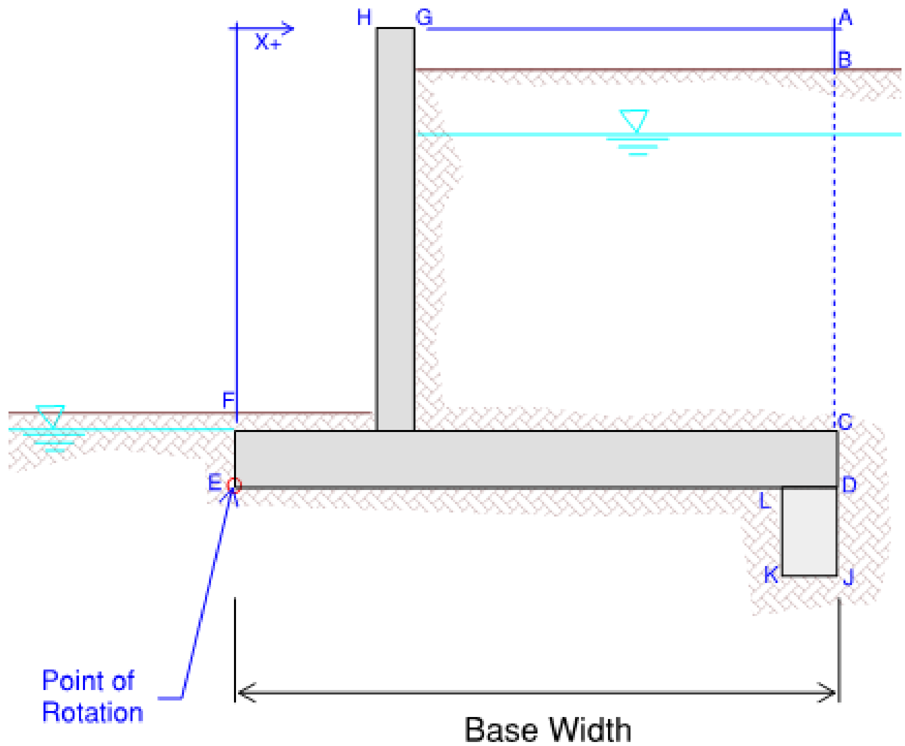


Figure 1. Cantilever Wall Section

4.1 Point Locations (Refer to Figure 1 and Drawings)

A - Top of wall	$EL_A := 1189.9m$	$x_A := 3.25m$
B - Top of fill - reservoir side	$EL_B := 1189.75m$	$x_B := x_A = 3.25 \cdot m$
C - Top of Heel	$EL_C := 1187m$	$x_C := x_A = 3.25 \cdot m$
D - Heel side end of footing	$EL_D := EL_C - 500mm = 1186.50\ m$	$x_D := x_A = 3.25 \cdot m$
E - Toe side end of footing	$EL_E := EL_D = 1186.50 \cdot m$	$x_E := 0m$
F - Top of Fill - land side	$EL_F := EL_C + 333mm = 1187.33 \cdot m$	$x_F := x_E = 0$
G - Heel side face of wall stem	$EL_G := EL_A = 1189.90 \cdot m$	$x_G := 1.25m$
H - Toe side face of wall stem	$EL_H := EL_A = 1189.90 \cdot m$	$x_H := x_G - 0.500m = 0.75 \cdot m$

J - Bottom of key - heel side	$EL_J := EL_C - 2m = 1185.00 \cdot m$	$x_J := x_D = 3.25\,m$
K - Bottom of key - toe side	$EL_K := EL_J = 1185.00 \cdot m$	$x_K := x_J - 450mm = 2.8 \cdot m$
L - Top of key	$EL_L := EL_D = 1186.50 \cdot m$	$x_L := x_K = 2.8\,m$

4.2 Additional Analysis Dimensions

Analysis Width	$b := 1m$
Length of base	$L_{base} := x_D - x_E = 3.25 \cdot m$
Thickness of base	$t_{base} := EL_C - EL_D = 500 \cdot mm$
Length of stem	$L_{stem} := EL_A - EL_C = 2900 \cdot mm$
Thickness of stem	$t_{stem} := x_G - x_H = 500 \cdot mm$
Length of Heel	$L_{heel} := x_A - x_G = 2000 \cdot mm$
Length of Toe	$L_{toe} := x_H - x_F = 750 \cdot mm$
Thickness of Key	$t_{key} := x_J - x_K = 450 \cdot mm$
Height of Key	$h_{key} := EL_D - EL_J = 1500 \cdot mm$

5.0 UPLIFT & HYDROSTATIC LOADS

5.1 Uplift Pressures for Stability Analyses

Determine water pressures for designated coordinates using full headwater uplift pressure at the heel and full tailwater uplift pressure at the toe. Uplift distribution is assumed linear from heel to toe.

Hydrostatic pressure at Heel $\quad u_h := \gamma_w \cdot (EL_{hw} - EL_J) = 20 \cdot kPa$

Hydrostatic pressure at Toe $\quad u_t := \gamma_w \cdot (EL_{tw} - EL_E) = 5 \cdot kPa$

Total uplift loads on base $\quad P_u := \frac{(u_h + u_t)}{2} \cdot L_{base} \cdot b = 39.85 \cdot kN$

Uplift resultant location $\quad x_u := \frac{L_{base}}{2} + \frac{L_{base}}{6} \cdot \frac{(u_h - u_t)}{u_t + u_h} = 1.95 \cdot m$

Uplift Moment about Toe $\quad M_u := P_u \cdot x_u = 77.7 \cdot kN \cdot m$

5.2 Headwater Hydrostatic Load - Heel Side

Headwater hydrostatic load $P_{hw} := \frac{1}{2} u_h \cdot (EL_{hw} - EL_J) \cdot b = 19.6 \cdot kN$

Headwater moment arm $y_{hw} := \frac{1}{3}(EL_{hw} - EL_J) - h_{key} = -0.83 \cdot m$

Headwater Moment about Toe $M_{hw} := P_{hw} \cdot y_{hw} = -16.4 \cdot kN \cdot m$

5.3 Tailwater Hydrostatic Load - Toe Side

Tailwater hydrostatic load $P_{tw} := \frac{1}{2} \gamma_w \cdot (EL_{tw} - EL_K)^2 \cdot b = 19.62 \cdot kN$

Tailwater moment arm $y_{tw} := h_{key} - \frac{1}{3}(EL_{tw} - EL_K) = 0.83 \cdot m$

Tailwater Moment about Toe $M_{tw} := P_{tw} \cdot y_{tw} = 16.35 \cdot kN \cdot m$

6.0 LATERAL EARTH PRESSURE

6.1 Lateral Soil Load on Toe Side

Soil pressure at Saturation Level

$$p_{tw} := \begin{cases} k_o \cdot \gamma_{soilm} \cdot (EL_F - EL_{tw}) & \text{if } EL_F > EL_{tw} \\ 0psf & \text{otherwise} \end{cases} = 4.0 \cdot kPa$$

Soil pressure at Toe - base elevation

$$p_E := \begin{cases} p_{tw} + k_o \cdot (\gamma_{soilsat} - \gamma_w) \cdot (EL_{tw} - EL_J) & \text{if } EL_F > EL_{tw} \\ k_o \cdot (\gamma_{soilsat} - \gamma_w) \cdot (EL_F - EL_J) & \text{otherwise} \end{cases}$$

$$p_E = 16.04 \cdot kPa$$

Total soil loads on Wall

$$P_{soil\_t} := \left[0.5 \cdot (EL_F - EL_{tw}) \cdot p_{tw} + p_{tw} \cdot (EL_{tw} - EL_J) \ldots + 0.5 \cdot (p_E - p_{tw}) \cdot (EL_{tw} - EL_J) \right] \cdot b = 20.65 \cdot kN$$

Resultant location

$$y_{soil\_t} := \begin{cases} 0 & \text{if } P_{soil\_t} = 0 \\ h_{key} - \dfrac{\left[0.5 \cdot (EL_F - EL_{tw}) \cdot p_{tw} \cdot \left[(EL_{tw} - EL_J) + \frac{1}{3}(EL_F - EL_{tw}) \right] + p_{tw} \cdot \frac{1}{2} (EL_{tw} - EL_J)^2 \ldots + 0.5 \cdot (p_E - p_{tw}) \cdot (EL_{tw} - EL_J)^2 \cdot \frac{1}{3} \right] \cdot b}{P_{soil\_t}} & \text{otherwise} \end{cases}$$

$$y_{soil\_t} = 0.66 \cdot m$$

Moment about Toe $M_{soil\_t} := P_{soil\_t} \cdot y_{soil\_t} = 13.62 \cdot kN \cdot m$

6.2 Lateral Soil Load on Heel Side

Soil pressure at Saturation Level

$$p_{hw} := \begin{cases} k_o \cdot \gamma_{soilm} \cdot (EL_B - EL_{hw}) & \text{if } EL_B > EL_{hw} \\ 0psf & \text{otherwise} \end{cases} = 32.6 \cdot kPa$$

Soil pressure at Heel - base elevation

$$p_D := \begin{cases} p_{hw} + k_o \cdot (\gamma_{soilsat} - \gamma_w) \cdot (EL_{hw} - EL_J) & \text{if } EL_B > EL_{hw} \\ k_o \cdot (\gamma_{soilsat} - \gamma_w) \cdot (EL_B - EL_J) & \text{otherwise} \end{cases}$$

$$p_D = 44.72 \cdot kPa$$

Total soil loads on Base

$$P_{soil\_h} := \left[0.5 \cdot (EL_B - EL_{hw}) \cdot p_{hw} + p_{hw} \cdot (EL_{hw} - EL_J) \dots + 0.5 \cdot (p_D - p_{hw}) \cdot (EL_{hw} - EL_J) \right] \cdot b$$

$$P_{soil\_h} = 122.22 \cdot kN$$

Resultant location

$$y_{soil\_h} := \frac{\left[0.5 \cdot (EL_B - EL_{hw}) \cdot p_{hw} \cdot \left[EL_{hw} - EL_J + \frac{1}{3}(EL_B - EL_{hw}) \right] + p_{hw} \cdot \frac{1}{2} (EL_{hw} - EL_J)^2 \dots + 0.5 \cdot (p_D - p_{hw}) \cdot (EL_{hw} - EL_J)^2 \cdot \frac{1}{3} \right] \cdot b}{P_{soil\_h}} - h_{key}$$

$$y_{soil\_h} = 0.17 \cdot m$$

Moment about Toe

$$M_{soil\_h} := P_{soil\_h} \cdot y_{soil\_h} = 20.9 \cdot kN \cdot m$$

6.3 Surcharge Soil Load - Heel Side

Surcharge soil pressure

$$p_{sur} := k_o \cdot \gamma_{soilm} \cdot h_{sur} = 0 \cdot kPa$$

Soil load on wall

$$P_{sur} := p_{sur} \cdot (EL_B - EL_J) \cdot b = 0 \cdot kN$$

Resultant location

$$y_{sur} := \frac{1}{2} \cdot (EL_B - EL_J) - h_{key} = 0.88\, m$$

Moment about Toe

$$M_{sur} := P_{sur} \cdot y_{sur} = 0 \cdot kN \cdot m$$

6.4 Seismic Lateral Soil Load on Toe Side - Woods Method (Data Source 3)

Weighted Average of unit weights

$$\gamma_{EQ\_t} := \frac{\left[\gamma_{soilsat}\cdot\left(EL_F - EL_{tw}\right) + \left(\gamma_{soilsat} - \gamma_w\right)\cdot\left(EL_{tw} - EL_J\right)\right]}{\left(EL_F - EL_J\right)}$$

$$\gamma_{EQ\_t} = 11.59\cdot\frac{kN}{m^3}$$

Seismic Lat. soil load on Wall

$$P_{E\_soil\_t} := \gamma_{EQ\_t}\cdot\left(EL_F - EL_J\right)^2\cdot b\cdot k_h = 11.99\cdot kN$$

Resultant location

$$y_{E\_soil\_t} := h_{key} - 0.63\left(EL_F - EL_J\right) = 0.03\ m$$

Moment about Toe

$$M_{E\_soil\_t} := P_{E\_soil\_t}\cdot y_{E\_soil\_t} = 0.36\cdot kN\cdot m$$

6.5 Seismic Lateral Soil Load on Heel Side - Woods Method (Data Source 3)

Weighted Average of unit weights

$$\gamma_{EQ\_h} := \frac{\left[\gamma_{soilsat}\cdot\left(EL_B - EL_{hw}\right) + \left(\gamma_{soilsat} - \gamma_w\right)\cdot\left(EL_{hw} - EL_J\right)\right]}{\left(EL_B - EL_J\right)}$$

$$\gamma_{EQ\_h} = 15.87\cdot\frac{kN}{m^3}$$

Seismic Lat. soil loads on Wal

$$P_{E\_soil\_h} := \gamma_{EQ\_h}\cdot\left(EL_B - EL_J\right)^2\cdot b\cdot k_h = 68.03\cdot kN$$

Resultant location

$$y_{E\_soil\_h} := 0.63\left(EL_B - EL_J\right) - h_{key} = 1.49\ m$$

Moment about Toe

$$M_{E\_soil\_h} := P_{E\_soil\_h}\cdot y_{E\_soil\_h} = 101.54\cdot kN\cdot m$$

7.0 GRAVITY LOADS

7.1 Weight of Concrete

Weight of Wall footing/base

$$W_{conc} := \gamma_c\cdot\left(t_{base}\cdot L_{base} + L_{stem}\cdot t_{stem} + t_{key}\cdot h_{key}\right)\cdot b = 88.13\cdot kN$$

Resultant location

$$x_{conc} := \frac{\left[\begin{array}{l}\frac{1}{2}t_{base}\cdot L_{base}{}^2 + L_{stem}\cdot t_{stem}\cdot\left(L_{toe} + 0.5t_{stem}\right)\ \ldots \\ + t_{key}\cdot h_{key}\cdot\left(L_{base} - 0.5t_{key}\right)\end{array}\right]}{t_{base}\cdot L_{base} + L_{stem}\cdot t_{stem} + t_{key}\cdot h_{key}} = 1.64\ m$$

$$y_{conc} := \frac{\left[\frac{1}{2}t_{base}^{2}\cdot L_{base} + L_{stem}\cdot t_{stem}\cdot\left(\frac{1}{2}L_{stem} + t_{base}\right) \cdots \atop + t_{key}\cdot h_{key}\cdot(-0.5t_{key})\right]}{t_{base}\cdot L_{base} + L_{stem}\cdot t_{stem} + t_{key}\cdot h_{key}} = 0.82\,m$$

Moment about Toe $M_{conc} := W_{conc}\cdot x_{conc} = 144.11\cdot kN\cdot m$

7.2 Weight of Soil on Heel

Weight of Soil on heel

$$W_{soil\_h} := b \cdot L_{heel} \cdot \begin{cases} (\gamma_{soilsat} - \gamma_w)\cdot(EL_B - EL_C) & \text{if } EL_B < EL_{hw} \\ \gamma_{soilm}\cdot(EL_B - EL_{hw}) + (\gamma_{soilsat} - \gamma_w)\cdot \max[0, (EL_{hw} - EL_C)] & \text{otherwise} \end{cases}$$

$$W_{soil\_h} = 110 \cdot kN$$

Resultant location $x_{s\_h} := 0.5(x_B - x_G) + x_G = 2.25 \cdot m$

$y_{s\_h} := 0.5(EL_B - EL_C) + t_{base} = 1.88 \cdot m$

Moment about Toe $M_{soilw\_h} := W_{soil\_h} \cdot x_{s\_h} = 247.5 \cdot kN \cdot m$

7.3 Weight of Water on Heel

Weight of Water on heel $W_{w\_h} := \gamma_w \cdot \max[0kip, (EL_{hw} - EL_C)] \cdot L_{heel} \cdot b = 0 \cdot kN$

Resultant location $x_{w\_h} := 0.5(x_B - x_G) + x_G = 2.25 \cdot m$

$y_{w\_h} := 0.5(EL_{hw} - EL_C) + t_{base} = 0.5 \cdot m$

Moment about Toe $M_{w\_h} := W_{w\_h} \cdot x_{w\_h} = 0 \cdot kN \cdot m$

7.4 Weight of Soil on Toe

Weight of Soil on toe Note: Water and soil elevations MUST NOT be below footing elevation

$$W_{soil\_t} := b \cdot L_{toe} \cdot \begin{cases} (\gamma_{soilsat} - \gamma_w)\cdot(\max(0, EL_F - EL_C)) & \text{if } EL_F < EL_{tw} \\ \gamma_{soilm}\cdot \max(0, EL_F - EL_{tw}) + (\gamma_{soilsat} - \gamma_w)\cdot \max(EL_{tw} - EL_C, 0) & \text{otherwise} \end{cases}$$

$$W_{soil\_t} = 5 \cdot kN$$

Resultant location $x_{s\_t} := 0.5(x_H - x_E) = 0.38 \cdot m$

$y_{s\_t} := 0.5(EL_F - EL_C) + t_{base} = 0.67 \cdot m$

Moment about Toe $M_{soilw\_t} := W_{soil\_t} \cdot x_{s\_t} = 1.9 \cdot kN \cdot m$

7.5 Weight of Water on Toe

Weight of Water on toe $W_{w\_t} := \gamma_w \cdot \max[0kip, (EL_{tw} - EL_C)] \cdot L_{toe} \cdot b = 0 \cdot kN$

Resultant location $x_{w\_t} := 0.5(x_H - x_E) = 0.38 \cdot m$

$y_{w\_t} := 0.5(EL_{tw} - EL_C) + t_{base} = 0.5 \cdot m$

Moment about Toe $M_{w\_t} := W_{w\_t} \cdot x_{w\_t} = 0 \cdot kN \cdot m$

7.6 Weight of Soil under Footing and Above Failure Plane EJ

Depth of Soil Wedge Near Key $h_{s\_under} := (x_L - x_E) \cdot \frac{h_{key}}{L_{base}} = 1.29\,m$

Length of Soil Wedge $L_{s\_under} := x_L - x_E = 2.8\,m$

Weight of Soil Wedge Under Footing $W_{s\_under} := \gamma_{soilsat} \cdot (0.5 \cdot h_{s\_under} \cdot L_{s\_under}) \cdot b = 36.18 \cdot kN$

Resultant location $x_{s\_under} := \frac{2}{3}(x_L - x_E) = 1.87 \cdot m$

$y_{s\_under} := \frac{1}{3} h_{key} = 0.5 \cdot m$

Moment about Toe $M_{s\_under} := W_{s\_under} \cdot x_{s\_under} = 67.5 \cdot kN \cdot m$

7.7 Seismic Inertial Moments from Gravity Loads

Concrete

Due to vertical component $M_{Ev\_conc} := k_v \cdot W_{conc} \cdot x_{conc} = -4.32 \cdot kN \cdot m$

Due to horizontal component $M_{Eh\_conc} := k_h \cdot W_{conc} \cdot y_{conc} = 13.76 \cdot kN \cdot m$

Soils on Heel

Due to vertical component $M_{Ev\_soilw\_h} := k_v \cdot W_{soil\_h} \cdot x_{s\_h} = -7.42 \cdot kN \cdot m$

Due to horizontal component $M_{Eh\_soilw\_h} := k_h \cdot W_{soil\_h} \cdot y_{s\_h} = 39.19 \cdot kN \cdot m$

Soils on Toe

Due to vertical component $M_{Ev\_soilw\_t} := k_v \cdot W_{soil\_t} \cdot x_{s\_t} = -0.06 \cdot kN \cdot m$

Due to horizontal component $M_{Eh\_soilw\_t} := k_h \cdot W_{soil\_t} \cdot y_{s\_t} = 0.63 \cdot kN \cdot m$

Soil Under Base

Due to vertical component $M_{Ev\_s\_under} := k_v \cdot W_{s\_under} \cdot x_{s\_under} = -2.03 \cdot kN \cdot m$

Due to horizontal component $M_{Eh\_s\_under} := k_h \cdot W_{s\_under} \cdot (-y_{s\_under}) = -3.44 \cdot kN \cdot m$

Water on Heel

Due to vertical component $M_{Ev\_w\_h} := k_v \cdot W_{w\_h} \cdot x_{w\_h} = 0 \cdot kN \cdot m$

Due to horizontal component $M_{Eh\_w\_h} := k_h \cdot W_{w\_h} \cdot y_{w\_h} = 0 \cdot kN \cdot m$

Water on Toe

Due to vertical component $M_{Ev\_w\_t} := k_v \cdot W_{w\_t} \cdot x_{w\_t} = 0 \cdot kN \cdot m$

Due to horizontal component $M_{Eh\_w\_t} := k_h \cdot W_{w\_t} \cdot y_{w\_t} = 0 \cdot kN \cdot m$

Total Moment due to Horizontal Seismic Coefficient:

$$M_{EQ\_h} := M_{Eh\_conc} + M_{Eh\_soilw\_h} + M_{Eh\_soilw\_t} + M_{Eh\_s\_under} + M_{Eh\_w\_h} + M_{Eh\_w\_t} = 50.14 \cdot kN \cdot m$$

Total Moment due to Vertical Seismic Coefficient:

$$M_{EQ\_v} := M_{Ev\_conc} + M_{Ev\_soilw\_h} + M_{Ev\_soilw\_t} + M_{Ev\_s\_under} + M_{Ev\_w\_h} + M_{Ev\_w\_t} = -13.83 \cdot kN \cdot m$$

Net Seismic Moment $M_{EQ} := M_{EQ\_v} - M_{EQ\_h} - M_{E\_soil\_h} + M_{E\_soil\_t} = -165.15 \cdot kN \cdot m$

8.0 Overturning Stability Assessment - See Figure 2

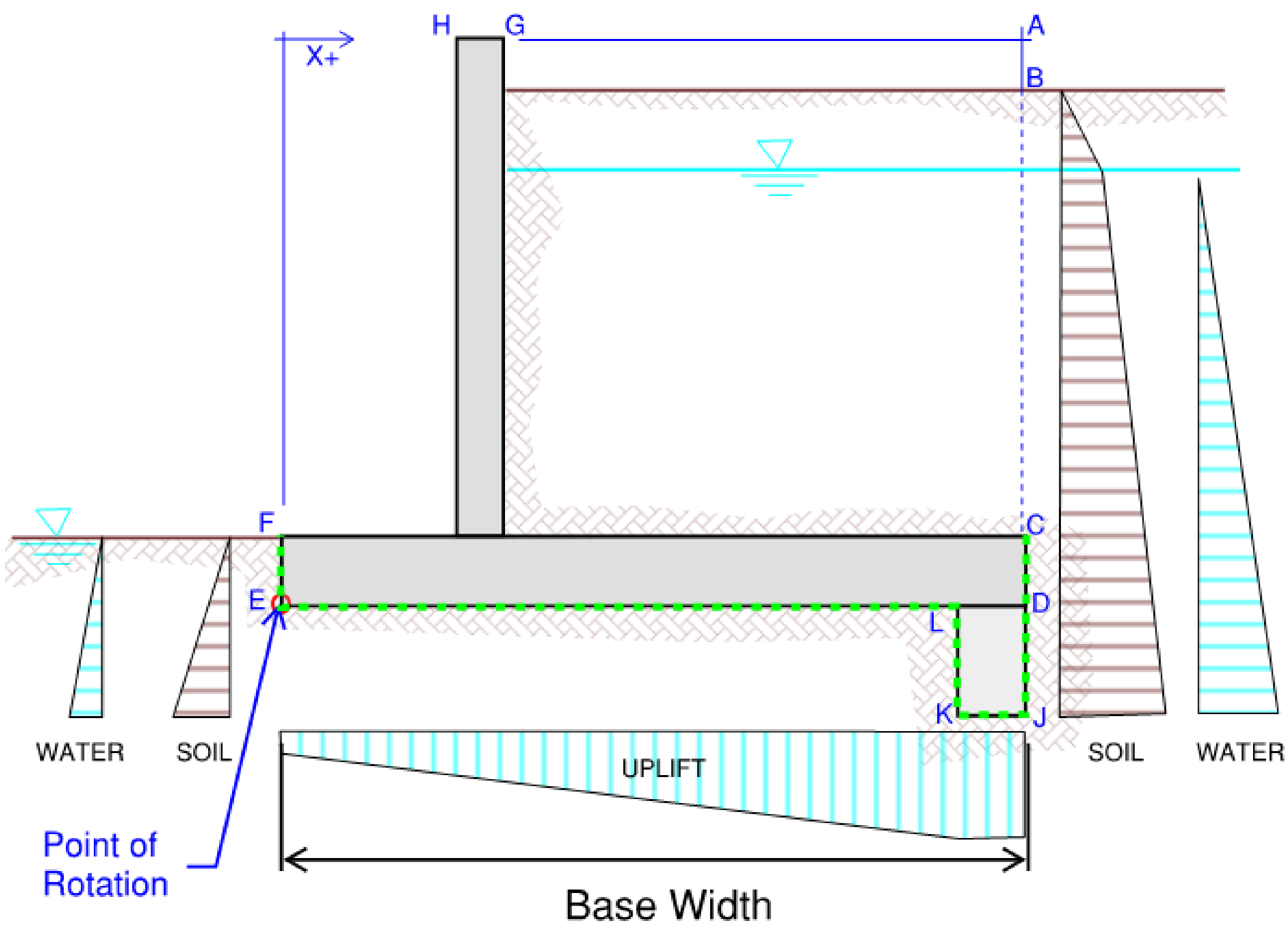


Figure 2. Free Body Diagram for Overturning Analysis

Uplift loads for Overturning

$$P_{u\_ot} := \left[\frac{1}{2}\left(u_h + u_t\right)\cdot\left(x_L - x_E\right) + u_h\cdot t_{key}\right]\cdot b = 43.16\cdot kN$$

Uplift resultant location

$$x_{u\_ot} := \frac{\left[\left[\frac{x_L - x_E}{2} + \frac{x_L - x_E}{6}\cdot\frac{\left(u_h - u_t\right)}{u_t + u_h}\right]\cdot\left[\frac{1}{2}\left(u_h + u_t\right)\cdot\left(x_L - x_E\right)\right] \cdots + \left(L_{base} - 0.5t_{key}\right)\cdot\left(u_h\cdot t_{key}\right)\right]}{\left[\frac{1}{2}\left(u_h + u_t\right)\cdot\left(x_L - x_E\right) + u_h\cdot t_{key}\right]}$$

$$x_{u\_ot} = 1.96\,m$$

Uplift Moment about Toe

$$M_{u\_ot} := P_{u\_ot}\cdot x_{u\_ot} = 84.4\cdot kN\cdot m$$

Vertical Seismic Loads

$$EQ_v := k_v\cdot\left(W_{conc} + W_{soil\_h} + W_{soil\_t} \cdots + W_{w\_h} + W_{w\_t}\right) = -6.09\cdot kN$$

Horizontal Seismic Loads

$$EQ_h := k_h\cdot\left(W_{conc} + W_{soil\_h} + W_{soil\_t} \cdots + W_{w\_h} + W_{w\_t}\right) = 38.59\cdot kN$$

Total Vertical Forces

$$\Sigma V_{ot} := W_{conc} + W_{soil\_h} + W_{soil\_t} \cdots + W_{w\_h} + W_{w\_t} - P_{u\_ot} + EQ_v = 153.9\cdot kN$$

Total Horizontal Forces

$$\Sigma H_{ot} := P_{hw} + P_{soil\_h} + P_{sur} - P_{tw} - P_{soil\_t} \cdots + P_{E\_soil\_t} + P_{E\_soil\_h} + EQ_h = 220.17\cdot kN$$

Total Resisting Moments - Static

$$\Sigma M_{r\_ot} := M_{conc} + M_{soilw\_h} + M_{w\_h} \cdots + M_{soilw\_t} + M_{w\_t} = 393.5\cdot kN\cdot m$$

Total Driving Moments - Static

$$\Sigma M_{d\_ot} := M_{hw} + M_{soil\_h} + M_{sur} + M_{u\_ot} \cdots + M_{tw} + M_{soil\_t} = 118.9\cdot kN\cdot m$$

Resultant Location from Toe

$$x_{r\_ot} := \frac{\Sigma M_{r\_ot} - \Sigma M_{d\_ot} + M_{EQ}}{\Sigma V_{ot}} = 0.71\cdot m$$

Normalized Resultant Location

$$\frac{x_{r\_ot}}{L_{base}} = 0.219$$

Eccentricity

$$e_{x\_ot} := \frac{L_{base}}{2} - x_{r\_ot} = 0.91\cdot m$$

Approx. Base in Compression $l_{comp\_ot} := \min\left[L_{base}, \frac{3}{2}\cdot\left(L_{base} - 2\cdot e_{x\_ot}\right)\right] = 2.13\cdot m$

Percent Base in Compression $Base\_Comp := \left(\frac{l_{comp\_ot}}{L_{base}}\right) = 65.7\cdot\%$

Resultant Location Check $check_{res} := if\left(Base\_Comp \geq Base\_Comp_{Req}, \text{"OK"}, \text{"NG"}\right) = \text{"OK"}$

9.0 Flotation Stability Assessment - See Figure 2

Calculated Flotation Safety Factor $FS_f := \frac{W_{conc} + W_{soil\_h} + W_{soil\_t} \cdots + W_{w\_h} + W_{w\_t} + EQ_v}{P_{u\_ot}} = 4.6$

Flotation Stability Check $check_{floatation} := if\left(FS_f \geq FS_{float}, \text{"OK"}, \text{"NG"}\right) = \text{"OK"}$

10.0 Sliding Stability Assessment - See Figure 3

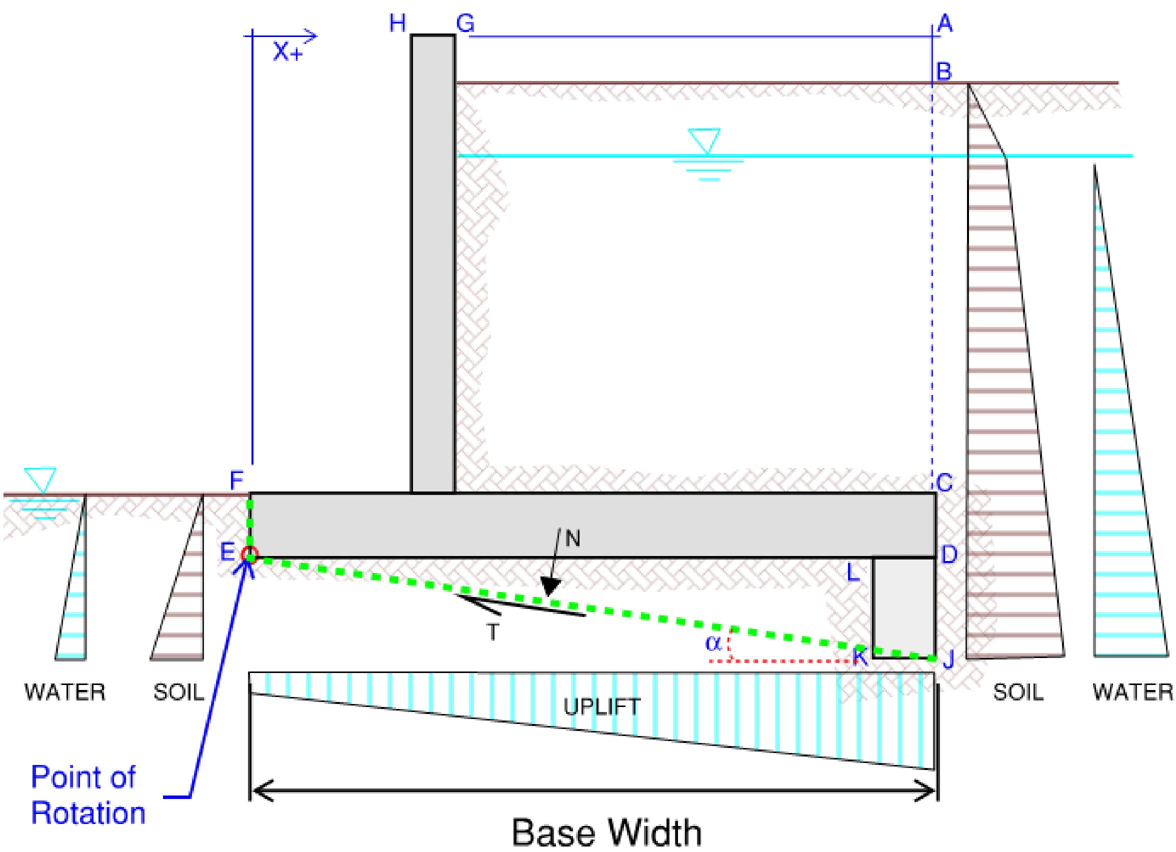


Figure 3. Free Body Diagram for Sliding Analysis

Length of Sliding Failure Plane, EJ $L_{fp} := \sqrt{L_{base}^{\,2} + h_{key}^{\,2}} = 3.58\,m$

Angle of Sliding Failure Plane From Horizontal $\alpha := \operatorname{atan}\left(\frac{h_{key}}{L_{base}}\right) = 24.8\cdot deg$

Total Vertical Forces $\Sigma V := W_{conc} + W_{soil\_h} + W_{soil\_t} \cdots + W_{w\_h} + W_{s\_under} + W_{w\_t} - P_u + EQ_v = 193.4\cdot kN$

Total Horizontal Forces $\Sigma H := P_{hw} + P_{soil\_h} + P_{sur} - P_{tw} - P_{soil\_t} + EQ_h = 140.16\cdot kN$

Total Resisting Moments - Static $\Sigma M_r := M_{conc} + M_{soilw\_h} + M_{w\_h} \cdots + M_{soilw\_t} + M_{w\_t} + M_{s\_under} = 461\ m\cdot kN$

Total Driving Moments - Static $\Sigma M_d := M_{hw} + M_{soil\_h} + M_{sur} + M_u \cdots + M_{tw} + M_{soil\_t} = 112.2\cdot kN\cdot m$

Normal Force on Sliding Failure Plane: $N_s := \Sigma H\cdot \sin(\alpha) + \Sigma V\cdot \cos(\alpha) = 234.3\cdot kN$

Tangential Force on Sliding Failure Plane: $T_s := \Sigma H\cdot \cos(\alpha) - \Sigma V\cdot \sin(\alpha) = 46.23\cdot kN$

Calculated Sliding Safety Factor $\boxed{FS_s := \frac{N_s\cdot \tan(0.95\phi_{soil})}{T_s} = 2.13}$

Sliding Stability Check $check_{sliding} := if\left(FS_s \ge FS_{Sliding}, \text{"OK"}, \text{"NG"}\right) = \text{"OK"}$

11.0 Bearing Capacity Assessment

Resultant Location from Toe $x_r := \frac{\Sigma M_r - \Sigma M_d + M_{EQ}}{N_s} = 0.78\cdot m$

Eccentricity of N_s from center of base $e_s := \frac{L_{fp}}{2} - x_r = 1.01\cdot m$

Approx. Base in Compression $l_{comp.s} := \min\left[L_{fp}, \frac{3}{2}\cdot\left(L_{fp} - 2\cdot e_s\right)\right] = 2.35\cdot m$

Updated Eccentricity $e_x := \frac{l_{comp.s} - L_{fp}}{2} + e_s = 0.39\cdot m$

Effective base pressure at Toe $q_t := \left(\frac{N_s}{l_{comp.s} \cdot b}\right) \cdot \left(1 + \frac{6 \cdot e_x}{l_{comp.s}}\right) = 199.23 \cdot kPa$

Effective base pressure at Heel $q_h := \max\left[\left(\frac{N_s}{l_{comp.s} \cdot b}\right) \cdot \left(1 - \frac{6 \cdot e_x}{l_{comp.s}}\right), 0\right] = 0.00 \cdot kPa$

Calculated Bearing Safety Factor $FS_b := \frac{Q_b}{\max(q_t, q_h)} = 2.26$

Bearing Pressure Check $check_{bearing} := if\left(FS_b \geq FS_{Bearing}, \text{"OK"}, \text{"NG"}\right) = \text{"OK"}$

12.0 Summary of Stability Assessments

Base Compression / Resultant Location $Base\_Comp = 65.7 \cdot \%$

Flotation Stability $FS_f = 4.6$

Sliding Stability $FS_s = 2.1$

Bearing Pressure $FS_b = 2.3$

STABILITY ANALYSIS FOR CANTILEVER WALL WITH KEY

Project / Client: Springbank Off-Stream Storage (SR1) / Alberta Transportation

Section Location: Intake Structure Wing Wall - Closest to Intake Structure

1.0 OBJECTIVE

For a particular load condition, analyze a reinforced concrete cantilever wall with shear key for overturning, sliding, flotation, and bearing capacity in accordance with criteria described in the listed references.

2.0 BACKGROUND INFORMATION

2.1 DATA SOURCES

1- Soils Report - Recommended Geotechnical Soil Parameters, SR-1 Low Level Outlet (LLO) Structures. July 19, 2019

2- Drawings - Design Drawings

3- Springbank Off-Stream Storage Project - Design Basis Memorandum (DBM) , 2019

2.2 REFERENCES

1. (CDA) Dam Safety Guidelines, 2007 (revised 2013).
2. "Water Control Structures Selected Design Guidelines," Alberta Transportation & Alberta Environment, Calgary Alberta, November 2004.

3.0 DESIGN PARAMETERS AND CRITERIA

3.1 Stability Analysis Criteria (Data source 2)

Load Case	$LC := 5$
Load Case Description	$\text{vlookup}(LC, CASES, 1)_0 = \text{"Post Earthquake"}$
Sliding Minimum Factor of Safety	$FS_{Sliding} := \text{vlookup}(LC, CASES, 2)_0 = 1.1$
Overturning Criteria	$Base\_Comp_{Req} := \text{vlookup}(LC, CASES, 3)_0 = 0.1 \cdot \%$
Bearing Capacity Minimum Factor of Safety	$FS_{Bearing} := \text{vlookup}(LC, CASES, 4)_0 = 1$
Flotation Minimum Factor of Safety	$FS_{float} := \text{vlookup}(LC, CASES, 5)_0 = 1.1$

3.2 Material Properties - Data Source 1 Unless Otherwise Noted

Unit Weight of Water	$\gamma_w := 9.81 \frac{kN}{m^3}$	
Unit Weight of Concrete	$\gamma_c := 23.5 \cdot \frac{kN}{m^3}$	Data Source 3
Unit Weight of Soil (Moist)	$\gamma_{soilm} := 20 \frac{kN}{m^3}$	
Soil Unit Weight Beneath Base (Saturated)	$\gamma_{soilsat} := 20 \frac{kN}{m^3}$	
Soil Cohesion - Drained	$c_{soil} := 0kPa$	
Soil Angle of Internal Friction - Drained	$\phi_{soil} := 24deg$	
Soil Allowable Bearing Pressure	$Q_b := 150kPa$	
Slope of backfill (Conservative)	$\beta := 0$	
At-rest lateral earth pressure coefficient	$k_o := 1 - \sin(\phi_{soil}) = 0.59$	

4.0 WALL SECTION DESCRIPTION

4.1 Point Locations (Refer to Figure 1 and Drawings)

A - Top of wall	$EL_A := 1189.9m$	$x_A := 3.25m$
B - Top of fill - reservoir side	$EL_B := 1189.75m$	$x_B := x_A = 3.25 \cdot m$
C - Top of Heel	$EL_C := 1187m$	$x_C := x_A = 3.25 \cdot m$
D - Heel side end of footing	$EL_D := EL_C - 500mm = 1186.50\ m$	$x_D := x_A = 3.25 \cdot m$
E - Toe side end of footing	$EL_E := EL_D = 1186.50 \cdot m$	$x_E := 0m$
F - Top of Fill - land side	$EL_F := EL_C + 0.333m = 1187.33 \cdot m$	$x_F := x_E = 0$
G - Heel side face of wall stem	$EL_G := EL_A = 1189.90 \cdot m$	$x_G := 1.25m$
H - Toe side face of wall stem	$EL_H := EL_A = 1189.90 \cdot m$	$x_H := x_G - 0.500m = 0.75 \cdot m$

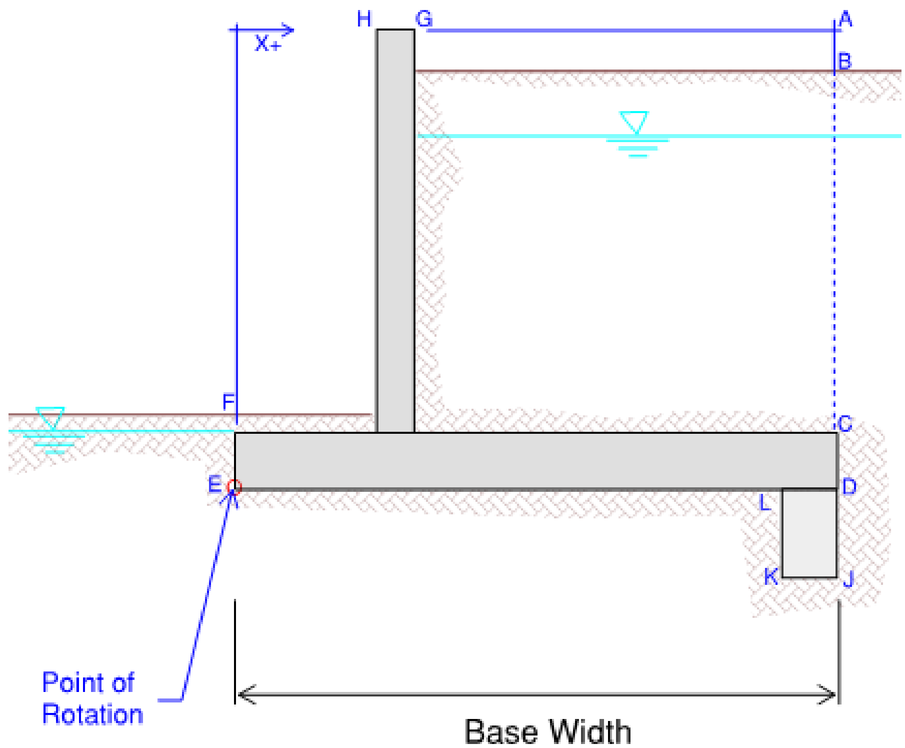


Figure 1. Cantilever Wall Section

J - Bottom of key - heel side $EL_J := EL_C - 2m = 1185.00 \cdot m$ $x_J := x_D = 3.25\,m$

K - Bottom of key - toe side $EL_K := EL_J = 1185.00 \cdot m$ $x_K := x_J - 450mm = 2.8 \cdot m$

L - Top of key $EL_L := EL_D = 1186.50 \cdot m$ $x_L := x_K = 2.8\,m$

Applied Loads Data Source 2

Heel side water elevation

$$EL_{hw} := \begin{cases} EL_B & \text{if } LC = 3 \\ (\text{vlookup}(LC, WaterEL, 1)_0 \cdot 1m) & \text{otherwise} \end{cases} = 1187$$

Toe side water elevation

$$EL_{tw} := \begin{cases} EL_F & \text{if } LC = 3 \\ (\text{vlookup}(LC, WaterEL, 2)_0 \cdot 1m) & \text{otherwise} \end{cases} = 1187$$

Equivalent soil surcharge:

$$h_{sur} := \begin{cases} 1.0m & \text{if } LC = 2 \\ 0 & \text{otherwise} \end{cases} = 0 \cdot m$$

4.2 Additional Analysis Dimensions

Analysis Width	$b := 1m$
Length of base	$L_{base} := (x_D - x_E) \cdot 0.657 = 2.14 \cdot m$
Thickness of base	$t_{base} := EL_C - EL_D = 500 \cdot mm$
Length of stem	$L_{stem} := EL_A - EL_C = 2.9 \cdot m$
Thickness of stem	$t_{stem} := x_G - x_H = 500 \cdot mm$
Length of Heel	$L_{heel} := x_A - x_G = 2000 \cdot mm$
Length of Toe	$L_{toe} := x_H - x_F = 750 \cdot mm$
Thickness of Key	$t_{key} := x_J - x_K = 450 \cdot mm$
Height of Key	$h_{key} := EL_D - EL_J = 1500 \cdot mm$

5.0 UPLIFT & HYDROSTATIC LOADS

5.1 Uplift Pressures for Stability Analyses

Determine water pressures for designated coordinates using full headwater uplift pressure at the heel and full tailwater uplift pressure at the toe. Uplift distribution is assumed linear from heel to toe.

Hydrostatic pressure at Heel	$u_h := \gamma_w \cdot (EL_{hw} - EL_J) = 20 \cdot kPa$
Hydrostatic pressure at Toe	$u_t := \gamma_w \cdot (EL_{tw} - EL_E) = 5 \cdot kPa$
Total uplift loads on base	$P_u := \frac{(u_h + u_t)}{2} \cdot L_{base} \cdot b = 26.18 \cdot kN$
Uplift resultant location	$x_u := \frac{L_{base}}{2} + \frac{L_{base}}{6} \cdot \frac{(u_h - u_t)}{u_t + u_h} = 1.28 \cdot m$
Uplift Moment about Toe	$M_u := P_u \cdot x_u = 33.5 \cdot kN \cdot m$

5.2 Headwater Hydrostatic Load - Heel Side

Headwater hydrostatic load $P_{hw} := \frac{1}{2} u_h \cdot (EL_{hw} - EL_J) \cdot b = 19.6 \cdot kN$

Headwater moment arm $y_{hw} := \frac{1}{3}(EL_{hw} - EL_J) - h_{key} = -0.83 \cdot m$

Headwater Moment about Toe $M_{hw} := P_{hw} \cdot y_{hw} = -16.4 \cdot kN \cdot m$

5.3 Tailwater Hydrostatic Load - Toe Side

Tailwater hydrostatic load $P_{tw} := \frac{1}{2} \gamma_w \cdot (EL_{tw} - EL_K)^2 \cdot b = 19.62 \cdot kN$

Tailwater moment arm $y_{tw} := h_{key} - \frac{1}{3}(EL_{tw} - EL_K) = 0.83 \cdot m$

Tailwater Moment about Toe $M_{tw} := P_{tw} \cdot y_{tw} = 16.35 \cdot kN \cdot m$

6.0 LATERAL EARTH PRESSURE

6.1 Lateral Soil Load on Toe Side

Soil pressure at Saturation Level

$$p_{tw} := \begin{vmatrix} k_o \cdot \gamma_{soilm} \cdot (EL_F - EL_{tw}) \text{ if } EL_F > EL_{tw} \\ 0psf \text{ otherwise} \end{vmatrix} = 4.0 \cdot kPa$$

Soil pressure at Toe - base elevation

$$p_E := \begin{vmatrix} p_{tw} + k_o \cdot (\gamma_{soilsat} - \gamma_w) \cdot (EL_{tw} - EL_J) \text{ if } EL_F > EL_{tw} \\ k_o \cdot (\gamma_{soilsat} - \gamma_w) \cdot (EL_F - EL_J) \text{ otherwise} \end{vmatrix}$$

$$p_E = 16.04 \cdot kPa$$

Total soil loads on Wall

$$P_{soil\_t} := \begin{bmatrix} 0.5 \cdot (EL_F - EL_{tw}) \cdot p_{tw} + p_{tw} \cdot (EL_{tw} - EL_J) \ldots \\ + 0.5 \cdot (p_E - p_{tw}) \cdot (EL_{tw} - EL_J) \end{bmatrix} \cdot b = 20.65 \cdot kN$$

Resultant location

$$y_{soil\_t} := \begin{vmatrix} 0 \text{ if } P_{soil\_t} = 0 \\ h_{key} - \dfrac{\begin{bmatrix} 0.5 \cdot (EL_F - EL_{tw}) \cdot p_{tw} \cdot \left[(EL_{tw} - EL_J) + \frac{1}{3}(EL_F - EL_{tw})\right] + p_{tw} \cdot \frac{1}{2}(EL_{tw} - EL_J)^2 \ldots \\ + 0.5 \cdot (p_E - p_{tw}) \cdot (EL_{tw} - EL_J)^2 \cdot \frac{1}{3} \end{bmatrix} \cdot b}{P_{soil\_t}} \text{ otherwise} \end{vmatrix}$$

$$y_{soil\_t} = 0.66 \cdot m$$

Moment about Toe $M_{soil\_t} := P_{soil\_t} \cdot y_{soil\_t} = 13.62 \cdot kN \cdot m$

6.2 Lateral Soil Load on Heel Side

Soil pressure at Saturation Level
$$p_{hw} := \begin{cases} k_o \cdot \gamma_{soilm} \cdot (EL_B - EL_{hw}) & \text{if } EL_B > EL_{hw} \\ 0psf & \text{otherwise} \end{cases} = 32.6 \cdot kPa$$

Soil pressure at Heel - base elevation
$$p_D := \begin{cases} p_{hw} + k_o \cdot (\gamma_{soilsat} - \gamma_w) \cdot (EL_{hw} - EL_J) & \text{if } EL_B > EL_{hw} \\ k_o \cdot (\gamma_{soilsat} - \gamma_w) \cdot (EL_B - EL_J) & \text{otherwise} \end{cases}$$

$$p_D = 44.72 \cdot kPa$$

Total soil loads on Base
$$P_{soil\_h} := \left[0.5 \cdot (EL_B - EL_{hw}) \cdot p_{hw} + p_{hw} \cdot (EL_{hw} - EL_J) \ldots + 0.5 \cdot (p_D - p_{hw}) \cdot (EL_{hw} - EL_J) \right] \cdot b$$

$$P_{soil\_h} = 122.22 \cdot kN$$

Resultant location
$$y_{soil\_h} := \frac{\left[0.5 \cdot (EL_B - EL_{hw}) \cdot p_{hw} \cdot \left[EL_{hw} - EL_J + \frac{1}{3} (EL_B - EL_{hw}) \right] + p_{hw} \cdot \frac{1}{2} (EL_{hw} - EL_J)^2 \ldots + 0.5 \cdot (p_D - p_{hw}) \cdot (EL_{hw} - EL_J)^2 \cdot \frac{1}{3} \right] \cdot b}{P_{soil\_h}} - h_{key}$$

$$y_{soil\_h} = 0.17 \cdot m$$

Moment about Toe $M_{soil\_h} := P_{soil\_h} \cdot y_{soil\_h} = 20.9 \cdot kN \cdot m$

6.3 Surcharge Soil Load - Heel Side

Surcharge soil pressure $p_{sur} := k_o \cdot \gamma_{soilm} \cdot h_{sur} = 0 \cdot kPa$

Soil load on wall $P_{sur} := p_{sur} \cdot (EL_B - EL_J) \cdot b = 0 \cdot kN$

Resultant location $y_{sur} := \frac{1}{2} \cdot (EL_B - EL_J) - h_{key} = 0.88\, m$

Moment about Toe $M_{sur} := P_{sur} \cdot y_{sur} = 0 \cdot kN \cdot m$

7.0 GRAVITY LOADS

7.1 Weight of Concrete

Weight of Wall footing/base $W_{conc} := \gamma_c \cdot (t_{base} \cdot L_{base} + L_{stem} \cdot t_{stem} + t_{key} \cdot h_{key}) \cdot b = 75.03 \cdot kN$

Resultant location $$x_{conc} := \frac{\left[\begin{array}{l}\frac{1}{2} t_{base} \cdot L_{base}^{\ 2} + L_{stem} \cdot t_{stem} \cdot (L_{toe} + 0.5 t_{stem}) \ ... \\ + t_{key} \cdot h_{key} \cdot (L_{base} - 0.5 t_{key})\end{array}\right]}{t_{base} \cdot L_{base} + L_{stem} \cdot t_{stem} + t_{key} \cdot h_{key}} = 1.22\,m$$

Moment about Toe $M_{conc} := W_{conc} \cdot x_{conc} = 91.16 \cdot kN \cdot m$

7.2 Weight of Soil on Heel

Weight of Soil on heel

$$W_{soil\_h} := b \cdot L_{heel} \cdot \left| \begin{array}{ll} (\gamma_{soilsat} - \gamma_w) \cdot (EL_B - EL_C) & \text{if } EL_B < EL_{hw} \\ \gamma_{soilm} \cdot (EL_B - EL_{hw}) + (\gamma_{soilsat} - \gamma_w) \cdot \max[0, (EL_{hw} - EL_C)] & \text{otherwise} \end{array} \right.$$

$W_{soil\_h} = 110 \cdot kN$

Resultant location $x_{soil\_h} := 0.5(x_B - x_G) + x_G = 2.25 \cdot m$

Moment about Toe $M_{soilw\_h} := W_{soil\_h} \cdot x_{soil\_h} = 247.5 \cdot kN \cdot m$

7.3 Weight of Water on Heel

Weight of Water on heel $W_{w\_h} := \gamma_w \cdot \max[0kip, (EL_{hw} - EL_C)] \cdot L_{heel} \cdot b = 0 \cdot kN$

Resultant location $x_{w\_h} := 0.5(x_B - x_G) + x_G = 2.25 \cdot m$

Moment about Toe $M_{w\_h} := W_{w\_h} \cdot x_{w\_h} = 0 \cdot kN \cdot m$

7.4 Weight of Soil on Toe

Weight of Soil on toe Note: Water and soil elevations MUST NOT be below footing elevation

$$W_{soil\_t} := b \cdot L_{toe} \cdot \left| \begin{array}{ll} (\gamma_{soilsat} - \gamma_w) \cdot (\max(0, EL_F - EL_C)) & \text{if } EL_F < EL_{tw} \\ \gamma_{soilm} \cdot \max(0, EL_F - EL_{tw}) + (\gamma_{soilsat} - \gamma_w) \cdot \max(EL_{tw} - EL_C, 0) & \text{otherwise} \end{array} \right.$$

$W_{soil\_t} = 5 \cdot kN$

Resultant location $x_{soil\_t} := 0.5(x_H - x_E) = 0.38 \cdot m$

Moment about Toe $M_{soilw\_t} := W_{soil\_t} \cdot x_{soil\_t} = 1.9 \cdot kN \cdot m$

7.5 Weight of Water on Toe

Weight of Water on toe $W_{w\_t} := \gamma_w \cdot \max\left[0kip, \left(EL_{tw} - EL_C\right)\right] \cdot L_{toe} \cdot b = 0 \cdot kN$

Resultant location $x_{w\_t} := 0.5\left(x_H - x_E\right) = 0.38 \cdot m$

Moment about Toe $M_{w\_t} := W_{w\_t} \cdot x_{w\_t} = 0 \cdot kN \cdot m$

7.6 Weight of Soil under Footing and Above Failure Plane EJ

Depth of Soil Wedge Near Key $h_{s\_under} := \left(x_L - x_E\right) \cdot \dfrac{h_{key}}{L_{base}} = 1.97\,m$

Length of Soil Wedge $L_{s\_under} := x_L - x_E = 2.8\,m$

Weight of Soil Wedge Under Footing $W_{s\_under} := \gamma_{soilsat} \cdot \left(0.5 \cdot h_{s\_under} \cdot L_{s\_under}\right) \cdot b = 55.08 \cdot kN$

Resultant location $x_{s\_under} := \dfrac{2}{3}\left(x_L - x_E\right) = 1.87 \cdot m$

Moment about Toe $M_{s\_under} := W_{s\_under} \cdot x_{s\_under} = 102.8 \cdot kN \cdot m$

8.0 Overturning Stability Assessment - See Figure 2

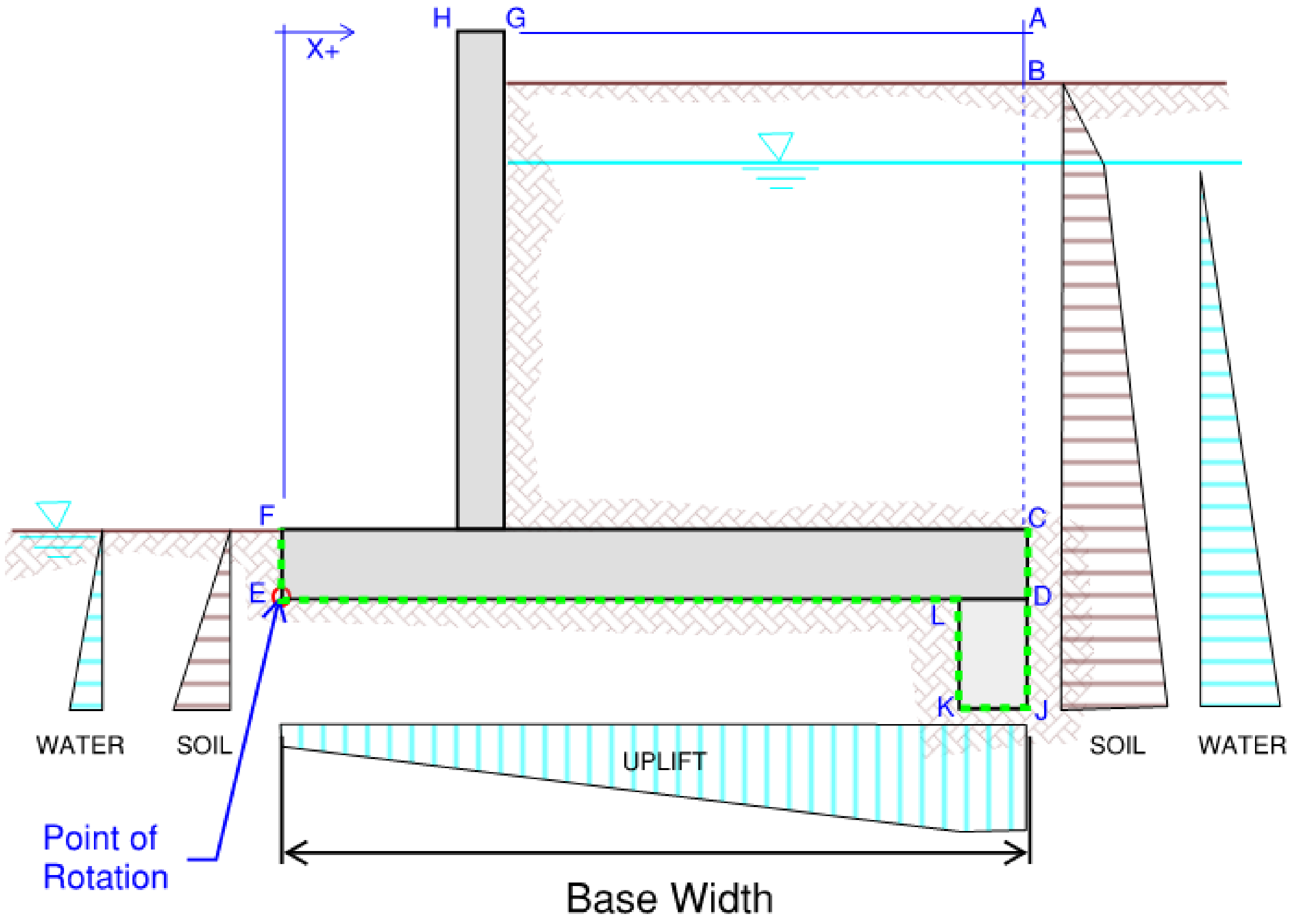


Figure 2. Free Body Diagram for Overturning Analysis

Uplift loads for Overturning

$$P_{u\_ot} := \left[\frac{1}{2}\left(u_h + u_t\right)\cdot\left(x_L - x_E\right) + u_h\cdot t_{key}\right]\cdot b = 43.16\cdot kN$$

Uplift resultant location

$$x_{u\_ot} := \frac{\left[\left[\frac{x_L - x_E}{2} + \frac{x_L - x_E}{6}\cdot\frac{\left(u_h - u_t\right)}{u_t + u_h}\right]\cdot\left[\frac{1}{2}\left(u_h + u_t\right)\cdot\left(x_L - x_E\right)\right] \ldots \\ + \left(L_{base} - 0.5t_{key}\right)\cdot\left(u_h\cdot t_{key}\right)\right]}{\left[\frac{1}{2}\left(u_h + u_t\right)\cdot\left(x_L - x_E\right) + u_h\cdot t_{key}\right]}$$

$$x_{u\_ot} = 1.73\,m$$

Uplift Moment about Toe

$$M_{u\_ot} := P_{u\_ot}\cdot x_{u\_ot} = 74.5\cdot kN\cdot m$$

Total Vertical Forces

$$\Sigma V_{ot} := W_{conc} + W_{soil\_h} + W_{soil\_t} \cdots + W_{w\_h} + W_{w\_t} - P_{u\_ot} = 146.9 \cdot kN$$

Total Horizontal Forces

$$\Sigma H_{ot} := P_{hw} + P_{soil\_h} + P_{sur} - P_{tw} - P_{soil\_t} = 101.56 \cdot kN$$

Total Resisting Moments

$$\Sigma M_{r\_ot} := M_{conc} + M_{soilw\_h} + M_{w\_h} \cdots + M_{soilw\_t} + M_{w\_t} = 340.5 \cdot kN \cdot m$$

Total Driving Moments

$$\Sigma M_{d\_ot} := M_{hw} + M_{soil\_h} + M_{sur} + M_{u\_ot} \cdots + M_{tw} + M_{soil\_t} = 109 \cdot kN \cdot m$$

Resultant Location from Toe

$$x_{r\_ot} := \frac{\Sigma M_{r\_ot} - \Sigma M_{d\_ot}}{\Sigma V_{ot}} = 1.58 \cdot m$$

Normalized Resultant Location

$$\frac{x_{r\_ot}}{L_{base}} = 0.738$$

Eccentricity

$$e_{x\_ot} := \frac{L_{base}}{2} - x_{r\_ot} = -0.51 \cdot m$$

Approx. Base in Compression

$$l_{comp\_ot} := \min\left[L_{base}, \frac{3}{2} \cdot \left(L_{base} - 2 \cdot e_{x\_ot}\right)\right] = 2.14 \cdot m$$

Percent Base in Compression

$$\boxed{Base\_Comp := \left(\frac{l_{comp\_ot}}{L_{base}}\right) = 100 \cdot \%}$$

Resultant Location Check

$$check_{res} := if\left(Base\_Comp \geq Base\_Comp_{Req}, \text{"OK"}, \text{"NG"}\right) = \text{"OK"}$$

9.0 Flotation Stability Assessment - See Figure 2

Calculated Flotation Safety Factor

$$\boxed{FS_f := \frac{W_{conc} + W_{soil\_h} + W_{soil\_t} \cdots + W_{w\_h} + W_{w\_t}}{P_{u\_ot}} = 4.4}$$

Flotation Stability Check

$$check_{floatation} := if\left(FS_f \geq FS_{float}, \text{"OK"}, \text{"NG"}\right) = \text{"OK"}$$

10.0 Sliding Stability Assessment - See Figure 3

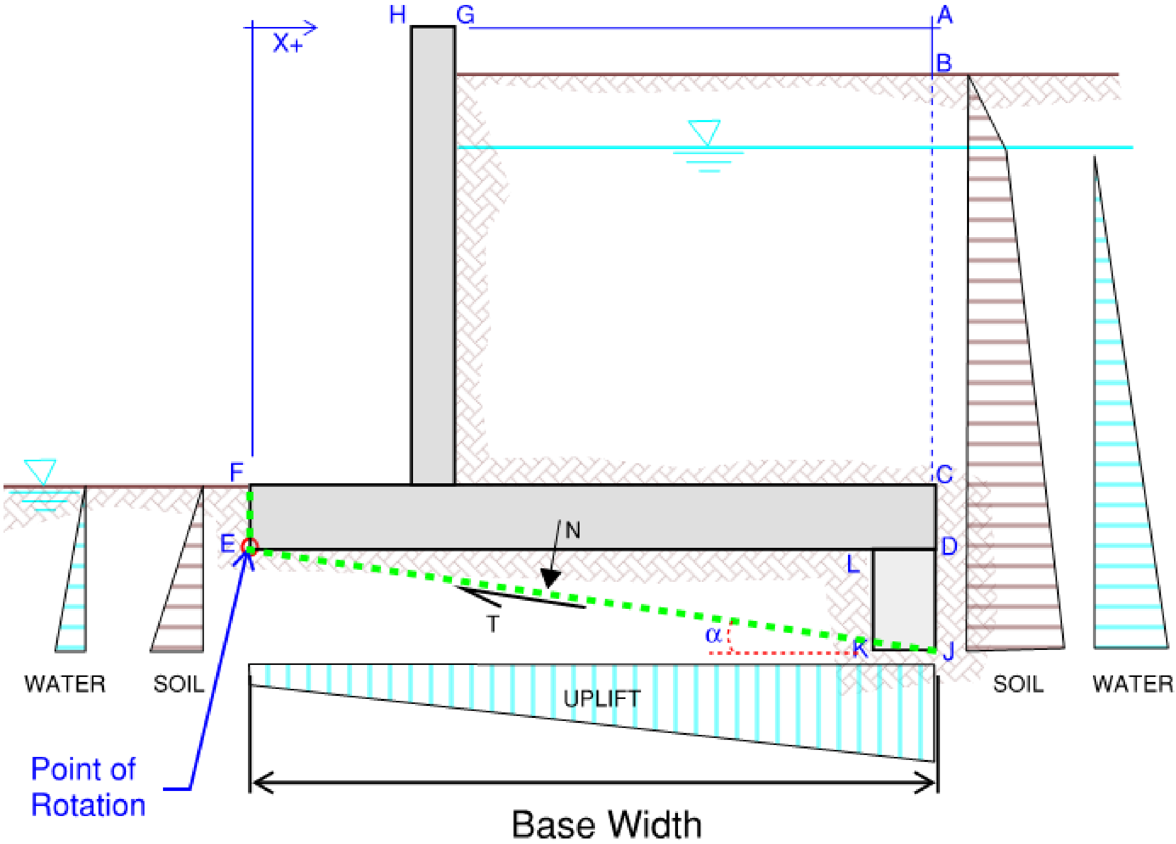


Figure 3. Free Body Diagram for Sliding Analysis

Length of Sliding Failure Plane, EJ $\quad L_{fp} := \sqrt{L_{base}^2 + h_{key}^2} = 2.61\ \text{m}$

Angle of Sliding Failure Plane From Horizontal $\quad \alpha := \operatorname{atan}\left(\frac{h_{key}}{L_{base}}\right) = 35.1 \cdot \text{deg}$

Total Vertical Forces $\quad \Sigma V := W_{conc} + W_{soil\_h} + W_{soil\_t} \cdots + W_{w\_h} + W_{s\_under} + W_{w\_t} - P_u = 218.9 \cdot \text{kN}$

Total Horizontal Forces $\quad \Sigma H := P_{hw} + P_{soil\_h} + P_{sur} - P_{tw} - P_{soil\_t} = 101.56 \cdot \text{kN}$

Total Resisting Moments $\quad \Sigma M_r := M_{conc} + M_{soilw\_h} + M_{w\_h} \cdots + M_{soilw\_t} + M_{w\_t} + M_{s\_under} = 443.3\ \text{m} \cdot \text{kN}$

Total Driving Moments $\quad \Sigma M_d := M_{hw} + M_{soil\_h} + M_{sur} + M_u \cdots + M_{tw} + M_{soil\_t} = 68 \cdot \text{kN} \cdot \text{m}$

Normal Force on Sliding Failure Plane: $N_s := \Sigma H \cdot \sin(\alpha) + \Sigma V \cdot \cos(\alpha) = 237.51 \cdot kN$

Tangential Force on Sliding Failure Plane: $T_s := \Sigma H \cdot \cos(\alpha) - \Sigma V \cdot \sin(\alpha) = -42.73 \cdot kN$

Calculated Sliding Safety Factor $\boxed{FS_s := \frac{\left|N_s \cdot \tan\left(0.95\phi_{soil}\right)\right|}{\left|T_s\right|} = 2.34}$

Sliding Stability Check $check_{sliding} := if\left(FS_s \geq FS_{Sliding}, "OK", "NG"\right) = "OK"$

11.0 Bearing Capacity Assessment

Resultant Location from Toe $x_r := \frac{\Sigma M_r - \Sigma M_d}{N_s} = 1.58 \cdot m$

Eccentricity of N_s from center of base $e_s := \frac{L_{fp}}{2} - x_r = -0.28 \cdot m$

Approx. Base in Compression $l_{comp.s} := \min\left[L_{fp}, \frac{3}{2} \cdot \left(L_{fp} - 2 \cdot e_s\right)\right] = 2.61 \cdot m$

Updated Eccentricity $e_x := \frac{l_{comp.s} - L_{fp}}{2} + e_s = -0.28 \cdot m$

Effective base pressure at Toe $q_t := \left(\frac{N_s}{l_{comp.s} \cdot b}\right) \cdot \left(1 + \frac{6 \cdot e_x}{l_{comp.s}}\right) = 33.37 \cdot kPa$

Effective base pressure at Heel $q_h := \max\left[\left(\frac{N_s}{l_{comp.s} \cdot b}\right) \cdot \left(1 - \frac{6 \cdot e_x}{l_{comp.s}}\right), 0\right] = 148.67 \cdot kPa$

Calculated Bearing Safety Factor $\boxed{FS_b := \frac{Q_b}{\max\left(q_t, q_h\right)} = 1.01}$

Bearing Pressure Check $check_{bearing} := if\left(FS_b \geq FS_{Bearing}, "OK", "NG"\right) = "OK"$

12.0 Summary of Stability Assessments

Base Compression / Resultant Location	$Base\_Comp = 100 \cdot \%$	$check_{res} = "OK"$
Flotation Stability	$FS_f = 4.4$	$check_{floatation} = "OK"$
Sliding Stability	$FS_s = 2.3$	$check_{sliding} = "OK"$
Bearing Pressure	$FS_b = 1.0$	$check_{bearing} = "OK"$

13.0 Structural Loads

13.1 Shear and Moment at Stem Base - See Figure 4

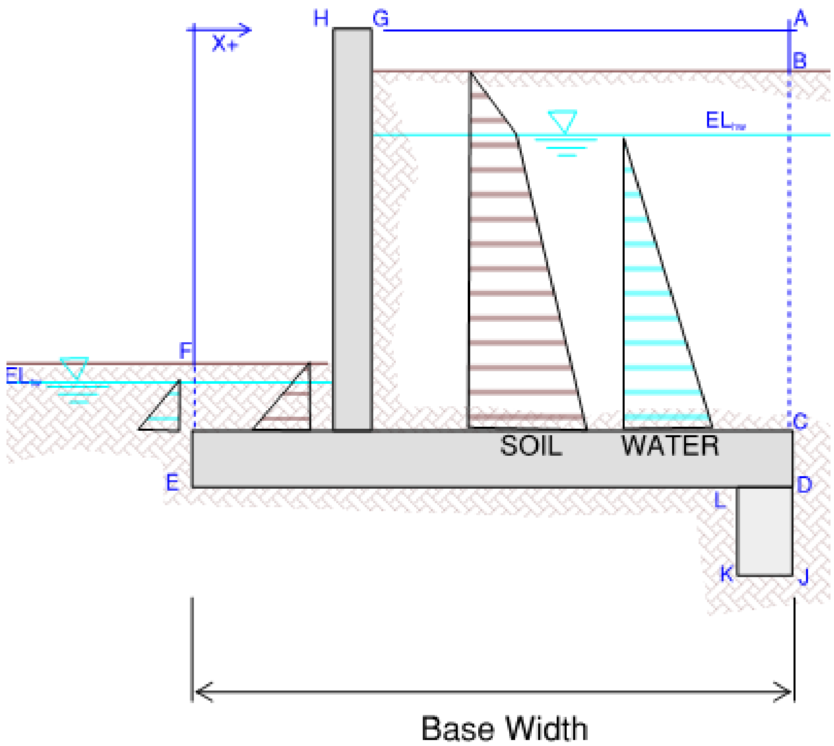


Figure 4 - Loads on Stem

13.1.1 Hydrostatic Load at Stem Base

Heel side hydrostatic load $P_{hw\_stem} := \frac{1}{2}\gamma_w \cdot \left(EL_{hw} - EL_C\right)^2 \cdot b = 0.0 \cdot kN$

Heel side moment at stem base $M_{hw\_stem} := P_{hw\_stem} \cdot \left(\frac{EL_{hw} - EL_C}{3}\right) = 0 \cdot kN \cdot m$

Toe side hydrostatic load $P_{tw\_stem} := \frac{1}{2}\gamma_w \cdot \left(EL_{tw} - EL_C\right)^2 \cdot b = 0.0 \cdot kN$

Toe side moment at stem base $M_{tw\_stem} := P_{tw\_stem} \cdot \left(\frac{EL_{tw} - EL_C}{3}\right) = 0 \cdot kN \cdot m$

13.1.2 Lateral Soil Loads at Stem Base

Soil pressure at saturation level - Toe Side

$$p_t := \begin{cases} k_o \cdot \gamma_{soilm} \cdot (EL_F - EL_{tw}) & \text{if } EL_F > EL_{tw} \\ 0psf & \text{otherwise} \end{cases} = 3.95 \cdot kPa$$

Soil pressure at stem base - Toe Side

$$p_{C.t} := \begin{cases} p_t + k_o \cdot (\gamma_{soilsat} - \gamma_w) \cdot (EL_{tw} - EL_C) & \text{if } EL_F > EL_{tw} \\ k_o \cdot (\gamma_{soilsat} - \gamma_w) \cdot (EL_F - EL_C) & \text{otherwise} \end{cases}$$

$$p_{C.t} = 3.95 \cdot kPa$$

Lateral soil loads at stem base - Toe Side

$$P_{s\_t} := \left[0.5 \cdot (EL_F - EL_{tw}) \cdot p_t + p_t \cdot (EL_{tw} - EL_C) \ldots + 0.5 \cdot (p_{C.t} - p_t) \cdot (EL_{tw} - EL_C)\right] \cdot b = 0.66 \cdot kN$$

Resultant location

$$y_{s\_t} := \begin{cases} 0 & \text{if } P_{s\_t} = 0 \\ \dfrac{\left[0.5 \cdot (EL_F - EL_{tw}) \cdot p_t \cdot \left[(EL_{tw} - EL_C) + \frac{1}{3}(EL_F - EL_{tw})\right] + p_t \cdot \frac{1}{2}(EL_{tw} - EL_C)^2 \ldots + 0.5 \cdot (p_{C.t} - p_t) \cdot (EL_{tw} - EL_C)^2 \cdot \frac{1}{3}\right] \cdot b}{P_{s\_t}} & \text{otherwise} \end{cases}$$

$$y_{s\_t} = 0.11 \cdot m$$

Lateral soil moment at stem base - Toe Side

$$M_{s\_t} := P_{s\_t} \cdot y_{s\_t} = 0.07 \cdot kN \cdot m$$

Soil pressure at saturation level - Heel Side

$$p_h := \begin{cases} k_o \cdot \gamma_{soilm} \cdot (EL_B - EL_{hw}) & \text{if } EL_B > EL_{hw} \\ 0kPa & \text{otherwise} \end{cases} = 32.63 \cdot kPa$$

Soil pressure at stem base - Heel Side

$$p_{C.h} := \begin{cases} p_h + k_o \cdot (\gamma_{soilsat} - \gamma_w) \cdot (EL_{hw} - EL_C) & \text{if } EL_B > EL_{tw} \\ k_o \cdot (\gamma_{soilsat} - \gamma_w) \cdot (EL_B - EL_C) & \text{otherwise} \end{cases}$$

$$p_{C.h} = 32.63 \cdot kPa$$

Lateral soil loads at stem base - Heel Side

$$P_{s\_h} := \left[0.5 \cdot (EL_B - EL_{hw}) \cdot p_h + p_h \cdot (EL_{hw} - EL_C) \ldots + 0.5 \cdot (p_{C.h} - p_h) \cdot (EL_{hw} - EL_C)\right] \cdot b = 44.87 \cdot kN$$

Resultant location

$$y_{s\_h} := \begin{cases} 0 & \text{if } P_{s\_h} = 0 \\ \dfrac{\left[0.5\cdot\left(EL_B - EL_{hw}\right)\cdot p_h\cdot\left[\left(EL_{hw} - EL_C\right) + \frac{1}{3}\left(EL_B - EL_{hw}\right)\right] + p_h\cdot\frac{1}{2}\left(EL_{hw} - EL_C\right)^2 \ldots \\ + 0.5\cdot\left(p_{C.h} - p_h\right)\cdot\left(EL_{hw} - EL_C\right)^2\cdot\frac{1}{3}\right]\cdot b}{P_{s\_h}} & \text{otherwise} \end{cases}$$

$$y_{s\_h} = 0.92\cdot m$$

Lateral soil moment at stem base - Heel Side $M_{s\_h} := P_{s\_h}\cdot y_{s\_h} = 41.13\cdot kN\cdot m$

13.1.3 Surcharge Loads at Stem Base

Surcharge load at stem base $P_{sur\_stem} := p_{sur}\cdot\left(EL_B - EL_C\right)\cdot b = 0\cdot kN$

Surcharge Moment about Toe $M_{sur\_stem} := P_{sur}\cdot\frac{1}{2}\left(EL_B - EL_C\right) = 0\cdot kN\cdot m$

13.2 Shear and Moment on Heel - See Figure 5

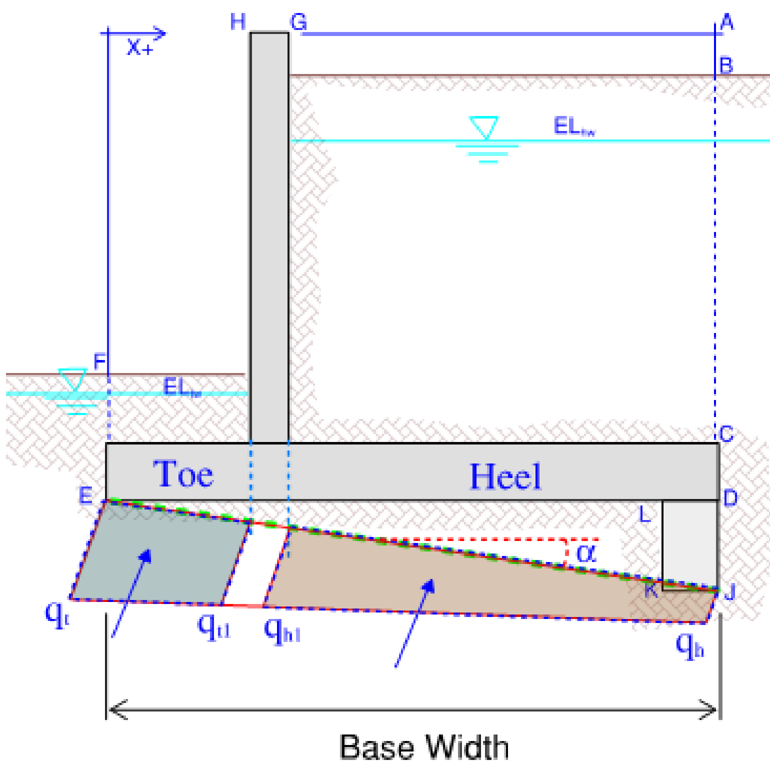


Figure 5 - Loads on Base (Heel & Toe)

13.2.1 Weight of Concrete Heel

Weight of Wall footing/base

$$W_{c\_heel} := \gamma_c \cdot \left(t_{base} \cdot L_{heel} + t_{key} \cdot h_{key}\right) \cdot b = 39.36 \cdot kN$$

Resultant location

$$x_{c\_heel} := \frac{\left[\frac{1}{2} t_{base} \cdot L_{heel}^{\ 2} \ldots \atop + t_{key} \cdot h_{key} \cdot \left(L_{heel} - 0.5 t_{key}\right)\right]}{t_{base} \cdot L_{heel} + t_{key} \cdot h_{key}} = 1.31\ m$$

Moment about stem base

$$M_{c\_heel} := W_{c\_heel} \cdot x_{c\_heel} = 51.66 \cdot kN \cdot m$$

13.2.2 Weight of Soil on Heel

Weight of Soil on heel

$$W_{s\_heel} := W_{soil\_h} = 110 \cdot kN$$

Moment about stem base

$$M_{s\_heel} := W_{s\_heel} \cdot \left(\frac{1}{2} L_{heel}\right) = 110 \cdot kN \cdot m$$

13.2.3 Weight of Water on Heel

Weight of Water on heel

$$W_{w\_heel} := W_{w\_h} = 0 \cdot kN$$

Moment about stem base

$$M_{w\_heel} := W_{w\_heel} \cdot \left(\frac{1}{2} L_{heel}\right) = 0 \cdot kN \cdot m$$

13.2.4 Weight of Concrete Toe

Weight of Wall footing/base

$$W_{c\_toe} := \gamma_c \cdot t_{base} \cdot L_{toe} \cdot b = 8.81 \cdot kN$$

Moment about stem base

$$M_{c\_toe} := W_{c\_toe} \cdot \left(\frac{1}{2} \cdot L_{toe}\right) = 3.3 \cdot kN \cdot m$$

13.2.5 Weight of Soil on Toe

Weight of Soil on Toe

$$W_{s\_toe} := W_{soil\_t} = 5 \cdot kN$$

Moment about stem base

$$M_{s\_toe} := W_{s\_toe} \cdot \left(\frac{1}{2} L_{toe}\right) = 1.9 \cdot kN \cdot m$$

13.2.6 Weight of Water on Toe

Weight of Water on Toe

$$W_{w\_toe} := W_{w\_t} = 0 \cdot kN$$

Moment about stem base

$$M_{w\_toe} := W_{w\_toe} \cdot \left(\frac{1}{2} L_{toe}\right) = 0 \cdot kN \cdot m$$

13.2.7 Bearing Pressures on Footing

Approx. Base in Compression $l_{comp.s} = 2.61\,m$

Effective base pressure at Toe $q_t = 33.37 \cdot kPa$

Effective base pressure at Heel $q_h = 148.67 \cdot kPa$

Compression length under Toe $L_{bearing\_t} := \dfrac{L_{toe}}{\cos(\alpha)} = 0.92\,m$

Compression length under Heel $L_{bearing\_h} := l_{comp.s} - \dfrac{(x_G - x_E)}{\cos(\alpha)} = 1.08\,m$

Bearing pressure under toe side of stem $q_{t1} := L_{bearing\_t} \cdot \left[\dfrac{(q_h - q_t)}{l_{comp.s}}\right] + q_t = 73.87 \cdot kPa$

Bearing pressure under heel side of stem $q_{h1} := \dfrac{(x_G - x_E)}{\cos(\alpha)} \cdot \left[\dfrac{(q_h - q_t)}{l_{comp.s}}\right] + q_t = 100.87 \cdot kPa$

13.2.8 Soil Reaction on Heel

Soil reaction load on Heel $P_{bearing\_h} := \dfrac{1}{2} \cdot (q_h + q_{h1}) \cdot L_{bearing\_h} \cdot b = 134.98 \cdot kN$

Resultant location $x_{bearing\_h} := \dfrac{L_{bearing\_h}}{2} + \dfrac{L_{bearing\_h}}{6} \cdot \dfrac{(q_h - q_{h1})}{q_{h1} + q_h} = 0.58\,m$

Vertical Component $P_{h\_v} := P_{bearing\_h} \cdot \cos(\alpha) = 110.45 \cdot kN$

Horizontal Component $P_{h\_h} := P_{bearing\_h} \cdot \sin(\alpha) = 77.59 \cdot kN$

Horizontal Moment Arm $x_{h\_h} := x_{bearing\_h} \cdot \cos(\alpha) = 0.47\,m$

Vertical Moment Arm $y_{h\_v} := \left[\dfrac{(x_G - x_E)}{\cos(\alpha)} + x_{bearing\_h}\right] \cdot \sin(\alpha) = 1.21\,m$

Moment on Heel $M_{bearing\_h} := P_{h\_v} \cdot x_{h\_h} + P_{h\_h} \cdot y_{h\_v} = 145.81 \cdot kN \cdot m$

13.2.9 Soil Reaction on Toe

Soil reaction load on Toe $$P_{bearing\_t} := \frac{1}{2} \cdot (q_t + q_{t1}) \cdot L_{bearing\_t} \cdot b = 49.14 \cdot kN$$

Resultant location $$x_{bearing\_t} := \frac{L_{bearing\_t}}{2} + \frac{L_{bearing\_t}}{6} \cdot \frac{(q_t - q_{t1})}{q_t + q_{t1}} = 0.4\,m$$

Vertical Component $$P_{t\_v} := P_{bearing\_t} \cdot \cos(\alpha) = 40.21 \cdot kN$$

Horizontal Component $$P_{t\_h} := P_{bearing\_t} \cdot \sin(\alpha) = 28.25 \cdot kN$$

Horizontal Moment Arm $$x_{t\_h} := x_{bearing\_t} \cdot \cos(\alpha) = 0.33\,m$$

Vertical Moment Arm $$y_{t\_v} := (L_{bearing\_t} - x_{bearing\_t}) \cdot \sin(\alpha) = 0.3\,m$$

Moment on Toe $$M_{bearing\_t} := P_{t\_v} \cdot x_{t\_h} + P_{t\_h} \cdot y_{t\_v} = 21.56 \cdot kN \cdot m$$

13.2.10 Uplift Pressure on Footing - Figure 6

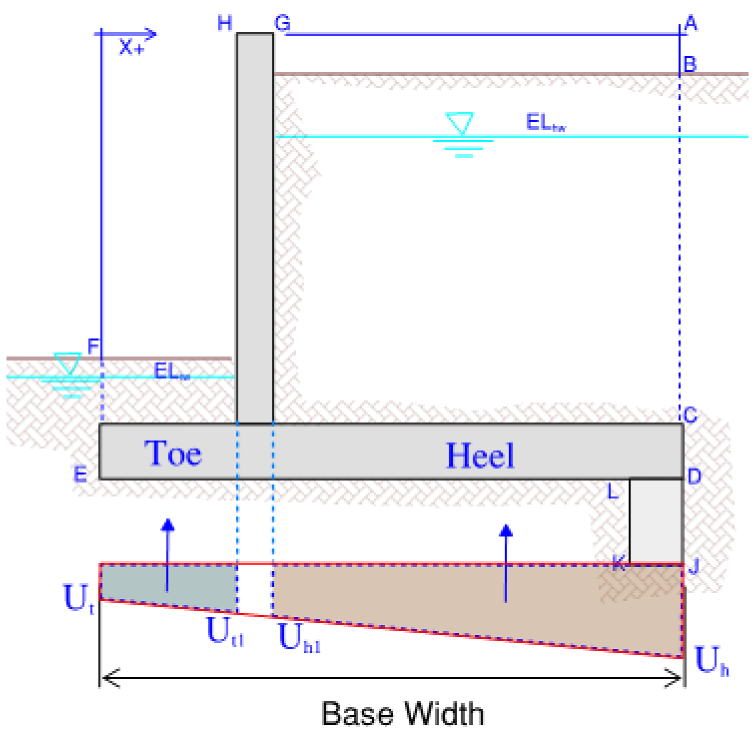


Figure 6 - Uplift Loads on Base (Heel & Toe)

Uplift pressure under toe side of stem $u_{t1} := L_{toe} \cdot \left[\frac{(u_h - u_t)}{L_{base}}\right] + u_t = 10.07 \cdot kPa$

Uplift pressure under heel side of stem $u_{h1} := (x_G - x_E) \cdot \left[\frac{(u_h - u_t)}{L_{base}}\right] + u_t = 13.52 \cdot kPa$

13.2.11 Uplift Loads Heel

Uplift load on Heel $P_{u\_h} := \frac{1}{2} \cdot (u_h + u_{h1}) \cdot L_{heel} \cdot b = 33.14 \cdot kN$

Moment Arm $x_{u\_h} := \frac{L_{heel}}{2} + \frac{L_{heel}}{6} \cdot \frac{(u_h - u_{h1})}{u_{h1} + u_h} = 1.06\,m$

Moment on Heel $M_{u\_h} := P_{u\_h} \cdot x_{u\_h} = 35.17 \cdot kN \cdot m$

13.2.12 Uplift Loads Toe

Uplift load on Toe $P_{u\_t} := \frac{1}{2} \cdot (u_t + u_{t1}) \cdot L_{toe} \cdot b = 5.62 \cdot kN$

Moment Arm $x_{u\_t} := \frac{L_{toe}}{2} + \frac{L_{toe}}{6} \cdot \frac{(u_t - u_{t1})}{u_{t1} + u_t} = 0.33\,m$

Moment on Toe $M_{u\_t} := P_{u\_t} \cdot x_{u\_t} = 1.86 \cdot kN \cdot m$

13.3 Structural Load Summary

Net shear at stem base $V_{stem} := P_{hw\_stem} - P_{tw\_stem} + P_{s\_h} - P_{s\_t} + P_{sur\_stem} = 44.2 \cdot kN$

Net moment at stem base $M_{stem} := M_{hw\_stem} - M_{tw\_stem} + M_{s\_h} - M_{s\_t} + M_{sur\_stem} = 41.1 \cdot kN \cdot m$

Net shear on Toe $V_t := W_{c\_toe} + W_{s\_toe} + W_{w\_toe} - P_{t\_v} - P_{u\_t} = -32 \cdot kN$

Net moment on Toe $M_t := M_{c\_toe} + M_{s\_toe} + M_{w\_toe} - M_{bearing\_t} - M_{u\_t} = -18.2 \cdot kN \cdot m$

Net shear on Heel $V_h := W_{c\_heel} + W_{s\_heel} + W_{w\_heel} - P_{h\_v} - P_{u\_h} = 5.8 \cdot kN$

Net moment on Heel $M_h := M_{c\_heel} + M_{s\_heel} + M_{w\_heel} - M_{bearing\_h} - M_{u\_h} = -19.3 \cdot kN \cdot m$

13.4 Controlling Structural Loads (Unfactored)

Stem cross section

$M_{stem} = 41.1 \cdot kN \cdot m$

$V_{stem} = 44.2 \cdot kN$

Toe cross section

$M_{toe} := M_t = -18.25 \cdot kN \cdot m$

$V_{toe} := V_t = -32 \cdot kN$

Heel cross section

$M_{heel} := \min\left(\max\left(M_{stem} - \left|M_{toe}\right|, M_h\right), M_{stem}\right) = 22.8 \cdot kN \cdot m$

APPENDIX E.5-2 GATE STRUCTURE

Appendix E.5-2 – Gate Structure Stability Calculations Springbank Off-Stream Storage/Alberta Transportation Table of Contents

Gate Structure - Model Input Calculations

LOAD CALCULATIONS - Snow and Wind Loads
SR1- Low Level Outlet Intake Tower

Source: 1. Alberta Building Code 2014, Volume 1

Objective: Estimate design wind and snow loads for the Gate Tower Structure at SR1.

1.0 Calculated Snow Load

- Importance category:	Post-Disaster	Table 4.1.2.1
- Importance factor for snow load:	$I_s := 1.25$	Table 4.1.6.2
- Basic roof snow load factor:	$C_b := 0.8$	4.1.6.2 (2)
- Wind exposure factor:	$C_w := 1.0$	4.1.6.2 (3)
- Slope factor:	$C_s := 1.0$	4.1.6.2 (5)
- Shape factor:	$C_a := 1.0$	4.1.6.2 (8)
- 1 in 50-year ground snow load factor:	$S_s := 1.1kPa$	Appendix C, Table C-2
- 1 in 50-year associated rain load:	$S_r := \min\left[0.1kPa, S_s \cdot (C_b \cdot C_w \cdot C_s \cdot C_a)\right]$ $S_r = 0.1 \cdot kPa$	Appendix C, Table C-2
Specified Snow Load:	$S := I_s \cdot \left[S_s \cdot (C_b \cdot C_w \cdot C_s \cdot C_a) + S_r\right]$ $\boxed{S = 1.23 \cdot kPa}$	4.1.6.2

2.0 Calculated Wind Load

- Height of structure:	$h := 30.2m$		
- Importance factor:	$I_W := 1.25$ (Post-Disaster)	Table 4.1.7.1	
- Exposure factor:	$C_e := \max\left[0.9, \left(\frac{h}{10m}\right)^{0.2}\right] = 1.25$	4.1.7.1 (5b)	
- Gust effect factor:	$C_g := 2.0$	4.1.7.1 (6)	
- External Pressure Coefficient:	$C_p := 1.0$	4.1.7.1	(Conservative)
-Reference Velocity Pressure:	$q := 0.48kPa$	Table C-2	1/50 return
Specified Wind Load:	$\boxed{p := I_W \cdot q \cdot (C_e \cdot C_g \cdot C_p) = 1.5 \cdot kPa}$	4.1.7.1	(All directions)

LOAD CALCULATIONS

Project / Client: Alberta Transportation

Subject: Miscellaneous Load Calculations

Objective:

Determine gravity loads due to the pedestrian bridge, upper room, ladders, and landings.

References:

1. Alberta Building Code, 2014.
2. Design Drawings.

PEDESTRIAN BRIDGE

The loads imposed on the gate tower by the pedestrian bridge will be estimated based on information provided by Contech. Since the preliminary reactions received are for a 140'x12' bridge, the reactions will bound the anticipated reactions for the actual bridge which will be approximately 10' wide with the same span.

Width Between Bridge Supports: $b_{bs} := 11\text{ft} + 9\text{in} = 3.58\,\text{m}$

Ratio of Actual Span to Provided Span: $r_s := 1.0 = 1$

Reactions from Drawings (Each Base Plate)

Dead Load: $P_{D.p} := 44.0\text{kip} = 195.72\cdot\text{kN}$

Uniform Live Load: $P_{L.p} := 37.8\text{kip} = 168.14\cdot\text{kN}$

Vehicle Load: $P_{V.p} := 10.0\text{kip} = 44.48\cdot\text{kN}$

$11.205\text{kip} = 49.84\cdot\text{kN}$

Wind Uplift: $P_{U.p} := -14.35\text{kip} = -63.83\cdot\text{kN}$

Wind: $M_{W.p} := 11.205\text{kip}\cdot b_{bs} = 178.51\cdot\text{kN}\cdot\text{m}$

$H_{W.p} := 23.685\text{kip} = 105.36\cdot\text{kN}$

Thermal: $L_{T.p} := 6.6\text{kip}$

Adjusted Reactions for Actual Span

Number of Base Plates on Gate Tower: $n_{bp} := 2$

Dead Load: $P_{D.bridge} := n_{bp} \cdot P_{D.p} = 391.44 \cdot kN$

Uniform Live Load: $P_{L.bridge} := n_{bp} \cdot P_{L.p} = 336.29 \cdot kN$

Vehicle Load: $P_{V.bridge} := n_{bp} \cdot P_{V.p} = 88.96 \cdot kN$

Wind Uplift: $P_{W.bridge} := n_{bp} \cdot P_{U.p} = -127.66 \cdot kN$

Wind: $M_{WY.bridge} := M_{W.p} = 178.51\,m \cdot kN$

$H_{WX.bridge} := H_{W.p} = 105.36 \cdot kN$

Thermal: $L_{T.bridge} := n_{bp} \cdot L_{T.p} = 58.72 \cdot kN$

UPPER ROOM

The weight of the upper room is modeled based on tributary elevations. The weight of the bottom half is applied to the top of the tower and the weight of the top half is applied to a rigid link at the mean roof elevation.

Upper Room Material: Matl := "Concrete"

Unit Weight of Concrete: $\gamma_c := 23.5 \frac{kN}{m^3}$

Unit Weight of Steel: $\gamma_s := 77.0 \frac{kN}{m^3}$

WALLS

Wall thickness: $t_w := 0.2m$

Wall Length (Y-Direction): $L_y := 6.1m$

Wall Length (X-Direction): $L_x := 4.7m$

Average Wall Height: $H_w := 3.059m$

Wall Perimeter: $Pe_w := 2 \cdot L_y + 2 \cdot L_x = 21.6\,m$

Tributary Wall Dead Load: $P_{D.wall} := \gamma_c \cdot t_w \cdot Pe_w \cdot \frac{H_w}{2} = 155.27 \cdot kN$

ROOF

Roof Slope:	$\theta := \operatorname{atan}\left(\frac{1}{50}\right) = 1.15 \cdot deg$
Roof Length (Y-Direction):	$L_{r.y} := \frac{6.3m}{\cos(\theta)} = 6.3013\, m$
Roof Length (X-Direction):	$L_{r.x} := 5.3m$
Roof Area:	$A_{roof} := L_{r.y} \cdot L_{r.x} = 33.4\, m^2$
Roof Thickness:	$t_r := 0.2m$
Roof Snow Load:	$p_{S.R} := 1.23kPa$
Roof Live Load (REF. 1, Table 4.1.5.3):	$p_{L.R} := 1kPa$
Assumed Hoist Weight:	$W_{hoist} := 250lbf = 1.11 \cdot kN$
Hoist Track Assumed Weight:	$w_{track} := 40 \frac{lbf}{ft} = 0.58 \cdot \frac{kN}{m}$
Hoist Track Assumed Length:	$l_{track} := 4m = 13.12 \cdot ft$
Roof Dead Load:	$\boxed{P_{D.roof} := \gamma_c \cdot A_{roof} \cdot t_r + W_{hoist} + w_{track} \cdot l_{track} = 160.41 \cdot kN}$
Roof Live Load:	$\boxed{P_{L.roof} := p_{L.R} \cdot A_{roof} = 33.4 \cdot kN}$
Roof Snow Load:	$\boxed{P_{S.roof} := p_{S.R} \cdot A_{roof} = 41.08 \cdot kN}$

FLOOR

Floor weight is conservatively estimated assuming constant thickness concrete over the entire floor area with no deck.

Floor Area:	$A_{floor} := 9.7m^2$
Assumed Slab Thickness:	$t_{slab} := 0.15m$
Floor Collateral Dead Load:	$p_{D.floor} := 2.4kPa$
Floor Live Load (REF. 1, Table 4.1.5.3, Storage Areas):	$p_{L.floor} := 4.8kPa$
Floor Dead Load:	$P_{D.floor} := A_{floor} \cdot (\gamma_c \cdot t_{slab} + p_{D.floor}) = 57.47 \cdot kN$
Floor Live Load:	$P_{L.floor} := p_{L.floor} \cdot A_{floor} = 46.56 \cdot kN$

WIND

Wind Load Pressure:	$p := 1.5kPa$	
Wind Area for X-Direction:	$A_{w.x} := H_w \cdot L_y = 18.66\ m^2$	
Wind Area for Y-Direction:	$A_{w.y} := H_w \cdot L_x = 14.38\ m^2$	
Wind Area for Roof Uplift:	$A_{w.u} := L_{r.x} \cdot L_{r.y} = 33.4\ m^2$	
Wind Load X-Direction (Windward + Leeward):	$H_{WX.room} := p \cdot A_{w.x} = 27.99 \cdot kN$	Applied to top & bottom
Wind Load Y-Direction (Windward + Leeward):	$H_{WY.room} := p \cdot A_{w.y} = 21.57 \cdot kN$	Applied to top & bottom
Wind Load Uplift:	$P_{W.room} := p \cdot A_{w.u} = 50.1 \cdot kN$	

LANDINGS

Landing Member Size: Mem := "MC310x60"

Landing Member Weight: $w_{member} := 60\frac{kg}{m}\cdot g = 0.59\cdot\frac{kN}{m}$

Landing Length: $L_{landing} := 4m$

Landing Width: $B_{landing} := 2m$

Assumed Grating Weight: $w_{grating} := 0.2\frac{kN}{m}$

Floor Live Load (REF. 1, Table 4.1.5.3, Service Rooms): $p_{L.grating} := 3.6kPa$

Landing Dead Load: $P_{D.landing} := \left(2\cdot w_{member} + w_{grating}\right)\cdot L_{landing} = 5.51\cdot kN$

Landing Live Load: $P_{L.landing} := p_{L.grating}\cdot\left(L_{landing}\cdot B_{landing}\right) = 28.8\cdot kN$

LADDERS

Ladder Bar Thickness: $t_{l.v} := 12mm$

Ladder Bar Width: $b_{l.v} := 75mm$

Ladder Rung Thickness/Width: $t_{rung} := 19mm$

Ladder Rung Length: $l_{rung} := 400mm$

Ladder Rung Spacing: $s_{rung} := 0.3m$

Ladder Dead Load: $P_{D.ladder} := \gamma_s\cdot\left[2\cdot t_{l.v}\cdot b_{l.v} + t_{rung}{}^2\cdot l_{rung}\cdot\left(\frac{1}{s_{rung}}\right)\right] = 0.18\cdot\frac{kN}{m}$

GATES

Assumed Gate Weight: $W_{gate} := 2tonf = 17.79\cdot kN$

Gate Dead Load: $P_{D.gate} := 2\cdot W_{gate} = 35.59\cdot kN$

HYDROSTATIC/SOIL LOAD CALCULATIONS

Project / Client: Springbank Off-Stream Storage/Alberta Transportation

Subject: Load Calculations for Stability Analysis

Objective:

Determine additional loads on the gate tower due to surrounding water and soil for stability analysis.

References:

1. Design Drawings.

Material Properties:

Unit Weight of Soil: $\gamma_{soil} := 20\frac{kN}{m^3}$

Unit Weight of Water: $\gamma_w := 9.8\frac{kN}{m^3}$

Coefficient of Lateral Earth Pressure: $K_o := 0.59$

Tower Geometry:

Offset from Outlet Works CL to Foundation CL: $e_f := 0.25m$

Section Widths (Exposed to Soil)

Section 1, 2: $b_{1.1} := 6.4m$ $b_{1.2} := 10.5m$

Section 3-6: $b_{2.1} := 4.2m$ $b_{2.2} := 6.4m$

Section 7: $b_{3.1} := 3.6m$ $b_{3.2} := 5.8m$

Soil Weight (U1, U2, UN1, UN2, UN4, E1, E2):

1x3 Identity Vector: $I := \begin{pmatrix} 1 \\ 1 \\ 1 \end{pmatrix}$

Soil Column Areas: $A_s := \begin{pmatrix} 25.72 \\ 39.59 \\ 44.97 \end{pmatrix} \cdot m^2$

Soil Column Heights: $H_s := \begin{pmatrix} 2.40 \\ 12.740 \\ 2 \end{pmatrix} \cdot m$

Soil Column Eccentricites (X-Direction): $e_{x.s} := \begin{pmatrix} 0 \\ 0 \\ 0 \end{pmatrix} \cdot m$

Soil Column Eccentricites (Y-Direction): $e_{y.s} := \begin{pmatrix} 0.042 \\ -0.3602 \\ -0.2757 \end{pmatrix} \cdot m + e_f = \begin{pmatrix} 0.29 \\ -0.11 \\ -0.03 \end{pmatrix} m$

Uniform Surcharge Height: $H_{sur} := 2 \cdot m$

Soil Column Weights: $w_s := \gamma_{soil} \cdot diag(A_s) \cdot diag(H_s) \cdot I = \begin{pmatrix} 1234.56 \\ 10087.53 \\ 1798.8 \end{pmatrix} \cdot kN$

Soil Column Total Weight: $W_s := w_s \cdot I = 13120.89 \cdot kN$

Soil Column Net Eccentricity (X-Direction): $e_{x.n.soil} := \dfrac{w_s \cdot e_{x.s}}{w_s \cdot I} = 0$

Soil Column Net Eccentricity (Y-Direction): $e_{y.n.soil} := \dfrac{w_s \cdot e_{y.s}}{w_s \cdot I} = -0.061\ m$

Soil Lateral Pressures (UN4-1):

Uniform Distributed Lateral Load Due to Surcharge (Section1, 2): $w_{sur1.1} := H_{sur} \cdot \gamma_{soil} \cdot K_o \cdot b_{1.1} = 151.04 \cdot \dfrac{kN}{m}$

Uniform Distributed Lateral Load Due to Surcharge (Section 3-6): $w_{sur2.1} := H_{sur} \cdot \gamma_{soil} \cdot K_o \cdot b_{2.1} = 99.12 \cdot \dfrac{kN}{m}$

Uniform Distributed Lateral Load Due to Surcharge (Section 7): $w_{sur3.1} := H_{sur} \cdot \gamma_{soil} \cdot K_o \cdot b_{3.1} = 84.96 \cdot \dfrac{kN}{m}$

Soil Lateral Pressures (UN4-2):

Uniform Distributed Lateral Load Due to Surcharge (Section1, 2): $w_{sur1.2} := H_{sur} \cdot \gamma_{soil} \cdot K_o \cdot b_{1.2} = 247.8 \cdot \dfrac{kN}{m}$

Uniform Distributed Lateral Load Due to Surcharge (Section 3-6): $w_{sur2.2} := H_{sur} \cdot \gamma_{soil} \cdot K_o \cdot b_{2.2} = 151.04 \cdot \dfrac{kN}{m}$

Uniform Distributed Lateral Load Due to Surcharge (Section 7): $w_{sur3.2} := H_{sur} \cdot \gamma_{soil} \cdot K_o \cdot b_{3.2} = 136.88 \cdot \dfrac{kN}{m}$

Water Weight (UN1):

1x4 Identity Vector: $I := \begin{pmatrix} 1 \\ 1 \\ 1 \end{pmatrix}$

Water Column Areas: $A_{UN1} := \begin{pmatrix} 14.02 \\ 4.8 \\ 9.6 \end{pmatrix} \cdot m^2$

Water Column Heights: $H_{UN1} := \begin{pmatrix} 1.6 \\ 2.04 \\ 1.43 \end{pmatrix} \cdot m$

Water Column Eccentricites (X-Direction): $e_{x.UN1} := \begin{pmatrix} 0 \\ 0 \\ 0 \end{pmatrix} \cdot m$

Water Column Eccentricites (Y-Direction): $e_{y.UN1} := \begin{pmatrix} 0.127 \\ 0 \\ 0 \end{pmatrix} \cdot m + e_f = \begin{pmatrix} 0.38 \\ 0.25 \\ 0.25 \end{pmatrix} m$

Water Column Weights: $w_{UN1} := \gamma_w \cdot \mathrm{diag}(A_{UN1}) \cdot \mathrm{diag}(H_{UN1}) \cdot I = \begin{pmatrix} 219.83 \\ 95.96 \\ 134.53 \end{pmatrix} \cdot kN$

Water Column Total Weight: $\boxed{W_{UN1} := w_{UN1} \cdot I = 450.33 \cdot kN}$

Water Column Net Eccentricity (X-Direction): $\boxed{e_{x.n.UN1} := \dfrac{w_{UN1} \cdot e_{x.UN1}}{w_{UN1} \cdot I} = 0}$

Water Column Net Eccentricity (Y-Direction): $\boxed{e_{y.n.UN1} := \dfrac{w_{UN1} \cdot e_{y.UN1}}{w_{UN1} \cdot I} = 0.312\ m}$

Water Weight (UN2):

Water Column Areas:

$$A_{UN2} := \begin{pmatrix} 8.26 \\ 2.4 \\ 4.8 \end{pmatrix} \cdot m^2$$

Water Column Heights:

$$H_{UN2} := H_{UN1} = \begin{pmatrix} 1.6 \\ 2.04 \\ 1.43 \end{pmatrix} m$$

Water Column Eccentricites (X-Direction):

$$e_{x.UN2} := \begin{pmatrix} 0 \\ 0 \\ 0 \end{pmatrix} \cdot m$$

Water Column Eccentricites (Y-Direction):

$$e_{y.UN2} := \begin{pmatrix} 2.38 \\ 1.30 \\ 1.30 \end{pmatrix} \cdot m + e_f = \begin{pmatrix} 2.63 \\ 1.55 \\ 1.55 \end{pmatrix} m$$

Water Column Weights:

$$w_{UN2} := \gamma_w \cdot \text{diag}(A_{UN2}) \cdot \text{diag}(H_{UN2}) \cdot I = \begin{pmatrix} 129.52 \\ 47.98 \\ 67.27 \end{pmatrix} \cdot kN$$

Water Column Total Weight:

$$\boxed{W_{UN2} := w_{UN2} \cdot I = 244.76 \cdot kN}$$

Water Column Net Eccentricity (X-Direction):

$$\boxed{e_{x.n.UN2} := \frac{w_{UN2} \cdot e_{x.UN2}}{w_{UN2} \cdot I} = 0}$$

Water Column Net Eccentricity (Y-Direction):

$$\boxed{e_{y.n.UN2} := \frac{w_{UN2} \cdot e_{y.UN2}}{w_{UN2} \cdot I} = 2.121\ m}$$

Water Weight (E1):

1x4 Identity Vector: $I := \begin{pmatrix} 1 \\ 1 \\ 1 \end{pmatrix}$

$40kPa = 835.42 \cdot psf$

Water Column Areas: $A_{E1} := \begin{pmatrix} 14.02 \\ 4.8 \\ 9.6 \end{pmatrix} \cdot m^2$

Water Column Heights: $H_{E1} := \begin{pmatrix} 1.60 \\ 2.04 \\ 23.5 \end{pmatrix} \cdot m$

Water Column Eccentricites (X-Direction): $e_{x.E1} := \begin{pmatrix} 0 \\ 0 \\ 0 \end{pmatrix} \cdot m$

Water Column Eccentricites (Y-Direction): $e_{y.E1} := \begin{pmatrix} 0.127 \\ 0 \\ 0 \end{pmatrix} \cdot m + e_f = \begin{pmatrix} 0.38 \\ 0.25 \\ 0.25 \end{pmatrix} m$

Water Column Weights: $w_{E1} := \gamma_w \cdot diag(A_{E1}) \cdot diag(H_{E1}) \cdot I = \begin{pmatrix} 219.83 \\ 95.96 \\ 2210.88 \end{pmatrix} \cdot kN$

Water Column Total Weight: $\boxed{W_{E1} := w_{E1} \cdot I = 2526.68 \cdot kN}$

Water Column Net Eccentricity (X-Direction): $\boxed{e_{x.n.E1} := \frac{w_{E1} \cdot e_{x.E1}}{w_{E1} \cdot I} = 0}$

Water Column Net Eccentricity (Y-Direction): $\boxed{e_{y.n.E1} := \frac{w_{E1} \cdot e_{y.E1}}{w_{E1} \cdot I} = 0.261\ m}$

Water Weight (E2):

Water Column Areas: $A_{E2} := \begin{pmatrix} 8.26 \\ 2.4 \\ 4.8 \end{pmatrix} \cdot m^2$

Water Column Heights: $H_{E2} := H_{E1} = \begin{pmatrix} 1.6 \\ 2.04 \\ 23.5 \end{pmatrix} m$

Water Column Eccentricites (X-Direction): $e_{x.E2} := \begin{pmatrix} 0 \\ 0 \\ 0 \end{pmatrix} \cdot m$

Water Column Eccentricites (Y-Direction): $e_{y.E2} := \begin{pmatrix} 2.38 \\ 1.30 \\ 1.30 \end{pmatrix} \cdot m + \blacksquare$

Water Column Weights: $w_{E2} := \gamma_w \cdot diag(A_{E2}) \cdot diag(H_{E2}) \cdot I = \begin{pmatrix} 129.52 \\ 47.98 \\ 1105.44 \end{pmatrix} \cdot kN$

Water Column Total Weight: $\boxed{W_{E2} := w_{E2} \cdot I = 1282.94 \cdot kN}$

Water Column Net Eccentricity (X-Direction): $\boxed{e_{x.n.E2} := \frac{w_{E2} \cdot e_{x.E2}}{w_{E2} \cdot I} = 0}$

Water Column Net Eccentricity (Y-Direction): $\boxed{e_{y.n.E2} := \frac{w_{E2} \cdot e_{y.E2}}{w_{E2} \cdot I} = \blacksquare}$

Uplift Parameters:

Footing Width: $B_f := 6.4m$

Footing Length: $L_f := 10.5m$

Footing Area: $A_f := B_f \cdot L_f = 67.2\,m^2$

Uplift (U1, U2):

Elevation Head: $h_U := 1.8m$

Uplift Pressure: $p_U := \gamma_w \cdot h_U = 17.64 \cdot kPa$

Uplift Force: $\boxed{U_U := p_U \cdot A_f = 1185.41 \cdot kN}$

Uplift (UN1, UN2):

Elevation Head: $h_{UN} := 6.87m$

Uplift Pressure: $p_{UN} := \gamma_w \cdot h_{UN} = 67.33 \cdot kPa$

Uplift Force: $\boxed{U_{UN} := p_{UN} \cdot A_f = 4524.31 \cdot kN}$

Uplift (E1, E2):

Elevation Head: $h_E := 28.94m$

Uplift Pressure: $p_E := \gamma_w \cdot h_E = 283.61 \cdot kPa$

Uplift Force: $\boxed{U_E := p_E \cdot A_f = 19058.73 \cdot kN}$

Hydrostatic Gate Loads (UN1, UN2):

Flow Chamber Width: $b_{flow} := 1.2m$

Flow Chamber Height: $h_{flow} := 1.6m$

Water Level Elevation: $EL_{UN} := 1191.43m$

Top of Flow Chamber Elevation: $EL_T := 1187.96m$

Bottom of Flow Chamber Elevation: $EL_B := 1186.36m$

Pressure at Top of Chamber: $p_{T.UN} := \gamma_w \cdot (EL_{UN} - EL_T) = 34.01 \cdot kPa$

Pressure at Bottom of Chamber: $p_{B.UN} := \gamma_w \cdot (EL_{UN} - EL_B) = 49.69 \cdot kPa$

Total Load on Gate: $F_{UN} := \frac{1}{2} \cdot (p_{T.UN} + p_{B.UN}) \cdot h_{flow} \cdot b_{flow} = 80.34 \cdot kN$

Load Applied to Each Joint (2 Total): $\boxed{P_{UN} := \frac{F_{UN}}{2} = 40.17 \cdot kN}$

Hydrostatic Gate Loads (E1, E2):

Water Level Elevation: $EL_E := 1213.5m$

Pressure at Top of Chamber: $p_{T.E} := \gamma_w \cdot (EL_E - EL_T) = 250.29 \cdot kPa$

Pressure at Bottom of Chamber: $p_{B.E} := \gamma_w \cdot (EL_E - EL_B) = 265.97 \cdot kPa$

Total Load on Gate: $F_E := \frac{1}{2} \cdot (p_{T.E} + p_{B.E}) \cdot h_{flow} \cdot b_{flow} = 495.61 \cdot kN$

Load Applied to Each Joint (2 Total): $\boxed{P_E := \frac{F_E}{2} = 247.81 \cdot kN}$

Project: Springbank Off-Stream Storage Project - SR1
By: A. Garland Date: 10/1/2019
Checked: C. Gabriel Date: 10/11/2019

TOWER JOINT WIND LOADS

Node #	Elevation (m)	Above Soil? (Yes/No)	Trib. Height Below (m)	Trib. Height Above (m)	Joint Tributary Area Exposed to Wind - Y Direction (m^2)	Joint Tributary Area Exposed to Wind - X Direction (m^2)	Design Wind Pressure (kPa)	Lateral Load Applied to Joint - Y (kN)	Lateral Load Applied to Joint - X (kN)
								(Windward+Leeward)	
1.0	1184.6	No							
2.0	1185.2	No							
3.0	1185.8	No							
4.0	1186.4	No							
5.0	1188.0	No							
6.0	1188.8	No							
7.0	1190.0	No							
8.0	1191.4	No							
9.0	1192.5	No							
10.0	1194.0	No							
11.0	1195.5	No							
12.0	1197.0	No							
13.0	1198.5	No							
14.0	1200.0	No							
15.0	1201.5	No							
16.0	1203.5	Yes	0.0	0.5	1.8	3.1	1.5	**5.4**	**9.2**
17.0	1204.5	Yes	0.5	0.8	4.5	7.6	1.5	**13.5**	**22.9**
18.0	1206.0	Yes	0.8	0.8	5.4	9.2	1.5	**16.2**	**27.5**
19.0	1207.5	Yes	0.8	0.8	5.4	9.2	1.5	**16.2**	**27.5**
20.0	1209.0	Yes	0.8	0.8	5.4	9.2	1.5	**16.2**	**27.5**
21.0	1210.5	Yes	0.8	0.6	4.9	8.4	1.5	**14.8**	**25.1**
22.0	1211.7	Yes	0.6	0.5	4.0	6.8	1.5	**12.1**	**20.5**
23.0	1212.7	Yes	0.5	0.4	3.2	5.4	1.5	**9.5**	**16.1**
24.0	1213.5	Yes	0.4	0.0	1.4	2.3	1.5	**4.1**	**7.0**

Project: Springbank Off-Stream Storage Project - SR1
By: A. Garland Date: 10/1/2019
Checked: C. Gabriel Date: 10/10/2019

TOWER JOINT SOIL MASSES (WOOD'S METHOD)

Node #	Elevation (m)	Top of Trib. Area Elevation (m)	Bottom of Trib. Area Elevation (m)	Top Tributary Length (m)	Bottom Tributary Length (m)	Total Tributary Length (m)	Height of Soil from Base (m)	Weight per Unit Width (kN)	Tributary Weight - X Direction Motion (kN)	Tributary Weight - Y Direction Motion (kN)
1.0	1184.6	1184.9	1184.6	0.3	0.0	0.3	18.94	113.6	**1136.4**	**727.3**
2.0	1185.2	1185.5	1184.9	0.3	0.3	0.6		227.3	**2272.8**	**1454.6**
3.0	1185.8	1186.1	1185.5	0.3	0.3	0.6		227.3	**2272.8**	**1454.6**
4.0	1186.4	1187.2	1186.1	0.8	0.3	1.1		416.7	**4166.8**	**2000.1**
5.0	1188.0	1188.4	1187.2	0.4	0.8	1.2		454.6	**4545.6**	**1909.2**
6.0	1188.8	1189.4	1188.4	0.6	0.4	1.0		386.4	**3863.8**	**1622.8**
7.0	1190.0	1190.7	1189.4	0.7	0.6	1.3		505.7	**4163.2**	**2123.9**
8.0	1191.4	1192.0	1190.7	0.5	0.7	1.3		473.5	**3172.5**	**1988.7**
9.0	1192.5	1193.3	1192.0	0.8	0.5	1.3		486.8	**3261.3**	**2044.4**
10.0	1194.0	1194.8	1193.3	0.8	0.8	1.5		568.2	**3806.9**	**2386.4**
11.0	1195.5	1196.3	1194.8	0.8	0.8	1.5		568.2	**3806.9**	**2386.4**
12.0	1197.0	1197.8	1196.3	0.8	0.8	1.5		568.2	**3806.9**	**2386.4**
13.0	1198.5	1199.3	1197.8	0.8	0.8	1.5		568.2	**3806.9**	**2386.4**
14.0	1200.0	1200.8	1199.3	0.8	0.8	1.5		568.2	**3806.9**	**2386.4**
15.0	1201.5	1202.5	1200.8	1.0	0.8	1.8		662.9	**4214.2**	**2556.9**
16.0	1203.5	1203.5	1202.5	0.0	1.0	1.0		378.8	**2310.7**	**1363.7**
17.0	1204.5									
18.0	1206.0									
19.0	1207.5									
20.0	1209.0									
21.0	1210.5									
22.0	1211.7									
23.0	1212.7									
24.0	1213.5									

Project:	Springbank Off-Stream Storage Project - SR1		
By:	A. Garland	Date:	10/1/2019
Checked:	C. Gabriel	Date:	10/14/2019

TOWER JOINT PSEUDO STATIC SEISMIC LOADS

Seismic Coefficients		
Component	Accel. (g)	Description
Horizontal	0.28	(PGA)
Vertical	0.1568	(0.56*PGA)

SAP2000 OUTPUT: Assembled Joint Masses

Joint	MassSource	U1	U2	U3
Text	Text	KN-s2/m	KN-s2/m	KN-s2/m
1.0	MASS_CASE_1	161.9	120.2	46.0
2.0	MASS_CASE_1	323.8	240.4	92.0
3.0	MASS_CASE_1	323.8	240.4	92.0
4.0	MASS_CASE_1	522.0	301.1	97.1
5.0	MASS_CASE_1	546.0	277.2	82.5
6.0	MASS_CASE_1	470.6	242.0	76.6
7.0	MASS_CASE_1	505.7	297.7	81.1
8.0	MASS_CASE_1	383.0	262.3	59.5
9.0	MASS_CASE_1	389.8	265.7	57.2
10.0	MASS_CASE_1	454.5	309.6	66.3
11.0	MASS_CASE_1	454.6	309.8	66.5
12.0	MASS_CASE_1	454.6	309.8	66.5
13.0	MASS_CASE_1	455.2	310.4	67.0
14.0	MASS_CASE_1	454.6	309.8	66.5
15.0	MASS_CASE_1	492.4	323.4	62.7
16.0	MASS_CASE_1	280.4	183.9	44.8
17.0	MASS_CASE_1	36.9	36.9	36.9
18.0	MASS_CASE_1	44.2	44.2	44.2
19.0	MASS_CASE_1	44.8	44.8	44.8
20.0	MASS_CASE_1	44.2	44.2	44.2
21.0	MASS_CASE_1	40.4	40.4	40.4
22.0	MASS_CASE_1	33.0	33.0	33.0
23.0	MASS_CASE_1	26.0	26.0	26.0
24.0	MASS_CASE_1	14.8	14.8	14.8
40.0	MASS_CASE_1	39.5	39.5	39.5
56.0	MASS_CASE_1	0.0	0.0	0.0
57.0	MASS_CASE_1	29.9	29.9	29.9
58.0	MASS_CASE_1	29.2	29.2	29.2
SumAccelUX	MASS_CASE_1	7821.8	0.0	0.0
SumAccelUY	MASS_CASE_1	0.0	5208.6	0.0
SumAccelUZ	MASS_CASE_1	0.0	0.0	1645.2

Static Seismic Loads			
Joint	Load Case		
	EQX_STATIC	EQY_STATIC	EQZ_STATIC
1.0	444.2	329.7	70.7
2.0	888.5	659.5	141.4
3.0	888.5	659.5	141.4
4.0	1432.5	826.2	149.3
5.0	1498.3	760.6	126.8
6.0	1291.2	664.1	117.6
7.0	1387.6	816.9	124.7
8.0	1051.1	719.8	91.5
9.0	1069.5	729.0	87.9
10.0	1247.1	849.6	101.8
11.0	1247.5	850.1	102.1
12.0	1247.5	850.1	102.1
13.0	1249.1	851.6	103.0
14.0	1247.5	850.1	102.1
15.0	1351.2	887.5	96.4
16.0	769.5	504.5	68.8
17.0	101.1	101.1	56.6
18.0	121.4	121.4	68.0
19.0	122.9	122.9	68.8
20.0	121.4	121.4	68.0
21.0	110.9	110.9	62.1
22.0	90.6	90.6	50.8
23.0	71.2	71.2	39.9
24.0	40.7	40.7	22.8
40.0	108.3	108.3	60.7
56.0	0.0	0.0	0.0
57.0	82.1	82.1	46.0
58.0	80.2	80.2	44.9

Project: Springbank Off-Stream Storage — By: ACG - 10/09/2019
Title: Foundation Stiffness Calculations Per FEMA 356 — Checked: CG - 10/09/2019
Structure: Low Level Outlet Gate Tower

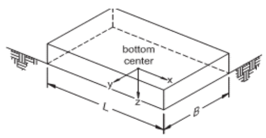
FEMA equations are to be used with U.S. Customary Units, therefore, the inputs are converted from SI for use with the equations and the final values are converted back.

B (m)	L (m)	D (m)	d (m)	h (m)	L/B	D/B	G (MPa)	v
6.40	10.00	18.94	1.8	18.04	1.56	2.96	10	0.45

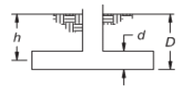
B (ft)	L (ft)	D (ft)	d (ft)	h (ft)	L/B	D/B	G (psf)	v
21.0	32.8	62.1	5.9	59.19	1.56	2.96	208,854	0.45

Chapter 4: Foundations and Geologic Site Hazards

Degree of Freedom	Stiffness of Foundation at Surface	Note
Translation along x-axis	$K_{x,sur} = \frac{GB}{2-v}\left[3.4\left(\frac{L}{B}\right)^{0.65} + 1.2\right]$	
Translation along y-axis	$K_{y,sur} = \frac{GB}{2-v}\left[3.4\left(\frac{L}{B}\right)^{0.65} + 0.4\frac{L}{B} + 0.8\right]$	
Translation along z-axis	$K_{z,sur} = \frac{GB}{1-v}\left[1.55\left(\frac{L}{B}\right)^{0.75} + 0.8\right]$	
Rocking about x-axis	$K_{xx,sur} = \frac{GB^3}{1-v}\left[0.4\left(\frac{L}{B}\right) + 0.1\right]$	
Rocking about y-axis	$K_{yy,sur} = \frac{GB^3}{1-v}\left[0.47\left(\frac{L}{B}\right)^{2.4} + 0.034\right]$	Orient axes such that $L \geq B$
Torsion about z-axis	$K_{zz,sur} = GB^3\left[0.53\left(\frac{L}{B}\right)^{2.45} + 0.51\right]$	



Degree of Freedom	Correction Factor for Embedment	Note
Translation along x-axis	$\beta_x = \left(1 + 0.21\sqrt{\frac{D}{B}}\right) \cdot \left[1 + 1.6\left(\frac{hd(B+L)}{BL^2}\right)^{0.4}\right]$	
Translation along y-axis	$\beta_y = \beta_x$	
Translation along z-axis	$\beta_z = \left[1 + \frac{1}{21}\frac{D}{B}\left(2 + 2.6\frac{B}{L}\right)\right] \cdot \left[1 + 0.32\left(\frac{d(B+L)}{BL}\right)^{2/3}\right]$	d = height of effective sidewall contact (may be less than total foundation height)
Rocking about x-axis	$\beta_{xx} = 1 + 2.5\frac{d}{B}\left[1 + \frac{2d}{B}\left(\frac{d}{D}\right)^{-0.2}\sqrt{\frac{B}{L}}\right]$	h = depth to centroid of effective sidewall contact
Rocking about y-axis	$\beta_{yy} = 1 + 1.4\left(\frac{d}{L}\right)^{0.6}\left[1.5 + 3.7\left(\frac{d}{L}\right)^{1.9}\left(\frac{d}{D}\right)^{-0.6}\right]$	For each degree of freedom, calculate $K_{emb} = \beta K_{sur}$
Torsion about z-axis	$\beta_{zz} = 1 + 2.6\left(1 + \frac{B}{L}\right)\left(\frac{d}{B}\right)^{0.9}$	



FEMA 356, Figure 4-4

Note: When L = B, use x-axis rocking stiffness and embedment correction factor for Y-axis rocking

* Axis Orientation is based on FEMA 356. See below for SAP2000 equivalent.

$X_{fema} = Y_{SAP}$; $Y_{fema} = X_{SAP}$; $Z_{fema} = Z_{SAP}$

	Correction Factors for Embedment*					
	Translational			Rocking		Torsion
Site	β_x	β_y	β_z	β_{xx}	β_{yy}	β_{zz}
Gate Tower	3.38	3.38	1.81	2.21	2.04	2.36

	Stiffness of Foundation at Surface*					
	Translational (lb/ft)			Rocking (lb-ft/rad)		Torsion (lb-ft/rad)
Site	$k_{x,sur}$	$k_{y,sur}$	$k_{z,sur}$	$k_{xx,sur}$	$k_{yy,sur}$	$k_{zz,sur}$
Gate Tower	16,252,907	16,889,527	23,651,900	2,549,044,113	4,942,408,153	4,044,916,973

	Stiffness of Foundation With Embedment Corrections*					
	Translational (kip/ft)			Rocking (kip-ft/rad)		Torsion (kip-ft/rad)
Site	$k_{x,emb}$	$k_{y,emb}$	$k_{z,emb}$	$k_{xx,emb}$	$k_{yy,emb}$	$k_{zz,emb}$
Gate Tower	55,014	57,169	42,716	5,632,691	10,096,448	9,551,854

	Stiffness of Foundation With Embedment Corrections*					
	Translational (kN/m)			Rocking (kN-m/rad)		Torsion (kN-m/rad)
Site	$k_{x,emb}$	$k_{y,emb}$	$k_{z,emb}$	$k_{xx,emb}$	$k_{yy,emb}$	$k_{zz,emb}$
Gate Tower	802,877	834,326	623,391	7,637,928	13,690,784	12,952,314

Nodal Stiffnesses

	Nodes
	Total
mid	466
edge	86

	Translational (kN/m)			Rocking (kN-m/rad)		Torsion (kN-m/rad)
	$k_{x,emb}$	$k_{y,emb}$	$k_{z,emb}$	$k_{xx,emb}$	$k_{yy,emb}$	$k_{zz,emb}$
mid	1577	1639	1225	15006	26897	25447
edge	789	820	612	7503	13449	12723

Project: **Springbank Off-Stream Storage** By: ACG - 10/09/2019
Title: **Non-Linear Soil Springs (Y-Direction, Saturated)** Checked: CG - 10/09/2019
Structure: **Low Level Outlet Gate Tower**

TABLE: Link Property Definitions 11 - Multilinear Plastic

Link	DOF	Fixed	NonLinear	TransKE	RotKE	TransCE	RotCE	DJ	HysType	PivotAlpha1	PivotAlpha2	PivotBeta1	PivotBeta2	PivotEta	Force	Displ	Moment	Rotation
				KN/mm	KN-mm/rad	KN-s/mm	KN-mm-s/rad	m							KN	m	KN-mm	Radians
17Y	U1	No	Yes	0		0			Kinematic						0	-0.11228		
17Y	U1														0	-0.10637		
17Y	U1														0	-0.08273		
17Y	U1														0	-0.05909		
17Y	U1														0	-0.03546		
17Y	U1														0	-0.0325		
17Y	U1														0	-0.02955		
17Y	U1														0	-0.02659		
17Y	U1														0	-0.02364		
17Y	U1														0	-0.02068		
17Y	U1														0	-0.01773		
17Y	U1														0	-0.01477		
17Y	U1														0	-0.01182		
17Y	U1														0	-0.00886		
17Y	U1														0	-0.00591		
17Y	U1														0	-0.00295		
17Y	U1														0	0		
17Y	U1														0	0.00295		
17Y	U1														0	0.00591		
17Y	U1														0	0.00886		
17Y	U1														0	0.01182		
17Y	U1														0	0.01477		
17Y	U1														0	0.01773		
17Y	U1														0	0.02068		
17Y	U1														0	0.02364		
17Y	U1														0	0.02659		
17Y	U1														0	0.02955		
17Y	U1														0	0.0325		
17Y	U1														0	0.03546		
17Y	U1														0	0.05909		
17Y	U1														0	0.08273		
17Y	U1														0	0.10637		
17Y	U1														0	0.11228		
16Y	U1	No	Yes	0		0			Kinematic						-33.82029	-0.1488		
16Y	U1														-33.82029	-0.14097		
16Y	U1														-101.75482	-0.10964		
16Y	U1														-169.68935	-0.07831		
16Y	U1														-237.43071	-0.04699		
16Y	U1														-256.38452	-0.04307		
16Y	U1														-272.93659	-0.03916		
16Y	U1														-286.79127	-0.03524		
16Y	U1														-297.57243	-0.03133		
16Y	U1														-304.7868	-0.02741		
16Y	U1														-307.76166	-0.02349		
16Y	U1														-305.5295	-0.01958		
16Y	U1														-296.58743	-0.01566		
16Y	U1														-278.28095	-0.01175		
16Y	U1														-243.72516	-0.00783		
16Y	U1														-172.33971	-0.00392		
16Y	U1														0	0		
16Y	U1														172.33971	0.00392		
16Y	U1														243.72516	0.00783		
16Y	U1														278.28095	0.01175		
16Y	U1														296.58743	0.01566		

16Y	U1														305.5295	0.01958		
16Y	U1														307.76166	0.02349		
16Y	U1														304.7868	0.02741		
16Y	U1														297.57243	0.03133		
16Y	U1														286.79127	0.03524		
16Y	U1														272.93659	0.03916		
16Y	U1														256.38452	0.04307		
16Y	U1														237.43071	0.04699		
16Y	U1														169.68935	0.07831		
16Y	U1														101.75482	0.10964		
16Y	U1														33.82029	0.14097		
16Y	U1														33.82029	0.1488		
15Y	U1	No	Yes	0		0			Kinematic						-84.953225	-0.17993		
15Y	U1														-84.953225	-0.17046		
15Y	U1														-222.683075	-0.13258		
15Y	U1														-360.412925	-0.0947		
15Y	U1														-497.8189	-0.05682		
15Y	U1														-525.3498875	-0.05209		
15Y	U1														-548.6563625	-0.04735		
15Y	U1														-567.212075	-0.04262		
15Y	U1														-580.3471375	-0.03788		
15Y	U1														-587.1825125	-0.03315		
15Y	U1														-586.5188125	-0.02841		
15Y	U1														-576.6309875	-0.02368		
15Y	U1														-554.8414125	-0.01894		
15Y	U1														-516.43365	-0.01421		
15Y	U1														-449.3461375	-0.00947		
15Y	U1														-317.7357	-0.00474		
15Y	U1														0	0		
15Y	U1														317.7357	0.00474		
15Y	U1														449.3461375	0.00947		
15Y	U1														516.43365	0.01421		
15Y	U1														554.8414125	0.01894		
15Y	U1														576.6309875	0.02368		
15Y	U1														586.5188125	0.02841		
15Y	U1														587.1825125	0.03315		
15Y	U1														580.3471375	0.03788		
15Y	U1														567.212075	0.04262		
15Y	U1														548.6563625	0.04735		
15Y	U1														525.3498875	0.05209		
15Y	U1														497.8189	0.05682		
15Y	U1														360.412925	0.0947		
15Y	U1														222.683075	0.13258		
15Y	U1														84.953225	0.17046		
15Y	U1														84.953225	0.17993		
14Y	U1	No	Yes	0		0			Kinematic						-183.85314	-0.24046		
14Y	U1														-183.85314	-0.2278		
14Y	U1														-467.70324	-0.17718		
14Y	U1														-751.553355	-0.12656		
14Y	U1														-1035.403455	-0.07593		
14Y	U1														-1078.429815	-0.06961		
14Y	U1														-1114.1622	-0.06328		
14Y	U1														-1141.02855	-0.05695		
14Y	U1														-1157.76876	-0.05062		
14Y	U1														-1162.728675	-0.0443		
14Y	U1														-1153.65066	-0.03797		
14Y	U1														-1127.28744	-0.03164		
14Y	U1														-1078.6011	-0.02531		
14Y	U1														-998.73495	-0.01898		
14Y	U1														-865.264725	-0.01266		
14Y	U1														-611.83455	-0.00633		

14Y	U1														0	0		
14Y	U1														611.83455	0.00633		
14Y	U1														865.264725	0.01266		
14Y	U1														998.73495	0.01898		
14Y	U1														1078.6011	0.02531		
14Y	U1														1127.28744	0.03164		
14Y	U1														1153.65066	0.03797		
14Y	U1														1162.728675	0.0443		
14Y	U1														1157.76876	0.05062		
14Y	U1														1141.02855	0.05695		
14Y	U1														1114.1622	0.06328		
14Y	U1														1078.429815	0.06961		
14Y	U1														1035.403455	0.07593		
14Y	U1														751.553355	0.12656		
14Y	U1														467.70324	0.17718		
14Y	U1														183.85314	0.2278		
14Y	U1														183.85314	0.24046		
13Y	U1	No	Yes	0		0			Kinematic						-261.67101	-0.27202		
13Y	U1														-261.67101	-0.2577		
13Y	U1														-667.80039	-0.20044		
13Y	U1														-1073.92977	-0.14317		
13Y	U1														-1479.322185	-0.0859		
13Y	U1														-1527.219825	-0.07874		
13Y	U1														-1564.81704	-0.07158		
13Y	U1														-1590.810285	-0.06443		
13Y	U1														-1603.538655	-0.05727		
13Y	U1														-1600.821	-0.05011		
13Y	U1														-1579.6797	-0.04295		
13Y	U1														-1535.831745	-0.03579		
13Y	U1														-1462.635195	-0.02863		
13Y	U1														-1348.433745	-0.02148		
13Y	U1														-1163.97921	-0.01432		
13Y	U1														-823.057605	-0.00716		
13Y	U1														0	0		
13Y	U1														823.057605	0.00716		
13Y	U1														1163.97921	0.01432		
13Y	U1														1348.433745	0.02148		
13Y	U1														1462.635195	0.02863		
13Y	U1														1535.831745	0.03579		
13Y	U1														1579.6797	0.04295		
13Y	U1														1600.821	0.05011		
13Y	U1														1603.538655	0.05727		
13Y	U1														1590.810285	0.06443		
13Y	U1														1564.81704	0.07158		
13Y	U1														1527.219825	0.07874		
13Y	U1														1479.322185	0.0859		
13Y	U1														1073.92977	0.14317		
13Y	U1														667.80039	0.20044		
13Y	U1														261.67101	0.2577		
13Y	U1														261.67101	0.27202		
12Y	U1	No	Yes	0		0			Kinematic						-335.258175	-0.29589		
12Y	U1														-335.258175	-0.28031		
12Y	U1														-869.508525	-0.21802		
12Y	U1														-1403.75889	-0.15573		
12Y	U1														-1937.117985	-0.09344		
12Y	U1														-1988.73825	-0.08565		
12Y	U1														-2027.607945	-0.07787		
12Y	U1														-2052.105315	-0.07008		
12Y	U1														-2060.163375	-0.06229		
12Y	U1														-2049.067095	-0.05451		
12Y	U1														-2015.1093	-0.04672		

12Y	U1														-1952.957535	-0.03893		
12Y	U1														-1854.34482	-0.03115		
12Y	U1														-1704.77973	-0.02336		
12Y	U1														-1468.12113	-0.01557		
12Y	U1														-1038.11841	-0.00779		
12Y	U1														0	0		
12Y	U1														1038.11841	0.00779		
12Y	U1														1468.12113	0.01557		
12Y	U1														1704.77973	0.02336		
12Y	U1														1854.34482	0.03115		
12Y	U1														1952.957535	0.03893		
12Y	U1														2015.1093	0.04672		
12Y	U1														2049.067095	0.05451		
12Y	U1														2060.163375	0.06229		
12Y	U1														2052.105315	0.07008		
12Y	U1														2027.607945	0.07787		
12Y	U1														1988.73825	0.08565		
12Y	U1														1937.117985	0.09344		
12Y	U1														1403.75889	0.15573		
12Y	U1														869.508525	0.21802		
12Y	U1														335.258175	0.28031		
12Y	U1														335.258175	0.29589		
11Y	U1	No	Yes	0		0			Kinematic						-404.900325	-0.31312		
11Y	U1														-404.900325	-0.29664		
11Y	U1														-1068.13191	-0.23072		
11Y	U1														-1731.363495	-0.1648		
11Y	U1														-2394.59508	-0.09888		
11Y	U1														-2448.95049	-0.09064		
11Y	U1														-2489.153445	-0.0824		
11Y	U1														-2512.218855	-0.07416		
11Y	U1														-2515.67418	-0.06592		
11Y	U1														-2496.2712	-0.05768		
11Y	U1														-2449.57422	-0.04944		
11Y	U1														-2369.20269	-0.0412		
11Y	U1														-2245.266765	-0.03296		
11Y	U1														-2060.44359	-0.02472		
11Y	U1														-1771.706085	-0.01648		
11Y	U1														-1252.78539	-0.00824		
11Y	U1														0	0		
11Y	U1														1252.78539	0.00824		
11Y	U1														1771.706085	0.01648		
11Y	U1														2060.44359	0.02472		
11Y	U1														2245.266765	0.03296		
11Y	U1														2369.20269	0.0412		
11Y	U1														2449.57422	0.04944		
11Y	U1														2496.2712	0.05768		
11Y	U1														2515.67418	0.06592		
11Y	U1														2512.218855	0.07416		
11Y	U1														2489.153445	0.0824		
11Y	U1														2448.95049	0.09064		
11Y	U1														2394.59508	0.09888		
11Y	U1														1731.363495	0.1648		
11Y	U1														1068.13191	0.23072		
11Y	U1														404.900325	0.29664		
11Y	U1														404.900325	0.31312		
10Y	U1	No	Yes	0		0			Kinematic						-471.494955	-0.32476		
10Y	U1														-471.494955	-0.30767		
10Y	U1														-1260.90333	-0.2393		
10Y	U1														-2050.311705	-0.17093		
10Y	U1														-2838.520245	-0.10256		
10Y	U1														-2898.189825	-0.09401		

10Y	U1														-2940.2367	-0.08546		
10Y	U1														-2962.407015	-0.07692		
10Y	U1														-2961.82725	-0.06837		
10Y	U1														-2934.72195	-0.05982		
10Y	U1														-2875.935105	-0.05128		
10Y	U1														-2778.049905	-0.04273		
10Y	U1														-2629.57182	-0.03419		
10Y	U1														-2410.37703	-0.02564		
10Y	U1														-2070.612165	-0.01709		
10Y	U1														-1464.14391	-0.00855		
10Y	U1														0	0		
10Y	U1														1464.14391	0.00855		
10Y	U1														2070.612165	0.01709		
10Y	U1														2410.37703	0.02564		
10Y	U1														2629.57182	0.03419		
10Y	U1														2778.049905	0.04273		
10Y	U1														2875.935105	0.05128		
10Y	U1														2934.72195	0.05982		
10Y	U1														2961.82725	0.06837		
10Y	U1														2962.407015	0.07692		
10Y	U1														2940.2367	0.08546		
10Y	U1														2898.189825	0.09401		
10Y	U1														2838.520245	0.10256		
10Y	U1														2050.311705	0.17093		
10Y	U1														1260.90333	0.2393		
10Y	U1														471.494955	0.30767		
10Y	U1														471.494955	0.32476		
9Y	U1	No	Yes	0		0			Kinematic						-444.3365438	-0.33188		
9Y	U1														-444.3365438	-0.31441		
9Y	U1														-1199.168768	-0.24454		
9Y	U1														-1954.000991	-0.17467		
9Y	U1														-2707.710528	-0.1048		
9Y	U1														-2761.342898	-0.09607		
9Y	U1														-2798.383101	-0.08734		
9Y	U1														-2816.706365	-0.0786		
9Y	U1														-2813.603554	-0.06987		
9Y	U1														-2785.514999	-0.06114		
9Y	U1														-2727.579126	-0.0524		
9Y	U1														-2632.802673	-0.04367		
9Y	U1														-2490.348245	-0.03493		
9Y	U1														-2281.248131	-0.0262		
9Y	U1														-1958.585544	-0.01747		
9Y	U1														-1384.929123	-0.00873		
9Y	U1														0	0		
9Y	U1														1384.929123	0.00873		
9Y	U1														1958.585544	0.01747		
9Y	U1														2281.248131	0.0262		
9Y	U1														2490.348245	0.03493		
9Y	U1														2632.802673	0.04367		
9Y	U1														2727.579126	0.0524		
9Y	U1														2785.514999	0.06114		
9Y	U1														2813.603554	0.06987		
9Y	U1														2816.706365	0.0786		
9Y	U1														2798.383101	0.08734		
9Y	U1														2761.342898	0.09607		
9Y	U1														2707.710528	0.1048		
9Y	U1														1954.000991	0.17467		
9Y	U1														1199.168768	0.24454		
9Y	U1														444.3365438	0.31441		
9Y	U1														444.3365438	0.33188		
8Y	U1	No	Yes	0		0			Kinematic						-405.077525	-0.3351		

8Y	U1														-405.077525	-0.31747		
8Y	U1														-1097.958575	-0.24692		
8Y	U1														-1790.839638	-0.17637		
8Y	U1														-2482.700075	-0.10582		
8Y	U1														-2530.556563	-0.097		
8Y	U1														-2563.287338	-0.08818		
8Y	U1														-2578.9543	-0.07937		
8Y	U1														-2575.086275	-0.07055		
8Y	U1														-2548.436163	-0.06173		
8Y	U1														-2494.569188	-0.05291		
8Y	U1														-2407.106038	-0.04409		
8Y	U1														-2276.16105	-0.03527		
8Y	U1														-2084.434463	-0.02646		
8Y	U1														-1789.16475	-0.01764		
8Y	U1														-1265.130525	-0.00882		
8Y	U1														0	0		
8Y	U1														1265.130525	0.00882		
8Y	U1														1789.16475	0.01764		
8Y	U1														2084.434463	0.02646		
8Y	U1														2276.16105	0.03527		
8Y	U1														2407.106038	0.04409		
8Y	U1														2494.569188	0.05291		
8Y	U1														2548.436163	0.06173		
8Y	U1														2575.086275	0.07055		
8Y	U1														2578.9543	0.07937		
8Y	U1														2563.287338	0.08818		
8Y	U1														2530.556563	0.097		
8Y	U1														2482.700075	0.10582		
8Y	U1														1790.839638	0.17637		
8Y	U1														1097.958575	0.24692		
8Y	U1														405.077525	0.31747		
8Y	U1														405.077525	0.3351		
7Y	U1	No	Yes	0		0			Kinematic						-290.0493356	-0.33516		
7Y	U1														-290.0493356	-0.31752		
7Y	U1														-786.2373356	-0.24696		
7Y	U1														-1282.425336	-0.1764		
7Y	U1														-1777.882568	-0.10584		
7Y	U1														-1812.136348	-0.09702		
7Y	U1														-1835.559581	-0.0882		
7Y	U1														-1846.764516	-0.07938		
7Y	U1														-1843.981665	-0.07056		
7Y	U1														-1824.885981	-0.06174		
7Y	U1														-1786.301976	-0.05292		
7Y	U1														-1723.661768	-0.0441		
7Y	U1														-1629.8868	-0.03528		
7Y	U1														-1492.589728	-0.02646		
7Y	U1														-1281.151903	-0.01764		
7Y	U1														-905.9112045	-0.00882		
7Y	U1														0	0		
7Y	U1														905.9112045	0.00882		
7Y	U1														1281.151903	0.01764		
7Y	U1														1492.589728	0.02646		
7Y	U1														1629.8868	0.03528		
7Y	U1														1723.661768	0.0441		
7Y	U1														1786.301976	0.05292		
7Y	U1														1824.885981	0.06174		
7Y	U1														1843.981665	0.07056		
7Y	U1														1846.764516	0.07938		
7Y	U1														1835.559581	0.0882		
7Y	U1														1812.136348	0.09702		
7Y	U1														1777.882568	0.10584		

7Y	U1														1282.425336	0.1764		
7Y	U1														786.2373356	0.24696		
7Y	U1														290.0493356	0.31752		
7Y	U1														290.0493356	0.33516		
6Y	U1	No	Yes	0		0			Kinematic						-423.683877	-0.42634		
6Y	U1														-423.683877	-0.4039		
6Y	U1														-1143.005125	-0.31414		
6Y	U1														-1862.326373	-0.22439		
6Y	U1														-2580.576846	-0.13463		
6Y	U1														-2631.812435	-0.12341		
6Y	U1														-2667.226835	-0.11219		
6Y	U1														-2684.794112	-0.10097		
6Y	U1														-2681.931145	-0.08975		
6Y	U1														-2655.243845	-0.07854		
6Y	U1														-2600.096821	-0.06732		
6Y	U1														-2509.822129	-0.0561		
6Y	U1														-2374.086526	-0.04488		
6Y	U1														-2174.804424	-0.03366		
6Y	U1														-1867.238306	-0.02244		
6Y	U1														-1320.336868	-0.01122		
6Y	U1														0	0		
6Y	U1														1320.336868	0.01122		
6Y	U1														1867.238306	0.02244		
6Y	U1														2174.804424	0.03366		
6Y	U1														2374.086526	0.04488		
6Y	U1														2509.822129	0.0561		
6Y	U1														2600.096821	0.06732		
6Y	U1														2655.243845	0.07854		
6Y	U1														2681.931145	0.08975		
6Y	U1														2684.794112	0.10097		
6Y	U1														2667.226835	0.11219		
6Y	U1														2631.812435	0.12341		
6Y	U1														2580.576846	0.13463		
6Y	U1														1862.326373	0.22439		
6Y	U1														1143.005125	0.31414		
6Y	U1														423.683877	0.4039		
6Y	U1														423.683877	0.42634		
5Y	U1	No	Yes	0		0			Kinematic						-101.852916	-0.09576		
5Y	U1														-101.852916	-0.09072		
5Y	U1														-276.092916	-0.07056		
5Y	U1														-450.332916	-0.0504		
5Y	U1														-624.316308	-0.03024		
5Y	U1														-636.344764	-0.02772		
5Y	U1														-644.570003	-0.0252		
5Y	U1														-648.504692	-0.02268		
5Y	U1														-647.527485	-0.02016		
5Y	U1														-640.821896	-0.01764		
5Y	U1														-627.272844	-0.01512		
5Y	U1														-605.276276	-0.0126		
5Y	U1														-572.346522	-0.01008		
5Y	U1														-524.133665	-0.00756		
5Y	U1														-449.885744	-0.00504		
5Y	U1														-318.117261	-0.00252		
5Y	U1														0	0		
5Y	U1														318.117261	0.00252		
5Y	U1														449.885744	0.00504		
5Y	U1														524.133665	0.00756		
5Y	U1														572.346522	0.01008		
5Y	U1														605.276276	0.0126		
5Y	U1														627.272844	0.01512		
5Y	U1														640.821896	0.01764		

5Y	U1														647.527485	0.02016		
5Y	U1														648.504692	0.02268		
5Y	U1														644.570003	0.0252		
5Y	U1														636.344764	0.02772		
5Y	U1														624.316308	0.03024		
5Y	U1														450.332916	0.0504		
5Y	U1														276.092916	0.07056		
5Y	U1														101.852916	0.09072		
5Y	U1														101.852916	0.09576		
4Y	U1	No	Yes	0		0			Kinematic						-74.074848	-0.09576		
4Y	U1														-74.074848	-0.09072		
4Y	U1														-200.794848	-0.07056		
4Y	U1														-327.514848	-0.0504		
4Y	U1														-454.048224	-0.03024		
4Y	U1														-462.796192	-0.02772		
4Y	U1														-468.778184	-0.0252		
4Y	U1														-471.639776	-0.02268		
4Y	U1														-470.92908	-0.02016		
4Y	U1														-466.052288	-0.01764		
4Y	U1														-456.198432	-0.01512		
4Y	U1														-440.200928	-0.0126		
4Y	U1														-416.252016	-0.01008		
4Y	U1														-381.18812	-0.00756		
4Y	U1														-327.189632	-0.00504		
4Y	U1														-231.358008	-0.00252		
4Y	U1														0	0		
4Y	U1														231.358008	0.00252		
4Y	U1														327.189632	0.00504		
4Y	U1														381.18812	0.00756		
4Y	U1														416.252016	0.01008		
4Y	U1														440.200928	0.0126		
4Y	U1														456.198432	0.01512		
4Y	U1														466.052288	0.01764		
4Y	U1														470.92908	0.02016		
4Y	U1														471.639776	0.02268		
4Y	U1														468.778184	0.0252		
4Y	U1														462.796192	0.02772		
4Y	U1														454.048224	0.03024		
4Y	U1														327.514848	0.0504		
4Y	U1														200.794848	0.07056		
4Y	U1														74.074848	0.09072		
4Y	U1														74.074848	0.09576		
3Y	U1	No	Yes	0		0			Kinematic						-83.334204	-0.09576		
3Y	U1														-83.334204	-0.09072		
3Y	U1														-225.894204	-0.07056		
3Y	U1														-368.454204	-0.0504		
3Y	U1														-510.804252	-0.03024		
3Y	U1														-520.645716	-0.02772		
3Y	U1														-527.375457	-0.0252		
3Y	U1														-530.594748	-0.02268		
3Y	U1														-529.795215	-0.02016		
3Y	U1														-524.308824	-0.01764		
3Y	U1														-513.223236	-0.01512		
3Y	U1														-495.226044	-0.0126		
3Y	U1														-468.283518	-0.01008		
3Y	U1														-428.836635	-0.00756		
3Y	U1														-368.088336	-0.00504		
3Y	U1														-260.277759	-0.00252		
3Y	U1														0	0		
3Y	U1														260.277759	0.00252		
3Y	U1														368.088336	0.00504		

3Y	U1														428.836635	0.00756		
3Y	U1														468.283518	0.01008		
3Y	U1														495.226044	0.0126		
3Y	U1														513.223236	0.01512		
3Y	U1														524.308824	0.01764		
3Y	U1														529.795215	0.02016		
3Y	U1														530.594748	0.02268		
3Y	U1														527.375457	0.0252		
3Y	U1														520.645716	0.02772		
3Y	U1														510.804252	0.03024		
3Y	U1														368.454204	0.0504		
3Y	U1														225.894204	0.07056		
3Y	U1														83.334204	0.09072		
3Y	U1														83.334204	0.09576		
2Y	U1	No	Yes	0		0			Kinematic						-331.149303	-0.25368		
2Y	U1														-331.149303	-0.24033		
2Y	U1														-897.647103	-0.18693		
2Y	U1														-1464.144903	-0.13352		
2Y	U1														-2030.642703	-0.08011		
2Y	U1														-2068.915932	-0.07343		
2Y	U1														-2095.658231	-0.06676		
2Y	U1														-2108.450898	-0.06008		
2Y	U1														-2105.273727	-0.05341		
2Y	U1														-2083.472186	-0.04673		
2Y	U1														-2039.420822	-0.04006		
2Y	U1														-1967.904504	-0.03338		
2Y	U1														-1860.841634	-0.0267		
2Y	U1														-1704.089583	-0.02003		
2Y	U1														-1462.691034	-0.01335		
2Y	U1														-1034.27874	-0.00668		
2Y	U1														0	0		
2Y	U1														1034.27874	0.00668		
2Y	U1														1462.691034	0.01335		
2Y	U1														1704.089583	0.02003		
2Y	U1														1860.841634	0.0267		
2Y	U1														1967.904504	0.03338		
2Y	U1														2039.420822	0.04006		
2Y	U1														2083.472186	0.04673		
2Y	U1														2105.273727	0.05341		
2Y	U1														2108.450898	0.06008		
2Y	U1														2095.658231	0.06676		
2Y	U1														2068.915932	0.07343		
2Y	U1														2030.642703	0.08011		
2Y	U1														1464.144903	0.13352		
2Y	U1														897.647103	0.18693		
2Y	U1														331.149303	0.24033		
2Y	U1														331.149303	0.25368		

Project:	**Springbank Off-Stream Storage**	By:	ACG - 10/09/2019
Title:	**Non-Linear Soil Springs (X-Direction, Saturated)**	Checked:	CG - 10/09/2019
Structure:	**Low Level Outlet Gate Tower**		

TABLE: Link Property Definitions 11 - Multilinear Plastic

Link	DOF	Fixed	NonLinear	TransKE	RotKE	TransCE	RotCE	DJ	HysType	PivotAlpha1	PivotAlpha2	PivotBeta1	PivotBeta2	PivotEta	Force	Displ	Moment	Rotation
				KN/mm	KN-mm/rad	KN-s/mm	KN-mm-s/rad	mm							KN	m	KN-mm	Radians
17X	U1	No	Yes	0		0			Kinematic						0	-0.19025		
17X	U1														0	-0.18024		
17X	U1														0	-0.14018		
17X	U1														0	-0.10013		
17X	U1														0	-0.06008		
17X	U1														0	-0.05507		
17X	U1														0	-0.05007		
17X	U1														0	-0.04506		
17X	U1														0	-0.04005		
17X	U1														0	-0.03505		
17X	U1														0	-0.03004		
17X	U1														0	-0.02503		
17X	U1														0	-0.02003		
17X	U1														0	-0.01502		
17X	U1														0	-0.01001		
17X	U1														0	-0.00501		
17X	U1														0	0		
17X	U1														0	0.00501		
17X	U1														0	0.01001		
17X	U1														0	0.01502		
17X	U1														0	0.02003		
17X	U1														0	0.02503		
17X	U1														0	0.03004		
17X	U1														0	0.03505		
17X	U1														0	0.04005		
17X	U1														0	0.04506		
17X	U1														0	0.05007		
17X	U1														0	0.05507		
17X	U1														0	0.06008		
17X	U1														0	0.10013		
17X	U1														0	0.14018		
17X	U1														0	0.18024		
17X	U1														0	0.19025		
16X	U1	No	Yes	0		0			Kinematic						-36.35339	-0.22791		
16X	U1														-36.35339	-0.21592		
16X	U1														-129.36686	-0.16794		
16X	U1														-222.38034	-0.11995		
16X	U1														-315.10123	-0.07197		
16X	U1														-345.70477	-0.06597		
16X	U1														-372.75884	-0.05998		
16X	U1														-395.82926	-0.05398		
16X	U1														-414.36386	-0.04798		
16X	U1														-427.63877	-0.04198		
16X	U1														-434.66696	-0.03599		
16X	U1														-434.02892	-0.02999		
16X	U1														-423.51885	-0.02399		
16X	U1														-399.23482	-0.01799		
16X	U1														-350.98012	-0.012		
16X	U1														-248.18043	-0.006		
16X	U1														0	0		
16X	U1														248.18043	0.006		
16X	U1														350.98012	0.012		
16X	U1														399.23482	0.01799		
16X	U1														423.51885	0.02399		

16X	U1														434.02892	0.02999		
16X	U1														434.66696	0.03599		
16X	U1														427.63877	0.04198		
16X	U1														414.36386	0.04798		
16X	U1														395.82926	0.05398		
16X	U1														372.75884	0.05998		
16X	U1														345.70477	0.06597		
16X	U1														315.10123	0.07197		
16X	U1														222.38034	0.11995		
16X	U1														129.36686	0.16794		
16X	U1														36.35339	0.21592		
16X	U1														36.35339	0.22791		
15X	U1	No	Yes	0		0			Kinematic						-89.723275	-0.2623		
15X	U1														-89.723275	-0.24849		
15X	U1														-258.72955	-0.19327		
15X	U1														-427.735825	-0.13805		
15X	U1														-596.2801625	-0.08283		
15X	U1														-640.392125	-0.07593		
15X	U1														-678.704175	-0.06903		
15X	U1														-710.5005625	-0.06212		
15X	U1														-734.8705875	-0.05522		
15X	U1														-750.6198375	-0.04832		
15X	U1														-756.119125	-0.04142		
15X	U1														-749.0254	-0.03451		
15X	U1														-725.6996125	-0.02761		
15X	U1														-679.7179	-0.02071		
15X	U1														-594.467925	-0.01381		
15X	U1														-420.3523	-0.0069		
15X	U1														0	0		
15X	U1														420.3523	0.0069		
15X	U1														594.467925	0.01381		
15X	U1														679.7179	0.02071		
15X	U1														725.6996125	0.02761		
15X	U1														749.0254	0.03451		
15X	U1														756.119125	0.04142		
15X	U1														750.6198375	0.04832		
15X	U1														734.8705875	0.05522		
15X	U1														710.5005625	0.06212		
15X	U1														678.704175	0.06903		
15X	U1														640.392125	0.07593		
15X	U1														596.2801625	0.08283		
15X	U1														427.735825	0.13805		
15X	U1														258.72955	0.19327		
15X	U1														89.723275	0.24849		
15X	U1														89.723275	0.2623		
14X	U1	No	Yes	0		0			Kinematic						-196.42986	-0.32846		
14X	U1														-196.42986	-0.31117		
14X	U1														-518.959875	-0.24202		
14X	U1														-841.48989	-0.17287		
14X	U1														-1164.019905	-0.10372		
14X	U1														-1230.05466	-0.09508		
14X	U1														-1286.82672	-0.08644		
14X	U1														-1332.31422	-0.07779		
14X	U1														-1364.9277	-0.06915		
14X	U1														-1382.581665	-0.0605		
14X	U1														-1382.430705	-0.05186		
14X	U1														-1360.38237	-0.04322		
14X	U1														-1310.0838	-0.03457		
14X	U1														-1220.341905	-0.02593		
14X	U1														-1062.491085	-0.01729		
14X	U1														-751.29465	-0.00864		

14X	U1														0	0		
14X	U1														751.29465	0.00864		
14X	U1														1062.491085	0.01729		
14X	U1														1220.341905	0.02593		
14X	U1														1310.0838	0.03457		
14X	U1														1360.38237	0.04322		
14X	U1														1382.430705	0.05186		
14X	U1														1382.581665	0.0605		
14X	U1														1364.9277	0.06915		
14X	U1														1332.31422	0.07779		
14X	U1														1286.82672	0.08644		
14X	U1														1230.05466	0.09508		
14X	U1														1164.019905	0.10372		
14X	U1														841.48989	0.17287		
14X	U1														518.959875	0.24202		
14X	U1														196.42986	0.31117		
14X	U1														196.42986	0.32846		
13X	U1	No	Yes	0		0			Kinematic						-287.175855	-0.36927		
13X	U1														-287.175855	-0.34983		
13X	U1														-733.787625	-0.27209		
13X	U1														-1180.399395	-0.19435		
13X	U1														-1627.011165	-0.11661		
13X	U1														-1700.11494	-0.10689		
13X	U1														-1761.42666	-0.09718		
13X	U1														-1808.396835	-0.08746		
13X	U1														-1838.99166	-0.07774		
13X	U1														-1850.54157	-0.06802		
13X	U1														-1839.403365	-0.05831		
13X	U1														-1800.337005	-0.04859		
13X	U1														-1725.211665	-0.03887		
13X	U1														-1599.725715	-0.02915		
13X	U1														-1387.567425	-0.01944		
13X	U1														-981.15834	-0.00972		
13X	U1														0	0		
13X	U1														981.15834	0.00972		
13X	U1														1387.567425	0.01944		
13X	U1														1599.725715	0.02915		
13X	U1														1725.211665	0.03887		
13X	U1														1800.337005	0.04859		
13X	U1														1839.403365	0.05831		
13X	U1														1850.54157	0.06802		
13X	U1														1838.99166	0.07774		
13X	U1														1808.396835	0.08746		
13X	U1														1761.42666	0.09718		
13X	U1														1700.11494	0.10689		
13X	U1														1627.011165	0.11661		
13X	U1														1180.399395	0.19435		
13X	U1														733.787625	0.27209		
13X	U1														287.175855	0.34983		
13X	U1														287.175855	0.36927		
12X	U1	No	Yes	0		0			Kinematic						-377.508015	-0.40443		
12X	U1														-377.508015	-0.38315		
12X	U1														-958.661895	-0.298		
12X	U1														-1539.81576	-0.21286		
12X	U1														-2119.838145	-0.12772		
12X	U1														-2199.82407	-0.11707		
12X	U1														-2264.295645	-0.10643		
12X	U1														-2311.297845	-0.09579		
12X	U1														-2338.340235	-0.08514		
12X	U1														-2342.153055	-0.0745		
12X	U1														-2318.273145	-0.06386		

12X	U1														-2260.280895	-0.05321		
12X	U1														-2158.218465	-0.04257		
12X	U1														-1994.593125	-0.03193		
12X	U1														-1725.28608	-0.02129		
12X	U1														-1219.961475	-0.01064		
12X	U1														0	0		
12X	U1														1219.961475	0.01064		
12X	U1														1725.28608	0.02129		
12X	U1														1994.593125	0.03193		
12X	U1														2158.218465	0.04257		
12X	U1														2260.280895	0.05321		
12X	U1														2318.273145	0.06386		
12X	U1														2342.153055	0.0745		
12X	U1														2338.340235	0.08514		
12X	U1														2311.297845	0.09579		
12X	U1														2264.295645	0.10643		
12X	U1														2199.82407	0.11707		
12X	U1														2119.838145	0.12772		
12X	U1														1539.81576	0.21286		
12X	U1														958.661895	0.298		
12X	U1														377.508015	0.38315		
12X	U1														377.508015	0.40443		
11X	U1	No	Yes	0		0			Kinematic						-465.73026	-0.43437		
11X	U1														-465.73026	-0.41151		
11X	U1														-1188.72432	-0.32006		
11X	U1														-1911.718395	-0.22862		
11X	U1														-2633.401815	-0.13717		
11X	U1														-2718.47526	-0.12574		
11X	U1														-2785.2252	-0.11431		
11X	U1														-2831.332605	-0.10288		
11X	U1														-2853.842655	-0.09145		
11X	U1														-2848.87509	-0.08002		
11X	U1														-2811.13257	-0.06858		
11X	U1														-2732.995515	-0.05715		
11X	U1														-2602.647765	-0.04572		
11X	U1														-2399.352705	-0.03429		
11X	U1														-2071.08165	-0.02286		
11X	U1														-1464.475875	-0.01143		
11X	U1														0	0		
11X	U1														1464.475875	0.01143		
11X	U1														2071.08165	0.02286		
11X	U1														2399.352705	0.03429		
11X	U1														2602.647765	0.04572		
11X	U1														2732.995515	0.05715		
11X	U1														2811.13257	0.06858		
11X	U1														2848.87509	0.08002		
11X	U1														2853.842655	0.09145		
11X	U1														2831.332605	0.10288		
11X	U1														2785.2252	0.11431		
11X	U1														2718.47526	0.12574		
11X	U1														2633.401815	0.13717		
11X	U1														1911.718395	0.22862		
11X	U1														1188.72432	0.32006		
11X	U1														465.73026	0.41151		
11X	U1														465.73026	0.43437		
10X	U1	No	Yes	0		0			Kinematic						-551.208075	-0.4595		
10X	U1														-551.208075	-0.43531		
10X	U1														-1420.554795	-0.33858		
10X	U1														-2289.901515	-0.24184		
10X	U1														-3157.75845	-0.1451		
10X	U1														-3247.45992	-0.13301		

10X	U1														-3316.007295	-0.12092		
10X	U1														-3360.714315	-0.10883		
10X	U1														-3378.157485	-0.09674		
10X	U1														-3363.84036	-0.08464		
10X	U1														-3311.623755	-0.07255		
10X	U1														-3212.67696	-0.06046		
10X	U1														-3053.308365	-0.04837		
10X	U1														-2809.508745	-0.03628		
10X	U1														-2421.283425	-0.02418		
10X	U1														-1712.10594	-0.01209		
10X	U1														0	0		
10X	U1														1712.10594	0.01209		
10X	U1														2421.283425	0.02418		
10X	U1														2809.508745	0.03628		
10X	U1														3053.308365	0.04837		
10X	U1														3212.67696	0.06046		
10X	U1														3311.623755	0.07255		
10X	U1														3363.84036	0.08464		
10X	U1														3378.157485	0.09674		
10X	U1														3360.714315	0.10883		
10X	U1														3316.007295	0.12092		
10X	U1														3247.45992	0.13301		
10X	U1														3157.75845	0.1451		
10X	U1														2289.901515	0.24184		
10X	U1														1420.554795	0.33858		
10X	U1														551.208075	0.43531		
10X	U1														551.208075	0.4595		
9X	U1	No	Yes	0		0			Kinematic						-581.0690463	-0.48022		
9X	U1														-581.0690463	-0.45494		
9X	U1														-1514.054933	-0.35384		
9X	U1														-2447.040833	-0.25275		
9X	U1														-3378.49688	-0.15165		
9X	U1														-3464.828304	-0.13901		
9X	U1														-3529.1674	-0.12637		
9X	U1														-3568.714078	-0.11374		
9X	U1														-3579.899276	-0.1011		
9X	U1														-3558.034783	-0.08846		
9X	U1														-3496.71894	-0.07582		
9X	U1														-3386.743429	-0.06319		
9X	U1														-3213.833356	-0.05055		
9X	U1														-2952.97178	-0.03791		
9X	U1														-2541.844608	-0.02527		
9X	U1														-1797.35556	-0.01264		
9X	U1														0	0		
9X	U1														1797.35556	0.01264		
9X	U1														2541.844608	0.02527		
9X	U1														2952.97178	0.03791		
9X	U1														3213.833356	0.05055		
9X	U1														3386.743429	0.06319		
9X	U1														3496.71894	0.07582		
9X	U1														3558.034783	0.08846		
9X	U1														3579.899276	0.1011		
9X	U1														3568.714078	0.11374		
9X	U1														3529.1674	0.12637		
9X	U1														3464.828304	0.13901		
9X	U1														3378.49688	0.15165		
9X	U1														2447.040833	0.25275		
9X	U1														1514.054933	0.35384		
9X	U1														581.0690463	0.45494		
9X	U1														581.0690463	0.48022		
8X	U1	No	Yes	0		0			Kinematic						-584.034725	-0.49442		

8X	U1														-584.034725	-0.4684		
8X	U1														-1535.405875	-0.36431		
8X	U1														-2486.777038	-0.26022		
8X	U1														-3436.633013	-0.15613		
8X	U1														-3518.281688	-0.14312		
8X	U1														-3577.9694	-0.13011		
8X	U1														-3612.895225	-0.1171		
8X	U1														-3619.488675	-0.10409		
8X	U1														-3593.059225	-0.09108		
8X	U1														-3527.201763	-0.07807		
8X	U1														-3412.702838	-0.06506		
8X	U1														-3235.281125	-0.05204		
8X	U1														-2969.918213	-0.03903		
8X	U1														-2554.427138	-0.02602		
8X	U1														-1806.25275	-0.01301		
8X	U1														0	0		
8X	U1														1806.25275	0.01301		
8X	U1														2554.427138	0.02602		
8X	U1														2969.918213	0.03903		
8X	U1														3235.281125	0.05204		
8X	U1														3412.702838	0.06506		
8X	U1														3527.201763	0.07807		
8X	U1														3593.059225	0.09108		
8X	U1														3619.488675	0.10409		
8X	U1														3612.895225	0.1171		
8X	U1														3577.9694	0.13011		
8X	U1														3518.281688	0.14312		
8X	U1														3436.633013	0.15613		
8X	U1														2486.777038	0.26022		
8X	U1														1535.405875	0.36431		
8X	U1														584.034725	0.4684		
8X	U1														584.034725	0.49442		
7X	U1	No	Yes	0		0			Kinematic						-454.0014769	-0.5061		
7X	U1														-454.0014769	-0.47946		
7X	U1														-1203.257797	-0.37292		
7X	U1														-1952.514109	-0.26637		
7X	U1														-2700.604674	-0.15982		
7X	U1														-2761.018006	-0.1465		
7X	U1														-2804.422839	-0.13318		
7X	U1														-2828.646873	-0.11987		
7X	U1														-2830.920782	-0.10655		
7X	U1														-2807.606247	-0.09323		
7X	U1														-2753.734774	-0.07991		
7X	U1														-2662.159367	-0.06659		
7X	U1														-2521.802702	-0.05327		
7X	U1														-2313.265339	-0.03996		
7X	U1														-1988.407815	-0.02664		
7X	U1														-1406.016646	-0.01332		
7X	U1														0	0		
7X	U1														1406.016646	0.01332		
7X	U1														1988.407815	0.02664		
7X	U1														2313.265339	0.03996		
7X	U1														2521.802702	0.05327		
7X	U1														2662.159367	0.06659		
7X	U1														2753.734774	0.07991		
7X	U1														2807.606247	0.09323		
7X	U1														2830.920782	0.10655		
7X	U1														2828.646873	0.11987		
7X	U1														2804.422839	0.13318		
7X	U1														2761.018006	0.1465		
7X	U1														2700.604674	0.15982		

7X	U1														1952.514109	0.26637		
7X	U1														1203.257797	0.37292		
7X	U1														454.0014769	0.47946		
7X	U1														454.0014769	0.5061		
6X	U1	No	Yes	0		0			Kinematic						-631.2274284	-0.68368		
6X	U1														-631.2274284	-0.6477		
6X	U1														-1625.700572	-0.50377		
6X	U1														-2620.173715	-0.35983		
6X	U1														-3612.937339	-0.2159		
6X	U1														-3716.320418	-0.19791		
6X	U1														-3795.450212	-0.17992		
6X	U1														-3847.247444	-0.16192		
6X	U1														-3867.787837	-0.14393		
6X	U1														-3851.91727	-0.12594		
6X	U1														-3792.598598	-0.10795		
6X	U1														-3679.709527	-0.08996		
6X	U1														-3497.555724	-0.07197		
6X	U1														-3218.614845	-0.05397		
6X	U1														-2774.09808	-0.03598		
6X	U1														-1961.583563	-0.01799		
6X	U1														0	0		
6X	U1														1961.583563	0.01799		
6X	U1														2774.09808	0.03598		
6X	U1														3218.614845	0.05397		
6X	U1														3497.555724	0.07197		
6X	U1														3679.709527	0.08996		
6X	U1														3792.598598	0.10795		
6X	U1														3851.91727	0.12594		
6X	U1														3867.787837	0.14393		
6X	U1														3847.247444	0.16192		
6X	U1														3795.450212	0.17992		
6X	U1														3716.320418	0.19791		
6X	U1														3612.937339	0.2159		
6X	U1														2620.173715	0.35983		
6X	U1														1625.700572	0.50377		
6X	U1														631.2274284	0.6477		
6X	U1														631.2274284	0.68368		
5X	U1	No	Yes	0		0			Kinematic						-714.406891	-0.69416		
5X	U1														-714.406891	-0.65762		
5X	U1														-1846.147765	-0.51148		
5X	U1														-2977.888628	-0.36534		
5X	U1														-4107.713357	-0.21921		
5X	U1														-4221.117098	-0.20094		
5X	U1														-4307.221028	-0.18267		
5X	U1														-4362.555945	-0.16441		
5X	U1														-4382.700388	-0.14614		
5X	U1														-4361.846962	-0.12787		
5X	U1														-4292.066383	-0.1096		
5X	U1														-4161.952993	-0.09134		
5X	U1														-3953.82361	-0.07307		
5X	U1														-3636.674613	-0.0548		
5X	U1														-3133.10129	-0.03653		
5X	U1														-2215.437169	-0.01827		
5X	U1														0	0		
5X	U1														2215.437169	0.01827		
5X	U1														3133.10129	0.03653		
5X	U1														3636.674613	0.0548		
5X	U1														3953.82361	0.07307		
5X	U1														4161.952993	0.09134		
5X	U1														4292.066383	0.1096		
5X	U1														4361.846962	0.12787		

5X	U1														4382.700388	0.14614		
5X	U1														4362.555945	0.16441		
5X	U1														4307.221028	0.18267		
5X	U1														4221.117098	0.20094		
5X	U1														4107.713357	0.21921		
5X	U1														2977.888628	0.36534		
5X	U1														1846.147765	0.51148		
5X	U1														714.406891	0.65762		
5X	U1														714.406891	0.69416		
4X	U1	No	Yes	0		0			Kinematic						-547.270464	-0.70536		
4X	U1														-547.270464	-0.66823		
4X	U1														-1419.820792	-0.51974		
4X	U1														-2292.371112	-0.37124		
4X	U1														-3163.4676	-0.22274		
4X	U1														-3247.518608	-0.20418		
4X	U1														-3310.763472	-0.18562		
4X	U1														-3350.555656	-0.16706		
4X	U1														-3363.522	-0.1485		
4X	U1														-3345.231808	-0.12993		
4X	U1														-3289.635312	-0.11137		
4X	U1														-3188.030344	-0.09281		
4X	U1														-3026.925928	-0.07425		
4X	U1														-2782.67376	-0.05569		
4X	U1														-2396.300872	-0.03712		
4X	U1														-1694.4406	-0.01856		
4X	U1														0	0		
4X	U1														1694.4406	0.01856		
4X	U1														2396.300872	0.03712		
4X	U1														2782.67376	0.05569		
4X	U1														3026.925928	0.07425		
4X	U1														3188.030344	0.09281		
4X	U1														3289.635312	0.11137		
4X	U1														3345.231808	0.12993		
4X	U1														3363.522	0.1485		
4X	U1														3350.555656	0.16706		
4X	U1														3310.763472	0.18562		
4X	U1														3247.518608	0.20418		
4X	U1														3163.4676	0.22274		
4X	U1														2292.371112	0.37124		
4X	U1														1419.820792	0.51974		
4X	U1														547.270464	0.66823		
4X	U1														547.270464	0.70536		
3X	U1	No	Yes	0		0			Kinematic						-668.773422	-0.72542		
3X	U1														-668.773422	-0.68724		
3X	U1														-1748.722509	-0.53452		
3X	U1														-2828.671587	-0.3818		
3X	U1														-3908.620674	-0.22908		
3X	U1														-4003.776603	-0.20999		
3X	U1														-4075.444899	-0.1909		
3X	U1														-4118.660361	-0.17181		
3X	U1														-4129.324245	-0.15272		
3X	U1														-4102.05231	-0.13363		
3X	U1														-4029.492375	-0.11454		
3X	U1														-3901.068756	-0.09545		
3X	U1														-3700.387611	-0.07636		
3X	U1														-3398.7231	-0.05727		
3X	U1														-2924.584884	-0.03818		
3X	U1														-2067.993801	-0.01909		
3X	U1														0	0		
3X	U1														2067.993801	0.01909		
3X	U1														2924.584884	0.03818		

3X	U1														3398.7231	0.05727		
3X	U1														3700.387611	0.07636		
3X	U1														3901.068756	0.09545		
3X	U1														4029.492375	0.11454		
3X	U1														4102.05231	0.13363		
3X	U1														4129.324245	0.15272		
3X	U1														4118.660361	0.17181		
3X	U1														4075.444899	0.1909		
3X	U1														4003.776603	0.20999		
3X	U1														3908.620674	0.22908		
3X	U1														2828.671587	0.3818		
3X	U1														1748.722509	0.53452		
3X	U1														668.773422	0.68724		
3X	U1														668.773422	0.72542		
2X	U1	No	Yes	0		0			Kinematic						-1009.965308	-0.7354		
2X	U1														-1009.965308	-0.69669		
2X	U1														-2652.173604	-0.54187		
2X	U1														-4294.381914	-0.38705		
2X	U1														-5936.590224	-0.23223		
2X	U1														-6076.18823	-0.21288		
2X	U1														-6180.408702	-0.19353		
2X	U1														-6241.781295	-0.17417		
2X	U1														-6254.128868	-0.15482		
2X	U1														-6209.336624	-0.13547		
2X	U1														-6096.323493	-0.11612		
2X	U1														-5899.149959	-0.09676		
2X	U1														-5593.108577	-0.07741		
2X	U1														-5134.914257	-0.05806		
2X	U1														-4416.948576	-0.03871		
2X	U1														-3123.254295	-0.01935		
2X	U1														0	0		
2X	U1														3123.254295	0.01935		
2X	U1														4416.948576	0.03871		
2X	U1														5134.914257	0.05806		
2X	U1														5593.108577	0.07741		
2X	U1														5899.149959	0.09676		
2X	U1														6096.323493	0.11612		
2X	U1														6209.336624	0.13547		
2X	U1														6254.128868	0.15482		
2X	U1														6241.781295	0.17417		
2X	U1														6180.408702	0.19353		
2X	U1														6076.18823	0.21288		
2X	U1														5936.590224	0.23223		
2X	U1														4294.381914	0.38705		
2X	U1														2652.173604	0.54187		
2X	U1														1009.965308	0.69669		
2X	U1														1009.965308	0.7354		

Project:	**Springbank Off-Stream Storage**	By:	ACG - 10/09/2019
Title:	**Non-Linear Soil Springs (Y-Direction, Dry)**	Checked:	CG - 10/09/2019
Structure:	**Low Level Outlet Gate Tower**		

TABLE: Link Property Definitions 11 - Multilinear Plastic

Link	DOF	Fixed	NonLinear	TransKE	RotKE	TransCE	RotCE	DJ	HysType	PivotAlpha1	PivotAlpha2	PivotBeta1	PivotBeta2	PivotEta	Force	Displ	Moment	Rotation
				KN/mm	KN-mm/rad	KN-s/mm	KN-mm-s/rad	mm							KN	m	KN-mm	Radians
17Y	U1	No	Yes	0		0			Kinematic						-432	-1.26		
17Y	U1														-432	-1.008		
17Y	U1														-403.2	-0.76491		
17Y	U1														-374.4	-0.56868		
17Y	U1														-345.6	-0.41288		
17Y	U1														-316.8	-0.29152		
17Y	U1														-288	-0.19911		
17Y	U1														-259.2	-0.13064		
17Y	U1														-230.4	-0.08156		
17Y	U1														-201.6	-0.04781		
17Y	U1														-172.8	-0.0258		
17Y	U1														-144	-0.01244		
17Y	U1														-115.2	-0.0051		
17Y	U1														-86.4	-0.00161		
17Y	U1														-57.6	-0.00031858		
17Y	U1														-28.8	-0.00001991		
17Y	U1														0	0		
17Y	U1														28.8	0.00001991		
17Y	U1														57.6	0.00031858		
17Y	U1														86.4	0.00161		
17Y	U1														115.2	0.0051		
17Y	U1														144	0.01244		
17Y	U1														172.8	0.0258		
17Y	U1														201.6	0.04781		
17Y	U1														230.4	0.08156		
17Y	U1														259.2	0.13064		
17Y	U1														288	0.19911		
17Y	U1														316.8	0.29152		
17Y	U1														345.6	0.41288		
17Y	U1														374.4	0.56868		
17Y	U1														403.2	0.76491		
17Y	U1														432	1.008		
17Y	U1														432	1.26		
16Y	U1	No	Yes	0		0			Kinematic						-976	-1.26		
16Y	U1														-976	-1.008		
16Y	U1														-910.93333	-0.76491		
16Y	U1														-845.86667	-0.56868		
16Y	U1														-780.8	-0.41288		
16Y	U1														-715.73333	-0.29152		
16Y	U1														-650.66667	-0.19911		
16Y	U1														-585.6	-0.13064		
16Y	U1														-520.53333	-0.08156		
16Y	U1														-455.46667	-0.04781		
16Y	U1														-390.4	-0.0258		
16Y	U1														-325.33333	-0.01244		
16Y	U1														-260.26667	-0.0051		
16Y	U1														-195.2	-0.00161		
16Y	U1														-130.13333	-0.00031858		

16Y	U1														-65.06667	-0.00001991		
16Y	U1														0	0		
16Y	U1														65.06667	0.00001991		
16Y	U1														130.13333	0.00031858		
16Y	U1														195.2	0.00161		
16Y	U1														260.26667	0.0051		
16Y	U1														325.33333	0.01244		
16Y	U1														390.4	0.0258		
16Y	U1														455.46667	0.04781		
16Y	U1														520.53333	0.08156		
16Y	U1														585.6	0.13064		
16Y	U1														650.66667	0.19911		
16Y	U1														715.73333	0.29152		
16Y	U1														780.8	0.41288		
16Y	U1														845.86667	0.56868		
16Y	U1														910.93333	0.76491		
16Y	U1														976	1.008		
16Y	U1														976	1.26		
15Y	U1	No	Yes	0		0			Kinematic						-1360	-1.26		
15Y	U1														-1360	-1.008		
15Y	U1														-1269.333338	-0.76491		
15Y	U1														-1178.666663	-0.56868		
15Y	U1														-1088	-0.41288		
15Y	U1														-997.3333375	-0.29152		
15Y	U1														-906.6666625	-0.19911		
15Y	U1														-816	-0.13064		
15Y	U1														-725.3333375	-0.08156		
15Y	U1														-634.6666625	-0.04781		
15Y	U1														-544	-0.0258		
15Y	U1														-453.3333375	-0.01244		
15Y	U1														-362.6666625	-0.0051		
15Y	U1														-272	-0.00161		
15Y	U1														-181.3333375	-0.00031858		
15Y	U1														-90.6666625	-0.00001991		
15Y	U1														0	0		
15Y	U1														90.6666625	0.00001991		
15Y	U1														181.3333375	0.00031858		
15Y	U1														272	0.00161		
15Y	U1														362.6666625	0.0051		
15Y	U1														453.3333375	0.01244		
15Y	U1														544	0.0258		
15Y	U1														634.6666625	0.04781		
15Y	U1														725.3333375	0.08156		
15Y	U1														816	0.13064		
15Y	U1														906.6666625	0.19911		
15Y	U1														997.3333375	0.29152		
15Y	U1														1088	0.41288		
15Y	U1														1178.666663	0.56868		
15Y	U1														1269.333338	0.76491		
15Y	U1														1360	1.008		
15Y	U1														1360	1.26		
14Y	U1	No	Yes	0		0			Kinematic						-2163	-1.47		
14Y	U1														-2163	-1.176		
14Y	U1														-2018.800005	-0.89239		
14Y	U1														-1874.599995	-0.66346		

14Y	U1														-1730.4	-0.48169		
14Y	U1														-1586.200005	-0.34011		
14Y	U1														-1441.999995	-0.2323		
14Y	U1														-1297.8	-0.15241		
14Y	U1														-1153.600005	-0.09515		
14Y	U1														-1009.399995	-0.05577		
14Y	U1														-865.2	-0.03011		
14Y	U1														-721.000005	-0.01452		
14Y	U1														-576.799995	-0.00595		
14Y	U1														-432.6	-0.00188		
14Y	U1														-288.400005	-0.00037167		
14Y	U1														-144.199995	-0.00002323		
14Y	U1														0	0		
14Y	U1														144.199995	0.00002323		
14Y	U1														288.400005	0.00037167		
14Y	U1														432.6	0.00188		
14Y	U1														576.799995	0.00595		
14Y	U1														721.000005	0.01452		
14Y	U1														865.2	0.03011		
14Y	U1														1009.399995	0.05577		
14Y	U1														1153.600005	0.09515		
14Y	U1														1297.8	0.15241		
14Y	U1														1441.999995	0.2323		
14Y	U1														1586.200005	0.34011		
14Y	U1														1730.4	0.48169		
14Y	U1														1874.599995	0.66346		
14Y	U1														2018.800005	0.89239		
14Y	U1														2163	1.176		
14Y	U1														2163	1.47		
13Y	U1	No	Yes	0		0			Kinematic						-2442	-1.47		
13Y	U1														-2442	-1.176		
13Y	U1														-2279.200005	-0.89239		
13Y	U1														-2116.399995	-0.66346		
13Y	U1														-1953.6	-0.48169		
13Y	U1														-1790.800005	-0.34011		
13Y	U1														-1627.999995	-0.2323		
13Y	U1														-1465.2	-0.15241		
13Y	U1														-1302.400005	-0.09515		
13Y	U1														-1139.599995	-0.05577		
13Y	U1														-976.8	-0.03011		
13Y	U1														-814.000005	-0.01452		
13Y	U1														-651.199995	-0.00595		
13Y	U1														-488.4	-0.00188		
13Y	U1														-325.600005	-0.00037167		
13Y	U1														-162.799995	-0.00002323		
13Y	U1														0	0		
13Y	U1														162.799995	0.00002323		
13Y	U1														325.600005	0.00037167		
13Y	U1														488.4	0.00188		
13Y	U1														651.199995	0.00595		
13Y	U1														814.000005	0.01452		
13Y	U1														976.8	0.03011		
13Y	U1														1139.599995	0.05577		
13Y	U1														1302.400005	0.09515		
13Y	U1														1465.2	0.15241		

13Y	U1														1627.999995	0.2323		
13Y	U1														1790.800005	0.34011		
13Y	U1														1953.6	0.48169		
13Y	U1														2116.399995	0.66346		
13Y	U1														2279.200005	0.89239		
13Y	U1														2442	1.176		
13Y	U1														2442	1.47		
12Y	U1	No	Yes	0		0			Kinematic						-2721	-1.47		
12Y	U1														-2721	-1.176		
12Y	U1														-2539.600005	-0.89239		
12Y	U1														-2358.199995	-0.66346		
12Y	U1														-2176.8	-0.48169		
12Y	U1														-1995.400005	-0.34011		
12Y	U1														-1813.999995	-0.2323		
12Y	U1														-1632.6	-0.15241		
12Y	U1														-1451.200005	-0.09515		
12Y	U1														-1269.799995	-0.05577		
12Y	U1														-1088.4	-0.03011		
12Y	U1														-907.000005	-0.01452		
12Y	U1														-725.599995	-0.00595		
12Y	U1														-544.2	-0.00188		
12Y	U1														-362.800005	-0.00037167		
12Y	U1														-181.399995	-0.00002323		
12Y	U1														0	0		
12Y	U1														181.399995	0.00002323		
12Y	U1														362.800005	0.00037167		
12Y	U1														544.2	0.00188		
12Y	U1														725.599995	0.00595		
12Y	U1														907.000005	0.01452		
12Y	U1														1088.4	0.03011		
12Y	U1														1269.799995	0.05577		
12Y	U1														1451.200005	0.09515		
12Y	U1														1632.6	0.15241		
12Y	U1														1813.999995	0.2323		
12Y	U1														1995.400005	0.34011		
12Y	U1														2176.8	0.48169		
12Y	U1														2358.199995	0.66346		
12Y	U1														2539.600005	0.89239		
12Y	U1														2721	1.176		
12Y	U1														2721	1.47		
11Y	U1	No	Yes	0		0			Kinematic						-3000	-1.47		
11Y	U1														-3000	-1.176		
11Y	U1														-2800.000005	-0.89239		
11Y	U1														-2599.999995	-0.66346		
11Y	U1														-2400	-0.48169		
11Y	U1														-2200.000005	-0.34011		
11Y	U1														-1999.999995	-0.2323		
11Y	U1														-1800	-0.15241		
11Y	U1														-1600.000005	-0.09515		
11Y	U1														-1399.999995	-0.05577		
11Y	U1														-1200	-0.03011		
11Y	U1														-1000.000005	-0.01452		
11Y	U1														-799.999995	-0.00595		
11Y	U1														-600	-0.00188		
11Y	U1														-400.000005	-0.00037167		

11Y	U1														-199.999995	-0.00002323		
11Y	U1														0	0		
11Y	U1														199.999995	0.00002323		
11Y	U1														400.000005	0.00037167		
11Y	U1														600	0.00188		
11Y	U1														799.999995	0.00595		
11Y	U1														1000.000005	0.01452		
11Y	U1														1200	0.03011		
11Y	U1														1399.999995	0.05577		
11Y	U1														1600.000005	0.09515		
11Y	U1														1800	0.15241		
11Y	U1														1999.999995	0.2323		
11Y	U1														2200.000005	0.34011		
11Y	U1														2400	0.48169		
11Y	U1														2599.999995	0.66346		
11Y	U1														2800.000005	0.89239		
11Y	U1														3000	1.176		
11Y	U1														3000	1.47		
10Y	U1	No	Yes	0		0			Kinematic						-3279	-1.47		
10Y	U1														-3279	-1.176		
10Y	U1														-3060.400005	-0.89239		
10Y	U1														-2841.799995	-0.66346		
10Y	U1														-2623.2	-0.48169		
10Y	U1														-2404.600005	-0.34011		
10Y	U1														-2185.999995	-0.2323		
10Y	U1														-1967.4	-0.15241		
10Y	U1														-1748.800005	-0.09515		
10Y	U1														-1530.199995	-0.05577		
10Y	U1														-1311.6	-0.03011		
10Y	U1														-1093.000005	-0.01452		
10Y	U1														-874.399995	-0.00595		
10Y	U1														-655.8	-0.00188		
10Y	U1														-437.200005	-0.00037167		
10Y	U1														-218.599995	-0.00002323		
10Y	U1														0	0		
10Y	U1														218.599995	0.00002323		
10Y	U1														437.200005	0.00037167		
10Y	U1														655.8	0.00188		
10Y	U1														874.399995	0.00595		
10Y	U1														1093.000005	0.01452		
10Y	U1														1311.6	0.03011		
10Y	U1														1530.199995	0.05577		
10Y	U1														1748.800005	0.09515		
10Y	U1														1967.4	0.15241		
10Y	U1														2185.999995	0.2323		
10Y	U1														2404.600005	0.34011		
10Y	U1														2623.2	0.48169		
10Y	U1														2841.799995	0.66346		
10Y	U1														3060.400005	0.89239		
10Y	U1														3279	1.176		
10Y	U1														3279	1.47		
9Y	U1	No	Yes	0		0			Kinematic						-3261.5	-1.47		
9Y	U1														-3261.5	-1.176		
9Y	U1														-3044.066671	-0.89239		
9Y	U1														-2826.633329	-0.66346		

9Y	U1														-2609.2	-0.48169		
9Y	U1														-2391.766671	-0.34011		
9Y	U1														-2174.333329	-0.2323		
9Y	U1														-1956.9	-0.15241		
9Y	U1														-1739.466671	-0.09515		
9Y	U1														-1522.033329	-0.05577		
9Y	U1														-1304.6	-0.03011		
9Y	U1														-1087.166671	-0.01452		
9Y	U1														-869.7333288	-0.00595		
9Y	U1														-652.3	-0.00188		
9Y	U1														-434.8666713	-0.00037167		
9Y	U1														-217.4333288	-0.00002323		
9Y	U1														0	0		
9Y	U1														217.4333288	0.00002323		
9Y	U1														434.8666713	0.00037167		
9Y	U1														652.3	0.00188		
9Y	U1														869.7333288	0.00595		
9Y	U1														1087.166671	0.01452		
9Y	U1														1304.6	0.03011		
9Y	U1														1522.033329	0.05577		
9Y	U1														1739.466671	0.09515		
9Y	U1														1956.9	0.15241		
9Y	U1														2174.333329	0.2323		
9Y	U1														2391.766671	0.34011		
9Y	U1														2609.2	0.48169		
9Y	U1														2826.633329	0.66346		
9Y	U1														3044.066671	0.89239		
9Y	U1														3261.5	1.176		
9Y	U1														3261.5	1.47		
8Y	U1	No	Yes	0		0			Kinematic						-3158.75	-1.47		
8Y	U1														-3158.75	-1.176		
8Y	U1														-2948.166663	-0.89239		
8Y	U1														-2737.583338	-0.66346		
8Y	U1														-2527	-0.48169		
8Y	U1														-2316.416663	-0.34011		
8Y	U1														-2105.833338	-0.2323		
8Y	U1														-1895.25	-0.15241		
8Y	U1														-1684.666663	-0.09515		
8Y	U1														-1474.083338	-0.05577		
8Y	U1														-1263.5	-0.03011		
8Y	U1														-1052.916663	-0.01452		
8Y	U1														-842.3333375	-0.00595		
8Y	U1														-631.75	-0.00188		
8Y	U1														-421.1666625	-0.00037167		
8Y	U1														-210.5833375	-0.00002323		
8Y	U1														0	0		
8Y	U1														210.5833375	0.00002323		
8Y	U1														421.1666625	0.00037167		
8Y	U1														631.75	0.00188		
8Y	U1														842.3333375	0.00595		
8Y	U1														1052.916663	0.01452		
8Y	U1														1263.5	0.03011		
8Y	U1														1474.083338	0.05577		
8Y	U1														1684.666663	0.09515		
8Y	U1														1895.25	0.15241		

8Y	U1														2105.833338	0.2323		
8Y	U1														2316.416663	0.34011		
8Y	U1														2527	0.48169		
8Y	U1														2737.583338	0.66346		
8Y	U1														2948.166663	0.89239		
8Y	U1														3158.75	1.176		
8Y	U1														3158.75	1.47		
7Y	U1	No	Yes	0		0			Kinematic						-2400.39	-1.47		
7Y	U1														-2400.39	-1.176		
7Y	U1														-2240.364	-0.89239		
7Y	U1														-2080.338	-0.66346		
7Y	U1														-1920.312	-0.48169		
7Y	U1														-1760.286	-0.34011		
7Y	U1														-1600.26	-0.2323		
7Y	U1														-1440.234	-0.15241		
7Y	U1														-1280.208	-0.09515		
7Y	U1														-1120.182	-0.05577		
7Y	U1														-960.156	-0.03011		
7Y	U1														-800.13	-0.01452		
7Y	U1														-640.104	-0.00595		
7Y	U1														-480.078	-0.00188		
7Y	U1														-320.052	-0.00037167		
7Y	U1														-160.026	-0.00002323		
7Y	U1														0	0		
7Y	U1														160.026	0.00002323		
7Y	U1														320.052	0.00037167		
7Y	U1														480.078	0.00188		
7Y	U1														640.104	0.00595		
7Y	U1														800.13	0.01452		
7Y	U1														960.156	0.03011		
7Y	U1														1120.182	0.05577		
7Y	U1														1280.208	0.09515		
7Y	U1														1440.234	0.15241		
7Y	U1														1600.26	0.2323		
7Y	U1														1760.286	0.34011		
7Y	U1														1920.312	0.48169		
7Y	U1														2080.338	0.66346		
7Y	U1														2240.364	0.89239		
7Y	U1														2400.39	1.176		
7Y	U1														2400.39	1.47		
6Y	U1	No	Yes	0		0			Kinematic						-3441.3984	-1.89		
6Y	U1														-3441.3984	-1.512		
6Y	U1														-3211.97184	-1.14736		
6Y	U1														-2982.54528	-0.85302		
6Y	U1														-2753.11872	-0.61932		
6Y	U1														-2523.69216	-0.43728		
6Y	U1														-2294.2656	-0.29867		
6Y	U1														-2064.83904	-0.19596		
6Y	U1														-1835.41248	-0.12233		
6Y	U1														-1605.98592	-0.07171		
6Y	U1														-1376.55936	-0.03871		
6Y	U1														-1147.1328	-0.01867		
6Y	U1														-917.70624	-0.00765		
6Y	U1														-688.27968	-0.00242		
6Y	U1														-458.85312	-0.00047787		

6Y	U1														-229.42656	-0.00002987		
6Y	U1														0	0		
6Y	U1														229.42656	0.00002987		
6Y	U1														458.85312	0.00047787		
6Y	U1														688.27968	0.00242		
6Y	U1														917.70624	0.00765		
6Y	U1														1147.1328	0.01867		
6Y	U1														1376.55936	0.03871		
6Y	U1														1605.98592	0.07171		
6Y	U1														1835.41248	0.12233		
6Y	U1														2064.83904	0.19596		
6Y	U1														2294.2656	0.29867		
6Y	U1														2523.69216	0.43728		
6Y	U1														2753.11872	0.61932		
6Y	U1														2982.54528	0.85302		
6Y	U1														3211.97184	1.14736		
6Y	U1														3441.3984	1.512		
6Y	U1														3441.3984	1.89		
5Y	U1	No	Yes	0		0			Kinematic						-950.4	-4.20E-01		
5Y	U1														-950.4	-0.336		
5Y	U1														-887.04	-0.25497		
5Y	U1														-823.68	-0.18956		
5Y	U1														-760.32	-0.13763		
5Y	U1														-696.96	-0.09717		
5Y	U1														-633.6	-0.06637		
5Y	U1														-570.24	-0.04355		
5Y	U1														-506.88	-0.02719		
5Y	U1														-443.52	-0.01594		
5Y	U1														-380.16	-0.0086		
5Y	U1														-316.8	-0.00415		
5Y	U1														-253.44	-0.0017		
5Y	U1														-190.08	-0.0005376		
5Y	U1														-126.72	-0.00010619		
5Y	U1														-63.36	-6.63704E-06		
5Y	U1														0	0		
5Y	U1														63.36	6.64E-06		
5Y	U1														126.72	0.00010619		
5Y	U1														190.08	0.0005376		
5Y	U1														253.44	0.0017		
5Y	U1														316.8	0.00415		
5Y	U1														380.16	0.0086		
5Y	U1														443.52	0.01594		
5Y	U1														506.88	0.02719		
5Y	U1														570.24	0.04355		
5Y	U1														633.6	0.06637		
5Y	U1														696.96	0.09717		
5Y	U1														760.32	0.13763		
5Y	U1														823.68	0.18956		
5Y	U1														887.04	0.25497		
5Y	U1														950.4	0.336		
5Y	U1														950.4	0.42		
4Y	U1	No	Yes	0		0			Kinematic						-691.2	-4.20E-01		
4Y	U1														-691.2	-0.336		
4Y	U1														-645.12	-0.25497		
4Y	U1														-599.04	-0.18956		

4Y	U1														-552.96	-0.13763		
4Y	U1														-506.88	-0.09717		
4Y	U1														-460.8	-0.06637		
4Y	U1														-414.72	-0.04355		
4Y	U1														-368.64	-0.02719		
4Y	U1														-322.56	-0.01594		
4Y	U1														-276.48	-0.0086		
4Y	U1														-230.4	-0.00415		
4Y	U1														-184.32	-0.0017		
4Y	U1														-138.24	-0.0005376		
4Y	U1														-92.16	-0.00010619		
4Y	U1														-46.08	-6.63704E-06		
4Y	U1														0	0		
4Y	U1														46.08	6.64E-06		
4Y	U1														92.16	0.00010619		
4Y	U1														138.24	0.0005376		
4Y	U1														184.32	0.0017		
4Y	U1														230.4	0.00415		
4Y	U1														276.48	0.0086		
4Y	U1														322.56	0.01594		
4Y	U1														368.64	0.02719		
4Y	U1														414.72	0.04355		
4Y	U1														460.8	0.06637		
4Y	U1														506.88	0.09717		
4Y	U1														552.96	0.13763		
4Y	U1														599.04	0.18956		
4Y	U1														645.12	0.25497		
4Y	U1														691.2	0.336		
4Y	U1														691.2	0.42		
3Y	U1	No	Yes	0		0			Kinematic						-777.6	-4.20E-01		
3Y	U1														-777.6	-0.336		
3Y	U1														-725.76	-0.25497		
3Y	U1														-673.92	-0.18956		
3Y	U1														-622.08	-0.13763		
3Y	U1														-570.24	-0.09717		
3Y	U1														-518.4	-0.06637		
3Y	U1														-466.56	-0.04355		
3Y	U1														-414.72	-0.02719		
3Y	U1														-362.88	-0.01594		
3Y	U1														-311.04	-0.0086		
3Y	U1														-259.2	-0.00415		
3Y	U1														-207.36	-0.0017		
3Y	U1														-155.52	-0.0005376		
3Y	U1														-103.68	-0.00010619		
3Y	U1														-51.84	-6.63704E-06		
3Y	U1														0	0		
3Y	U1														51.84	6.64E-06		
3Y	U1														103.68	0.00010619		
3Y	U1														155.52	0.0005376		
3Y	U1														207.36	0.0017		
3Y	U1														259.2	0.00415		
3Y	U1														311.04	0.0086		
3Y	U1														362.88	0.01594		
3Y	U1														414.72	0.02719		
3Y	U1														466.56	0.04355		

3Y	U1														518.4	0.06637		
3Y	U1														570.24	0.09717		
3Y	U1														622.08	0.13763		
3Y	U1														673.92	0.18956		
3Y	U1														725.76	0.25497		
3Y	U1														777.6	0.336		
3Y	U1														777.6	0.42		
2Y	U1	No	Yes	0		0			Kinematic						-3089.988	-1.11265		
2Y	U1														-3089.988	-0.89012		
2Y	U1														-2883.9888	-0.67545		
2Y	U1														-2677.9896	-0.50218		
2Y	U1														-2471.9904	-0.36459		
2Y	U1														-2265.9912	-0.25743		
2Y	U1														-2059.992	-0.17583		
2Y	U1														-1853.9928	-0.11536		
2Y	U1														-1647.9936	-0.07202		
2Y	U1														-1441.9944	-0.04222		
2Y	U1														-1235.9952	-0.02279		
2Y	U1														-1029.996	-0.01099		
2Y	U1														-823.9968	-0.0045		
2Y	U1														-617.9976	-0.00142		
2Y	U1														-411.9984	-0.00028132		
2Y	U1														-205.9992	-0.00001758		
2Y	U1														0	0		
2Y	U1														205.9992	0.00001758		
2Y	U1														411.9984	0.00028132		
2Y	U1														617.9976	0.00142		
2Y	U1														823.9968	0.0045		
2Y	U1														1029.996	0.01099		
2Y	U1														1235.9952	0.02279		
2Y	U1														1441.9944	0.04222		
2Y	U1														1647.9936	0.07202		
2Y	U1														1853.9928	0.11536		
2Y	U1														2059.992	0.17583		
2Y	U1														2265.9912	0.25743		
2Y	U1														2471.9904	0.36459		
2Y	U1														2677.9896	0.50218		
2Y	U1														2883.9888	0.67545		
2Y	U1														3089.988	0.89012		
2Y	U1														3089.988	1.11265		

Project:	Springbank Off-Stream Storage	By: ACG - 10/09/2019
Title:	Non-Linear Soil Springs (X-Direction, Dry)	Checked: CG - 10/09/2019
Structure:	Low Level Outlet Gate Tower	

TABLE: Link Property Definitions 11 - Multilinear Plastic

Link	DOF	Fixed	NonLinear	TransKE	RotKE	TransCE	RotCE	DJ	HysType	PivotAlpha1	PivotAlpha2	PivotBeta1	PivotBeta2	PivotEta	Force	Displ	Moment	Rotation
				KN/mm	KN-mm/rad	KN-s/mm	KN-mm-s/rad	mm							KN	m	KN-mm	Radians
17X	U1	No	Yes	0		0			Kinematic						-732	-2.135		
17X	U1														-732	-1.708		
17X	U1														-683.2	-1.29609		
17X	U1														-634.4	-0.9636		
17X	U1														-585.6	-0.6996		
17X	U1														-536.8	-0.49396		
17X	U1														-488	-0.33738		
17X	U1														-439.2	-0.22136		
17X	U1														-390.4	-0.13819		
17X	U1														-341.6	-0.08101		
17X	U1														-292.8	-0.04372		
17X	U1														-244	-0.02109		
17X	U1														-195.2	-0.00864		
17X	U1														-146.4	-0.00273		
17X	U1														-97.6	-0.00053981		
17X	U1														-48.8	-0.00003374		
17X	U1														0	0		
17X	U1														48.8	0.00003374		
17X	U1														97.6	0.00053981		
17X	U1														146.4	0.00273		
17X	U1														195.2	0.00864		
17X	U1														244	0.02109		
17X	U1														292.8	0.04372		
17X	U1														341.6	0.08101		
17X	U1														390.4	0.13819		
17X	U1														439.2	0.22136		
17X	U1														488	0.33738		
17X	U1														536.8	0.49396		
17X	U1														585.6	0.6996		
17X	U1														634.4	0.9636		
17X	U1														683.2	1.29609		
17X	U1														732	1.708		
17X	U1														732	2.135		
16X	U1	No	Yes	0		0			Kinematic						-1626	-2.135		
16X	U1														-1626	-1.708		
16X	U1														-1517.6	-1.29609		
16X	U1														-1409.2	-0.9636		
16X	U1														-1300.8	-0.6996		
16X	U1														-1192.4	-0.49396		
16X	U1														-1084	-0.33738		
16X	U1														-975.6	-0.22136		
16X	U1														-867.2	-0.13819		
16X	U1														-758.8	-0.08101		
16X	U1														-650.4	-0.04372		
16X	U1														-542	-0.02109		
16X	U1														-433.6	-0.00864		
16X	U1														-325.2	-0.00273		
16X	U1														-216.8	-0.00053981		
16X	U1														-108.4	-0.00003374		

16X	U1														0	0		
16X	U1														108.4	0.00003374		
16X	U1														216.8	0.00053981		
16X	U1														325.2	0.00273		
16X	U1														433.6	0.00864		
16X	U1														542	0.02109		
16X	U1														650.4	0.04372		
16X	U1														758.8	0.08101		
16X	U1														867.2	0.13819		
16X	U1														975.6	0.22136		
16X	U1														1084	0.33738		
16X	U1														1192.4	0.49396		
16X	U1														1300.8	0.6996		
16X	U1														1409.2	0.9636		
16X	U1														1517.6	1.29609		
16X	U1														1626	1.708		
16X	U1														1626	2.135		
15X	U1	No	Yes	0		0			Kinematic						-2235	-2.135		
15X	U1														-2235	-1.708		
15X	U1														-2086	-1.29609		
15X	U1														-1937	-0.9636		
15X	U1														-1788	-0.6996		
15X	U1														-1639	-0.49396		
15X	U1														-1490	-0.33738		
15X	U1														-1341	-0.22136		
15X	U1														-1192	-0.13819		
15X	U1														-1043	-0.08101		
15X	U1														-894	-0.04372		
15X	U1														-745	-0.02109		
15X	U1														-596	-0.00864		
15X	U1														-447	-0.00273		
15X	U1														-298	-0.00053981		
15X	U1														-149	-0.00003374		
15X	U1														0	0		
15X	U1														149	0.00003374		
15X	U1														298	0.00053981		
15X	U1														447	0.00273		
15X	U1														596	0.00864		
15X	U1														745	0.02109		
15X	U1														894	0.04372		
15X	U1														1043	0.08101		
15X	U1														1192	0.13819		
15X	U1														1341	0.22136		
15X	U1														1490	0.33738		
15X	U1														1639	0.49396		
15X	U1														1788	0.6996		
15X	U1														1937	0.9636		
15X	U1														2086	1.29609		
15X	U1														2235	1.708		
15X	U1														2235	2.135		
14X	U1	No	Yes	0		0			Kinematic						-3325.5	-2.345		
14X	U1														-3325.5	-1.876		
14X	U1														-3103.8	-1.42357		
14X	U1														-2882.1	-1.05838		
14X	U1														-2660.4	-0.76841		
14X	U1														-2438.7	-0.54255		

14X	U1														-2217	-0.37057		
14X	U1														-1995.3	-0.24313		
14X	U1														-1773.6	-0.15178		
14X	U1														-1551.9	-0.08897		
14X	U1														-1330.2	-0.04803		
14X	U1														-1108.5	-0.02316		
14X	U1														-886.8	-0.00949		
14X	U1														-665.1	-0.003		
14X	U1														-443.4	-0.00059291		
14X	U1														-221.7	-0.00003706		
14X	U1														0	0		
14X	U1														221.7	0.00003706		
14X	U1														443.4	0.00059291		
14X	U1														665.1	0.003		
14X	U1														886.8	0.00949		
14X	U1														1108.5	0.02316		
14X	U1														1330.2	0.04803		
14X	U1														1551.9	0.08897		
14X	U1														1773.6	0.15178		
14X	U1														1995.3	0.24313		
14X	U1														2217	0.37057		
14X	U1														2438.7	0.54255		
14X	U1														2660.4	0.76841		
14X	U1														2882.1	1.05838		
14X	U1														3103.8	1.42357		
14X	U1														3325.5	1.876		
14X	U1														3325.5	2.345		
13X	U1	No	Yes	0		0			Kinematic						-3717	-2.345		
13X	U1														-3717	-1.876		
13X	U1														-3469.2	-1.42357		
13X	U1														-3221.4	-1.05838		
13X	U1														-2973.6	-0.76841		
13X	U1														-2725.8	-0.54255		
13X	U1														-2478	-0.37057		
13X	U1														-2230.2	-0.24313		
13X	U1														-1982.4	-0.15178		
13X	U1														-1734.6	-0.08897		
13X	U1														-1486.8	-0.04803		
13X	U1														-1239	-0.02316		
13X	U1														-991.2	-0.00949		
13X	U1														-743.4	-0.003		
13X	U1														-495.6	-0.00059291		
13X	U1														-247.8	-0.00003706		
13X	U1														0	0		
13X	U1														247.8	0.00003706		
13X	U1														495.6	0.00059291		
13X	U1														743.4	0.003		
13X	U1														991.2	0.00949		
13X	U1														1239	0.02316		
13X	U1														1486.8	0.04803		
13X	U1														1734.6	0.08897		
13X	U1														1982.4	0.15178		
13X	U1														2230.2	0.24313		
13X	U1														2478	0.37057		
13X	U1														2725.8	0.54255		
13X	U1														2973.6	0.76841		

13X	U1														3221.4	1.05838		
13X	U1														3469.2	1.42357		
13X	U1														3717	1.876		
13X	U1														3717	2.345		
12X	U1	No	Yes	0		0			Kinematic						-4108.5	-2.345		
12X	U1														-4108.5	-1.876		
12X	U1														-3834.6	-1.42357		
12X	U1														-3560.7	-1.05838		
12X	U1														-3286.8	-0.76841		
12X	U1														-3012.9	-0.54255		
12X	U1														-2739	-0.37057		
12X	U1														-2465.1	-0.24313		
12X	U1														-2191.2	-0.15178		
12X	U1														-1917.3	-0.08897		
12X	U1														-1643.4	-0.04803		
12X	U1														-1369.5	-0.02316		
12X	U1														-1095.6	-0.00949		
12X	U1														-821.7	-0.003		
12X	U1														-547.8	-0.00059291		
12X	U1														-273.9	-0.00003706		
12X	U1														0	0		
12X	U1														273.9	0.00003706		
12X	U1														547.8	0.00059291		
12X	U1														821.7	0.003		
12X	U1														1095.6	0.00949		
12X	U1														1369.5	0.02316		
12X	U1														1643.4	0.04803		
12X	U1														1917.3	0.08897		
12X	U1														2191.2	0.15178		
12X	U1														2465.1	0.24313		
12X	U1														2739	0.37057		
12X	U1														3012.9	0.54255		
12X	U1														3286.8	0.76841		
12X	U1														3560.7	1.05838		
12X	U1														3834.6	1.42357		
12X	U1														4108.5	1.876		
12X	U1														4108.5	2.345		
11X	U1	No	Yes	0		0			Kinematic						-4500	-2.345		
11X	U1														-4500	-1.876		
11X	U1														-4200	-1.42357		
11X	U1														-3900	-1.05838		
11X	U1														-3600	-0.76841		
11X	U1														-3300	-0.54255		
11X	U1														-3000	-0.37057		
11X	U1														-2700	-0.24313		
11X	U1														-2400	-0.15178		
11X	U1														-2100	-0.08897		
11X	U1														-1800	-0.04803		
11X	U1														-1500	-0.02316		
11X	U1														-1200	-0.00949		
11X	U1														-900	-0.003		
11X	U1														-600	-0.00059291		
11X	U1														-300	-0.00003706		
11X	U1														0	0		
11X	U1														300	0.00003706		
11X	U1														600	0.00059291		

11X	U1														900	0.003		
11X	U1														1200	0.00949		
11X	U1														1500	0.02316		
11X	U1														1800	0.04803		
11X	U1														2100	0.08897		
11X	U1														2400	0.15178		
11X	U1														2700	0.24313		
11X	U1														3000	0.37057		
11X	U1														3300	0.54255		
11X	U1														3600	0.76841		
11X	U1														3900	1.05838		
11X	U1														4200	1.42357		
11X	U1														4500	1.876		
11X	U1														4500	2.345		
10X	U1	No	Yes	0		0			Kinematic						-4891.5	-2.345		
10X	U1														-4891.5	-1.876		
10X	U1														-4565.4	-1.42357		
10X	U1														-4239.3	-1.05838		
10X	U1														-3913.2	-0.76841		
10X	U1														-3587.1	-0.54255		
10X	U1														-3261	-0.37057		
10X	U1														-2934.9	-0.24313		
10X	U1														-2608.8	-0.15178		
10X	U1														-2282.7	-0.08897		
10X	U1														-1956.6	-0.04803		
10X	U1														-1630.5	-0.02316		
10X	U1														-1304.4	-0.00949		
10X	U1														-978.3	-0.003		
10X	U1														-652.2	-0.00059291		
10X	U1														-326.1	-0.00003706		
10X	U1														0	0		
10X	U1														326.1	0.00003706		
10X	U1														652.2	0.00059291		
10X	U1														978.3	0.003		
10X	U1														1304.4	0.00949		
10X	U1														1630.5	0.02316		
10X	U1														1956.6	0.04803		
10X	U1														2282.7	0.08897		
10X	U1														2608.8	0.15178		
10X	U1														2934.9	0.24313		
10X	U1														3261	0.37057		
10X	U1														3587.1	0.54255		
10X	U1														3913.2	0.76841		
10X	U1														4239.3	1.05838		
10X	U1														4565.4	1.42357		
10X	U1														4891.5	1.876		
10X	U1														4891.5	2.345		
9X	U1	No	Yes	0		0			Kinematic						-4842.75	-2.345		
9X	U1														-4842.75	-1.876		
9X	U1														-4519.9	-1.42357		
9X	U1														-4197.05	-1.05838		
9X	U1														-3874.2	-0.76841		
9X	U1														-3551.35	-0.54255		
9X	U1														-3228.5	-0.37057		
9X	U1														-2905.65	-0.24313		
9X	U1														-2582.8	-0.15178		

9X	U1														-2259.95	-0.08897		
9X	U1														-1937.1	-0.04803		
9X	U1														-1614.25	-0.02316		
9X	U1														-1291.4	-0.00949		
9X	U1														-968.55	-0.003		
9X	U1														-645.7	-0.00059291		
9X	U1														-322.85	-0.00003706		
9X	U1														0	0		
9X	U1														322.85	0.00003706		
9X	U1														645.7	0.00059291		
9X	U1														968.55	0.003		
9X	U1														1291.4	0.00949		
9X	U1														1614.25	0.02316		
9X	U1														1937.1	0.04803		
9X	U1														2259.95	0.08897		
9X	U1														2582.8	0.15178		
9X	U1														2905.65	0.24313		
9X	U1														3228.5	0.37057		
9X	U1														3551.35	0.54255		
9X	U1														3874.2	0.76841		
9X	U1														4197.05	1.05838		
9X	U1														4519.9	1.42357		
9X	U1														4842.75	1.876		
9X	U1														4842.75	2.345		
8X	U1	No	Yes	0		0			Kinematic						-4674.375	-2.345		
8X	U1														-4674.375	-1.876		
8X	U1														-4362.75	-1.42357		
8X	U1														-4051.125	-1.05838		
8X	U1														-3739.5	-0.76841		
8X	U1														-3427.875	-0.54255		
8X	U1														-3116.25	-0.37057		
8X	U1														-2804.625	-0.24313		
8X	U1														-2493	-0.15178		
8X	U1														-2181.375	-0.08897		
8X	U1														-1869.75	-0.04803		
8X	U1														-1558.125	-0.02316		
8X	U1														-1246.5	-0.00949		
8X	U1														-934.875	-0.003		
8X	U1														-623.25	-0.00059291		
8X	U1														-311.625	-0.00003706		
8X	U1														0	0		
8X	U1														311.625	0.00003706		
8X	U1														623.25	0.00059291		
8X	U1														934.875	0.003		
8X	U1														1246.5	0.00949		
8X	U1														1558.125	0.02316		
8X	U1														1869.75	0.04803		
8X	U1														2181.375	0.08897		
8X	U1														2493	0.15178		
8X	U1														2804.625	0.24313		
8X	U1														3116.25	0.37057		
8X	U1														3427.875	0.54255		
8X	U1														3739.5	0.76841		
8X	U1														4051.125	1.05838		
8X	U1														4362.75	1.42357		
8X	U1														4674.375	1.876		

8X	U1														4674.375	2.345		
7X	U1	No	Yes	0		0			Kinematic						-3541.515	-2.345		
7X	U1														-3541.515	-1.876		
7X	U1														-3305.414	-1.42357		
7X	U1														-3069.313	-1.05838		
7X	U1														-2833.212	-0.76841		
7X	U1														-2597.111	-0.54255		
7X	U1														-2361.01	-0.37057		
7X	U1														-2124.909	-0.24313		
7X	U1														-1888.808	-0.15178		
7X	U1														-1652.707	-0.08897		
7X	U1														-1416.606	-0.04803		
7X	U1														-1180.505	-0.02316		
7X	U1														-944.404	-0.00949		
7X	U1														-708.303	-0.003		
7X	U1														-472.202	-0.00059291		
7X	U1														-236.101	-0.00003706		
7X	U1														0	0		
7X	U1														236.101	0.00003706		
7X	U1														472.202	0.00059291		
7X	U1														708.303	0.003		
7X	U1														944.404	0.00949		
7X	U1														1180.505	0.02316		
7X	U1														1416.606	0.04803		
7X	U1														1652.707	0.08897		
7X	U1														1888.808	0.15178		
7X	U1														2124.909	0.24313		
7X	U1														2361.01	0.37057		
7X	U1														2597.111	0.54255		
7X	U1														2833.212	0.76841		
7X	U1														3069.313	1.05838		
7X	U1														3305.414	1.42357		
7X	U1														3541.515	1.876		
7X	U1														3541.515	2.345		
6X	U1	No	Yes	0		0			Kinematic						-5884.992	-3.5		
6X	U1														-5884.992	-2.8		
6X	U1														-5492.6592	-2.12474		
6X	U1														-5100.3264	-1.57967		
6X	U1														-4707.9936	-1.14688		
6X	U1														-4315.6608	-0.80977		
6X	U1														-3923.328	-0.55309		
6X	U1														-3530.9952	-0.36288		
6X	U1														-3138.6624	-0.22654		
6X	U1														-2746.3296	-0.1328		
6X	U1														-2353.9968	-0.07168		
6X	U1														-1961.664	-0.03457		
6X	U1														-1569.3312	-0.01416		
6X	U1														-1176.9984	-0.00448		
6X	U1														-784.6656	-0.00088494		
6X	U1														-392.3328	-0.00005531		
6X	U1														0	0		
6X	U1														392.3328	0.00005531		
6X	U1														784.6656	0.00088494		
6X	U1														1176.9984	0.00448		
6X	U1														1569.3312	0.01416		
6X	U1														1961.664	0.03457		

6X	U1														2353.9968	0.07168		
6X	U1														2746.3296	0.1328		
6X	U1														3138.6624	0.22654		
6X	U1														3530.9952	0.36288		
6X	U1														3923.328	0.55309		
6X	U1														4315.6608	0.80977		
6X	U1														4707.9936	1.14688		
6X	U1														5100.3264	1.57967		
6X	U1														5492.6592	2.12474		
6X	U1														5884.992	2.8		
6X	U1														5884.992	3.5		
5X	U1	No	Yes	0		0			Kinematic						-6531.36	-3.5		
5X	U1														-6531.36	-2.8		
5X	U1														-6095.936	-2.12474		
5X	U1														-5660.512	-1.57967		
5X	U1														-5225.088	-1.14688		
5X	U1														-4789.664	-0.80977		
5X	U1														-4354.24	-0.55309		
5X	U1														-3918.816	-0.36288		
5X	U1														-3483.392	-0.22654		
5X	U1														-3047.968	-0.1328		
5X	U1														-2612.544	-0.07168		
5X	U1														-2177.12	-0.03457		
5X	U1														-1741.696	-0.01416		
5X	U1														-1306.272	-0.00448		
5X	U1														-870.848	-0.00088494		
5X	U1														-435.424	-0.00005531		
5X	U1														0	0		
5X	U1														435.424	0.00005531		
5X	U1														870.848	0.00088494		
5X	U1														1306.272	0.00448		
5X	U1														1741.696	0.01416		
5X	U1														2177.12	0.03457		
5X	U1														2612.544	0.07168		
5X	U1														3047.968	0.1328		
5X	U1														3483.392	0.22654		
5X	U1														3918.816	0.36288		
5X	U1														4354.24	0.55309		
5X	U1														4789.664	0.80977		
5X	U1														5225.088	1.14688		
5X	U1														5660.512	1.57967		
5X	U1														6095.936	2.12474		
5X	U1														6531.36	2.8		
5X	U1														6531.36	3.5		
4X	U1	No	Yes	0		0			Kinematic						-4903.68	-3.5		
4X	U1														-4903.68	-2.8		
4X	U1														-4576.768	-2.12474		
4X	U1														-4249.856	-1.57967		
4X	U1														-3922.944	-1.14688		
4X	U1														-3596.032	-0.80977		
4X	U1														-3269.12	-0.55309		
4X	U1														-2942.208	-0.36288		
4X	U1														-2615.296	-0.22654		
4X	U1														-2288.384	-0.1328		
4X	U1														-1961.472	-0.07168		
4X	U1														-1634.56	-0.03457		

4X	U1														-1307.648	-0.01416		
4X	U1														-980.736	-0.00448		
4X	U1														-653.824	-0.00088494		
4X	U1														-326.912	-0.00005531		
4X	U1														0	0		
4X	U1														326.912	0.00005531		
4X	U1														653.824	0.00088494		
4X	U1														980.736	0.00448		
4X	U1														1307.648	0.01416		
4X	U1														1634.56	0.03457		
4X	U1														1961.472	0.07168		
4X	U1														2288.384	0.1328		
4X	U1														2615.296	0.22654		
4X	U1														2942.208	0.36288		
4X	U1														3269.12	0.55309		
4X	U1														3596.032	0.80977		
4X	U1														3922.944	1.14688		
4X	U1														4249.856	1.57967		
4X	U1														4576.768	2.12474		
4X	U1														4903.68	2.8		
4X	U1														4903.68	3.5		
3X	U1	No	Yes	0		0			Kinematic						-5862.24	-3.5		
3X	U1														-5862.24	-2.8		
3X	U1														-5471.424	-2.12474		
3X	U1														-5080.608	-1.57967		
3X	U1														-4689.792	-1.14688		
3X	U1														-4298.976	-0.80977		
3X	U1														-3908.16	-0.55309		
3X	U1														-3517.344	-0.36288		
3X	U1														-3126.528	-0.22654		
3X	U1														-2735.712	-0.1328		
3X	U1														-2344.896	-0.07168		
3X	U1														-1954.08	-0.03457		
3X	U1														-1563.264	-0.01416		
3X	U1														-1172.448	-0.00448		
3X	U1														-781.632	-0.00088494		
3X	U1														-390.816	-0.00005531		
3X	U1														0	0		
3X	U1														390.816	0.00005531		
3X	U1														781.632	0.00088494		
3X	U1														1172.448	0.00448		
3X	U1														1563.264	0.01416		
3X	U1														1954.08	0.03457		
3X	U1														2344.896	0.07168		
3X	U1														2735.712	0.1328		
3X	U1														3126.528	0.22654		
3X	U1														3517.344	0.36288		
3X	U1														3908.16	0.55309		
3X	U1														4298.976	0.80977		
3X	U1														4689.792	1.14688		
3X	U1														5080.608	1.57967		
3X	U1														5471.424	2.12474		
3X	U1														5862.24	2.8		
3X	U1														5862.24	3.5		
2X	U1	No	Yes	0		0			Kinematic						-9084.96	-3.5		
2X	U1														-9084.96	-2.8		

2X	U1														-8479.296	-2.12474		
2X	U1														-7873.632	-1.57967		
2X	U1														-7267.968	-1.14688		
2X	U1														-6662.304	-0.80977		
2X	U1														-6056.64	-0.55309		
2X	U1														-5450.976	-0.36288		
2X	U1														-4845.312	-0.22654		
2X	U1														-4239.648	-0.1328		
2X	U1														-3633.984	-0.07168		
2X	U1														-3028.32	-0.03457		
2X	U1														-2422.656	-0.01416		
2X	U1														-1816.992	-0.00448		
2X	U1														-1211.328	-0.00088494		
2X	U1														-605.664	-0.00005531		
2X	U1														0	0		
2X	U1														605.664	0.00005531		
2X	U1														1211.328	0.00088494		
2X	U1														1816.992	0.00448		
2X	U1														2422.656	0.01416		
2X	U1														3028.32	0.03457		
2X	U1														3633.984	0.07168		
2X	U1														4239.648	0.1328		
2X	U1														4845.312	0.22654		
2X	U1														5450.976	0.36288		
2X	U1														6056.64	0.55309		
2X	U1														6662.304	0.80977		
2X	U1														7267.968	1.14688		
2X	U1														7873.632	1.57967		
2X	U1														8479.296	2.12474		
2X	U1														9084.96	2.8		
2X	U1														9084.96	3.5		

Gate Structure - SAP2000 Report Output

License #2010*1NRDSQ492PZEHHT

SAP2000 Analysis Report

Prepared by

Stantec Consulting Ltd.

Model Name: Gate_Tower_Analysis_Dry.sdb

2 July 2020

Contents

List of Figures

List of Tables

1. Model geometry

This section provides model geometry information, including items such as joint coordinates, joint restraints, and element connectivity.

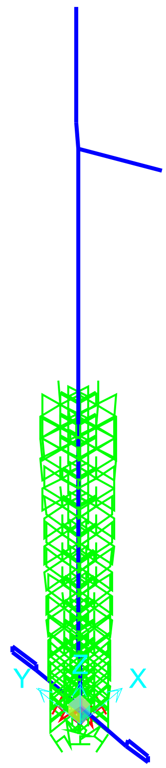


Figure 1: Finite element model

1.1. Joint coordinates

Table 1: Joint Coordinates

Table 1: Joint Coordinates

Joint	CoordSys	CoordType	GlobalX	GlobalY	GlobalZ
			mm	mm	mm
1	GLOBAL	Cartesian	0.	0.	0.
2	GLOBAL	Cartesian	0.	0.	900.
3	GLOBAL	Cartesian	0.	0.	1800.
4	GLOBAL	Cartesian	0.	0.	2700.06
5	GLOBAL	Cartesian	0.	0.	3400.
6	GLOBAL	Cartesian	0.	0.	4900.
7	GLOBAL	Cartesian	0.	0.	5440.
8	GLOBAL	Cartesian	0.	0.	6690.
9	GLOBAL	Cartesian	0.	0.	7940.
10	GLOBAL	Cartesian	0.	0.	9440.
11	GLOBAL	Cartesian	0.	0.	10940.
12	GLOBAL	Cartesian	0.	0.	12440.
13	GLOBAL	Cartesian	0.	0.	13940.

Table 1: Joint Coordinates

Joint	CoordSys	CoordType	GlobalX	GlobalY	GlobalZ
			mm	mm	mm
14	GLOBAL	Cartesian	0.	0.	15440.
15	GLOBAL	Cartesian	0.	0.	16940.
16	GLOBAL	Cartesian	0.	0.	17940.
17	GLOBAL	Cartesian	0.	0.	18940.
18	GLOBAL	Cartesian	0.	0.	19940.
19	GLOBAL	Cartesian	0.	0.	21440.
20	GLOBAL	Cartesian	0.	0.	22940.
21	GLOBAL	Cartesian	0.	0.	24440.
22	GLOBAL	Cartesian	0.	0.	25940.
23	GLOBAL	Cartesian	0.	0.	27180.
24	GLOBAL	Cartesian	0.	0.	28180.
25	GLOBAL	Cartesian	0.	0.	28940.
26	GLOBAL	Cartesian	1000.	0.	900.
27	GLOBAL	Cartesian	1000.	0.	1800.
28	GLOBAL	Cartesian	1000.	0.	2700.06
29	GLOBAL	Cartesian	1000.	0.	3400.
30	GLOBAL	Cartesian	1000.	0.	4900.
31	GLOBAL	Cartesian	1000.	0.	5440.
32	GLOBAL	Cartesian	1000.	0.	6690.
33	GLOBAL	Cartesian	1000.	0.	7940.
34	GLOBAL	Cartesian	1000.	0.	9440.
35	GLOBAL	Cartesian	1000.	0.	10940.
36	GLOBAL	Cartesian	1000.	0.	12440.
37	GLOBAL	Cartesian	1000.	0.	13940.
38	GLOBAL	Cartesian	1000.	0.	15440.
39	GLOBAL	Cartesian	1000.	0.	16940.
40	GLOBAL	Cartesian	1000.	0.	17940.
41	GLOBAL	Cartesian	0.	-3450.	28180.
42	GLOBAL	Cartesian	0.	1000.	900.
43	GLOBAL	Cartesian	0.	1000.	1800.
44	GLOBAL	Cartesian	0.	1000.	2700.06
45	GLOBAL	Cartesian	0.	1000.	3400.
46	GLOBAL	Cartesian	0.	1000.	4900.
47	GLOBAL	Cartesian	0.	1000.	5440.
48	GLOBAL	Cartesian	0.	1000.	6690.
49	GLOBAL	Cartesian	0.	1000.	7940.
50	GLOBAL	Cartesian	0.	1000.	9440.
51	GLOBAL	Cartesian	0.	1000.	10940.
52	GLOBAL	Cartesian	0.	1000.	12440.
53	GLOBAL	Cartesian	0.	1000.	13940.
54	GLOBAL	Cartesian	0.	1000.	15440.
55	GLOBAL	Cartesian	0.	1000.	16940.
56	GLOBAL	Cartesian	0.	1000.	17940.
57	GLOBAL	Cartesian	0.	0.	32111.
58	GLOBAL	Cartesian	0.	5000.	1350.
59	GLOBAL	Cartesian	0.	-4500.	1350.
60	GLOBAL	Cartesian	1000.	0.	18940.
61	GLOBAL	Cartesian	0.	1000.	18940.
62	GLOBAL	Cartesian	0.	3200.	1350.
66	GLOBAL	Cartesian	0.	-3200.	1350.
76	GLOBAL	Cartesian	0.	5000.	1800.
77	GLOBAL	Cartesian	0.	3200.	1800.
78	GLOBAL	Cartesian	0.	-3200.	1800.
79	GLOBAL	Cartesian	0.	-4500.	1800.

Table 1: Joint Coordinates

Joint	CoordSys	CoordType	GlobalX	GlobalY	GlobalZ
			mm	mm	mm
81	GLOBAL	Cartesian	0.	0.	1350.

1.2. Joint restraints

Table 2: Joint Restraint Assignments

Table 2: Joint Restraint Assignments

Joint	U1	U2	U3	R1	R2	R3
26	Yes	Yes	Yes	Yes	Yes	Yes
27	Yes	Yes	Yes	Yes	Yes	Yes
28	Yes	Yes	Yes	Yes	Yes	Yes
29	Yes	Yes	Yes	Yes	Yes	Yes
30	Yes	Yes	Yes	Yes	Yes	Yes
31	Yes	Yes	Yes	Yes	Yes	Yes
32	Yes	Yes	Yes	Yes	Yes	Yes
33	Yes	Yes	Yes	Yes	Yes	Yes
34	Yes	Yes	Yes	Yes	Yes	Yes
35	Yes	Yes	Yes	Yes	Yes	Yes
36	Yes	Yes	Yes	Yes	Yes	Yes
37	Yes	Yes	Yes	Yes	Yes	Yes
38	Yes	Yes	Yes	Yes	Yes	Yes
39	Yes	Yes	Yes	Yes	Yes	Yes
40	Yes	Yes	Yes	Yes	Yes	Yes
42	Yes	Yes	Yes	Yes	Yes	Yes
43	Yes	Yes	Yes	Yes	Yes	Yes
44	Yes	Yes	Yes	Yes	Yes	Yes
45	Yes	Yes	Yes	Yes	Yes	Yes
46	Yes	Yes	Yes	Yes	Yes	Yes
47	Yes	Yes	Yes	Yes	Yes	Yes
48	Yes	Yes	Yes	Yes	Yes	Yes
49	Yes	Yes	Yes	Yes	Yes	Yes
50	Yes	Yes	Yes	Yes	Yes	Yes
51	Yes	Yes	Yes	Yes	Yes	Yes
52	Yes	Yes	Yes	Yes	Yes	Yes
53	Yes	Yes	Yes	Yes	Yes	Yes
54	Yes	Yes	Yes	Yes	Yes	Yes
55	Yes	Yes	Yes	Yes	Yes	Yes
56	Yes	Yes	Yes	Yes	Yes	Yes
60	Yes	Yes	Yes	Yes	Yes	Yes
61	Yes	Yes	Yes	Yes	Yes	Yes

1.3. Element connectivity

Table 3: Connectivity - Frame

Table 3: Connectivity - Frame

Frame	JointI	JointJ	Length
			mm
1	1	2	900.
4	4	5	699.94
5	5	6	1500.
6	6	7	540.
7	7	8	1250.
8	8	9	1250.
9	9	10	1500.
10	10	11	1500.
11	11	12	1500.
12	12	13	1500.
13	13	14	1500.
14	14	15	1500.
15	15	16	1000.
16	16	17	1000.
17	17	18	1000.
18	18	19	1500.
19	19	20	1500.
20	20	21	1500.
21	21	22	1500.
22	22	23	1240.
23	23	24	1000.
24	24	25	760.
25	24	41	3450.
26	25	57	3171.
27	3	4	900.06
29	77	76	1800.
30	78	79	1300.
32	62	77	450.
33	62	58	1800.
34	58	76	450.
36	66	78	450.
37	59	79	450.
38	66	59	1300.
39	62	81	3200.
40	81	66	3200.
41	2	81	450.
42	81	3	450.

Table 4: Frame Section Assignments

Table 4: Frame Section Assignments

Frame	AnalSect	DesignSect	MatProp
1	1	N.A.	CLASS_A1_30MPa
4	3	3	CLASS_A1_30MPa
5	4	4	CLASS_A1_30MPa
6	5	5	CLASS_A1_30MPa

Table 4: Frame Section Assignments

Frame	AnalSect	DesignSect	MatProp
7	6	6	CLASS_A1_30MPa
8	6	6	CLASS_A1_30MPa
9	6	6	CLASS_A1_30MPa
10	6	6	CLASS_A1_30MPa
11	6	6	CLASS_A1_30MPa
12	6	6	CLASS_A1_30MPa
13	6	6	CLASS_A1_30MPa
14	6	6	CLASS_A1_30MPa
15	7	7	CLASS_A1_30MPa
16	7	7	CLASS_A1_30MPa
17	7	7	CLASS_A1_30MPa
18	7	7	CLASS_A1_30MPa
19	7	7	CLASS_A1_30MPa
20	7	7	CLASS_A1_30MPa
21	7	7	CLASS_A1_30MPa
22	7	7	CLASS_A1_30MPa
23	7	7	CLASS_A1_30MPa
24	7	7	CLASS_A1_30MPa
25	Rigid_Link	N.A.	Default
26	Rigid_Link	N.A.	Default
27	3	3	CLASS_A1_30MPa
29	A	N.A.	Default
30	B	N.A.	Default
32	Rigid_Link	N.A.	Default
33	Rigid_Link	N.A.	Default
34	Rigid_Link	N.A.	Default
36	Rigid_Link	N.A.	Default
37	Rigid_Link	N.A.	Default
38	Rigid_Link	N.A.	Default
39	Rigid_Link	N.A.	Default
40	Rigid_Link	N.A.	Default
41	2	N.A.	CLASS_A1_30MPa
42	2	N.A.	CLASS_A1_30MPa

2. Material properties

This section provides material property information for materials used in the model.

Table 5: Material Properties 02 - Basic Mechanical Properties

Table 5: Material Properties 02 - Basic Mechanical Properties

Material	UnitWeight	UnitMass	E1	G12	U12	A1
	KN/mm3	KN-s2/mm4	KN/mm2	KN/mm2		1/C
4000Psi	2.3563E-08	2.4028E-12	24.85558	10.35649	0.2	9.9000E-06
A416Gr270	7.6973E-08	7.8490E-12	196.5006			1.1700E-05
A615Gr60	7.6973E-08	7.8490E-12	199.94798			1.1700E-05
A992Fy50	7.6973E-08	7.8490E-12	199.94798	76.90307	0.3	1.1700E-05
CLASS_A1_30MPa	2.3500E-08	2.3963E-12	24.64752	10.2698	0.2	1.0000E-05
G30.18-92	7.6973E-08	7.8490E-12	199.94798			1.1700E-05
RIGID	0.0000E+00	0.0000E+00	1.	0.38462	0.3	0.0000E+00

Table 6: Material Properties 03a - Steel Data

Table 6: Material Properties 03a - Steel Data

Material	Fy	Fu	FinalSlope
	KN/mm2	KN/mm2	
A992Fy50	0.34474	0.44816	-0.1

Table 7: Material Properties 03b - Concrete Data

Table 7: Material Properties 03b - Concrete Data

Material	Fc	eFc	FinalSlope
	KN/mm2	KN/mm2	
4000Psi	0.02758	0.02758	-0.1
CLASS_A1_30MPa	0.03	0.03	-0.1

Table 8: Material Properties 03e - Rebar Data

Table 8: Material Properties 03e - Rebar Data

Material	Fy	Fu	FinalSlope
	KN/mm2	KN/mm2	
A615Gr60	0.41369	0.62053	-0.1
G30.18-92	0.4	0.54	-0.1

Table 9: Material Properties 03f - Tendon Data

Table 9: Material Properties 03f - Tendon Data

Material	Fy	Fu	FinalSlope
	KN/mm2	KN/mm2	
A416Gr270	1.68991	1.86158	-0.1

3. Section properties

This section provides section property information for objects used in the model.

3.1. Frames

Table 10: Frame Section Properties 01 - General, Part 1 of 5

Table 10: Frame Section Properties 01 - General, Part 1 of 5

SectionName	Material	Shape	t3	t2	Area	TorsConst	I33	I22
			mm	mm	mm2	mm4	mm4	mm4
1	CLASS_A1_30MPa	SD Section			67200000.	5.702E+14	2.294E+14	6.174E+14
2	CLASS_A1_30MPa	SD Section			62928000.	4.853E+14	2.216E+14	5.176E+14
3	CLASS_A1_30MPa	SD Section			18662223.2	1.163E+13	3.834E+13	6.203E+13
4	CLASS_A1_30MPa	SD Section			22080000.	8.502E+13	3.894E+13	8.204E+13
5	CLASS_A1_30MPa	SD Section			22641976.84	8.906E+13	3.904E+13	8.855E+13
6	CLASS_A1_30MPa	SD Section			17841976.84	7.962E+13	3.501E+13	7.880E+13
7	CLASS_A1_30MPa	SD Section			12471976.84	4.414E+13	1.828E+13	5.044E+13
A	CLASS_A1_30MPa	SD Section			4711065.17	1.741E+12	2.618E+12	4.933E+12
B	CLASS_A1_30MPa	SD Section			5462153.19	8.484E+11	4.648E+12	9.255E+12
Rigid_Link	RIGID	General	0.01	0.01	1.000E+12	1.000E+12	1.000E+18	1.000E+18

Table 10: Frame Section Properties 01 - General, Part 2 of 5

Table 10: Frame Section Properties 01 - General, Part 2 of 5

SectionName	I23	AS2	AS3
	mm4	mm2	mm2
1	0.	56000277.07	56000277.07
2	0.	51546062.37	53160796.39
3	0.	18662223.2	15772549.97
4	0.	12478822.93	17632303.72
5	0.	13845806.93	18155373.29
6	0.	10775936.02	12081062.4
7	0.	7853660.87	7921017.33
A	0.	3277457.78	2709170.75
B	0.	4114152.58	2998692.31
Rigid_Link	0.	1.000E+12	1.000E+12

Table 10: Frame Section Properties 01 - General, Part 3 of 5

Table 10: Frame Section Properties 01 - General, Part 3 of 5

SectionName	S33	S22	Z33	Z22	R33	R22
	mm3	mm3	mm3	mm3	mm	mm
1	7.168E+10	1.176E+11	1.075E+11	1.764E+11	1847.521	3031.089
2	6.948E+10	9.314E+10	1.027E+11	1.559E+11	1876.761	2867.883
3	1.826E+10	1.896E+10	2.555E+10	2.937E+10	1433.333	1823.064
4	1.854E+10	2.564E+10	2.678E+10	3.677E+10	1327.96	1927.565
5	1.859E+10	2.384E+10	2.700E+10	3.868E+10	1313.161	1977.621
6	1.667E+10	2.134E+10	2.268E+10	3.244E+10	1400.827	2101.505
7	1.016E+10	1.445E+10	1.358E+10	2.155E+10	1210.81	2010.981
A	1922020258.	3288382805.	2759728383.	4079249816.	745.532	1023.239
B	2943543185.	4560782553.	4040355824.	5976815407.	922.483	1301.668
Rigid_Link	0.	0.	0.	0.	0.	0.

Table 10: Frame Section Properties 01 - General, Part 4 of 5

Table 10: Frame Section Properties 01 - General, Part 4 of 5

SectionName	EccV2	AMod	A2Mod	A3Mod	JMod	I2Mod	I3Mod	MMod
	mm							
1		1.	1.	1.	1.	1.	1.	1.
2		1.	1.	1.	1.	1.	1.	1.
3		1.	1.	1.	1.	1.	1.	1.
4		1.	1.	1.	1.	1.	1.	1.
5		1.	1.	1.	1.	1.	1.	1.
6		1.	1.	1.	1.	1.	1.	1.
7		1.	1.	1.	1.	1.	1.	1.
A		1.	1.	1.	1.	1.	1.	1.
B		1.	1.	1.	1.	1.	1.	1.
Rigid_Link	0.	1.	1.	1.	1.	1.	1.	1.

Table 10: Frame Section Properties 01 - General, Part 5 of 5

Table 10: Frame Section Properties 01 - General, Part 5 of 5

SectionName	WMod
1	1.
2	1.
3	1.
4	1.
5	1.
6	1.
7	1.
A	1.
B	1.
Rigid_Link	1.

3.2. Solids

Table 11: Solid Property Definitions

Table 11: Solid Property Definitions

SolidProp	Material	MatAngleA	MatAngleB	MatAngleC
		Degrees	Degrees	Degrees
Solid1	4000Psi	0.	0.	0.

4. Load patterns

This section provides loading information as applied to the model.

4.1. Definitions

Table 12: Load Pattern Definitions

Table 12: Load Pattern Definitions

LoadPat	DesignType	SelfWtMult	AutoLoad
DEAD	Dead	1.	
DEAD_BRIDGE	Super Dead	0.	
DEAD_UPPER-ROOM	Super Dead	0.	
DEAD_ACCESS_LADDER	Super Dead	0.	
DEAD_LANDINGS	Super Dead	0.	
DEAD_GATES	Super Dead	0.	
LIVE_BRIDGE	Live	0.	
LIVE_UPPER-ROOM	Live	0.	
LIVE_LANDINGS	Live	0.	
SNOW_UPPER-ROOM	Snow	0.	
THERMAL_BRIDGE	Temperature	0.	
WIND_X_BRIDGE	Wind	0.	None
WIND_X_UPPER-ROOM	Wind	0.	None
WIND_Y_UPPER-ROOM	Wind	0.	None
WIND_X_MAIN_STRUCTURE	Wind	0.	None
WIND_Y_MAIN_STRUCTURE	Wind	0.	None
EQX_STATIC	Quake	0.	None
EQY_STATIC	Quake	0.	None
EQZ_STATIC	Quake	0.	None
HYDRO_UN	Live	0.	
HYDRO_E	Live	0.	
EARTH_X_UN	Live	0.	

Table 12: Load Pattern Definitions

LoadPat	DesignType	SelfWtMult	AutoLoad
EARTH_Y_UN	Live	0.	
SUR_Y	Live	0.	
SUR_X	Live	0.	

5. Load cases

This section provides load case information.

5.1. Definitions

Table 13: Load Case Definitions, Part 1 of 2

Table 13: Load Case Definitions, Part 1 of 2

Case	Type	InitialCond	ModalCase	BaseCase	MassSource	DesActOpt
MODAL	LinModal	Zero				Prog Det
TOWER_DEAD	NonStatic	Zero				Prog Det
TOWER_LIVE	NonStatic	Zero				Prog Det
TOWER_HYDRO_UN	NonStatic	Zero				Prog Det
TOWER_HYDRO_E	NonStatic	Zero				Prog Det
TOWER_SNOW	NonStatic	Zero				Prog Det
TOWER_THERMAL_BRIDGE	NonStatic	Zero				Prog Det
TOWER_WIND_X	NonStatic	Zero				Prog Det
TOWER_WIND_Y	NonStatic	Zero				Prog Det
WIND_X_BB	NonStatic	Zero				Prog Det
WIND_Y_BB	NonStatic	Zero				Prog Det
TOWER_EQX_STATIC	NonStatic	Zero				Prog Det
TOWER_EQY_STATIC	NonStatic	Zero				Prog Det
TOWER_EQZ_STATIC	NonStatic	Zero				Prog Det
DEAD_CONSTRUCTION	LinStatic	Zero				Prog Det
EARTH_X_UN	NonStatic	Zero				Prog Det
EARTH_Y_UN	NonStatic	Zero				Prog Det
SUR_Y	NonStatic	Zero				Prog Det
SUR_X	NonStatic	Zero				Prog Det

Table 13: Load Case Definitions, Part 2 of 2

Table 13: Load Case Definitions, Part 2 of 2

Case	DesignAct
MODAL	Other

Table 13: Load Case Definitions, Part 2 of 2

Case	DesignAct
TOWER_DEAD	Non-Composite
TOWER_LIVE	Short-Term Composite
TOWER_HYDRO_UN	Short-Term Composite
TOWER_HYDRO_E	Short-Term Composite
TOWER_SNOW	Short-Term Composite
TOWER_THERMAL_BRIDGE	Short-Term Composite
TOWER_WIND_X	Short-Term Composite
TOWER_WIND_Y	Short-Term Composite
WIND_X_BB	Short-Term Composite
WIND_Y_BB	Short-Term Composite
TOWER_EQX_STATIC	Short-Term Composite
TOWER_EQY_STATIC	Short-Term Composite
TOWER_EQZ_STATIC	Short-Term Composite
DEAD_CONSTRUCTION	Non-Composite
EARTH_X_UN	Short-Term Composite
EARTH_Y_UN	Short-Term Composite
SUR_Y	Short-Term Composite
SUR_X	Short-Term Composite

5.2. Static case load assignments

Table 14: Case - Static 1 - Load Assignments

Table 14: Case - Static 1 - Load Assignments

Case	LoadType	LoadName	LoadSF
TOWER_DEAD	Load pattern	DEAD	1.
TOWER_DEAD	Load pattern	DEAD_ACCESS_LADDER	1.
TOWER_DEAD	Load pattern	DEAD_BRIDGE	1.
TOWER_DEAD	Load pattern	DEAD_GATES	1.
TOWER_DEAD	Load pattern	DEAD_LANDINGS	1.
TOWER_DEAD	Load pattern	DEAD_UPPER-ROOM	1.
TOWER_LIVE	Load pattern	LIVE_BRIDGE	1.

Table 14: Case - Static 1 - Load Assignments

Case	LoadType	LoadName	LoadSF
TOWER_LIVE	Load pattern	LIVE_LANDINGS	1.
TOWER_LIVE	Load pattern	LIVE_UPPER-ROOM	1.
TOWER_HYDRO_UN	Load pattern	HYDRO_UN	1.
TOWER_HYDRO_E	Load pattern	HYDRO_E	1.
TOWER_SNOW	Load pattern	SNOW_UPPER-ROOM	1.
TOWER_THERMAL_BRIDGE	Load pattern	THERMAL_BRIDGE	1.
TOWER_WIND_X	Load pattern	WIND_X_MAIN_STRUCTURE	1.
TOWER_WIND_X	Load pattern	WIND_X_BRIDGE	1.
TOWER_WIND_X	Load pattern	WIND_X_UPPER-ROOM	1.
TOWER_WIND_Y	Load pattern	WIND_Y_MAIN_STRUCTURE	1.
TOWER_WIND_Y	Load pattern	WIND_Y_UPPER-ROOM	1.
WIND_X_BB	Load pattern	WIND_X_UPPER-ROOM	1.
WIND_X_BB	Load pattern	WIND_X_BRIDGE	1.
WIND_Y_BB	Load pattern	WIND_Y_UPPER-ROOM	1.
TOWER_EQX_STATIC	Load pattern	EQX_STATIC	1.
TOWER_EQY_STATIC	Load pattern	EQY_STATIC	1.
TOWER_EQZ_STATIC	Load pattern	EQZ_STATIC	1.
DEAD_CONSTRUCTION	Load pattern	DEAD	1.
DEAD_CONSTRUCTION	Load pattern	DEAD_ACCESS_LADDER	1.
DEAD_CONSTRUCTION	Load pattern	DEAD_BRIDGE	1.
DEAD_CONSTRUCTION	Load pattern	DEAD_GATES	1.
DEAD_CONSTRUCTION	Load pattern	DEAD_LANDINGS	1.
DEAD_CONSTRUCTION	Load pattern	DEAD_UPPER-ROOM	1.
EARTH_X_UN	Load pattern	EARTH_X_UN	1.
EARTH_Y_UN	Load pattern	EARTH_Y_UN	1.
SUR_Y	Load pattern	SUR_Y	1.
SUR_X	Load pattern	SUR_X	1.

5.3. Response spectrum case load assignments

Table 15: Function - Response Spectrum - User

Table 15: Function - Response Spectrum - User

Name	Period Sec	Accel	FuncDamp
RS_HORZ	0.05	0.33	0.05
RS_HORZ	0.1	0.47	
RS_HORZ	0.2	0.64	
RS_HORZ	0.3	0.69	
RS_HORZ	0.5	0.52	
RS_HORZ	1.	0.26	
RS_HORZ	2.	0.11	
RS_HORZ	5.	0.034	
RS_HORZ	10.	0.0087	
RS_VERT	0.05	0.3102	0.05
RS_VERT	0.1	0.3807	
RS_VERT	0.2	0.32	
RS_VERT	0.3	0.276	
RS_VERT	0.5	0.1872	
RS_VERT	1.	0.0962	
RS_VERT	2.	0.0473	
RS_VERT	5.	0.0163	
RS_VERT	10.	0.0066	

6. Load combinations

This section provides load combination information.

Table 16: Combination Definitions

Table 16: Combination Definitions

ComboName	ComboType	CaseName	ScaleFactor
U1-1	Linear Add	TOWER_DEAD	1.
U1-1		TOWER_SNOW	1.
U1-1		TOWER_THERMAL_BRIDGE	-1.
U1-2	Linear Add	TOWER_DEAD	1.
U1-2		TOWER_SNOW	1.
U1-2		TOWER_LIVE	1.
U1-2		TOWER_THERMAL_BRIDGE	-1.
U1-3	Linear Add	TOWER_DEAD	1.
U1-3		TOWER_SNOW	1.
U1-3		TOWER_LIVE	1.
U1-3		TOWER_WIND_X	1.
U1-3		TOWER_THERMAL_BRIDGE	-1.
U1-4+	Linear Add	TOWER_DEAD	1.
U1-4+		TOWER_SNOW	1.
U1-4+		TOWER_LIVE	1.
U1-4+		TOWER_WIND_Y	1.
U1-4+		TOWER_THERMAL_BRIDGE	1.

Table 16: Combination Definitions

ComboName	ComboType	CaseName	ScaleFactor
U2-1	Linear Add	TOWER_DEAD	1.
U2-1		TOWER_LIVE	1.
U2-1		TOWER_WIND_X	1.
U2-1		TOWER_THERMAL_BRIDGE	1.
U2-2+	Linear Add	TOWER_DEAD	1.
U2-2+		TOWER_LIVE	1.
U2-2+		TOWER_WIND_Y	1.
U2-2+		TOWER_THERMAL_BRIDGE	1.
U2-3	Linear Add	TOWER_DEAD	1.
U2-3		TOWER_WIND_X	1.
U2-3		TOWER_THERMAL_BRIDGE	1.
U2-4+	Linear Add	TOWER_DEAD	1.
U2-4+		TOWER_WIND_Y	1.
U2-4+		TOWER_THERMAL_BRIDGE	1.
UN1-1	Linear Add	TOWER_DEAD	1.
UN1-1		TOWER_HYDRO_UN	1.
UN1-1		TOWER_THERMAL_BRIDGE	1.
UN1-2	Linear Add	TOWER_DEAD	1.
UN1-2		TOWER_LIVE	1.
UN1-2		TOWER_HYDRO_UN	1.
UN1-2		TOWER_THERMAL_BRIDGE	1.
UN1-3	Linear Add	TOWER_DEAD	1.
UN1-3		TOWER_LIVE	1.
UN1-3		TOWER_WIND_X	1.
UN1-3		TOWER_HYDRO_UN	1.
UN1-3		TOWER_THERMAL_BRIDGE	1.
UN1-4+	Linear Add	TOWER_DEAD	1.
UN1-4+		TOWER_LIVE	1.
UN1-4+		TOWER_WIND_Y	1.
UN1-4+		TOWER_HYDRO_UN	1.
UN1-4+		TOWER_THERMAL_BRIDGE	1.
UN1-5	Linear Add	TOWER_DEAD	1.
UN1-5		TOWER_WIND_X	1.
UN1-5		TOWER_HYDRO_UN	1.
UN1-5		TOWER_THERMAL_BRIDGE	1.
UN1-6+	Linear Add	TOWER_DEAD	1.

Table 16: Combination Definitions

ComboName	ComboType	CaseName	ScaleFactor
UN1-6+		TOWER_WIND_Y	1.
UN1-6+		TOWER_HYDRO_UN	1.
UN1-6+		TOWER_THERMAL_BRIDGE	1.
UN2-1	Linear Add	TOWER_DEAD	1.
UN2-1		TOWER_HYDRO_UN	1.
UN2-1		TOWER_THERMAL_BRIDGE	1.
UN2-2	Linear Add	TOWER_DEAD	1.
UN2-2		TOWER_LIVE	1.
UN2-2		TOWER_HYDRO_UN	1.
UN2-2		TOWER_THERMAL_BRIDGE	1.
UN2-3	Linear Add	TOWER_DEAD	1.
UN2-3		TOWER_LIVE	1.
UN2-3		TOWER_WIND_X	1.
UN2-3		TOWER_HYDRO_UN	1.
UN2-3		TOWER_THERMAL_BRIDGE	1.
UN2-4+	Linear Add	TOWER_DEAD	1.
UN2-4+		TOWER_LIVE	1.
UN2-4+		TOWER_WIND_Y	1.
UN2-4+		TOWER_HYDRO_UN	1.
UN2-4+		TOWER_THERMAL_BRIDGE	1.
UN2-5	Linear Add	TOWER_DEAD	1.
UN2-5		TOWER_WIND_X	1.
UN2-5		TOWER_HYDRO_UN	1.
UN2-5		TOWER_THERMAL_BRIDGE	1.
UN2-6+	Linear Add	TOWER_DEAD	1.
UN2-6+		TOWER_WIND_Y	1.
UN2-6+		TOWER_HYDRO_UN	1.
UN2-6+		TOWER_THERMAL_BRIDGE	1.
E1-1	Linear Add	TOWER_DEAD	1.
E1-1		TOWER_HYDRO_E	1.
E1-1		TOWER_THERMAL_BRIDGE	1.
E1-2	Linear Add	TOWER_DEAD	1.
E1-2		TOWER_LIVE	1.
E1-2		TOWER_HYDRO_E	1.
E1-2		TOWER_THERMAL_BRIDGE	1.

Table 16: Combination Definitions

ComboName	ComboType	CaseName	ScaleFactor
E1-3	Linear Add	TOWER_DEAD	1.
E1-3		WIND_X_BB	1.
E1-3		TOWER_HYDRO_E	1.
E1-3		TOWER_THERMAL_BRIDGE	1.
E1-4+	Linear Add	TOWER_DEAD	1.
E1-4+		WIND_Y_BB	1.
E1-4+		TOWER_HYDRO_E	1.
E1-4+		TOWER_THERMAL_BRIDGE	1.
E2-1	Linear Add	TOWER_DEAD	1.
E2-1		TOWER_HYDRO_E	1.
E2-1		TOWER_THERMAL_BRIDGE	1.
E2-2	Linear Add	TOWER_DEAD	1.
E2-2		TOWER_LIVE	1.
E2-2		TOWER_HYDRO_E	1.
E2-2		TOWER_THERMAL_BRIDGE	1.
E2-3	Linear Add	TOWER_DEAD	1.
E2-3		WIND_X_BB	1.
E2-3		TOWER_HYDRO_E	1.
E2-3		TOWER_THERMAL_BRIDGE	1.
E2-4+	Linear Add	TOWER_DEAD	1.
E2-4+		WIND_Y_BB	1.
E2-4+		TOWER_HYDRO_E	1.
E2-4+		TOWER_THERMAL_BRIDGE	1.
PE-1	Linear Add	TOWER_DEAD	1.
PE-1		TOWER_WIND_X	1.
PE-1		TOWER_THERMAL_BRIDGE	1.
PE-2+	Linear Add	TOWER_DEAD	1.
PE-2+		TOWER_WIND_Y	1.
PE-2+		TOWER_THERMAL_BRIDGE	1.
U1-4-	Linear Add	TOWER_DEAD	1.
U1-4-		TOWER_SNOW	1.
U1-4-		TOWER_LIVE	1.
U1-4-		TOWER_WIND_Y	-1.
U1-4-		TOWER_THERMAL_BRIDGE	-1.
U2-2-	Linear Add	TOWER_DEAD	1.
U2-2-		TOWER_LIVE	1.
U2-2-		TOWER_WIND_Y	-1.
U2-2-		TOWER_THERMAL_BRIDGE	-1.

Table 16: Combination Definitions

ComboName	ComboType	CaseName	ScaleFactor
U2-4-	Linear Add	TOWER_DEAD	1.
U2-4-		TOWER_WIND_Y	-1.
U2-4-		TOWER_THERMAL_BRIDGE	-1.
UN1-4-	Linear Add	TOWER_DEAD	1.
UN1-4-		TOWER_LIVE	1.
UN1-4-		TOWER_WIND_Y	-1.
UN1-4-		TOWER_HYDRO_UN	1.
UN1-4-		TOWER_THERMAL_BRIDGE	-1.
UN1-6-	Linear Add	TOWER_DEAD	1.
UN1-6-		TOWER_WIND_Y	-1.
UN1-6-		TOWER_HYDRO_UN	1.
UN1-6-		TOWER_THERMAL_BRIDGE	-1.
UN2-4-	Linear Add	TOWER_DEAD	1.
UN2-4-		TOWER_LIVE	1.
UN2-4-		TOWER_WIND_Y	-1.
UN2-4-		TOWER_HYDRO_UN	1.
UN2-4-		TOWER_THERMAL_BRIDGE	-1.
UN2-6-	Linear Add	TOWER_DEAD	1.
UN2-6-		TOWER_WIND_Y	-1.
UN2-6-		TOWER_HYDRO_UN	1.
UN2-6-		TOWER_THERMAL_BRIDGE	-1.
E1-4-	Linear Add	TOWER_DEAD	1.
E1-4-		WIND_Y_BB	-1.
E1-4-		TOWER_HYDRO_E	1.
E1-4-		TOWER_THERMAL_BRIDGE	-1.
E2-4-	Linear Add	TOWER_DEAD	1.
E2-4-		WIND_Y_BB	-1.
E2-4-		TOWER_HYDRO_E	1.
E2-4-		TOWER_THERMAL_BRIDGE	-1.
PE-2-	Linear Add	TOWER_DEAD	1.
PE-2-		TOWER_WIND_Y	-1.
PE-2-		TOWER_THERMAL_BRIDGE	-1.
E3-1	Linear Add	TOWER_EQX_STATIC	0.3
E3-1		TOWER_EQY_STATIC	0.3
E3-1		TOWER_EQZ_STATIC	1.

Table 16: Combination Definitions

ComboName	ComboType	CaseName	ScaleFactor
E3-1		TOWER_DEAD	1.
E3-2	Linear Add	TOWER_EQX_STATIC	0.3
E3-2		TOWER_EQY_STATIC	-0.3
E3-2		TOWER_EQZ_STATIC	1.
E3-2		TOWER_DEAD	1.
E3-3	Linear Add	TOWER_EQX_STATIC	-0.3
E3-3		TOWER_EQY_STATIC	-0.3
E3-3		TOWER_EQZ_STATIC	1.
E3-3		TOWER_DEAD	1.
E3-4	Linear Add	TOWER_EQX_STATIC	-0.3
E3-4		TOWER_EQY_STATIC	0.3
E3-4		TOWER_EQZ_STATIC	1.
E3-4		TOWER_DEAD	1.
E3-5	Linear Add	TOWER_EQX_STATIC	0.3
E3-5		TOWER_EQY_STATIC	0.3
E3-5		TOWER_EQZ_STATIC	-1.
E3-5		TOWER_DEAD	1.
E3-6	Linear Add	TOWER_EQX_STATIC	0.3
E3-6		TOWER_EQY_STATIC	-0.3
E3-6		TOWER_EQZ_STATIC	-1.
E3-6		TOWER_DEAD	1.
E3-7	Linear Add	TOWER_EQX_STATIC	-0.3
E3-7		TOWER_EQY_STATIC	-0.3
E3-7		TOWER_EQZ_STATIC	-1.
E3-7		TOWER_DEAD	1.
E3-8	Linear Add	TOWER_EQX_STATIC	-0.3
E3-8		TOWER_EQY_STATIC	0.3
E3-8		TOWER_EQZ_STATIC	-1.
E3-8		TOWER_DEAD	1.
E3-9	Linear Add	TOWER_EQX_STATIC	1.
E3-9		TOWER_EQY_STATIC	0.3
E3-9		TOWER_EQZ_STATIC	0.3
E3-9		TOWER_DEAD	1.
E3-10	Linear Add	TOWER_EQX_STATIC	1.

Table 16: Combination Definitions

ComboName	ComboType	CaseName	ScaleFactor
E3-10		TOWER_EQY_STATIC	-0.3
E3-10		TOWER_EQZ_STATIC	0.3
E3-10		TOWER_DEAD	1.
E3-11	Linear Add	TOWER_EQX_STATIC	-1.
E3-11		TOWER_EQY_STATIC	-0.3
E3-11		TOWER_EQZ_STATIC	0.3
E3-11		TOWER_DEAD	1.
E3-12	Linear Add	TOWER_EQX_STATIC	-1.
E3-12		TOWER_EQY_STATIC	0.3
E3-12		TOWER_EQZ_STATIC	0.3
E3-12		TOWER_DEAD	1.
E3-13	Linear Add	TOWER_EQX_STATIC	1.
E3-13		TOWER_EQY_STATIC	0.3
E3-13		TOWER_EQZ_STATIC	-0.3
E3-13		TOWER_DEAD	1.
E3-14	Linear Add	TOWER_EQX_STATIC	1.
E3-14		TOWER_EQY_STATIC	-0.3
E3-14		TOWER_EQZ_STATIC	-0.3
E3-14		TOWER_DEAD	1.
E3-15	Linear Add	TOWER_EQX_STATIC	-1.
E3-15		TOWER_EQY_STATIC	-0.3
E3-15		TOWER_EQZ_STATIC	-0.3
E3-15		TOWER_DEAD	1.
E3-16	Linear Add	TOWER_EQX_STATIC	-1.
E3-16		TOWER_EQY_STATIC	0.3
E3-16		TOWER_EQZ_STATIC	-0.3
E3-16		TOWER_DEAD	1.
E3-17	Linear Add	TOWER_EQX_STATIC	0.3
E3-17		TOWER_EQY_STATIC	1.
E3-17		TOWER_EQZ_STATIC	0.3
E3-17		TOWER_DEAD	1.
E3-18	Linear Add	TOWER_EQX_STATIC	0.3
E3-18		TOWER_EQY_STATIC	-1.

Table 16: Combination Definitions

ComboName	ComboType	CaseName	ScaleFactor
E3-18		TOWER_EQZ_STATIC	0.3
E3-18		TOWER_DEAD	1.
E3-19	Linear Add	TOWER_EQX_STATIC	-0.3
E3-19		TOWER_EQY_STATIC	-1.
E3-19		TOWER_EQZ_STATIC	0.3
E3-19		TOWER_DEAD	1.
E3-20	Linear Add	TOWER_EQX_STATIC	-0.3
E3-20		TOWER_EQY_STATIC	1.
E3-20		TOWER_EQZ_STATIC	0.3
E3-20		TOWER_DEAD	1.
E3-21	Linear Add	TOWER_EQX_STATIC	0.3
E3-21		TOWER_EQY_STATIC	1.
E3-21		TOWER_EQZ_STATIC	-0.3
E3-21		TOWER_DEAD	1.
E3-22	Linear Add	TOWER_EQX_STATIC	0.3
E3-22		TOWER_EQY_STATIC	-1.
E3-22		TOWER_EQZ_STATIC	-0.3
E3-22		TOWER_DEAD	1.
E3-23	Linear Add	TOWER_EQX_STATIC	-0.3
E3-23		TOWER_EQY_STATIC	-1.
E3-23		TOWER_EQZ_STATIC	-0.3
E3-23		TOWER_DEAD	1.
E3-24	Linear Add	TOWER_EQX_STATIC	-0.3
E3-24		TOWER_EQY_STATIC	1.
E3-24		TOWER_EQZ_STATIC	-0.3
E3-24		TOWER_DEAD	1.
UN3-1	Linear Add	DEAD_CONSTRUCTION	1.
UN4-1	Linear Add	TOWER_DEAD	1.
UN4-1		EARTH_X_UN	1.
UN4-1		EARTH_Y_UN	1.
UN4-1		TOWER_THERMAL_BRIDGE	1.
UN4-2	Linear Add	TOWER_DEAD	1.
UN4-2		TOWER_LIVE	1.
UN4-2		EARTH_X_UN	1.
UN4-2		EARTH_Y_UN	1.
UN4-2		TOWER_THERMAL_BRIDGE	1.

Table 16: Combination Definitions

ComboName	ComboType	CaseName	ScaleFactor
S_1	Linear Add	TOWER_DEAD	1.4
S_1		TOWER_THERMAL_BRIDGE	1.
S_1		TOWER_HYDRO_E	1.5
S_2A	Linear Add	TOWER_DEAD	1.25
S_2A		TOWER_LIVE	1.5
S_2A		TOWER_SNOW	1.
S_2A		TOWER_THERMAL_BRIDGE	1.
S_2A		TOWER_HYDRO_E	1.5
S_2B	Linear Add	TOWER_DEAD	1.25
S_2B		TOWER_LIVE	1.5
S_2B		TOWER_WIND_X	0.4
S_2B		TOWER_THERMAL_BRIDGE	1.
S_2B		TOWER_HYDRO_E	1.5
S_2C	Linear Add	TOWER_DEAD	1.25
S_2C		TOWER_LIVE	1.5
S_2C		TOWER_WIND_Y	0.4
S_2C		TOWER_THERMAL_BRIDGE	1.
S_2D	Linear Add	TOWER_DEAD	1.25
S_2D		TOWER_WIND_Y	-0.4
S_2D		TOWER_LIVE	1.5
S_2D		TOWER_THERMAL_BRIDGE	-1.
S_2D		TOWER_HYDRO_E	1.5
S_2E	Linear Add	TOWER_DEAD	0.9
S_2E		TOWER_LIVE	1.5
S_2E		TOWER_SNOW	1.
S_2E		TOWER_THERMAL_BRIDGE	1.
S_2E		TOWER_HYDRO_E	1.5
S_2F	Linear Add	TOWER_DEAD	0.9
S_2F		TOWER_LIVE	1.5
S_2F		TOWER_WIND_X	0.4
S_2F		TOWER_THERMAL_BRIDGE	1.
S_2F		TOWER_HYDRO_E	1.5
S_2G	Linear Add	TOWER_DEAD	0.9
S_2G		TOWER_LIVE	1.5
S_2G		TOWER_WIND_Y	0.4
S_2G		TOWER_THERMAL_BRIDGE	1.
S_2H	Linear Add	TOWER_DEAD	0.9
S_2H		TOWER_LIVE	1.5

Table 16: Combination Definitions

ComboName	ComboType	CaseName	ScaleFactor
S_2H		TOWER_WIND_Y	-0.4
S_2H		TOWER_THERMAL_BRIDGE	-1.
S_2H		TOWER_HYDRO_E	1.5
S_3A	Linear Add	TOWER_DEAD	1.25
S_3A		TOWER_LIVE	1.
S_3A		TOWER_SNOW	1.5
S_3A		TOWER_THERMAL_BRIDGE	1.
S_3A		TOWER_HYDRO_E	1.5
S_3B	Linear Add	TOWER_DEAD	1.25
S_3B		TOWER_SNOW	1.5
S_3B		TOWER_WIND_X	0.4
S_3B		TOWER_THERMAL_BRIDGE	1.
S_3B		TOWER_HYDRO_E	1.5
S_3C	Linear Add	TOWER_DEAD	1.25
S_3C		TOWER_SNOW	1.5
S_3C		TOWER_WIND_Y	0.4
S_3C		TOWER_THERMAL_BRIDGE	1.
S_3D	Linear Add	TOWER_DEAD	1.25
S_3D		TOWER_SNOW	1.5
S_3D		TOWER_WIND_Y	-0.4
S_3D		TOWER_THERMAL_BRIDGE	-1.
S_3D		TOWER_HYDRO_E	1.5
S_3E	Linear Add	TOWER_DEAD	0.9
S_3E		TOWER_LIVE	1.
S_3E		TOWER_SNOW	1.5
S_3E		TOWER_THERMAL_BRIDGE	1.
S_3E		TOWER_HYDRO_E	1.5
S_3F	Linear Add	TOWER_DEAD	0.9
S_3F		TOWER_SNOW	1.5
S_3F		TOWER_WIND_X	0.4
S_3F		TOWER_THERMAL_BRIDGE	1.
S_3F		TOWER_HYDRO_E	1.5
S_3G	Linear Add	TOWER_DEAD	0.9
S_3G		TOWER_SNOW	1.5
S_3G		TOWER_WIND_Y	0.4
S_3G		TOWER_THERMAL_BRIDGE	1.
S_3G		TOWER_HYDRO_E	1.5

Table 16: Combination Definitions

ComboName	ComboType	CaseName	ScaleFactor
S_3H	Linear Add	TOWER_DEAD	0.9
S_3H		TOWER_SNOW	1.5
S_3H		TOWER_WIND_Y	-0.4
S_3H		TOWER_THERMAL_BRIDGE	-1.
S_3H		TOWER_HYDRO_E	1.5
S_4A	Linear Add	TOWER_DEAD	1.25
S_4A		TOWER_LIVE	0.5
S_4A		TOWER_WIND_X	1.4
S_4A		TOWER_THERMAL_BRIDGE	1.
S_4A		TOWER_HYDRO_E	1.5
S_4B	Linear Add	TOWER_DEAD	1.25
S_4B		TOWER_LIVE	0.5
S_4B		TOWER_WIND_Y	1.4
S_4B		TOWER_THERMAL_BRIDGE	1.
S_4C	Linear Add	TOWER_DEAD	1.25
S_4C		TOWER_LIVE	0.5
S_4C		TOWER_WIND_Y	-1.4
S_4C		TOWER_THERMAL_BRIDGE	-1.
S_4C		TOWER_HYDRO_E	1.5
S_4D	Linear Add	TOWER_DEAD	1.25
S_4D		TOWER_SNOW	0.5
S_4D		TOWER_WIND_X	1.4
S_4D		TOWER_THERMAL_BRIDGE	1.
S_4D		TOWER_HYDRO_E	1.5
S_4E	Linear Add	TOWER_DEAD	1.25
S_4E		TOWER_SNOW	0.5
S_4E		TOWER_WIND_Y	1.4
S_4E		TOWER_THERMAL_BRIDGE	1.
S_4F	Linear Add	TOWER_DEAD	1.25
S_4F		TOWER_SNOW	0.5
S_4F		TOWER_WIND_Y	-1.4
S_4F		TOWER_THERMAL_BRIDGE	-1.
S_4F		TOWER_HYDRO_E	1.5
S_4G	Linear Add	TOWER_DEAD	0.9
S_4G		TOWER_LIVE	0.5
S_4G		TOWER_WIND_X	1.4
S_4G		TOWER_THERMAL_BRIDGE	1.

Table 16: Combination Definitions

ComboName	ComboType	CaseName	ScaleFactor
S_4G		TOWER_HYDRO_E	1.5
S_4H	Linear Add	TOWER_DEAD	0.9
S_4H		TOWER_LIVE	0.5
S_4H		TOWER_WIND_Y	1.4
S_4H		TOWER_THERMAL_BRIDGE	1.
S_4I	Linear Add	TOWER_DEAD	0.9
S_4I		TOWER_LIVE	0.5
S_4I		TOWER_WIND_Y	-1.4
S_4I		TOWER_THERMAL_BRIDGE	-1.
S_4I		TOWER_HYDRO_E	1.5
S_4J	Linear Add	TOWER_DEAD	0.9
S_4J		TOWER_SNOW	0.5
S_4J		TOWER_WIND_X	1.4
S_4J		TOWER_THERMAL_BRIDGE	1.
S_4J		TOWER_HYDRO_E	1.5
S_4K	Linear Add	TOWER_DEAD	0.9
S_4K		TOWER_SNOW	0.5
S_4K		TOWER_WIND_Y	1.4
S_4K		TOWER_THERMAL_BRIDGE	1.
S_4L	Linear Add	TOWER_DEAD	0.9
S_4L		TOWER_SNOW	0.5
S_4L		TOWER_WIND_Y	-1.4
S_4L		TOWER_THERMAL_BRIDGE	-1.
S_4L		TOWER_HYDRO_E	1.5
S_5A	Linear Add	E3-1	1.
S_5B	Linear Add	E3-2	1.
S_5C	Linear Add	E3-3	1.
S_5D	Linear Add	E3-4	1.
S_5E	Linear Add	E3-5	1.
S_5E		TOWER_LIVE	0.5
S_5F	Linear Add	E3-6	1.
S_5F		TOWER_LIVE	0.5
S_5G	Linear Add	E3-7	1.
S_5G		TOWER_LIVE	0.5
S_5H	Linear Add	E3-8	1.
S_5H		TOWER_LIVE	0.5
S_5I	Linear Add	E3-9	1.
S_5J	Linear Add	E3-10	1.
S_5K	Linear Add	E3-11	1.
S_5L	Linear Add	E3-12	1.
S_5M	Linear Add	E3-13	1.
S_5M		TOWER_LIVE	0.5
S_5N	Linear Add	E3-14	1.

Table 16: Combination Definitions

ComboName	ComboType	CaseName	ScaleFactor
S_5N		TOWER_LIVE	0.5
S_5O	Linear Add	E3-15	1.
S_5O		TOWER_LIVE	0.5
S_5P	Linear Add	E3-16	1.
S_5P		TOWER_LIVE	0.5
S_5Q	Linear Add	E3-17	1.
S_5R	Linear Add	E3-18	1.
S_5S	Linear Add	E3-19	1.
S_5T	Linear Add	E3-20	1.
S_5U	Linear Add	E3-21	1.
S_5U		TOWER_LIVE	0.5
S_5V	Linear Add	E3-22	1.
S_5V		TOWER_LIVE	0.5
S_5W	Linear Add	E3-23	1.
S_5W		TOWER_LIVE	0.5
S_5X	Linear Add	E3-24	1.
S_5X		TOWER_LIVE	0.5
SER_SD	Linear Add	TOWER_DEAD	1.
SER_SD		TOWER_LIVE	1.
SER_SD		TOWER_WIND_X	1.
SER_SD		TOWER_THERMAL_BRIDGE	1.
SER_SD		TOWER_HYDRO_E	1.
SER_SD		TOWER_WIND_Y	1.
S_4A_UN	Linear Add	TOWER_DEAD	1.25
S_4A_UN		TOWER_WIND_X	1.4
S_4A_UN		TOWER_THERMAL_BRIDGE	1.
S_4A_UN		TOWER_LIVE	0.5
S_4A_UN		SUR_X	1.5
S_4B_UN	Linear Add	TOWER_DEAD	1.25
S_4B_UN		TOWER_WIND_Y	1.4
S_4B_UN		TOWER_THERMAL_BRIDGE	1.
S_4B_UN		TOWER_LIVE	0.5
S_4B_UN		SUR_Y	1.5
S_4C_UN	Linear Add	TOWER_DEAD	1.25
S_4C_UN		TOWER_WIND_Y	-1.4
S_4C_UN		TOWER_THERMAL_BRIDGE	1.
S_4C_UN		TOWER_LIVE	0.5
S_4C_UN		SUR_Y	-1.5
S_4D_UN	Linear Add	TOWER_DEAD	1.25
S_4D_UN		TOWER_WIND_X	1.4
S_4D_UN		TOWER_THERMAL_BRIDGE	1.
S_4D_UN		TOWER_SNOW	0.5
S_4D_UN		SUR_X	1.5
S_4E_UN	Linear Add	TOWER_DEAD	1.25

Table 16: Combination Definitions

ComboName	ComboType	CaseName	ScaleFactor
S_4E_UN		TOWER_WIND_Y	1.4
S_4E_UN		TOWER_THERMAL_BRIDGE	1.
S_4E_UN		TOWER_SNOW	0.5
S_4E_UN		SUR_Y	1.5
S_4F_UN	Linear Add	TOWER_DEAD	1.25
S_4F_UN		TOWER_WIND_Y	-1.4
S_4F_UN		TOWER_THERMAL_BRIDGE	-1.
S_4F_UN		TOWER_SNOW	0.5
S_4F_UN		SUR_Y	-1.5
S_4G_UN	Linear Add	TOWER_DEAD	0.9
S_4G_UN		TOWER_WIND_X	1.4
S_4G_UN		TOWER_THERMAL_BRIDGE	1.
S_4G_UN		TOWER_LIVE	0.5
S_4G_UN		SUR_X	1.5
S_4H_UN	Linear Add	TOWER_DEAD	0.9
S_4H_UN		TOWER_WIND_Y	1.4
S_4H_UN		TOWER_THERMAL_BRIDGE	1.
S_4H_UN		TOWER_LIVE	0.5
S_4H_UN		SUR_Y	1.5
S_4I_UN	Linear Add	TOWER_DEAD	0.9
S_4I_UN		TOWER_WIND_Y	-1.4
S_4I_UN		TOWER_THERMAL_BRIDGE	-1.
S_4I_UN		TOWER_LIVE	0.5
S_4I_UN		SUR_Y	-1.5
S_4J_UN	Linear Add	TOWER_DEAD	0.9
S_4J_UN		TOWER_WIND_X	1.4
S_4J_UN		TOWER_THERMAL_BRIDGE	1.
S_4J_UN		TOWER_SNOW	0.5
S_4J_UN		SUR_X	1.5
S_4K_UN	Linear Add	TOWER_DEAD	0.9
S_4K_UN		TOWER_WIND_Y	1.4
S_4K_UN		TOWER_THERMAL_BRIDGE	1.
S_4K_UN		TOWER_SNOW	0.5
S_4K_UN		SUR_Y	1.5
S_4L_UN	Linear Add	TOWER_DEAD	0.9
S_4L_UN		TOWER_WIND_Y	-1.4
S_4L_UN		TOWER_THERMAL_BRIDGE	-1.
S_4L_UN		TOWER_SNOW	0.5
S_4L_UN		SUR_Y	-1.5

7. Design preferences

This section provides the design preferences for each type of design, which typically include material reduction factors, framing type, stress ratio limit, deflection limits, and other code specific items.

7.1. Steel design

Table 17: Preferences - Steel Design - AISC 360-10, Part 1 of 4

Table 17: Preferences - Steel Design - AISC 360-10, Part 1 of 4

THDesign	FrameType	PatLLF	SRatioLimit	MaxIter	SDC	SeisCode	SeisLoad	ImpFactor
Envelopes	SMF	0.75	0.95	1	D	Yes	Yes	1.

Table 17: Preferences - Steel Design - AISC 360-10, Part 2 of 4

Table 17: Preferences - Steel Design - AISC 360-10, Part 2 of 4

SystemRho	SystemSds	SystemR	SystemCd	Omega0	Provision	AMethod	SOMethod	SRMethod
1.	0.5	8.	5.5	3.	LRFD	Direct Analysis	General 2nd Order	Tau-b Fixed

Table 17: Preferences - Steel Design - AISC 360-10, Part 3 of 4

Table 17: Preferences - Steel Design - AISC 360-10, Part 3 of 4

NLCoeff	PhiB	PhiC	PhiTY	PhiTF	PhiV	PhiVRolledI	PhiVT	PlugWeld
0.002	0.9	0.9	0.9	0.75	0.9	1.	0.9	Yes

Table 17: Preferences - Steel Design - AISC 360-10, Part 4 of 4

Table 17: Preferences - Steel Design - AISC 360-10, Part 4 of 4

HSSWelding	HSSReduceT	CheckDefl	DLRat	SDLAndLLRat	LLRat	TotalRat	NetRat
ERW	No	No	120.	120.	360.	240.	240.

7.2. Concrete design

Table 18: Preferences - Concrete Design - CSA-A233-14

Table 18: Preferences - Concrete Design - CSA-A233-14

THDesign	NumCurves	NumPoints	MinEccen	PatLLF	UFLimit	PhiS	PhiC
Envelopes	24	11	Yes	0.75	0.95	0.85	0.65

7.3. Aluminum design

Table 19: Preferences - Aluminum Design - AA-ASD 2000

Table 19: Preferences - Aluminum Design - AA-ASD 2000

FrameType	SRatioLimit	LatFact	UseLatFact
Moment Frame	1.	1.333333	No

7.4. Cold formed design

Table 20: Preferences - Cold Formed Design - AISI-ASD96

Table 20: Preferences - Cold Formed Design - AISI-ASD96

FrameType	SRatioLimit	OmegaBS	OmegaBUS	OmegaBLTB	OmegaVS	OmegaVNS	OmegaT	OmegaC
Braced Frame	1.	1.67	1.67	1.67	1.67	1.5	1.67	1.8

8. Design overwrites

This section provides the design overwrites for each type of design, which are assigned to individual members of the structure.

8.1. Concrete design

Table 21: Overwrites - Concrete Design - CSA-A233-14, Part 1 of 3

Table 21: Overwrites - Concrete Design - CSA-A233-14, Part 1 of 3

Frame	DesignSect	FrameType	RLLF	XLMajor	XLMinor	XKMajor
4	Program Determined	Conventional	1.	18.1	18.1	2.
5	Program Determined	Conventional	1.	36.2	36.2	2.
6	Program Determined	Conventional	1.	23.3	23.3	2.
7	Program Determined	Conventional	1.	20.2	20.2	2.
8	Program Determined	Conventional	1.	27.	27.	2.
9	Program Determined	Conventional	1.	19.3	19.3	2.
10	Program Determined	Conventional	1.	19.3	19.3	2.
11	Program Determined	Conventional	1.	19.3	19.3	2.
12	Program Determined	Conventional	1.	19.3	19.3	2.
13	Program Determined	Conventional	1.	19.3	19.3	2.
14	Program Determined	Conventional	1.	19.3	19.3	2.
15	Program Determined	Conventional	1.	14.5	14.5	2.
16	Program Determined	Conventional	1.	28.9	28.9	2.
17	Program Determined	Conventional	1.	19.3	19.3	2.
18	Program Determined	Conventional	1.	19.3	19.3	2.
19	Program Determined	Conventional	1.	19.3	19.3	2.
20	Program Determined	Conventional	1.	19.3	19.3	2.
21	Program Determined	Conventional	1.	23.3	23.3	2.

Table 21: Overwrites - Concrete Design - CSA-A233-14, Part 1 of 3

Frame	DesignSect	FrameType	RLLF	XLMajor	XLMinor	XKMajor
22	Program Determined	Conventional	1.	28.9	28.9	2.
23	Program Determined	Conventional	1.	38.1	38.1	2.
24	Program Determined	Program Determined	0.	0.	0.	0.
27	Program Determined	Program Determined	0.	0.	0.	0.

Table 21: Overwrites - Concrete Design - CSA-A233-14, Part 2 of 3

Table 21: Overwrites - Concrete Design - CSA-A233-14, Part 2 of 3

Frame	XKMinor	CmMajor	CmMinor	DbMajor	DbMinor	DsMajor	DsMinor
4	2.	0.	0.	0.	0.	0.	0.
5	2.	0.	0.	0.	0.	0.	0.
6	2.	0.	0.	0.	0.	0.	0.
7	2.	0.	0.	0.	0.	0.	0.
8	2.	0.	0.	0.	0.	0.	0.
9	2.	0.	0.	0.	0.	0.	0.
10	2.	0.	0.	0.	0.	0.	0.
11	2.	0.	0.	0.	0.	0.	0.
12	2.	0.	0.	0.	0.	0.	0.
13	2.	0.	0.	0.	0.	0.	0.
14	2.	0.	0.	0.	0.	0.	0.
15	2.	0.	0.	0.	0.	0.	0.
16	2.	0.	0.	0.	0.	0.	0.
17	2.	0.	0.	0.	0.	0.	0.
18	2.	0.	0.	0.	0.	0.	0.
19	2.	0.	0.	0.	0.	0.	0.
20	2.	0.	0.	0.	0.	0.	0.
21	2.	0.	0.	0.	0.	0.	0.
22	2.	0.	0.	0.	0.	0.	0.
23	2.	0.	0.	0.	0.	0.	0.
24	0.	0.	0.	0.	0.	0.	0.
27	0.	0.	0.	0.	0.	0.	0.

Table 21: Overwrites - Concrete Design - CSA-A233-14, Part 3 of 3

Table 21: Overwrites - Concrete Design - CSA-A233-14, Part 3 of 3

Frame	Rd	Ro	MaxAggSize
			mm
4	1.	1.	0.
5	1.	1.	0.
6	1.	1.	0.
7	1.	1.	0.
8	1.	1.	0.
9	1.	1.	0.
10	1.	1.	0.
11	1.	1.	0.
12	1.	1.	0.
13	1.	1.	0.
14	1.	1.	0.
15	1.	1.	0.
16	1.	1.	0.
17	1.	1.	0.

Table 21: Overwrites - Concrete Design - CSA-A233-14, Part 3 of 3

Frame	Rd	Ro	MaxAggSize
			mm
18	1.	1.	0.
19	1.	1.	0.
20	1.	1.	0.
21	1.	1.	0.
22	1.	1.	0.
23	1.	1.	0.
24	0.	0.	0.
27	0.	0.	0.

SAP2000

License #2010*1NRDSQ492PZEHHT

SAP2000 Analysis Report

Prepared by

Stantec Consulting Ltd.

Model Name: Gate_Tower_Analysis_Saturated.sdb

2 July 2020

Contents

List of Figures

List of Tables

1. Model geometry

This section provides model geometry information, including items such as joint coordinates, joint restraints, and element connectivity.

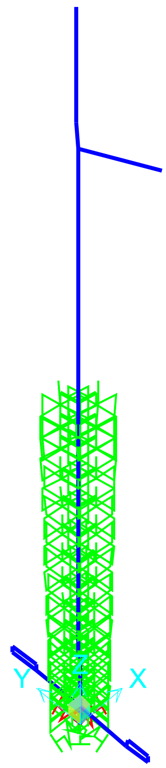


Figure 1: Finite element model

1.1. Joint coordinates

Table 1: Joint Coordinates

Table 1: Joint Coordinates

Joint	CoordSys	CoordType	GlobalX	GlobalY	GlobalZ
			mm	mm	mm
1	GLOBAL	Cartesian	0.	0.	0.
2	GLOBAL	Cartesian	0.	0.	900.
3	GLOBAL	Cartesian	0.	0.	1800.
4	GLOBAL	Cartesian	0.	0.	2700.06
5	GLOBAL	Cartesian	0.	0.	3400.
6	GLOBAL	Cartesian	0.	0.	4900.
7	GLOBAL	Cartesian	0.	0.	5440.
8	GLOBAL	Cartesian	0.	0.	6690.
9	GLOBAL	Cartesian	0.	0.	7940.
10	GLOBAL	Cartesian	0.	0.	9440.
11	GLOBAL	Cartesian	0.	0.	10940.
12	GLOBAL	Cartesian	0.	0.	12440.
13	GLOBAL	Cartesian	0.	0.	13940.

Table 1: Joint Coordinates

Joint	CoordSys	CoordType	GlobalX	GlobalY	GlobalZ
			mm	mm	mm
14	GLOBAL	Cartesian	0.	0.	15440.
15	GLOBAL	Cartesian	0.	0.	16940.
16	GLOBAL	Cartesian	0.	0.	17940.
17	GLOBAL	Cartesian	0.	0.	18940.
18	GLOBAL	Cartesian	0.	0.	19940.
19	GLOBAL	Cartesian	0.	0.	21440.
20	GLOBAL	Cartesian	0.	0.	22940.
21	GLOBAL	Cartesian	0.	0.	24440.
22	GLOBAL	Cartesian	0.	0.	25940.
23	GLOBAL	Cartesian	0.	0.	27180.
24	GLOBAL	Cartesian	0.	0.	28180.
25	GLOBAL	Cartesian	0.	0.	28940.
26	GLOBAL	Cartesian	1000.	0.	900.
27	GLOBAL	Cartesian	1000.	0.	1800.
28	GLOBAL	Cartesian	1000.	0.	2700.06
29	GLOBAL	Cartesian	1000.	0.	3400.
30	GLOBAL	Cartesian	1000.	0.	4900.
31	GLOBAL	Cartesian	1000.	0.	5440.
32	GLOBAL	Cartesian	1000.	0.	6690.
33	GLOBAL	Cartesian	1000.	0.	7940.
34	GLOBAL	Cartesian	1000.	0.	9440.
35	GLOBAL	Cartesian	1000.	0.	10940.
36	GLOBAL	Cartesian	1000.	0.	12440.
37	GLOBAL	Cartesian	1000.	0.	13940.
38	GLOBAL	Cartesian	1000.	0.	15440.
39	GLOBAL	Cartesian	1000.	0.	16940.
40	GLOBAL	Cartesian	1000.	0.	17940.
41	GLOBAL	Cartesian	0.	-3450.	28180.
42	GLOBAL	Cartesian	0.	1000.	900.
43	GLOBAL	Cartesian	0.	1000.	1800.
44	GLOBAL	Cartesian	0.	1000.	2700.06
45	GLOBAL	Cartesian	0.	1000.	3400.
46	GLOBAL	Cartesian	0.	1000.	4900.
47	GLOBAL	Cartesian	0.	1000.	5440.
48	GLOBAL	Cartesian	0.	1000.	6690.
49	GLOBAL	Cartesian	0.	1000.	7940.
50	GLOBAL	Cartesian	0.	1000.	9440.
51	GLOBAL	Cartesian	0.	1000.	10940.
52	GLOBAL	Cartesian	0.	1000.	12440.
53	GLOBAL	Cartesian	0.	1000.	13940.
54	GLOBAL	Cartesian	0.	1000.	15440.
55	GLOBAL	Cartesian	0.	1000.	16940.
56	GLOBAL	Cartesian	0.	1000.	17940.
57	GLOBAL	Cartesian	0.	0.	32111.
58	GLOBAL	Cartesian	0.	5000.	1350.
59	GLOBAL	Cartesian	0.	-4500.	1350.
60	GLOBAL	Cartesian	1000.	0.	18940.
61	GLOBAL	Cartesian	0.	1000.	18940.
62	GLOBAL	Cartesian	0.	3200.	1350.
66	GLOBAL	Cartesian	0.	-3200.	1350.
76	GLOBAL	Cartesian	0.	5000.	1800.
77	GLOBAL	Cartesian	0.	3200.	1800.
78	GLOBAL	Cartesian	0.	-3200.	1800.
79	GLOBAL	Cartesian	0.	-4500.	1800.

Table 1: Joint Coordinates

Joint	CoordSys	CoordType	GlobalX	GlobalY	GlobalZ
			mm	mm	mm
81	GLOBAL	Cartesian	0.	0.	1350.

1.2. Joint restraints

Table 2: Joint Restraint Assignments

Table 2: Joint Restraint Assignments

Joint	U1	U2	U3	R1	R2	R3
26	Yes	Yes	Yes	Yes	Yes	Yes
27	Yes	Yes	Yes	Yes	Yes	Yes
28	Yes	Yes	Yes	Yes	Yes	Yes
29	Yes	Yes	Yes	Yes	Yes	Yes
30	Yes	Yes	Yes	Yes	Yes	Yes
31	Yes	Yes	Yes	Yes	Yes	Yes
32	Yes	Yes	Yes	Yes	Yes	Yes
33	Yes	Yes	Yes	Yes	Yes	Yes
34	Yes	Yes	Yes	Yes	Yes	Yes
35	Yes	Yes	Yes	Yes	Yes	Yes
36	Yes	Yes	Yes	Yes	Yes	Yes
37	Yes	Yes	Yes	Yes	Yes	Yes
38	Yes	Yes	Yes	Yes	Yes	Yes
39	Yes	Yes	Yes	Yes	Yes	Yes
40	Yes	Yes	Yes	Yes	Yes	Yes
42	Yes	Yes	Yes	Yes	Yes	Yes
43	Yes	Yes	Yes	Yes	Yes	Yes
44	Yes	Yes	Yes	Yes	Yes	Yes
45	Yes	Yes	Yes	Yes	Yes	Yes
46	Yes	Yes	Yes	Yes	Yes	Yes
47	Yes	Yes	Yes	Yes	Yes	Yes
48	Yes	Yes	Yes	Yes	Yes	Yes
49	Yes	Yes	Yes	Yes	Yes	Yes
50	Yes	Yes	Yes	Yes	Yes	Yes
51	Yes	Yes	Yes	Yes	Yes	Yes
52	Yes	Yes	Yes	Yes	Yes	Yes
53	Yes	Yes	Yes	Yes	Yes	Yes
54	Yes	Yes	Yes	Yes	Yes	Yes
55	Yes	Yes	Yes	Yes	Yes	Yes
56	Yes	Yes	Yes	Yes	Yes	Yes
60	Yes	Yes	Yes	Yes	Yes	Yes
61	Yes	Yes	Yes	Yes	Yes	Yes

1.3. Element connectivity

Table 3: Connectivity - Frame

Table 3: Connectivity - Frame

Frame	JointI	JointJ	Length mm
1	1	2	900.
4	4	5	699.94
5	5	6	1500.
6	6	7	540.
7	7	8	1250.
8	8	9	1250.
9	9	10	1500.
10	10	11	1500.
11	11	12	1500.
12	12	13	1500.
13	13	14	1500.
14	14	15	1500.
15	15	16	1000.
16	16	17	1000.
17	17	18	1000.
18	18	19	1500.
19	19	20	1500.
20	20	21	1500.
21	21	22	1500.
22	22	23	1240.
23	23	24	1000.
24	24	25	760.
25	24	41	3450.
26	25	57	3171.
27	3	4	900.06
29	77	76	1800.
30	78	79	1300.
32	62	77	450.
33	62	58	1800.
34	58	76	450.
36	66	78	450.
37	59	79	450.
38	66	59	1300.
39	62	81	3200.
40	81	66	3200.
41	2	81	450.
42	81	3	450.

Table 4: Frame Section Assignments

Table 4: Frame Section Assignments

Frame	AnalSect	DesignSect	MatProp
1	1	N.A.	CLASS_A1_30MPa
4	3	3	CLASS_A1_30MPa
5	4	4	CLASS_A1_30MPa
6	5	5	CLASS_A1_30MPa

Table 4: Frame Section Assignments

Frame	AnalSect	DesignSect	MatProp
7	6	6	CLASS_A1_30MPa
8	6	6	CLASS_A1_30MPa
9	6	6	CLASS_A1_30MPa
10	6	6	CLASS_A1_30MPa
11	6	6	CLASS_A1_30MPa
12	6	6	CLASS_A1_30MPa
13	6	6	CLASS_A1_30MPa
14	6	6	CLASS_A1_30MPa
15	7	7	CLASS_A1_30MPa
16	7	7	CLASS_A1_30MPa
17	7	7	CLASS_A1_30MPa
18	7	7	CLASS_A1_30MPa
19	7	7	CLASS_A1_30MPa
20	7	7	CLASS_A1_30MPa
21	7	7	CLASS_A1_30MPa
22	7	7	CLASS_A1_30MPa
23	7	7	CLASS_A1_30MPa
24	7	7	CLASS_A1_30MPa
25	Rigid_Link	N.A.	Default
26	Rigid_Link	N.A.	Default
27	3	3	CLASS_A1_30MPa
29	A	N.A.	Default
30	B	N.A.	Default
32	Rigid_Link	N.A.	Default
33	Rigid_Link	N.A.	Default
34	Rigid_Link	N.A.	Default
36	Rigid_Link	N.A.	Default
37	Rigid_Link	N.A.	Default
38	Rigid_Link	N.A.	Default
39	Rigid_Link	N.A.	Default
40	Rigid_Link	N.A.	Default
41	2	N.A.	CLASS_A1_30MPa
42	2	N.A.	CLASS_A1_30MPa

2. Material properties

This section provides material property information for materials used in the model.

Table 5: Material Properties 02 - Basic Mechanical Properties

Table 5: Material Properties 02 - Basic Mechanical Properties

Material	UnitWeight	UnitMass	E1	G12	U12	A1
	KN/mm3	KN-s2/mm4	KN/mm2	KN/mm2		1/C
4000Psi	2.3563E-08	2.4028E-12	24.85558	10.35649	0.2	9.9000E-06
A416Gr270	7.6973E-08	7.8490E-12	196.5006			1.1700E-05
A615Gr60	7.6973E-08	7.8490E-12	199.94798			1.1700E-05
A992Fy50	7.6973E-08	7.8490E-12	199.94798	76.90307	0.3	1.1700E-05
CLASS_A1_30MPa	2.3500E-08	2.3963E-12	24.64752	10.2698	0.2	1.0000E-05
G30.18-92	7.6973E-08	7.8490E-12	199.94798			1.1700E-05
RIGID	0.0000E+00	0.0000E+00	1.	0.38462	0.3	0.0000E+00

Table 6: Material Properties 03a - Steel Data

Table 6: Material Properties 03a - Steel Data

Material	Fy	Fu	FinalSlope
	KN/mm2	KN/mm2	
A992Fy50	0.34474	0.44816	-0.1

Table 7: Material Properties 03b - Concrete Data

Table 7: Material Properties 03b - Concrete Data

Material	Fc	eFc	FinalSlope
	KN/mm2	KN/mm2	
4000Psi	0.02758	0.02758	-0.1
CLASS_A1_30MPa	0.03	0.03	-0.1

Table 8: Material Properties 03e - Rebar Data

Table 8: Material Properties 03e - Rebar Data

Material	Fy	Fu	FinalSlope
	KN/mm2	KN/mm2	
A615Gr60	0.41369	0.62053	-0.1
G30.18-92	0.4	0.54	-0.1

Table 9: Material Properties 03f - Tendon Data

Table 9: Material Properties 03f - Tendon Data

Material	Fy	Fu	FinalSlope
	KN/mm2	KN/mm2	
A416Gr270	1.68991	1.86158	-0.1

3. Section properties

This section provides section property information for objects used in the model.

3.1. Frames

Table 10: Frame Section Properties 01 - General, Part 1 of 5

Table 10: Frame Section Properties 01 - General, Part 1 of 5

SectionName	Material	Shape	t3	t2	Area	TorsConst	I33	I22
			mm	mm	mm2	mm4	mm4	mm4
1	CLASS_A1_30MPa	SD Section			67200000.	5.702E+14	2.294E+14	6.174E+14
2	CLASS_A1_30MPa	SD Section			62928000.	4.853E+14	2.216E+14	5.176E+14
3	CLASS_A1_30MPa	SD Section			18662223.2	1.163E+13	3.834E+13	6.203E+13
4	CLASS_A1_30MPa	SD Section			22080000.	8.502E+13	3.894E+13	8.204E+13
5	CLASS_A1_30MPa	SD Section			22641976.84	8.906E+13	3.904E+13	8.855E+13
6	CLASS_A1_30MPa	SD Section			17841976.84	7.962E+13	3.501E+13	7.880E+13
7	CLASS_A1_30MPa	SD Section			12471976.84	4.414E+13	1.828E+13	5.044E+13
A	CLASS_A1_30MPa	SD Section			4711065.17	1.741E+12	2.618E+12	4.933E+12
B	CLASS_A1_30MPa	SD Section			5462153.19	8.484E+11	4.648E+12	9.255E+12
Rigid_Link	RIGID	General	0.01	0.01	1.000E+12	1.000E+12	1.000E+18	1.000E+18

Table 10: Frame Section Properties 01 - General, Part 2 of 5

Table 10: Frame Section Properties 01 - General, Part 2 of 5

SectionName	I23	AS2	AS3
	mm4	mm2	mm2
1	0.	56000277.07	56000277.07
2	0.	51546062.37	53160796.39
3	0.	18662223.2	15772549.97
4	0.	12478822.93	17632303.72
5	0.	13845806.93	18155373.29
6	0.	10775936.02	12081062.4
7	0.	7853660.87	7921017.33
A	0.	3277457.78	2709170.75
B	0.	4114152.58	2998692.31
Rigid_Link	0.	1.000E+12	1.000E+12

Table 10: Frame Section Properties 01 - General, Part 3 of 5

Table 10: Frame Section Properties 01 - General, Part 3 of 5

SectionName	S33	S22	Z33	Z22	R33	R22
	mm3	mm3	mm3	mm3	mm	mm
1	7.168E+10	1.176E+11	1.075E+11	1.764E+11	1847.521	3031.089
2	6.948E+10	9.314E+10	1.027E+11	1.559E+11	1876.761	2867.883
3	1.826E+10	1.896E+10	2.555E+10	2.937E+10	1433.333	1823.064
4	1.854E+10	2.564E+10	2.678E+10	3.677E+10	1327.96	1927.565
5	1.859E+10	2.384E+10	2.700E+10	3.868E+10	1313.161	1977.621
6	1.667E+10	2.134E+10	2.268E+10	3.244E+10	1400.827	2101.505
7	1.016E+10	1.445E+10	1.358E+10	2.155E+10	1210.81	2010.981
A	1922020258.	3288382805.	2759728383.	4079249816.	745.532	1023.239
B	2943543185.	4560782553.	4040355824.	5976815407.	922.483	1301.668
Rigid_Link	0.	0.	0.	0.	0.	0.

Table 10: Frame Section Properties 01 - General, Part 4 of 5

Table 10: Frame Section Properties 01 - General, Part 4 of 5

SectionName	EccV2	AMod	A2Mod	A3Mod	JMod	I2Mod	I3Mod	MMod
	mm							
1		1.	1.	1.	1.	1.	1.	1.
2		1.	1.	1.	1.	1.	1.	1.
3		1.	1.	1.	1.	1.	1.	1.
4		1.	1.	1.	1.	1.	1.	1.
5		1.	1.	1.	1.	1.	1.	1.
6		1.	1.	1.	1.	1.	1.	1.
7		1.	1.	1.	1.	1.	1.	1.
A		1.	1.	1.	1.	1.	1.	1.
B		1.	1.	1.	1.	1.	1.	1.
Rigid_Link	0.	1.	1.	1.	1.	1.	1.	1.

Table 10: Frame Section Properties 01 - General, Part 5 of 5

Table 10: Frame Section Properties 01 - General, Part 5 of 5

SectionName	WMod
1	1.
2	1.
3	1.
4	1.
5	1.
6	1.
7	1.
A	1.
B	1.
Rigid_Link	1.

3.2. Solids

Table 11: Solid Property Definitions

Table 11: Solid Property Definitions

SolidProp	Material	MatAngleA	MatAngleB	MatAngleC
		Degrees	Degrees	Degrees
Solid1	4000Psi	0.	0.	0.

4. Load patterns

This section provides loading information as applied to the model.

4.1. Definitions

Table 12: Load Pattern Definitions

Table 12: Load Pattern Definitions

LoadPat	DesignType	SelfWtMult	AutoLoad
DEAD	Dead	1.	
DEAD_BRIDGE	Super Dead	0.	
DEAD_UPPER-ROOM	Super Dead	0.	
DEAD_ACCESS_LADDER	Super Dead	0.	
DEAD_LANDINGS	Super Dead	0.	
DEAD_GATES	Super Dead	0.	
LIVE_BRIDGE	Live	0.	
LIVE_UPPER-ROOM	Live	0.	
LIVE_LANDINGS	Live	0.	
SNOW_UPPER-ROOM	Snow	0.	
THERMAL_BRIDGE	Temperature	0.	
WIND_X_BRIDGE	Wind	0.	None
WIND_X_UPPER-ROOM	Wind	0.	None
WIND_Y_UPPER-ROOM	Wind	0.	None
WIND_X_MAIN_STRUCTURE	Wind	0.	None
WIND_Y_MAIN_STRUCTURE	Wind	0.	None
EQX_STATIC	Quake	0.	None
EQY_STATIC	Quake	0.	None
EQZ_STATIC	Quake	0.	None
HYDRO_UN	Live	0.	
HYDRO_E	Live	0.	
EARTH_X_UN	Live	0.	

Table 12: Load Pattern Definitions

LoadPat	DesignType	SelfWtMult	AutoLoad
EARTH_Y_UN	Live	0.	
SUR_Y	Live	0.	
SUR_X	Live	0.	

5. Load cases

This section provides load case information.

5.1. Definitions

Table 13: Load Case Definitions, Part 1 of 2

Table 13: Load Case Definitions, Part 1 of 2

Case	Type	InitialCond	ModalCase	BaseCase	MassSource	DesActOpt
MODAL	LinModal	Zero				Prog Det
TOWER_DEAD	NonStatic	Zero				Prog Det
TOWER_LIVE	NonStatic	Zero				Prog Det
TOWER_HYDRO_UN	NonStatic	Zero				Prog Det
TOWER_HYDRO_E	NonStatic	Zero				Prog Det
TOWER_SNOW	NonStatic	Zero				Prog Det
TOWER_THERMAL_BRIDGE	NonStatic	Zero				Prog Det
TOWER_WIND_X	NonStatic	Zero				Prog Det
TOWER_WIND_Y	NonStatic	Zero				Prog Det
WIND_X_BB	NonStatic	Zero				Prog Det
WIND_Y_BB	NonStatic	Zero				Prog Det
TOWER_EQX_STATIC	NonStatic	Zero				Prog Det
TOWER_EQY_STATIC	NonStatic	Zero				Prog Det
TOWER_EQZ_STATIC	NonStatic	Zero				Prog Det
DEAD_CONSTRUCTION	LinStatic	Zero				Prog Det
SUR_Y	NonStatic	Zero				Prog Det
SUR_X	NonStatic	Zero				Prog Det

Table 13: Load Case Definitions, Part 2 of 2

Table 13: Load Case Definitions, Part 2 of 2

Case	DesignAct
MODAL	Other
TOWER_DEAD	Non-Composite

Table 13: Load Case Definitions, Part 2 of 2

Case	DesignAct
TOWER_LIVE	Short-Term Composite
TOWER_HYDRO_UN	Short-Term Composite
TOWER_HYDRO_E	Short-Term Composite
TOWER_SNOW	Short-Term Composite
TOWER_THERMAL_BRIDGE	Short-Term Composite
TOWER_WIND_X	Short-Term Composite
TOWER_WIND_Y	Short-Term Composite
WIND_X_BB	Short-Term Composite
WIND_Y_BB	Short-Term Composite
TOWER_EQX_STATIC	Short-Term Composite
TOWER_EQY_STATIC	Short-Term Composite
TOWER_EQZ_STATIC	Short-Term Composite
DEAD_CONSTRUCTION	Non-Composite
SUR_Y	Short-Term Composite
SUR_X	Short-Term Composite

5.2. *Static case load assignments*

Table 14: Case - Static 1 - Load Assignments

Table 14: Case - Static 1 - Load Assignments

Case	LoadType	LoadName	LoadSF
TOWER_DEAD	Load pattern	DEAD	1.
TOWER_DEAD	Load pattern	DEAD_ACCESS_LADDER	1.
TOWER_DEAD	Load pattern	DEAD_BRIDGE	1.
TOWER_DEAD	Load pattern	DEAD_GATES	1.
TOWER_DEAD	Load pattern	DEAD_LANDINGS	1.
TOWER_DEAD	Load pattern	DEAD_UPPER-ROOM	1.
TOWER_LIVE	Load pattern	LIVE_BRIDGE	1.
TOWER_LIVE	Load pattern	LIVE_LANDINGS	1.
TOWER_LIVE	Load pattern	LIVE_UPPER-ROOM	1.
TOWER_HYDRO_UN	Load pattern	HYDRO_UN	1.

Table 14: Case - Static 1 - Load Assignments

Case	LoadType	LoadName	LoadSF
TOWER_HYDRO_E	Load pattern	HYDRO_E	1.
TOWER_SNOW	Load pattern	SNOW_UPPER-ROOM	1.
TOWER_THERMAL_BRIDGE	Load pattern	THERMAL_BRIDGE	1.
TOWER_WIND_X	Load pattern	WIND_X_MAIN_STRUCTURE	1.
TOWER_WIND_X	Load pattern	WIND_X_BRIDGE	1.
TOWER_WIND_X	Load pattern	WIND_X_UPPER-ROOM	1.
TOWER_WIND_Y	Load pattern	WIND_Y_MAIN_STRUCTURE	1.
TOWER_WIND_Y	Load pattern	WIND_Y_UPPER-ROOM	1.
WIND_X_BB	Load pattern	WIND_X_UPPER-ROOM	1.
WIND_X_BB	Load pattern	WIND_X_BRIDGE	1.
WIND_Y_BB	Load pattern	WIND_Y_UPPER-ROOM	1.
TOWER_EQX_STATIC	Load pattern	EQX_STATIC	1.
TOWER_EQY_STATIC	Load pattern	EQY_STATIC	1.
TOWER_EQZ_STATIC	Load pattern	EQZ_STATIC	1.
DEAD_CONSTRUCTION	Load pattern	DEAD	1.
DEAD_CONSTRUCTION	Load pattern	DEAD_ACCESS_LADDER	1.
DEAD_CONSTRUCTION	Load pattern	DEAD_BRIDGE	1.
DEAD_CONSTRUCTION	Load pattern	DEAD_GATES	1.
DEAD_CONSTRUCTION	Load pattern	DEAD_LANDINGS	1.
DEAD_CONSTRUCTION	Load pattern	DEAD_UPPER-ROOM	1.
SUR_Y	Load pattern	SUR_Y	1.
SUR_X	Load pattern	SUR_X	1.

5.3. Response spectrum case load assignments

Table 15: Function - Response Spectrum - User

Table 15: Function - Response Spectrum - User

Name	Period Sec	Accel	FuncDamp
RS_HORZ	0.05	0.33	0.05
RS_HORZ	0.1	0.47	
RS_HORZ	0.2	0.64	
RS_HORZ	0.3	0.69	
RS_HORZ	0.5	0.52	

Table 15: Function - Response Spectrum - User

Name	Period Sec	Accel	FuncDamp
RS_HORZ	1.	0.26	
RS_HORZ	2.	0.11	
RS_HORZ	5.	0.034	
RS_HORZ	10.	0.0087	
RS_VERT	0.05	0.3102	0.05
RS_VERT	0.1	0.3807	
RS_VERT	0.2	0.32	
RS_VERT	0.3	0.276	
RS_VERT	0.5	0.1872	
RS_VERT	1.	0.0962	
RS_VERT	2.	0.0473	
RS_VERT	5.	0.0163	
RS_VERT	10.	0.0066	

6. Load combinations

This section provides load combination information.

Table 16: Combination Definitions

Table 16: Combination Definitions

ComboName	ComboType	CaseName	ScaleFactor
U1-1	Linear Add	TOWER_DEAD	1.
U1-1		TOWER_SNOW	1.
U1-1		TOWER_THERMAL_BRIDGE	-1.
U1-2	Linear Add	TOWER_DEAD	1.
U1-2		TOWER_SNOW	1.
U1-2		TOWER_LIVE	1.
U1-2		TOWER_THERMAL_BRIDGE	-1.
U1-3	Linear Add	TOWER_DEAD	1.
U1-3		TOWER_SNOW	1.
U1-3		TOWER_LIVE	1.
U1-3		TOWER_WIND_X	1.
U1-3		TOWER_THERMAL_BRIDGE	-1.
U1-4+	Linear Add	TOWER_DEAD	1.
U1-4+		TOWER_SNOW	1.
U1-4+		TOWER_LIVE	1.
U1-4+		TOWER_WIND_Y	1.
U1-4+		TOWER_THERMAL_BRIDGE	1.
U2-1	Linear Add	TOWER_DEAD	1.
U2-1		TOWER_LIVE	1.
U2-1		TOWER_WIND_X	1.
U2-1		TOWER_THERMAL_BRIDGE	1.
U2-2+	Linear Add	TOWER_DEAD	1.

Table 16: Combination Definitions

ComboName	ComboType	CaseName	ScaleFactor
U2-2+		TOWER_LIVE	1.
U2-2+		TOWER_WIND_Y	1.
U2-2+		TOWER_THERMAL_BRIDGE	1.
U2-3	Linear Add	TOWER_DEAD	1.
U2-3		TOWER_WIND_X	1.
U2-3		TOWER_THERMAL_BRIDGE	1.
U2-4+	Linear Add	TOWER_DEAD	1.
U2-4+		TOWER_WIND_Y	1.
U2-4+		TOWER_THERMAL_BRIDGE	1.
UN1-1	Linear Add	TOWER_DEAD	1.
UN1-1		TOWER_HYDRO_UN	1.
UN1-1		TOWER_THERMAL_BRIDGE	1.
UN1-2	Linear Add	TOWER_DEAD	1.
UN1-2		TOWER_LIVE	1.
UN1-2		TOWER_HYDRO_UN	1.
UN1-2		TOWER_THERMAL_BRIDGE	1.
UN1-3	Linear Add	TOWER_DEAD	1.
UN1-3		TOWER_LIVE	1.
UN1-3		TOWER_WIND_X	1.
UN1-3		TOWER_HYDRO_UN	1.
UN1-3		TOWER_THERMAL_BRIDGE	1.
UN1-4+	Linear Add	TOWER_DEAD	1.
UN1-4+		TOWER_LIVE	1.
UN1-4+		TOWER_WIND_Y	1.
UN1-4+		TOWER_HYDRO_UN	1.
UN1-4+		TOWER_THERMAL_BRIDGE	1.
UN1-5	Linear Add	TOWER_DEAD	1.
UN1-5		TOWER_WIND_X	1.
UN1-5		TOWER_HYDRO_UN	1.
UN1-5		TOWER_THERMAL_BRIDGE	1.
UN1-6+	Linear Add	TOWER_DEAD	1.
UN1-6+		TOWER_WIND_Y	1.
UN1-6+		TOWER_HYDRO_UN	1.
UN1-6+		TOWER_THERMAL_BRIDGE	1.
UN2-1	Linear Add	TOWER_DEAD	1.

Table 16: Combination Definitions

ComboName	ComboType	CaseName	ScaleFactor
UN2-1		TOWER_HYDRO_UN	1.
UN2-1		TOWER_THERMAL_BRIDGE	1.
UN2-2	Linear Add	TOWER_DEAD	1.
UN2-2		TOWER_LIVE	1.
UN2-2		TOWER_HYDRO_UN	1.
UN2-2		TOWER_THERMAL_BRIDGE	1.
UN2-3	Linear Add	TOWER_DEAD	1.
UN2-3		TOWER_LIVE	1.
UN2-3		TOWER_WIND_X	1.
UN2-3		TOWER_HYDRO_UN	1.
UN2-3		TOWER_THERMAL_BRIDGE	1.
UN2-4+	Linear Add	TOWER_DEAD	1.
UN2-4+		TOWER_LIVE	1.
UN2-4+		TOWER_WIND_Y	1.
UN2-4+		TOWER_HYDRO_UN	1.
UN2-4+		TOWER_THERMAL_BRIDGE	1.
UN2-5	Linear Add	TOWER_DEAD	1.
UN2-5		TOWER_WIND_X	1.
UN2-5		TOWER_HYDRO_UN	1.
UN2-5		TOWER_THERMAL_BRIDGE	1.
UN2-6+	Linear Add	TOWER_DEAD	1.
UN2-6+		TOWER_WIND_Y	1.
UN2-6+		TOWER_HYDRO_UN	1.
UN2-6+		TOWER_THERMAL_BRIDGE	1.
E1-1	Linear Add	TOWER_DEAD	1.
E1-1		TOWER_HYDRO_E	1.
E1-1		TOWER_THERMAL_BRIDGE	1.
E1-2	Linear Add	TOWER_DEAD	1.
E1-2		TOWER_LIVE	1.
E1-2		TOWER_HYDRO_E	1.
E1-2		TOWER_THERMAL_BRIDGE	1.
E1-3	Linear Add	TOWER_DEAD	1.
E1-3		WIND_X_BB	1.
E1-3		TOWER_HYDRO_E	1.
E1-3		TOWER_THERMAL_BRIDGE	1.
E1-4+	Linear Add	TOWER_DEAD	1.

Table 16: Combination Definitions

ComboName	ComboType	CaseName	ScaleFactor
E1-4+		WIND_Y_BB	1.
E1-4+		TOWER_HYDRO_E	1.
E1-4+		TOWER_THERMAL_BRIDGE	1.
E2-1	Linear Add	TOWER_DEAD	1.
E2-1		TOWER_HYDRO_E	1.
E2-1		TOWER_THERMAL_BRIDGE	1.
E2-2	Linear Add	TOWER_DEAD	1.
E2-2		TOWER_LIVE	1.
E2-2		TOWER_HYDRO_E	1.
E2-2		TOWER_THERMAL_BRIDGE	1.
E2-3	Linear Add	TOWER_DEAD	1.
E2-3		WIND_X_BB	1.
E2-3		TOWER_HYDRO_E	1.
E2-3		TOWER_THERMAL_BRIDGE	1.
E2-4+	Linear Add	TOWER_DEAD	1.
E2-4+		WIND_Y_BB	1.
E2-4+		TOWER_HYDRO_E	1.
E2-4+		TOWER_THERMAL_BRIDGE	1.
PE-1	Linear Add	TOWER_DEAD	1.
PE-1		TOWER_WIND_X	1.
PE-1		TOWER_THERMAL_BRIDGE	1.
PE-2+	Linear Add	TOWER_DEAD	1.
PE-2+		TOWER_WIND_Y	1.
PE-2+		TOWER_THERMAL_BRIDGE	1.
U1-4-	Linear Add	TOWER_DEAD	1.
U1-4-		TOWER_SNOW	1.
U1-4-		TOWER_LIVE	1.
U1-4-		TOWER_WIND_Y	-1.
U1-4-		TOWER_THERMAL_BRIDGE	-1.
U2-2-	Linear Add	TOWER_DEAD	1.
U2-2-		TOWER_LIVE	1.
U2-2-		TOWER_WIND_Y	-1.
U2-2-		TOWER_THERMAL_BRIDGE	-1.
U2-4-	Linear Add	TOWER_DEAD	1.
U2-4-		TOWER_WIND_Y	-1.
U2-4-		TOWER_THERMAL_BRIDGE	-1.
UN1-4-	Linear Add	TOWER_DEAD	1.
UN1-4-		TOWER_LIVE	1.

Table 16: Combination Definitions

ComboName	ComboType	CaseName	ScaleFactor
UN1-4-		TOWER_WIND_Y	-1.
UN1-4-		TOWER_HYDRO_UN	1.
UN1-4-		TOWER_THERMAL_BRIDGE	-1.
UN1-6-	Linear Add	TOWER_DEAD	1.
UN1-6-		TOWER_WIND_Y	-1.
UN1-6-		TOWER_HYDRO_UN	1.
UN1-6-		TOWER_THERMAL_BRIDGE	-1.
UN2-4-	Linear Add	TOWER_DEAD	1.
UN2-4-		TOWER_LIVE	1.
UN2-4-		TOWER_WIND_Y	-1.
UN2-4-		TOWER_HYDRO_UN	1.
UN2-4-		TOWER_THERMAL_BRIDGE	-1.
UN2-6-	Linear Add	TOWER_DEAD	1.
UN2-6-		TOWER_WIND_Y	-1.
UN2-6-		TOWER_HYDRO_UN	1.
UN2-6-		TOWER_THERMAL_BRIDGE	-1.
E1-4-	Linear Add	TOWER_DEAD	1.
E1-4-		WIND_Y_BB	-1.
E1-4-		TOWER_HYDRO_E	1.
E1-4-		TOWER_THERMAL_BRIDGE	-1.
E2-4-	Linear Add	TOWER_DEAD	1.
E2-4-		WIND_Y_BB	-1.
E2-4-		TOWER_HYDRO_E	1.
E2-4-		TOWER_THERMAL_BRIDGE	-1.
PE-2-	Linear Add	TOWER_DEAD	1.
PE-2-		TOWER_WIND_Y	-1.
PE-2-		TOWER_THERMAL_BRIDGE	-1.
E3-1	Linear Add	TOWER_EQX_STATIC	0.3
E3-1		TOWER_EQY_STATIC	0.3
E3-1		TOWER_EQZ_STATIC	1.
E3-1		TOWER_DEAD	1.
E3-2	Linear Add	TOWER_EQX_STATIC	0.3
E3-2		TOWER_EQY_STATIC	-0.3
E3-2		TOWER_EQZ_STATIC	1.
E3-2		TOWER_DEAD	1.

Table 16: Combination Definitions

ComboName	ComboType	CaseName	ScaleFactor
E3-3	Linear Add	TOWER_EQX_STATIC	-0.3
E3-3		TOWER_EQY_STATIC	-0.3
E3-3		TOWER_EQZ_STATIC	1.
E3-3		TOWER_DEAD	1.
E3-4	Linear Add	TOWER_EQX_STATIC	-0.3
E3-4		TOWER_EQY_STATIC	0.3
E3-4		TOWER_EQZ_STATIC	1.
E3-4		TOWER_DEAD	1.
E3-5	Linear Add	TOWER_EQX_STATIC	0.3
E3-5		TOWER_EQY_STATIC	0.3
E3-5		TOWER_EQZ_STATIC	-1.
E3-5		TOWER_DEAD	1.
E3-6	Linear Add	TOWER_EQX_STATIC	0.3
E3-6		TOWER_EQY_STATIC	-0.3
E3-6		TOWER_EQZ_STATIC	-1.
E3-6		TOWER_DEAD	1.
E3-7	Linear Add	TOWER_EQX_STATIC	-0.3
E3-7		TOWER_EQY_STATIC	-0.3
E3-7		TOWER_EQZ_STATIC	-1.
E3-7		TOWER_DEAD	1.
E3-8	Linear Add	TOWER_EQX_STATIC	-0.3
E3-8		TOWER_EQY_STATIC	0.3
E3-8		TOWER_EQZ_STATIC	-1.
E3-8		TOWER_DEAD	1.
E3-9	Linear Add	TOWER_EQX_STATIC	1.
E3-9		TOWER_EQY_STATIC	0.3
E3-9		TOWER_EQZ_STATIC	0.3
E3-9		TOWER_DEAD	1.
E3-10	Linear Add	TOWER_EQX_STATIC	1.
E3-10		TOWER_EQY_STATIC	-0.3
E3-10		TOWER_EQZ_STATIC	0.3
E3-10		TOWER_DEAD	1.
E3-11	Linear Add	TOWER_EQX_STATIC	-1.

Table 16: Combination Definitions

ComboName	ComboType	CaseName	ScaleFactor
E3-11		TOWER_EQY_STATIC	-0.3
E3-11		TOWER_EQZ_STATIC	0.3
E3-11		TOWER_DEAD	1.
E3-12	Linear Add	TOWER_EQX_STATIC	-1.
E3-12		TOWER_EQY_STATIC	0.3
E3-12		TOWER_EQZ_STATIC	0.3
E3-12		TOWER_DEAD	1.
E3-13	Linear Add	TOWER_EQX_STATIC	1.
E3-13		TOWER_EQY_STATIC	0.3
E3-13		TOWER_EQZ_STATIC	-0.3
E3-13		TOWER_DEAD	1.
E3-14	Linear Add	TOWER_EQX_STATIC	1.
E3-14		TOWER_EQY_STATIC	-0.3
E3-14		TOWER_EQZ_STATIC	-0.3
E3-14		TOWER_DEAD	1.
E3-15	Linear Add	TOWER_EQX_STATIC	-1.
E3-15		TOWER_EQY_STATIC	-0.3
E3-15		TOWER_EQZ_STATIC	-0.3
E3-15		TOWER_DEAD	1.
E3-16	Linear Add	TOWER_EQX_STATIC	-1.
E3-16		TOWER_EQY_STATIC	0.3
E3-16		TOWER_EQZ_STATIC	-0.3
E3-16		TOWER_DEAD	1.
E3-17	Linear Add	TOWER_EQX_STATIC	0.3
E3-17		TOWER_EQY_STATIC	1.
E3-17		TOWER_EQZ_STATIC	0.3
E3-17		TOWER_DEAD	1.
E3-18	Linear Add	TOWER_EQX_STATIC	0.3
E3-18		TOWER_EQY_STATIC	-1.
E3-18		TOWER_EQZ_STATIC	0.3
E3-18		TOWER_DEAD	1.
E3-19	Linear Add	TOWER_EQX_STATIC	-0.3
E3-19		TOWER_EQY_STATIC	-1.

Table 16: Combination Definitions

ComboName	ComboType	CaseName	ScaleFactor
E3-19		TOWER_EQZ_STATIC	0.3
E3-19		TOWER_DEAD	1.
E3-20	Linear Add	TOWER_EQX_STATIC	-0.3
E3-20		TOWER_EQY_STATIC	1.
E3-20		TOWER_EQZ_STATIC	0.3
E3-20		TOWER_DEAD	1.
E3-21	Linear Add	TOWER_EQX_STATIC	0.3
E3-21		TOWER_EQY_STATIC	1.
E3-21		TOWER_EQZ_STATIC	-0.3
E3-21		TOWER_DEAD	1.
E3-22	Linear Add	TOWER_EQX_STATIC	0.3
E3-22		TOWER_EQY_STATIC	-1.
E3-22		TOWER_EQZ_STATIC	-0.3
E3-22		TOWER_DEAD	1.
E3-23	Linear Add	TOWER_EQX_STATIC	-0.3
E3-23		TOWER_EQY_STATIC	-1.
E3-23		TOWER_EQZ_STATIC	-0.3
E3-23		TOWER_DEAD	1.
E3-24	Linear Add	TOWER_EQX_STATIC	-0.3
E3-24		TOWER_EQY_STATIC	1.
E3-24		TOWER_EQZ_STATIC	-0.3
E3-24		TOWER_DEAD	1.
UN3-1	Linear Add	DEAD_CONSTRUCTION	1.
UN4-1	Linear Add	TOWER_DEAD	1.
UN4-1		TOWER_THERMAL_BRIDGE	1.
UN4-1		TOWER_WIND_Y	1.
UN4-1		SUR_Y	1.
UN4-2	Linear Add	TOWER_DEAD	1.
UN4-2		TOWER_WIND_X	1.
UN4-2		SUR_X	1.
S_1	Linear Add	TOWER_DEAD	1.4
S_1		TOWER_THERMAL_BRIDGE	1.
S_1		TOWER_HYDRO_E	1.5
S_2A	Linear Add	TOWER_DEAD	1.25
S_2A		TOWER_LIVE	1.5
S_2A		TOWER_SNOW	1.

Table 16: Combination Definitions

ComboName	ComboType	CaseName	ScaleFactor
S_2A		TOWER_THERMAL_BRIDGE	1.
S_2A		TOWER_HYDRO_E	1.5
S_2B	Linear Add	TOWER_DEAD	1.25
S_2B		TOWER_LIVE	1.5
S_2B		TOWER_WIND_X	0.4
S_2B		TOWER_THERMAL_BRIDGE	1.
S_2B		TOWER_HYDRO_E	1.5
S_2C	Linear Add	TOWER_DEAD	1.25
S_2C		TOWER_LIVE	1.5
S_2C		TOWER_WIND_Y	0.4
S_2C		TOWER_THERMAL_BRIDGE	1.
S_2D	Linear Add	TOWER_DEAD	1.25
S_2D		TOWER_WIND_Y	-0.4
S_2D		TOWER_LIVE	1.5
S_2D		TOWER_THERMAL_BRIDGE	-1.
S_2D		TOWER_HYDRO_E	1.5
S_2E	Linear Add	TOWER_DEAD	0.9
S_2E		TOWER_LIVE	1.5
S_2E		TOWER_SNOW	1.
S_2E		TOWER_THERMAL_BRIDGE	1.
S_2E		TOWER_HYDRO_E	1.5
S_2F	Linear Add	TOWER_DEAD	0.9
S_2F		TOWER_LIVE	1.5
S_2F		TOWER_WIND_X	0.4
S_2F		TOWER_THERMAL_BRIDGE	1.
S_2F		TOWER_HYDRO_E	1.5
S_2G	Linear Add	TOWER_DEAD	0.9
S_2G		TOWER_LIVE	1.5
S_2G		TOWER_WIND_Y	0.4
S_2G		TOWER_THERMAL_BRIDGE	1.
S_2H	Linear Add	TOWER_DEAD	0.9
S_2H		TOWER_LIVE	1.5
S_2H		TOWER_WIND_Y	-0.4
S_2H		TOWER_THERMAL_BRIDGE	-1.
S_2H		TOWER_HYDRO_E	1.5
S_3A	Linear Add	TOWER_DEAD	1.25
S_3A		TOWER_LIVE	1.
S_3A		TOWER_SNOW	1.5

Table 16: Combination Definitions

ComboName	ComboType	CaseName	ScaleFactor
S_3A		TOWER_THERMAL_BRIDGE	1.
S_3A		TOWER_HYDRO_E	1.5
S_3B	Linear Add	TOWER_DEAD	1.25
S_3B		TOWER_SNOW	1.5
S_3B		TOWER_WIND_X	0.4
S_3B		TOWER_THERMAL_BRIDGE	1.
S_3B		TOWER_HYDRO_E	1.5
S_3C	Linear Add	TOWER_DEAD	1.25
S_3C		TOWER_SNOW	1.5
S_3C		TOWER_WIND_Y	0.4
S_3C		TOWER_THERMAL_BRIDGE	1.
S_3D	Linear Add	TOWER_DEAD	1.25
S_3D		TOWER_SNOW	1.5
S_3D		TOWER_WIND_Y	-0.4
S_3D		TOWER_THERMAL_BRIDGE	-1.
S_3D		TOWER_HYDRO_E	1.5
S_3E	Linear Add	TOWER_DEAD	0.9
S_3E		TOWER_LIVE	1.
S_3E		TOWER_SNOW	1.5
S_3E		TOWER_THERMAL_BRIDGE	1.
S_3E		TOWER_HYDRO_E	1.5
S_3F	Linear Add	TOWER_DEAD	0.9
S_3F		TOWER_SNOW	1.5
S_3F		TOWER_WIND_X	0.4
S_3F		TOWER_THERMAL_BRIDGE	1.
S_3F		TOWER_HYDRO_E	1.5
S_3G	Linear Add	TOWER_DEAD	0.9
S_3G		TOWER_SNOW	1.5
S_3G		TOWER_WIND_Y	0.4
S_3G		TOWER_THERMAL_BRIDGE	1.
S_3G		TOWER_HYDRO_E	1.5
S_3H	Linear Add	TOWER_DEAD	0.9
S_3H		TOWER_SNOW	1.5
S_3H		TOWER_WIND_Y	-0.4
S_3H		TOWER_THERMAL_BRIDGE	-1.
S_3H		TOWER_HYDRO_E	1.5
S_4A	Linear Add	TOWER_DEAD	1.25

Table 16: Combination Definitions

ComboName	ComboType	CaseName	ScaleFactor
S_4A		TOWER_LIVE	0.5
S_4A		TOWER_WIND_X	1.4
S_4A		TOWER_THERMAL_BRIDGE	1.
S_4A		TOWER_HYDRO_E	1.5
S_4B	Linear Add	TOWER_DEAD	1.25
S_4B		TOWER_LIVE	0.5
S_4B		TOWER_WIND_Y	1.4
S_4B		TOWER_THERMAL_BRIDGE	1.
S_4C	Linear Add	TOWER_DEAD	1.25
S_4C		TOWER_LIVE	0.5
S_4C		TOWER_WIND_Y	-1.4
S_4C		TOWER_THERMAL_BRIDGE	-1.
S_4C		TOWER_HYDRO_E	1.5
S_4D	Linear Add	TOWER_DEAD	1.25
S_4D		TOWER_SNOW	0.5
S_4D		TOWER_WIND_X	1.4
S_4D		TOWER_THERMAL_BRIDGE	1.
S_4D		TOWER_HYDRO_E	1.5
S_4E	Linear Add	TOWER_DEAD	1.25
S_4E		TOWER_SNOW	0.5
S_4E		TOWER_WIND_Y	1.4
S_4E		TOWER_THERMAL_BRIDGE	1.
S_4F	Linear Add	TOWER_DEAD	1.25
S_4F		TOWER_SNOW	0.5
S_4F		TOWER_WIND_Y	-1.4
S_4F		TOWER_THERMAL_BRIDGE	-1.
S_4F		TOWER_HYDRO_E	1.5
S_4G	Linear Add	TOWER_DEAD	0.9
S_4G		TOWER_LIVE	0.5
S_4G		TOWER_WIND_X	1.4
S_4G		TOWER_THERMAL_BRIDGE	1.
S_4G		TOWER_HYDRO_E	1.5
S_4H	Linear Add	TOWER_DEAD	0.9
S_4H		TOWER_LIVE	0.5
S_4H		TOWER_WIND_Y	1.4
S_4H		TOWER_THERMAL_BRIDGE	1.
S_4I	Linear Add	TOWER_DEAD	0.9

Table 16: Combination Definitions

ComboName	ComboType	CaseName	ScaleFactor
S_4I		TOWER_LIVE	0.5
S_4I		TOWER_WIND_Y	-1.4
S_4I		TOWER_THERMAL_BRIDGE	-1.
S_4I		TOWER_HYDRO_E	1.5
S_4J	Linear Add	TOWER_DEAD	0.9
S_4J		TOWER_SNOW	0.5
S_4J		TOWER_WIND_X	1.4
S_4J		TOWER_THERMAL_BRIDGE	1.
S_4J		TOWER_HYDRO_E	1.5
S_4K	Linear Add	TOWER_DEAD	0.9
S_4K		TOWER_SNOW	0.5
S_4K		TOWER_WIND_Y	1.4
S_4K		TOWER_THERMAL_BRIDGE	1.
S_4L	Linear Add	TOWER_DEAD	0.9
S_4L		TOWER_SNOW	0.5
S_4L		TOWER_WIND_Y	-1.4
S_4L		TOWER_THERMAL_BRIDGE	-1.
S_4L		TOWER_HYDRO_E	1.5
S_5A	Linear Add	E3-1	1.
S_5B	Linear Add	E3-2	1.
S_5C	Linear Add	E3-3	1.
S_5D	Linear Add	E3-4	1.
S_5E	Linear Add	E3-5	1.
S_5E		TOWER_LIVE	0.5
S_5F	Linear Add	E3-6	1.
S_5F		TOWER_LIVE	0.5
S_5G	Linear Add	E3-7	1.
S_5G		TOWER_LIVE	0.5
S_5H	Linear Add	E3-8	1.
S_5H		TOWER_LIVE	0.5
S_5I	Linear Add	E3-9	1.
S_5J	Linear Add	E3-10	1.
S_5K	Linear Add	E3-11	1.
S_5L	Linear Add	E3-12	1.
S_5M	Linear Add	E3-13	1.
S_5M		TOWER_LIVE	0.5
S_5N	Linear Add	E3-14	1.
S_5N		TOWER_LIVE	0.5
S_5O	Linear Add	E3-15	1.
S_5O		TOWER_LIVE	0.5
S_5P	Linear Add	E3-16	1.
S_5P		TOWER_LIVE	0.5
S_5Q	Linear Add	E3-17	1.
S_5R	Linear Add	E3-18	1.
S_5S	Linear Add	E3-19	1.

Table 16: Combination Definitions

ComboName	ComboType	CaseName	ScaleFactor
S_5T	Linear Add	E3-20	1.
S_5U	Linear Add	E3-21	1.
S_5U		TOWER_LIVE	0.5
S_5V	Linear Add	E3-22	1.
S_5V		TOWER_LIVE	0.5
S_5W	Linear Add	E3-23	1.
S_5W		TOWER_LIVE	0.5
S_5X	Linear Add	E3-24	1.
S_5X		TOWER_LIVE	0.5
SER_SD	Linear Add	TOWER_DEAD	1.
SER_SD		TOWER_LIVE	1.
SER_SD		TOWER_WIND_X	1.
SER_SD		TOWER_THERMAL_BRIDGE	1.
SER_SD		TOWER_HYDRO_E	1.
SER_SD		TOWER_WIND_Y	1.
S_4A_UN	Linear Add	TOWER_DEAD	1.25
S_4A_UN		TOWER_WIND_X	1.4
S_4A_UN		TOWER_THERMAL_BRIDGE	1.
S_4A_UN		TOWER_LIVE	0.5
S_4A_UN		SUR_X	1.5
S_4B_UN	Linear Add	TOWER_DEAD	1.25
S_4B_UN		TOWER_WIND_Y	1.4
S_4B_UN		TOWER_THERMAL_BRIDGE	1.
S_4B_UN		TOWER_LIVE	0.5
S_4B_UN		SUR_Y	1.5
S_4C_UN	Linear Add	TOWER_DEAD	1.25
S_4C_UN		TOWER_WIND_Y	-1.4
S_4C_UN		TOWER_THERMAL_BRIDGE	1.
S_4C_UN		TOWER_LIVE	0.5
S_4C_UN		SUR_Y	-1.5
S_4D_UN	Linear Add	TOWER_DEAD	1.25
S_4D_UN		TOWER_WIND_X	1.4
S_4D_UN		TOWER_THERMAL_BRIDGE	1.
S_4D_UN		TOWER_SNOW	0.5
S_4D_UN		SUR_X	1.5
S_4E_UN	Linear Add	TOWER_DEAD	1.25
S_4E_UN		TOWER_WIND_Y	1.4
S_4E_UN		TOWER_THERMAL_BRIDGE	1.
S_4E_UN		TOWER_SNOW	0.5
S_4E_UN		SUR_Y	1.5
S_4F_UN	Linear Add	TOWER_DEAD	1.25
S_4F_UN		TOWER_WIND_Y	-1.4

Table 16: Combination Definitions

ComboName	ComboType	CaseName	ScaleFactor
S_4F_UN		TOWER_THERMAL_BRIDGE	-1.
S_4F_UN		TOWER_SNOW	0.5
S_4F_UN		SUR_Y	-1.5
S_4G_UN	Linear Add	TOWER_DEAD	0.9
S_4G_UN		TOWER_WIND_X	1.4
S_4G_UN		TOWER_THERMAL_BRIDGE	1.
S_4G_UN		TOWER_LIVE	0.5
S_4G_UN		SUR_X	1.5
S_4H_UN	Linear Add	TOWER_DEAD	0.9
S_4H_UN		TOWER_WIND_Y	1.4
S_4H_UN		TOWER_THERMAL_BRIDGE	1.
S_4H_UN		TOWER_LIVE	0.5
S_4H_UN		SUR_Y	1.5
S_4I_UN	Linear Add	TOWER_DEAD	0.9
S_4I_UN		TOWER_WIND_Y	-1.4
S_4I_UN		TOWER_THERMAL_BRIDGE	-1.
S_4I_UN		TOWER_LIVE	0.5
S_4I_UN		SUR_Y	-1.5
S_4J_UN	Linear Add	TOWER_DEAD	0.9
S_4J_UN		TOWER_WIND_X	1.4
S_4J_UN		TOWER_THERMAL_BRIDGE	1.
S_4J_UN		TOWER_SNOW	0.5
S_4J_UN		SUR_X	1.5
S_4K_UN	Linear Add	TOWER_DEAD	0.9
S_4K_UN		TOWER_WIND_Y	1.4
S_4K_UN		TOWER_THERMAL_BRIDGE	1.
S_4K_UN		TOWER_SNOW	0.5
S_4K_UN		SUR_Y	1.5
S_4L_UN	Linear Add	TOWER_DEAD	0.9
S_4L_UN		TOWER_WIND_Y	-1.4
S_4L_UN		TOWER_THERMAL_BRIDGE	-1.
S_4L_UN		TOWER_SNOW	0.5
S_4L_UN		SUR_Y	-1.5

7. Design preferences

This section provides the design preferences for each type of design, which typically include material reduction factors, framing type, stress ratio limit, deflection limits, and other code specific items.

7.1. Steel design

Table 17: Preferences - Steel Design - AISC 360-10, Part 1 of 4

Table 17: Preferences - Steel Design - AISC 360-10, Part 1 of 4

THDesign	FrameType	PatLLF	SRatioLimit	MaxIter	SDC	SeisCode	SeisLoad	ImpFactor
Envelopes	SMF	0.75	0.95	1	D	Yes	Yes	1.

Table 17: Preferences - Steel Design - AISC 360-10, Part 2 of 4

Table 17: Preferences - Steel Design - AISC 360-10, Part 2 of 4

SystemRho	SystemSds	SystemR	SystemCd	Omega0	Provision	AMethod	SOMethod	SRMethod
1.	0.5	8.	5.5	3.	LRFD	Direct Analysis	General 2nd Order	Tau-b Fixed

Table 17: Preferences - Steel Design - AISC 360-10, Part 3 of 4

Table 17: Preferences - Steel Design - AISC 360-10, Part 3 of 4

NLCoeff	PhiB	PhiC	PhiTY	PhiTF	PhiV	PhiVRolledI	PhiVT	PlugWeld
0.002	0.9	0.9	0.9	0.75	0.9	1.	0.9	Yes

Table 17: Preferences - Steel Design - AISC 360-10, Part 4 of 4

Table 17: Preferences - Steel Design - AISC 360-10, Part 4 of 4

HSSWelding	HSSReduceT	CheckDefl	DLRat	SDLAndLLRat	LLRat	TotalRat	NetRat
ERW	No	No	120.	120.	360.	240.	240.

7.2. Concrete design

Table 18: Preferences - Concrete Design - CSA-A233-14

Table 18: Preferences - Concrete Design - CSA-A233-14

THDesign	NumCurves	NumPoints	MinEccen	PatLLF	UFLimit	PhiS	PhiC
Envelopes	24	11	Yes	0.75	0.95	0.85	0.65

7.3. Aluminum design

Table 19: Preferences - Aluminum Design - AA-ASD 2000

Table 19: Preferences - Aluminum Design - AA-ASD 2000

FrameType	SRatioLimit	LatFact	UseLatFact
Moment Frame	1.	1.333333	No

7.4. Cold formed design

Table 20: Preferences - Cold Formed Design - AISI-ASD96

Table 20: Preferences - Cold Formed Design - AISI-ASD96

FrameType	SRatioLimit	OmegaBS	OmegaBUS	OmegaBLTB	OmegaVS	OmegaVNS	OmegaT	OmegaC
Braced Frame	1.	1.67	1.67	1.67	1.67	1.5	1.67	1.8

8. Design overwrites

This section provides the design overwrites for each type of design, which are assigned to individual members of the structure.

8.1. Concrete design

Table 21: Overwrites - Concrete Design - CSA-A233-14, Part 1 of 3

Table 21: Overwrites - Concrete Design - CSA-A233-14, Part 1 of 3

Frame	DesignSect	FrameType	RLLF	XLMajor	XLMinor	XKMajor
4	Program Determined	Conventional	1.	18.1	18.1	2.
5	Program Determined	Conventional	1.	36.2	36.2	2.
6	Program Determined	Conventional	1.	23.3	23.3	2.
7	Program Determined	Conventional	1.	20.2	20.2	2.
8	Program Determined	Conventional	1.	27.	27.	2.
9	Program Determined	Conventional	1.	19.3	19.3	2.
10	Program Determined	Conventional	1.	19.3	19.3	2.
11	Program Determined	Conventional	1.	19.3	19.3	2.
12	Program Determined	Conventional	1.	19.3	19.3	2.
13	Program Determined	Conventional	1.	19.3	19.3	2.
14	Program Determined	Conventional	1.	19.3	19.3	2.
15	Program Determined	Conventional	1.	14.5	14.5	2.
16	Program Determined	Conventional	1.	28.9	28.9	2.
17	Program Determined	Conventional	1.	19.3	19.3	2.
18	Program Determined	Conventional	1.	19.3	19.3	2.
19	Program Determined	Conventional	1.	19.3	19.3	2.
20	Program Determined	Conventional	1.	19.3	19.3	2.
21	Program Determined	Conventional	1.	23.3	23.3	2.

Table 21: Overwrites - Concrete Design - CSA-A233-14, Part 1 of 3

Frame	DesignSect	FrameType	RLLF	XLMajor	XLMinor	XKMajor
22	Program Determined	Conventional	1.	28.9	28.9	2.
23	Program Determined	Conventional	1.	38.1	38.1	2.
24	Program Determined	Program Determined	0.	0.	0.	0.
27	Program Determined	Program Determined	0.	0.	0.	0.

Table 21: Overwrites - Concrete Design - CSA-A233-14, Part 2 of 3

Table 21: Overwrites - Concrete Design - CSA-A233-14, Part 2 of 3

Frame	XKMinor	CmMajor	CmMinor	DbMajor	DbMinor	DsMajor	DsMinor
4	2.	0.	0.	0.	0.	0.	0.
5	2.	0.	0.	0.	0.	0.	0.
6	2.	0.	0.	0.	0.	0.	0.
7	2.	0.	0.	0.	0.	0.	0.
8	2.	0.	0.	0.	0.	0.	0.
9	2.	0.	0.	0.	0.	0.	0.
10	2.	0.	0.	0.	0.	0.	0.
11	2.	0.	0.	0.	0.	0.	0.
12	2.	0.	0.	0.	0.	0.	0.
13	2.	0.	0.	0.	0.	0.	0.
14	2.	0.	0.	0.	0.	0.	0.
15	2.	0.	0.	0.	0.	0.	0.
16	2.	0.	0.	0.	0.	0.	0.
17	2.	0.	0.	0.	0.	0.	0.
18	2.	0.	0.	0.	0.	0.	0.
19	2.	0.	0.	0.	0.	0.	0.
20	2.	0.	0.	0.	0.	0.	0.
21	2.	0.	0.	0.	0.	0.	0.
22	2.	0.	0.	0.	0.	0.	0.
23	2.	0.	0.	0.	0.	0.	0.
24	0.	0.	0.	0.	0.	0.	0.
27	0.	0.	0.	0.	0.	0.	0.

Table 21: Overwrites - Concrete Design - CSA-A233-14, Part 3 of 3

Table 21: Overwrites - Concrete Design - CSA-A233-14, Part 3 of 3

Frame	Rd	Ro	MaxAggSize
			mm
4	1.	1.	0.
5	1.	1.	0.
6	1.	1.	0.
7	1.	1.	0.
8	1.	1.	0.
9	1.	1.	0.
10	1.	1.	0.
11	1.	1.	0.
12	1.	1.	0.
13	1.	1.	0.
14	1.	1.	0.
15	1.	1.	0.
16	1.	1.	0.
17	1.	1.	0.

Table 21: Overwrites - Concrete Design - CSA-A233-14, Part 3 of 3

Frame	Rd	Ro	MaxAggSize
			mm
18	1.	1.	0.
19	1.	1.	0.
20	1.	1.	0.
21	1.	1.	0.
22	1.	1.	0.
23	1.	1.	0.
24	0.	0.	0.
27	0.	0.	0.

Gate Structure - Stability Analysis

GATE TOWER STATIC STABILITY ANALYSIS SUMMARY

Job Name:	Springbank Off-Stream Storage Project	Number:	110773396
Site:	Gate Tower	Originator:	ACG 7/2/2020

Results Summary:

SR-1 - Summary of Intake Structure Static Stability Assessment

Load Case	Load Category	Sliding Stability Safety Factor		Base Area in Compression(1)		Bearing Pressures (3) (kPa)				Flotation Safety Factor	
						Long Term		Short Term			
		Required	Calculated	Required	Calculated	Required	Calculated	Required	Calculated	Required	Calculated
1- Empty Reservoir	Usual	1.5	>10	100%	100%	427.0	411.9	569.3	423.8	1.5	>10
2- 10-Year Flood, Gates Open	Unusual	1.3	>10	100%	100%	427.0	367.8	569.3	383.8	1.3	6.10
3- 10-Year Flood, Front Gate Closed	Unusual	1.3	>10	100%	100%	427.0	353.0	569.3	368.6	1.3	5.95
4- Staged Construction	Unusual	1.3	>10	100%	100%	250.0	203.3	NA		1.3	>10
5- Crane Adjacent to Tower	Unusual	1.3	>10	100%	100%	NA		569.3	428.0	1.3	>10
6- Max Pool, Gates Open	Extreme	1.1	>10	75%	100%	427.0	349.9	569.3	359.1	1.1	2.16
7- Max Pool, Front Gate Closed	Extreme	1.1	>10	75%	100%	427.0	337.4	569.3	345.4	1.1	2.03

(1)- 100% base compression = resultant within the middle 1/3
75% base compression = resultant within the middle 1/2
>0% base compression = resultant within the base
(2)- Additional future fill doesn't control by inspection. Since bearing capacity is governed by differential settlement between tower and conduit, additional fill will only increase bearing capacity.
(3)- Bearing pressure limits are based on the values shown in the table below.

Allowable Bearing Capacity (kPa)		Ultimate Bearing Capacity (kPa)	
Construction	250	Construction	750
Final Embankment Configuration*	427	Final Embankment Configuration*	1281

*Based on the allowable bearing pressure due to differential settlement between conduit and the gate tower, multiplied by a safety factor of 3.

GATE TOWER STATIC STABILITY ANALYSIS SUMMARY			
Job Name:	Springbank Off-Stream Storage Project	Number:	110773396
Site:	Gate Tower	Originator:	ACG 7/2/2020

Detailed Load Cases:

LC #	Designation	Condition Classification	Description	Dead	Live	Soil	Water				Snow	Wind				EQ (24 Cases)	Soil Springs	
							10-Year Flood		Max Pool			Tower Wind		Upper Building/Bridge				
							Gates Open*	Front Gate Closed	Back Gate Closed*	Front Gate Closed		Wind-X	Wind-Y	Wind-X	Wind-Y		Saturated	Dry
1	U1-1	Usual	Empy Reservoir, Winter															
	U1-2																	
	U1-3																	
	U1-4+												+		+			
	U1-4-												-		-			
	U2-1	Usual	Empy Reservoir, Summer															
	U2-2+												+		+			
	U2-2-												-		-			
	U2-3																	
	U2-4+												+		+			
	U2-4-												-		-			
2	UN1-1	Unusual	10-Year Flood															
	UN1-2																	
	UN1-3																	
	UN1-4+												+		+			
	UN1-4-												-		-			
	UN1-5																	
	UN1-6+												+		+			
	UN1-6-												-		-			
3	UN2-1	Unusual	10-Year Flood															
	UN2-2																	
	UN2-3																	
	UN2-4+												+		+			
	UN2-4-												-		-			
	UN2-5																	
	UN2-6+												+		+			
	UN2-6-												-		-			
4	UN3-1	Unusual	Staged Construction															
5	UN4-1	Unusual	Crane Adjacent to Tower										+		+			
	UN4-2																	
6	E1-1	Extreme	Max Pool															
	E1-2																	
	E1-3																	
	E1-4+														+			
	E1-4-														-			
7	E2-1	Extreme	Max Pool															
	E2-2																	
	E2-3																	
	E2-4+														+			
	E2-4-														-			
8**	E3	Extreme	Extreme Earthquake															
9	PE-1	Usual	Post-Earthquake															
	PE-2+												+		+			
	PE-2-												-		-			

*Gates open bounds back gate closed.
**Seismic includes 24 combinations of EQx, EQy, EQz
***Includes lateral earth pressure due to 1m of surcharge in the same direction of the wind to account for construction loads.
****Tower is not operational, therefore, water surrounds the tower but is not within it.

GATE TOWER STATIC STABILITY ANALYSIS SUMMARY

Job Name:	Springbank Off-Stream Storage Project	Number:	110773396
Site:	Gate Tower	Originator:	ACG 7/2/2020

SAP2000 Reactions:

TABLE: Joint Reactions

Joint	OutputCase	CaseType	F1	F2	F3	M1	M2	M3
Text	Text	Text	KN	KN	KN	KN-m	KN-m	KN-m
1	U1-1	Combination	0.00	-8.01	14251.18	-37.63	0.00	0.00
1	U1-2	Combination	0.00	-9.06	14811.43	-40.21	0.00	0.00
1	U1-3	Combination	2.14	-8.67	14633.57	-39.31	1.45	-363.49
1	U1-4+	Combination	0.00	-6.06	14761.32	-33.41	0.00	0.00
1	U2-1	Combination	2.14	-7.29	14592.49	-36.27	1.45	-363.49
1	U2-2+	Combination	0.00	-6.04	14720.24	-33.30	0.00	0.00
1	U2-3	Combination	2.14	-6.24	14032.24	-33.70	1.45	-363.49
1	U2-4+	Combination	0.00	-4.99	14159.99	-30.72	0.00	0.00
1	U1-4-	Combination	0.00	-10.69	14861.54	-44.08	0.00	0.00
1	U2-2-	Combination	0.00	-10.67	14820.46	-43.96	0.00	0.00
1	U2-4-	Combination	0.00	-9.62	14260.21	-41.39	0.00	0.00
1	UN1-1	Combination	0.00	-83.78	14210.10	-251.47	0.00	0.00
1	UN1-2	Combination	0.00	-138.53	14770.30	-410.74	0.00	0.00
1	UN1-3	Combination	279.47	-117.76	14592.54	-350.37	-647.45	-363.49
1	UN1-4+	Combination	0.00	-40.16	14720.20	12.75	0.00	0.00
1	UN1-5	Combination	279.47	-63.01	14032.34	-191.10	-647.45	-363.49
1	UN1-6+	Combination	0.00	14.59	14160.00	172.02	0.00	0.00
1	UN2-1	Combination	0.00	-83.78	14210.10	-251.47	0.00	0.00
1	UN2-2	Combination	0.00	-138.53	14770.30	-410.74	0.00	0.00
1	UN2-3	Combination	279.47	-117.76	14592.54	-350.37	-647.45	-363.49
1	UN2-4+	Combination	0.00	-40.16	14720.20	12.75	0.00	0.00
1	UN2-5	Combination	279.47	-63.01	14032.34	-191.10	-647.45	-363.49
1	UN2-6+	Combination	0.00	14.59	14160.00	172.02	0.00	0.00
1	UN1-4-	Combination	0.00	-326.40	14820.40	-1200.90	0.00	0.00
1	UN1-6-	Combination	0.00	-271.65	14260.20	-1041.63	0.00	0.00
1	UN2-4-	Combination	0.00	-326.40	14820.40	-1200.90	0.00	0.00
1	UN2-6-	Combination	0.00	-271.65	14260.20	-1041.63	0.00	0.00
1	UN3-1	Combination	0.00	-146.50	14210.10	-450.19	0.00	0.00
1	UN4-1	Combination	0.00	-289.86	14160.00	1115.09	0.00	0.00
1	UN4-2	Combination	-139.28	-125.73	14032.34	-389.82	-1673.39	-698.33
1	E1-1	Combination	0.00	9.13	14210.10	-171.95	0.00	0.00

1	E1-2	Combination	0.00	-45.62	14770.30	-331.22	0.00	0.00
1	E1-3	Combination	149.40	29.90	14032.34	-111.58	-324.78	-363.49
1	E1-4+	Combination	0.00	46.77	14160.00	-23.37	0.00	0.00
1	E2-1	Combination	0.00	9.13	14210.10	-171.95	0.00	0.00
1	E2-2	Combination	0.00	-45.62	14770.30	-331.22	0.00	0.00
1	E2-3	Combination	149.40	29.90	14032.34	-111.58	-324.78	-363.49
1	E2-4+	Combination	0.00	46.77	14160.00	-23.37	0.00	0.00
1	E1-4-	Combination	0.00	-118.02	14260.20	-687.19	0.00	0.00
1	E2-4-	Combination	0.00	-118.02	14260.20	-687.19	0.00	0.00

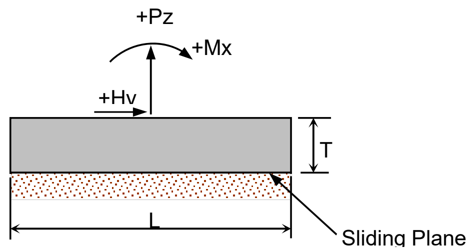
GATE TOWER STABILITY ANALYSIS

Job Name:	Springbank Off-Stream Storage Project	Number:	110773396		
Site:	Gate Tower	Originator:	ACG 7/2/2020	Checker:	CG
Load Case:	U1-1 Empty Reservoir, Winter				

Input Data:

Footing Data:

Footing Length, L =	10.50	m
Footing Width, B =	6.40	m
Footing Thickness, T =	0.00	m
Coef. of Base Friction, μ =	0.510	
Ultimate Bearing, Pall =	1281.00	kPa

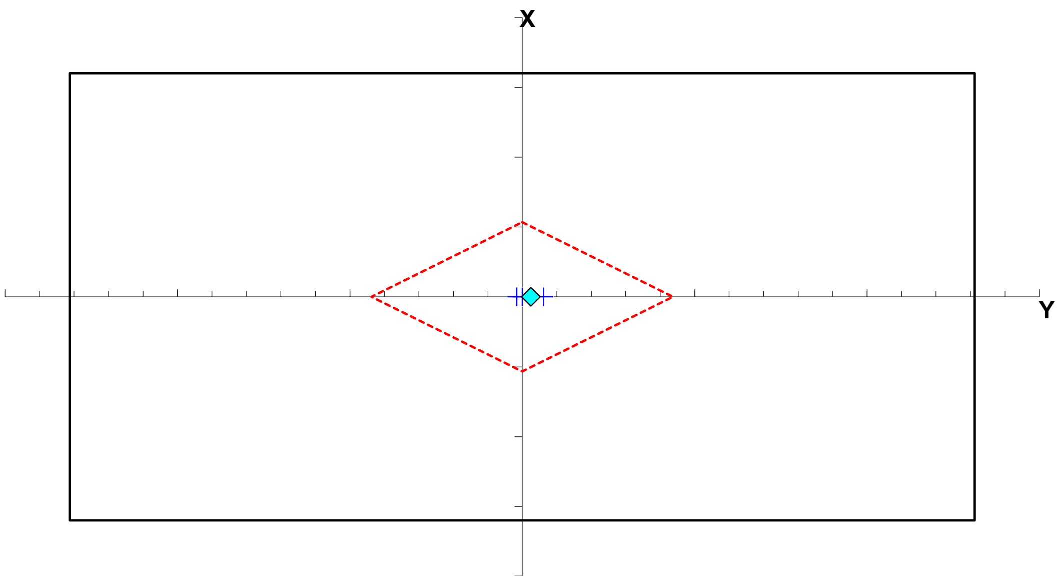


Nomenclature

Loading Data:

Direction of Wind Force: N/A

	Uplift	Vertical Soil	Not Used	Internal Hydrostatic	Not Used	SAP2000 Reaction
Yp (m.) =	0.00	-0.06				0.25
Xp (m.) =	0.00	0.00				0.00
Pz (kN) =	1185.41	-13120.89				-14251.18
Hy (kN) =	0.00	0.00				8.01
Hx (kN) =	0.00	0.00				0.00
My (kN-m) =	0.00	0.00				0.00
Mx (kN-m) =	0.00	0.00				-37.63



FOOTING PLAN

Note: Is the "Kern" area of footing (When resultant of loads falls within "Kern", entire footing base is in bearing.)

Results:

Total Resultant Load and Eccentricities:

ΣPy =	-26186.66	kN
ey =	0.10	m (<= L/6)
ex =	0.00	
ΣHy =	8.01	kN
ΣHx =	0.00	kN
H resultant =	8.01	kN
ΣMry =	N.A.	kN-m
ΣMoy =	N.A.	kN-m
ΣMrx =	140940.94	kN-m
ΣMox =	6185.77	kN-m

Sliding Check:

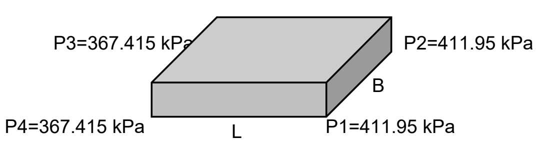
Frict =	13355.20	kN
FS(slid) =	1667.732	

% Base Area in Compression:

Dist. y =	N.A.	m
Dist. x =	N.A.	m
Brg. Ly =	10.500	m
Brg. Lx =	6.400	m
%Brg. Area =	100.00	%
Biaxial Case =	N.A.	

Gross Soil Bearing Corner Pressures:

P_1 =	411.950	kPa
P_2 =	411.950	kPa
P_3 =	367.415	kPa
P_4 =	367.415	kPa



CORNER PRESSURES

Summary of Results:

Sliding Check:

FS(slid) =	1667.73	> 1.5	OK

Bearing Area:

%Brg. Area =	100.00%	< 100%	OK

Bearing Pressure Check:

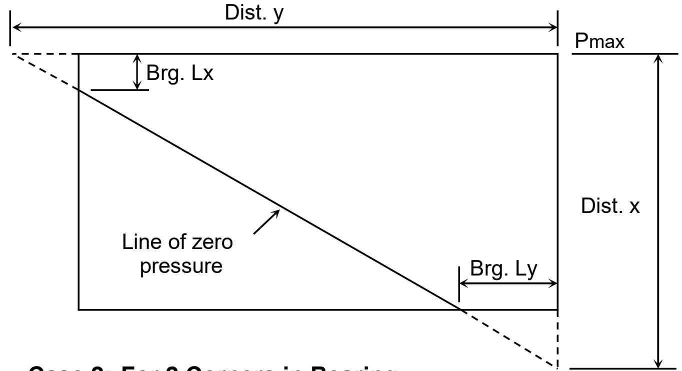
FS(brg) =	3.11	> 3.0	OK

Flotation Check:

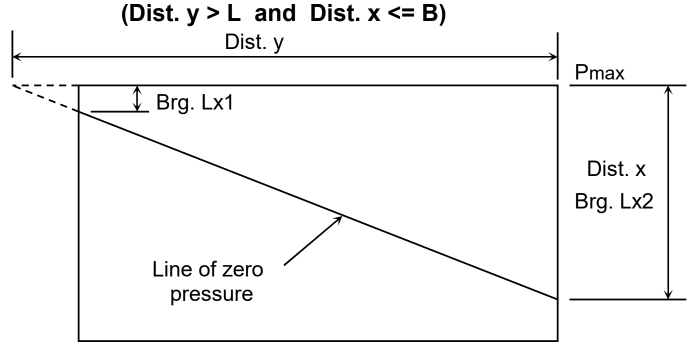
FS (float) =	23.09	> 1.5	OK

Nomenclature for Biaxial Eccentricity:

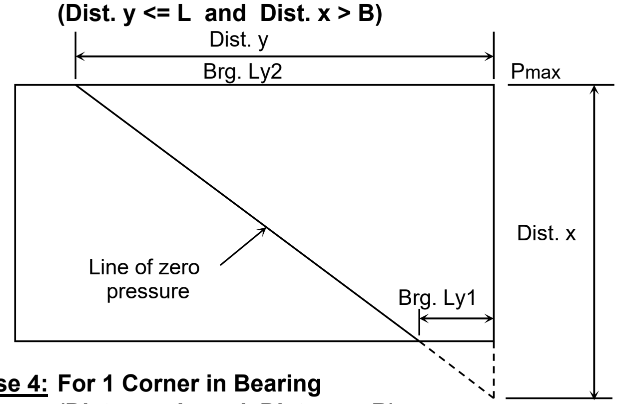
Case 1: For 3 Corners in Bearing
(Dist. y > L and Dist. x > B)



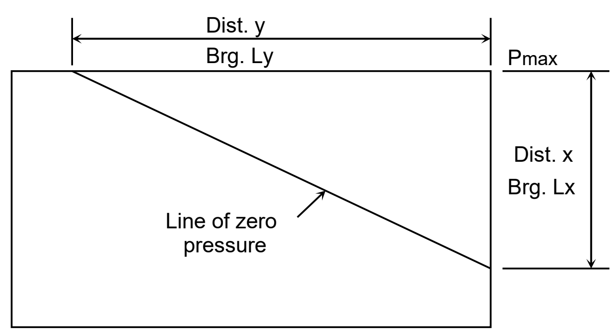
Case 2: For 2 Corners in Bearing
(Dist. y > L and Dist. x <= B)



Case 3: For 2 Corners in Bearing
(Dist. y <= L and Dist. x > B)



Case 4: For 1 Corner in Bearing
(Dist. y <= L and Dist. x <= B)



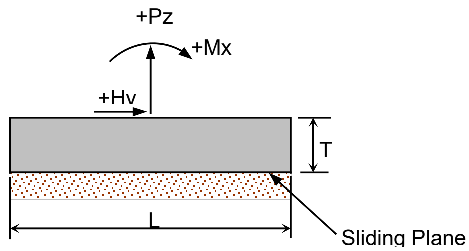
GATE TOWER STABILITY ANALYSIS

Job Name:	Springbank Off-Stream Storage Project	Number:	110773396		
Site:	Gate Tower	Originator:	ACG 7/2/2020	Checker:	CG
Load Case:	U1-2 Empty Reservoir, Winter				

Input Data:

Footing Data:

Footing Length, L =	10.50	m
Footing Width, B =	6.40	m
Footing Thickness, T =	0.00	m
Coef. of Base Friction, μ =	0.510	
Ultimate Bearing, Pall =	1281.00	kPa

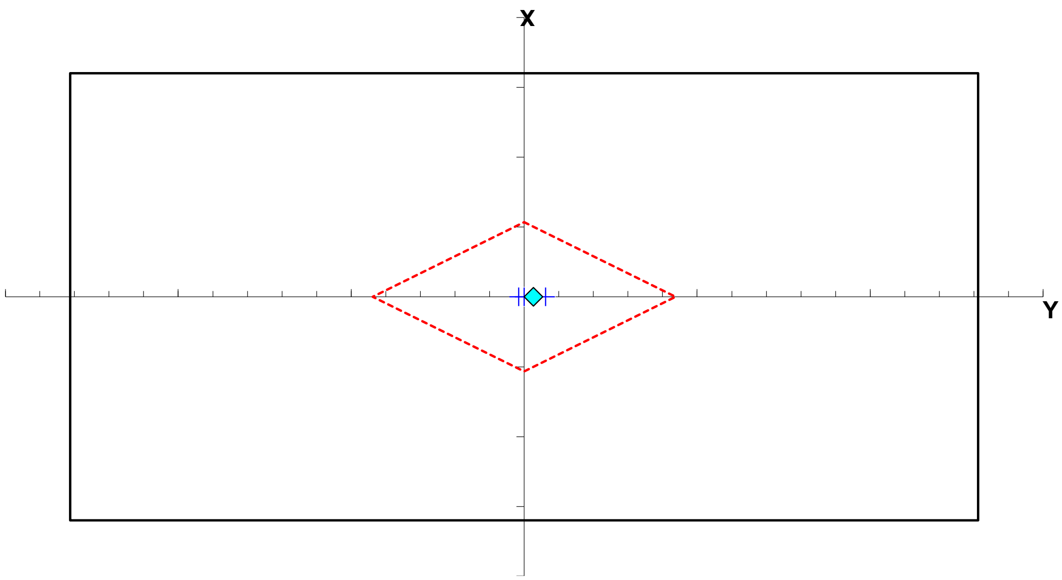


Nomenclature

Loading Data:

Direction of Wind Force: N/A

	Uplift	Vertical Soil	Not Used	Internal Hydrostatic	Not Used	SAP2000 Reaction
Yp (m.) =	0.00	**-0.06**				**0.25**
Xp (m.) =	0.00	**0.00**				0.00
Pz (kN) =	1185.41	**-13120.89**				**-14811.43**
Hy (kN) =	0.00	**0.00**				**9.06**
Hx (kN) =	0.00	**0.00**				**0.00**
My (kN-m) =	0.00	**0.00**				**0.00**
Mx (kN-m) =	0.00	**0.00**				**-40.21**



FOOTING PLAN

Note: Is the "Kern" area of footing (When resultant of loads falls within "Kern", entire footing base is in bearing.)

Results:

Total Resultant Load and Eccentricities:

ΣPy =	-26746.91	kN
ey =	0.11	m (<= L/6)
ex =	0.00	
ΣHy =	9.06	kN
ΣHx =	0.00	kN
H resultant =	9.06	kN
ΣMry =	N.A.	kN-m
ΣMoy =	N.A.	kN-m
ΣMrx =	143742.18	kN-m
ΣMox =	6183.20	kN-m

Sliding Check:

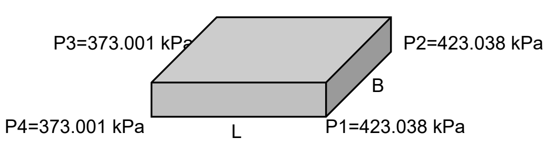
Frict =	13640.92	kN
FS(slid) =	1506.119	

% Base Area in Compression:

Dist. y =	N.A.	m
Dist. x =	N.A.	m
Brg. Ly =	10.500	m
Brg. Lx =	6.400	m
%Brg. Area =	100.00	%
Biaxial Case =	N.A.	

Gross Soil Bearing Corner Pressures:

P_1 =	423.038	kPa
P_2 =	423.038	kPa
P_3 =	373.001	kPa
P_4 =	373.001	kPa



CORNER PRESSURES

Summary of Results:

Sliding Check:

FS(slid) =	1506.12	> 1.5	OK

Bearing Area:

%Brg. Area =	100.00%	< 100%	OK

Bearing Pressure Check:

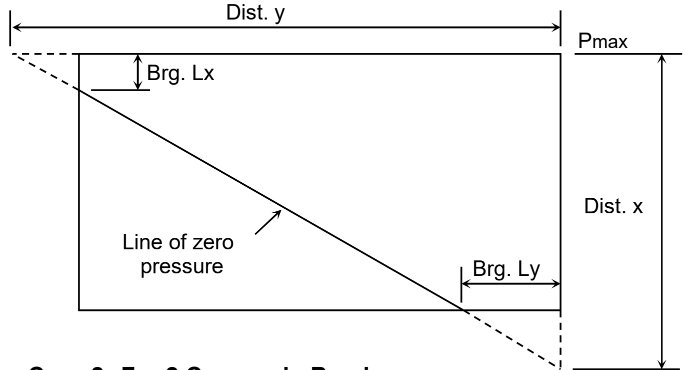
FS(brg) =	3.03	> 2.25	OK

Flotation Check:

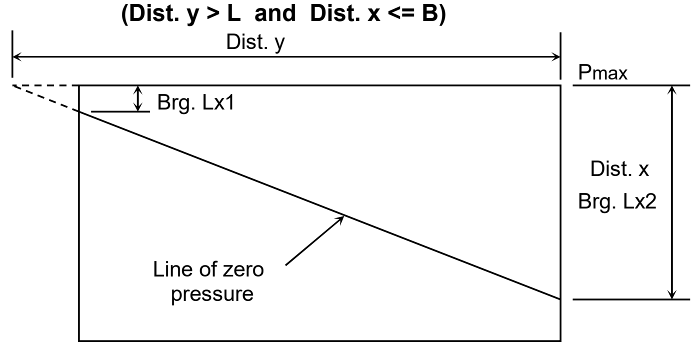
FS (float) =	23.56	> 1.5	OK

Nomenclature for Biaxial Eccentricity:

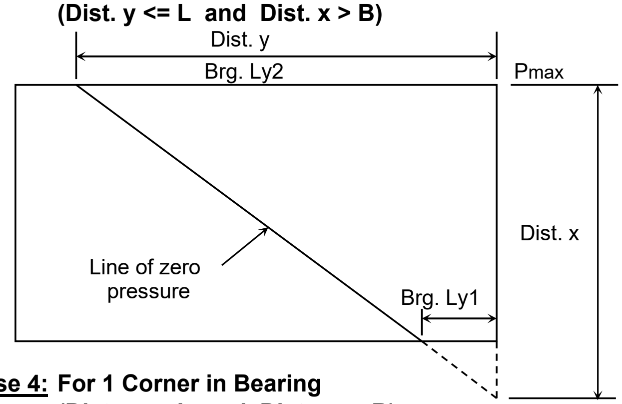
Case 1: For 3 Corners in Bearing
(Dist. y > L and Dist. x > B)



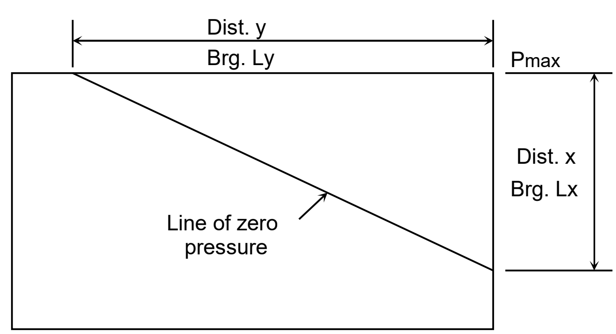
Case 2: For 2 Corners in Bearing
(Dist. y > L and Dist. x <= B)



Case 3: For 2 Corners in Bearing
(Dist. y <= L and Dist. x > B)



Case 4: For 1 Corner in Bearing
(Dist. y <= L and Dist. x <= B)



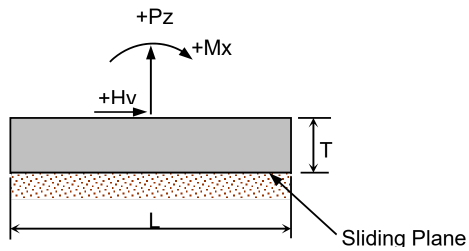
GATE TOWER STABILITY ANALYSIS

Job Name:	Springbank Off-Stream Storage Project	Number:	110773396
Site:	Gate Tower	Originator:	ACG 7/2/2020 Checker: CG
Load Case:	U1-3 Empty Reservoir, Winter		

Input Data:

Footing Data:

Footing Length, L =	10.50	m
Footing Width, B =	6.40	m
Footing Thickness, T =	0.00	m
Coef. of Base Friction, μ =	0.510	
Ultimate Bearing, Pall =	1281.00	kPa

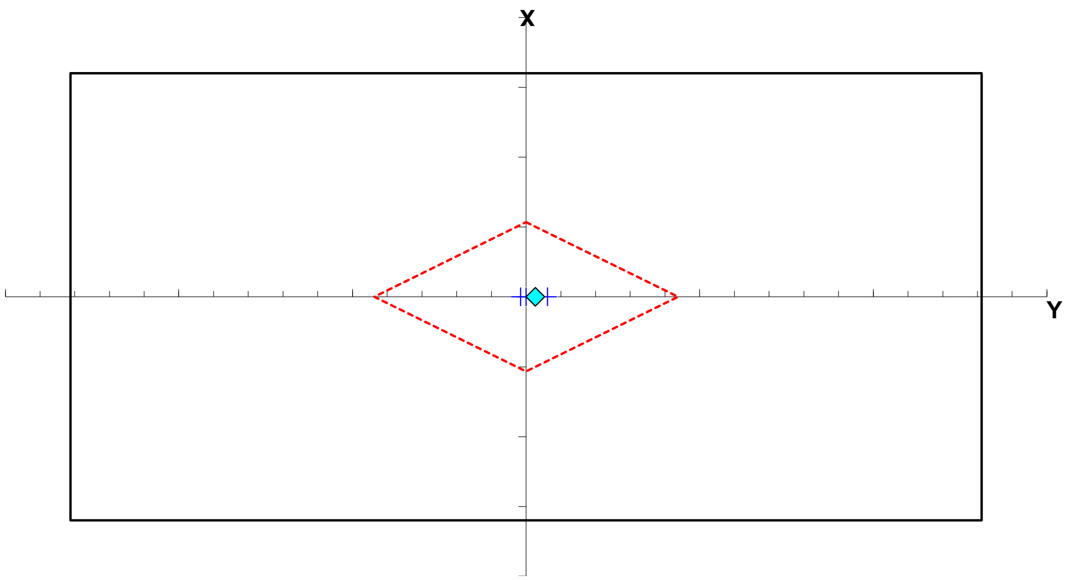


Nomenclature

Loading Data:

Direction of Wind Force: X-DIRECTION

	Uplift	Vertical Soil	Not Used	Internal Hydrostatic	Not Used	SAP2000 Reaction
Yp (m.) =	0.00	-0.06				0.25
Xp (m.) =	0.00	0.00				0.00
Pz (kN) =	1185.41	-13120.89				-14633.57
Hy (kN) =	0.00	0.00				8.67
Hx (kN) =	0.00	0.00				2.14
My (kN-m) =	0.00	0.00				-1.45
Mx (kN-m) =	0.00	0.00				-39.31



FOOTING PLAN

Note: Is the "Kern" area of footing (When resultant of loads falls within "Kern", entire footing base is in bearing.)

Results:

Total Resultant Load and Eccentricities:

ΣPy =	-26569.05	kN
ey =	0.11	m (<= L/6)
ex =	0.00	
ΣHy =	8.67	kN
ΣHx =	2.14	kN
H resultant =	8.93	kN
ΣMry =	N.A.	kN-m
ΣMoy =	N.A.	kN-m
ΣMrx =	142852.90	kN-m
ΣMox =	6184.10	kN-m

Sliding Check:

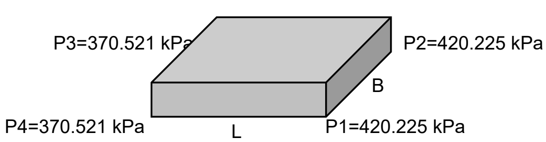
Frict =	13550.22	kN
FS(slid) =	1517.306	

% Base Area in Compression:

Dist. y =	N.A.	m
Dist. x =	N.A.	m
Brg. Ly =	10.500	m
Brg. Lx =	6.400	m
%Brg. Area =	100.00	%
Biaxial Case =	N.A.	

Gross Soil Bearing Corner Pressures:

P_1 =	420.225	kPa
P_2 =	420.225	kPa
P_3 =	370.521	kPa
P_4 =	370.521	kPa



CORNER PRESSURES

Summary of Results:

Sliding Check:

FS(slid) =	1517.31	> 1.5	OK

Bearing Area:

%Brg. Area =	100.00%	< 100%	OK

Bearing Pressure Check:

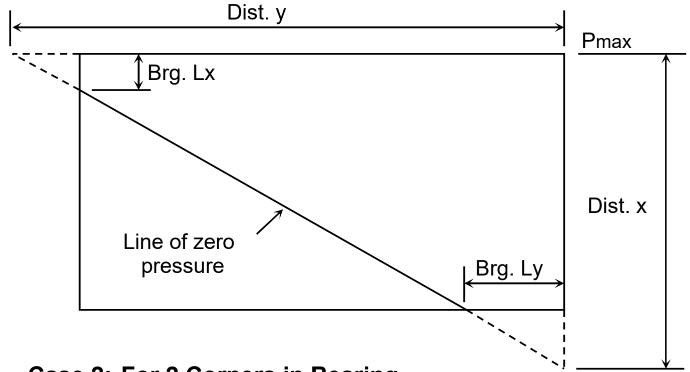
FS(brg) =	3.05	> 2.25	OK

Flotation Check:

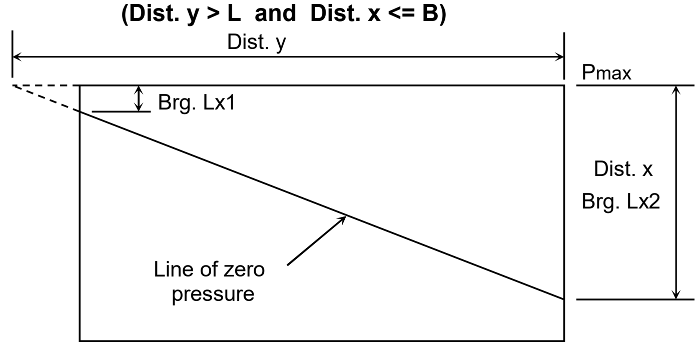
FS (float) =	23.41	> 1.5	OK

Nomenclature for Biaxial Eccentricity:

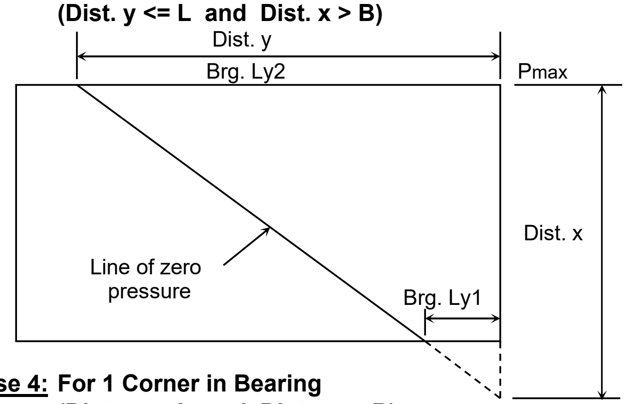
Case 1: For 3 Corners in Bearing
(Dist. y > L and Dist. x > B)



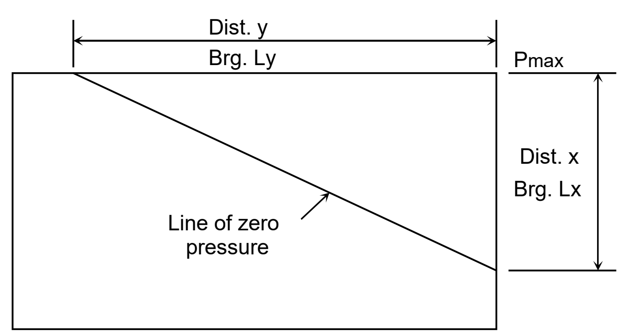
Case 2: For 2 Corners in Bearing
(Dist. y > L and Dist. x <= B)



Case 3: For 2 Corners in Bearing
(Dist. y <= L and Dist. x > B)



Case 4: For 1 Corner in Bearing
(Dist. y <= L and Dist. x <= B)

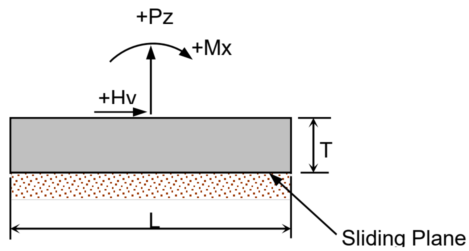


GATE TOWER STABILITY ANALYSIS						
Job Name:	Springbank Off-Stream Storage Project	Number:	110773396			
Site:	Gate Tower	Originator:	ACG	7/2/2020	Checker:	CG
Load Case:	U1-4+ Empty Reservoir, Winter					

Input Data:

Footing Data:

Footing Length, L =	10.50	m
Footing Width, B =	6.40	m
Footing Thickness, T =	0.00	m
Coef. of Base Friction, μ =	0.510	
Ultimate Bearing, Pall =	1281.00	kPa

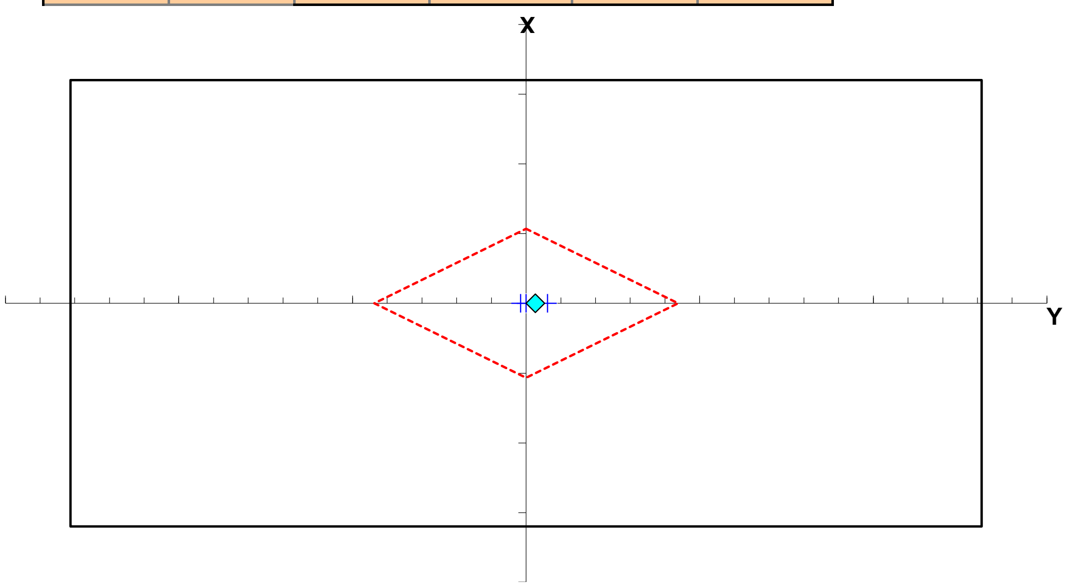


Nomenclature

Loading Data:

Direction of Wind Force: Y-DIRECTION

	Uplift	Vertical Soil	Not Used	Internal Hydrostatic	Not Used	SAP2000 Reaction
Yp (m.) =	0.00	-0.06				0.25
Xp (m.) =	0.00	0.00				0.00
Pz (kN) =	1185.41	-13120.89				-14761.32
Hy (kN) =	0.00	0.00				6.06
Hx (kN) =	0.00	0.00				0.00
My (kN-m) =	0.00	0.00				0.00
Mx (kN-m) =	0.00	0.00				-33.41



FOOTING PLAN

Note: Is the "Kern" area of footing (When resultant of loads falls within "Kern", entire footing base is in bearing.)

Results:

Total Resultant Load and Eccentricities:

ΣPy =	-26696.80	kN
ey =	0.11	m (<= L/6)
ex =	0.00	
ΣHy =	6.06	kN
ΣHx =	0.00	kN
H resultant =	6.06	kN
ΣMry =	N.A.	kN-m
ΣMoy =	N.A.	kN-m
ΣMrx =	143491.62	kN-m
ΣMox =	6189.99	kN-m

Sliding Check:

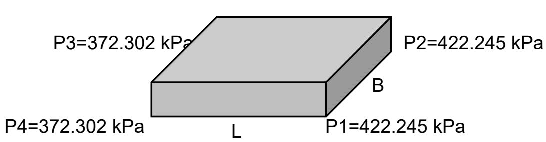
Frict =	13615.37	kN
FS(slid) =	2246.760	

% Base Area in Compression:

Dist. y =	N.A.	m
Dist. x =	N.A.	m
Brg. Ly =	10.500	m
Brg. Lx =	6.400	m
%Brg. Area =	100.00	%
Biaxial Case =	N.A.	

Gross Soil Bearing Corner Pressures:

P1 =	422.245	kPa
P2 =	422.245	kPa
P3 =	372.302	kPa
P4 =	372.302	kPa



CORNER PRESSURES

Summary of Results:

Sliding Check:

FS(slid) =	2246.76	> 1.5	OK

Bearing Area:

%Brg. Area =	100.00%	< 100%	OK

Bearing Pressure Check:

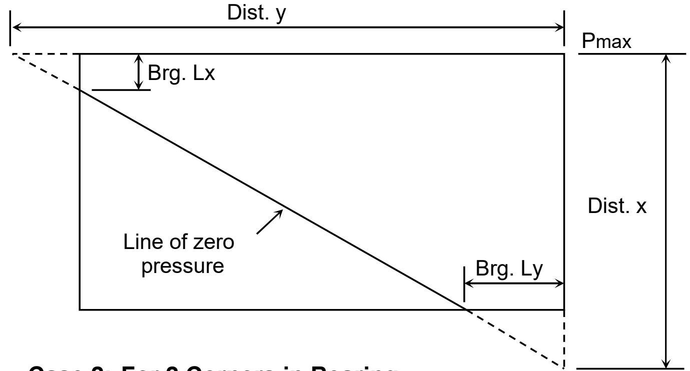
FS(brg) =	3.03	> 2.25	OK

Flotation Check:

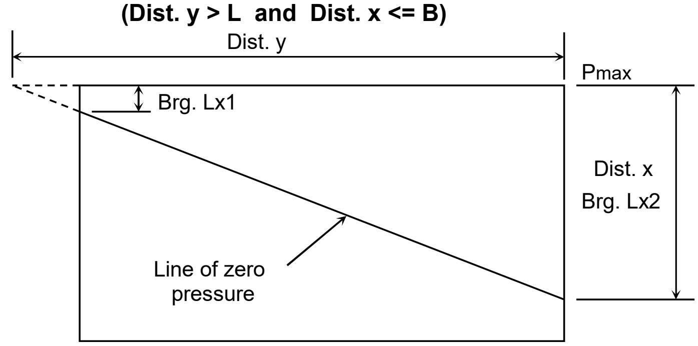
FS (float) =	23.52	> 1.5	OK

Nomenclature for Biaxial Eccentricity:

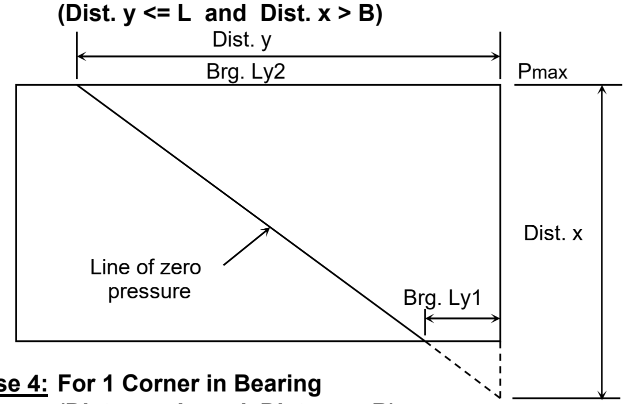
Case 1: For 3 Corners in Bearing
(Dist. y > L and Dist. x > B)



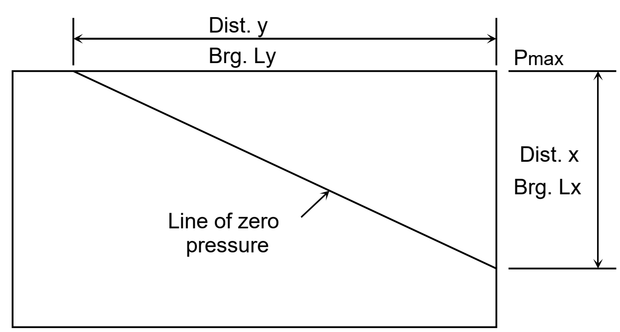
Case 2: For 2 Corners in Bearing
(Dist. y > L and Dist. x <= B)



Case 3: For 2 Corners in Bearing
(Dist. y <= L and Dist. x > B)



Case 4: For 1 Corner in Bearing
(Dist. y <= L and Dist. x <= B)



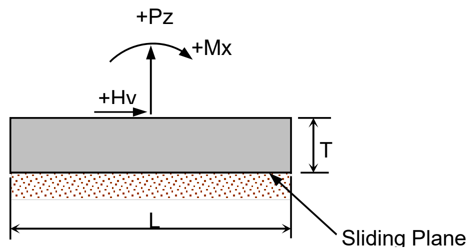
GATE TOWER STABILITY ANALYSIS

Job Name:	Springbank Off-Stream Storage Project	Number:	110773396		
Site:	Gate Tower	Originator:	ACG 7/2/2020	Checker:	CG
Load Case:	U1-4- Empty Reservoir, Winter				

Input Data:

Footing Data:

Footing Length, L =	10.50	m
Footing Width, B =	6.40	m
Footing Thickness, T =	0.00	m
Coef. of Base Friction, μ =	0.510	
Ultimate Bearing, Pall =	1281.00	kPa

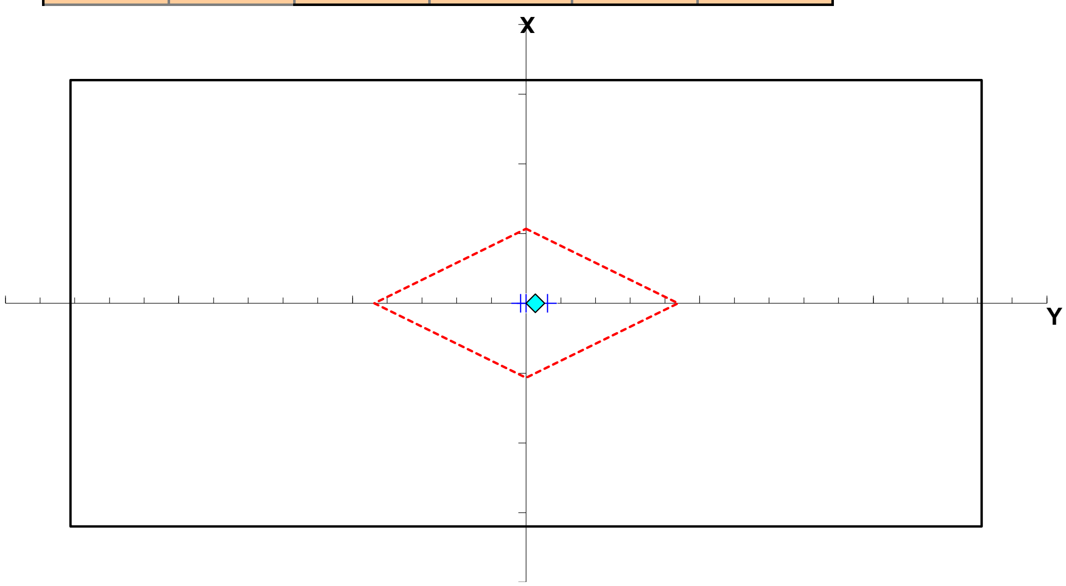


Nomenclature

Loading Data:

Direction of Wind Force: Y-DIRECTION

	Uplift	Vertical Soil	Not Used	Internal Hydrostatic	Not Used	SAP2000 Reaction
Yp (m.) =	0.00	**-0.06**				**0.25**
Xp (m.) =	0.00	**0.00**				0.00
Pz (kN) =	1185.41	**-13120.89**				**-14861.54**
Hy (kN) =	0.00	**0.00**				**10.69**
Hx (kN) =	0.00	**0.00**				**0.00**
My (kN-m) =	0.00	**0.00**				**0.00**
Mx (kN-m) =	0.00	**0.00**				**-44.08**



FOOTING PLAN

Note: Is the "Kern" area of footing (When resultant of loads falls within "Kern", entire footing base is in bearing.)

Results:

Total Resultant Load and Eccentricities:

ΣPy =	-26797.02	kN
ey =	0.11	m (<= L/6)
ex =	0.00	
ΣHy =	10.69	kN
ΣHx =	0.00	kN
H resultant =	10.69	kN
ΣMry =	N.A.	kN-m
ΣMoy =	N.A.	kN-m
ΣMrx =	143992.75	kN-m
ΣMox =	6179.33	kN-m

Sliding Check:

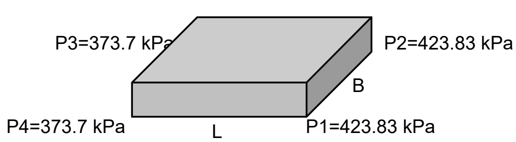
Frict =	13666.48	kN
FS(slid) =	1278.914	

% Base Area in Compression:

Dist. y =	N.A.	m
Dist. x =	N.A.	m
Brg. Ly =	10.500	m
Brg. Lx =	6.400	m
%Brg. Area =	100.00	%
Biaxial Case =	N.A.	

Gross Soil Bearing Corner Pressures:

P_1 =	423.830	kPa
P_2 =	423.830	kPa
P_3 =	373.700	kPa
P_4 =	373.700	kPa



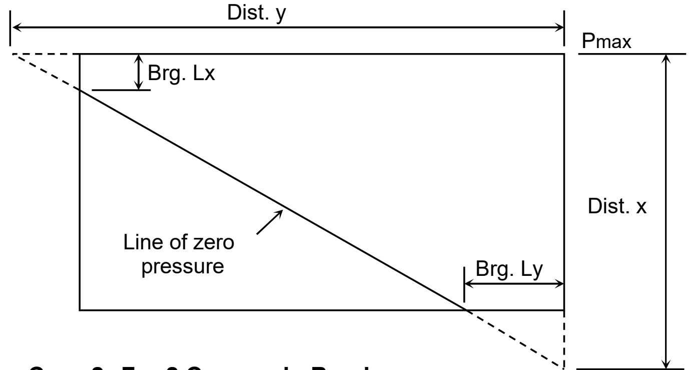
CORNER PRESSURES

Summary of Results:

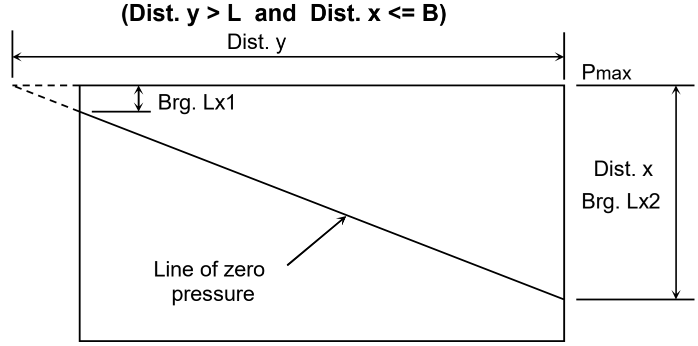
Sliding Check:			
FS(slid) =	1278.91	> 1.5	OK
Bearing Area:			
%Brg. Area =	100.00%	< 100%	OK
Bearing Pressure Check:			
FS(brg) =	3.02	> 2.25	OK
Flotation Check:			
FS (float) =	23.61	> 1.5	OK

Nomenclature for Biaxial Eccentricity:

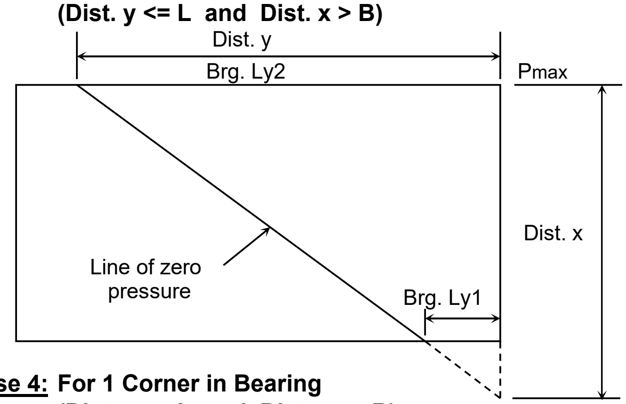
Case 1: For 3 Corners in Bearing
(Dist. y > L and Dist. x > B)



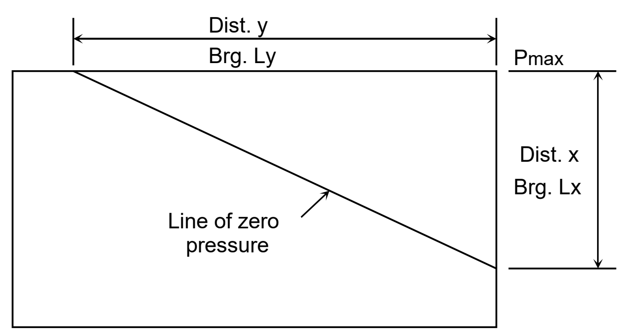
Case 2: For 2 Corners in Bearing
(Dist. y > L and Dist. x <= B)



Case 3: For 2 Corners in Bearing
(Dist. y <= L and Dist. x > B)



Case 4: For 1 Corner in Bearing
(Dist. y <= L and Dist. x <= B)



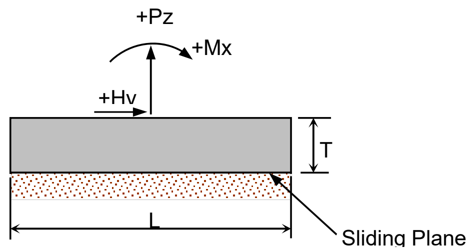
GATE TOWER STABILITY ANALYSIS

Job Name:	Springbank Off-Stream Storage Project	Number:	110773396		
Site:	Gate Tower	Originator:	ACG 7/2/2020	Checker:	CG
Load Case:	U2-1 Empty Reservoir, Summer				

Input Data:

Footing Data:

Footing Length, L =	10.50	m
Footing Width, B =	6.40	m
Footing Thickness, T =	0.00	m
Coef. of Base Friction, μ =	0.510	
Ultimate Bearing, Pall =	1281.00	kPa

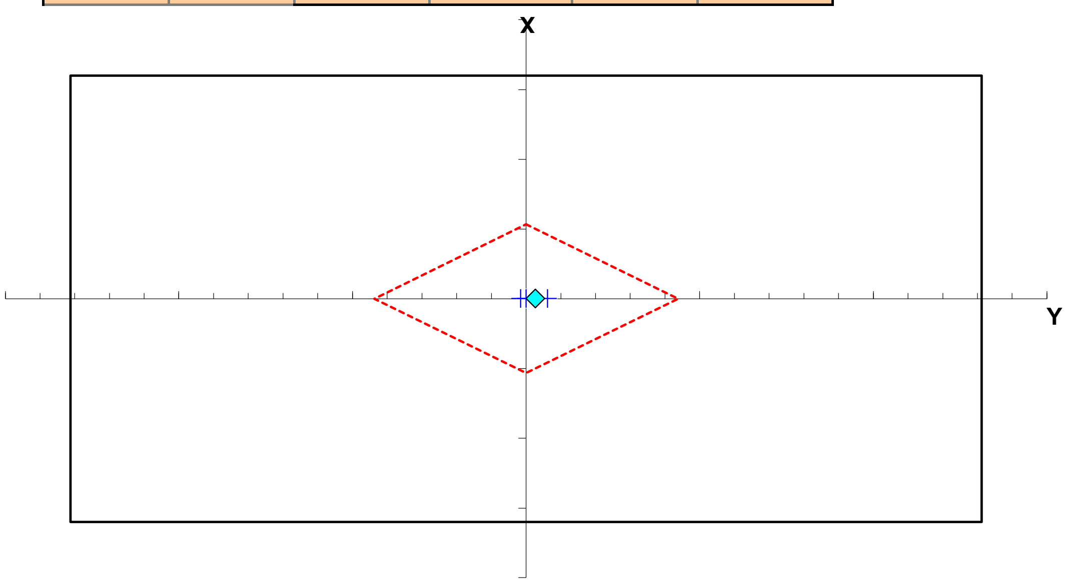


Nomenclature

Loading Data:

Direction of Wind Force: X-DIRECTION

	Uplift	Vertical Soil	Not Used	Internal Hydrostatic	Not Used	SAP2000 Reaction
Yp (m.) =	0.00	-0.06				0.25
Xp (m.) =	0.00	0.00				0.00
Pz (kN) =	1185.41	-13120.89				-14592.49
Hy (kN) =	0.00	0.00				7.29
Hx (kN) =	0.00	0.00				2.14
My (kN-m) =	0.00	0.00				-1.45
Mx (kN-m) =	0.00	0.00				-36.27



FOOTING PLAN

Note: Is the "Kern" area of footing (When resultant of loads falls within "Kern", entire footing base is in bearing.)

Results:

Total Resultant Load and Eccentricities:

ΣPy =	-26527.97	kN
ey =	0.11	m (<= L/6)
ex =	0.00	
ΣHy =	7.29	kN
ΣHx =	2.14	kN
H resultant =	7.59	kN
ΣMry =	N.A.	kN-m
ΣMoy =	N.A.	kN-m
ΣMrx =	142647.50	kN-m
ΣMox =	6187.13	kN-m

Sliding Check:

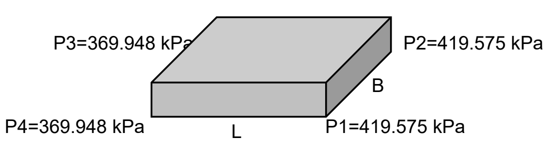
Frict =	13529.26	kN
FS(slid) =	1781.785	

% Base Area in Compression:

Dist. y =	N.A.	m
Dist. x =	N.A.	m
Brg. Ly =	10.500	m
Brg. Lx =	6.400	m
%Brg. Area =	100.00	%
Biaxial Case =	N.A.	

Gross Soil Bearing Corner Pressures:

P_1 =	419.575	kPa
P_2 =	419.575	kPa
P_3 =	369.948	kPa
P_4 =	369.948	kPa



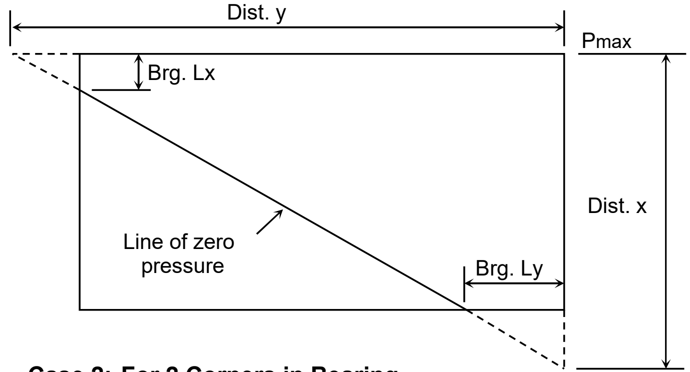
CORNER PRESSURES

Summary of Results:

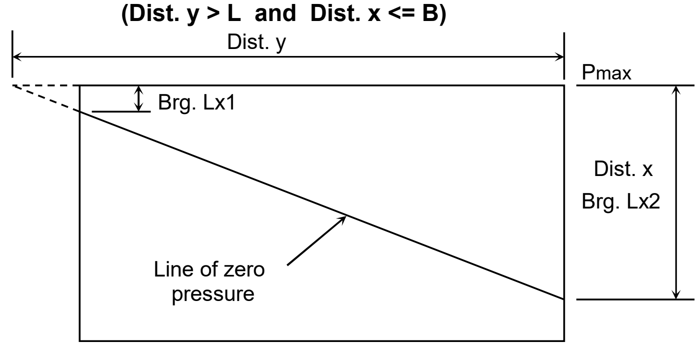
Sliding Check:			
FS(slid) =	1781.79	> 1.5	OK
Bearing Area:			
%Brg. Area =	100.00%	< 100%	OK
Bearing Pressure Check:			
FS(brg) =	3.05	> 2.25	OK
Flotation Check:			
FS (float) =	23.38	> 1.5	OK

Nomenclature for Biaxial Eccentricity:

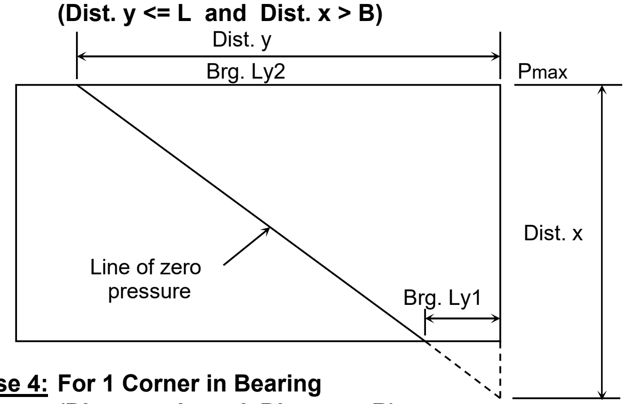
Case 1: For 3 Corners in Bearing
(Dist. y > L and Dist. x > B)



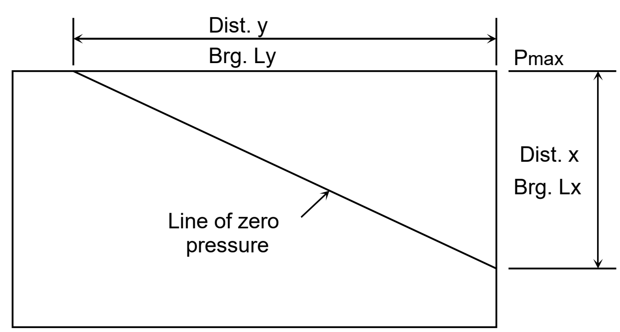
Case 2: For 2 Corners in Bearing
(Dist. y > L and Dist. x <= B)



Case 3: For 2 Corners in Bearing
(Dist. y <= L and Dist. x > B)



Case 4: For 1 Corner in Bearing
(Dist. y <= L and Dist. x <= B)



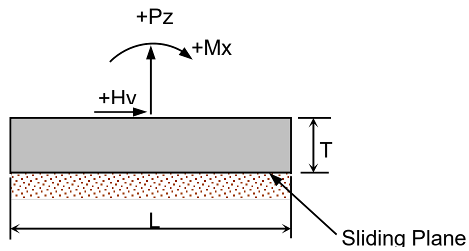
GATE TOWER STABILITY ANALYSIS

Job Name:	Springbank Off-Stream Storage Project	Number:	110773396		
Site:	Gate Tower	Originator:	ACG 7/2/2020	Checker:	CG
Load Case:	U2-2+ Empty Reservoir, Summer				

Input Data:

Footing Data:

Footing Length, L =	10.50	m
Footing Width, B =	6.40	m
Footing Thickness, T =	0.00	m
Coef. of Base Friction, μ =	0.510	
Ultimate Bearing, Pall =	1281.00	kPa

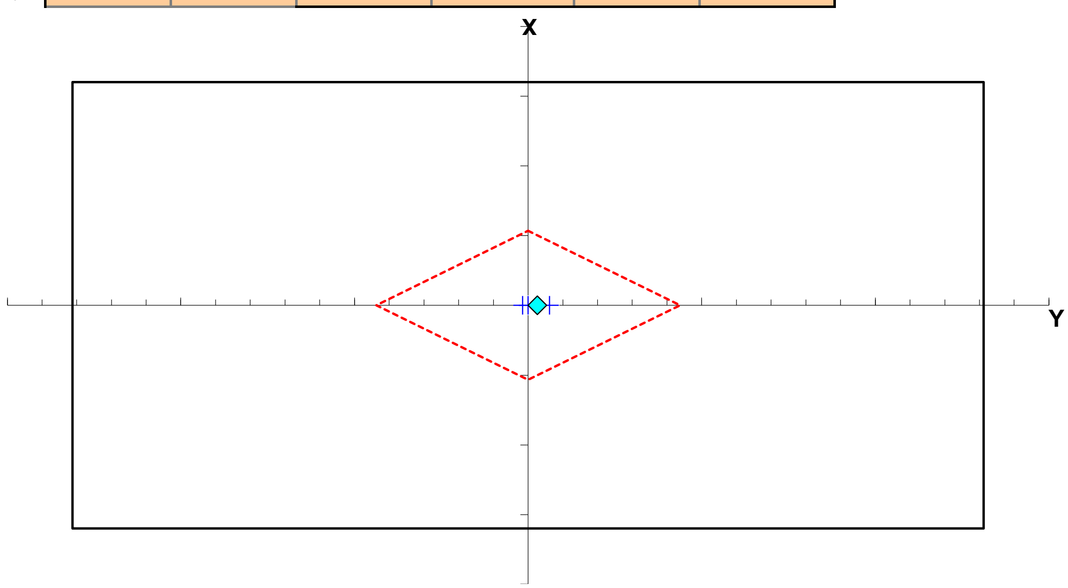


Nomenclature

Loading Data:

Direction of Wind Force: Y-DIRECTION

	Uplift	Vertical Soil	Not Used	Internal Hydrostatic	Not Used	SAP2000 Reaction
Yp (m.) =	0.00	-0.06				0.25
Xp (m.) =	0.00	0.00				0.00
Pz (kN) =	1185.41	-13120.89				-14720.24
Hy (kN) =	0.00	0.00				6.04
Hx (kN) =	0.00	0.00				0.00
My (kN-m) =	0.00	0.00				0.00
Mx (kN-m) =	0.00	0.00				-33.30



FOOTING PLAN

Note: Is the "Kern" area of footing (When resultant of loads falls within "Kern", entire footing base is in bearing.)

Results:

Total Resultant Load and Eccentricities:

ΣPy =	-26655.72	kN
ey =	0.11	m (<= L/6)
ex =	0.00	
ΣHy =	6.04	kN
ΣHx =	0.00	kN
H resultant =	6.04	kN
ΣMry =	N.A.	kN-m
ΣMoy =	N.A.	kN-m
ΣMrx =	143286.22	kN-m
ΣMox =	6190.10	kN-m

Sliding Check:

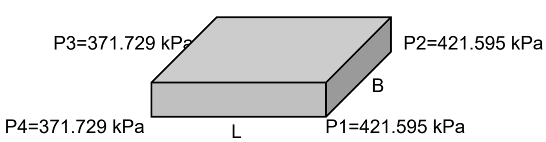
Frict =	13594.41	kN
FS(slid) =	2249.986	

% Base Area in Compression:

Dist. y =	N.A.	m
Dist. x =	N.A.	m
Brg. Ly =	10.500	m
Brg. Lx =	6.400	m
%Brg. Area =	100.00	%
Biaxial Case =	N.A.	

Gross Soil Bearing Corner Pressures:

P_1 =	421.595	kPa
P_2 =	421.595	kPa
P_3 =	371.729	kPa
P_4 =	371.729	kPa



CORNER PRESSURES

Summary of Results:

Sliding Check:

FS(slid) =	2249.99	> 1.5	OK

Bearing Area:

%Brg. Area =	100.00%	< 100%	OK

Bearing Pressure Check:

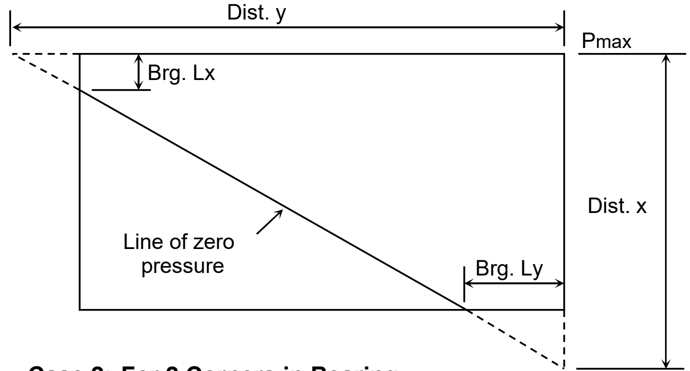
FS(brg) =	3.04	> 2.25	OK

Flotation Check:

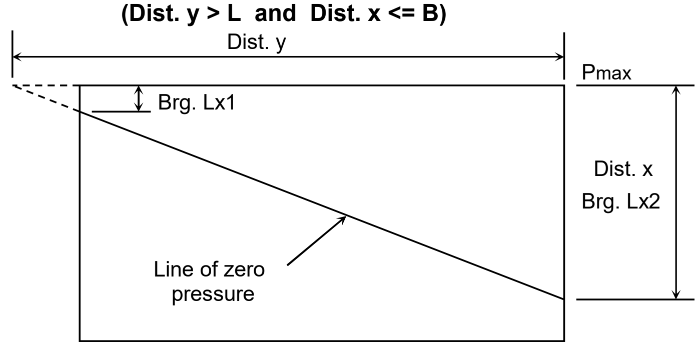
FS (float) =	23.49	> 1.5	OK

Nomenclature for Biaxial Eccentricity:

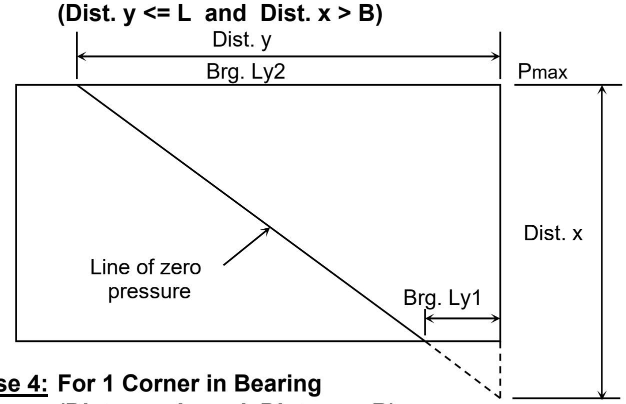
Case 1: For 3 Corners in Bearing
(Dist. y > L and Dist. x > B)



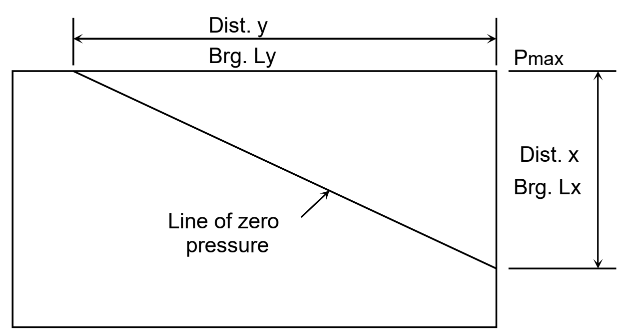
Case 2: For 2 Corners in Bearing
(Dist. y > L and Dist. x <= B)



Case 3: For 2 Corners in Bearing
(Dist. y <= L and Dist. x > B)



Case 4: For 1 Corner in Bearing
(Dist. y <= L and Dist. x <= B)



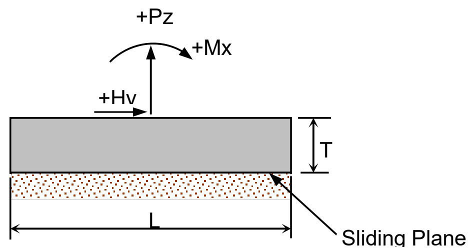
GATE TOWER STABILITY ANALYSIS

Job Name:	Springbank Off-Stream Storage Project	Number:	110773396			
Site:	Gate Tower	Originator:	ACG	7/2/2020	Checker:	CG
Load Case:	U2-2- Empty Reservoir, Summer					

Input Data:

Footing Data:

Footing Length, L =	10.50	m
Footing Width, B =	6.40	m
Footing Thickness, T =	0.00	m
Coef. of Base Friction, μ =	0.510	
Ultimate Bearing, Pall =	1281.00	kPa

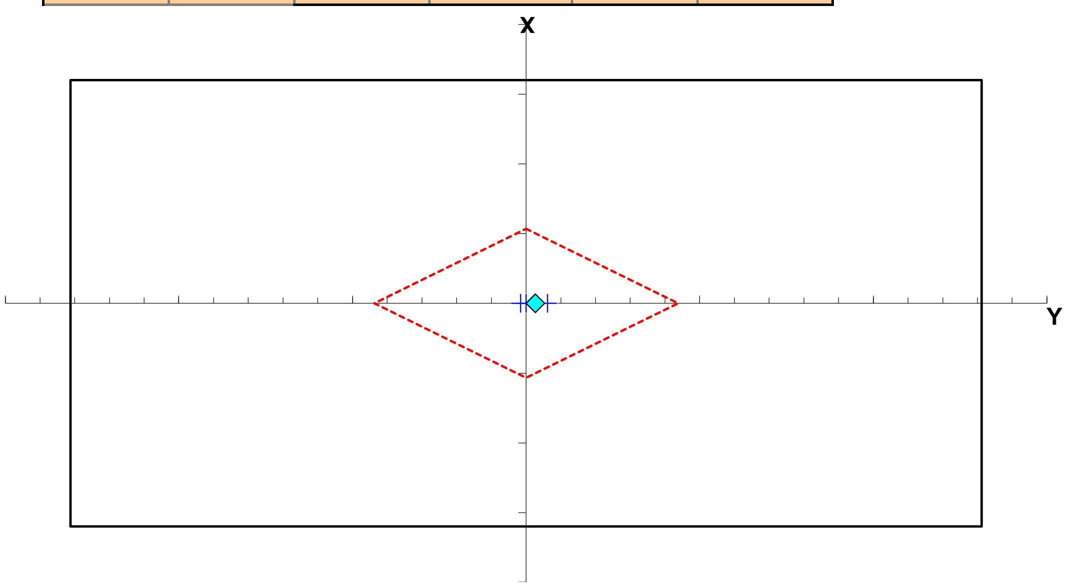


Nomenclature

Loading Data:

Direction of Wind Force: Y-DIRECTION

	Uplift	Vertical Soil	Not Used	Internal Hydrostatic	Not Used	SAP2000 Reaction
Yp (m.) =	0.00	**-0.06**				**0.25**
Xp (m.) =	0.00	**0.00**				0.00
Pz (kN) =	1185.41	**-13120.89**				**-14820.46**
Hy (kN) =	0.00	**0.00**				**10.67**
Hx (kN) =	0.00	**0.00**				**0.00**
My (kN-m) =	0.00	**0.00**				**0.00**
Mx (kN-m) =	0.00	**0.00**				**-43.96**



FOOTING PLAN

Note: Is the "Kern" area of footing (When resultant of loads falls within "Kern", entire footing base is in bearing.)

Results:

Total Resultant Load and Eccentricities:

ΣPy =	-26755.94	kN
ey =	0.11	m (<= L/6)
ex =	0.00	
ΣHy =	10.67	kN
ΣHx =	0.00	kN
H resultant =	10.67	kN
ΣMry =	N.A.	kN-m
ΣMoy =	N.A.	kN-m
ΣMrx =	143787.35	kN-m
ΣMox =	6179.44	kN-m

Sliding Check:

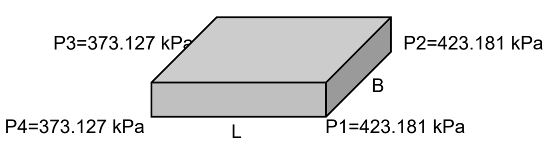
Frict =	13645.53	kN
FS(slid) =	1279.108	

% Base Area in Compression:

Dist. y =	N.A.	m
Dist. x =	N.A.	m
Brg. Ly =	10.500	m
Brg. Lx =	6.400	m
%Brg. Area =	100.00	%
Biaxial Case =	N.A.	

Gross Soil Bearing Corner Pressures:

P_1 =	423.181	kPa
P_2 =	423.181	kPa
P_3 =	373.127	kPa
P_4 =	373.127	kPa



CORNER PRESSURES

Summary of Results:

Sliding Check:

FS(slid) =	1279.11	> 1.5	OK

Bearing Area:

%Brg. Area =	100.00%	< 100%	OK

Bearing Pressure Check:

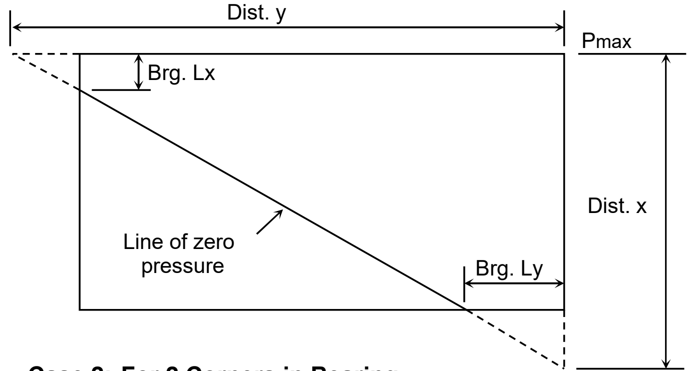
FS(brg) =	3.03	> 2.25	OK

Flotation Check:

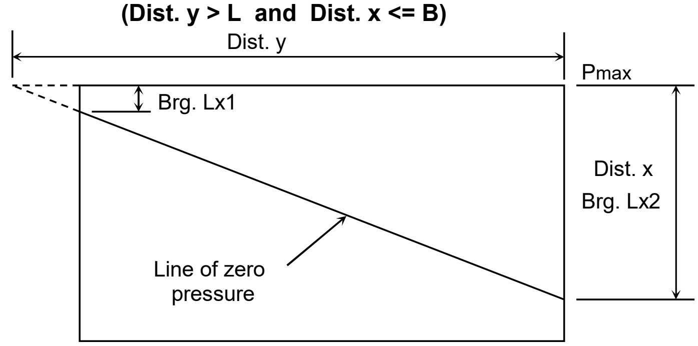
FS (float) =	23.57	> 1.5	OK

Nomenclature for Biaxial Eccentricity:

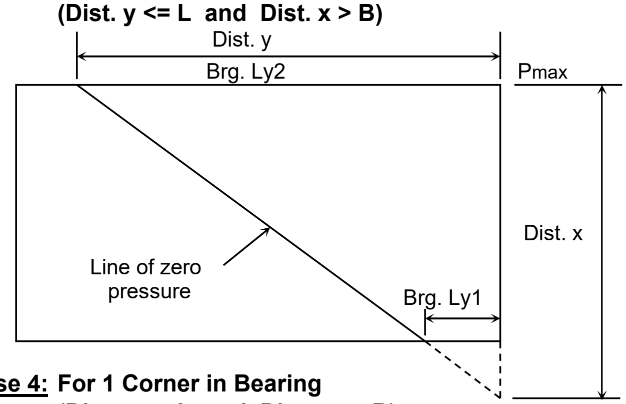
Case 1: For 3 Corners in Bearing
(Dist. y > L and Dist. x > B)



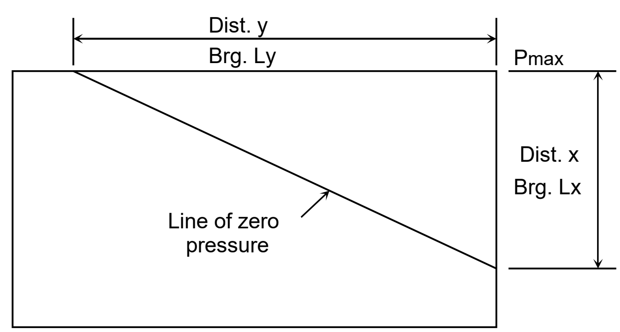
Case 2: For 2 Corners in Bearing
(Dist. y > L and Dist. x <= B)



Case 3: For 2 Corners in Bearing
(Dist. y <= L and Dist. x > B)



Case 4: For 1 Corner in Bearing
(Dist. y <= L and Dist. x <= B)



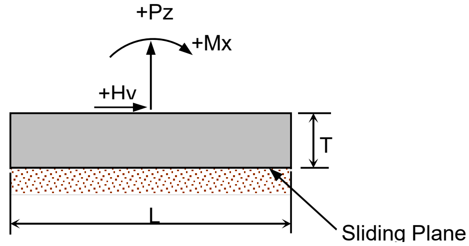
GATE TOWER STABILITY ANALYSIS

Job Name:	Springbank Off-Stream Storage Project	Number:	110773396			
Site:	Gate Tower	Originator:	ACG	7/2/2020	Checker:	CG
Load Case:	U2-3 Empty Reservoir, Summer					

Input Data:

Footing Data:

Footing Length, L =	10.50	m
Footing Width, B =	6.40	m
Footing Thickness, T =	0.00	m
Coef. of Base Friction, μ =	0.510	
Ultimate Bearing, Pall =	1281.00	kPa

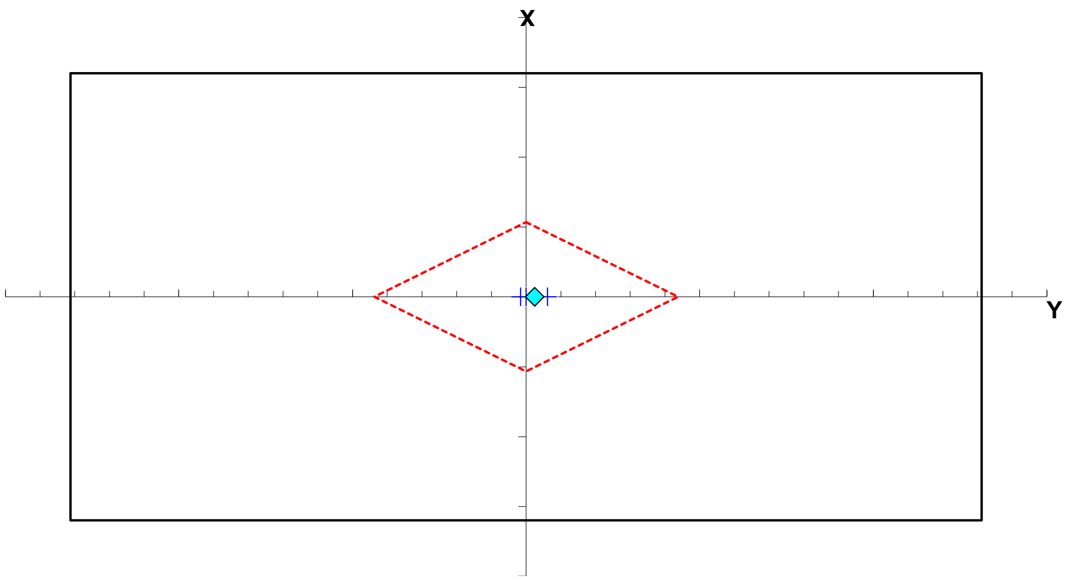


Nomenclature

Loading Data:

Direction of Wind Force: X-DIRECTION

	Uplift	Vertical Soil	Not Used	Internal Hydrostatic	Not Used	SAP2000 Reaction
Yp (m.) =	0.00	**-0.06**				**0.25**
Xp (m.) =	0.00	**0.00**				0.00
Pz (kN) =	1185.41	**-13120.89**				**-14032.24**
Hy (kN) =	0.00	**0.00**				**6.24**
Hx (kN) =	0.00	**0.00**				**2.14**
My (kN-m) =	0.00	**0.00**				**-1.45**
Mx (kN-m) =	0.00	**0.00**				**-33.70**



FOOTING PLAN

Note: Is the "Kern" area of footing (When resultant of loads falls within "Kern", entire footing base is in bearing.)

Results:

Total Resultant Load and Eccentricities:

ΣPy =	-25967.72	kN
ey =	0.10	m (<= L/6)
ex =	0.00	
ΣHy =	6.24	kN
ΣHx =	2.14	kN
H resultant =	6.59	kN
ΣMry =	N.A.	kN-m
ΣMoy =	N.A.	kN-m
ΣMrx =	139846.26	kN-m
ΣMox =	6189.71	kN-m

Sliding Check:

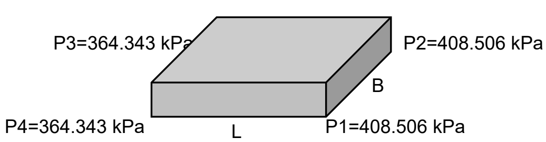
Frict =	13243.54	kN
FS(slid) =	2008.348	

% Base Area in Compression:

Dist. y =	N.A.	m
Dist. x =	N.A.	m
Brg. Ly =	10.500	m
Brg. Lx =	6.400	m
%Brg. Area =	100.00	%
Biaxial Case =	N.A.	

Gross Soil Bearing Corner Pressures:

P_1 =	408.506	kPa
P_2 =	408.506	kPa
P_3 =	364.343	kPa
P_4 =	364.343	kPa



CORNER PRESSURES

Summary of Results:

Sliding Check:

FS(slid) =	2008.35	> 1.5	OK

Bearing Area:

%Brg. Area =	100.00%	< 100%	OK

Bearing Pressure Check:

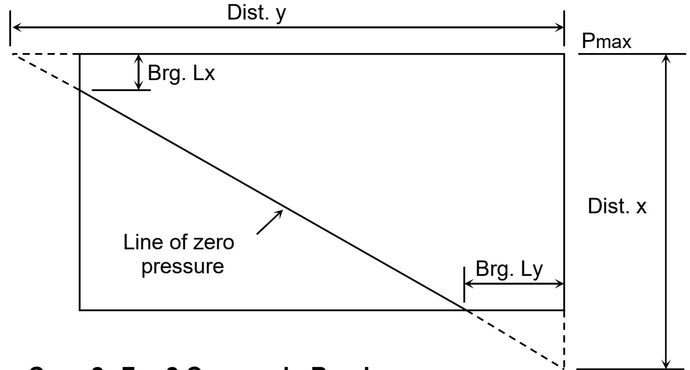
FS(brg) =	3.14	> 2.25	OK

Flotation Check:

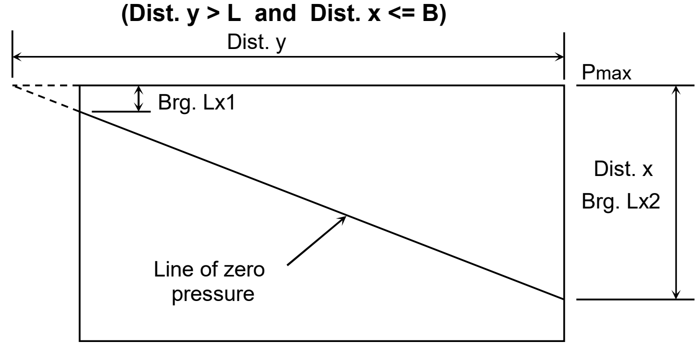
FS (float) =	22.91	> 1.5	OK

Nomenclature for Biaxial Eccentricity:

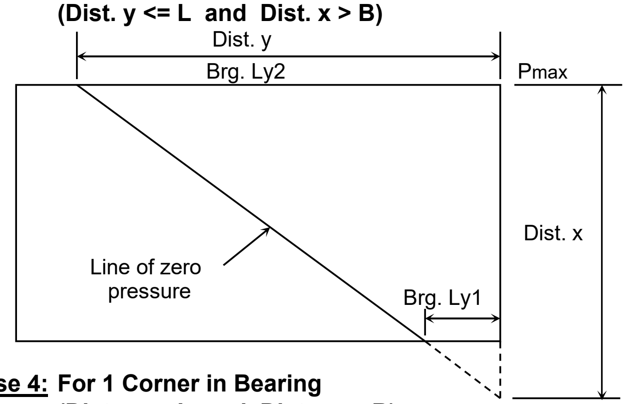
Case 1: For 3 Corners in Bearing
(Dist. y > L and Dist. x > B)



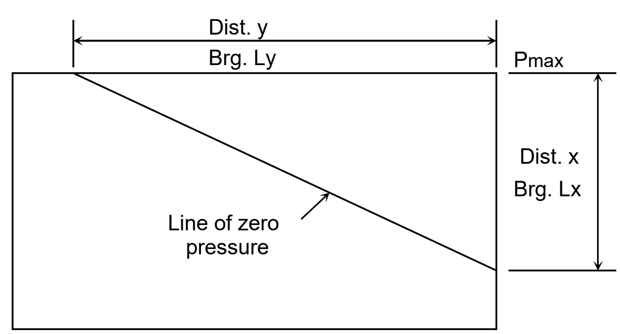
Case 2: For 2 Corners in Bearing
(Dist. y > L and Dist. x <= B)



Case 3: For 2 Corners in Bearing
(Dist. y <= L and Dist. x > B)



Case 4: For 1 Corner in Bearing
(Dist. y <= L and Dist. x <= B)



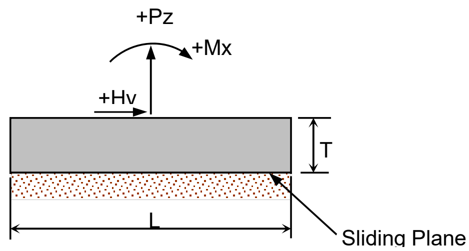
GATE TOWER STABILITY ANALYSIS

Job Name:	Springbank Off-Stream Storage Project	Number:	110773396		
Site:	Gate Tower	Originator:	ACG 7/2/2020	Checker:	CG
Load Case:	U2-4+ Empty Reservoir, Summer				

Input Data:

Footing Data:

Footing Length, L =	10.50	m
Footing Width, B =	6.40	m
Footing Thickness, T =	0.00	m
Coef. of Base Friction, µ =	0.510	
Ultimate Bearing, Pall =	1281.00	kPa

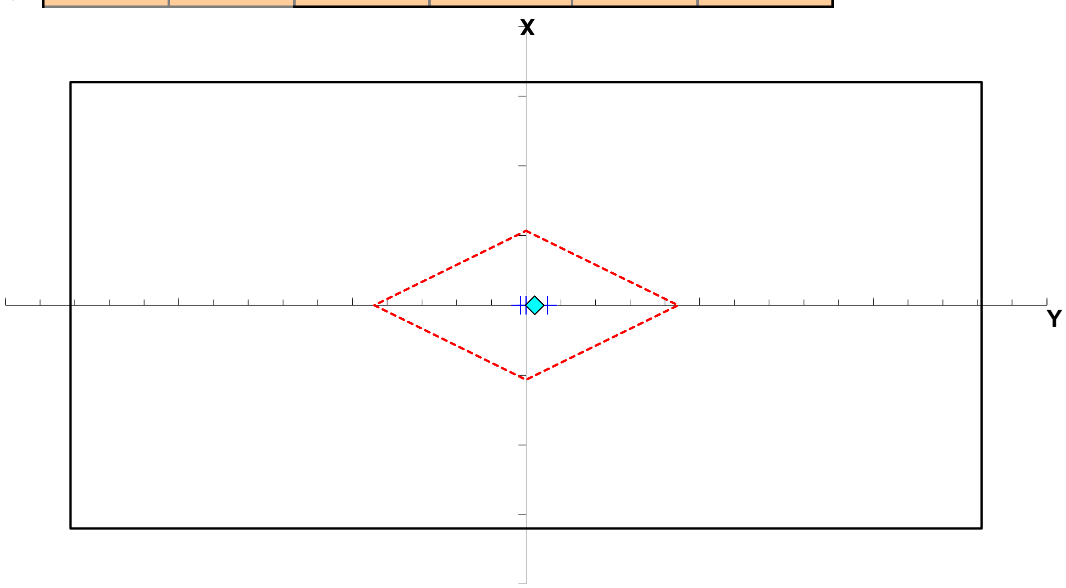


Nomenclature

Loading Data:

Direction of Wind Force: Y-DIRECTION

	Uplift	Vertical Soil	Not Used	Internal Hydrostatic	Not Used	SAP2000 Reaction
Yp (m.) =	0.00	-0.06				0.25
Xp (m.) =	0.00	0.00				0.00
Pz (kN) =	1185.41	-13120.89				-14159.99
Hy (kN) =	0.00	0.00				4.99
Hx (kN) =	0.00	0.00				0.00
My (kN-m) =	0.00	0.00				0.00
Mx (kN-m) =	0.00	0.00				-30.72



FOOTING PLAN

Note: Is the "Kern" area of footing (When resultant of loads falls within "Kern", entire footing base is in bearing.)

Results:

Total Resultant Load and Eccentricities:

ΣPy =	-26095.47	kN
ey =	0.10	m (<= L/6)
ex =	0.00	
ΣHy =	4.99	kN
ΣHx =	0.00	kN
H resultant =	4.99	kN
ΣMry =	N.A.	kN-m
ΣMoy =	N.A.	kN-m
ΣMrx =	140484.98	kN-m
ΣMox =	6192.68	kN-m

Sliding Check:

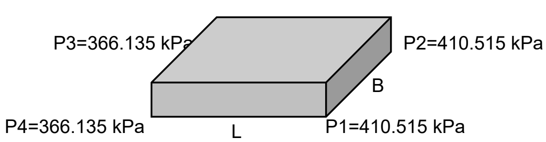
Frict =	13308.69	kN
FS(slid) =	2664.936	

% Base Area in Compression:

Dist. y =	N.A.	m
Dist. x =	N.A.	m
Brg. Ly =	10.500	m
Brg. Lx =	6.400	m
%Brg. Area =	100.00	%
Biaxial Case =	N.A.	

Gross Soil Bearing Corner Pressures:

P_1 =	410.515	kPa
P_2 =	410.515	kPa
P_3 =	366.135	kPa
P_4 =	366.135	kPa



CORNER PRESSURES

Summary of Results:

Sliding Check:

FS(slid) =	**2664.94**	> 1.5	OK

Bearing Area:

%Brg. Area =	**100.00%**	< 100%	OK

Bearing Pressure Check:

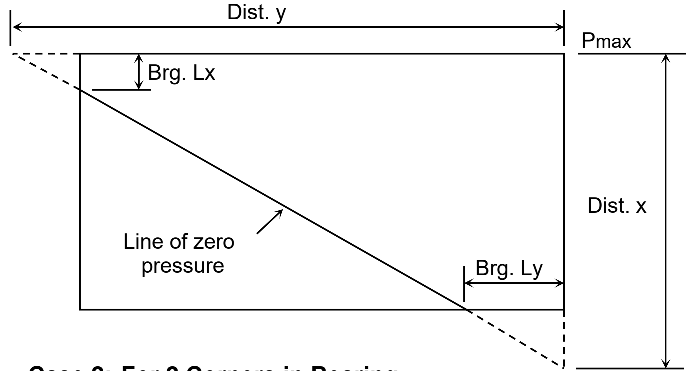
FS(brg) =	**3.12**	> 2.25	OK

Flotation Check:

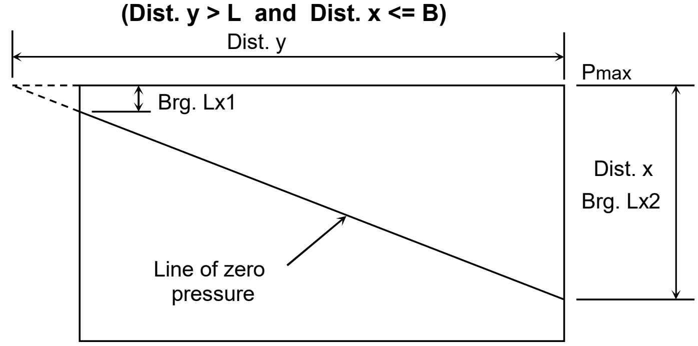
FS (float) =	**23.01**	> 1.5	OK

Nomenclature for Biaxial Eccentricity:

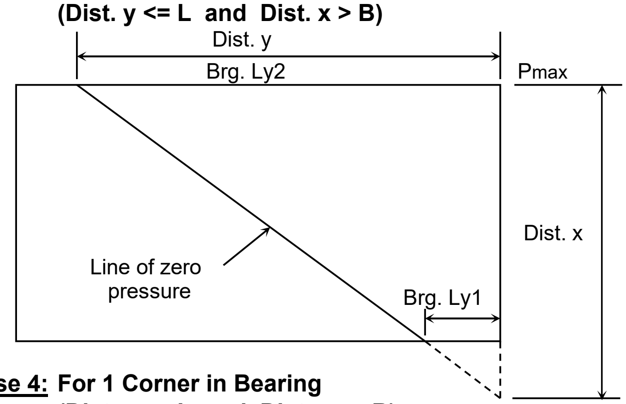
Case 1: For 3 Corners in Bearing
(Dist. y > L and Dist. x > B)



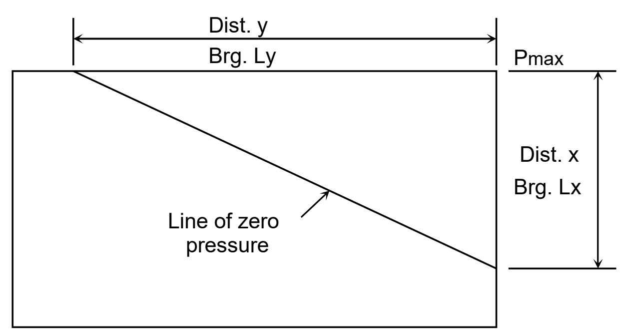
Case 2: For 2 Corners in Bearing
(Dist. y > L and Dist. x <= B)



Case 3: For 2 Corners in Bearing
(Dist. y <= L and Dist. x > B)



Case 4: For 1 Corner in Bearing
(Dist. y <= L and Dist. x <= B)



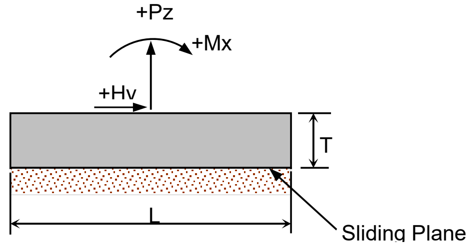
GATE TOWER STABILITY ANALYSIS

Job Name:	Springbank Off-Stream Storage Project	Number:	110773396
Site:	Gate Tower	Originator:	ACG 7/2/2020 Checker: CG
Load Case:	U2-4- Empty Reservoir, Summer		

Input Data:

Footing Data:

Footing Length, L =	10.50	m
Footing Width, B =	6.40	m
Footing Thickness, T =	0.00	m
Coef. of Base Friction, μ =	0.510	
Ultimate Bearing, Pall =	1281.00	kPa

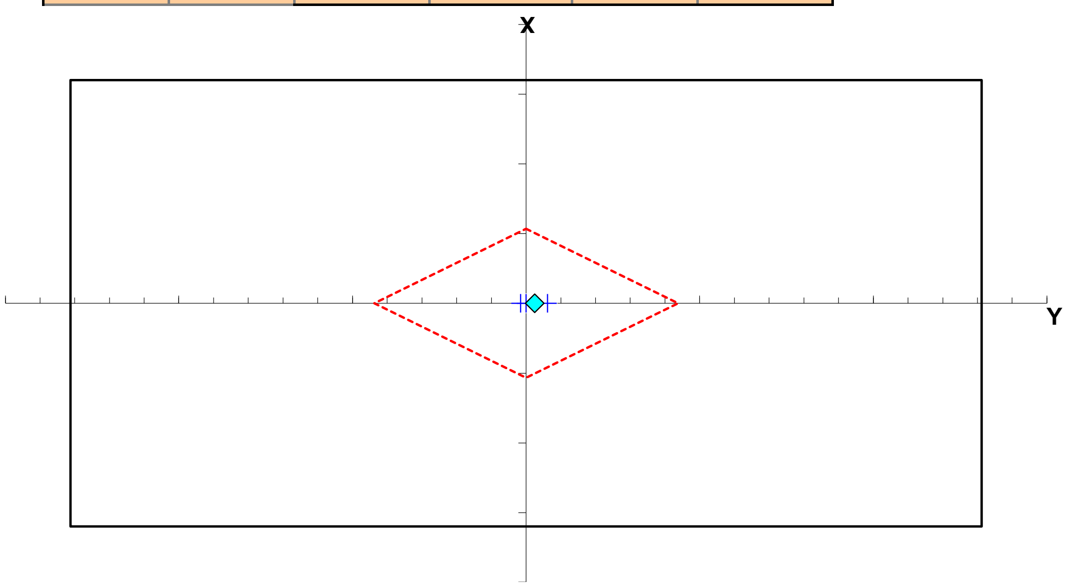


Nomenclature

Loading Data:

Direction of Wind Force: Y-DIRECTION

	Uplift	Vertical Soil	Not Used	Internal Hydrostatic	Not Used	SAP2000 Reaction
Yp (m.) =	0.00	-0.06				0.25
Xp (m.) =	0.00	0.00				0.00
Pz (kN) =	1185.41	-13120.89				-14260.21
Hy (kN) =	0.00	0.00				9.62
Hx (kN) =	0.00	0.00				0.00
My (kN-m) =	0.00	0.00				0.00
Mx (kN-m) =	0.00	0.00				-41.39



FOOTING PLAN

Note: Is the "Kern" area of footing (When resultant of loads falls within "Kern", entire footing base is in bearing.)

Results:

Total Resultant Load and Eccentricities:

ΣPy =	-26195.69	kN
ey =	0.10	m (<= L/6)
ex =	0.00	
ΣHy =	9.62	kN
ΣHx =	0.00	kN
H resultant =	9.62	kN
ΣMry =	N.A.	kN-m
ΣMoy =	N.A.	kN-m
ΣMrx =	140986.11	kN-m
ΣMox =	6182.02	kN-m

Sliding Check:

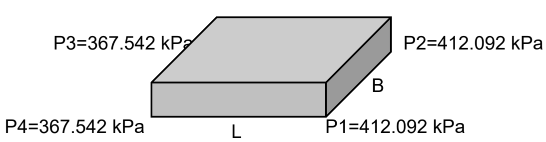
Frict =	13359.80	kN
FS(slid) =	1388.897	

% Base Area in Compression:

Dist. y =	N.A.	m
Dist. x =	N.A.	m
Brg. Ly =	10.500	m
Brg. Lx =	6.400	m
%Brg. Area =	100.00	%
Biaxial Case =	N.A.	

Gross Soil Bearing Corner Pressures:

P_1 =	412.092	kPa
P_2 =	412.092	kPa
P_3 =	367.542	kPa
P_4 =	367.542	kPa



CORNER PRESSURES

Summary of Results:

Sliding Check:

FS(slid) =	1388.90	> 1.5	OK

Bearing Area:

%Brg. Area =	100.00%	< 100%	OK

Bearing Pressure Check:

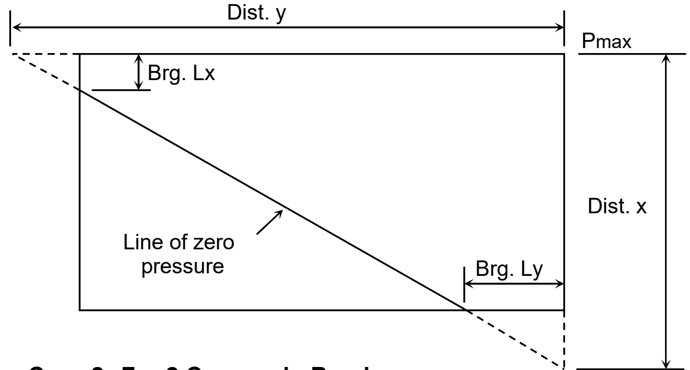
FS(brg) =	3.11	> 2.25	OK

Flotation Check:

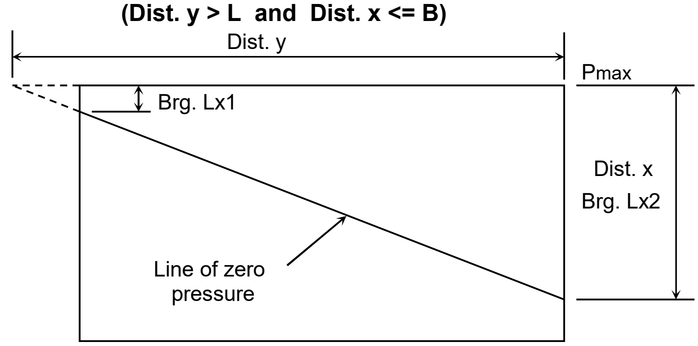
FS (float) =	23.10	> 1.5	OK

Nomenclature for Biaxial Eccentricity:

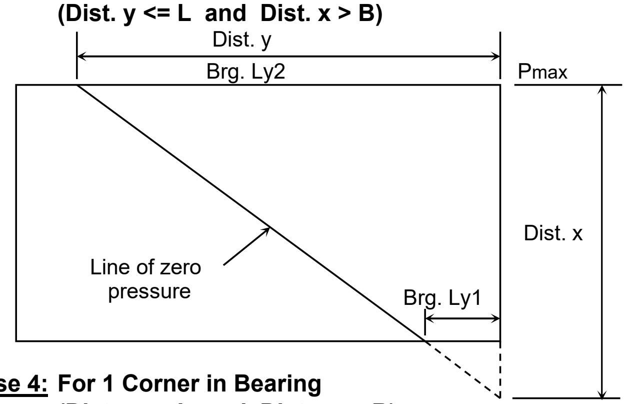
Case 1: For 3 Corners in Bearing
(Dist. y > L and Dist. x > B)



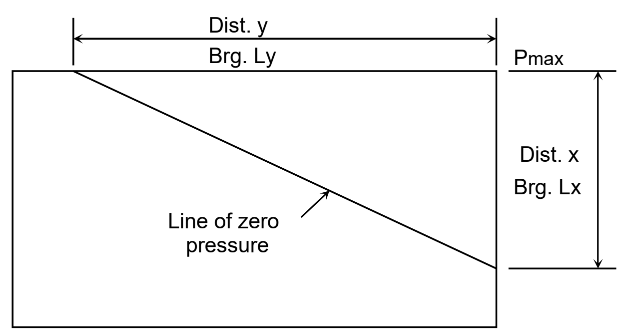
Case 2: For 2 Corners in Bearing
(Dist. y > L and Dist. x <= B)



Case 3: For 2 Corners in Bearing
(Dist. y <= L and Dist. x > B)



Case 4: For 1 Corner in Bearing
(Dist. y <= L and Dist. x <= B)



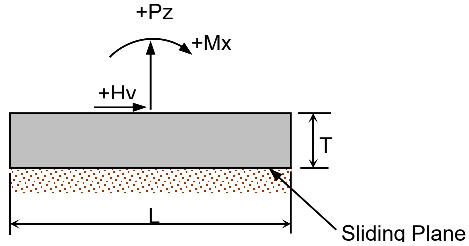
GATE TOWER STABILITY ANALYSIS

Job Name:	Springbank Off-Stream Storage Project	Number:	110773396			
Site:	Gate Tower	Originator:	ACG	7/2/2020	Checker:	CG
Load Case:	UN1-1 10-Year Flood, Gates Open					

Input Data:

Footing Data:

Footing Length, L =	10.50	m
Footing Width, B =	6.40	m
Footing Thickness, T =	0.00	m
Coef. of Base Friction, μ =	0.510	
Ultimate Bearing, Pall =	1281.00	kPa

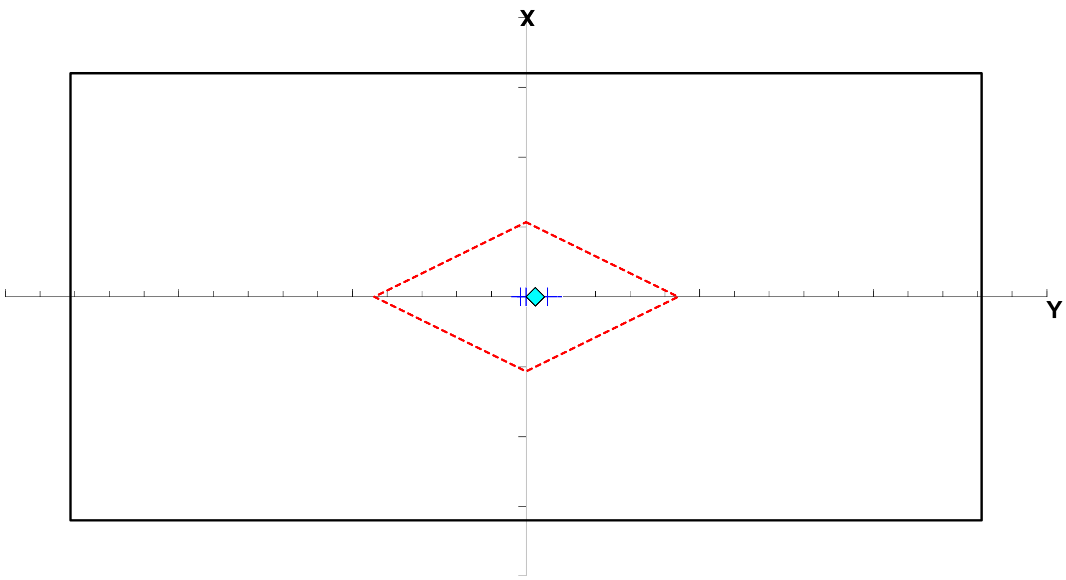


Nomenclature

Loading Data:

Direction of Wind Force: N/A

	Uplift	Vertical Soil	Not Used	Internal Hydrostatic	Not Used	SAP2000 Reaction
Yp (m.) =	0.00	**-0.06**		0.31		**0.25**
Xp (m.) =	0.00	**0.00**		0.00		0.00
Pz (kN) =	**4524.31**	**-13120.89**		-450.33		**-14210.10**
Hy (kN) =	0.00	**0.00**		0.00		**83.78**
Hx (kN) =	0.00	**0.00**		0.00		**0.00**
My (kN-m) =	0.00	**0.00**		0.00		**0.00**
Mx (kN-m) =	0.00	**0.00**		0.00		**-251.47**



FOOTING PLAN

Note: Is the "Kern" area of footing (When resultant of loads falls within "Kern", entire footing base is in bearing.)

Results:

Total Resultant Load and Eccentricities:

ΣPy =	-23257.01	kN
ey =	0.11	m (<= L/6)
ex =	0.00	
ΣHy =	83.78	kN
ΣHx =	0.00	kN
H resultant =	83.78	kN
ΣMry =	N.A.	kN-m
ΣMoy =	N.A.	kN-m
ΣMrx =	142959.27	kN-m
ΣMox =	23501.15	kN-m

Sliding Check:

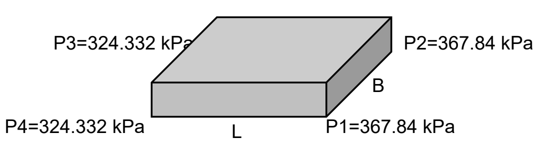
Frict =	11861.07	kN
FS(slid) =	141.569	

% Base Area in Compression:

Dist. y =	N.A.	m
Dist. x =	N.A.	m
Brg. Ly =	10.500	m
Brg. Lx =	6.400	m
%Brg. Area =	100.00	%
Biaxial Case =	N.A.	

Gross Soil Bearing Corner Pressures:

P1 =	367.840	kPa
P2 =	367.840	kPa
P3 =	324.332	kPa
P4 =	324.332	kPa



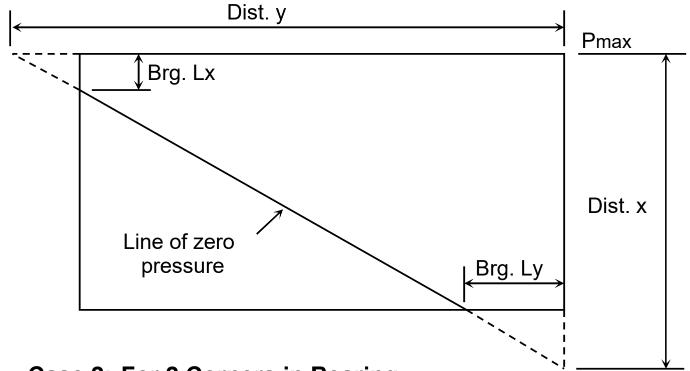
CORNER PRESSURES

Summary of Results:

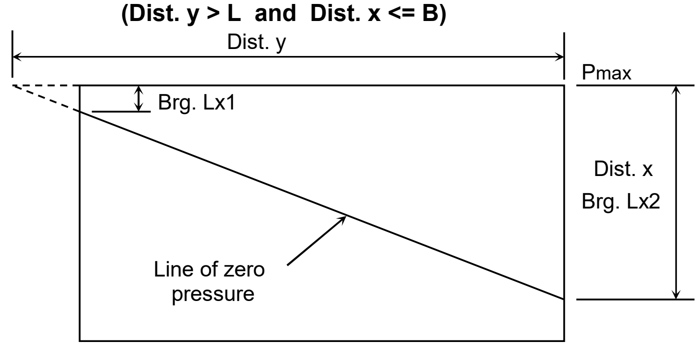
Sliding Check:			
FS(slid) =	141.57	> 1.3	OK
Bearing Area:			
%Brg. Area =	100.00%	< 100%	OK
Bearing Pressure Check:			
FS(brg) =	3.48	> 3.0	OK
Flotation Check:			
FS (float) =	6.14	> 1.3	OK

Nomenclature for Biaxial Eccentricity:

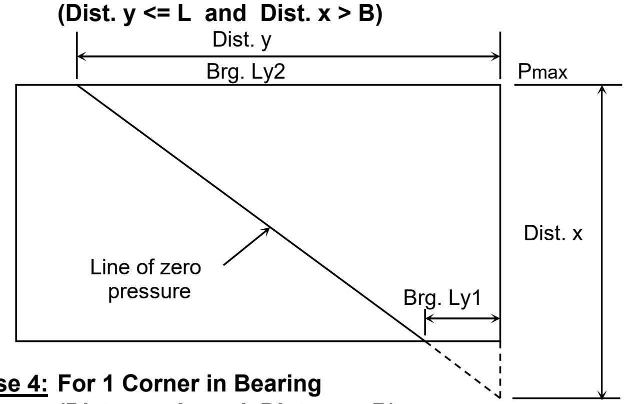
Case 1: For 3 Corners in Bearing
(Dist. y > L and Dist. x > B)



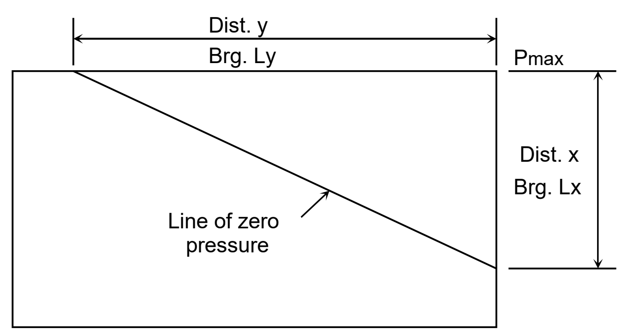
Case 2: For 2 Corners in Bearing
(Dist. y > L and Dist. x <= B)



Case 3: For 2 Corners in Bearing
(Dist. y <= L and Dist. x > B)



Case 4: For 1 Corner in Bearing
(Dist. y <= L and Dist. x <= B)



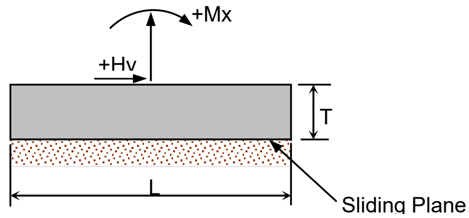
GATE TOWER STABILITY ANALYSIS

Job Name:	Springbank Off-Stream Storage Project	Number:	110773396			
Site:	Gate Tower	Originator:	ACG	7/2/2020	Checker:	CG
Load Case:	UN1-2 10-Year Flood, Gates Open					

Input Data:

Footing Data:

Footing Length, L =	10.50	m
Footing Width, B =	6.40	m
Footing Thickness, T =	0.00	m
Coef. of Base Friction, μ =	0.510	
Ultimate Bearing, Pall =	1281.00	kPa

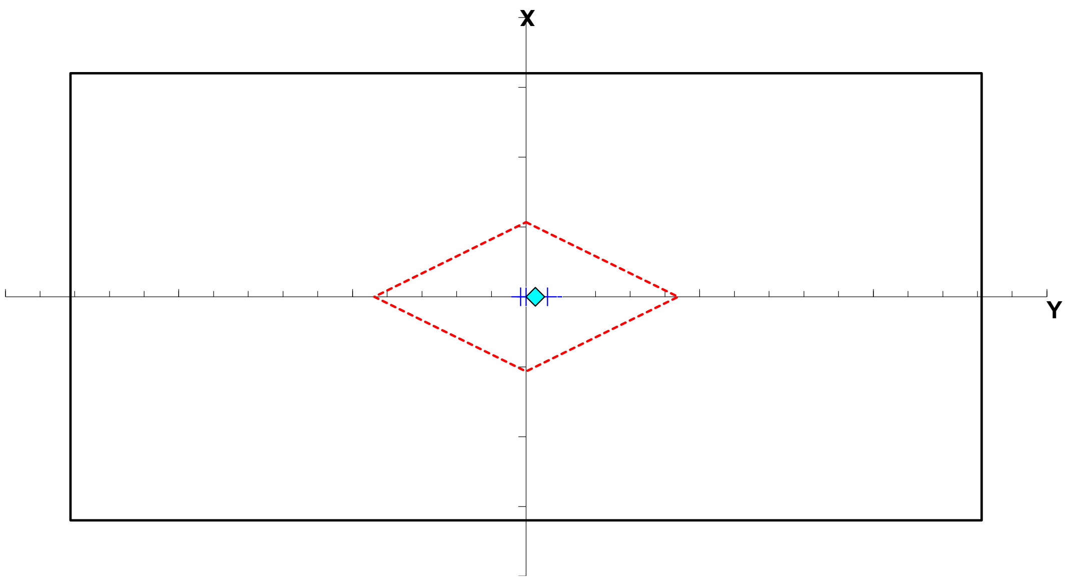


Nomenclature

Loading Data:

Direction of Wind Force: N/A

	Uplift	Vertical Soil	Not Used	Internal Hydrostatic	Not Used	SAP2000 Reaction
Yp (m.) =	0.00	**-0.06**		0.31		**0.25**
Xp (m.) =	0.00	**0.00**		0.00		0.00
Pz (kN) =	4524.31	**-13120.89**		-450.33		**-14770.30**
Hy (kN) =	0.00	**0.00**		0.00		**138.53**
Hx (kN) =	0.00	**0.00**		0.00		**0.00**
My (kN-m) =	0.00	**0.00**		0.00		**0.00**
Mx (kN-m) =	0.00	**0.00**		0.00		**-410.74**



FOOTING PLAN

Note: Is the "Kern" area of footing (When resultant of loads falls within "Kern", entire footing base is in bearing.)

Results:

Total Resultant Load and Eccentricities:

ΣPy =	-23817.21	kN
ey =	0.11	m (<= L/6)
ex =	0.00	
ΣHy =	138.53	kN
ΣHx =	0.00	kN
H resultant =	138.53	kN
ΣMry =	N.A.	kN-m
ΣMoy =	N.A.	kN-m
ΣMrx =	145760.27	kN-m
ΣMox =	23341.88	kN-m

Sliding Check:

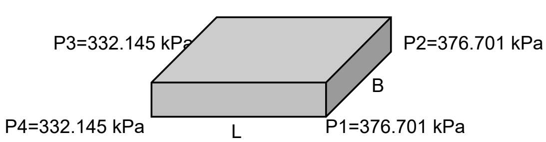
Frict =	12146.78	kN
FS(slid) =	87.682	

% Base Area in Compression:

Dist. y =	N.A.	m
Dist. x =	N.A.	m
Brg. Ly =	10.500	m
Brg. Lx =	6.400	m
%Brg. Area =	100.00	%
Biaxial Case =	N.A.	

Gross Soil Bearing Corner Pressures:

P_1 =	376.701	kPa
P_2 =	376.701	kPa
P_3 =	332.145	kPa
P_4 =	332.145	kPa



CORNER PRESSURES

Summary of Results:

Sliding Check:

FS(slid) = **87.68** > 1.3 OK

Bearing Area:

%Brg. Area = **100.00%** < 100% OK

Bearing Pressure Check:

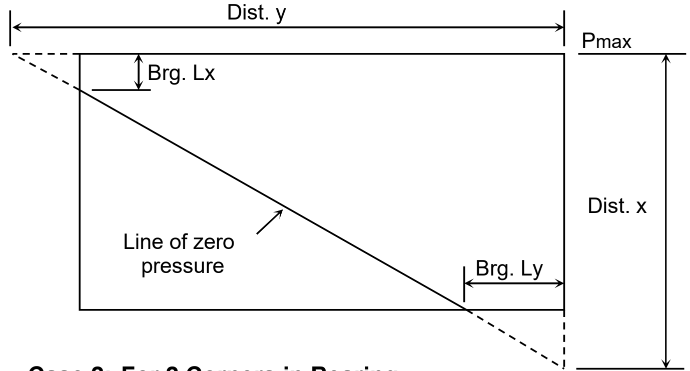
FS(brg) = **3.40** > 2.25 OK

Flotation Check:

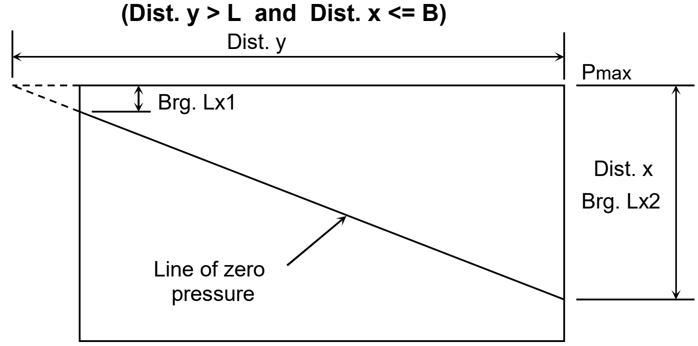
FS (float) = **6.26** > 1.3 OK

Nomenclature for Biaxial Eccentricity:

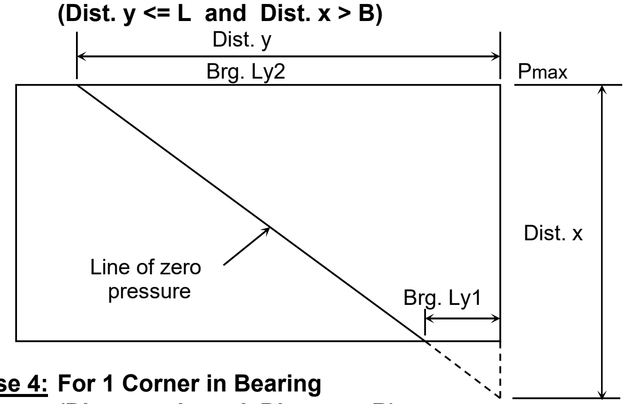
Case 1: For 3 Corners in Bearing (Dist. y > L and Dist. x > B)



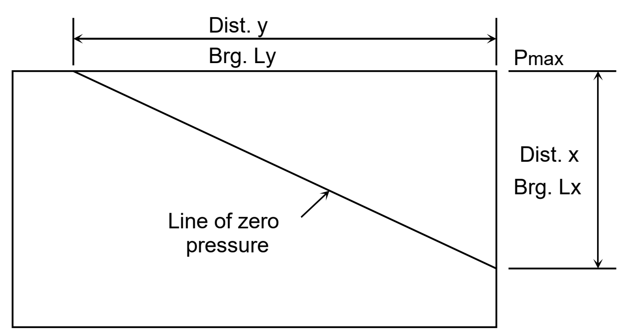
Case 2: For 2 Corners in Bearing (Dist. y > L and Dist. x <= B)



Case 3: For 2 Corners in Bearing (Dist. y <= L and Dist. x > B)



Case 4: For 1 Corner in Bearing (Dist. y <= L and Dist. x <= B)



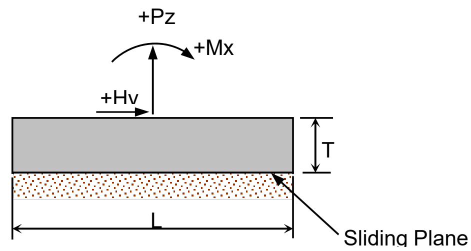
GATE TOWER STABILITY ANALYSIS

Job Name:	Springbank Off-Stream Storage Project	Number:	110773396		
Site:	Gate Tower	Originator:	ACG 7/2/2020	Checker:	CG
Load Case:	UN1-3 10-Year Flood, Gates Open				

Input Data:

Footing Data:

Footing Length, L =	10.50	m
Footing Width, B =	6.40	m
Footing Thickness, T =	0.00	m
Coef. of Base Friction, μ =	0.510	
Ultimate Bearing, Pall =	1281.00	kPa

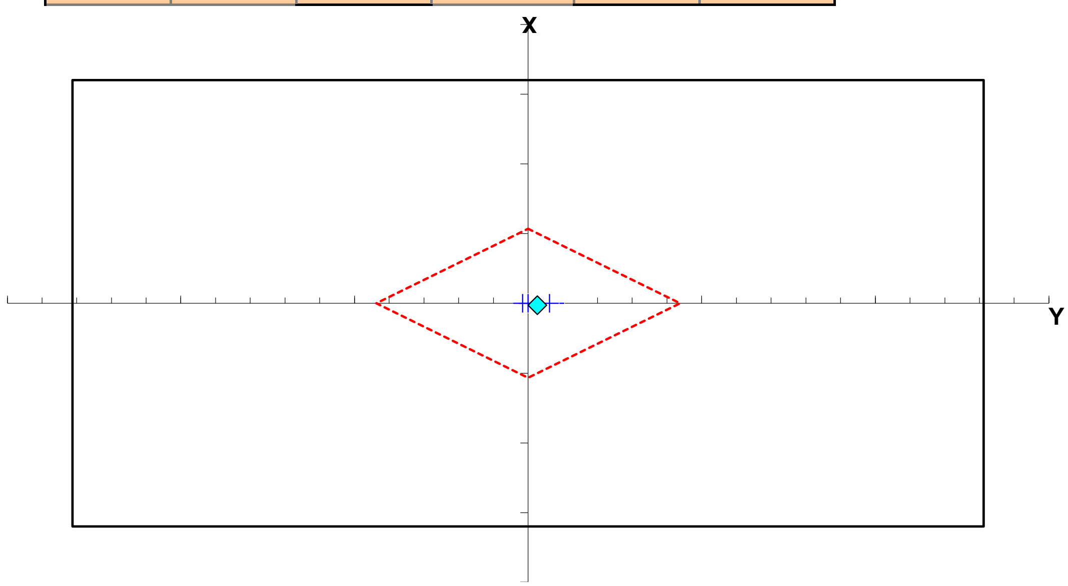


Nomenclature

Loading Data:

Direction of Wind Force: X-DIRECTION

	Uplift	Vertical Soil	Not Used	Internal Hydrostatic	Not Used	SAP2000 Reaction
Yp (m.) =	0.00	-0.06		0.31		0.25
Xp (m.) =	0.00	0.00		0.00		0.00
Pz (kN) =	4524.31	-13120.89		-450.33		-14592.54
Hy (kN) =	0.00	0.00		0.00		117.76
Hx (kN) =	0.00	0.00		0.00		279.47
My (kN-m) =	0.00	0.00		0.00		647.45
Mx (kN-m) =	0.00	0.00		0.00		-350.37



FOOTING PLAN

Note: Is the "Kern" area of footing (When resultant of loads falls within "Kern", entire footing base is in bearing.)

Results:

Total Resultant Load and Eccentricities:

ΣPy =	-23639.45	kN
ey =	0.11	m (<= L/6)
ex =	-0.03	m (<= B/6)
ΣHy =	117.76	kN
ΣHx =	279.47	kN
H resultant =	303.26	kN
ΣMry =	90124.03	kN-m
ΣMoy =	15125.24	kN-m
ΣMrx =	144871.47	kN-m
ΣMox =	23402.26	kN-m

Sliding Check:

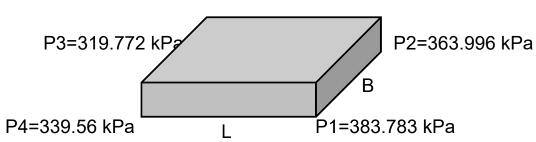
Frict =	12056.12	kN
FS(slid) =	39.754	

% Base Area in Compression:

Dist. y =	N.A.	m
Dist. x =	N.A.	m
Brg. Ly =	10.500	m
Brg. Lx =	6.400	m
%Brg. Area =	100.00	%
Biaxial Case =	N.A.	6*ex/L + 6*ez/B = 0.091

Gross Soil Bearing Corner Pressures:

P_1 =	383.783	kPa
P_2 =	363.996	kPa
P_3 =	319.772	kPa
P_4 =	339.560	kPa



CORNER PRESSURES

Summary of Results:

Sliding Check:

FS(slid) =	39.75	> 1.3	OK

Bearing Area:

%Brg. Area =	100.00%	< 100%	OK

Bearing Pressure Check:

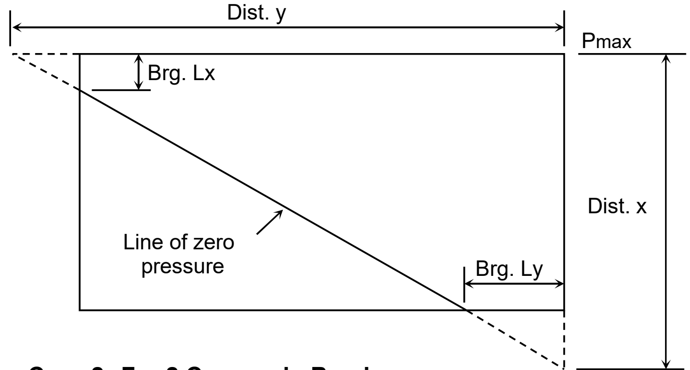
FS(brg) =	3.34	> 2.25	OK

Flotation Check:

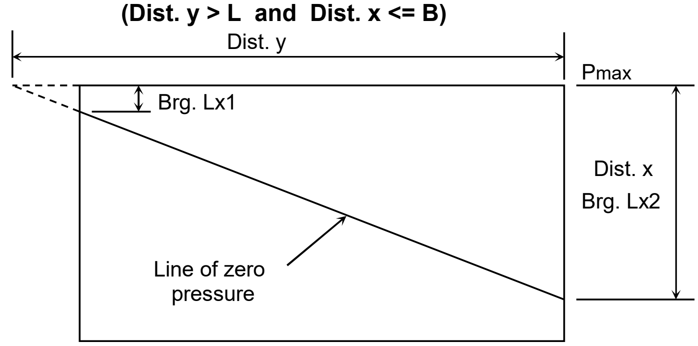
FS (float) =	6.22	> 1.3	OK

Nomenclature for Biaxial Eccentricity:

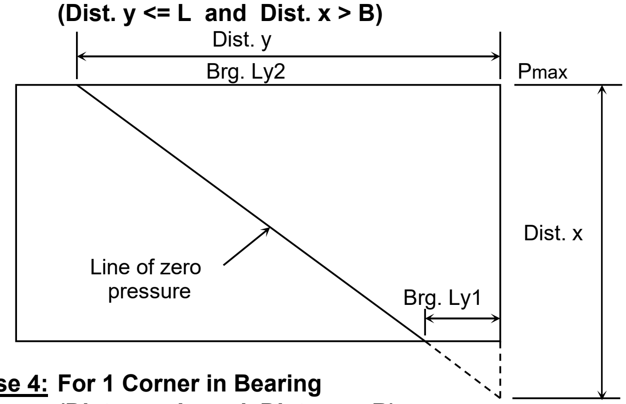
Case 1: For 3 Corners in Bearing
(Dist. y > L and Dist. x > B)



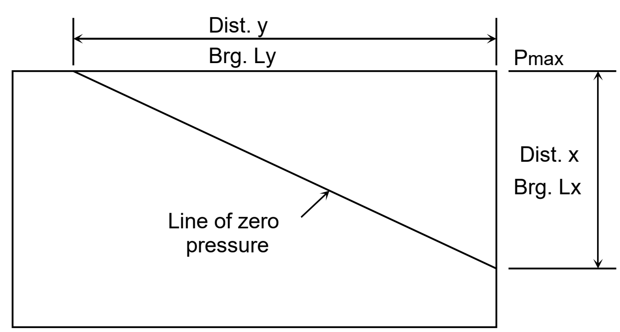
Case 2: For 2 Corners in Bearing
(Dist. y > L and Dist. x <= B)



Case 3: For 2 Corners in Bearing
(Dist. y <= L and Dist. x > B)



Case 4: For 1 Corner in Bearing
(Dist. y <= L and Dist. x <= B)



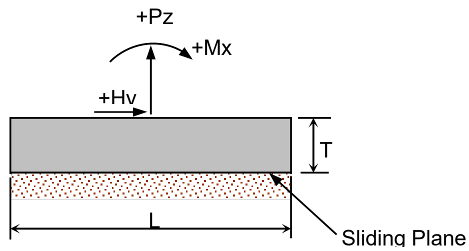
GATE TOWER STABILITY ANALYSIS

Job Name:	Springbank Off-Stream Storage Project	Number:	110773396			
Site:	Gate Tower	Originator:	ACG	7/2/2020	Checker:	CG
Load Case:	UN1-4+ 10-Year Flood, Gates Open					

Input Data:

Footing Data:

Footing Length, L =	10.50	m
Footing Width, B =	6.40	m
Footing Thickness, T =	0.00	m
Coef. of Base Friction, μ =	0.510	
Ultimate Bearing, Pall =	1281.00	kPa

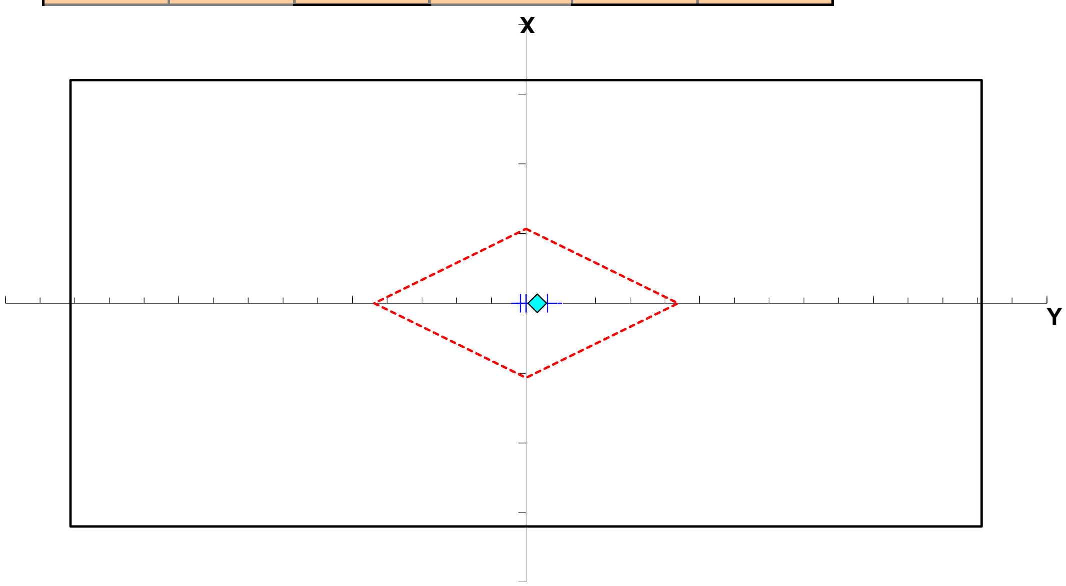


Nomenclature

Loading Data:

Direction of Wind Force: Y-DIRECTION

	Uplift	Vertical Soil	Not Used	Internal Hydrostatic	Not Used	SAP2000 Reaction
Yp (m.) =	0.00	**-0.06**		0.31		**0.25**
Xp (m.) =	0.00	**0.00**		0.00		0.00
Pz (kN) =	4524.31	**-13120.89**		-450.33		**-14720.20**
Hy (kN) =	0.00	**0.00**		0.00		**40.16**
Hx (kN) =	0.00	**0.00**		0.00		**0.00**
My (kN-m) =	0.00	**0.00**		0.00		**0.00**
Mx (kN-m) =	0.00	**0.00**		0.00		**12.75**



FOOTING PLAN

Note: Is the "Kern" area of footing (When resultant of loads falls within "Kern", entire footing base is in bearing.)

Results:

Total Resultant Load and Eccentricities:

ΣPy =	-23767.11	kN
ey =	0.13	m (<= L/6)
ex =	0.00	
ΣHy =	40.16	kN
ΣHx =	0.00	kN
H resultant =	40.16	kN
ΣMry =	N.A.	kN-m
ΣMoy =	N.A.	kN-m
ΣMrx =	145509.77	kN-m
ΣMox =	23765.38	kN-m

Sliding Check:

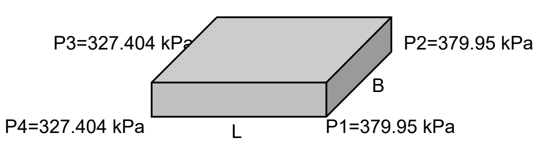
Frict =	12121.23	kN
FS(slid) =	301.861	

% Base Area in Compression:

Dist. y =	N.A.	m
Dist. x =	N.A.	m
Brg. Ly =	10.500	m
Brg. Lx =	6.400	m
%Brg. Area =	100.00	%
Biaxial Case =	N.A.	

Gross Soil Bearing Corner Pressures:

P_1 =	379.950	kPa
P_2 =	379.950	kPa
P_3 =	327.404	kPa
P_4 =	327.404	kPa



CORNER PRESSURES

Summary of Results:

Sliding Check:

FS(slid) =	**301.86**	> 1.3	OK

Bearing Area:

%Brg. Area =	**100.00%**	< 100%	OK

Bearing Pressure Check:

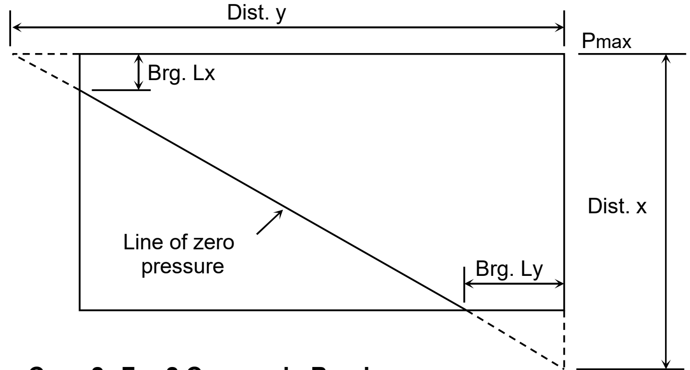
FS(brg) =	**3.37**	> 2.25	OK

Flotation Check:

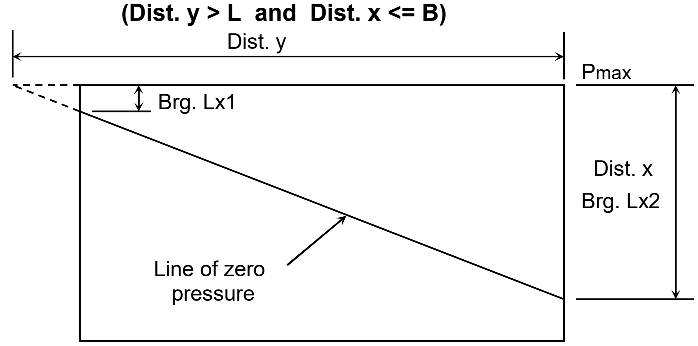
FS (float) =	**6.25**	> 1.3	OK

Nomenclature for Biaxial Eccentricity:

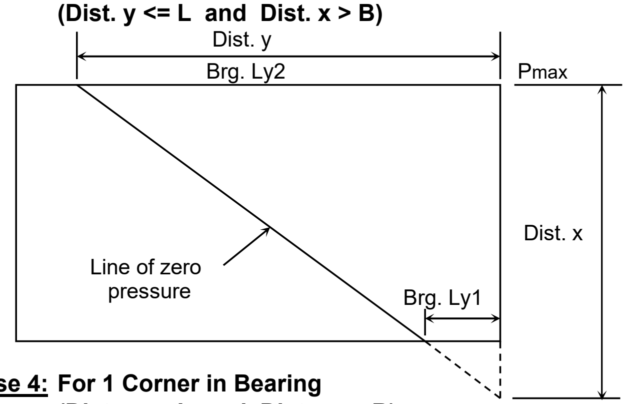
Case 1: For 3 Corners in Bearing
(Dist. y > L and Dist. x > B)



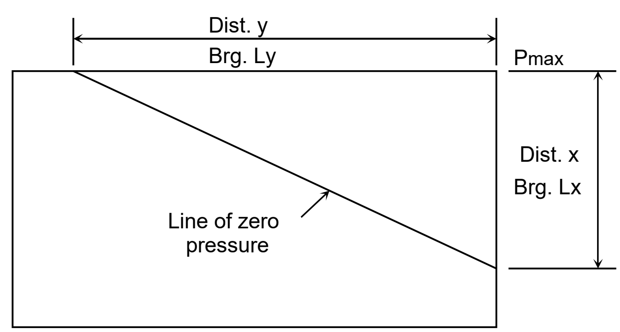
Case 2: For 2 Corners in Bearing
(Dist. y > L and Dist. x <= B)



Case 3: For 2 Corners in Bearing
(Dist. y <= L and Dist. x > B)



Case 4: For 1 Corner in Bearing
(Dist. y <= L and Dist. x <= B)



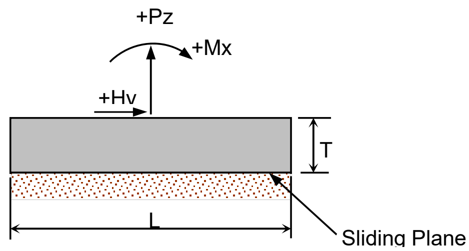
GATE TOWER STABILITY ANALYSIS

Job Name:	Springbank Off-Stream Storage Project	Number:	110773396
Site:	Gate Tower	Originator:	ACG 7/2/2020 Checker: CG
Load Case:	UN1-4- 10-Year Flood, Gates Open		

Input Data:

Footing Data:

Footing Length, L =	10.50	m
Footing Width, B =	6.40	m
Footing Thickness, T =	0.00	m
Coef. of Base Friction, μ =	0.510	
Ultimate Bearing, Pall =	1281.00	kPa

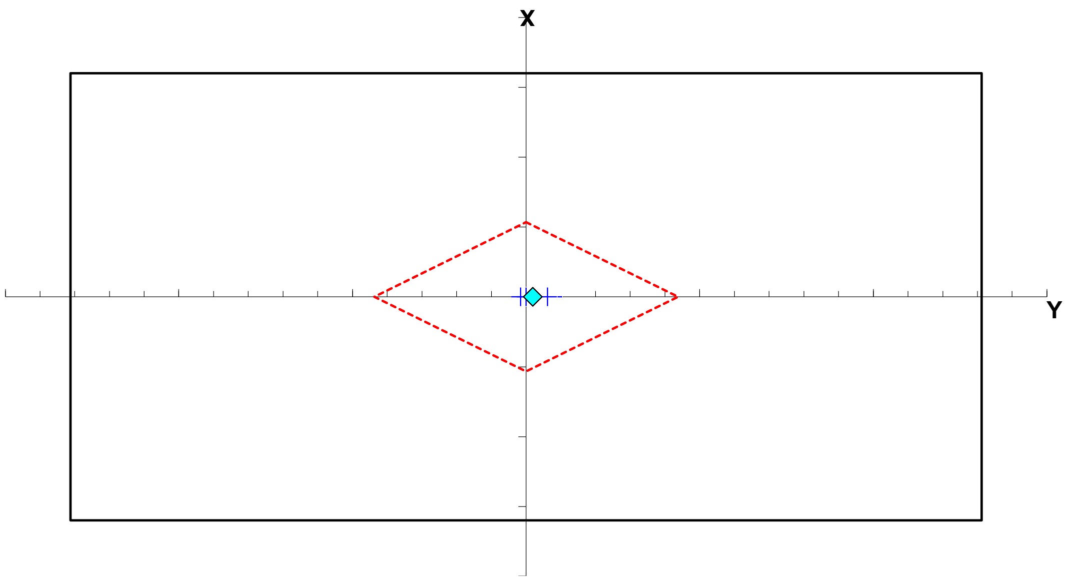


Nomenclature

Loading Data:

Direction of Wind Force: Y-DIRECTION

	Uplift	Vertical Soil	Not Used	Internal Hydrostatic	Not Used	SAP2000 Reaction
Yp (m.) =	0.00	**-0.06**		0.31		**0.25**
Xp (m.) =	0.00	**0.00**		0.00		0.00
Pz (kN) =	4524.31	**-13120.89**		-450.33		**-14820.40**
Hy (kN) =	0.00	**0.00**		0.00		**326.40**
Hx (kN) =	0.00	**0.00**		0.00		**0.00**
My (kN-m) =	0.00	**0.00**		0.00		**0.00**
Mx (kN-m) =	0.00	**0.00**		0.00		**-1200.90**



FOOTING PLAN

Note: Is the "Kern" area of footing (When resultant of loads falls within "Kern", entire footing base is in bearing.)

Results:

Total Resultant Load and Eccentricities:

ΣPy =	-23867.31	kN
ey =	0.08	m (<= L/6)
ex =	0.00	
ΣHy =	326.40	kN
ΣHx =	0.00	kN
H resultant =	326.40	kN
ΣMry =	N.A.	kN-m
ΣMoy =	N.A.	kN-m
ΣMrx =	146010.77	kN-m
ΣMox =	22551.72	kN-m

Sliding Check:

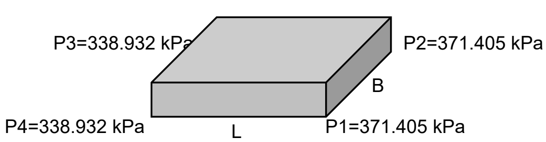
Frict =	12172.33	kN
FS(slid) =	37.292	

% Base Area in Compression:

Dist. y =	N.A.	m
Dist. x =	N.A.	m
Brg. Ly =	10.500	m
Brg. Lx =	6.400	m
%Brg. Area =	100.00	%
Biaxial Case =	N.A.	

Gross Soil Bearing Corner Pressures:

P_1 =	371.405	kPa
P_2 =	371.405	kPa
P_3 =	338.932	kPa
P_4 =	338.932	kPa



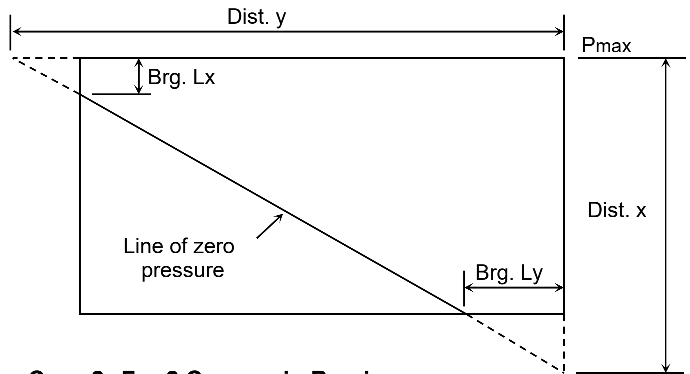
CORNER PRESSURES

Summary of Results:

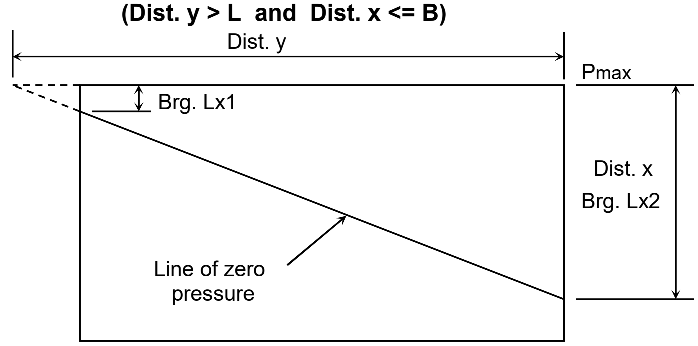
Sliding Check:			
FS(slid) =	37.29	> 1.3	OK
Bearing Area:			
%Brg. Area =	100.00%	< 100%	OK
Bearing Pressure Check:			
FS(brg) =	3.45	> 2.25	OK
Flotation Check:			
FS (float) =	6.28	> 1.3	OK

Nomenclature for Biaxial Eccentricity:

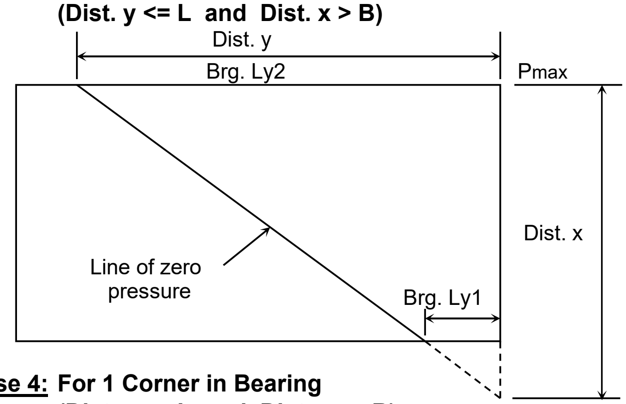
Case 1: For 3 Corners in Bearing
(Dist. y > L and Dist. x > B)



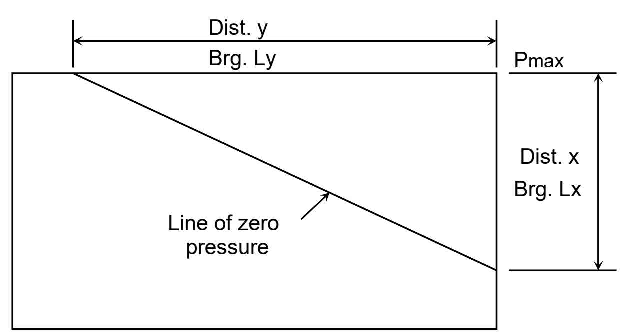
Case 2: For 2 Corners in Bearing
(Dist. y > L and Dist. x <= B)



Case 3: For 2 Corners in Bearing
(Dist. y <= L and Dist. x > B)



Case 4: For 1 Corner in Bearing
(Dist. y <= L and Dist. x <= B)



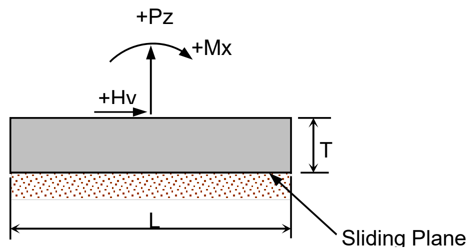
GATE TOWER STABILITY ANALYSIS

Job Name:	Springbank Off-Stream Storage Project	Number:	110773396		
Site:	Gate Tower	Originator:	ACG 7/2/2020	Checker:	CG
Load Case:	UN1-5 10-Year Flood, Gates Open				

Input Data:

Footing Data:

Footing Length, L =	10.50	m
Footing Width, B =	6.40	m
Footing Thickness, T =	0.00	m
Coef. of Base Friction, μ =	0.510	
Ultimate Bearing, Pall =	1281.00	kPa

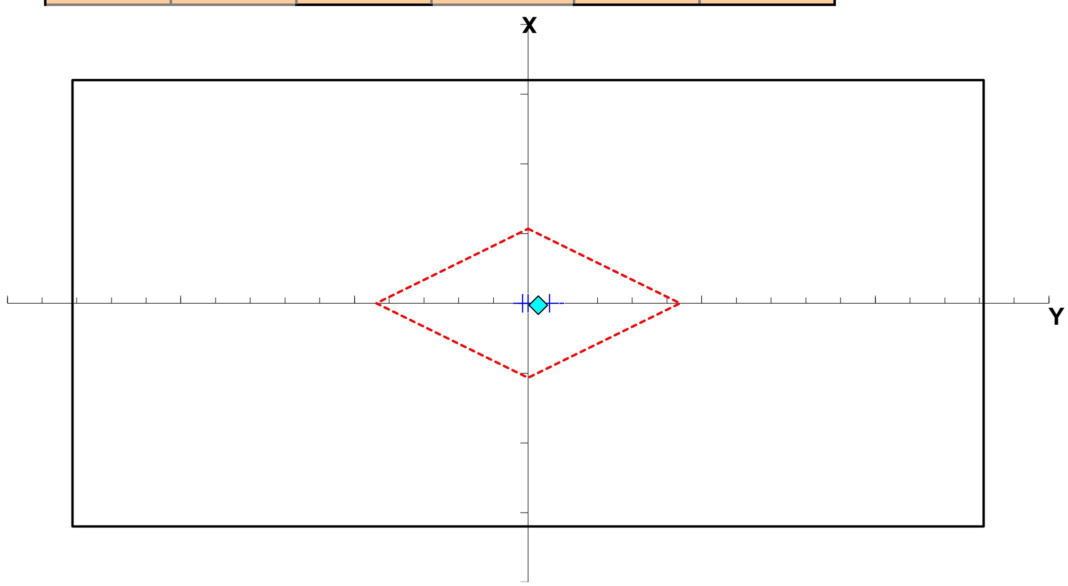


Nomenclature

Loading Data:

Direction of Wind Force: X-DIRECTION

	Uplift	Vertical Soil	Not Used	Internal Hydrostatic	Not Used	SAP2000 Reaction
Yp (m.) =	0.00	**-0.06**		0.31		**0.25**
Xp (m.) =	0.00	**0.00**		0.00		0.00
Pz (kN) =	4524.31	**-13120.89**		-450.33		**-14032.34**
Hy (kN) =	0.00	**0.00**		0.00		**63.01**
Hx (kN) =	0.00	**0.00**		0.00		**279.47**
My (kN-m) =	0.00	**0.00**		0.00		**647.45**
Mx (kN-m) =	0.00	**0.00**		0.00		**-191.10**



FOOTING PLAN

Note: Is the "Kern" area of footing (When resultant of loads falls within "Kern", entire footing base is in bearing.)

Results:

Total Resultant Load and Eccentricities:

ΣPy =	-23079.25	kN
ey =	0.12	m (<= L/6)
ex =	-0.03	m (<= B/6)
ΣHy =	63.01	kN
ΣHx =	279.47	kN
H resultant =	286.48	kN
ΣMry =	88331.39	kN-m
ΣMoy =	15125.24	kN-m
ΣMrx =	142070.47	kN-m
ΣMox =	23561.53	kN-m

Sliding Check:

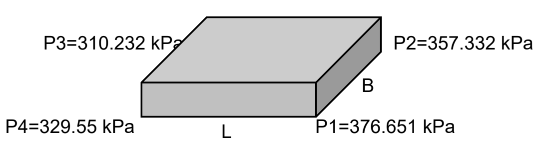
Frict =	11770.42	kN
FS(slid) =	41.086	

% Base Area in Compression:

Dist. y =	N.A.	m
Dist. x =	N.A.	m
Brg. Ly =	10.500	m
Brg. Lx =	6.400	m
%Brg. Area =	100.00	%
Biaxial Case =	N.A.	6*ex/L + 6*ez/B = 0.097

Gross Soil Bearing Corner Pressures:

P1 =	376.651	kPa
P2 =	357.332	kPa
P3 =	310.232	kPa
P4 =	329.550	kPa



CORNER PRESSURES

Summary of Results:

Sliding Check:

FS(slid) =	**41.09**	> 1.3	OK

Bearing Area:

%Brg. Area =	**100.00%**	< 100%	OK

Bearing Pressure Check:

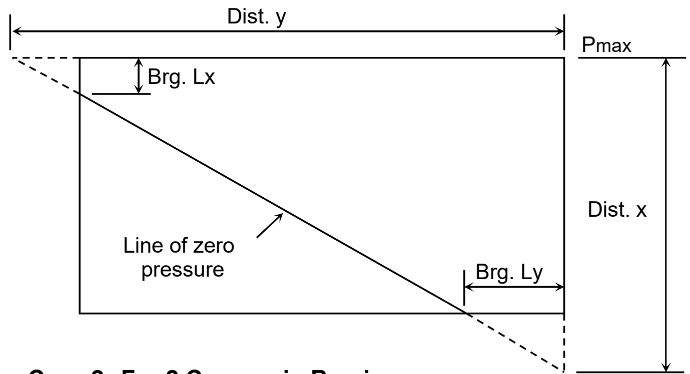
FS(brg) =	**3.40**	> 2.25	OK

Flotation Check:

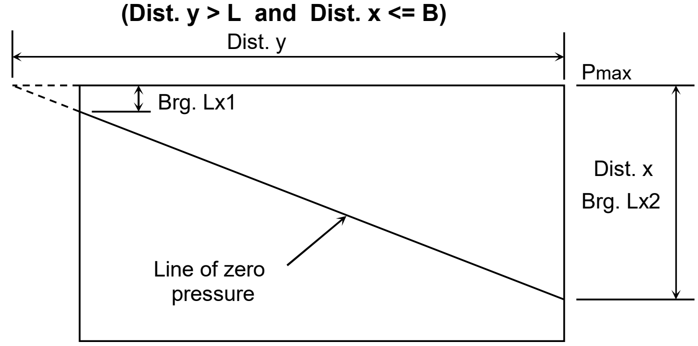
FS (float) =	**6.10**	> 1.3	OK

Nomenclature for Biaxial Eccentricity:

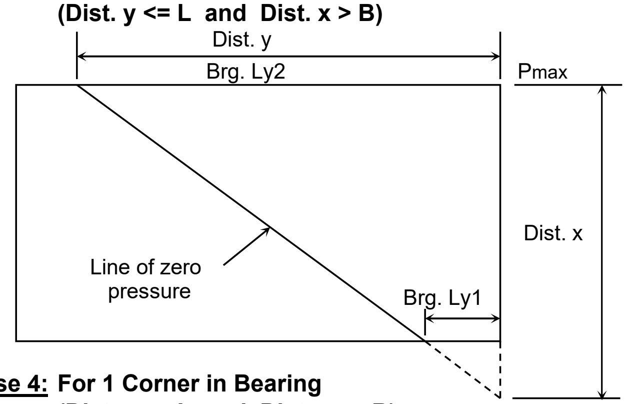
Case 1: For 3 Corners in Bearing
(Dist. y > L and Dist. x > B)



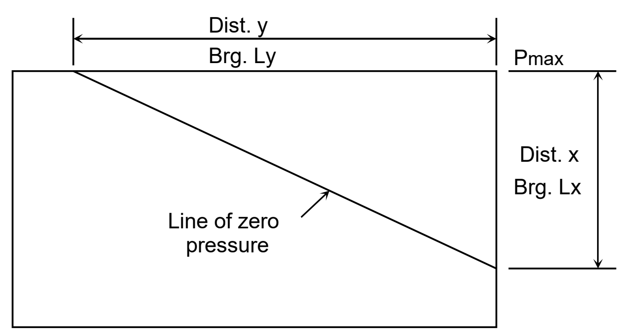
Case 2: For 2 Corners in Bearing
(Dist. y > L and Dist. x <= B)



Case 3: For 2 Corners in Bearing
(Dist. y <= L and Dist. x > B)



Case 4: For 1 Corner in Bearing
(Dist. y <= L and Dist. x <= B)



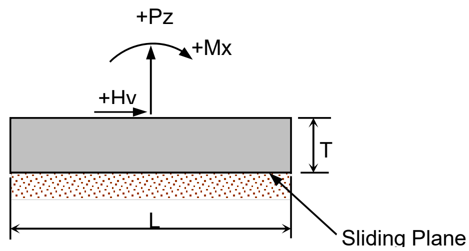
GATE TOWER STABILITY ANALYSIS

Job Name:	Springbank Off-Stream Storage Project	Number:	110773396		
Site:	Gate Tower	Originator:	ACG 7/2/2020	Checker:	CG
Load Case:	UN1-6+ 10-Year Flood, Gates Open				

Input Data:

Footing Data:

Footing Length, L =	10.50	m
Footing Width, B =	6.40	m
Footing Thickness, T =	0.00	m
Coef. of Base Friction, μ =	0.510	
Ultimate Bearing, Pall =	1281.00	kPa

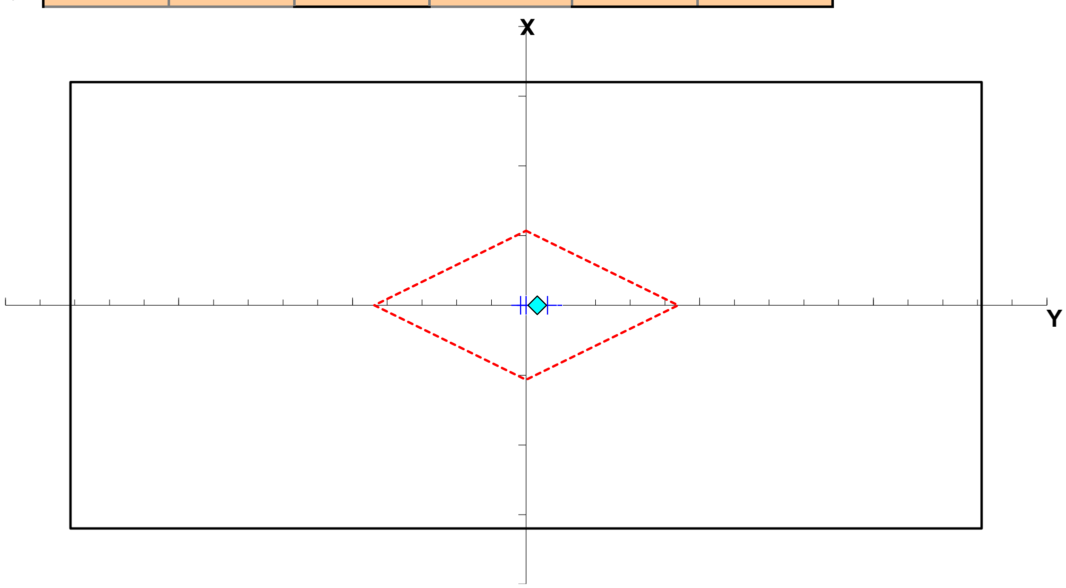


Nomenclature

Loading Data:

Direction of Wind Force: Y-DIRECTION

	Uplift	Vertical Soil	Not Used	Internal Hydrostatic	Not Used	SAP2000 Reaction
Yp (m.) =	0.00	**-0.06**		0.31		**0.25**
Xp (m.) =	0.00	**0.00**		0.00		0.00
Pz (kN) =	4524.31	**-13120.89**		-450.33		**-14160.00**
Hy (kN) =	0.00	**0.00**		0.00		**-14.59**
Hx (kN) =	0.00	**0.00**		0.00		**0.00**
My (kN-m) =	0.00	**0.00**		0.00		**0.00**
Mx (kN-m) =	0.00	**0.00**		0.00		**172.02**



FOOTING PLAN

Note: Is the "Kern" area of footing (When resultant of loads falls within "Kern", entire footing base is in bearing.)

Results:

Total Resultant Load and Eccentricities:

ΣPy =	-23206.91	kN
ey =	0.13	m (<= L/6)
ex =	0.00	
ΣHy =	-14.59	kN
ΣHx =	0.00	kN
H resultant =	14.59	kN
ΣMry =	N.A.	kN-m
ΣMoy =	N.A.	kN-m
ΣMrx =	142708.77	kN-m
ΣMox =	23924.65	kN-m

Sliding Check:

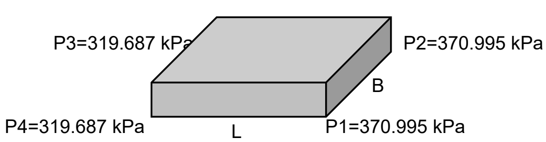
Frict =	11835.52	kN
FS(slid) =	810.986	

% Base Area in Compression:

Dist. y =	N.A.	m
Dist. x =	N.A.	m
Brg. Ly =	10.500	m
Brg. Lx =	6.400	m
%Brg. Area =	100.00	%
Biaxial Case =	N.A.	

Gross Soil Bearing Corner Pressures:

P_1 =	370.995	kPa
P_2 =	370.995	kPa
P_3 =	319.687	kPa
P_4 =	319.687	kPa



CORNER PRESSURES

Summary of Results:

Sliding Check:

FS(slid) =	810.99	> 1.3	OK

Bearing Area:

%Brg. Area =	100.00%	< 100%	OK

Bearing Pressure Check:

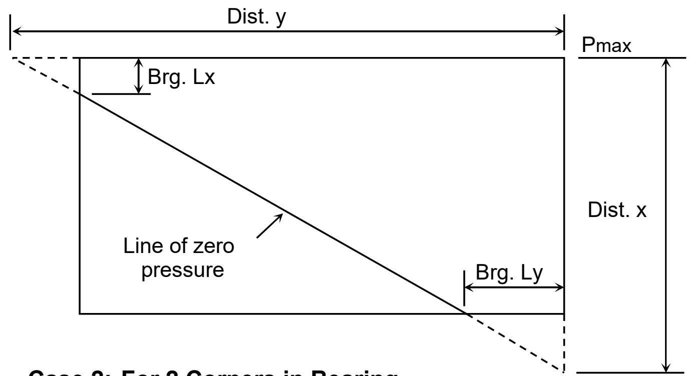
FS(brg) =	3.45	> 2.25	OK

Flotation Check:

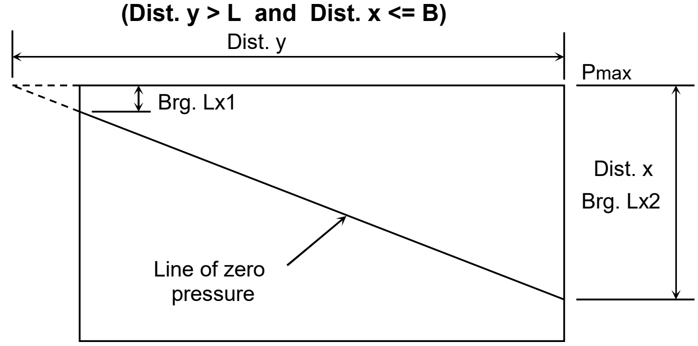
FS (float) =	6.13	> 1.3	OK

Nomenclature for Biaxial Eccentricity:

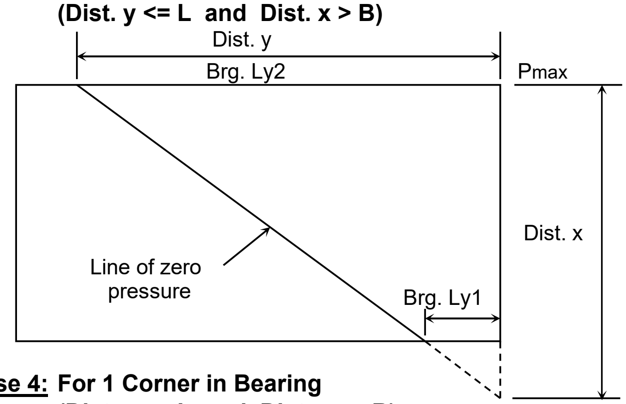
Case 1: For 3 Corners in Bearing
(Dist. y > L and Dist. x > B)



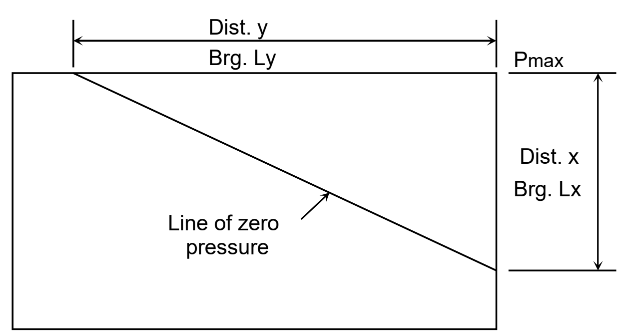
Case 2: For 2 Corners in Bearing
(Dist. y > L and Dist. x <= B)



Case 3: For 2 Corners in Bearing
(Dist. y <= L and Dist. x > B)



Case 4: For 1 Corner in Bearing
(Dist. y <= L and Dist. x <= B)



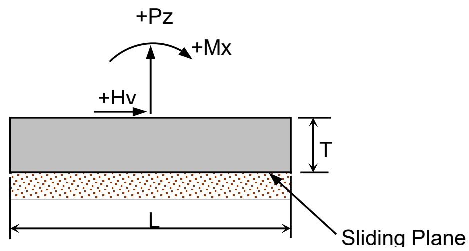
GATE TOWER STABILITY ANALYSIS

Job Name:	Springbank Off-Stream Storage Project	Number:	110773396		
Site:	Gate Tower	Originator:	ACG 7/2/2020	Checker:	CG
Load Case:	UN1-6- 10-Year Flood, Gates Open				

Input Data:

Footing Data:

Footing Length, L =	10.50	m
Footing Width, B =	6.40	m
Footing Thickness, T =	0.00	m
Coef. of Base Friction, μ =	0.510	
Ultimate Bearing, Pall =	1281.00	kPa

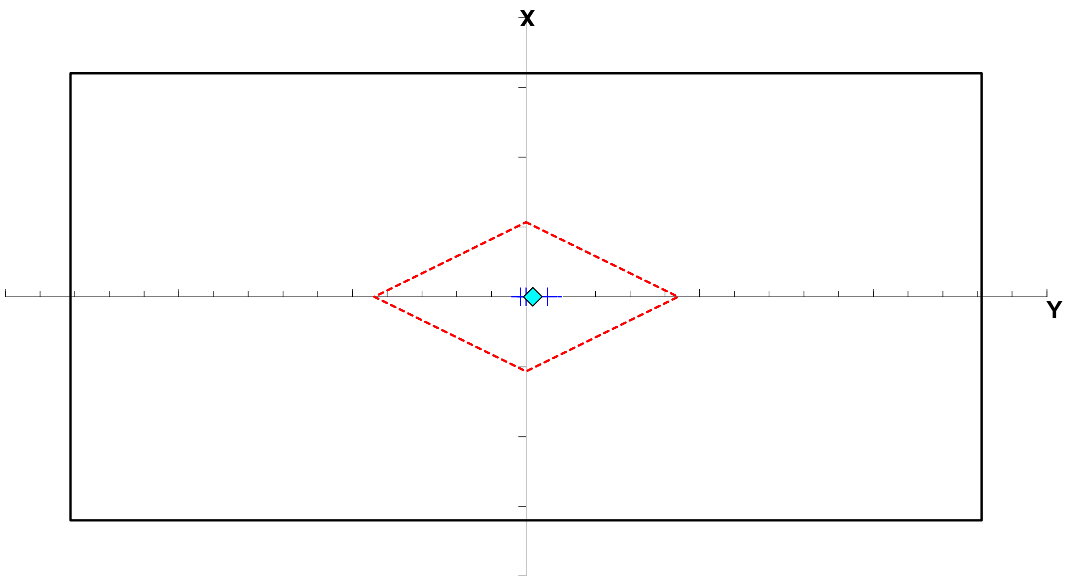


Nomenclature

Loading Data:

Direction of Wind Force: Y-DIRECTION

	Uplift	Vertical Soil	Not Used	Internal Hydrostatic	Not Used	SAP2000 Reaction
Yp (m.) =	0.00	**-0.06**		0.31		**0.25**
Xp (m.) =	0.00	**0.00**		0.00		0.00
Pz (kN) =	4524.31	**-13120.89**		-450.33		**-14260.20**
Hy (kN) =	0.00	**0.00**		0.00		**271.65**
Hx (kN) =	0.00	**0.00**		0.00		**0.00**
My (kN-m) =	0.00	**0.00**		0.00		**0.00**
Mx (kN-m) =	0.00	**0.00**		0.00		**-1041.63**



FOOTING PLAN

Note: Is the "Kern" area of footing (When resultant of loads falls within "Kern", entire footing base is in bearing.)

Results:

Total Resultant Load and Eccentricities:

ΣPy =	-23307.11	kN
ey =	0.08	m (<= L/6)
ex =	0.00	
ΣHy =	271.65	kN
ΣHx =	0.00	kN
H resultant =	271.65	kN
ΣMry =	N.A.	kN-m
ΣMoy =	N.A.	kN-m
ΣMrx =	143209.77	kN-m
ΣMox =	22710.99	kN-m

Sliding Check:

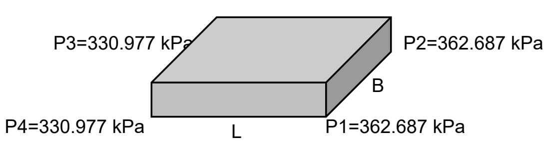
Frict =	11886.63	kN
FS(slid) =	43.757	

% Base Area in Compression:

Dist. y =	N.A.	m
Dist. x =	N.A.	m
Brg. Ly =	10.500	m
Brg. Lx =	6.400	m
%Brg. Area =	100.00	%
Biaxial Case =	N.A.	

Gross Soil Bearing Corner Pressures:

P_1 =	362.687	kPa
P_2 =	362.687	kPa
P_3 =	330.977	kPa
P_4 =	330.977	kPa



CORNER PRESSURES

Summary of Results:

Sliding Check:

FS(slid) =	43.76	> 1.3	OK

Bearing Area:

%Brg. Area =	100.00%	< 100%	OK

Bearing Pressure Check:

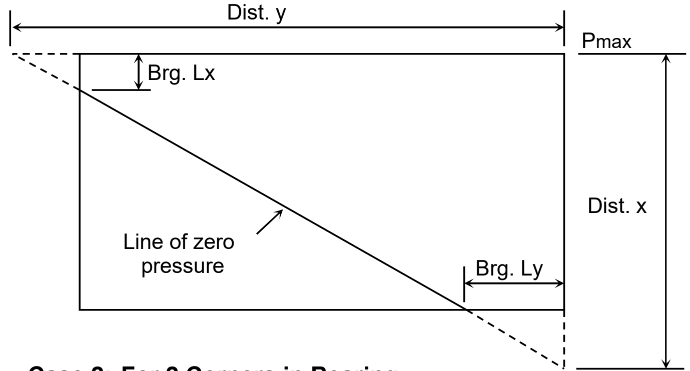
FS(brg) =	3.53	> 2.25	OK

Flotation Check:

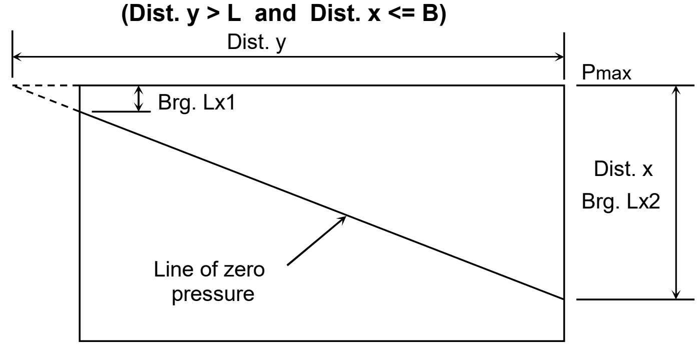
FS (float) =	6.15	> 1.3	OK

Nomenclature for Biaxial Eccentricity:

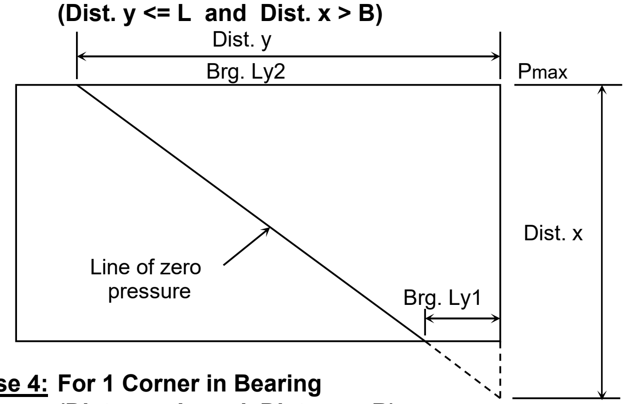
Case 1: For 3 Corners in Bearing
(Dist. y > L and Dist. x > B)



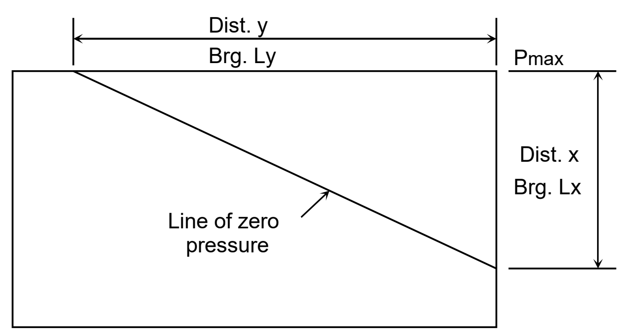
Case 2: For 2 Corners in Bearing
(Dist. y > L and Dist. x <= B)



Case 3: For 2 Corners in Bearing
(Dist. y <= L and Dist. x > B)



Case 4: For 1 Corner in Bearing
(Dist. y <= L and Dist. x <= B)



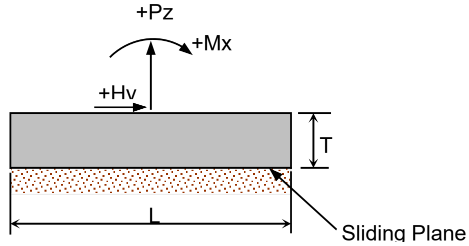
GATE TOWER STABILITY ANALYSIS

Job Name:	Springbank Off-Stream Storage Project	Number:	110773396			
Site:	Gate Tower	Originator:	ACG	7/2/2020	Checker:	CG
Load Case:	UN2-1 10-Year Flood, Front Gate Closed					

Input Data:

Footing Data:

Footing Length, L =	10.50	m
Footing Width, B =	6.40	m
Footing Thickness, T =	0.00	m
Coef. of Base Friction, μ =	0.510	
Ultimate Bearing, Pall =	1281.00	kPa

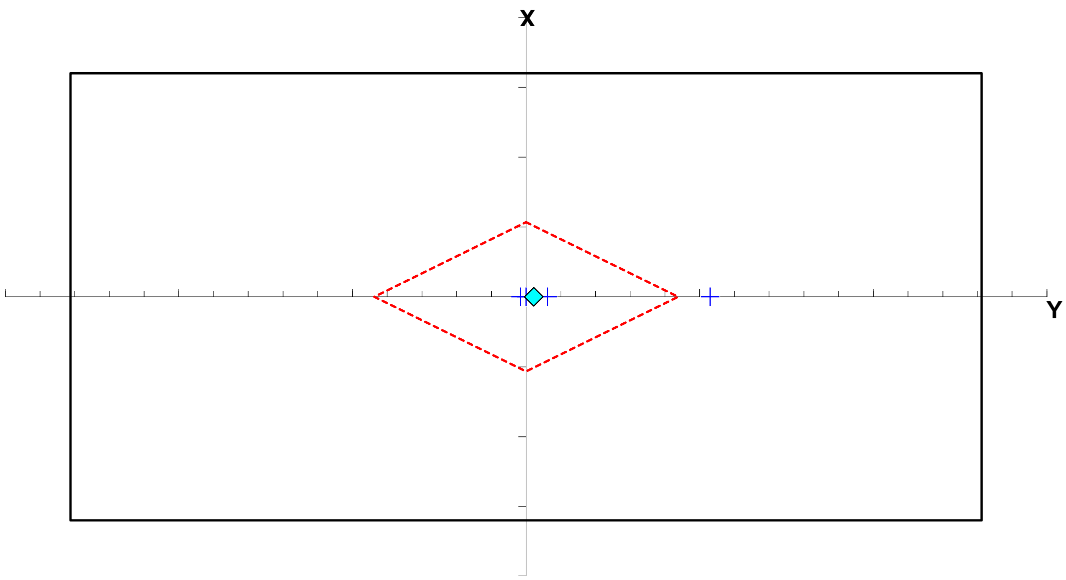


Nomenclature

Loading Data:

Direction of Wind Force: N/A

	Uplift	Vertical Soil	Not Used	Internal Hydrostatic	Not Used	SAP2000 Reaction
Yp (m.) =	0.00	**-0.06**		2.12		**0.25**
Xp (m.) =	0.00	**0.00**		0.00		0.00
Pz (kN) =	4524.31	**-13120.89**		244.76		**-14210.10**
Hy (kN) =	0.00	**0.00**		0.00		**83.78**
Hx (kN) =	0.00	**0.00**		0.00		**0.00**
My (kN-m) =	0.00	**0.00**		0.00		**0.00**
Mx (kN-m) =	0.00	**0.00**		0.00		**-251.47**



FOOTING PLAN

Note: Is the "Kern" area of footing (When resultant of loads falls within "Kern", entire footing base is in bearing.)

Results:

Total Resultant Load and Eccentricities:

ΣPy =	-22561.92	kN
ey =	0.09	m (<= L/6)
ex =	0.00	
ΣHy =	83.78	kN
ΣHx =	0.00	kN
H resultant =	83.78	kN
ΣMry =	N.A.	kN-m
ΣMoy =	N.A.	kN-m
ΣMrx =	140735.54	kN-m
ΣMox =	21697.03	kN-m

Sliding Check:

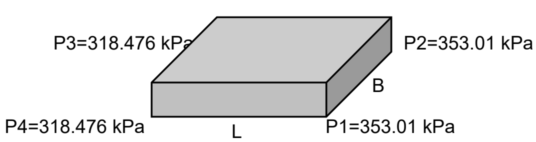
Frict =	11506.58	kN
FS(slid) =	137.338	

% Base Area in Compression:

Dist. y =	N.A.	m
Dist. x =	N.A.	m
Brg. Ly =	10.500	m
Brg. Lx =	6.400	m
%Brg. Area =	100.00	%
Biaxial Case =	N.A.	

Gross Soil Bearing Corner Pressures:

P_1 =	353.010	kPa
P_2 =	353.010	kPa
P_3 =	318.476	kPa
P_4 =	318.476	kPa



CORNER PRESSURES

Summary of Results:

Sliding Check:

FS(slid) =	137.34	> 1.3	OK

Bearing Area:

%Brg. Area =	100.00%	< 100%	OK

Bearing Pressure Check:

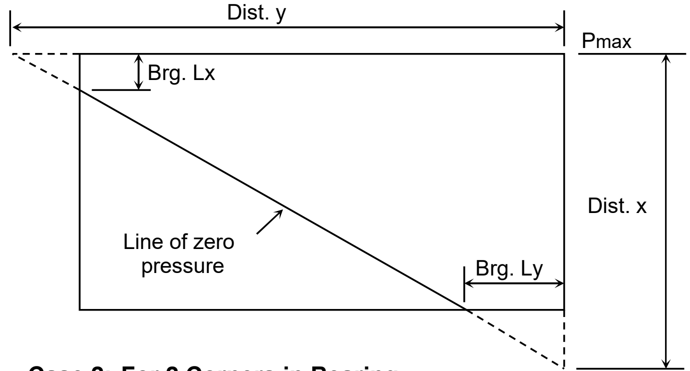
FS(brg) =	3.63	> 3.0	OK

Flotation Check:

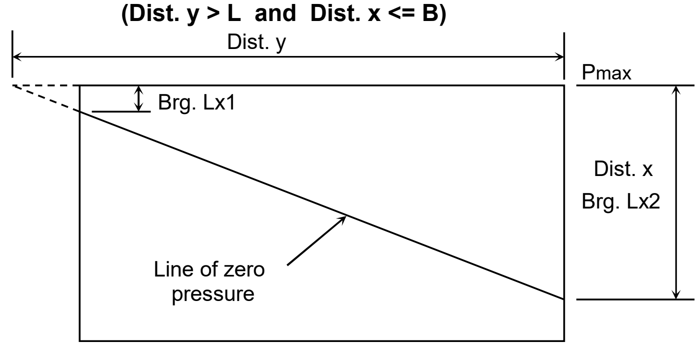
FS (float) =	5.99	> 1.3	OK

Nomenclature for Biaxial Eccentricity:

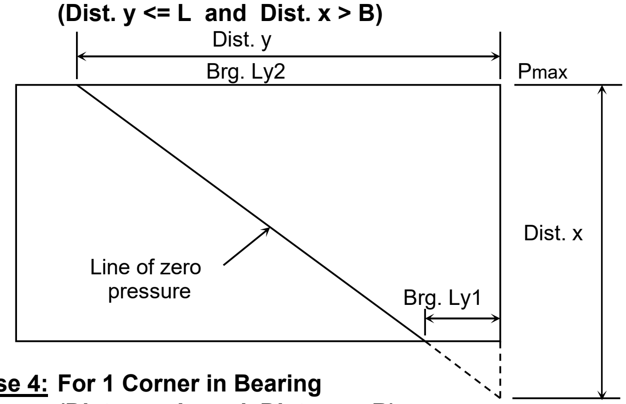
Case 1: For 3 Corners in Bearing
(Dist. y > L and Dist. x > B)



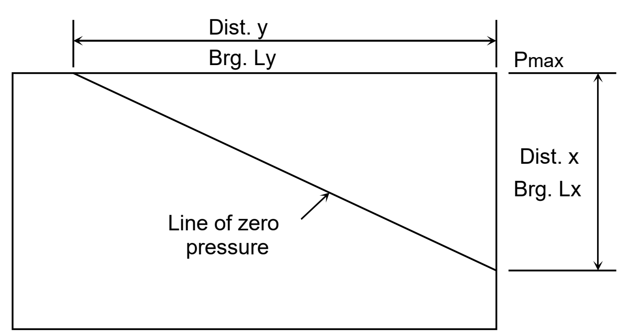
Case 2: For 2 Corners in Bearing
(Dist. y > L and Dist. x <= B)



Case 3: For 2 Corners in Bearing
(Dist. y <= L and Dist. x > B)



Case 4: For 1 Corner in Bearing
(Dist. y <= L and Dist. x <= B)



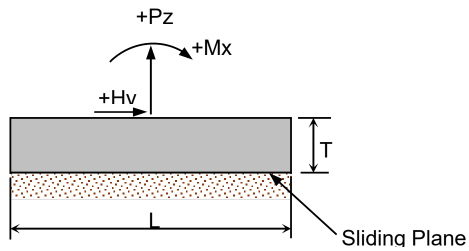
GATE TOWER STABILITY ANALYSIS

Job Name:	Springbank Off-Stream Storage Project	Number:	110773396		
Site:	Gate Tower	Originator:	ACG 7/2/2020	Checker:	CG
Load Case:	UN2-2 10-Year Flood, Front Gate Closed				

Input Data:

Footing Data:

Footing Length, L =	10.50	m
Footing Width, B =	6.40	m
Footing Thickness, T =	0.00	m
Coef. of Base Friction, μ =	0.510	
Ultimate Bearing, Pall =	1281.00	kPa

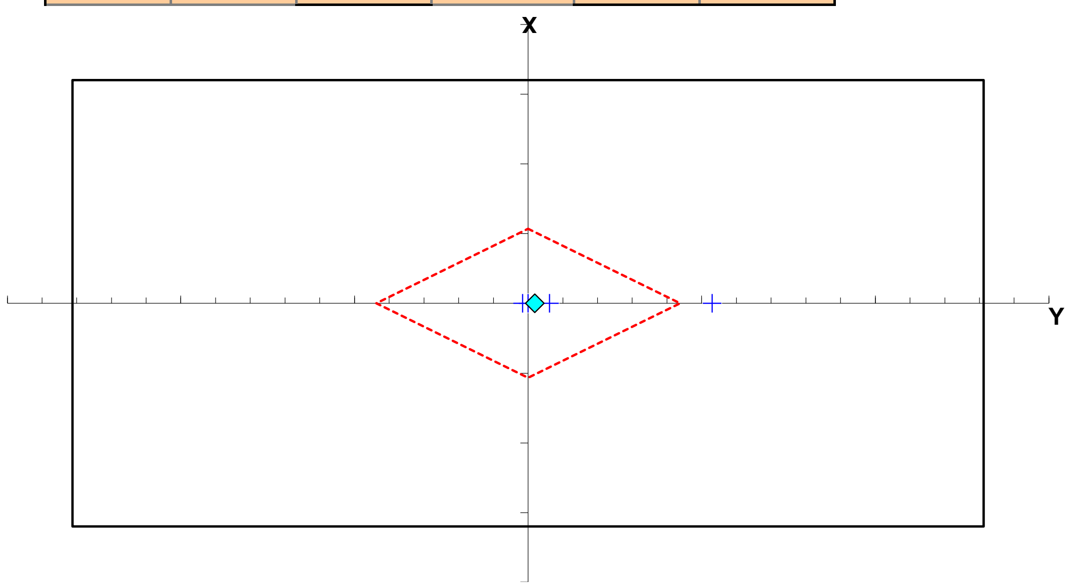


Nomenclature

Loading Data:

Direction of Wind Force: N/A

	Uplift	Vertical Soil	Not Used	Internal Hydrostatic	Not Used	SAP2000 Reaction
Yp (m.) =	0.00	**-0.06**		2.12		**0.25**
Xp (m.) =	0.00	**0.00**		0.00		0.00
Pz (kN) =	4524.31	**-13120.89**		244.76		**-14770.30**
Hy (kN) =	0.00	**0.00**		0.00		**138.53**
Hx (kN) =	0.00	**0.00**		0.00		**0.00**
My (kN-m) =	0.00	**0.00**		0.00		**0.00**
Mx (kN-m) =	0.00	**0.00**		0.00		**-410.74**



FOOTING PLAN

Note: Is the "Kern" area of footing (When resultant of loads falls within "Kern", entire footing base is in bearing.)

Results:

Total Resultant Load and Eccentricities:

ΣPy =	-23122.12	kN
ey =	0.08	m (<= L/6)
ex =	0.00	
ΣHy =	138.53	kN
ΣHx =	0.00	kN
H resultant =	138.53	kN
ΣMry =	N.A.	kN-m
ΣMoy =	N.A.	kN-m
ΣMrx =	143536.54	kN-m
ΣMox =	21537.76	kN-m

Sliding Check:

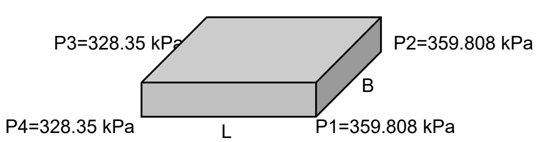
Frict =	11792.28	kN
FS(slid) =	85.123	

% Base Area in Compression:

Dist. y =	N.A.	m
Dist. x =	N.A.	m
Brg. Ly =	10.500	m
Brg. Lx =	6.400	m
%Brg. Area =	100.00	%
Biaxial Case =	N.A.	

Gross Soil Bearing Corner Pressures:

P_1 =	359.808	kPa
P_2 =	359.808	kPa
P_3 =	328.350	kPa
P_4 =	328.350	kPa



CORNER PRESSURES

Summary of Results:

Sliding Check:

FS(slid) =	85.12	> 1.3	OK

Bearing Area:

%Brg. Area =	100.00%	< 100%	OK

Bearing Pressure Check:

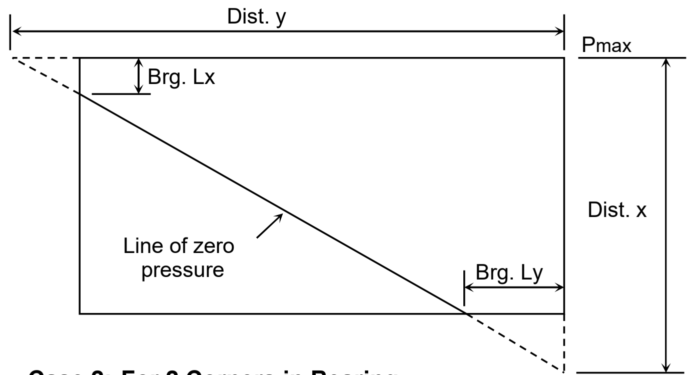
FS(brg) =	3.56	> 2.25	OK

Flotation Check:

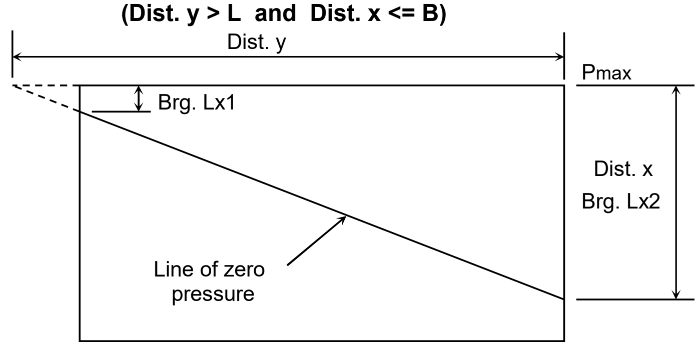
FS (float) =	6.11	> 1.3	OK

Nomenclature for Biaxial Eccentricity:

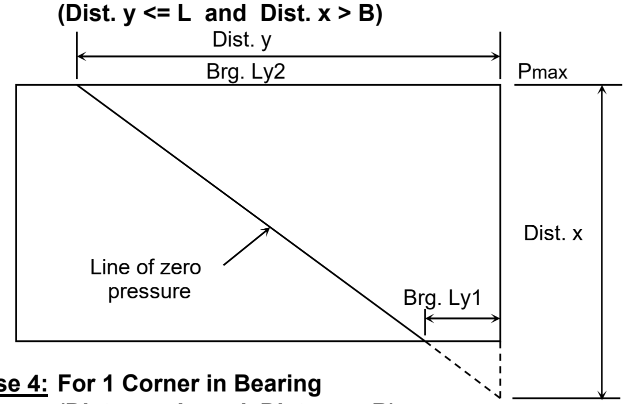
Case 1: For 3 Corners in Bearing
(Dist. y > L and Dist. x > B)



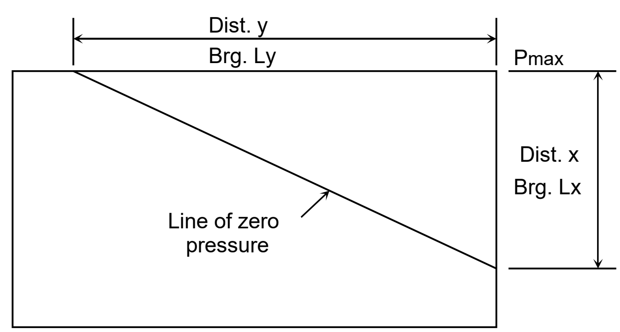
Case 2: For 2 Corners in Bearing
(Dist. y > L and Dist. x <= B)



Case 3: For 2 Corners in Bearing
(Dist. y <= L and Dist. x > B)



Case 4: For 1 Corner in Bearing
(Dist. y <= L and Dist. x <= B)



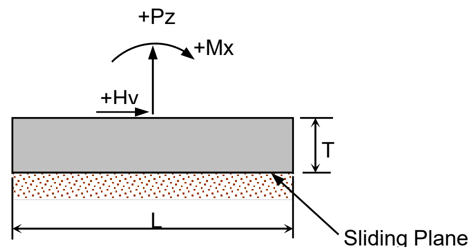
GATE TOWER STABILITY ANALYSIS

Job Name:	Springbank Off-Stream Storage Project	Number:	110773396			
Site:	Gate Tower	Originator:	ACG	7/2/2020	Checker:	CG
Load Case:	UN2-3 10-Year Flood, Front Gate Closed					

Input Data:

Footing Data:

Footing Length, L =	10.50	m
Footing Width, B =	6.40	m
Footing Thickness, T =	0.00	m
Coef. of Base Friction, μ =	0.510	
Ultimate Bearing, Pall =	1281.00	kPa

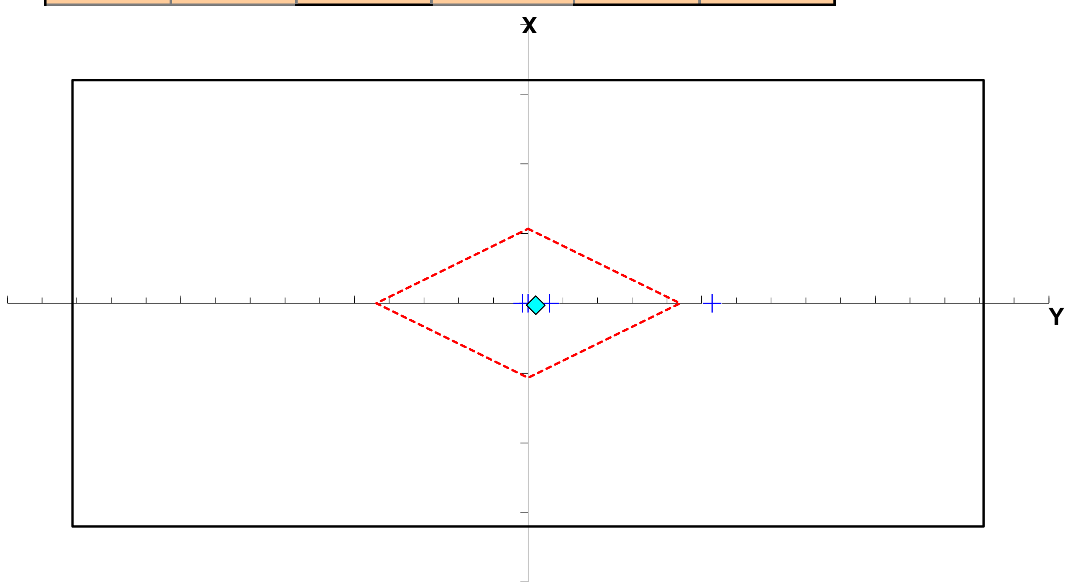


Nomenclature

Loading Data:

Direction of Wind Force: X-DIRECTION

	Uplift	Vertical Soil	Not Used	Internal Hydrostatic	Not Used	SAP2000 Reaction
Yp (m.) =	0.00	**-0.06**		2.12		**0.25**
Xp (m.) =	0.00	**0.00**		0.00		0.00
Pz (kN) =	4524.31	**-13120.89**		244.76		**-14592.54**
Hy (kN) =	0.00	**0.00**		0.00		**117.76**
Hx (kN) =	0.00	**0.00**		0.00		**279.47**
My (kN-m) =	0.00	**0.00**		0.00		**647.45**
Mx (kN-m) =	0.00	**0.00**		0.00		**-350.37**



FOOTING PLAN

Note: Is the "Kern" area of footing (When resultant of loads falls within "Kern", entire footing base is in bearing.)

Results:

Total Resultant Load and Eccentricities:

ΣPy =	-22944.36	kN
ey =	0.09	m (<= L/6)
ex =	-0.03	m (<= B/6)
ΣHy =	117.76	kN
ΣHx =	279.47	kN
H resultant =	303.26	kN
ΣMry =	88682.97	kN-m
ΣMoy =	15908.47	kN-m
ΣMrx =	142647.74	kN-m
ΣMox =	21598.13	kN-m

Sliding Check:

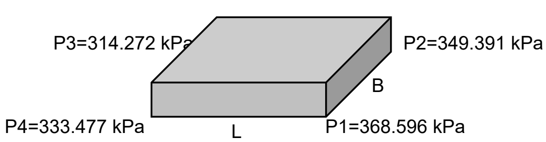
Frict =	11701.62	kN
FS(slid) =	38.586	

% Base Area in Compression:

Dist. y =	N.A.	m
Dist. x =	N.A.	m
Brg. Ly =	10.500	m
Brg. Lx =	6.400	m
%Brg. Area =	100.00	%
Biaxial Case =	N.A.	6*ex/L + 6*ez/B = 0.08

Gross Soil Bearing Corner Pressures:

P_1 =	368.596	kPa
P_2 =	349.391	kPa
P_3 =	314.272	kPa
P_4 =	333.477	kPa



CORNER PRESSURES

Summary of Results:

Sliding Check:

FS(slid) =	38.59	> 1.3	OK

Bearing Area:

%Brg. Area =	100.00%	< 100%	OK

Bearing Pressure Check:

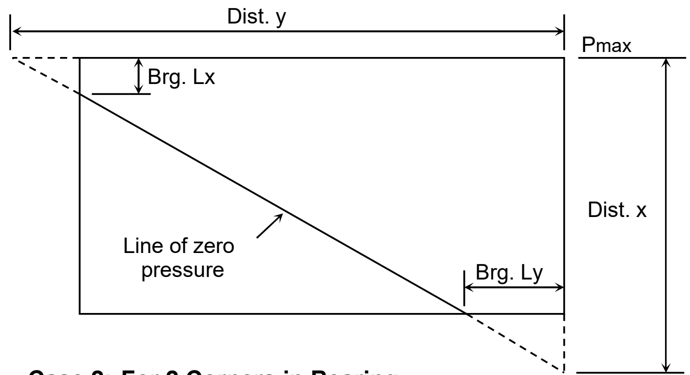
FS(brg) =	3.48	> 2.25	OK

Flotation Check:

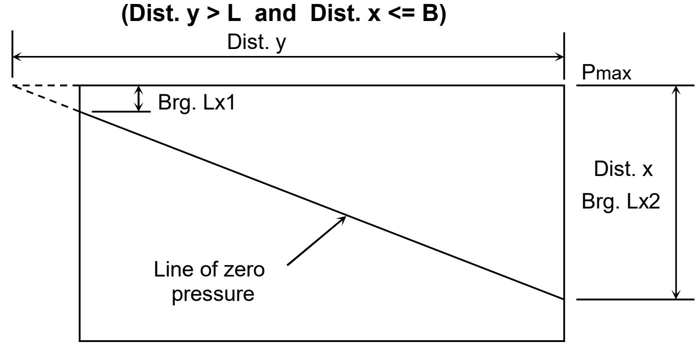
FS (float) =	6.07	> 1.3	OK

Nomenclature for Biaxial Eccentricity:

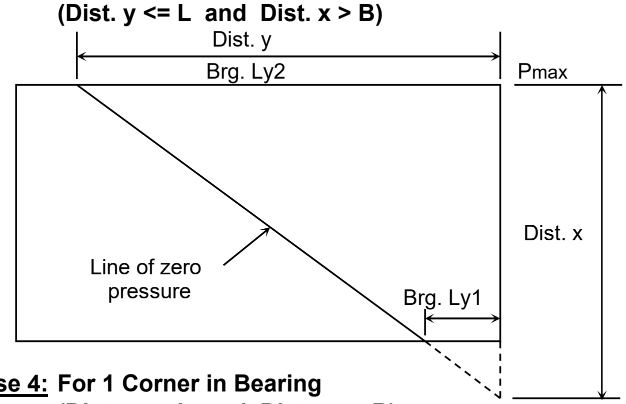
Case 1: For 3 Corners in Bearing
(Dist. y > L and Dist. x > B)



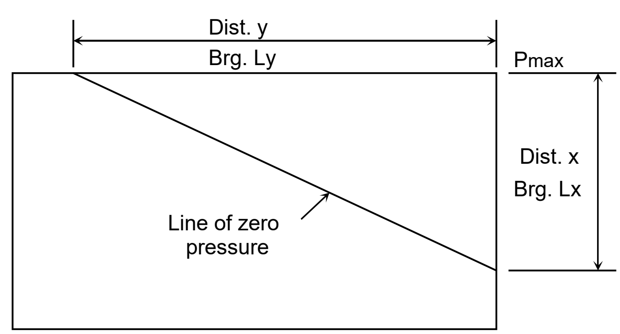
Case 2: For 2 Corners in Bearing
(Dist. y > L and Dist. x <= B)



Case 3: For 2 Corners in Bearing
(Dist. y <= L and Dist. x > B)



Case 4: For 1 Corner in Bearing
(Dist. y <= L and Dist. x <= B)



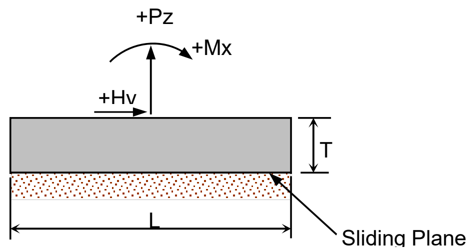
GATE TOWER STABILITY ANALYSIS

Job Name:	Springbank Off-Stream Storage Project	Number:	110773396
Site:	Gate Tower	Originator:	ACG 7/2/2020 Checker: CG
Load Case:	UN2-4+ 10-Year Flood, Front Gate Closed		

Input Data:

Footing Data:

Footing Length, L = 10.50 m
Footing Width, B = 6.40 m
Footing Thickness, T = 0.00 m
Coef. of Base Friction, μ = 0.510
Ultimate Bearing, Pall = 1281.00 kPa

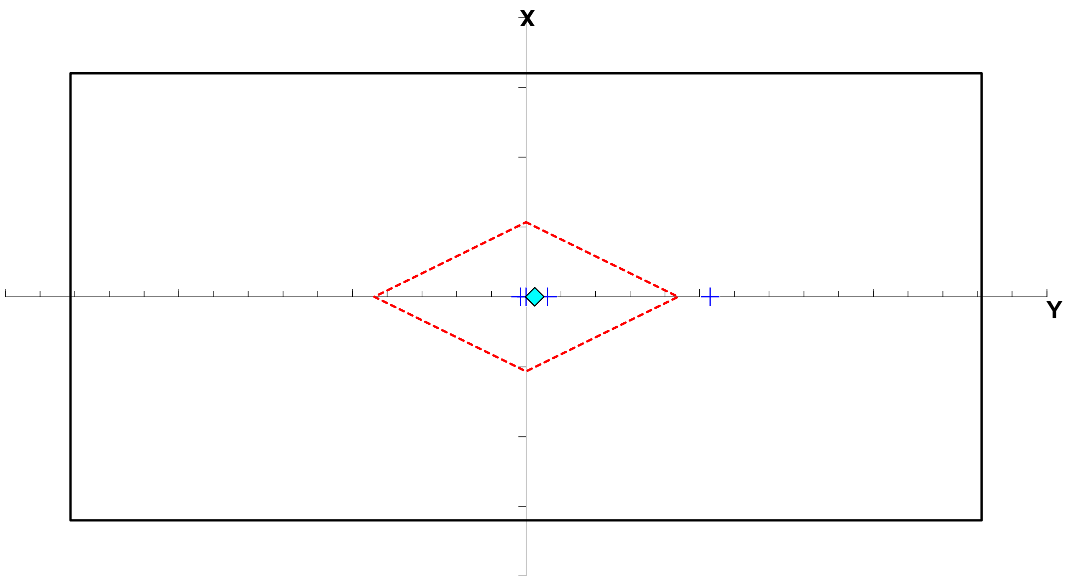


Nomenclature

Loading Data:

Direction of Wind Force: Y-DIRECTION

	Uplift	Vertical Soil	Not Used	Internal Hydrostatic	Not Used	SAP2000 Reaction
Yp (m.) =	0.00	**-0.06**		2.12		**0.25**
Xp (m.) =	0.00	**0.00**		0.00		0.00
Pz (kN) =	4524.31	**-13120.89**		244.76		**-14720.20**
Hy (kN) =	0.00	**0.00**		0.00		**40.16**
Hx (kN) =	0.00	**0.00**		0.00		**0.00**
My (kN-m) =	0.00	**0.00**		0.00		**0.00**
Mx (kN-m) =	0.00	**0.00**		0.00		**12.75**



FOOTING PLAN

Note: Is the "Kern" area of footing (When resultant of loads falls within "Kern", entire footing base is in bearing.)

Results:

Total Resultant Load and Eccentricities:

ΣPy =	-23072.02	kN
ey =	0.10	m (<= L/6)
ex =	0.00	
ΣHy =	40.16	kN
ΣHx =	0.00	kN
H resultant =	40.16	kN
ΣMry =	N.A.	kN-m
ΣMoy =	N.A.	kN-m
ΣMrx =	143286.04	kN-m
ΣMox =	21961.26	kN-m

Sliding Check:

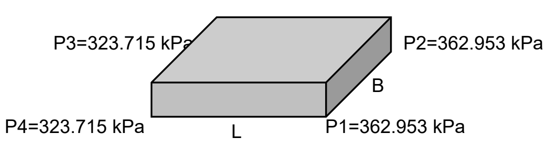
Frict =	11766.73	kN
FS(slid) =	293.033	

% Base Area in Compression:

Dist. y =	N.A.	m
Dist. x =	N.A.	m
Brg. Ly =	10.500	m
Brg. Lx =	6.400	m
%Brg. Area =	100.00	%
Biaxial Case =	N.A.	

Gross Soil Bearing Corner Pressures:

P_1 =	362.953	kPa
P_2 =	362.953	kPa
P_3 =	323.715	kPa
P_4 =	323.715	kPa



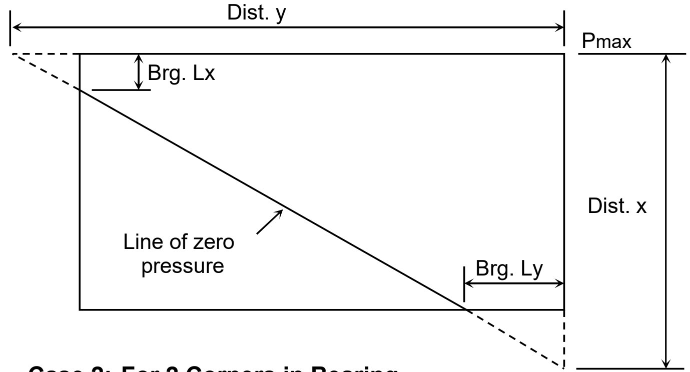
CORNER PRESSURES

Summary of Results:

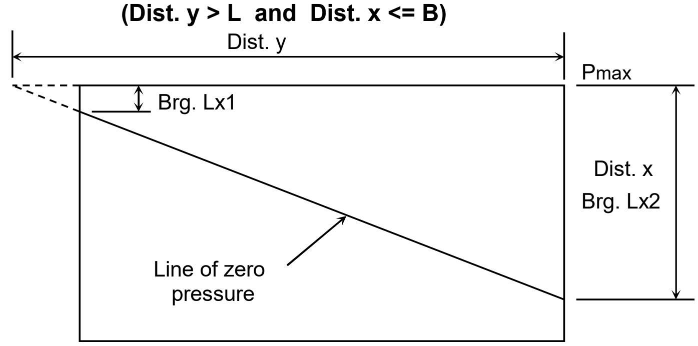
Sliding Check:			
FS(slid) =	**293.03**	> 1.3	OK
Bearing Area:			
%Brg. Area =	**100.00%**	< 100%	OK
Bearing Pressure Check:			
FS(brg) =	**3.53**	> 2.25	OK
Flotation Check:			
FS (float) =	**6.10**	> 1.3	OK

Nomenclature for Biaxial Eccentricity:

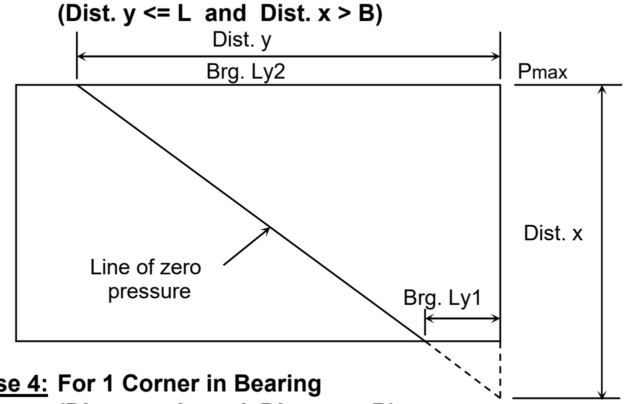
Case 1: For 3 Corners in Bearing
(Dist. y > L and Dist. x > B)



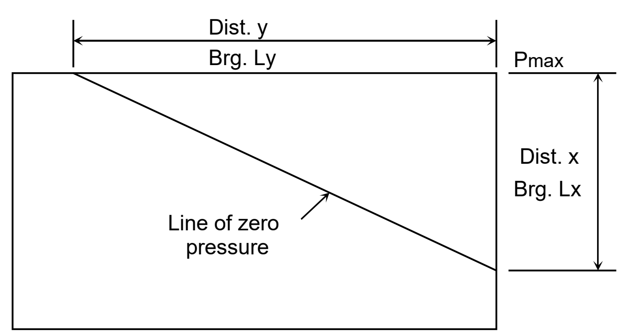
Case 2: For 2 Corners in Bearing
(Dist. y > L and Dist. x <= B)



Case 3: For 2 Corners in Bearing
(Dist. y <= L and Dist. x > B)



Case 4: For 1 Corner in Bearing
(Dist. y <= L and Dist. x <= B)



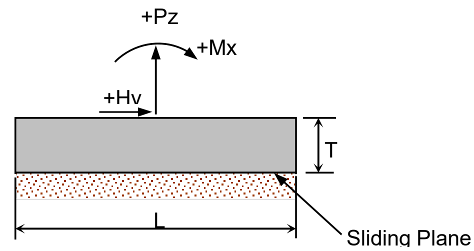
GATE TOWER STABILITY ANALYSIS

Job Name:	Springbank Off-Stream Storage Project	Number:	110773396			
Site:	Gate Tower	Originator:	ACG	7/2/2020	Checker:	CG
Load Case:	UN2-4- 10-Year Flood, Front Gate Closed					

Input Data:

Footing Data:

Footing Length, L =	10.50	m
Footing Width, B =	6.40	m
Footing Thickness, T =	0.00	m
Coef. of Base Friction, μ =	0.510	
Ultimate Bearing, Pall =	1281.00	kPa

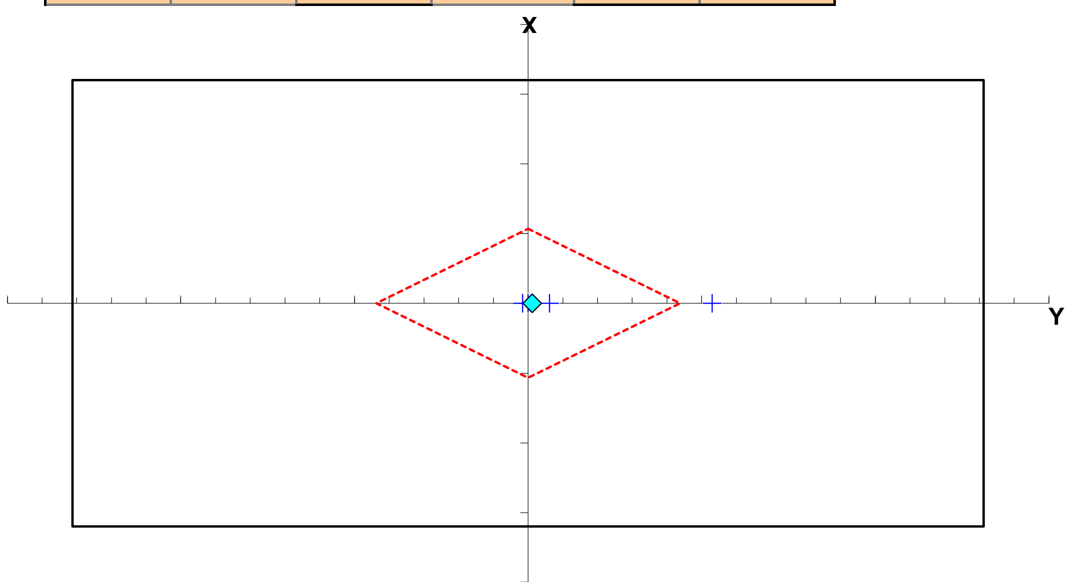


Nomenclature

Loading Data:

Direction of Wind Force: Y-DIRECTION

	Uplift	Vertical Soil	Not Used	Internal Hydrostatic	Not Used	SAP2000 Reaction
Yp (m.) =	0.00	**-0.06**		2.12		**0.25**
Xp (m.) =	0.00	**0.00**		0.00		0.00
Pz (kN) =	4524.31	**-13120.89**		244.76		**-14820.40**
Hy (kN) =	0.00	**0.00**		0.00		**326.40**
Hx (kN) =	0.00	**0.00**		0.00		**0.00**
My (kN-m) =	0.00	**0.00**		0.00		**0.00**
Mx (kN-m) =	0.00	**0.00**		0.00		**-1200.90**



FOOTING PLAN

Note: Is the "Kern" area of footing (When resultant of loads falls within "Kern", entire footing base is in bearing.)

Results:

Total Resultant Load and Eccentricities:

ΣPy =	-23172.22	kN
ey =	0.05	m (<= L/6)
ex =	0.00	
ΣHy =	326.40	kN
ΣHx =	0.00	kN
H resultant =	326.40	kN
ΣMry =	N.A.	kN-m
ΣMoy =	N.A.	kN-m
ΣMrx =	143787.04	kN-m
ΣMox =	20747.60	kN-m

Sliding Check:

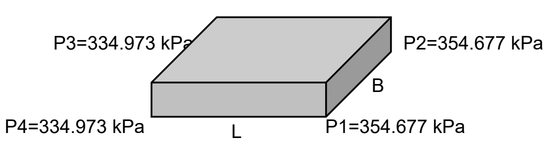
Frict =	11817.83	kN
FS(slid) =	36.206	

% Base Area in Compression:

Dist. y =	N.A.	m
Dist. x =	N.A.	m
Brg. Ly =	10.500	m
Brg. Lx =	6.400	m
%Brg. Area =	100.00	%
Biaxial Case =	N.A.	

Gross Soil Bearing Corner Pressures:

P_1 =	354.677	kPa
P_2 =	354.677	kPa
P_3 =	334.973	kPa
P_4 =	334.973	kPa



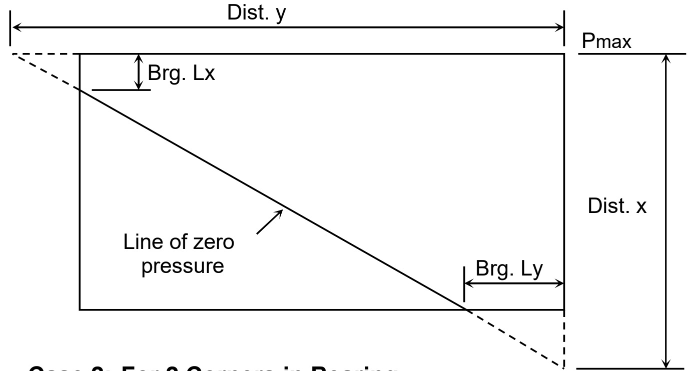
CORNER PRESSURES

Summary of Results:

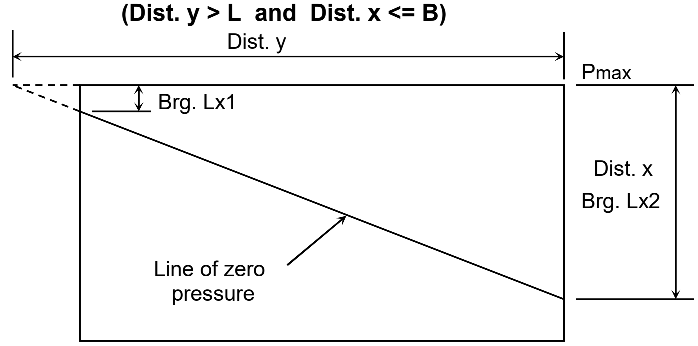
Sliding Check:			
FS(slid) =	36.21	> 1.3	OK
Bearing Area:			
%Brg. Area =	100.00%	< 100%	OK
Bearing Pressure Check:			
FS(brg) =	3.61	> 2.25	OK
Flotation Check:			
FS (float) =	6.12	> 1.3	OK

Nomenclature for Biaxial Eccentricity:

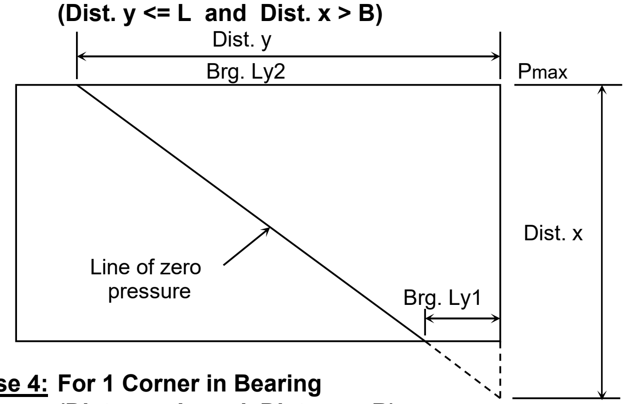
Case 1: For 3 Corners in Bearing
(Dist. y > L and Dist. x > B)



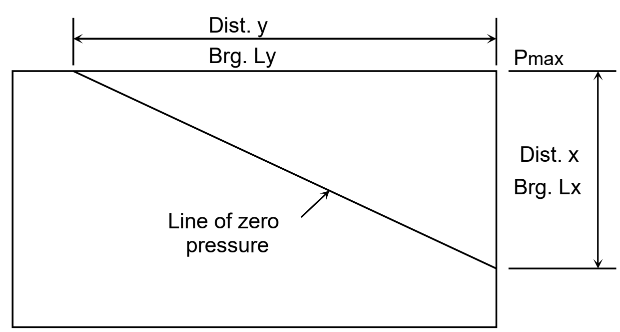
Case 2: For 2 Corners in Bearing
(Dist. y > L and Dist. x <= B)



Case 3: For 2 Corners in Bearing
(Dist. y <= L and Dist. x > B)



Case 4: For 1 Corner in Bearing
(Dist. y <= L and Dist. x <= B)



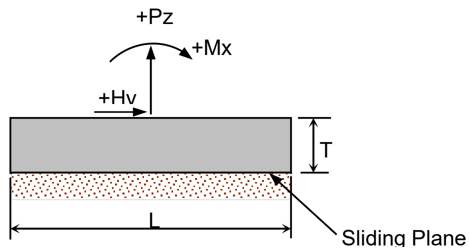
GATE TOWER STABILITY ANALYSIS

Job Name:	Springbank Off-Stream Storage Project	Number:	110773396		
Site:	Gate Tower	Originator:	ACG 7/2/2020	Checker:	CG
Load Case:	UN2-5 10-Year Flood, Front Gate Closed				

Input Data:

Footing Data:

Footing Length, L =	10.50	m
Footing Width, B =	6.40	m
Footing Thickness, T =	0.00	m
Coef. of Base Friction, μ =	0.510	
Ultimate Bearing, Pall =	1281.00	kPa

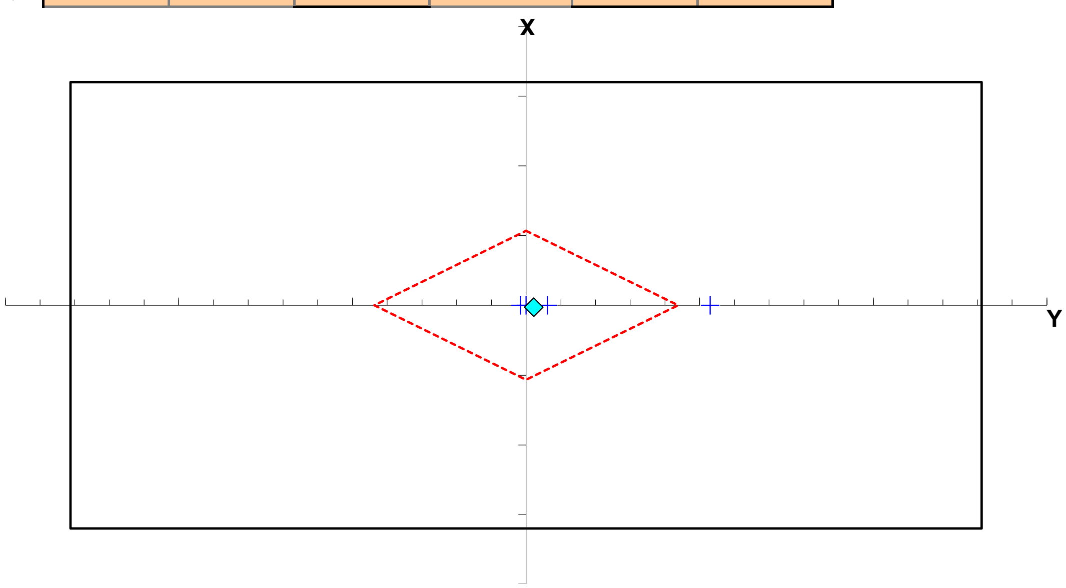


Nomenclature

Loading Data:

Direction of Wind Force: X-DIRECTION

	Uplift	Vertical Soil	Not Used	Internal Hydrostatic	Not Used	SAP2000 Reaction
Yp (m.) =	0.00	**-0.06**		2.12		**0.25**
Xp (m.) =	0.00	**0.00**		0.00		0.00
Pz (kN) =	4524.31	**-13120.89**		244.76		**-14032.34**
Hy (kN) =	0.00	**0.00**		0.00		**63.01**
Hx (kN) =	0.00	**0.00**		0.00		**279.47**
My (kN-m) =	0.00	**0.00**		0.00		**647.45**
Mx (kN-m) =	0.00	**0.00**		0.00		**-191.10**



FOOTING PLAN

Note: Is the "Kern" area of footing (When resultant of loads falls within "Kern", entire footing base is in bearing.)

Results:

Total Resultant Load and Eccentricities:

ΣPy =	-22384.16	kN
ey =	0.09	m (<= L/6)
ex =	-0.03	m (<= B/6)
ΣHy =	63.01	kN
ΣHx =	279.47	kN
H resultant =	286.48	kN
ΣMry =	86890.33	kN-m
ΣMoy =	15908.47	kN-m
ΣMrx =	139846.74	kN-m
ΣMox =	21757.40	kN-m

Sliding Check:

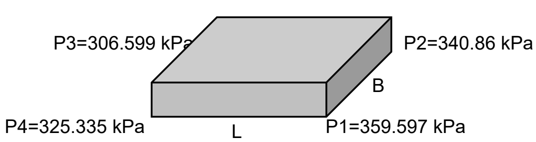
Frict =	11415.92	kN
FS(slid) =	39.848	

% Base Area in Compression:

Dist. y =	N.A.	m
Dist. x =	N.A.	m
Brg. Ly =	10.500	m
Brg. Lx =	6.400	m
%Brg. Area =	100.00	%
Biaxial Case =	N.A.	6*ex/L + 6*ez/B = 0.08

Gross Soil Bearing Corner Pressures:

P_1 =	359.597	kPa
P_2 =	340.860	kPa
P_3 =	306.599	kPa
P_4 =	325.335	kPa



CORNER PRESSURES

Summary of Results:

Sliding Check:

FS(slid) =	**39.85**	> 1.3	OK

Bearing Area:

%Brg. Area =	**100.00%**	< 100%	OK

Bearing Pressure Check:

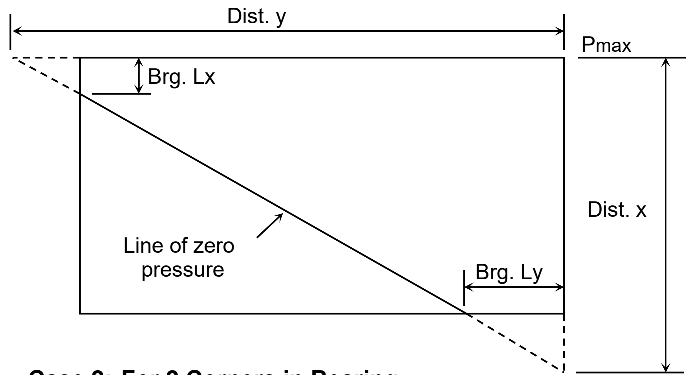
FS(brg) =	**3.56**	> 2.25	OK

Flotation Check:

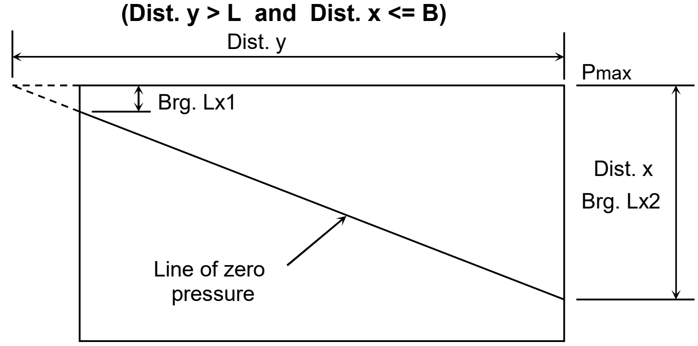
FS (float) =	**5.95**	> 1.3	OK

Nomenclature for Biaxial Eccentricity:

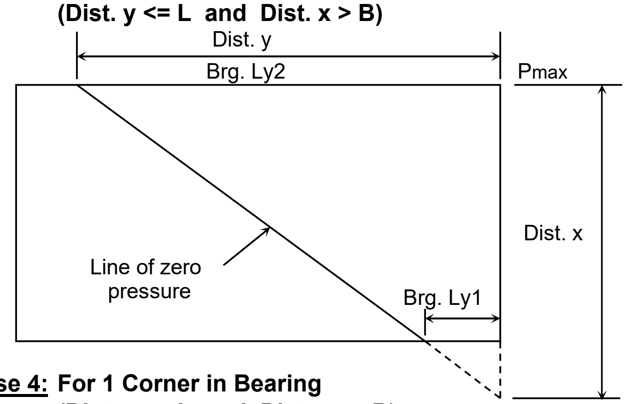
Case 1: For 3 Corners in Bearing
(Dist. y > L and Dist. x > B)



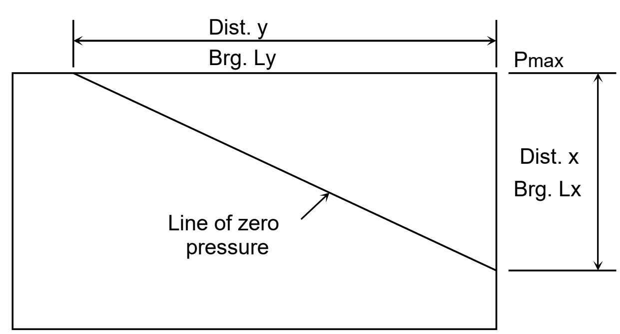
Case 2: For 2 Corners in Bearing
(Dist. y > L and Dist. x <= B)



Case 3: For 2 Corners in Bearing
(Dist. y <= L and Dist. x > B)



Case 4: For 1 Corner in Bearing
(Dist. y <= L and Dist. x <= B)



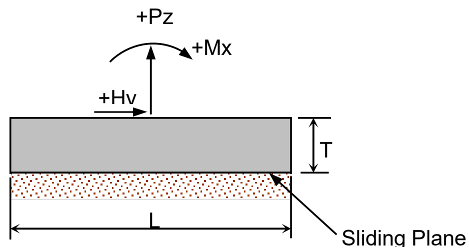
GATE TOWER STABILITY ANALYSIS

Job Name:	Springbank Off-Stream Storage Project	Number:	110773396		
Site:	Gate Tower	Originator:	ACG 7/2/2020	Checker:	CG
Load Case:	UN2-6+ 10-Year Flood, Front Gate Closed				

Input Data:

Footing Data:

Footing Length, L =	10.50	m
Footing Width, B =	6.40	m
Footing Thickness, T =	0.00	m
Coef. of Base Friction, μ =	0.510	
Ultimate Bearing, Pall =	1281.00	kPa

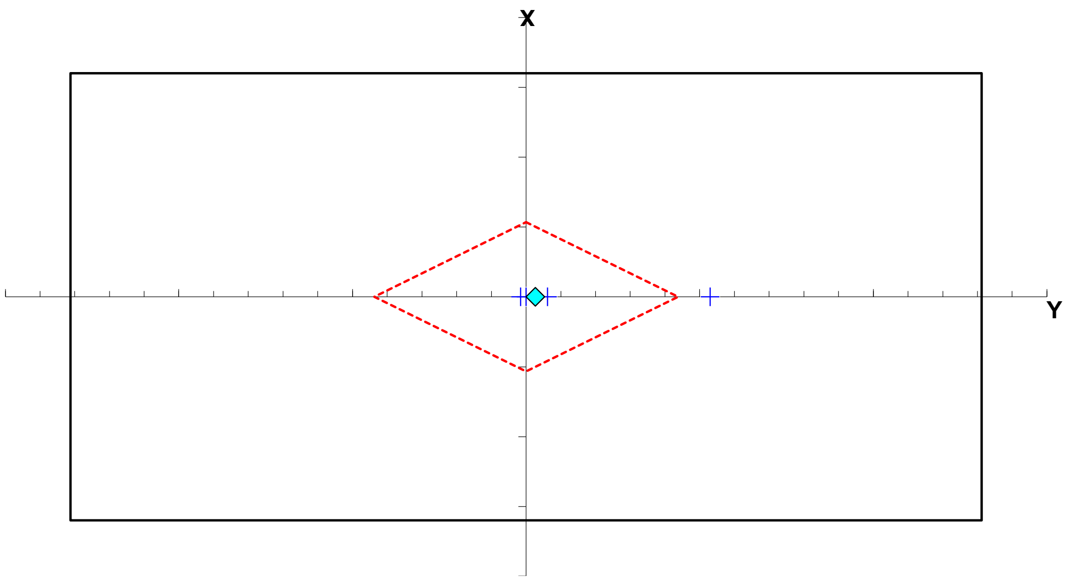


Nomenclature

Loading Data:

Direction of Wind Force: Y-DIRECTION

	Uplift	Vertical Soil	Not Used	Internal Hydrostatic	Not Used	SAP2000 Reaction
Yp (m.) =	0.00	-0.06		2.12		0.25
Xp (m.) =	0.00	0.00		0.00		0.00
Pz (kN) =	4524.31	-13120.89		244.76		-14160.00
Hy (kN) =	0.00	0.00		0.00		-14.59
Hx (kN) =	0.00	0.00		0.00		0.00
My (kN-m) =	0.00	0.00		0.00		0.00
Mx (kN-m) =	0.00	0.00		0.00		172.02



FOOTING PLAN

Note: Is the "Kern" area of footing (When resultant of loads falls within "Kern", entire footing base is in bearing.)

Results:

Total Resultant Load and Eccentricities:

ΣPy =	-22511.82	kN
ey =	0.11	m (<= L/6)
ex =	0.00	
ΣHy =	-14.59	kN
ΣHx =	0.00	kN
H resultant =	14.59	kN
ΣMry =	N.A.	kN-m
ΣMoy =	N.A.	kN-m
ΣMrx =	140485.04	kN-m
ΣMox =	22120.53	kN-m

Sliding Check:

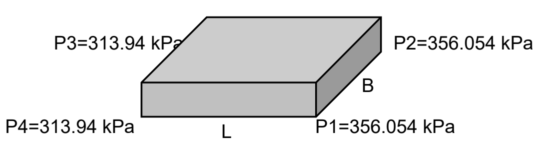
Frict =	11481.03	kN
FS(slid) =	786.695	

% Base Area in Compression:

Dist. y =	N.A.	m
Dist. x =	N.A.	m
Brg. Ly =	10.500	m
Brg. Lx =	6.400	m
%Brg. Area =	100.00	%
Biaxial Case =	N.A.	

Gross Soil Bearing Corner Pressures:

P_1 =	356.054	kPa
P_2 =	356.054	kPa
P_3 =	313.940	kPa
P_4 =	313.940	kPa



CORNER PRESSURES

Summary of Results:

Sliding Check:

FS(slid) =	786.70	> 1.3	OK

Bearing Area:

%Brg. Area =	100.00%	< 100%	OK

Bearing Pressure Check:

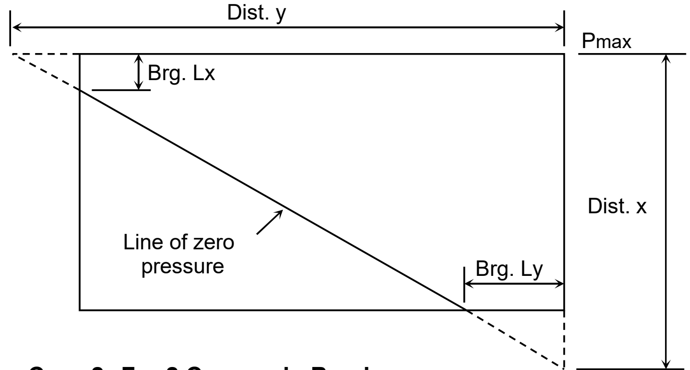
FS(brg) =	3.60	> 2.25	OK

Flotation Check:

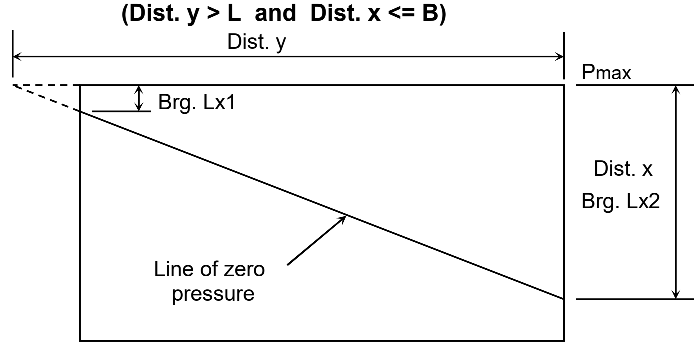
FS (float) =	5.98	> 1.3	OK

Nomenclature for Biaxial Eccentricity:

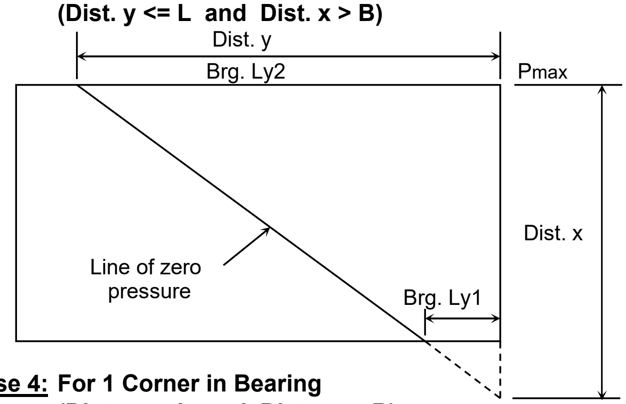
Case 1: For 3 Corners in Bearing
(Dist. y > L and Dist. x > B)



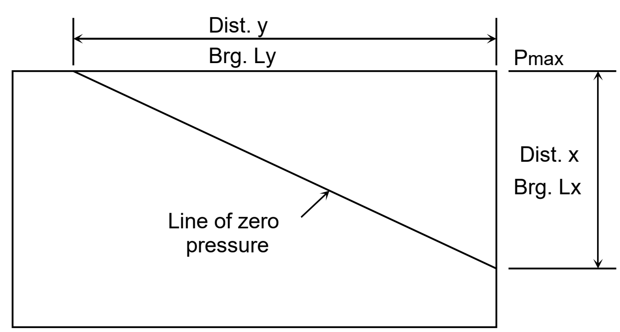
Case 2: For 2 Corners in Bearing
(Dist. y > L and Dist. x <= B)



Case 3: For 2 Corners in Bearing
(Dist. y <= L and Dist. x > B)



Case 4: For 1 Corner in Bearing
(Dist. y <= L and Dist. x <= B)



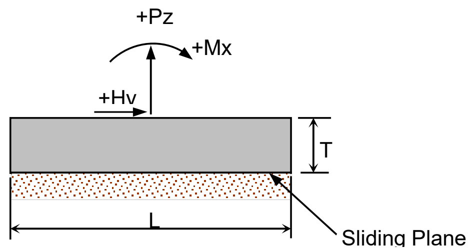
GATE TOWER STABILITY ANALYSIS

Job Name:	Springbank Off-Stream Storage Project	Number:	110773396			
Site:	Gate Tower	Originator:	ACG	7/2/2020	Checker:	CG
Load Case:	UN2-6- 10-Year Flood, Front Gate Closed					

Input Data:

Footing Data:

Footing Length, L =	10.50	m
Footing Width, B =	6.40	m
Footing Thickness, T =	0.00	m
Coef. of Base Friction, μ =	0.510	
Ultimate Bearing, Pall =	1281.00	kPa

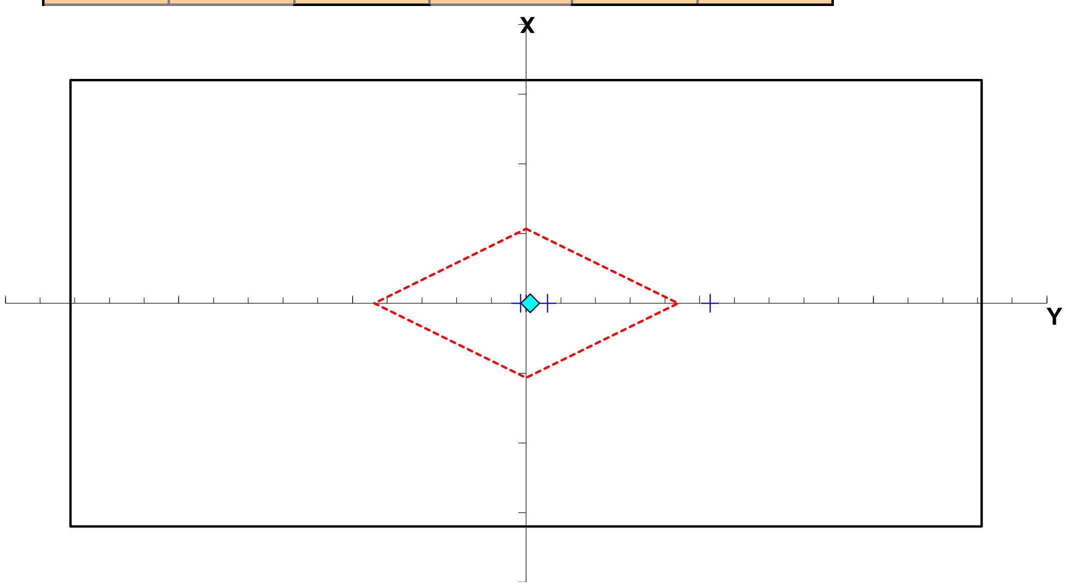


Nomenclature

Loading Data:

Direction of Wind Force: Y-DIRECTION

	Uplift	Vertical Soil	Not Used	Internal Hydrostatic	Not Used	SAP2000 Reaction
Yp (m.) =	0.00	**-0.06**		2.12		**0.25**
Xp (m.) =	0.00	**0.00**		0.00		0.00
Pz (kN) =	4524.31	**-13120.89**		244.76		**-14260.20**
Hy (kN) =	0.00	**0.00**		0.00		**271.65**
Hx (kN) =	0.00	**0.00**		0.00		**0.00**
My (kN-m) =	0.00	**0.00**		0.00		**0.00**
Mx (kN-m) =	0.00	**0.00**		0.00		**-1041.63**



FOOTING PLAN

Note: Is the "Kern" area of footing (When resultant of loads falls within "Kern", entire footing base is in bearing.)

Results:

Total Resultant Load and Eccentricities:

ΣPy =	-22612.02	kN
ey =	0.05	m (<= L/6)
ex =	0.00	
ΣHy =	271.65	kN
ΣHx =	0.00	kN
H resultant =	271.65	kN
ΣMry =	N.A.	kN-m
ΣMoy =	N.A.	kN-m
ΣMrx =	140986.04	kN-m
ΣMox =	20906.87	kN-m

Sliding Check:

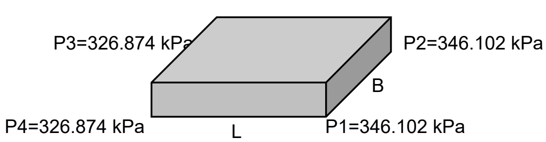
Frict =	11532.13	kN
FS(slid) =	42.452	

% Base Area in Compression:

Dist. y =	N.A.	m
Dist. x =	N.A.	m
Brg. Ly =	10.500	m
Brg. Lx =	6.400	m
%Brg. Area =	100.00	%
Biaxial Case =	N.A.	

Gross Soil Bearing Corner Pressures:

P_1 =	346.102	kPa
P_2 =	346.102	kPa
P_3 =	326.874	kPa
P_4 =	326.874	kPa



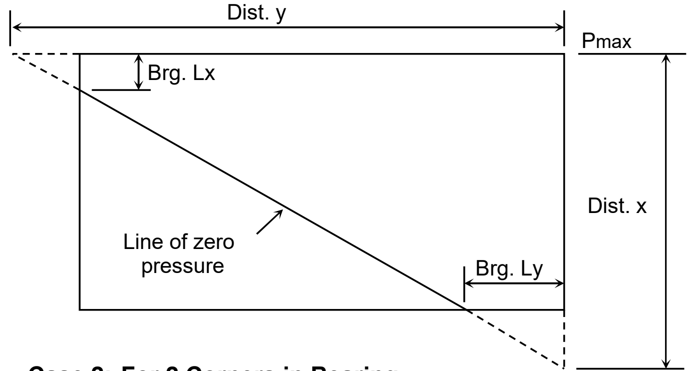
CORNER PRESSURES

Summary of Results:

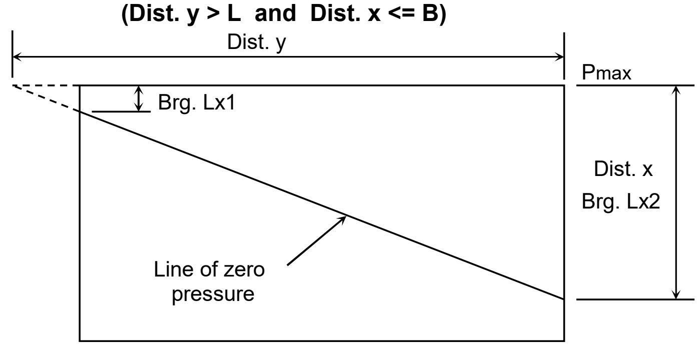
Sliding Check:			
FS(slid) =	42.45	> 1.3	OK
Bearing Area:			
%Brg. Area =	100.00%	< 100%	OK
Bearing Pressure Check:			
FS(brg) =	3.70	> 2.25	OK
Flotation Check:			
FS (float) =	6.00	> 1.3	OK

Nomenclature for Biaxial Eccentricity:

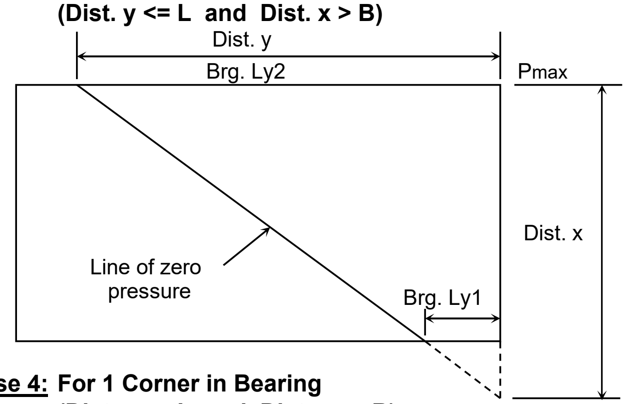
Case 1: For 3 Corners in Bearing
(Dist. y > L and Dist. x > B)



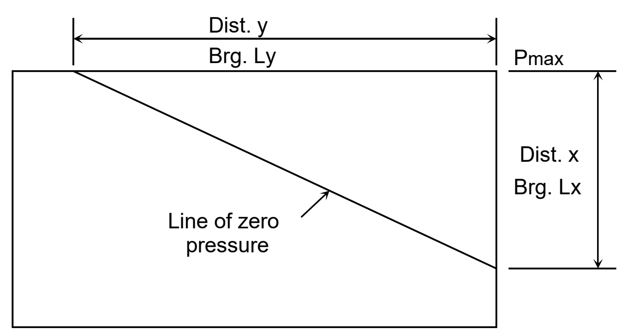
Case 2: For 2 Corners in Bearing
(Dist. y > L and Dist. x <= B)



Case 3: For 2 Corners in Bearing
(Dist. y <= L and Dist. x > B)



Case 4: For 1 Corner in Bearing
(Dist. y <= L and Dist. x <= B)



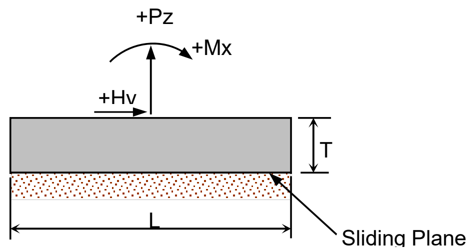
GATE TOWER STABILITY ANALYSIS

Job Name:	Springbank Off-Stream Storage Project	Number:	110773396		
Site:	Gate Tower	Originator:	ACG 7/2/2020	Checker:	CG
Load Case:	UN3-1 Construction				

Input Data:

Footing Data:

Footing Length, L =	10.50	m
Footing Width, B =	6.40	m
Footing Thickness, T =	0.00	m
Coef. of Base Friction, μ =	0.510	
Ultimate Bearing, Pall =	750.000	kPa

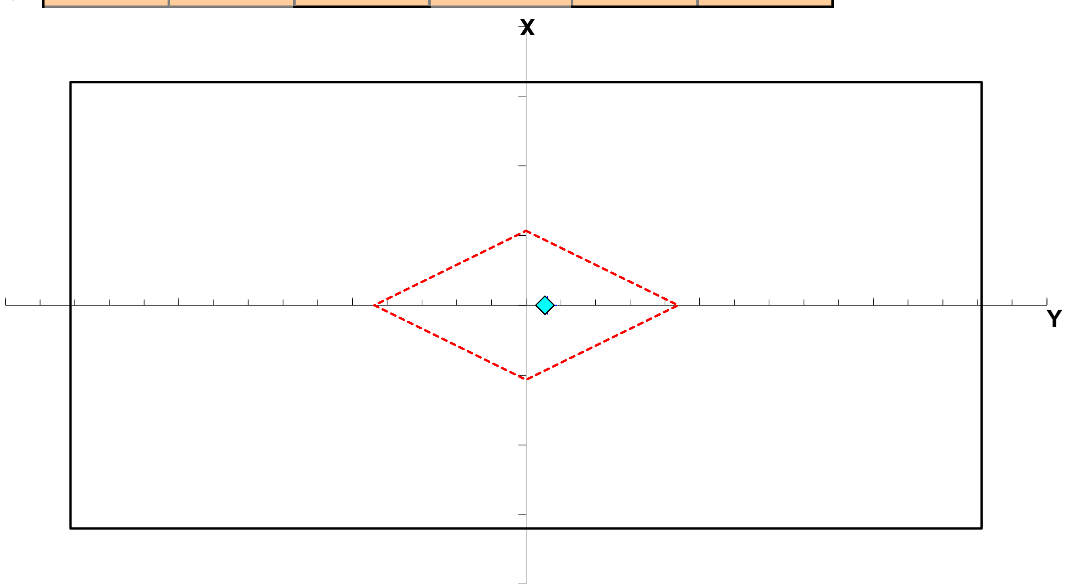


Nomenclature

Loading Data:

Direction of Wind Force: N/A

	Uplift	Vertical Soil	Not Used	Internal Hydrostatic	Not Used	SAP2000 Reaction
Yp (m.) =						0.25
Xp (m.) =						0.00
Pz (kN) =						-7105.05
Hy (kN) =						146.50
Hx (kN) =						0.00
My (kN-m) =						0.00
Mx (kN-m) =						-225.09



FOOTING PLAN

Note: Is the "Kern" area of footing (When resultant of loads falls within "Kern", entire footing base is in bearing.)

Results:

Total Resultant Load and Eccentricities:

ΣPy =	-7105.05	kN
ey =	0.22	m (<= L/6)
ex =	0.00	
ΣHy =	146.50	kN
ΣHx =	0.00	kN
H resultant =	146.50	kN
ΣMry =	N.A.	kN-m
ΣMoy =	N.A.	kN-m
ΣMrx =	39077.77	kN-m
ΣMox =	-225.09	kN-m

Sliding Check:

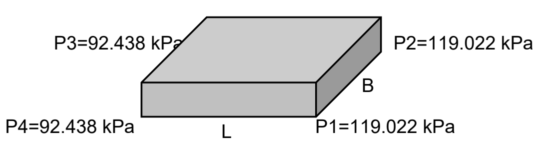
Frict =	3623.58	kN
FS(slid) =	24.734	

% Base Area in Compression:

Dist. y =	N.A.	m
Dist. x =	N.A.	m
Brg. Ly =	10.500	m
Brg. Lx =	6.400	m
%Brg. Area =	100.00	%
Biaxial Case =	N.A.	

Gross Soil Bearing Corner Pressures:

P_1 =	119.022	kPa
P_2 =	119.022	kPa
P_3 =	92.438	kPa
P_4 =	92.438	kPa



CORNER PRESSURES

Summary of Results:

Sliding Check:

FS(slid) =	2.47E+01	> 1.3	OK

Bearing Area:

%Brg. Area =	100.00%	< 100%	OK

Bearing Pressure Check:

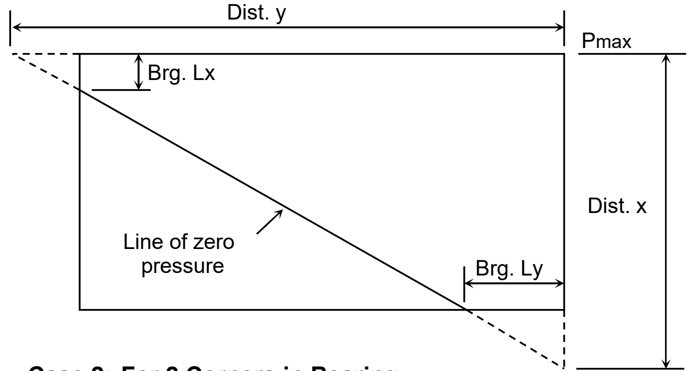
FS(brg) =	6.30	> 3.0	OK

Flotation Check:

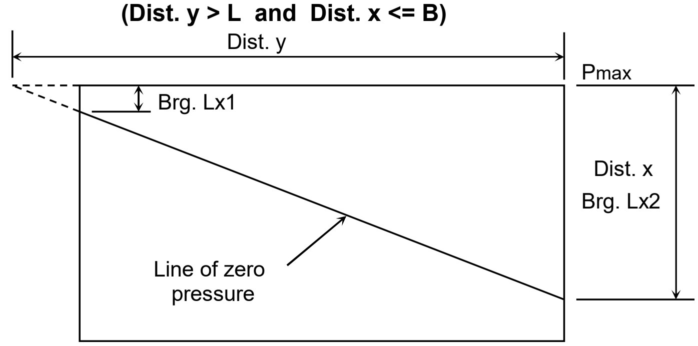
FS (float) =	10000.00	> 1.3	OK

Nomenclature for Biaxial Eccentricity:

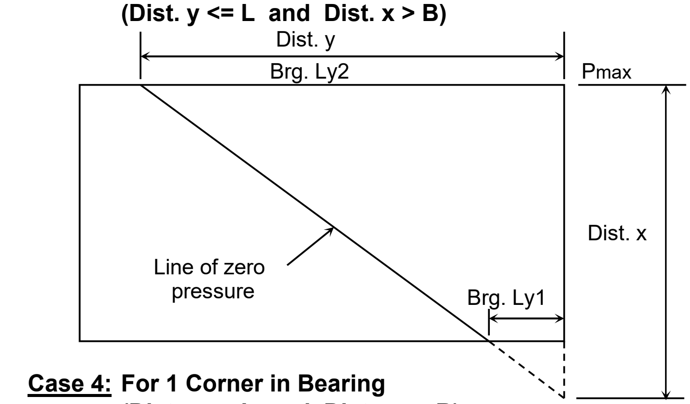
Case 1: For 3 Corners in Bearing
(Dist. y > L and Dist. x > B)



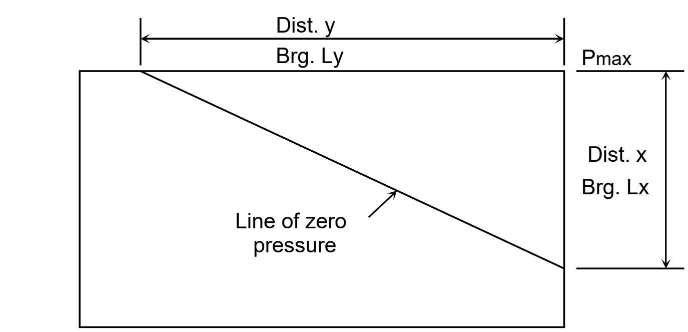
Case 2: For 2 Corners in Bearing
(Dist. y > L and Dist. x <= B)



Case 3: For 2 Corners in Bearing
(Dist. y <= L and Dist. x > B)



Case 4: For 1 Corner in Bearing
(Dist. y <= L and Dist. x <= B)



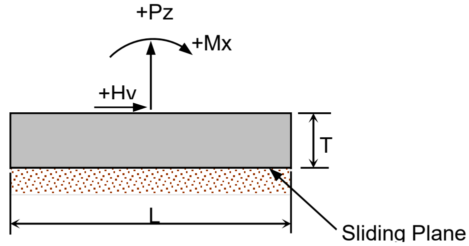
GATE TOWER STABILITY ANALYSIS

Job Name:	Springbank Off-Stream Storage Project	Number:	110773396		
Site:	Gate Tower	Originator:	ACG 7/2/2020	Checker:	CG
Load Case:	UN4-1 Crane Adjacent to Tower				

Input Data:

Footing Data:

Footing Length, L =	10.50	m
Footing Width, B =	6.40	m
Footing Thickness, T =	0.00	m
Coef. of Base Friction, μ =	0.510	
Ultimate Bearing, Pall =	1281.00	kPa

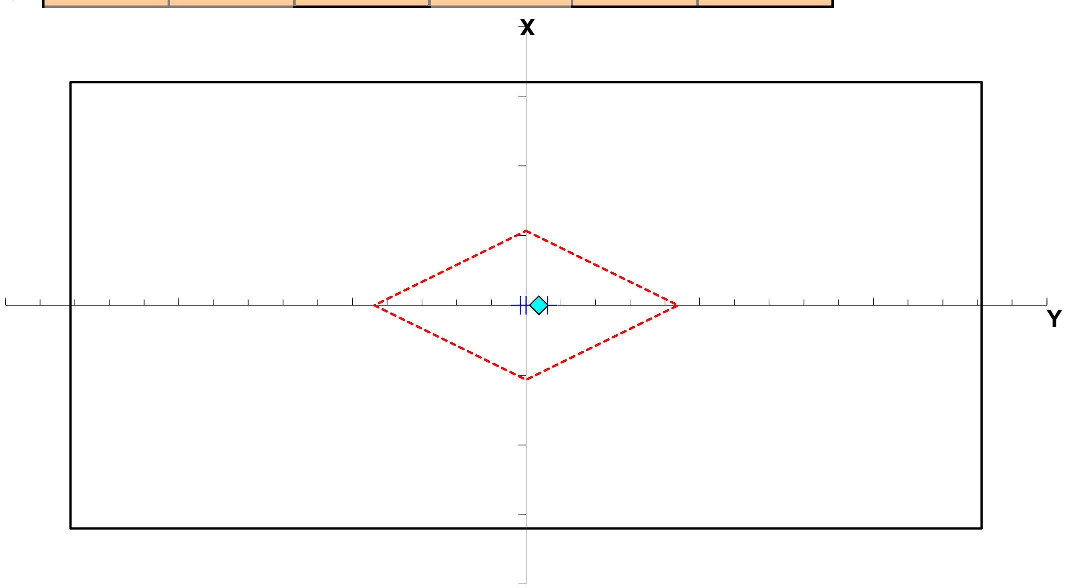


Nomenclature

Loading Data:

Direction of Wind Force: N/A

	Uplift	Vertical Soil	Not Used	Internal Hydrostatic	Not Used	SAP2000 Reaction
Yp (m.) =	0.00	**-0.06**				**0.25**
Xp (m.) =	0.00	**0.00**				0.00
Pz (kN) =	1185.41	**-13120.89**				**-14160.00**
Hy (kN) =	0.00	**0.00**				**289.86**
Hx (kN) =	0.00	**0.00**				**0.00**
My (kN-m) =	0.00	**0.00**				**0.00**
Mx (kN-m) =	0.00	**0.00**				**1115.09**



FOOTING PLAN

Note: Is the "Kern" area of footing (When resultant of loads falls within "Kern", entire footing base is in bearing.)

Results:

Total Resultant Load and Eccentricities:

ΣPy =	-26095.48	kN
ey =	0.15	m (<= L/6)
ex =	0.00	
ΣHy =	289.86	kN
ΣHx =	0.00	kN
H resultant =	289.86	kN
ΣMry =	N.A.	kN-m
ΣMoy =	N.A.	kN-m
ΣMrx =	140485.04	kN-m
ΣMox =	7338.49	kN-m

Sliding Check:

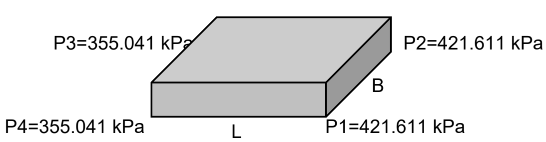
Frict =	13308.69	kN
FS(slid) =	45.914	

% Base Area in Compression:

Dist. y =	N.A.	m
Dist. x =	N.A.	m
Brg. Ly =	10.500	m
Brg. Lx =	6.400	m
%Brg. Area =	100.00	%
Biaxial Case =	N.A.	

Gross Soil Bearing Corner Pressures:

P_1 =	421.611	kPa
P_2 =	421.611	kPa
P_3 =	355.041	kPa
P_4 =	355.041	kPa



CORNER PRESSURES

Summary of Results:

Sliding Check:

FS(slid) = **4.59E+01** > 1.3 OK

Bearing Area:

%Brg. Area = **100.00%** < 100% OK

Bearing Pressure Check:

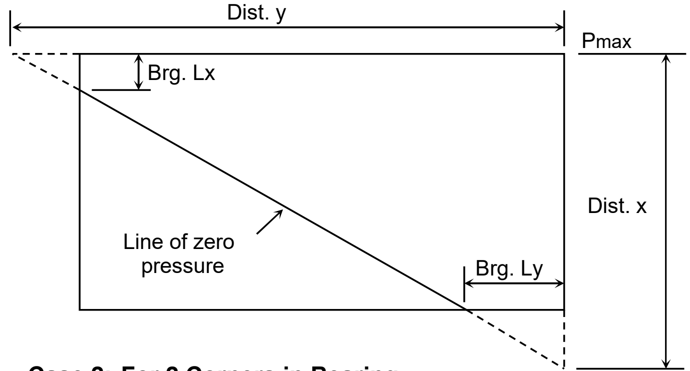
FS(brg) = **3.04** > 2.25 OK

Flotation Check:

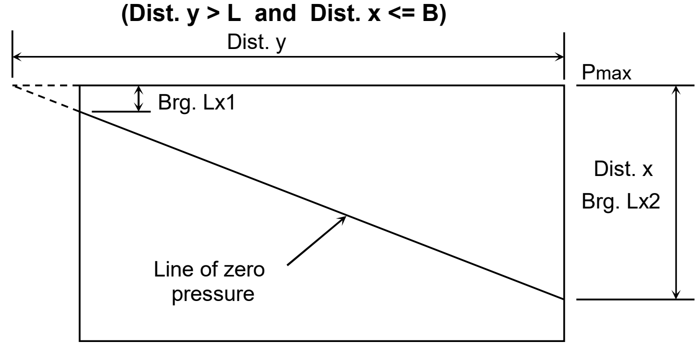
FS (float) = **23.01** > 1.3 OK

Nomenclature for Biaxial Eccentricity:

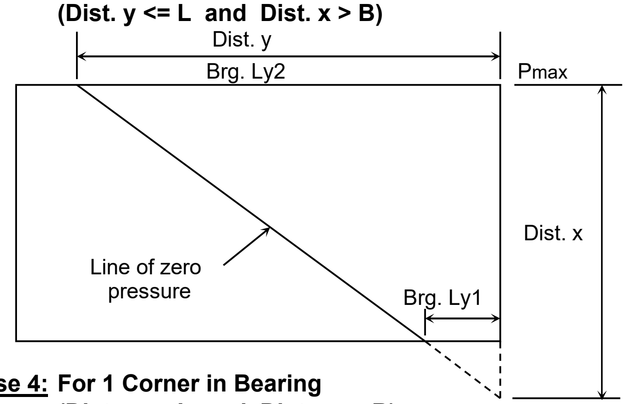
Case 1: For 3 Corners in Bearing
(Dist. y > L and Dist. x > B)



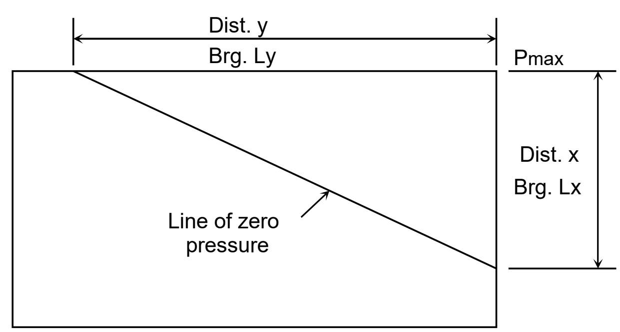
Case 2: For 2 Corners in Bearing
(Dist. y > L and Dist. x <= B)



Case 3: For 2 Corners in Bearing
(Dist. y <= L and Dist. x > B)



Case 4: For 1 Corner in Bearing
(Dist. y <= L and Dist. x <= B)



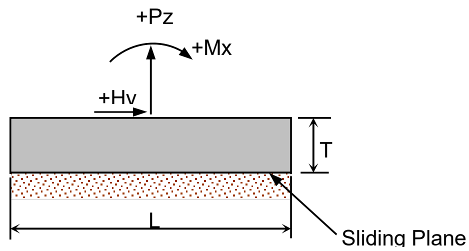
GATE TOWER STABILITY ANALYSIS

Job Name:	Springbank Off-Stream Storage Project	Number:	110773396				
Site:	Gate Tower	Originator:	ACG	7/2/2020	Checker:	CG	
Load Case:	UN4-2 Crane Adjacent to Tower						

Input Data:

Footing Data:

Footing Length, L =	10.50	m
Footing Width, B =	6.40	m
Footing Thickness, T =	0.00	m
Coef. of Base Friction, μ =	0.510	
Ultimate Bearing, Pall =	1281.00	kPa

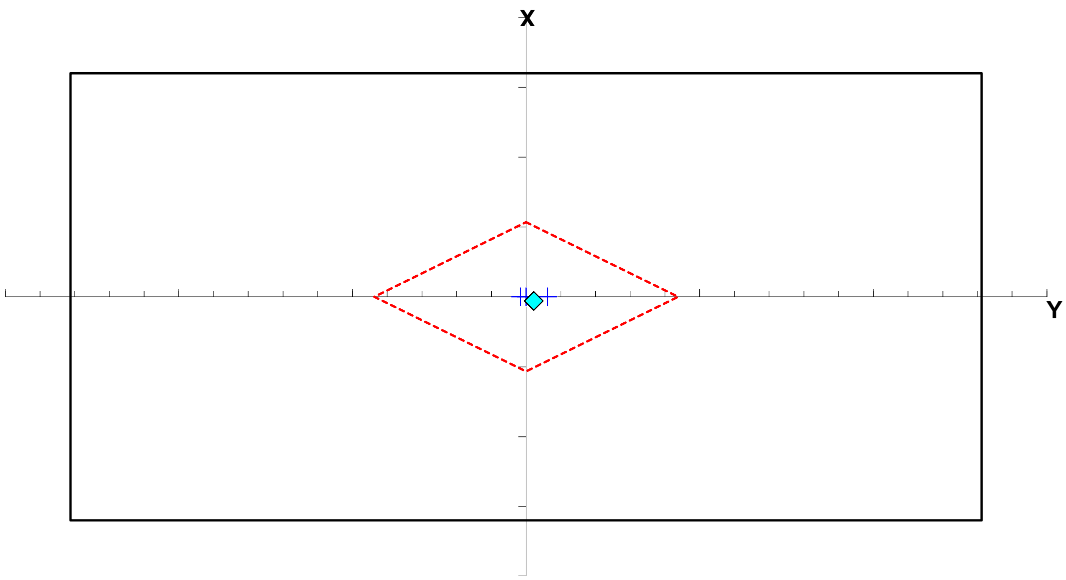


Nomenclature

Loading Data:

Direction of Wind Force: N/A

	Uplift	Vertical Soil	Not Used	Internal Hydrostatic	Not Used	SAP2000 Reaction
Yp (m.) =	0.00	-0.06				0.25
Xp (m.) =	0.00	0.00				0.00
Pz (kN) =	1185.41	-13120.89				-14032.34
Hy (kN) =	0.00	0.00				125.73
Hx (kN) =	0.00	0.00				-139.28
My (kN-m) =	0.00	0.00				1673.39
Mx (kN-m) =	0.00	0.00				-389.82



FOOTING PLAN

Note: Is the "Kern" area of footing (When resultant of loads falls within "Kern", entire footing base is in bearing.)

Results:

Total Resultant Load and Eccentricities:

ΣPy =	-25967.82	kN
ey =	0.09	m (<= L/6)
ex =	-0.06	m (<= B/6)
ΣHy =	125.73	kN
ΣHx =	-139.28	kN
H resultant =	187.63	kN
ΣMry =	86890.33	kN-m
ΣMoy =	5466.70	kN-m
ΣMrx =	139846.74	kN-m
ΣMox =	5833.59	kN-m

Sliding Check:

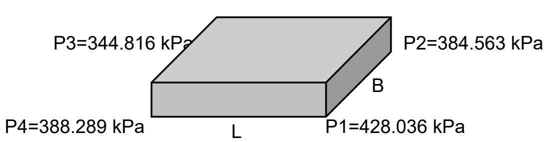
Frict =	13243.59	kN
FS(slid) =	70.582	

% Base Area in Compression:

Dist. y =	N.A.	m
Dist. x =	N.A.	m
Brg. Ly =	10.500	m
Brg. Lx =	6.400	m
%Brg. Area =	100.00	%
Biaxial Case =	N.A.	6*ex/L + 6*ez/B = 0.108

Gross Soil Bearing Corner Pressures:

P_1 =	428.036	kPa
P_2 =	384.563	kPa
P_3 =	344.816	kPa
P_4 =	388.289	kPa



CORNER PRESSURES

Summary of Results:

Sliding Check:

FS(slid) =	7.06E+01	> 1.3	OK

Bearing Area:

%Brg. Area =	100.00%	< 100%	OK

Bearing Pressure Check:

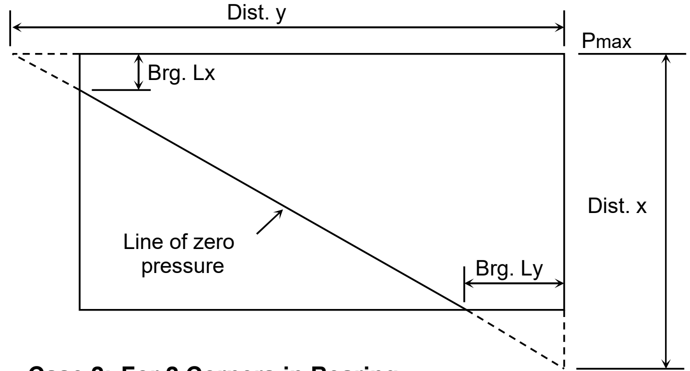
FS(brg) =	2.99	> 2.25	OK

Flotation Check:

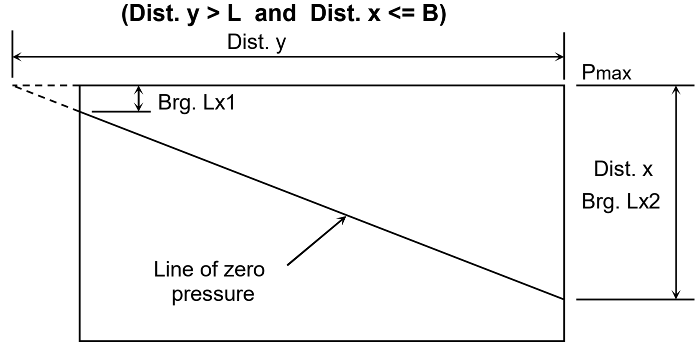
FS (float) =	22.91	> 1.3	OK

Nomenclature for Biaxial Eccentricity:

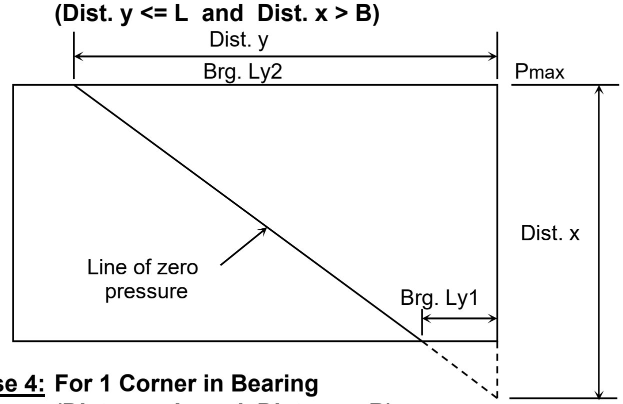
Case 1: For 3 Corners in Bearing
(Dist. y > L and Dist. x > B)



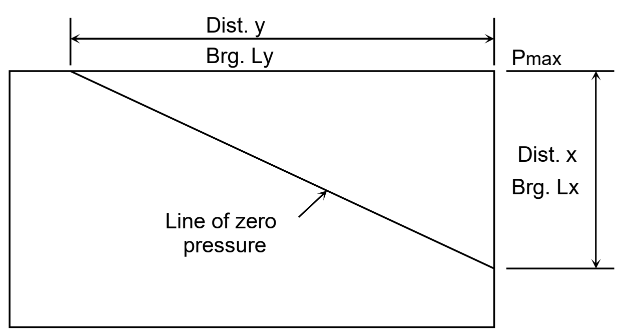
Case 2: For 2 Corners in Bearing
(Dist. y > L and Dist. x <= B)



Case 3: For 2 Corners in Bearing
(Dist. y <= L and Dist. x > B)



Case 4: For 1 Corner in Bearing
(Dist. y <= L and Dist. x <= B)



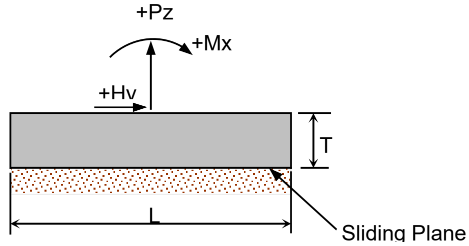
GATE TOWER STABILITY ANALYSIS

Job Name:	Springbank Off-Stream Storage Project	Number:	110773396		
Site:	Gate Tower	Originator:	ACG 7/2/2020	Checker:	CG
Load Case:	E1-1 Extreme Flood, Gates Closed				

Input Data:

Footing Data:

Footing Length, L =	10.50	m
Footing Width, B =	6.40	m
Footing Thickness, T =	0.00	m
Coef. of Base Friction, µ =	0.510	
Ultimate Bearing, Pall =	1281.00	kPa

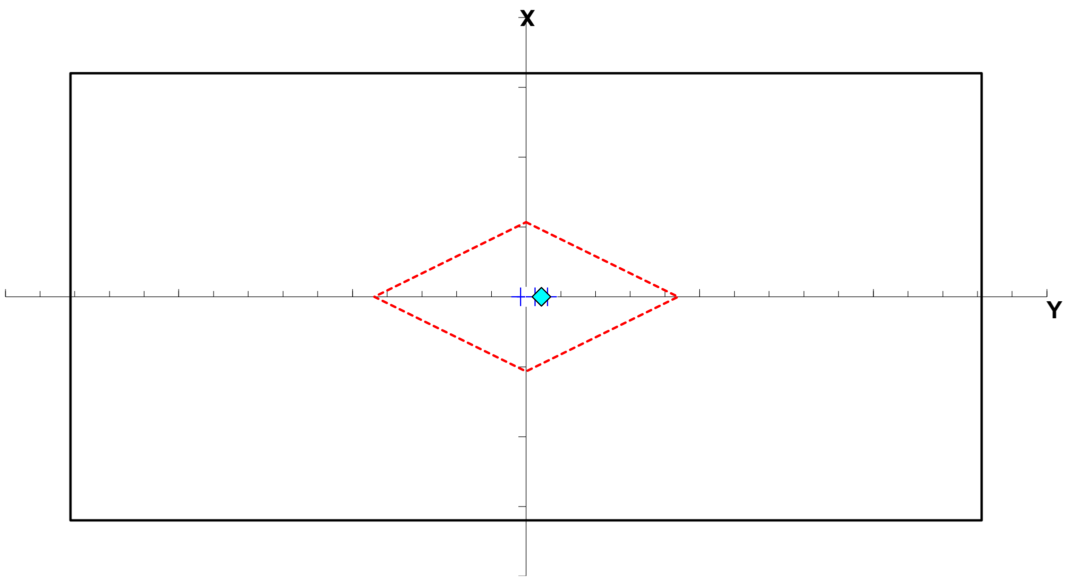


Nomenclature

Loading Data:

Direction of Wind Force: N/A

	Uplift	Vertical Soil	Not Used	Internal Hydrostatic	Not Used	SAP2000 Reaction
Yp (m.) =	0.00	**-0.06**		0.11		**0.25**
Xp (m.) =	0.00	**0.00**		0.00		0.00
Pz (kN) =	18151.17	**-13120.89**		-12139.03		**-14210.10**
Hy (kN) =	0.00	**0.00**		0.00		**-9.13**
Hx (kN) =	0.00	**0.00**		0.00		**0.00**
My (kN-m) =	0.00	**0.00**		0.00		**0.00**
Mx (kN-m) =	0.00	**0.00**		0.00		**-171.95**



FOOTING PLAN

Note: Is the "Kern" area of footing (When resultant of loads falls within "Kern", entire footing base is in bearing.)

Results:

Total Resultant Load and Eccentricities:

ΣPy =	-21318.85	kN
ey =	0.18	m (<= L/6)
ex =	0.00	
ΣHy =	-9.13	kN
ΣHx =	0.00	kN
H resultant =	9.13	kN
ΣMry =	N.A.	kN-m
ΣMoy =	N.A.	kN-m
ΣMrx =	203190.85	kN-m
ΣMox =	95121.69	kN-m

Sliding Check:

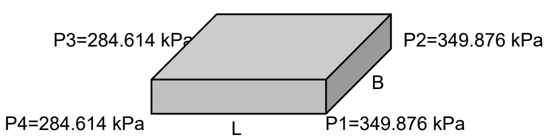
Frict =	10872.61	kN
FS(slid) =	1191.389	

% Base Area in Compression:

Dist. y =	N.A.	m
Dist. x =	N.A.	m
Brg. Ly =	10.500	m
Brg. Lx =	6.400	m
%Brg. Area =	100.00	%
Biaxial Case =	N.A.	

Gross Soil Bearing Corner Pressures:

P_1 =	349.876	kPa
P_2 =	349.876	kPa
P_3 =	284.614	kPa
P_4 =	284.614	kPa



CORNER PRESSURES

Summary of Results:

Sliding Check:

FS(slid) =	1191.39	> 1.1	OK

Bearing Area:

%Brg. Area =	100.00%	> 75%	OK

Bearing Pressure Check:

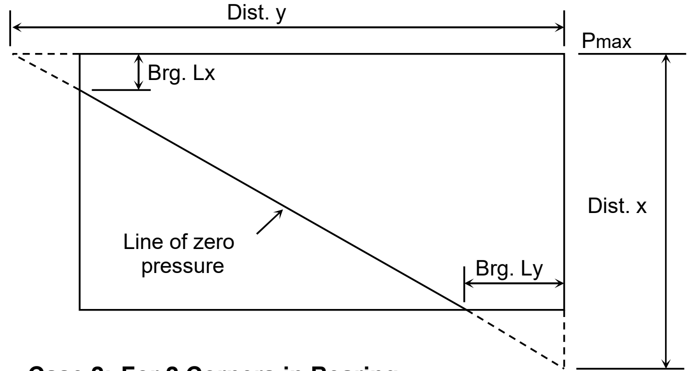
FS(brg) =	3.66	> 3.0	OK

Flotation Check:

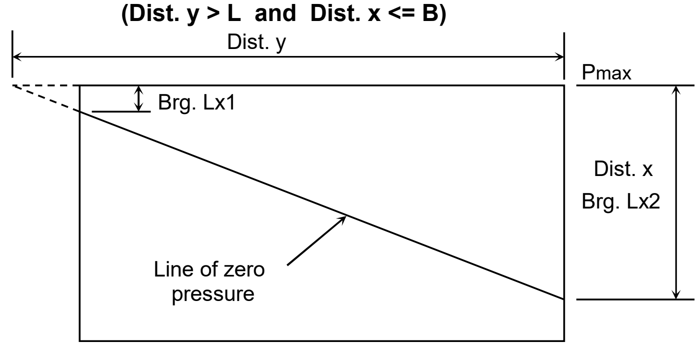
FS (float) =	2.17	> 1.1	OK

Nomenclature for Biaxial Eccentricity:

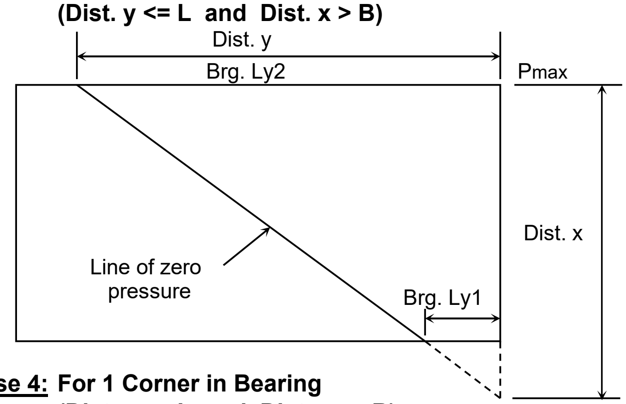
Case 1: For 3 Corners in Bearing (Dist. y > L and Dist. x > B)



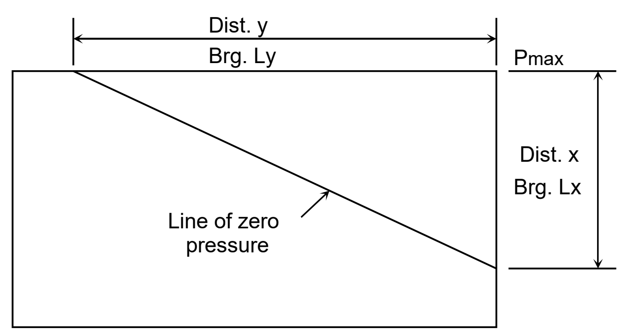
Case 2: For 2 Corners in Bearing (Dist. y > L and Dist. x <= B)



Case 3: For 2 Corners in Bearing (Dist. y <= L and Dist. x > B)



Case 4: For 1 Corner in Bearing (Dist. y <= L and Dist. x <= B)



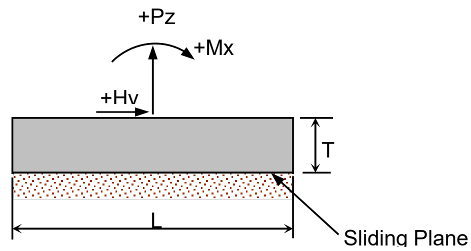
GATE TOWER STABILITY ANALYSIS

Job Name:	Springbank Off-Stream Storage Project	Number:	110773396		
Site:	Gate Tower	Originator:	ACG 7/2/2020	Checker:	CG
Load Case:	E1-2 Extreme Flood, Gates Closed				

Input Data:

Footing Data:

Footing Length, L =	10.50	m
Footing Width, B =	6.40	m
Footing Thickness, T =	0.00	m
Coef. of Base Friction, μ =	0.510	
Ultimate Bearing, Pall =	1281.00	kPa

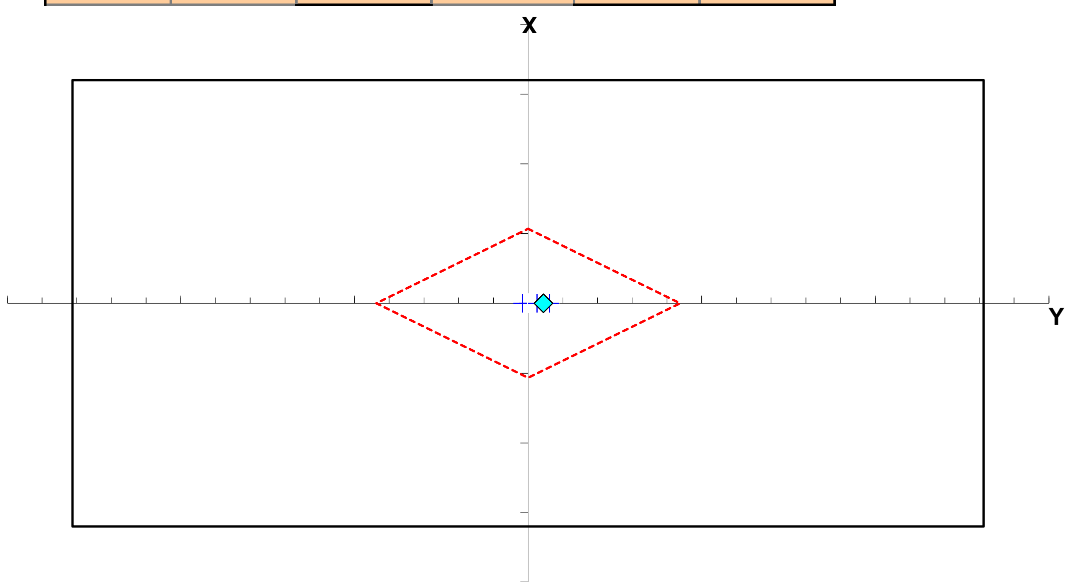


Nomenclature

Loading Data:

Direction of Wind Force: N/A

	Uplift	Vertical Soil	Not Used	Internal Hydrostatic	Not Used	SAP2000 Reaction
Yp (m.) =	0.00	**-0.06**		0.11		**0.25**
Xp (m.) =	0.00	**0.00**		0.00		0.00
Pz (kN) =	18151.17	**-13120.89**		-12139.03		**-14770.30**
Hy (kN) =	0.00	**0.00**		0.00		**45.62**
Hx (kN) =	0.00	**0.00**		0.00		**0.00**
My (kN-m) =	0.00	**0.00**		0.00		**0.00**
Mx (kN-m) =	0.00	**0.00**		0.00		**-331.22**



FOOTING PLAN

Note: Is the "Kern" area of footing (When resultant of loads falls within "Kern", entire footing base is in bearing.)

Results:

Total Resultant Load and Eccentricities:

ΣPy =	-21879.05	kN
ey =	0.18	m (<= L/6)
ex =	0.00	
ΣHy =	45.62	kN
ΣHx =	0.00	kN
H resultant =	45.62	kN
ΣMry =	N.A.	kN-m
ΣMoy =	N.A.	kN-m
ΣMrx =	205991.85	kN-m
ΣMox =	94962.42	kN-m

Sliding Check:

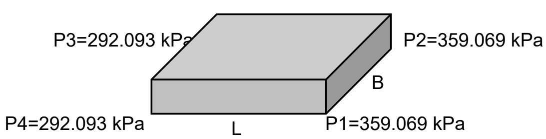
Frict =	11158.31	kN
FS(slid) =	244.571	

% Base Area in Compression:

Dist. y =	N.A.	m
Dist. x =	N.A.	m
Brg. Ly =	10.500	m
Brg. Lx =	6.400	m
%Brg. Area =	100.00	%
Biaxial Case =	N.A.	

Gross Soil Bearing Corner Pressures:

P_1 =	359.069	kPa
P_2 =	359.069	kPa
P_3 =	292.093	kPa
P_4 =	292.093	kPa



CORNER PRESSURES

Summary of Results:

Sliding Check:

FS(slid) =	244.57	> 1.1	OK

Bearing Area:

%Brg. Area =	100.00%	> 75%	OK

Bearing Pressure Check:

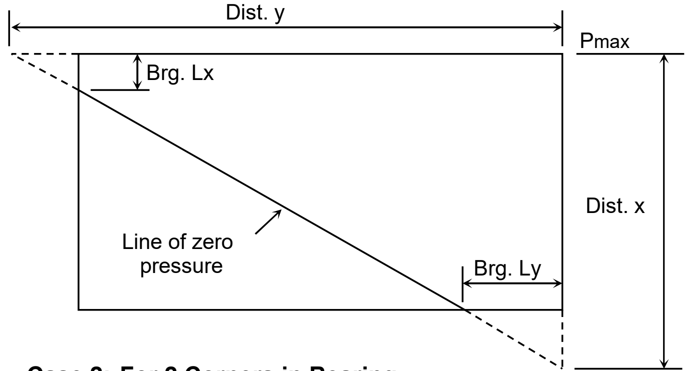
FS(brg) =	3.57	> 2.25	OK

Flotation Check:

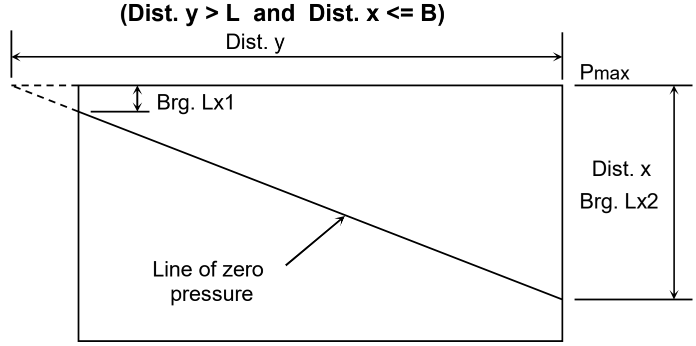
FS (float) =	2.21	> 1.1	OK

Nomenclature for Biaxial Eccentricity:

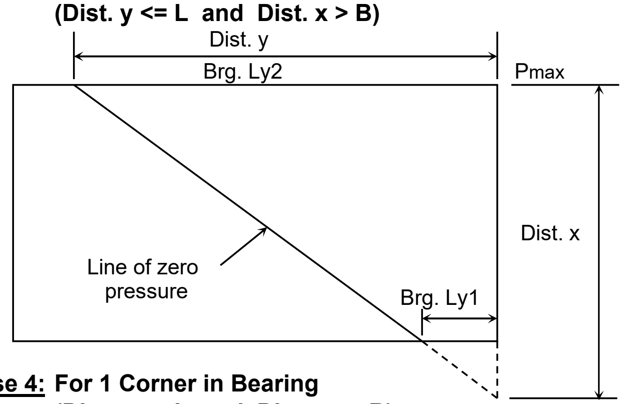
Case 1: For 3 Corners in Bearing
(Dist. y > L and Dist. x > B)



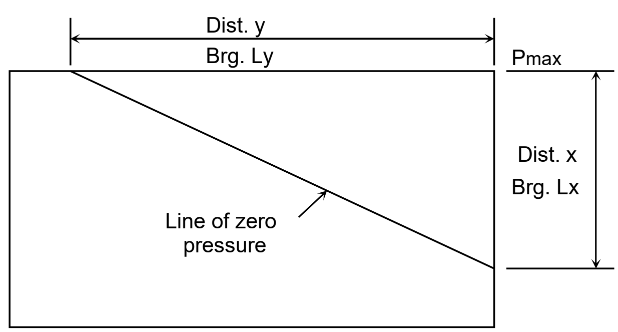
Case 2: For 2 Corners in Bearing
(Dist. y > L and Dist. x <= B)



Case 3: For 2 Corners in Bearing
(Dist. y <= L and Dist. x > B)



Case 4: For 1 Corner in Bearing
(Dist. y <= L and Dist. x <= B)



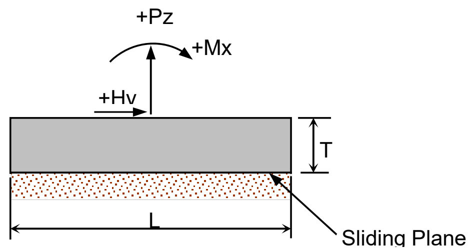
GATE TOWER STABILITY ANALYSIS

Job Name:	Springbank Off-Stream Storage Project	Number:	110773396			
Site:	Gate Tower	Originator:	ACG	7/2/2020	Checker:	CG
Load Case:	E1-3 Extreme Flood, Gates Closed					

Input Data:

Footing Data:

Footing Length, L =	10.50	m
Footing Width, B =	6.40	m
Footing Thickness, T =	0.00	m
Coef. of Base Friction, μ =	0.510	
Ultimate Bearing, Pall =	1281.00	kPa

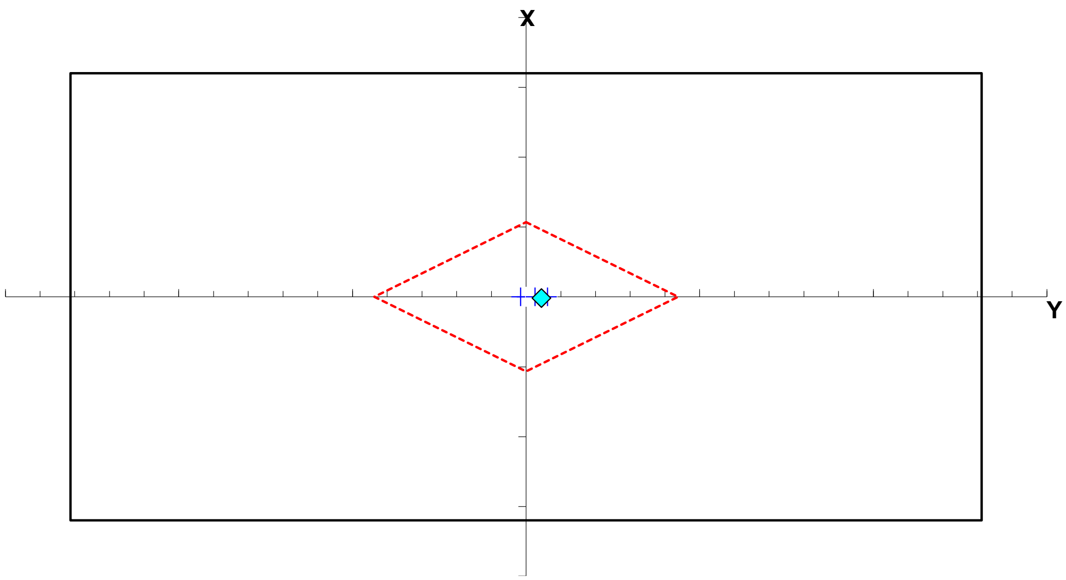


Nomenclature

Loading Data:

Direction of Wind Force: X-DIRECTION

	Uplift	Vertical Soil	Not Used	Internal Hydrostatic	Not Used	SAP2000 Reaction
Yp (m.) =	0.00	**-0.06**		0.11		**0.25**
Xp (m.) =	0.00	**0.00**		0.00		0.00
Pz (kN) =	18151.17	**-13120.89**		-12139.03		**-14032.34**
Hy (kN) =	0.00	**0.00**		0.00		**-29.90**
Hx (kN) =	0.00	**0.00**		0.00		**149.40**
My (kN-m) =	0.00	**0.00**		0.00		**324.78**
Mx (kN-m) =	0.00	**0.00**		0.00		**-111.58**



FOOTING PLAN

Note: Is the "Kern" area of footing (When resultant of loads falls within "Kern", entire footing base is in bearing.)

Results:

Total Resultant Load and Eccentricities:

ΣPy =	-21141.09	kN
ey =	0.18	m (<= L/6)
ex =	-0.02	m (<= B/6)
ΣHy =	-29.90	kN
ΣHx =	149.40	kN
H resultant =	152.36	kN
ΣMry =	125735.23	kN-m
ΣMoy =	58408.52	kN-m
ΣMrx =	202302.05	kN-m
ΣMox =	95182.06	kN-m

Sliding Check:

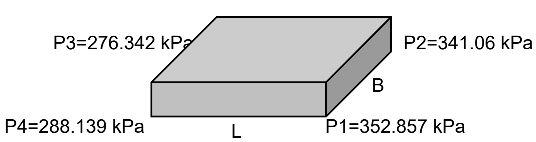
Frict =	10781.96	kN
FS(slid) =	70.764	

% Base Area in Compression:

Dist. y =	N.A.	m
Dist. x =	N.A.	m
Brg. Ly =	10.500	m
Brg. Lx =	6.400	m
%Brg. Area =	100.00	%
Biaxial Case =	N.A.	6*ex/L + 6*ez/B = 0.122

Gross Soil Bearing Corner Pressures:

P_1 =	352.857	kPa
P_2 =	341.060	kPa
P_3 =	276.342	kPa
P_4 =	288.139	kPa



CORNER PRESSURES

Summary of Results:

Sliding Check:

FS(slid) =	70.76	> 1.1	OK

Bearing Area:

%Brg. Area =	100.00%	> 75%	OK

Bearing Pressure Check:

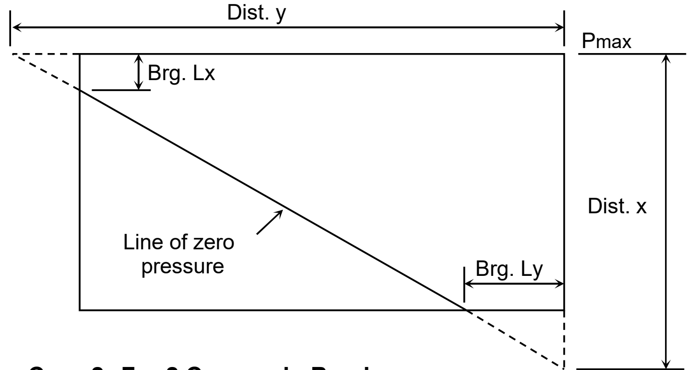
FS(brg) =	3.63	> 2.25	OK

Flotation Check:

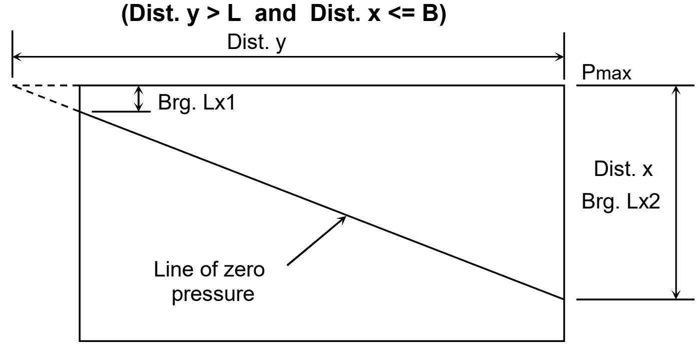
FS (float) =	2.16	> 1.1	OK

Nomenclature for Biaxial Eccentricity:

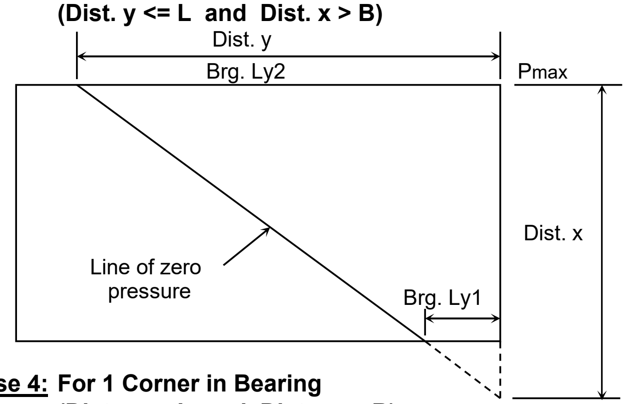
Case 1: For 3 Corners in Bearing
(Dist. y > L and Dist. x > B)



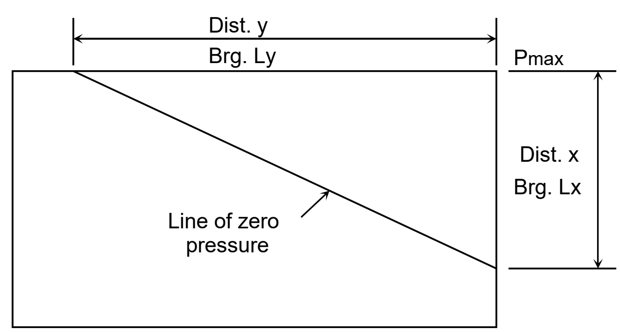
Case 2: For 2 Corners in Bearing
(Dist. y > L and Dist. x <= B)



Case 3: For 2 Corners in Bearing
(Dist. y <= L and Dist. x > B)



Case 4: For 1 Corner in Bearing
(Dist. y <= L and Dist. x <= B)



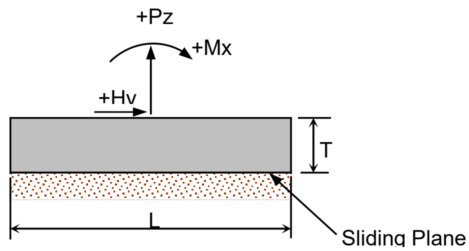
GATE TOWER STABILITY ANALYSIS

Job Name:	Springbank Off-Stream Storage Project	Number:	110773396		
Site:	Gate Tower	Originator:	ACG 7/2/2020	Checker:	CG
Load Case:	E2-4+ Extreme Flood, Front Gate Closed				

Input Data:

Footing Data:

Footing Length, L =	10.50	m
Footing Width, B =	6.40	m
Footing Thickness, T =	0.00	m
Coef. of Base Friction, μ =	0.510	
Ultimate Bearing, Pall =	1281.00	kPa

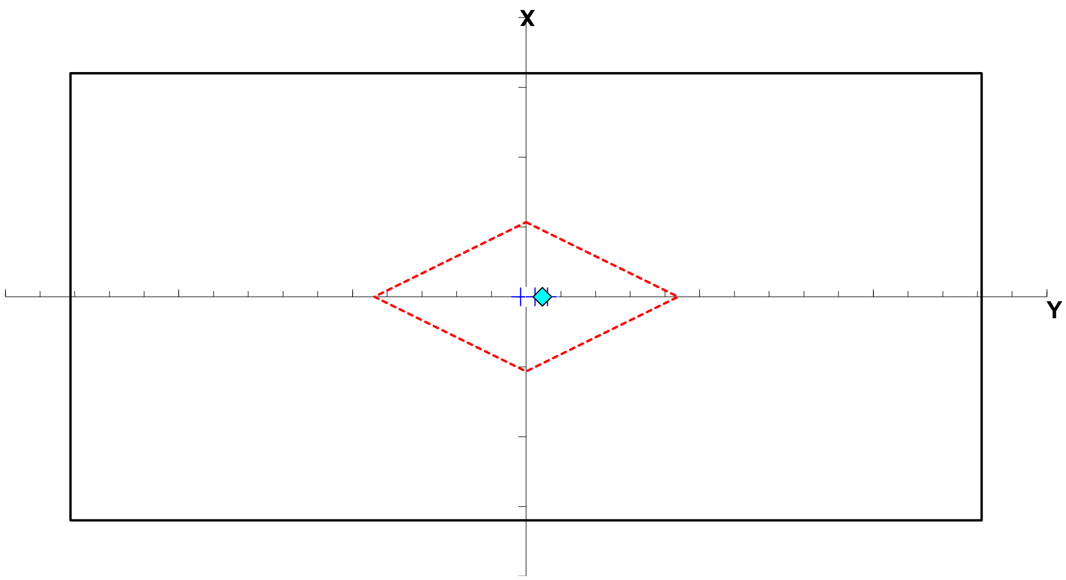


Nomenclature

Loading Data:

Direction of Wind Force: Y-DIRECTION

	Uplift	Vertical Soil	Not Used	Internal Hydrostatic	Not Used	SAP2000 Reaction
Yp (m.) =	0.00	**-0.06**		0.11		**0.25**
Xp (m.) =	0.00	**0.00**		0.00		0.00
Pz (kN) =	18151.17	**-13120.89**		-12139.03		**-14160.00**
Hy (kN) =	0.00	**0.00**		0.00		**-46.77**
Hx (kN) =	0.00	**0.00**		0.00		**0.00**
My (kN-m) =	0.00	**0.00**		0.00		**0.00**
Mx (kN-m) =	0.00	**0.00**		0.00		**-23.37**



FOOTING PLAN

Note: Is the "Kern" area of footing (When resultant of loads falls within "Kern", entire footing base is in bearing.)

Results:

Total Resultant Load and Eccentricities:

ΣPy =	-21268.75	kN
ey =	0.19	m (<= L/6)
ex =	0.00	
ΣHy =	-46.77	kN
ΣHx =	0.00	kN
H resultant =	46.77	kN
ΣMry =	N.A.	kN-m
ΣMoy =	N.A.	kN-m
ΣMrx =	202940.35	kN-m
ΣMox =	95270.27	kN-m

Sliding Check:

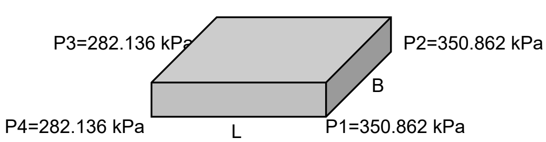
Frict =	10847.06	kN
FS(slid) =	231.904	

% Base Area in Compression:

Dist. y =	N.A.	m
Dist. x =	N.A.	m
Brg. Ly =	10.500	m
Brg. Lx =	6.400	m
%Brg. Area =	100.00	%
Biaxial Case =	N.A.	

Gross Soil Bearing Corner Pressures:

P1 =	350.862	kPa
P2 =	350.862	kPa
P3 =	282.136	kPa
P4 =	282.136	kPa



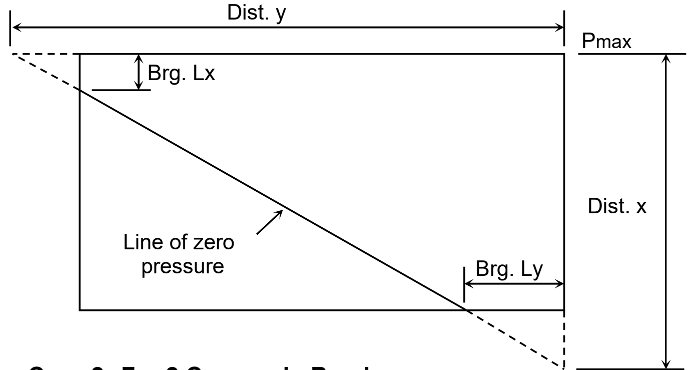
CORNER PRESSURES

Summary of Results:

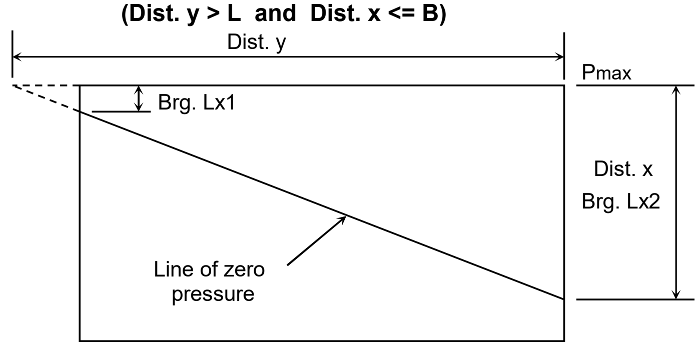
Sliding Check:			
FS(slid) =	231.90	> 1.1	OK
Bearing Area:			
%Brg. Area =	100.00%	> 75%	OK
Bearing Pressure Check:			
FS(brg) =	3.65	> 2.25	OK
Flotation Check:			
FS (float) =	2.17	> 1.1	OK

Nomenclature for Biaxial Eccentricity:

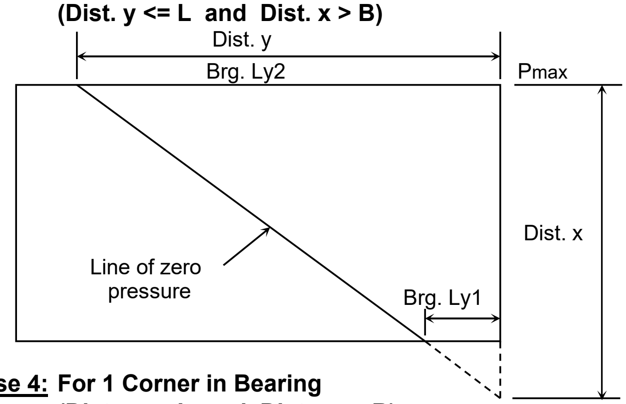
Case 1: For 3 Corners in Bearing
(Dist. y > L and Dist. x > B)



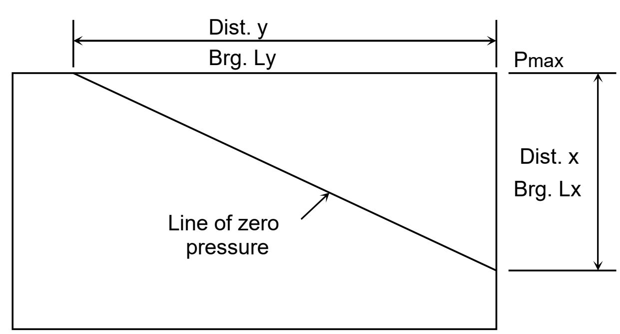
Case 2: For 2 Corners in Bearing
(Dist. y > L and Dist. x <= B)



Case 3: For 2 Corners in Bearing
(Dist. y <= L and Dist. x > B)



Case 4: For 1 Corner in Bearing
(Dist. y <= L and Dist. x <= B)



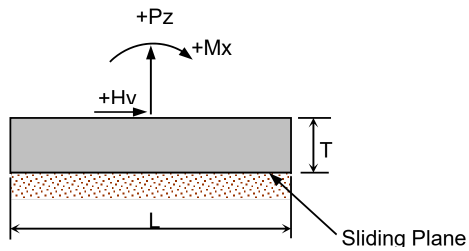
GATE TOWER STABILITY ANALYSIS

Job Name:	Springbank Off-Stream Storage Project	Number:	110773396
Site:	Gate Tower	Originator:	ACG 7/2/2020 Checker: CG
Load Case:	E2-4- Extreme Flood, Front Gate Closed		

Input Data:

Footing Data:

Footing Length, L =	10.50	m
Footing Width, B =	6.40	m
Footing Thickness, T =	0.00	m
Coef. of Base Friction, μ =	0.510	
Ultimate Bearing, Pall =	1281.00	kPa

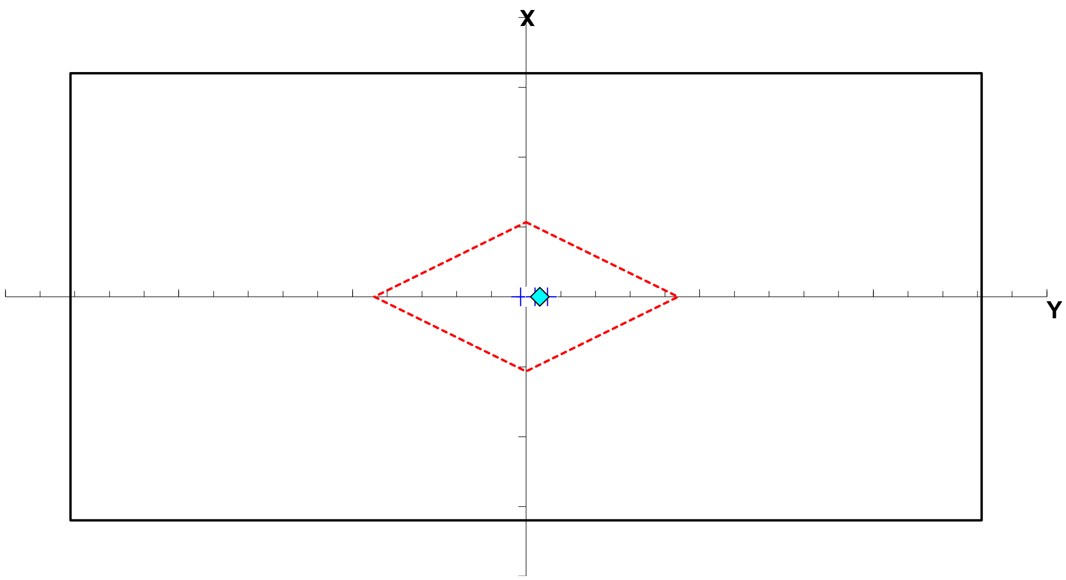


Nomenclature

Loading Data:

Direction of Wind Force: Y-DIRECTION

	Uplift	Vertical Soil	Not Used	Internal Hydrostatic	Not Used	SAP2000 Reaction
Yp (m.) =	0.00	**-0.06**		0.11		**0.25**
Xp (m.) =	0.00	**0.00**		0.00		0.00
Pz (kN) =	18151.17	**-13120.89**		-12139.03		**-14260.20**
Hy (kN) =	0.00	**0.00**		0.00		**118.02**
Hx (kN) =	0.00	**0.00**		0.00		**0.00**
My (kN-m) =	0.00	**0.00**		0.00		**0.00**
Mx (kN-m) =	0.00	**0.00**		0.00		**-687.19**



FOOTING PLAN

Note: Is the "Kern" area of footing (When resultant of loads falls within "Kern", entire footing base is in bearing.)

Results:

Total Resultant Load and Eccentricities:

ΣPy =	-21368.95	kN
ey =	0.16	m (<= L/6)
ex =	0.00	
ΣHy =	118.02	kN
ΣHx =	0.00	kN
H resultant =	118.02	kN
ΣMry =	N.A.	kN-m
ΣMoy =	N.A.	kN-m
ΣMrx =	203441.35	kN-m
ΣMox =	94606.45	kN-m

Sliding Check:

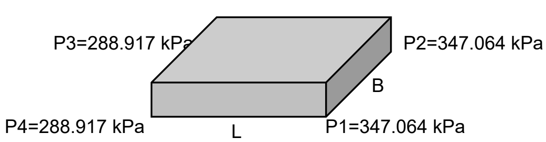
Frict =	10898.16	kN
FS(slid) =	92.345	

% Base Area in Compression:

Dist. y =	N.A.	m
Dist. x =	N.A.	m
Brg. Ly =	10.500	m
Brg. Lx =	6.400	m
%Brg. Area =	100.00	%
Biaxial Case =	N.A.	

Gross Soil Bearing Corner Pressures:

P_1 =	347.064	kPa
P_2 =	347.064	kPa
P_3 =	288.917	kPa
P_4 =	288.917	kPa



CORNER PRESSURES

Summary of Results:

Sliding Check:

FS(slid) =	92.34	> 1.1	OK

Bearing Area:

%Brg. Area =	100.00%	> 75%	OK

Bearing Pressure Check:

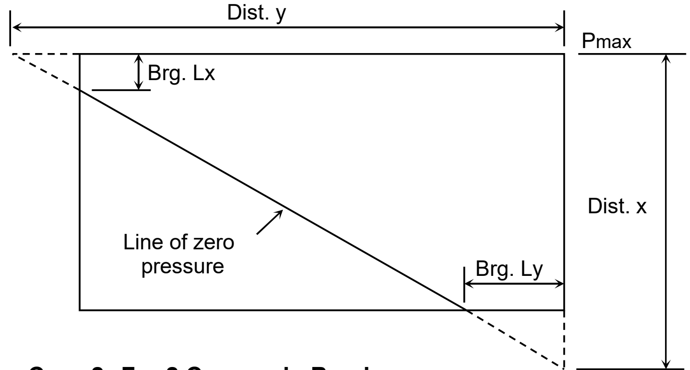
FS(brg) =	3.69	> 2.25	OK

Flotation Check:

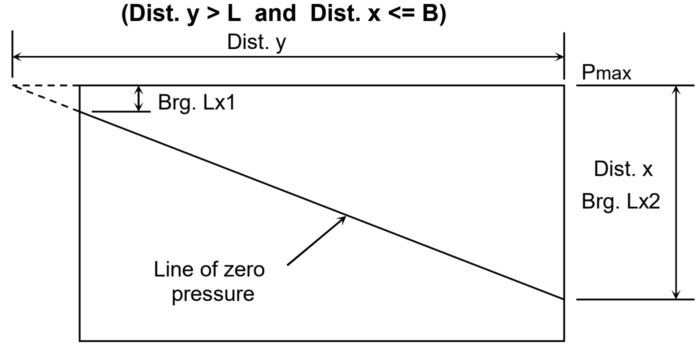
FS (float) =	2.18	> 1.1	OK

Nomenclature for Biaxial Eccentricity:

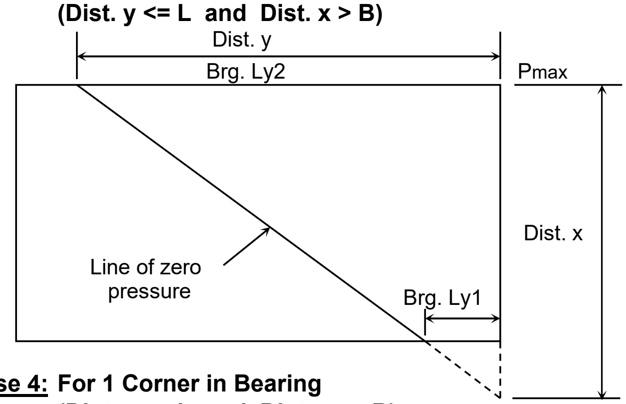
Case 1: For 3 Corners in Bearing
(Dist. y > L and Dist. x > B)



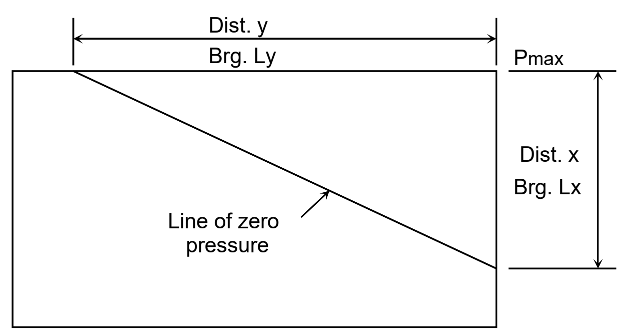
Case 2: For 2 Corners in Bearing
(Dist. y > L and Dist. x <= B)



Case 3: For 2 Corners in Bearing
(Dist. y <= L and Dist. x > B)



Case 4: For 1 Corner in Bearing
(Dist. y <= L and Dist. x <= B)



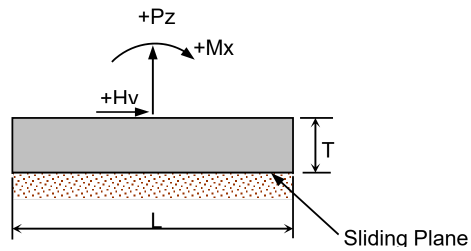
GATE TOWER STABILITY ANALYSIS

Job Name:	Springbank Off-Stream Storage Project	Number:	110773396		
Site:	Gate Tower	Originator:	ACG 7/2/2020	Checker:	CG
Load Case:	E2-1 Extreme Flood, Front Gate Closed				

Input Data:

Footing Data:

Footing Length, L =	10.50	m
Footing Width, B =	6.40	m
Footing Thickness, T =	0.00	m
Coef. of Base Friction, μ =	0.510	
Ultimate Bearing, Pall =	1281.00	kPa

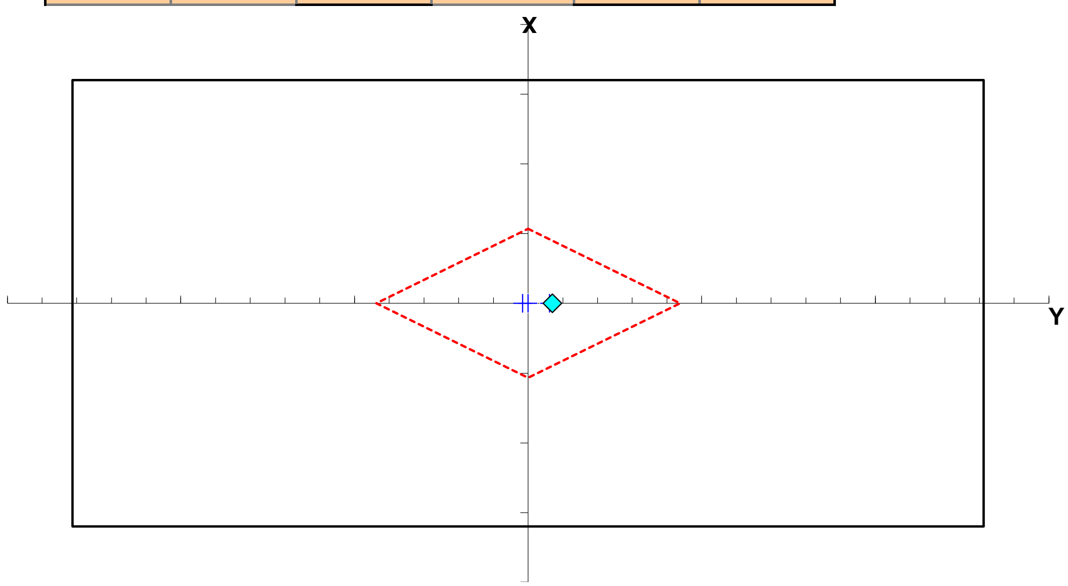


Nomenclature

Loading Data:

Direction of Wind Force: N/A

	Uplift	Vertical Soil	Not Used	Internal Hydrostatic	Not Used	SAP2000 Reaction
Yp (m.) =	0.00	**-0.06**		0.26		**0.25**
Xp (m.) =	0.00	**0.00**		0.00		0.00
Pz (kN) =	18715.65	**-13120.89**		-10932.93		**-14210.10**
Hy (kN) =	0.00	**0.00**		0.00		**-9.13**
Hx (kN) =	0.00	**0.00**		0.00		**0.00**
My (kN-m) =	0.00	**0.00**		0.00		**0.00**
Mx (kN-m) =	0.00	**0.00**		0.00		**-171.95**



FOOTING PLAN

Note: Is the "Kern" area of footing (When resultant of loads falls within "Kern", entire footing base is in bearing.)

Results:

Total Resultant Load and Eccentricities:

ΣPy =	-19548.27	kN
ey =	0.28	m (<= L/6)
ex =	0.00	
ΣHy =	-9.13	kN
ΣHx =	0.00	kN
H resultant =	9.13	kN
ΣMry =	N.A.	kN-m
ΣMoy =	N.A.	kN-m
ΣMrx =	195247.13	kN-m
ΣMox =	98085.21	kN-m

Sliding Check:

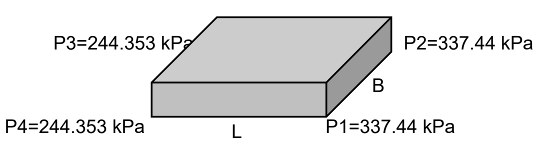
Frict =	9969.62	kN
FS(slid) =	1092.441	

% Base Area in Compression:

Dist. y =	N.A.	m
Dist. x =	N.A.	m
Brg. Ly =	10.500	m
Brg. Lx =	6.400	m
%Brg. Area =	100.00	%
Biaxial Case =	N.A.	

Gross Soil Bearing Corner Pressures:

P_1 =	337.440	kPa
P_2 =	337.440	kPa
P_3 =	244.353	kPa
P_4 =	244.353	kPa



CORNER PRESSURES

Summary of Results:

Sliding Check:

FS(slid) =	1092.44	> 1.1	OK

Bearing Area:

%Brg. Area =	100.00%	> 75%	OK

Bearing Pressure Check:

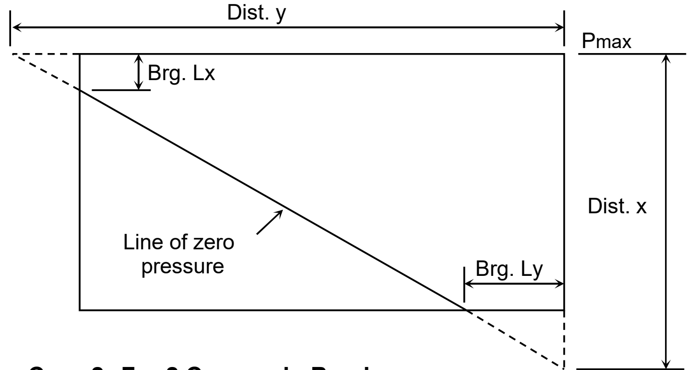
FS(brg) =	3.80	> 3.0	OK

Flotation Check:

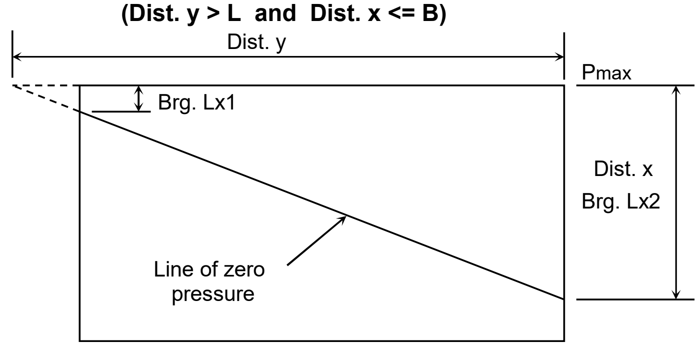
FS (float) =	2.04	> 1.1	OK

Nomenclature for Biaxial Eccentricity:

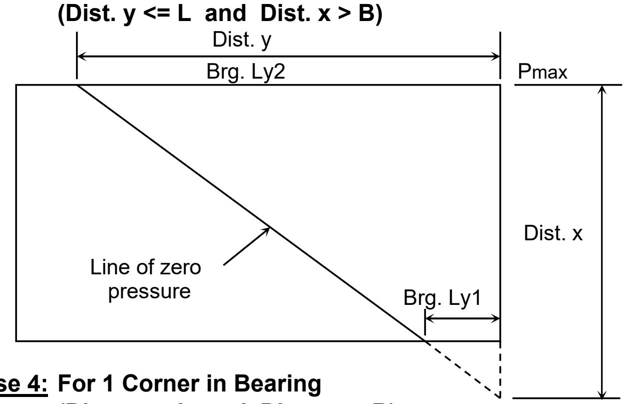
Case 1: For 3 Corners in Bearing
(Dist. y > L and Dist. x > B)



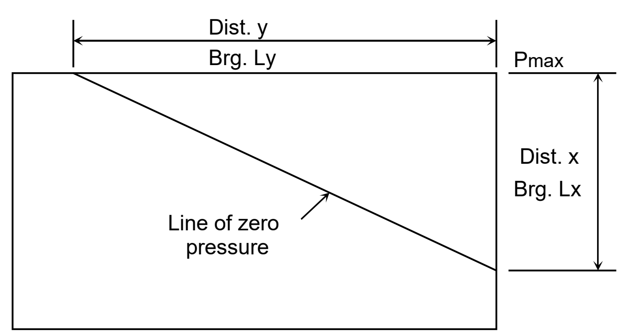
Case 2: For 2 Corners in Bearing
(Dist. y > L and Dist. x <= B)



Case 3: For 2 Corners in Bearing
(Dist. y <= L and Dist. x > B)



Case 4: For 1 Corner in Bearing
(Dist. y <= L and Dist. x <= B)

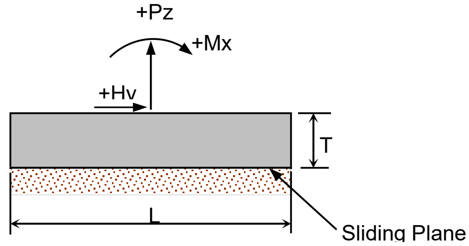


GATE TOWER STABILITY ANALYSIS					
Job Name:	Springbank Off-Stream Storage Project	Number:	110773396		
Site:	Gate Tower	Originator:	ACG	7/2/2020	Checker: CG
Load Case:	E2-2 Extreme Flood, Front Gate Closed				

Input Data:

Footing Data:

Footing Length, L =	10.50	m
Footing Width, B =	6.40	m
Footing Thickness, T =	0.00	m
Coef. of Base Friction, μ =	0.510	
Ultimate Bearing, Pall =	1281.00	kPa

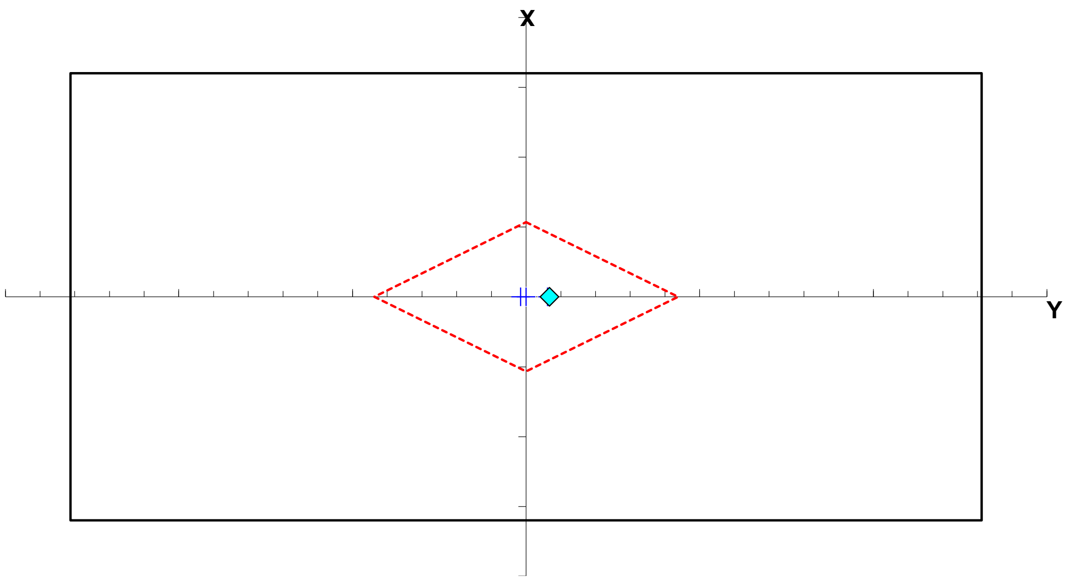


Nomenclature

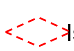
Loading Data:

Direction of Wind Force: N/A

	Uplift	Vertical Soil	Not Used	Internal Hydrostatic	Not Used	SAP2000 Reaction
Yp (m.) =	0.00	-0.06		0.26		0.25
Xp (m.) =	0.00	0.00		0.00		0.00
Pz (kN) =	18715.65	-13120.89		-10932.93		-14770.30
Hy (kN) =	0.00	0.00		0.00		45.62
Hx (kN) =	0.00	0.00		0.00		0.00
My (kN-m) =	0.00	0.00		0.00		0.00
Mx (kN-m) =	0.00	0.00		0.00		-331.22



FOOTING PLAN

Note:  Is the "Kern" area of footing (When resultant of loads falls within "Kern", entire footing base is in bearing.)

Results:

Total Resultant Load and Eccentricities:

ΣPy =	-20108.47	kN
ey =	0.27	m (<= L/6)
ex =	0.00	
ΣHy =	45.62	kN
ΣHx =	0.00	kN
H resultant =	45.62	kN
ΣMry =	N.A.	kN-m
ΣMoy =	N.A.	kN-m
ΣMrx =	198048.13	kN-m
ΣMox =	97925.94	kN-m

Sliding Check:

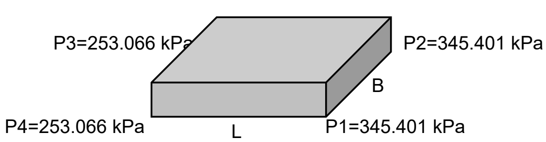
Frict =	10255.32	kN
FS(slid) =	224.779	

% Base Area in Compression:

Dist. y =	N.A.	m
Dist. x =	N.A.	m
Brg. Ly =	10.500	m
Brg. Lx =	6.400	m
%Brg. Area =	100.00	%
Biaxial Case =	N.A.	

Gross Soil Bearing Corner Pressures:

P1 =	345.401	kPa
P2 =	345.401	kPa
P3 =	253.066	kPa
P4 =	253.066	kPa



CORNER PRESSURES

Summary of Results:

Sliding Check:

FS(slid) = **224.78** > 1.1 OK

Bearing Area:

%Brg. Area = **100.00%** > 75% OK

Bearing Pressure Check:

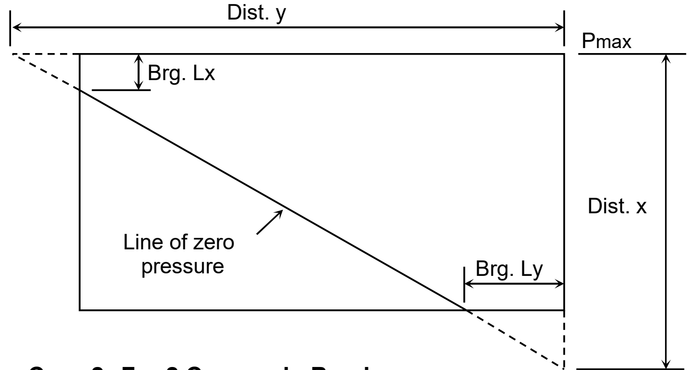
FS(brg) = **3.71** > 2.25 OK

Flotation Check:

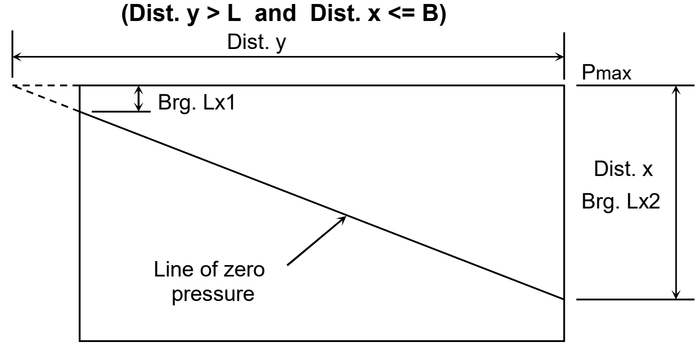
FS (float) = **2.07** > 1.1 OK

Nomenclature for Biaxial Eccentricity:

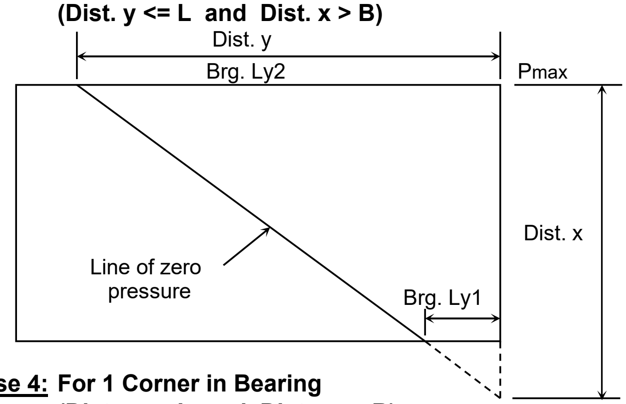
Case 1: For 3 Corners in Bearing (Dist. y > L and Dist. x > B)



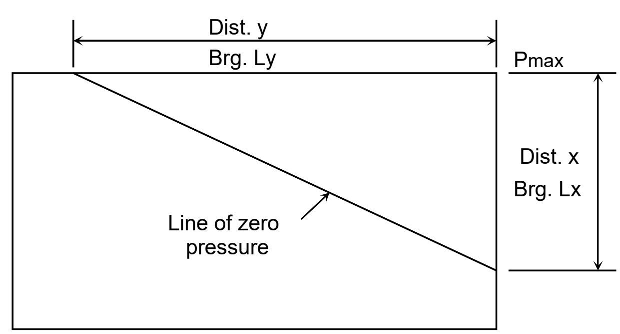
Case 2: For 2 Corners in Bearing (Dist. y > L and Dist. x <= B)



Case 3: For 2 Corners in Bearing (Dist. y <= L and Dist. x > B)



Case 4: For 1 Corner in Bearing (Dist. y <= L and Dist. x <= B)



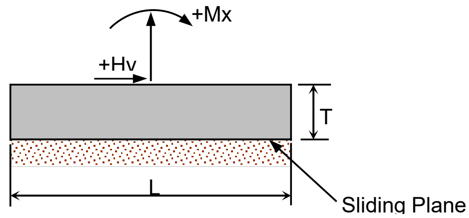
GATE TOWER STABILITY ANALYSIS

Job Name:	Springbank Off-Stream Storage Project	Number:	110773396		
Site:	Gate Tower	Originator:	ACG 7/2/2020	Checker:	CG
Load Case:	E2-3 Extreme Flood, Front Gate Closed				

Input Data:

Footing Data:

Footing Length, L =	10.50	m
Footing Width, B =	6.40	m
Footing Thickness, T =	0.00	m
Coef. of Base Friction, μ =	0.510	
Ultimate Bearing, Pall =	1281.00	kPa

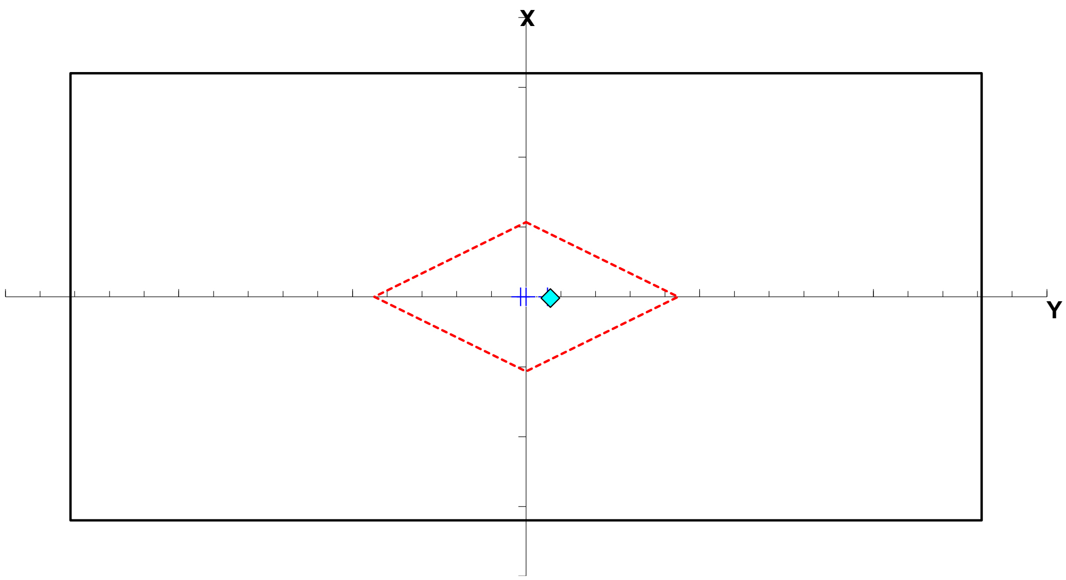


Nomenclature

Loading Data:

Direction of Wind Force: X-DIRECTION

	Uplift	Vertical Soil	Not Used	Internal Hydrostatic	Not Used	SAP2000 Reaction
Yp (m.) =	0.00	-0.06		0.26		0.25
Xp (m.) =	0.00	0.00		0.00		0.00
Pz (kN) =	18715.65	-13120.89		-10932.93		-14032.34
Hy (kN) =	0.00	0.00		0.00		-29.90
Hx (kN) =	0.00	0.00		0.00		149.40
My (kN-m) =	0.00	0.00		0.00		324.78
Mx (kN-m) =	0.00	0.00		0.00		-111.58



FOOTING PLAN

Note: Is the "Kern" area of footing (When resultant of loads falls within "Kern", entire footing base is in bearing.)

Results:

Total Resultant Load and Eccentricities:

ΣPy =	-19370.51	kN
ey =	0.28	m (<= L/6)
ex =	-0.02	m (<= B/6)
ΣHy =	-29.90	kN
ΣHx =	149.40	kN
H resultant =	152.36	kN
ΣMry =	121875.71	kN-m
ΣMoy =	60214.86	kN-m
ΣMrx =	194358.33	kN-m
ΣMox =	98145.58	kN-m

Sliding Check:

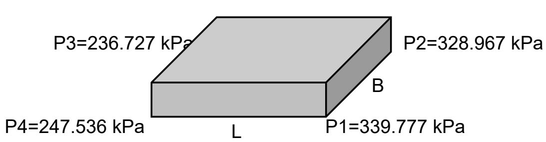
Frict =	9878.96	kN
FS(slid) =	64.838	

% Base Area in Compression:

Dist. y =	N.A.	m
Dist. x =	N.A.	m
Brg. Ly =	10.500	m
Brg. Lx =	6.400	m
%Brg. Area =	100.00	%
Biaxial Case =	N.A.	6*ex/L + 6*ez/B = 0.179

Gross Soil Bearing Corner Pressures:

P1 =	339.777	kPa
P2 =	328.967	kPa
P3 =	236.727	kPa
P4 =	247.536	kPa



CORNER PRESSURES

Summary of Results:

Sliding Check:

FS(slid) =	64.84	> 1.1	OK

Bearing Area:

%Brg. Area =	100.00%	> 75%	OK

Bearing Pressure Check:

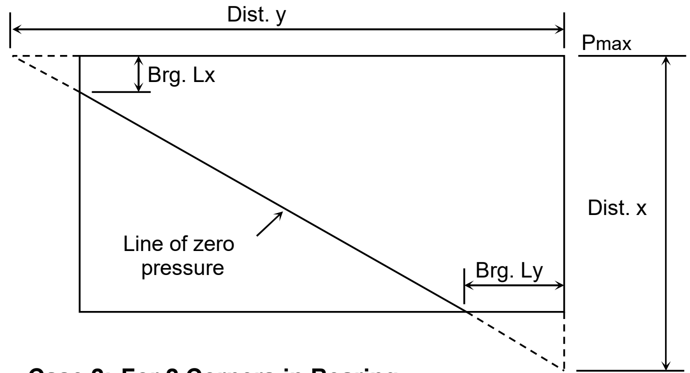
FS(brg) =	3.77	> 2.25	OK

Flotation Check:

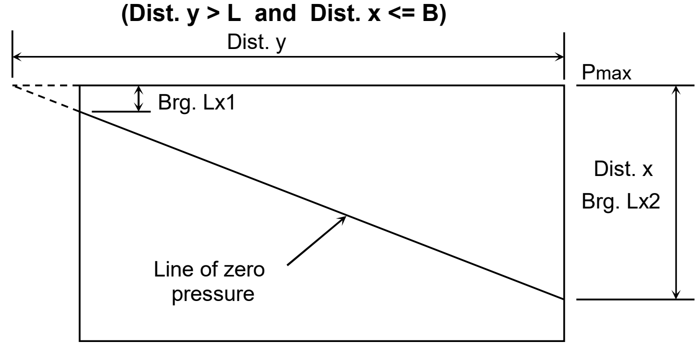
FS (float) =	2.03	> 1.1	OK

Nomenclature for Biaxial Eccentricity:

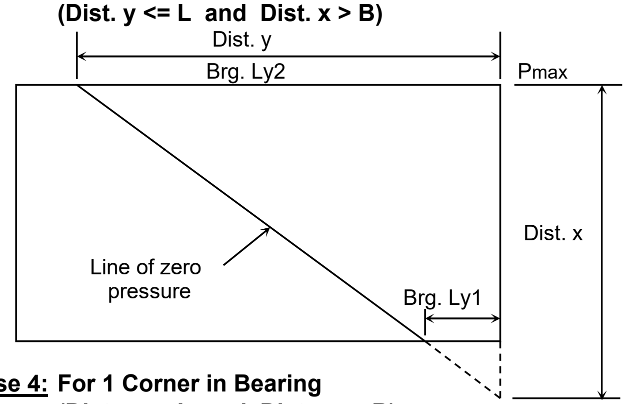
Case 1: For 3 Corners in Bearing
(Dist. y > L and Dist. x > B)



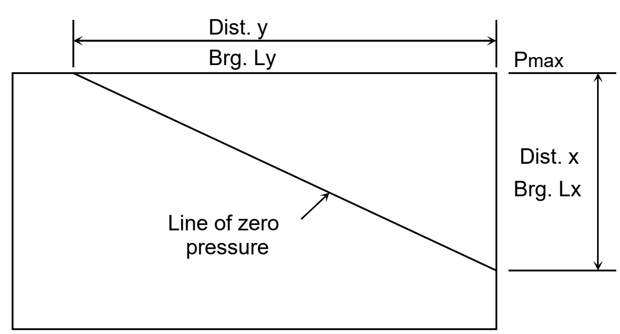
Case 2: For 2 Corners in Bearing
(Dist. y > L and Dist. x <= B)



Case 3: For 2 Corners in Bearing
(Dist. y <= L and Dist. x > B)



Case 4: For 1 Corner in Bearing
(Dist. y <= L and Dist. x <= B)



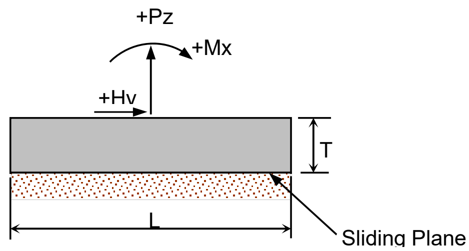
GATE TOWER STABILITY ANALYSIS

Job Name:	Springbank Off-Stream Storage Project	Number:	110773396
Site:	Gate Tower	Originator:	ACG 7/2/2020 Checker: CG
Load Case:	E2-4+ Extreme Flood, Front Gate Closed		

Input Data:

Footing Data:

Footing Length, L =	10.50	m
Footing Width, B =	6.40	m
Footing Thickness, T =	0.00	m
Coef. of Base Friction, μ =	0.510	
Ultimate Bearing, Pall =	1281.00	kPa

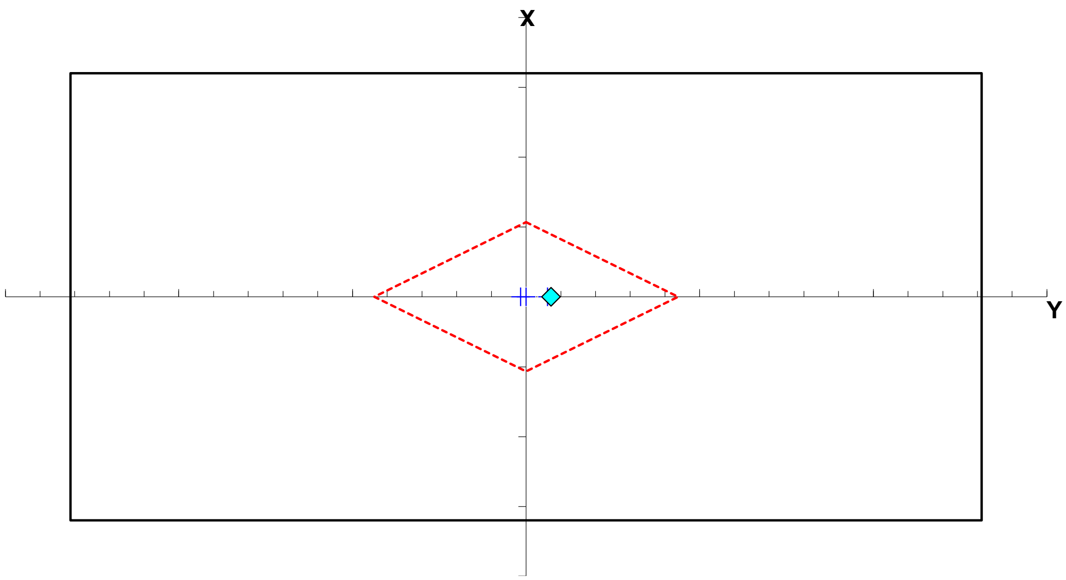


Nomenclature

Loading Data:

Direction of Wind Force: Y-DIRECTION

	Uplift	Vertical Soil	Not Used	Internal Hydrostatic	Not Used	SAP2000 Reaction
Yp (m.) =	0.00	**-0.06**		0.26		**0.25**
Xp (m.) =	0.00	**0.00**		0.00		0.00
Pz (kN) =	18715.65	**-13120.89**		-10932.93		**-14160.00**
Hy (kN) =	0.00	**0.00**		0.00		**-46.77**
Hx (kN) =	0.00	**0.00**		0.00		**0.00**
My (kN-m) =	0.00	**0.00**		0.00		**0.00**
Mx (kN-m) =	0.00	**0.00**		0.00		**-23.37**



FOOTING PLAN

Note: Is the "Kern" area of footing (When resultant of loads falls within "Kern", entire footing base is in bearing.)

Results:

Total Resultant Load and Eccentricities:

ΣPy =	-19498.17	kN
ey =	0.29	m (<= L/6)
ex =	0.00	
ΣHy =	-46.77	kN
ΣHx =	0.00	kN
H resultant =	46.77	kN
ΣMry =	N.A.	kN-m
ΣMoy =	N.A.	kN-m
ΣMrx =	194996.63	kN-m
ΣMox =	98233.79	kN-m

Sliding Check:

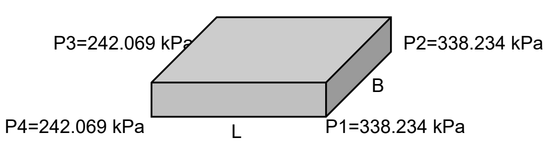
Frict =	9944.07	kN
FS(slid) =	212.598	

% Base Area in Compression:

Dist. y =	N.A.	m
Dist. x =	N.A.	m
Brg. Ly =	10.500	m
Brg. Lx =	6.400	m
%Brg. Area =	100.00	%
Biaxial Case =	N.A.	

Gross Soil Bearing Corner Pressures:

P_1 =	338.234	kPa
P_2 =	338.234	kPa
P_3 =	242.069	kPa
P_4 =	242.069	kPa



CORNER PRESSURES

Summary of Results:

Sliding Check:

FS(slid) =	212.60	> 1.1	OK

Bearing Area:

%Brg. Area =	100.00%	> 75%	OK

Bearing Pressure Check:

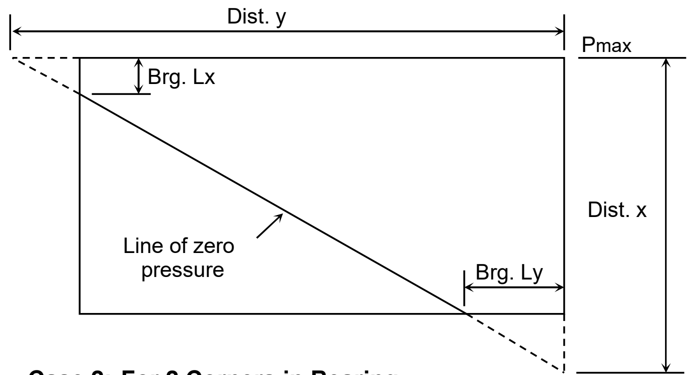
FS(brg) =	3.79	> 2.25	OK

Flotation Check:

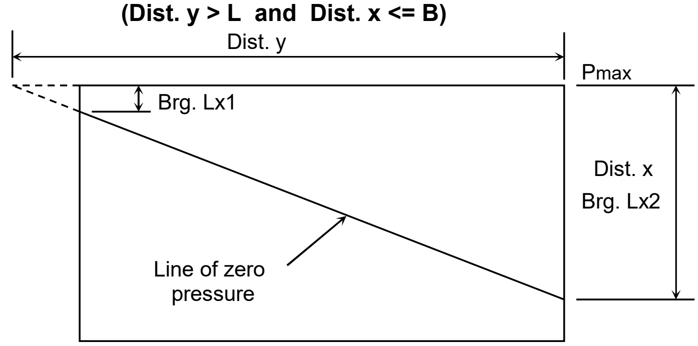
FS (float) =	2.04	> 1.1	OK

Nomenclature for Biaxial Eccentricity:

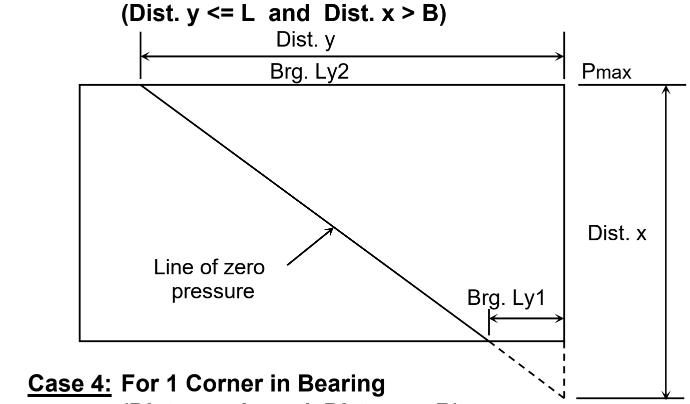
Case 1: **For 3 Corners in Bearing**
(Dist. y > L and Dist. x > B)



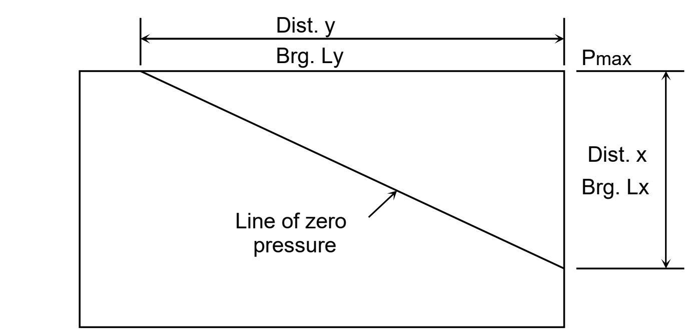
Case 2: **For 2 Corners in Bearing**
(Dist. y > L and Dist. x <= B)



Case 3: **For 2 Corners in Bearing**
(Dist. y <= L and Dist. x > B)



Case 4: **For 1 Corner in Bearing**
(Dist. y <= L and Dist. x <= B)



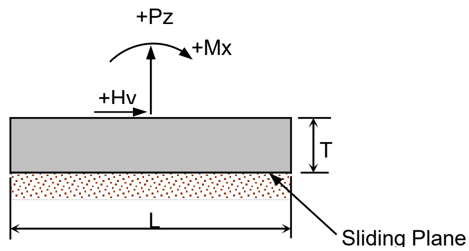
GATE TOWER STABILITY ANALYSIS

Job Name:	Springbank Off-Stream Storage Project	Number:	110773396
Site:	Gate Tower	Originator:	ACG 7/2/2020 Checker: CG
Load Case:	E2-4- Extreme Flood, Front Gate Closed		

Input Data:

Footing Data:

Footing Length, L =	10.50	m
Footing Width, B =	6.40	m
Footing Thickness, T =	0.00	m
Coef. of Base Friction, μ =	0.510	
Ultimate Bearing, Pall =	1281.00	kPa

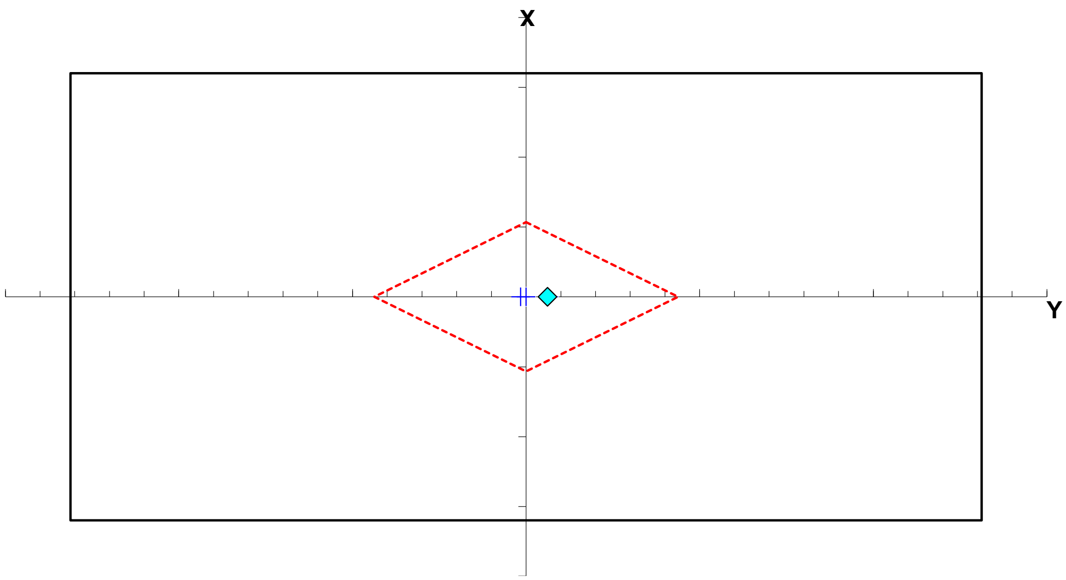


Nomenclature

Loading Data:

Direction of Wind Force: Y-DIRECTION

	Uplift	Vertical Soil	Not Used	Internal Hydrostatic	Not Used	SAP2000 Reaction
Yp (m.) =	0.00	**-0.06**		0.26		**0.25**
Xp (m.) =	0.00	**0.00**		0.00		0.00
Pz (kN) =	18715.65	**-13120.89**		-10932.93		**-14260.20**
Hy (kN) =	0.00	**0.00**		0.00		**118.02**
Hx (kN) =	0.00	**0.00**		0.00		**0.00**
My (kN-m) =	0.00	**0.00**		0.00		**0.00**
Mx (kN-m) =	0.00	**0.00**		0.00		**-687.19**



FOOTING PLAN

Note: Is the "Kern" area of footing (When resultant of loads falls within "Kern", entire footing base is in bearing.)

Results:

Total Resultant Load and Eccentricities:

ΣPy =	-19598.37	kN
ey =	0.25	m (<= L/6)
ex =	0.00	
ΣHy =	118.02	kN
ΣHx =	0.00	kN
H resultant =	118.02	kN
ΣMry =	N.A.	kN-m
ΣMoy =	N.A.	kN-m
ΣMrx =	195497.63	kN-m
ΣMox =	97569.97	kN-m

Sliding Check:

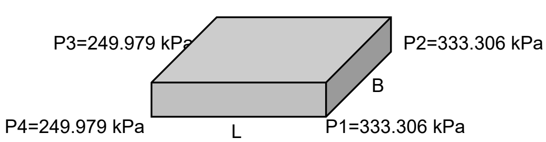
Frict =	9995.17	kN
FS(slid) =	84.693	

% Base Area in Compression:

Dist. y =	N.A.	m
Dist. x =	N.A.	m
Brg. Ly =	10.500	m
Brg. Lx =	6.400	m
%Brg. Area =	100.00	%
Biaxial Case =	N.A.	

Gross Soil Bearing Corner Pressures:

P1 =	333.306	kPa
P2 =	333.306	kPa
P3 =	249.979	kPa
P4 =	249.979	kPa



CORNER PRESSURES

Summary of Results:

Sliding Check:

FS(slid) = **84.69** > 1.1 OK

Bearing Area:

%Brg. Area = **100.00%** > 75% OK

Bearing Pressure Check:

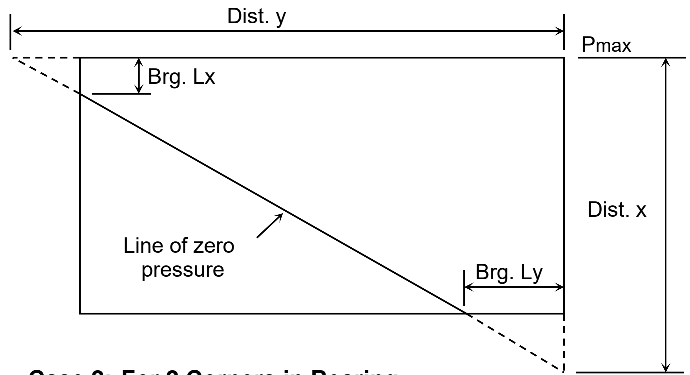
FS(brg) = **3.84** > 2.25 OK

Flotation Check:

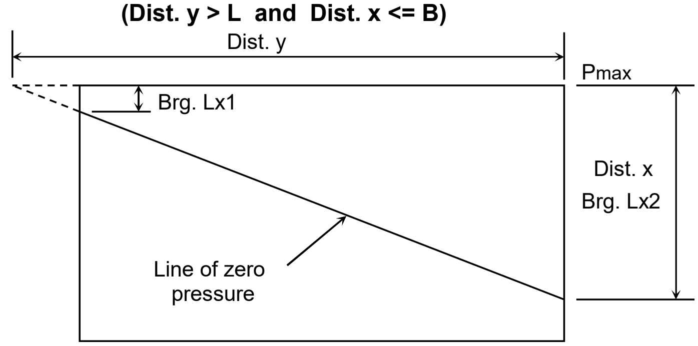
FS (float) = **2.05** > 1.1 OK

Nomenclature for Biaxial Eccentricity:

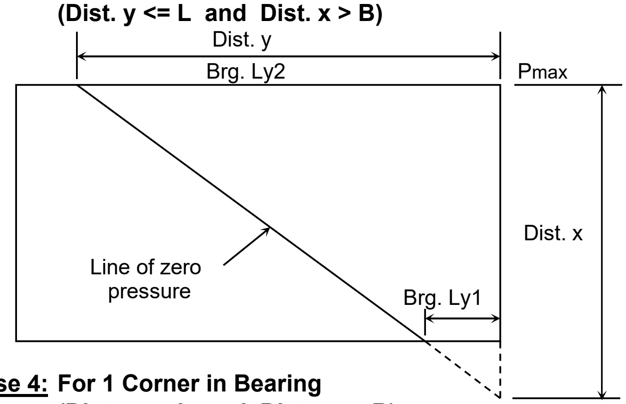
Case 1: For 3 Corners in Bearing
(Dist. y > L and Dist. x > B)



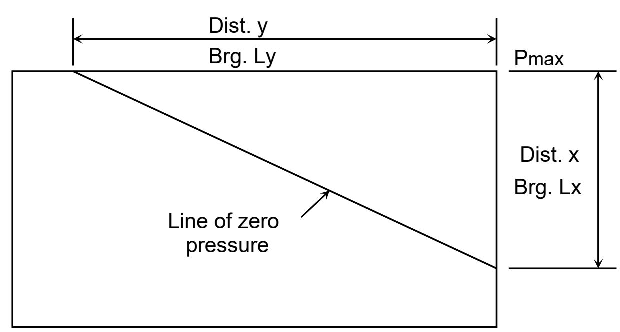
Case 2: For 2 Corners in Bearing
(Dist. y > L and Dist. x <= B)



Case 3: For 2 Corners in Bearing
(Dist. y <= L and Dist. x > B)



Case 4: For 1 Corner in Bearing
(Dist. y <= L and Dist. x <= B)



GATE TOWER SEISMIC STABILITY ANALYSIS SUMMARY

Job Name:	Springbank Off-Stream Storage Project	Number:	110773396
Site:	Gate Tower	Originator:	ACG 7/2/2020

Results Summary:

SR-1 - Summary of Intake Structure Static Stability Assessment									
Load Case	**Load Category**	**Sliding Stability Safety Factor**		**Base Area in Compression(1)**		**Bearing Pressures (2) (kPa)**		**Flotation Safety Factor**	
		Required	**Calculated**	**Required**	**Calculated**	**Required**	**Calculated**	**Required**	**Calculated**
7- Extreme Earthquake(3)	Extreme	N/A	>10	N/A	100%	N/A	718.2	N/A	>10
8- Post Earthquake	PE	1.1	>10	75%	100%	569.3	397.8	1.1	>10

(1)- 100% base compression = resultant within the middle 1/3
75% base compression = resultant within the middle 1/2
>0% base compression = resultant within the base
(2)- Bearing pressure limits are based on the values shown in the table below.
(3)- There are no criteria for seismic - results are provided for information only and to support the Post-Earthquake load case.

Allowable Bearing Capacity (kPa)		**Ultimate Bearing Capacity (kPa)**	
Staged Construction	250	Staged Construction	750
Final Embankment Configuration*	427	Final Embankment Configuration*	1281

*Based on the allowable bearing pressure due to differential settlement between conduit and the gate tower, multiplied by the safety factor of 3.

GATE TOWER SEISMIC STABILITY ANALYSIS SUMMARY

Job Name:	Springbank Off-Stream Storage Project	Number:	110773396
Site:	Gate Tower	Originator:	ACG 7/2/2020

Detailed Load Cases:

LC #	Condition Classification	Description	EQx Sign	EQx Value	EQy Sign	EQy Value	EQz Sign	EQz Value
E3-1	Extreme	Extreme Earthquake	+	0.3	+	0.3	+	1
E3-2			+		-		+	
E3-3			-		-		+	
E3-4			-		+		+	
E3-5			+		+		-	
E3-6			+		-		-	
E3-7			-		-		-	
E3-8			-		+		-	
E3-9			+	1	+	0.3	+	0.3
E3-10			+		-		+	
E3-11			-		-		+	
E3-12			-		+		+	
E3-13			+		+		-	
E3-14			+		-		-	
E3-15			-		-		-	
E3-16			-		+		-	
E3-17			+	0.3	+	1	+	0.3
E3-18			+		-		+	
E3-19			-		-		+	
E3-20			-		+		+	
E3-21			+		+		-	
E3-22			+		-		-	
E3-23			-		-		-	
E3-24			-		+		-	

GATE TOWER SEISMIC STABILITY ANALYSIS SUMMARY

Job Name:	Springbank Off-Stream Storage Project	Number:	110773396	
Site:	Gate Tower	Originator:	ACG	7/2/2020

SAP2000 Reactions:

TABLE: Joint Reactions

Joint	OutputCase	CaseType	F1	F2	F3	M1	M2	M3
Text	Text	Text	KN	KN	KN	KN-m	KN-m	KN-m
1	PE-1	Combination	2.14	-6.24	14032.24	-33.70	1.45	-363.49
1	PE-2+	Combination	0.00	-4.99	14159.99	-30.72	0.00	0.00
1	PE-2-	Combination	0.00	-9.62	14260.21	-41.39	0.00	0.00
1	E3-1	Combination	101.82	-158.84	12036.65	4944.13	-5409.29	-124.74
1	E3-2	Combination	101.82	145.99	12036.61	-5006.28	-5409.29	-124.74
1	E3-3	Combination	-101.82	145.99	12036.61	-5006.28	5409.29	124.74
1	E3-4	Combination	-101.82	-158.84	12036.65	4944.13	5409.29	124.74
1	E3-5	Combination	101.82	-160.60	16383.59	4934.17	-5409.29	-124.74
1	E3-6	Combination	101.82	144.23	16383.55	-5016.24	-5409.29	-124.74
1	E3-7	Combination	-101.82	144.23	16383.55	-5016.24	5409.29	124.74
1	E3-8	Combination	-101.82	-160.60	16383.59	4934.17	5409.29	124.74
1	E3-9	Combination	339.39	-159.46	13558.08	4940.64	-18030.97	-415.81
1	E3-10	Combination	339.39	145.37	13558.04	-5009.76	-18030.97	-415.81
1	E3-11	Combination	-339.39	145.37	13558.04	-5009.76	18030.97	415.81
1	E3-12	Combination	-339.39	-159.46	13558.08	4940.64	18030.97	415.81
1	E3-13	Combination	339.39	-159.99	14862.16	4937.65	-18030.97	-415.81
1	E3-14	Combination	339.39	144.84	14862.12	-5012.75	-18030.97	-415.81
1	E3-15	Combination	-339.39	144.84	14862.12	-5012.75	18030.97	415.81
1	E3-16	Combination	-339.39	-159.99	14862.16	4937.65	18030.97	415.81
1	E3-17	Combination	101.82	-515.09	13558.12	16549.45	-5409.29	-124.74
1	E3-18	Combination	101.82	501.01	13558.00	-16618.57	-5409.29	-124.74
1	E3-19	Combination	-101.82	501.01	13558.00	-16618.57	5409.29	124.74
1	E3-20	Combination	-101.82	-515.09	13558.12	16549.45	5409.29	124.74
1	E3-21	Combination	101.82	-515.62	14862.20	16546.46	-5409.29	-124.74
1	E3-22	Combination	101.82	500.48	14862.08	-16621.56	-5409.29	-124.74
1	E3-23	Combination	-101.82	500.48	14862.08	-16621.56	5409.29	124.74
1	E3-24	Combination	-101.82	-515.62	14862.20	16546.46	5409.29	124.74

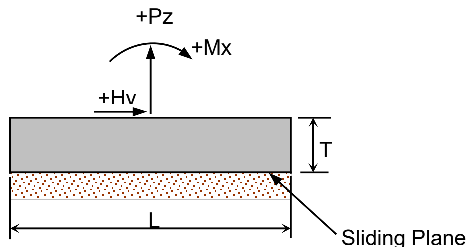
GATE TOWER STABILITY ANALYSIS

Job Name:	Springbank Off-Stream Storage Project	Number:	110773396		
Site:	Gate Tower	Originator:	ACG 7/2/2020	Checker:	CG
Load Case:	E3-1 Extreme Earthquake				

Input Data:

Footing Data:

Footing Length, L =	10.00	m
Footing Width, B =	6.40	m
Footing Thickness, T =	0.00	m
Coef. of Base Friction, μ =	0.51	
Ultimate Bearing, Pall =	1281.00	kPa

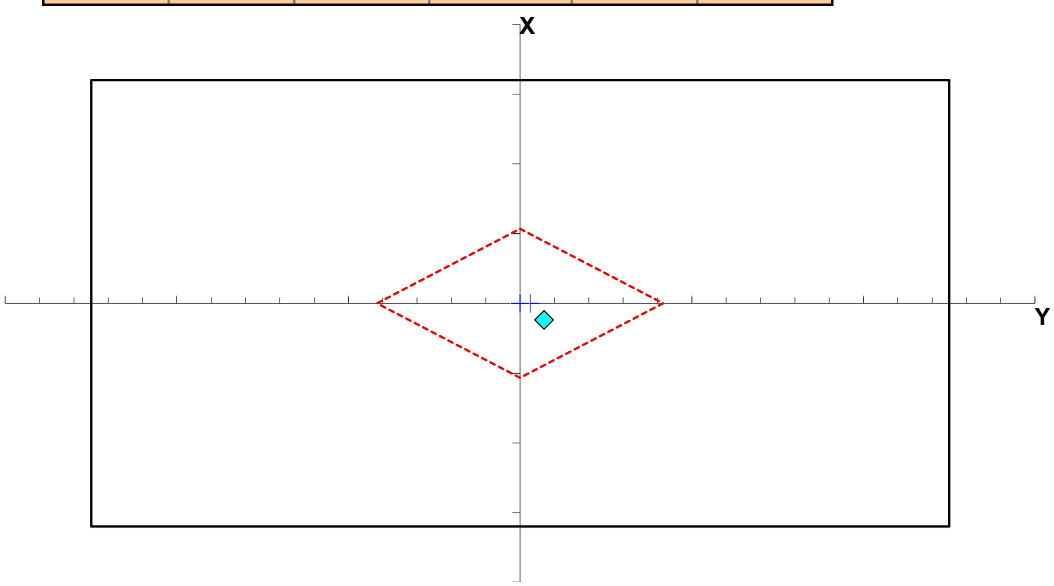


Nomenclature

Loading Data:

Direction of Seismic Load: COMBINED

	Uplift	Vertical Soil	Not Used	Not Used	Not Used	SAP2000 Reaction
Yp (m.) =	0.00	**0.12**				**0.00**
Xp (m.) =	0.00	0.00				0.00
Pz (kN) =	**1128.96**	**-11583.42**				**-12036.65**
Hy (kN) =	0.00	0.00				**158.84**
Hx (kN) =	0.00	0.00				**101.82**
My (kN-m) =	0.00	0.00				**5409.29**
Mx (kN-m) =	0.00	0.00				**4944.13**



FOOTING PLAN

Note: Is the "Kern" area of footing (When resultant of loads falls within "Kern", entire footing base is in bearing.)

Results:

Total Resultant Load and Eccentricities:

ΣPy =	-22491.11	kN
ey =	0.28	m (<= L/6)
ex =	-0.24	m (<= B/6)
ΣHy =	158.84	kN
ΣHx =	101.82	kN
H resultant =	188.67	kN
ΣMry =	75584.21	kN-m
ΣMoy =	9021.96	kN-m
ΣMrx =	116768.23	kN-m
ΣMox =	10588.93	kN-m

Sliding Check:

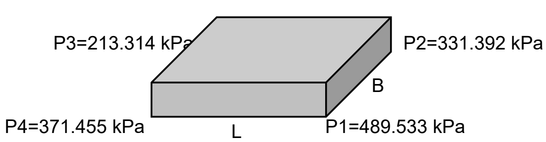
Frict =	11470.46	kN
FS(slid) =	60.795	

% Base Area in Compression:

Dist. y =	N.A.	m
Dist. x =	N.A.	m
Brg. Ly =	10.000	m
Brg. Lx =	6.400	m
%Brg. Area =	100.00	%
Biaxial Case =	N.A.	6*ex/L + 6*ez/B = 0.393

Gross Soil Bearing Corner Pressures:

P_1 =	489.533	kPa
P_2 =	331.392	kPa
P_3 =	213.314	kPa
P_4 =	371.455	kPa



CORNER PRESSURES

Summary of Results:

Sliding Check:

FS(slid) =	60.80	> 1	OK

Bearing Area:

%Brg. Area =	100.00%	> 1%	OK

Bearing Pressure Check:

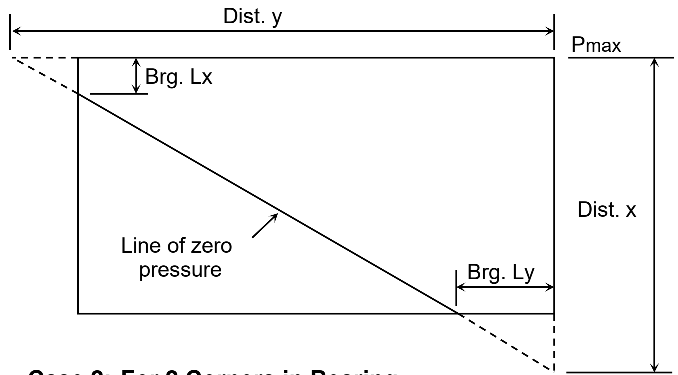
FS(brg) =	2.62	> 1.0	OK

Flotation Check:

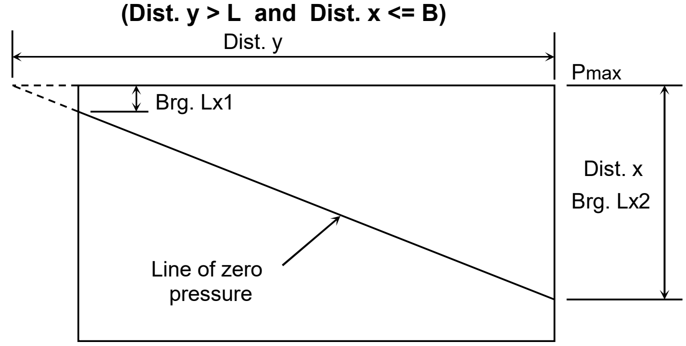
FS (float) =	20.92	> 1	OK

Nomenclature for Biaxial Eccentricity:

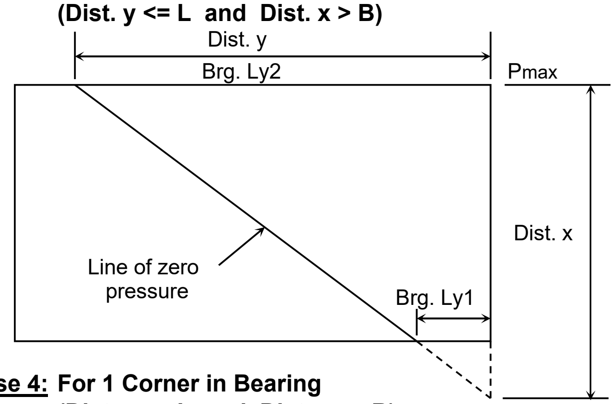
Case 1: For 3 Corners in Bearing
(Dist. y > L and Dist. x > B)



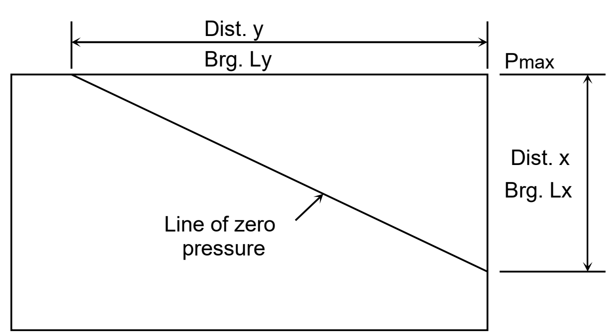
Case 2: For 2 Corners in Bearing
(Dist. y > L and Dist. x <= B)



Case 3: For 2 Corners in Bearing
(Dist. y <= L and Dist. x > B)



Case 4: For 1 Corner in Bearing
(Dist. y <= L and Dist. x <= B)



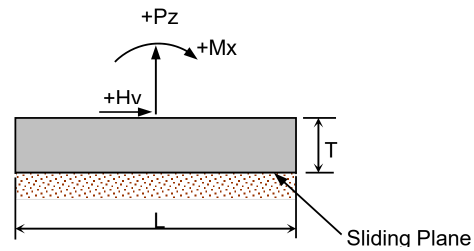
GATE TOWER STABILITY ANALYSIS

Job Name:	Springbank Off-Stream Storage Project	Number:	110773396			
Site:	Gate Tower	Originator:	ACG	7/2/2020	Checker:	CG
Load Case:	E3-2 Extreme Earthquake					

Input Data:

Footing Data:

Footing Length, L =	10.00	m
Footing Width, B =	6.40	m
Footing Thickness, T =	0.00	m
Coef. of Base Friction, μ =	0.51	
Ultimate Bearing, Pall =	1281.00	kPa

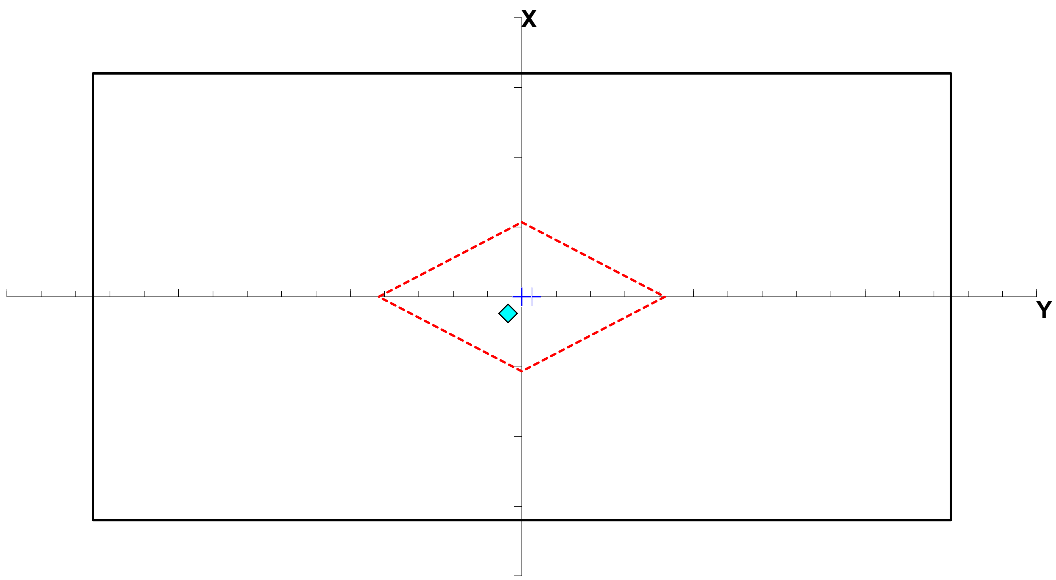


Nomenclature

Loading Data:

Direction of Seismic Load: COMBINED

	Uplift	Vertical Soil	Not Used	Not Used	Not Used	SAP2000 Reaction
Yp (m.) =	0.00	0.12				**0.00**
Xp (m.) =	0.00	0.00				0.00
Pz (kN) =	1128.96	-11583.42				**-12036.61**
Hy (kN) =	0.00	0.00				**-145.99**
Hx (kN) =	0.00	0.00				**101.82**
My (kN-m) =	0.00	0.00				**5409.29**
Mx (kN-m) =	0.00	0.00				**-5006.28**



FOOTING PLAN

Note: Is the "Kern" area of footing (When resultant of loads falls within "Kern", entire footing base is in bearing.)

Results:

Total Resultant Load and Eccentricities:

ΣPy =	-22491.07	kN
ey =	-0.16	m (<= L/6)
ex =	-0.24	m (<= B/6)
ΣHy =	-145.99	kN
ΣHx =	101.82	kN
H resultant =	177.99	kN
ΣMry =	75584.09	kN-m
ΣMoy =	9021.96	kN-m
ΣMrx =	119432.23	kN-m
ΣMox =	-10651.08	kN-m

Sliding Check:

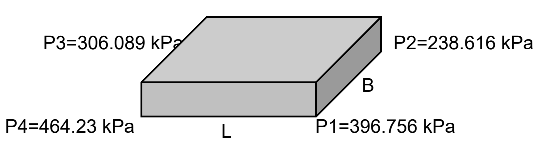
Frict =	11470.44	kN
FS(slid) =	64.446	

% Base Area in Compression:

Dist. y =	N.A.	m
Dist. x =	N.A.	m
Brg. Ly =	10.000	m
Brg. Lx =	6.400	m
%Brg. Area =	100.00	%
Biaxial Case =	N.A.	6*ex/L + 6*ez/B = 0.321

Gross Soil Bearing Corner Pressures:

P_1 =	396.756	kPa
P_2 =	238.616	kPa
P_3 =	306.089	kPa
P_4 =	464.230	kPa



CORNER PRESSURES

Summary of Results:

Sliding Check:

FS(slid) = **64.45** > 1 OK

Bearing Area:

%Brg. Area = **100.00%** > 1% OK

Bearing Pressure Check:

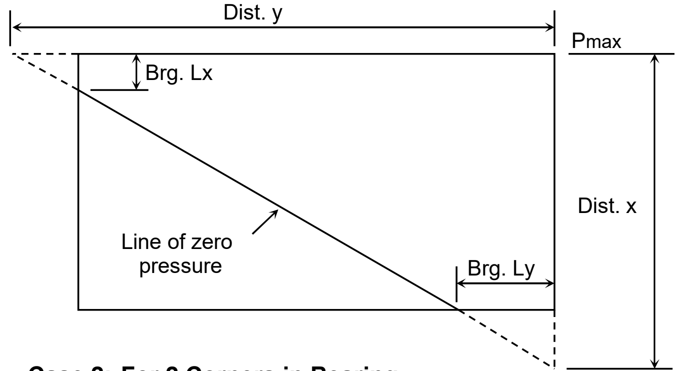
FS(brg) = **2.76** > 1.0 OK

Flotation Check:

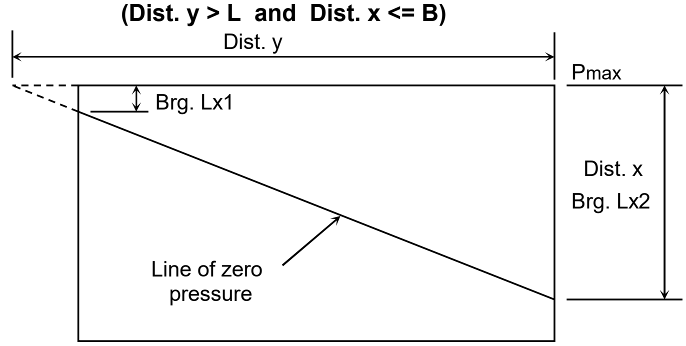
FS (float) = **20.92** > 1 OK

Nomenclature for Biaxial Eccentricity:

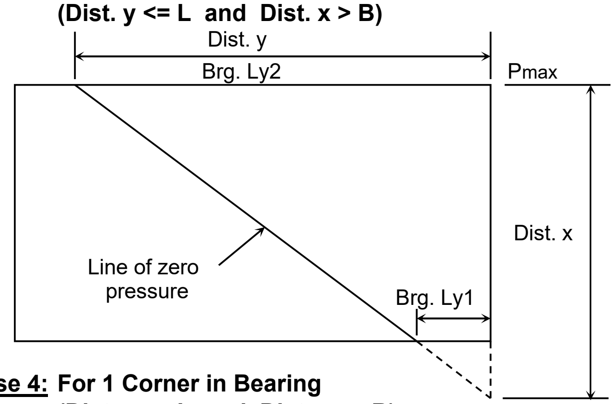
Case 1: For 3 Corners in Bearing (Dist. y > L and Dist. x > B)



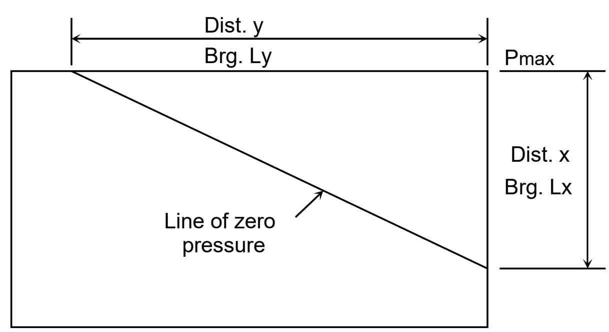
Case 2: For 2 Corners in Bearing (Dist. y > L and Dist. x <= B)



Case 3: For 2 Corners in Bearing (Dist. y <= L and Dist. x > B)



Case 4: For 1 Corner in Bearing (Dist. y <= L and Dist. x <= B)



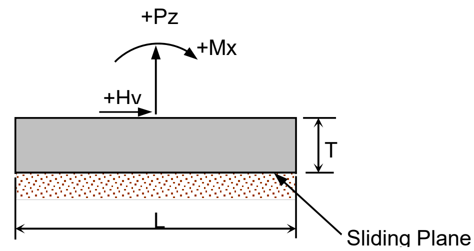
GATE TOWER STABILITY ANALYSIS

Job Name:	Springbank Off-Stream Storage Project	Number:	110773396			
Site:	Gate Tower	Originator:	ACG	7/2/2020	Checker:	CG
Load Case:	E3-3 Extreme Earthquake					

Input Data:

Footing Data:

Footing Length, L =	10.00	m
Footing Width, B =	6.40	m
Footing Thickness, T =	0.00	m
Coef. of Base Friction, μ =	0.51	
Ultimate Bearing, Pall =	1281.00	kPa

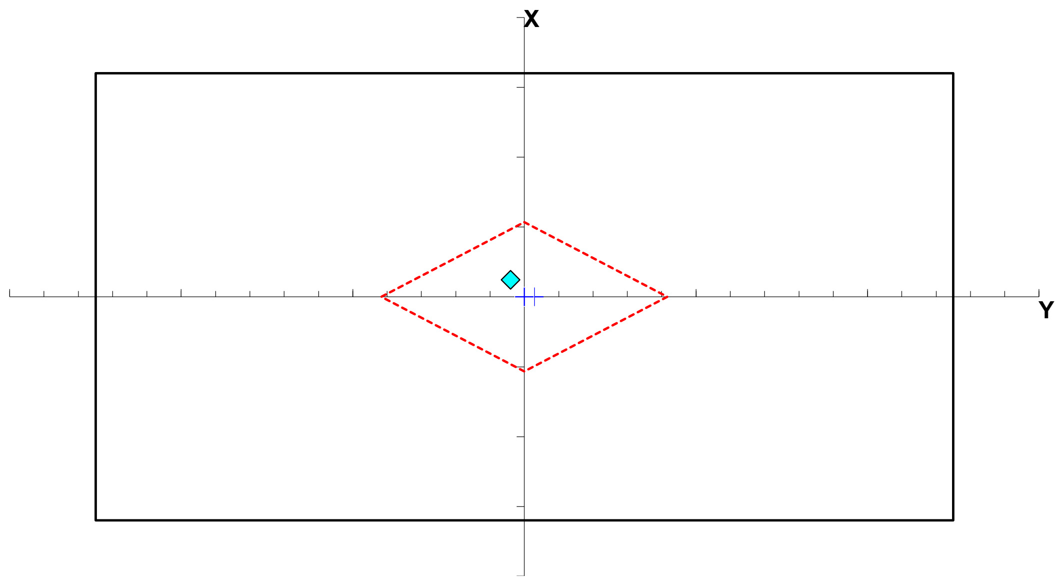


Nomenclature

Loading Data:

Direction of Seismic Load: COMBINED

	Uplift	Vertical Soil	Not Used	Not Used	Not Used	SAP2000 Reaction
Yp (m.) =	0.00	0.12				**0.00**
Xp (m.) =	0.00	0.00				0.00
Pz (kN) =	1128.96	-11583.42				**-12036.61**
Hy (kN) =	0.00	0.00				**-145.99**
Hx (kN) =	0.00	0.00				**-101.82**
My (kN-m) =	0.00	0.00				**-5409.29**
Mx (kN-m) =	0.00	0.00				**-5006.28**



FOOTING PLAN

Note: Is the "Kern" area of footing (When resultant of loads falls within "Kern", entire footing base is in bearing.)

Results:

Total Resultant Load and Eccentricities:

ΣPy =	-22491.07	kN
ey =	-0.16	m (<= L/6)
ex =	0.24	m (<= B/6)
ΣHy =	-145.99	kN
ΣHx =	-101.82	kN
H resultant =	177.99	kN
ΣMry =	75584.09	kN-m
ΣMoy =	-9021.96	kN-m
ΣMrx =	119432.23	kN-m
ΣMox =	-10651.08	kN-m

Sliding Check:

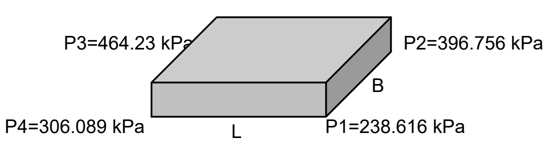
Frict =	11470.44	kN
FS(slid) =	64.446	

% Base Area in Compression:

Dist. y =	N.A.	m
Dist. x =	N.A.	m
Brg. Ly =	10.000	m
Brg. Lx =	6.400	m
%Brg. Area =	100.00	%
Biaxial Case =	N.A.	6*ex/L + 6*ez/B = 0.321

Gross Soil Bearing Corner Pressures:

P_1 =	238.616	kPa
P_2 =	396.756	kPa
P_3 =	464.230	kPa
P_4 =	306.089	kPa



CORNER PRESSURES

Summary of Results:

Sliding Check:

FS(slid) = **64.45** > 1 OK

Bearing Area:

%Brg. Area = **100.00%** > 1% OK

Bearing Pressure Check:

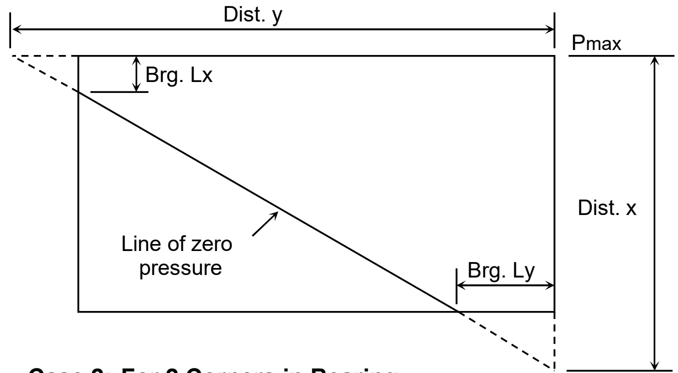
FS(brg) = **2.76** > 1.0 OK

Flotation Check:

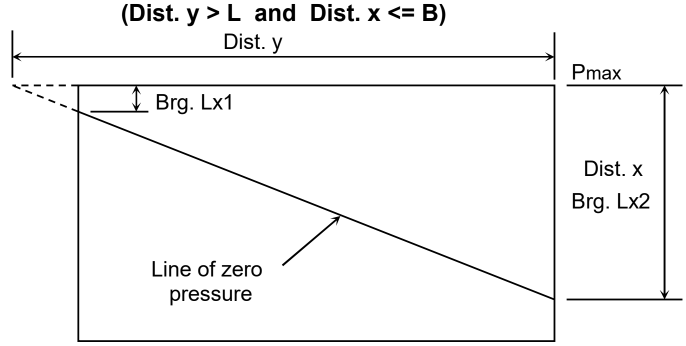
FS (float) = **20.92** > 1 OK

Nomenclature for Biaxial Eccentricity:

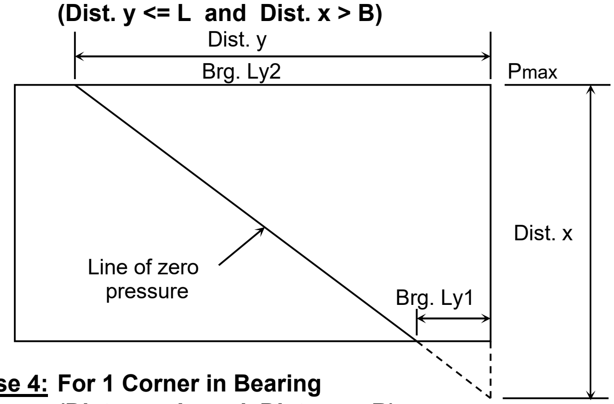
Case 1: For 3 Corners in Bearing (Dist. y > L and Dist. x > B)



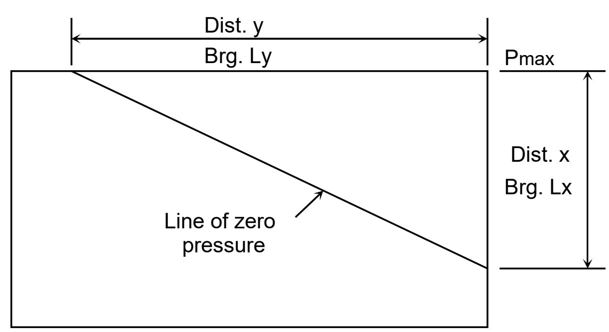
Case 2: For 2 Corners in Bearing (Dist. y > L and Dist. x <= B)



Case 3: For 2 Corners in Bearing (Dist. y <= L and Dist. x > B)



Case 4: For 1 Corner in Bearing (Dist. y <= L and Dist. x <= B)



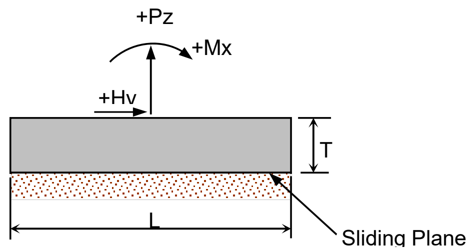
GATE TOWER STABILITY ANALYSIS

Job Name:	Springbank Off-Stream Storage Project	Number:	110773396		
Site:	Gate Tower	Originator:	ACG 7/2/2020	Checker:	CG
Load Case:	E3-4 Extreme Earthquake				

Input Data:

Footing Data:

Footing Length, L =	10.00	m
Footing Width, B =	6.40	m
Footing Thickness, T =	0.00	m
Coef. of Base Friction, μ =	0.51	
Ultimate Bearing, Pall =	1281.00	kPa

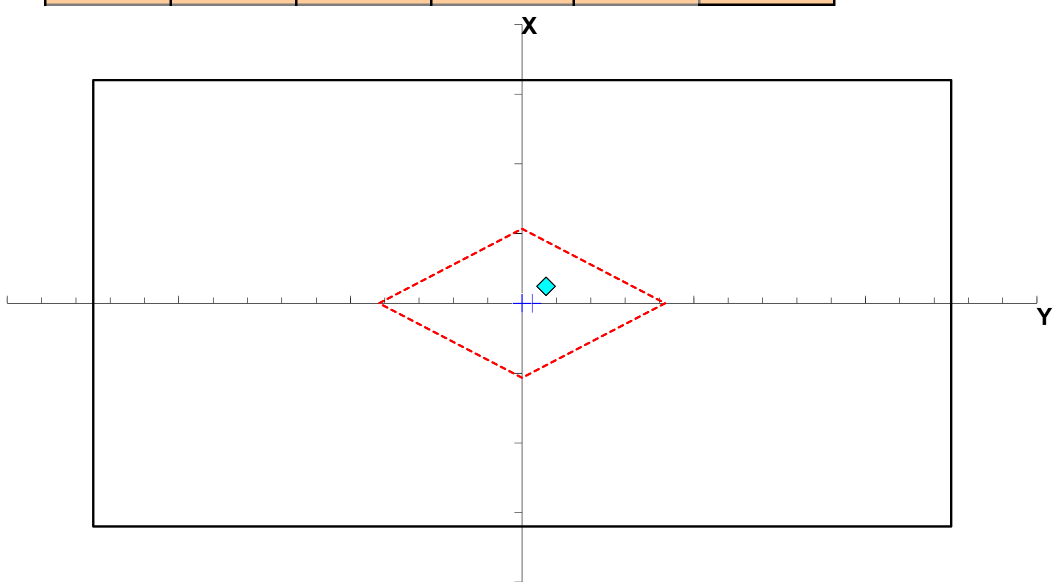


Nomenclature

Loading Data:

Direction of Seismic Load: COMBINED

	Uplift	Vertical Soil	Not Used	Not Used	Not Used	SAP2000 Reaction
Yp (m.) =	0.00	0.12				**0.00**
Xp (m.) =	0.00	0.00				0.00
Pz (kN) =	1128.96	-11583.42				**-12036.65**
Hy (kN) =	0.00	0.00				**158.84**
Hx (kN) =	0.00	0.00				**-101.82**
My (kN-m) =	0.00	0.00				**-5409.29**
Mx (kN-m) =	0.00	0.00				**4944.13**



FOOTING PLAN

Note: Is the "Kern" area of footing (When resultant of loads falls within "Kern", entire footing base is in bearing.)

Results:

Total Resultant Load and Eccentricities:

ΣPy =	-22491.11	kN
ey =	0.28	m (<= L/6)
ex =	0.24	m (<= B/6)
ΣHy =	158.84	kN
ΣHx =	-101.82	kN
H resultant =	188.67	kN
ΣMry =	75584.21	kN-m
ΣMoy =	-9021.96	kN-m
ΣMrx =	116768.23	kN-m
ΣMox =	10588.93	kN-m

Sliding Check:

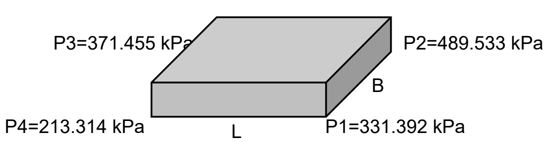
Frict =	11470.46	kN
FS(slid) =	60.795	

% Base Area in Compression:

Dist. y =	N.A.	m
Dist. x =	N.A.	m
Brg. Ly =	10.000	m
Brg. Lx =	6.400	m
%Brg. Area =	100.00	%
Biaxial Case =	N.A.	6*ex/L + 6*ez/B = 0.393

Gross Soil Bearing Corner Pressures:

P1 =	331.392	kPa
P2 =	489.533	kPa
P3 =	371.455	kPa
P4 =	213.314	kPa



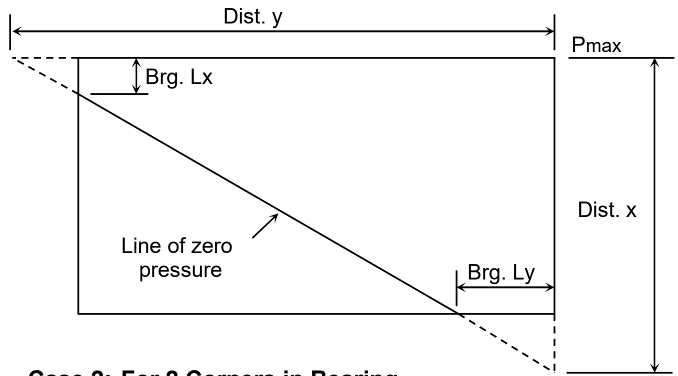
CORNER PRESSURES

Summary of Results:

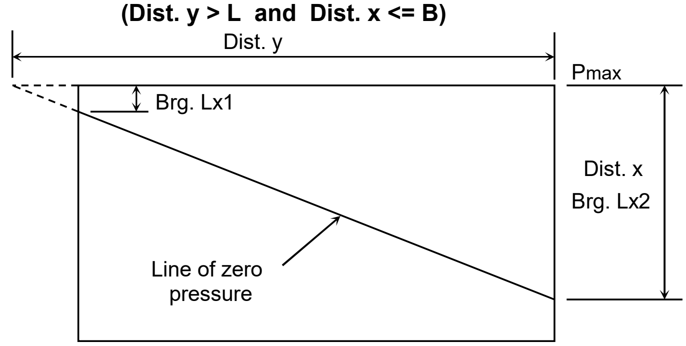
Sliding Check:			
FS(slid) =	60.80	> 1	OK
Bearing Area:			
%Brg. Area =	100.00%	> 1%	OK
Bearing Pressure Check:			
FS(brg) =	2.62	> 1.0	OK
Flotation Check:			
FS (float) =	20.92	> 1	OK

Nomenclature for Biaxial Eccentricity:

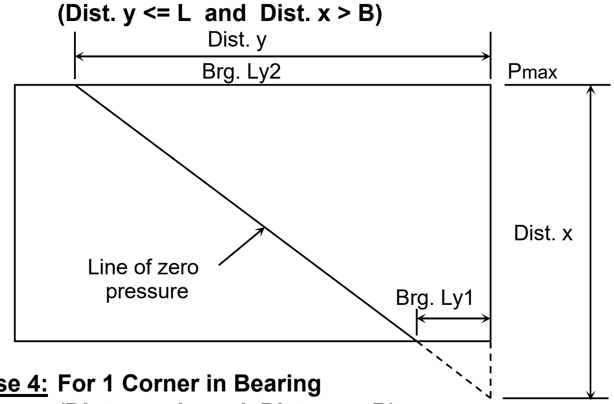
Case 1: For 3 Corners in Bearing
(Dist. y > L and Dist. x > B)



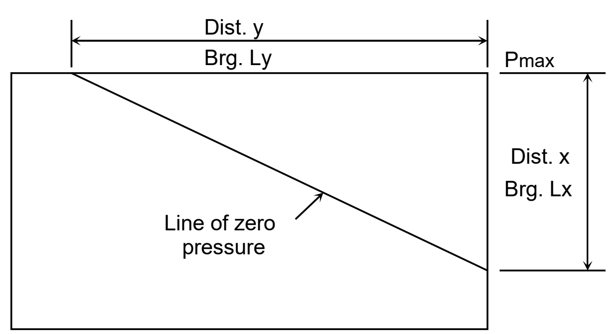
Case 2: For 2 Corners in Bearing
(Dist. y > L and Dist. x <= B)



Case 3: For 2 Corners in Bearing
(Dist. y <= L and Dist. x > B)



Case 4: For 1 Corner in Bearing
(Dist. y <= L and Dist. x <= B)



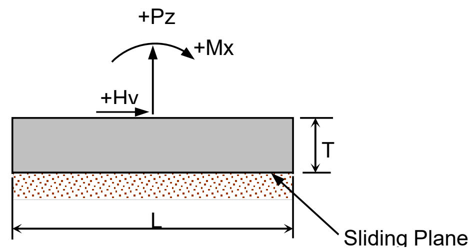
GATE TOWER STABILITY ANALYSIS

Job Name:	Springbank Off-Stream Storage Project	Number:	110773396		
Site:	Gate Tower	Originator:	ACG 7/2/2020	Checker:	CG
Load Case:	E3-5 Extreme Earthquake				

Input Data:

Footing Data:

Footing Length, L =	10.00	m
Footing Width, B =	6.40	m
Footing Thickness, T =	0.00	m
Coef. of Base Friction, μ =	0.51	
Ultimate Bearing, Pall =	1281.00	kPa

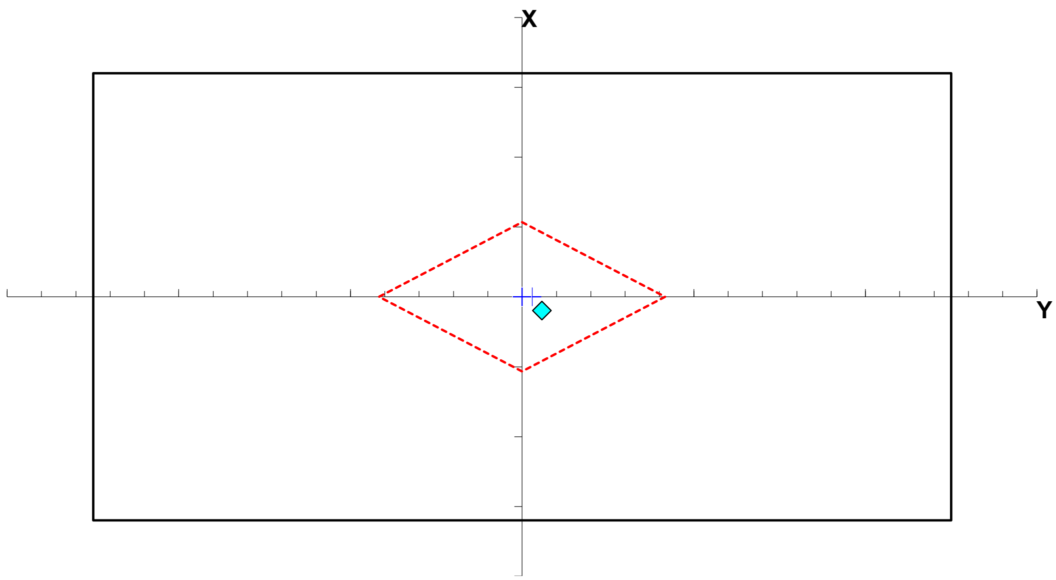


Nomenclature

Loading Data:

Direction of Seismic Load: COMBINED

	Uplift	Vertical Soil	Not Used	Not Used	Not Used	SAP2000 Reaction
Yp (m.) =	0.00	0.12				0.00
Xp (m.) =	0.00	0.00				0.00
Pz (kN) =	1128.96	-11583.42				-16383.59
Hy (kN) =	0.00	0.00				160.60
Hx (kN) =	0.00	0.00				101.82
My (kN-m) =	0.00	0.00				5409.29
Mx (kN-m) =	0.00	0.00				4934.17



FOOTING PLAN

Note: Is the "Kern" area of footing (When resultant of loads falls within "Kern", entire footing base is in bearing.)

Results:

Total Resultant Load and Eccentricities:

ΣPy =	-26838.05	kN
ey =	0.23	m (<= L/6)
ex =	-0.20	m (<= B/6)
ΣHy =	160.60	kN
ΣHx =	101.82	kN
H resultant =	190.15	kN
ΣMry =	89494.44	kN-m
ΣMoy =	9021.96	kN-m
ΣMrx =	138502.96	kN-m
ΣMox =	10578.97	kN-m

Sliding Check:

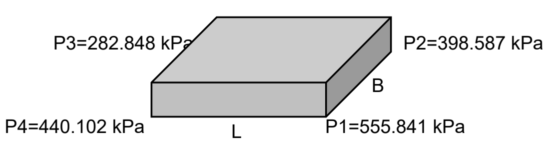
Frict =	13687.41	kN
FS(slid) =	71.980	

% Base Area in Compression:

Dist. y =	N.A.	m
Dist. x =	N.A.	m
Brg. Ly =	10.000	m
Brg. Lx =	6.400	m
%Brg. Area =	100.00	%
Biaxial Case =	N.A.	6*ex/L + 6*ez/B = 0.326

Gross Soil Bearing Corner Pressures:

P_1 =	555.841	kPa
P_2 =	398.587	kPa
P_3 =	282.848	kPa
P_4 =	440.102	kPa



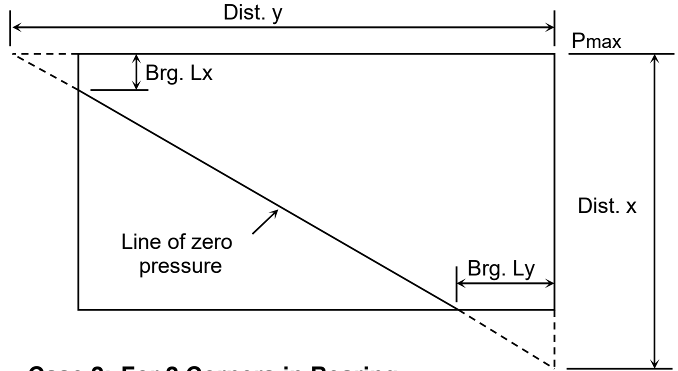
CORNER PRESSURES

Summary of Results:

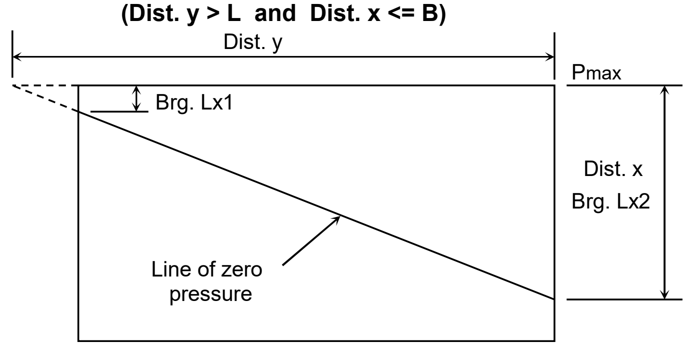
Sliding Check:			
FS(slid) =	71.98	> 1	OK
Bearing Area:			
%Brg. Area =	100.00%	> 1%	OK
Bearing Pressure Check:			
FS(brg) =	2.30	> 1.0	OK
Flotation Check:			
FS (float) =	24.77	> 1	OK

Nomenclature for Biaxial Eccentricity:

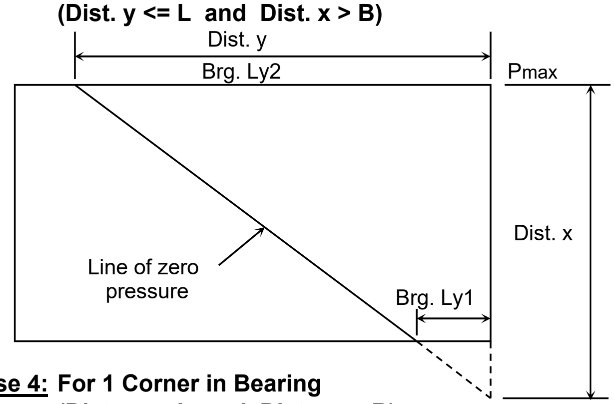
Case 1: For 3 Corners in Bearing
(Dist. y > L and Dist. x > B)



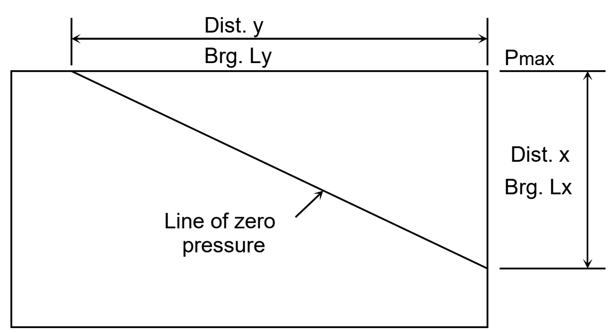
Case 2: For 2 Corners in Bearing
(Dist. y > L and Dist. x <= B)



Case 3: For 2 Corners in Bearing
(Dist. y <= L and Dist. x > B)



Case 4: For 1 Corner in Bearing
(Dist. y <= L and Dist. x <= B)



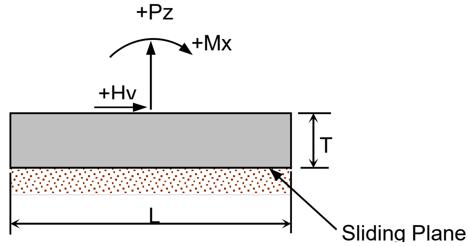
GATE TOWER STABILITY ANALYSIS

Job Name:	Springbank Off-Stream Storage Project	Number:	110773396
Site:	Gate Tower	Originator:	ACG 7/2/2020 Checker: CG
Load Case:	E3-6 Extreme Earthquake		

Input Data:

Footing Data:

Footing Length, L =	10.00	m
Footing Width, B =	6.40	m
Footing Thickness, T =	0.00	m
Coef. of Base Friction, μ =	0.51	
Ultimate Bearing, Pall =	1281.00	kPa

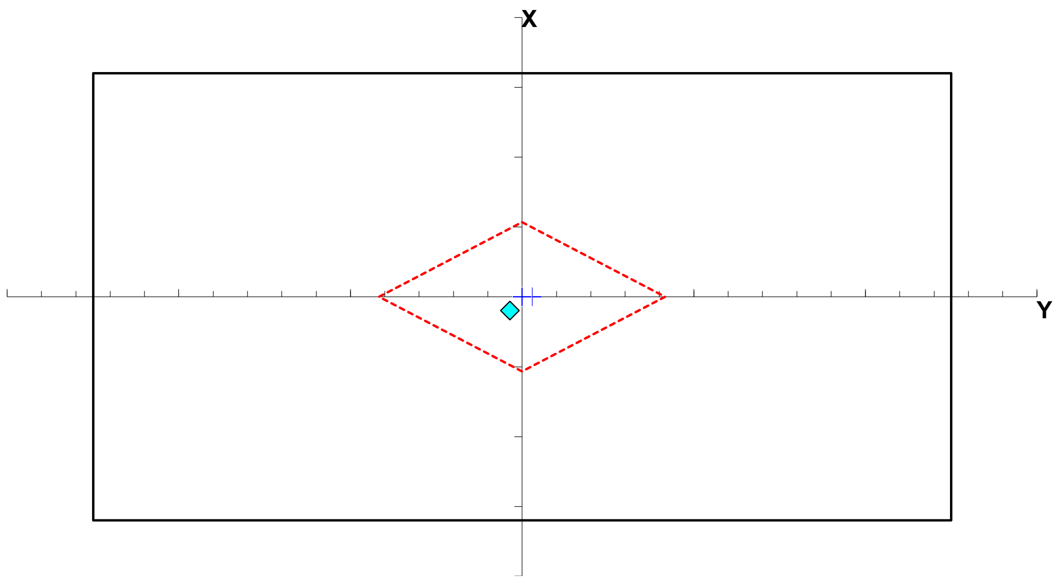


Nomenclature

Loading Data:

Direction of Seismic Load: COMBINED

	Uplift	Vertical Soil	Not Used	Not Used	Not Used	SAP2000 Reaction
Yp (m.) =	0.00	0.12				0.00
Xp (m.) =	0.00	0.00				0.00
Pz (kN) =	1128.96	-11583.42				-16383.55
Hy (kN) =	0.00	0.00				-144.23
Hx (kN) =	0.00	0.00				101.82
My (kN-m) =	0.00	0.00				5409.29
Mx (kN-m) =	0.00	0.00				-5016.24



FOOTING PLAN

Note: Is the "Kern" area of footing (When resultant of loads falls within "Kern", entire footing base is in bearing.)

Results:

Total Resultant Load and Eccentricities:

ΣPy =	-26838.01	kN
ey =	-0.14	m (<= L/6)
ex =	-0.20	m (<= B/6)
ΣHy =	-144.23	kN
ΣHx =	101.82	kN
H resultant =	176.55	kN
ΣMry =	89494.32	kN-m
ΣMoy =	9021.96	kN-m
ΣMrx =	141166.96	kN-m
ΣMox =	-10661.04	kN-m

Sliding Check:

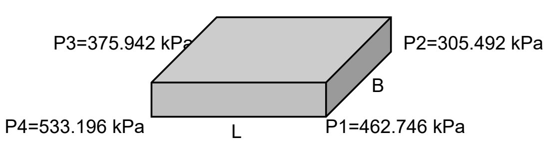
Frict =	13687.39	kN
FS(slid) =	77.529	

% Base Area in Compression:

Dist. y =	N.A.	m
Dist. x =	N.A.	m
Brg. Ly =	10.000	m
Brg. Lx =	6.400	m
%Brg. Area =	100.00	%
Biaxial Case =	N.A.	6*ex/L + 6*ez/B = 0.272

Gross Soil Bearing Corner Pressures:

P_1 =	462.746	kPa
P_2 =	305.492	kPa
P_3 =	375.942	kPa
P_4 =	533.196	kPa



CORNER PRESSURES

Summary of Results:

Sliding Check:

FS(slid) = **77.53** > 1 OK

Bearing Area:

%Brg. Area = **100.00%** > 1% OK

Bearing Pressure Check:

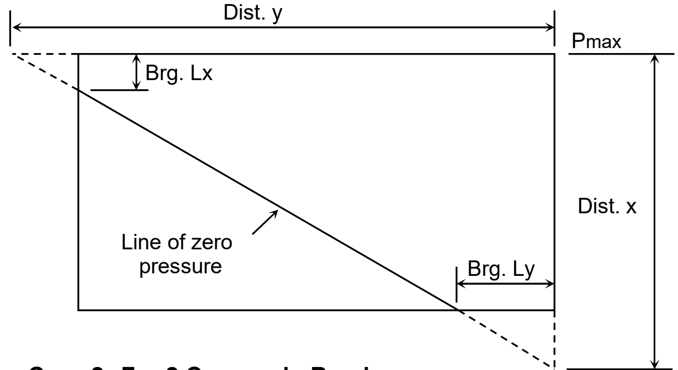
FS(brg) = **2.40** > 1.0 OK

Flotation Check:

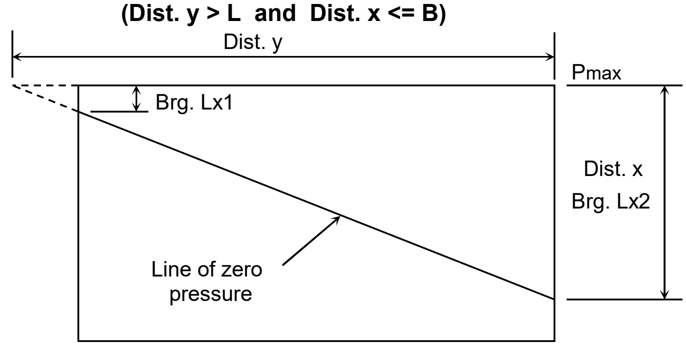
FS (float) = **24.77** > 1 OK

Nomenclature for Biaxial Eccentricity:

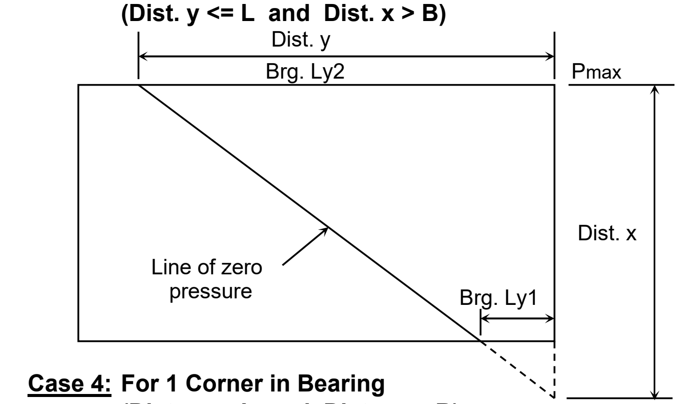
Case 1: For 3 Corners in Bearing
(Dist. y > L and Dist. x > B)



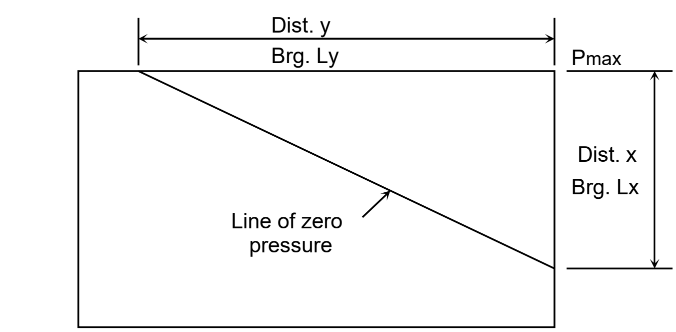
Case 2: For 2 Corners in Bearing
(Dist. y > L and Dist. x <= B)



Case 3: For 2 Corners in Bearing
(Dist. y <= L and Dist. x > B)



Case 4: For 1 Corner in Bearing
(Dist. y <= L and Dist. x <= B)



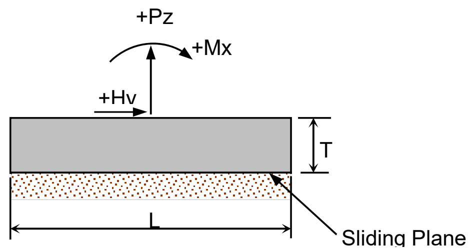
GATE TOWER STABILITY ANALYSIS

Job Name:	Springbank Off-Stream Storage Project	Number:	110773396
Site:	Gate Tower	Originator:	ACG 7/2/2020 Checker: CG
Load Case:	E3-7 Extreme Earthquake		

Input Data:

Footing Data:

Footing Length, L =	10.00	m
Footing Width, B =	6.40	m
Footing Thickness, T =	0.00	m
Coef. of Base Friction, μ =	0.51	
Ultimate Bearing, Pall =	1281.00	kPa

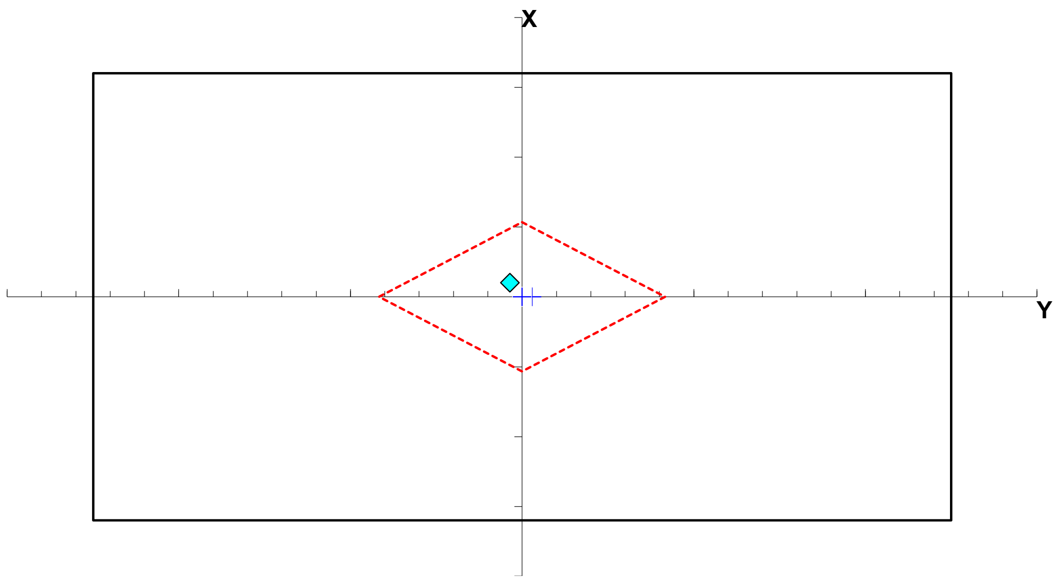


Nomenclature

Loading Data:

Direction of Seismic Load: COMBINED

	Uplift	Vertical Soil	Not Used	Not Used	Not Used	SAP2000 Reaction
Yp (m.) =	0.00	0.12				0.00
Xp (m.) =	0.00	0.00				0.00
Pz (kN) =	1128.96	-11583.42				-16383.55
Hy (kN) =	0.00	0.00				-144.23
Hx (kN) =	0.00	0.00				-101.82
My (kN-m) =	0.00	0.00				-5409.29
Mx (kN-m) =	0.00	0.00				-5016.24



FOOTING PLAN

Note: Is the "Kern" area of footing (When resultant of loads falls within "Kern", entire footing base is in bearing.)

Results:

Total Resultant Load and Eccentricities:

ΣPy =	-26838.01	kN
ey =	-0.14	m (<= L/6)
ex =	0.20	m (<= B/6)
ΣHy =	-144.23	kN
ΣHx =	-101.82	kN
H resultant =	176.55	kN
ΣMry =	89494.32	kN-m
ΣMoy =	-9021.96	kN-m
ΣMrx =	141166.96	kN-m
ΣMox =	-10661.04	kN-m

Sliding Check:

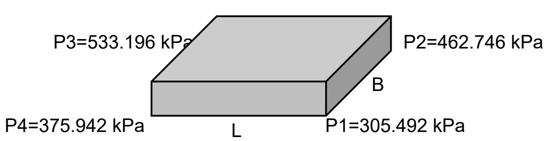
Frict =	13687.39	kN
FS(slid) =	77.529	

% Base Area in Compression:

Dist. y =	N.A.	m
Dist. x =	N.A.	m
Brg. Ly =	10.000	m
Brg. Lx =	6.400	m
%Brg. Area =	100.00	%
Biaxial Case =	N.A.	6*ex/L + 6*ez/B = 0.272

Gross Soil Bearing Corner Pressures:

P_1 =	305.492	kPa
P_2 =	462.746	kPa
P_3 =	533.196	kPa
P_4 =	375.942	kPa



CORNER PRESSURES

Summary of Results:

Sliding Check:

FS(slid) =	77.53	> 1	OK

Bearing Area:

%Brg. Area =	100.00%	> 1%	OK

Bearing Pressure Check:

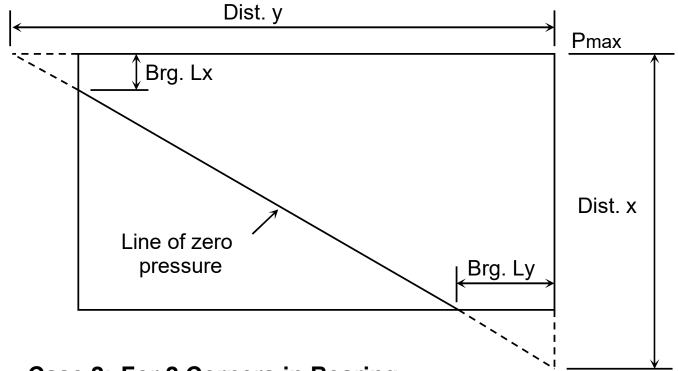
FS(brg) =	2.40	> 1.0	OK

Flotation Check:

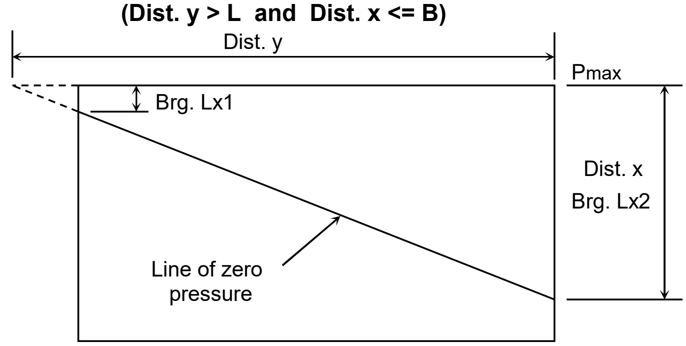
FS (float) =	24.77	> 1	OK

Nomenclature for Biaxial Eccentricity:

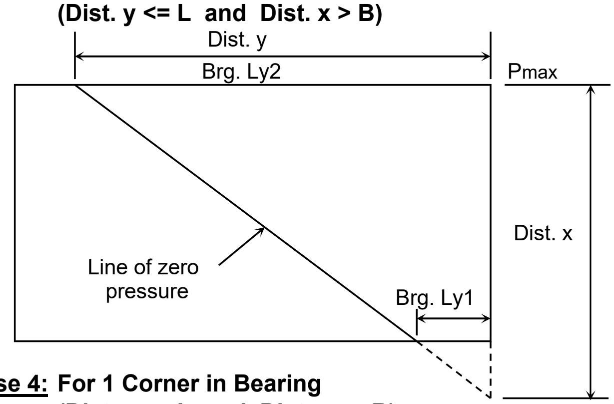
Case 1: For 3 Corners in Bearing
(Dist. y > L and Dist. x > B)



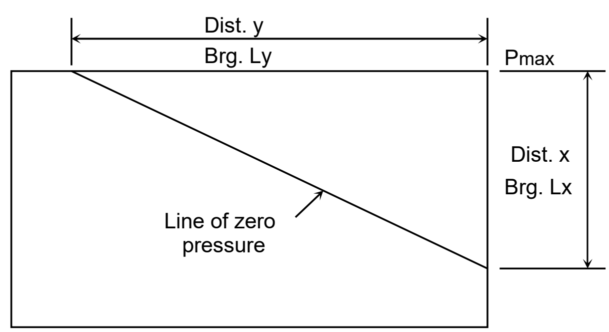
Case 2: For 2 Corners in Bearing
(Dist. y > L and Dist. x <= B)



Case 3: For 2 Corners in Bearing
(Dist. y <= L and Dist. x > B)



Case 4: For 1 Corner in Bearing
(Dist. y <= L and Dist. x <= B)



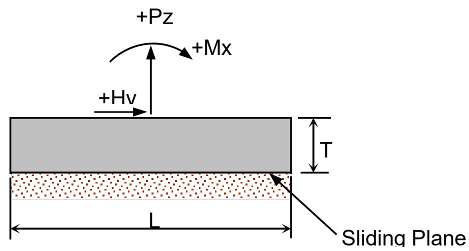
GATE TOWER STABILITY ANALYSIS

Job Name:	Springbank Off-Stream Storage Project	Number:	110773396
Site:	Gate Tower	Originator:	ACG 7/2/2020 Checker: CG
Load Case:	E3-8 Extreme Earthquake		

Input Data:

Footing Data:

Footing Length, L =	10.00	m
Footing Width, B =	6.40	m
Footing Thickness, T =	0.00	m
Coef. of Base Friction, μ =	0.51	
Ultimate Bearing, Pall =	1281.00	kPa

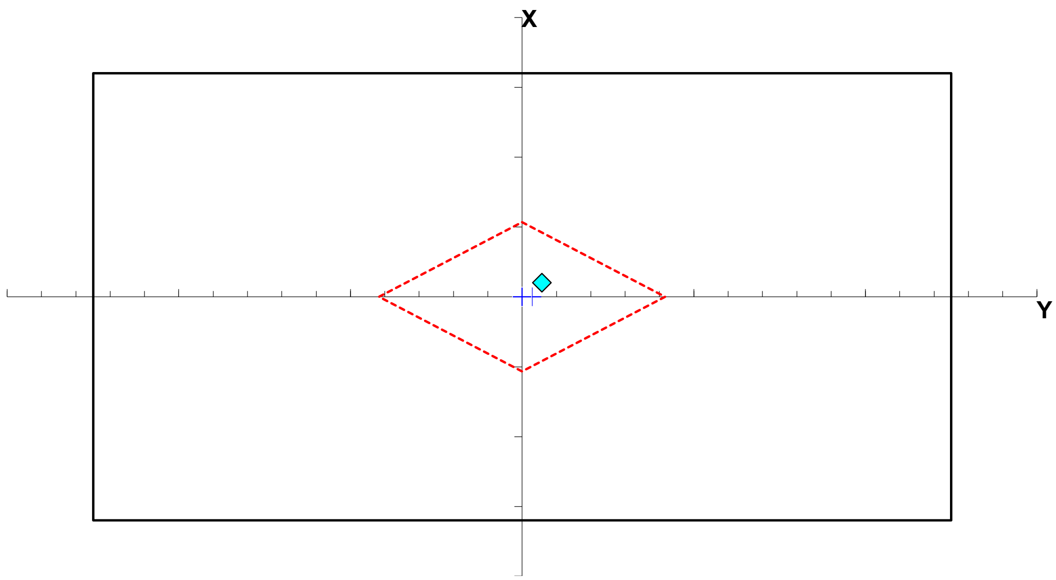


Nomenclature

Loading Data:

Direction of Seismic Load: COMBINED

	Uplift	Vertical Soil	Not Used	Not Used	Not Used	SAP2000 Reaction
Yp (m.) =	0.00	0.12				**0.00**
Xp (m.) =	0.00	0.00				0.00
Pz (kN) =	1128.96	-11583.42				**-16383.59**
Hy (kN) =	0.00	0.00				**160.60**
Hx (kN) =	0.00	0.00				**-101.82**
My (kN-m) =	0.00	0.00				**-5409.29**
Mx (kN-m) =	0.00	0.00				**4934.17**



FOOTING PLAN

Note: Is the "Kern" area of footing (When resultant of loads falls within "Kern", entire footing base is in bearing.)

Results:

Total Resultant Load and Eccentricities:

ΣPy =	-26838.05	kN
ey =	0.23	m (<= L/6)
ex =	0.20	m (<= B/6)
ΣHy =	160.60	kN
ΣHx =	-101.82	kN
H resultant =	190.15	kN
ΣMry =	89494.44	kN-m
ΣMoy =	-9021.96	kN-m
ΣMrx =	138502.96	kN-m
ΣMox =	10578.97	kN-m

Sliding Check:

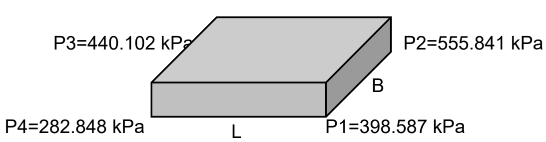
Frict =	13687.41	kN
FS(slid) =	71.980	

% Base Area in Compression:

Dist. y =	N.A.	m
Dist. x =	N.A.	m
Brg. Ly =	10.000	m
Brg. Lx =	6.400	m
%Brg. Area =	100.00	%
Biaxial Case =	N.A.	6*ex/L + 6*ez/B = 0.326

Gross Soil Bearing Corner Pressures:

P_1 =	398.587	kPa
P_2 =	555.841	kPa
P_3 =	440.102	kPa
P_4 =	282.848	kPa



CORNER PRESSURES

Summary of Results:

Sliding Check:

FS(slid) =	71.98	> 1	OK

Bearing Area:

%Brg. Area =	100.00%	> 1%	OK

Bearing Pressure Check:

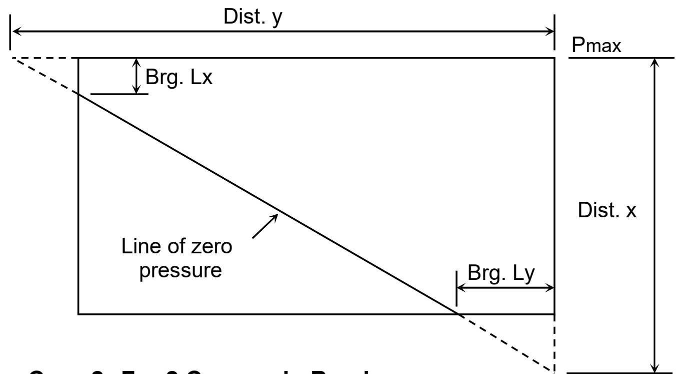
FS(brg) =	2.30	> 1.0	OK

Flotation Check:

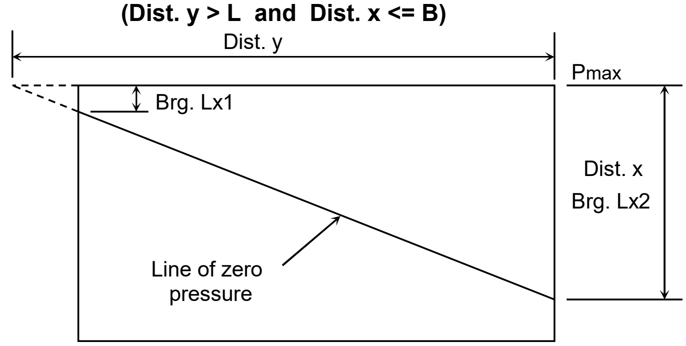
FS (float) =	24.77	> 1	OK

Nomenclature for Biaxial Eccentricity:

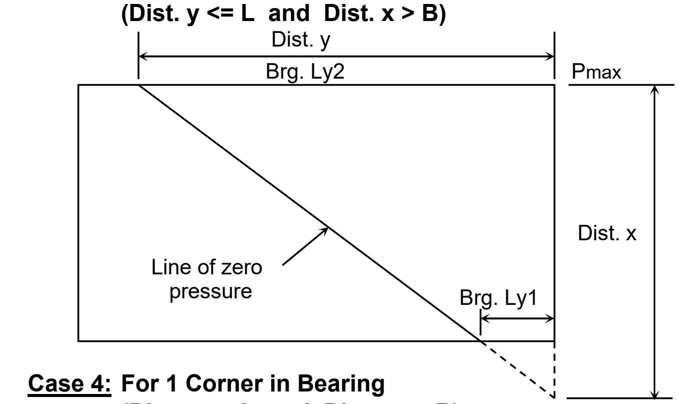
Case 1: For 3 Corners in Bearing
(Dist. y > L and Dist. x > B)



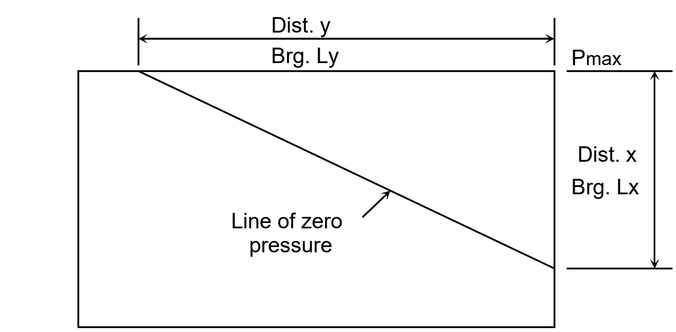
Case 2: For 2 Corners in Bearing
(Dist. y > L and Dist. x <= B)



Case 3: For 2 Corners in Bearing
(Dist. y <= L and Dist. x > B)



Case 4: For 1 Corner in Bearing
(Dist. y <= L and Dist. x <= B)



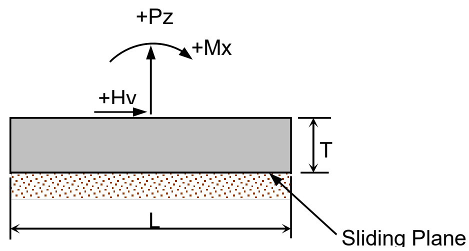
GATE TOWER STABILITY ANALYSIS

Job Name:	Springbank Off-Stream Storage Project	Number:	110773396			
Site:	Gate Tower	Originator:	ACG	7/2/2020	Checker:	CG
Load Case:	E3-9 Extreme Earthquake					

Input Data:

Footing Data:

Footing Length, L =	10.00	m
Footing Width, B =	6.40	m
Footing Thickness, T =	0.00	m
Coef. of Base Friction, μ =	0.51	
Ultimate Bearing, Pall =	1281.00	kPa

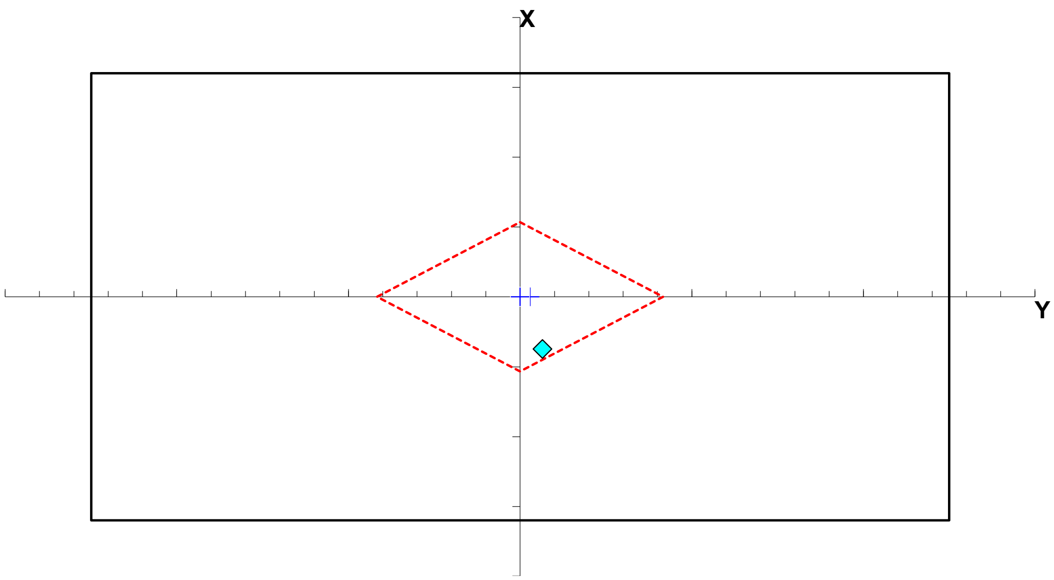


Nomenclature

Loading Data:

Direction of Seismic Load: COMBINED

	Uplift	Vertical Soil	Not Used	Not Used	Not Used	SAP2000 Reaction
Yp (m.) =	0.00	0.12				**0.00**
Xp (m.) =	0.00	0.00				0.00
Pz (kN) =	1128.96	-11583.42				**-13558.08**
Hy (kN) =	0.00	0.00				**159.46**
Hx (kN) =	0.00	0.00				**339.39**
My (kN-m) =	0.00	0.00				**18030.97**
Mx (kN-m) =	0.00	0.00				**4940.64**



FOOTING PLAN

Note: Is the "Kern" area of footing (When resultant of loads falls within "Kern", entire footing base is in bearing.)

Results:

Total Resultant Load and Eccentricities:

ΣPy =	-24012.54	kN
ey =	0.26	m (<= L/6)
ex =	-0.75	m (<= B/6)
ΣHy =	159.46	kN
ΣHx =	339.39	kN
H resultant =	374.98	kN
ΣMry =	80452.79	kN-m
ΣMoy =	21643.64	kN-m
ΣMrx =	124375.39	kN-m
ΣMox =	10585.44	kN-m

Sliding Check:

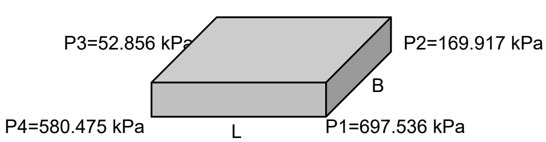
Frict =	12246.39	kN
FS(slid) =	32.659	

% Base Area in Compression:

Dist. y =	N.A.	m
Dist. x =	N.A.	m
Brg. Ly =	10.000	m
Brg. Lx =	6.400	m
%Brg. Area =	100.00	%
Biaxial Case =	N.A.	6*ex/L + 6*ez/B = 0.859

Gross Soil Bearing Corner Pressures:

P1 =	697.536	kPa
P2 =	169.917	kPa
P3 =	52.856	kPa
P4 =	580.475	kPa



CORNER PRESSURES

Summary of Results:

Sliding Check:

FS(slid) =	32.66	> 1	OK

Bearing Area:

%Brg. Area =	100.00%	> 1%	OK

Bearing Pressure Check:

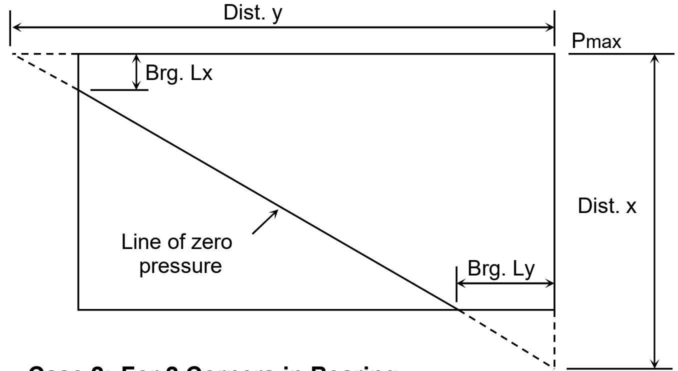
FS(brg) =	1.84	> 1.0	OK

Flotation Check:

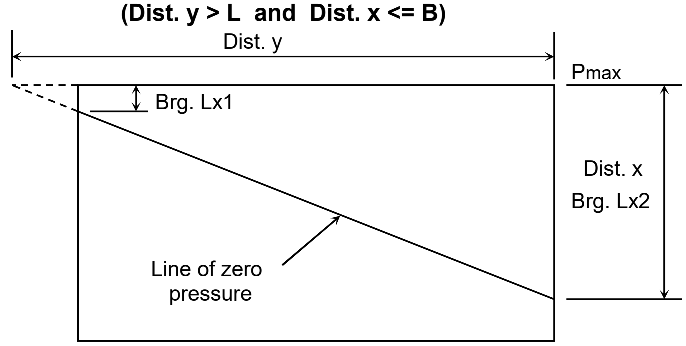
FS (float) =	22.27	> 1	OK

Nomenclature for Biaxial Eccentricity:

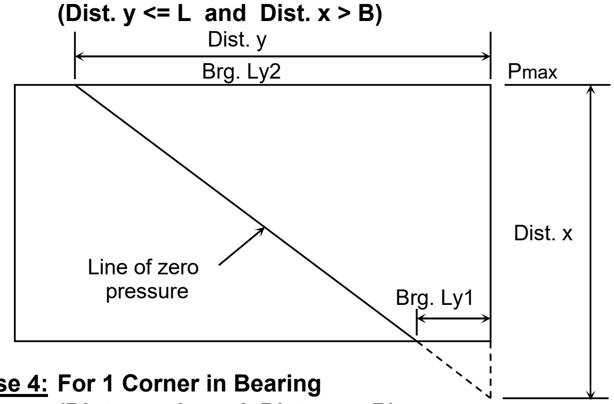
Case 1: For 3 Corners in Bearing (Dist. y > L and Dist. x > B)



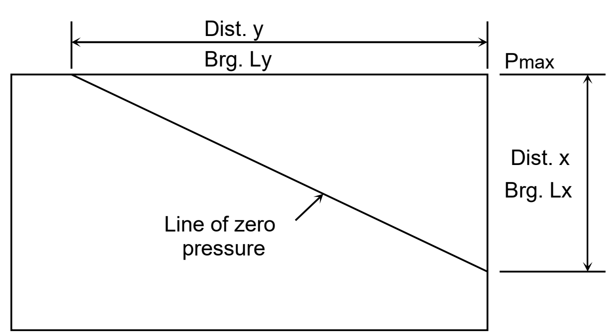
Case 2: For 2 Corners in Bearing (Dist. y > L and Dist. x <= B)



Case 3: For 2 Corners in Bearing (Dist. y <= L and Dist. x > B)



Case 4: For 1 Corner in Bearing (Dist. y <= L and Dist. x <= B)



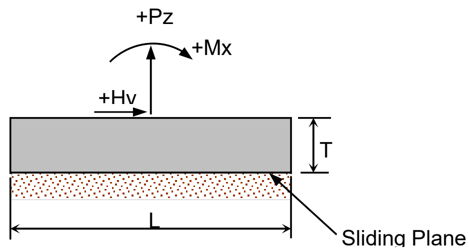
GATE TOWER STABILITY ANALYSIS

Job Name:	Springbank Off-Stream Storage Project	Number:	110773396
Site:	Gate Tower	Originator:	ACG 7/2/2020 Checker: CG
Load Case:	E3-10 Extreme Earthquake		

Input Data:

Footing Data:

Footing Length, L =	10.00	m
Footing Width, B =	6.40	m
Footing Thickness, T =	0.00	m
Coef. of Base Friction, μ =	0.51	
Ultimate Bearing, Pall =	1281.00	kPa

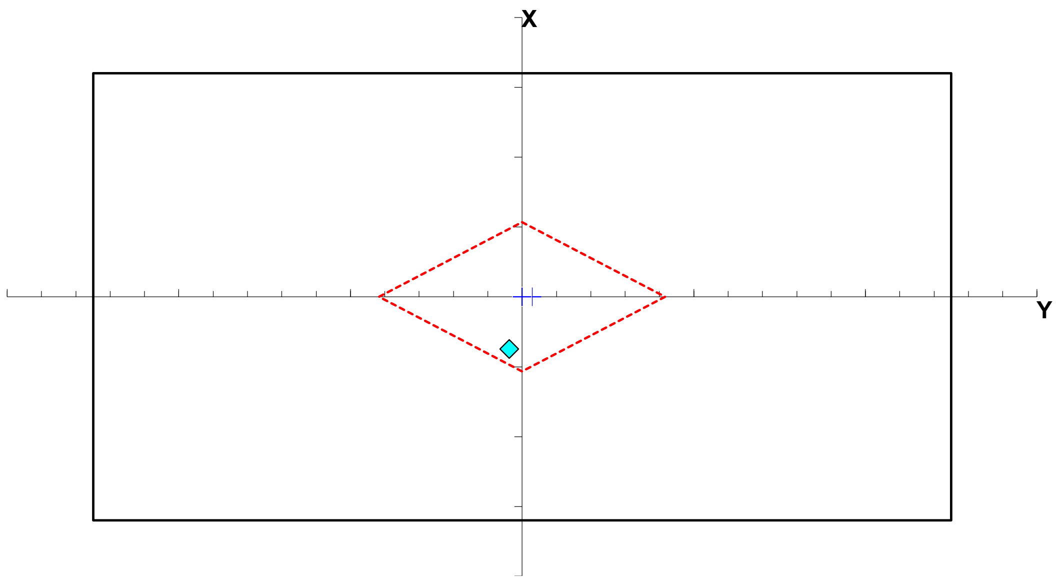


Nomenclature

Loading Data:

Direction of Seismic Load: COMBINED

	Uplift	Vertical Soil	Not Used	Not Used	Not Used	SAP2000 Reaction
Yp (m.) =	0.00	0.12				0.00
Xp (m.) =	0.00	0.00				0.00
Pz (kN) =	1128.96	-11583.42				-13558.04
Hy (kN) =	0.00	0.00				-145.37
Hx (kN) =	0.00	0.00				339.39
My (kN-m) =	0.00	0.00				18030.97
Mx (kN-m) =	0.00	0.00				-5009.76



FOOTING PLAN

Note: Is the "Kern" area of footing (When resultant of loads falls within "Kern", entire footing base is in bearing.)

Results:

Total Resultant Load and Eccentricities:

ΣPy =	-24012.50	kN
ey =	-0.15	m (<= L/6)
ex =	-0.75	m (<= B/6)
ΣHy =	-145.37	kN
ΣHx =	339.39	kN
H resultant =	369.21	kN
ΣMry =	80452.67	kN-m
ΣMoy =	21643.64	kN-m
ΣMrx =	127039.39	kN-m
ΣMox =	-10654.56	kN-m

Sliding Check:

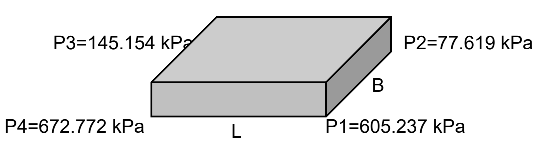
Frict =	12246.37	kN
FS(slid) =	33.169	

% Base Area in Compression:

Dist. y =	N.A.	m
Dist. x =	N.A.	m
Brg. Ly =	10.000	m
Brg. Lx =	6.400	m
%Brg. Area =	100.00	%
Biaxial Case =	N.A.	6*ex/L + 6*ez/B = 0.793

Gross Soil Bearing Corner Pressures:

P_1 =	605.237	kPa
P_2 =	77.619	kPa
P_3 =	145.154	kPa
P_4 =	672.772	kPa



CORNER PRESSURES

Summary of Results:

Sliding Check:

FS(slid) =	33.17	> 1	OK

Bearing Area:

%Brg. Area =	100.00%	> 1%	OK

Bearing Pressure Check:

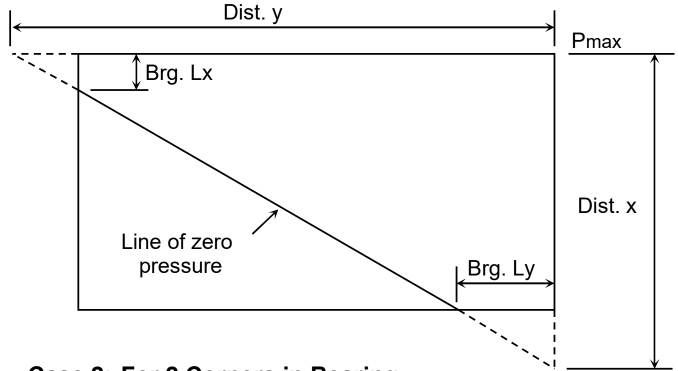
FS(brg) =	1.90	> 1.0	OK

Flotation Check:

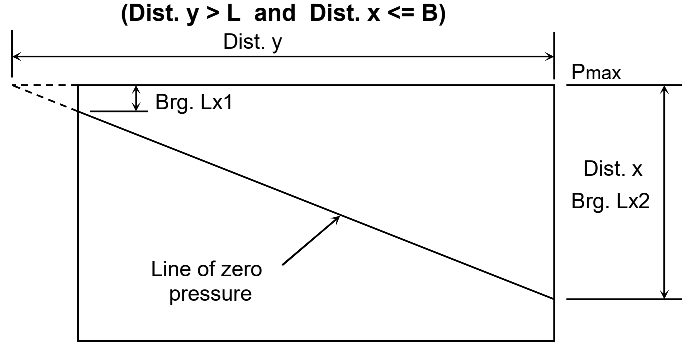
FS (float) =	22.27	> 1	OK

Nomenclature for Biaxial Eccentricity:

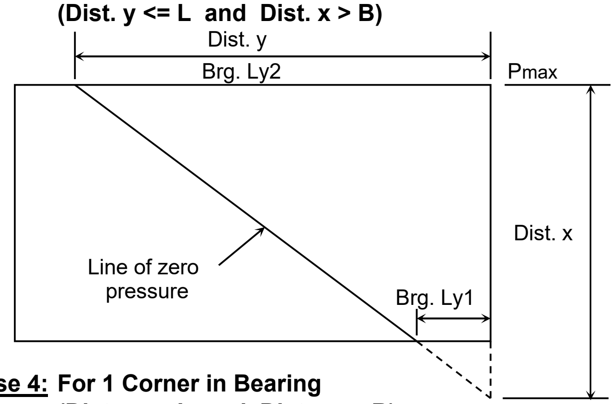
Case 1: For 3 Corners in Bearing
(Dist. y > L and Dist. x > B)



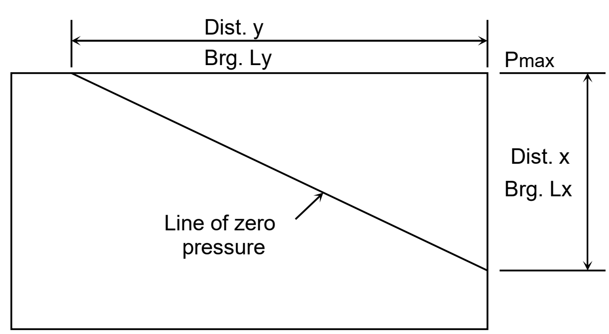
Case 2: For 2 Corners in Bearing
(Dist. y > L and Dist. x <= B)



Case 3: For 2 Corners in Bearing
(Dist. y <= L and Dist. x > B)



Case 4: For 1 Corner in Bearing
(Dist. y <= L and Dist. x <= B)



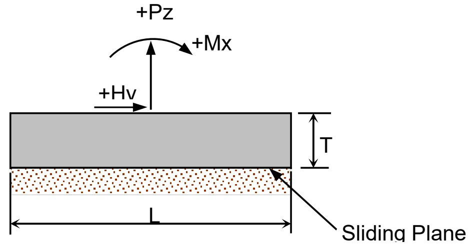
GATE TOWER STABILITY ANALYSIS

Job Name:	Springbank Off-Stream Storage Project	Number:	110773396		
Site:	Gate Tower	Originator:	ACG 7/2/2020	Checker:	CG
Load Case:	E3-11 Extreme Earthquake				

Input Data:

Footing Data:

Footing Length, L =	10.00	m
Footing Width, B =	6.40	m
Footing Thickness, T =	0.00	m
Coef. of Base Friction, μ =	0.51	
Ultimate Bearing, Pall =	1281.00	kPa

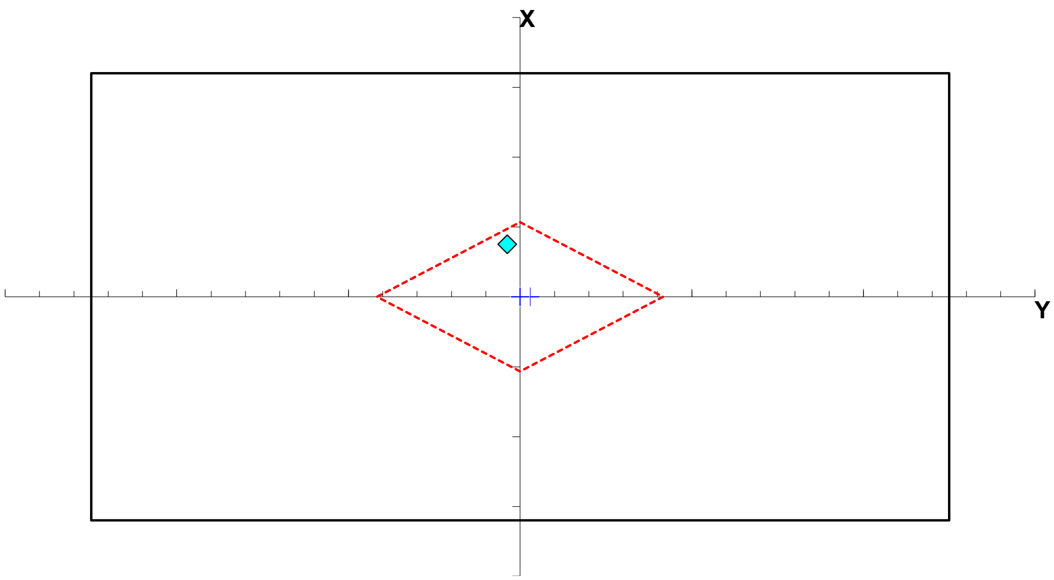


Nomenclature

Loading Data:

Direction of Seismic Load: COMBINED

	Uplift	Vertical Soil	Not Used	Not Used	Not Used	SAP2000 Reaction
Yp (m.) =	0.00	0.12				0.00
Xp (m.) =	0.00	0.00				0.00
Pz (kN) =	1128.96	-11583.42				-13558.04
Hy (kN) =	0.00	0.00				-145.37
Hx (kN) =	0.00	0.00				-339.39
My (kN-m) =	0.00	0.00				-18030.97
Mx (kN-m) =	0.00	0.00				-5009.76



FOOTING PLAN

Note: Is the "Kern" area of footing (When resultant of loads falls within "Kern", entire footing base is in bearing.)

Results:

Total Resultant Load and Eccentricities:

ΣPy =	-24012.50	kN
ey =	-0.15	m (<= L/6)
ex =	0.75	m (<= B/6)
ΣHy =	-145.37	kN
ΣHx =	-339.39	kN
H resultant =	369.21	kN
ΣMry =	80452.67	kN-m
ΣMoy =	-21643.64	kN-m
ΣMrx =	127039.39	kN-m
ΣMox =	-10654.56	kN-m

Sliding Check:

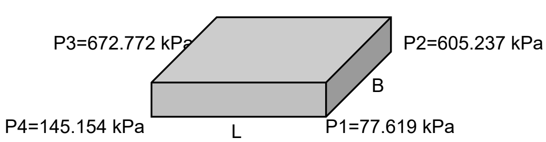
Frict =	12246.37	kN
FS(slid) =	33.169	

% Base Area in Compression:

Dist. y =	N.A.	m
Dist. x =	N.A.	m
Brg. Ly =	10.000	m
Brg. Lx =	6.400	m
%Brg. Area =	100.00	%
Biaxial Case =	N.A.	6*ex/L + 6*ez/B = 0.793

Gross Soil Bearing Corner Pressures:

P_1 =	77.619	kPa
P_2 =	605.237	kPa
P_3 =	672.772	kPa
P_4 =	145.154	kPa



CORNER PRESSURES

Summary of Results:

Sliding Check:

FS(slid) =	33.17	> 1	OK

Bearing Area:

%Brg. Area =	100.00%	> 1%	OK

Bearing Pressure Check:

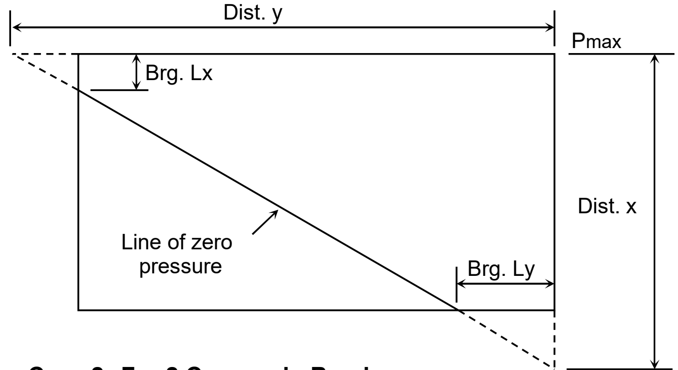
FS(brg) =	1.90	> 1.0	OK

Flotation Check:

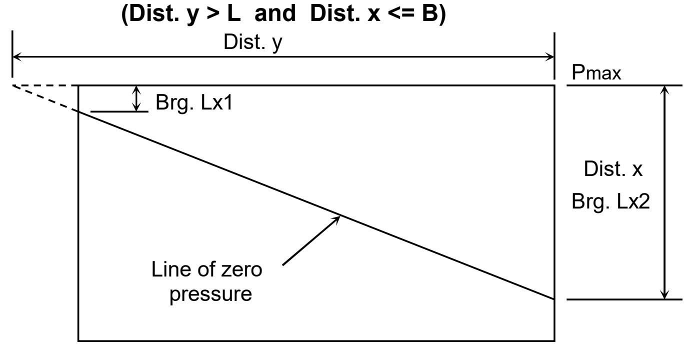
FS (float) =	22.27	> 1	OK

Nomenclature for Biaxial Eccentricity:

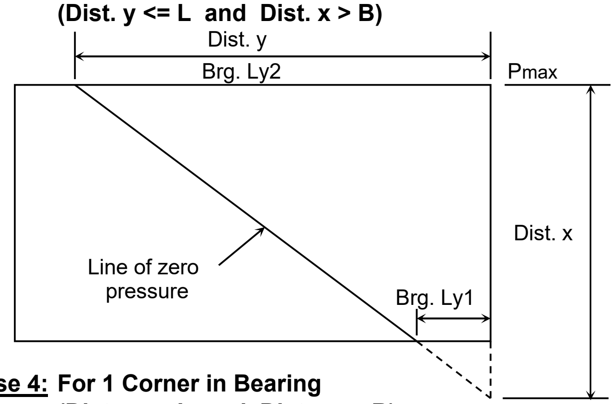
Case 1: For 3 Corners in Bearing
(Dist. y > L and Dist. x > B)



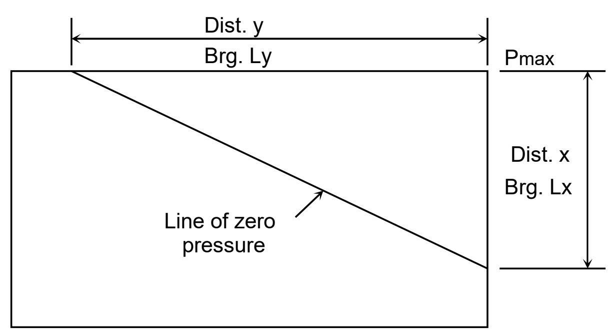
Case 2: For 2 Corners in Bearing
(Dist. y > L and Dist. x <= B)



Case 3: For 2 Corners in Bearing
(Dist. y <= L and Dist. x > B)



Case 4: For 1 Corner in Bearing
(Dist. y <= L and Dist. x <= B)



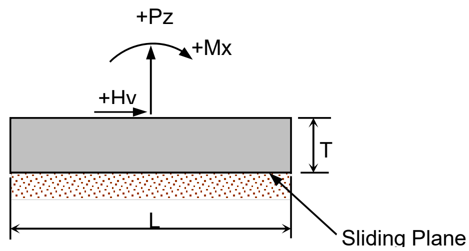
GATE TOWER STABILITY ANALYSIS

Job Name:	Springbank Off-Stream Storage Project	Number:	110773396
Site:	Gate Tower	Originator:	ACG 7/2/2020 Checker: CG
Load Case:	E3-12 Extreme Earthquake		

Input Data:

Footing Data:

Footing Length, L =	10.00	m
Footing Width, B =	6.40	m
Footing Thickness, T =	0.00	m
Coef. of Base Friction, μ =	0.51	
Ultimate Bearing, Pall =	1281.00	kPa

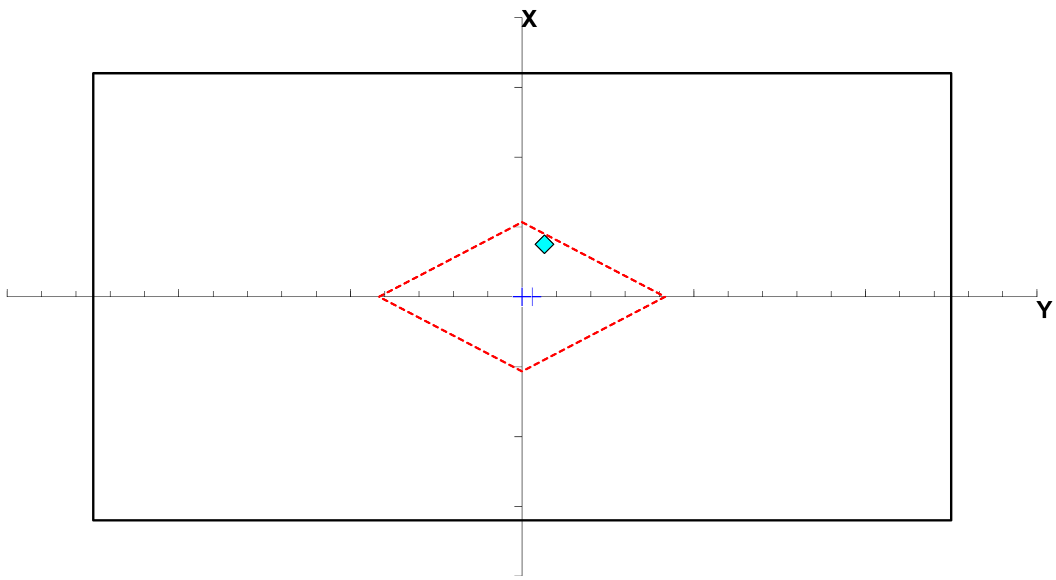


Nomenclature

Loading Data:

Direction of Seismic Load: COMBINED

	Uplift	Vertical Soil	Not Used	Not Used	Not Used	SAP2000 Reaction
Yp (m.) =	0.00	0.12				**0.00**
Xp (m.) =	0.00	0.00				0.00
Pz (kN) =	1128.96	-11583.42				**-13558.08**
Hy (kN) =	0.00	0.00				**159.46**
Hx (kN) =	0.00	0.00				**-339.39**
My (kN-m) =	0.00	0.00				**-18030.97**
Mx (kN-m) =	0.00	0.00				**4940.64**



FOOTING PLAN

Note: Is the "Kern" area of footing (When resultant of loads falls within "Kern", entire footing base is in bearing.)

Results:

Total Resultant Load and Eccentricities:

ΣPy =	-24012.54	kN
ey =	0.26	m (<= L/6)
ex =	0.75	m (<= B/6)
ΣHy =	159.46	kN
ΣHx =	-339.39	kN
H resultant =	374.98	kN
ΣMry =	80452.79	kN-m
ΣMoy =	-21643.64	kN-m
ΣMrx =	124375.39	kN-m
ΣMox =	10585.44	kN-m

Sliding Check:

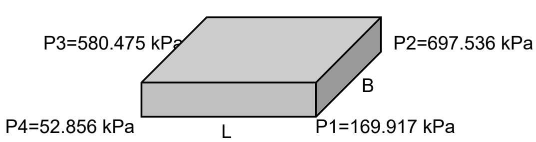
Frict =	12246.39	kN
FS(slid) =	32.659	

% Base Area in Compression:

Dist. y =	N.A.	m
Dist. x =	N.A.	m
Brg. Ly =	10.000	m
Brg. Lx =	6.400	m
%Brg. Area =	100.00	%
Biaxial Case =	N.A.	6*ex/L + 6*ez/B = 0.859

Gross Soil Bearing Corner Pressures:

P_1 =	169.917	kPa
P_2 =	697.536	kPa
P_3 =	580.475	kPa
P_4 =	52.856	kPa



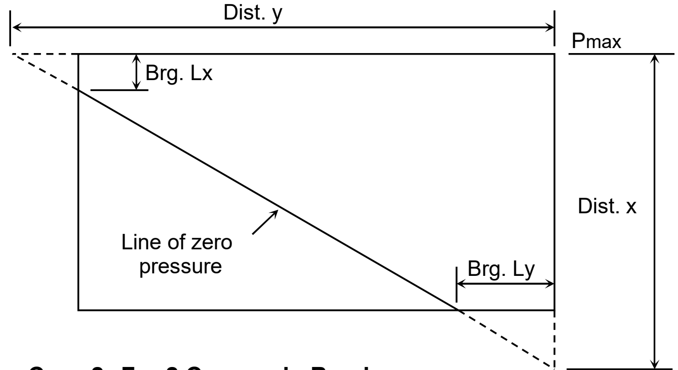
CORNER PRESSURES

Summary of Results:

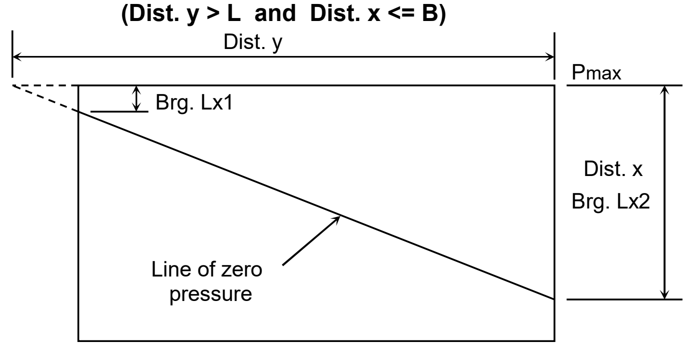
Sliding Check:			
FS(slid) =	32.66	> 1	OK
Bearing Area:			
%Brg. Area =	100.00%	> 1%	OK
Bearing Pressure Check:			
FS(brg) =	1.84	> 1.0	OK
Flotation Check:			
FS (float) =	22.27	> 1	OK

Nomenclature for Biaxial Eccentricity:

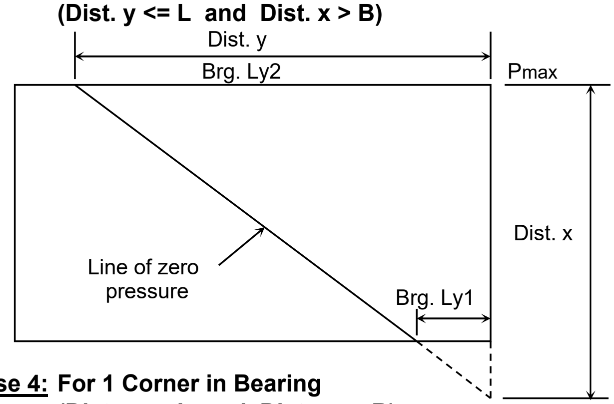
Case 1: For 3 Corners in Bearing (Dist. y > L and Dist. x > B)



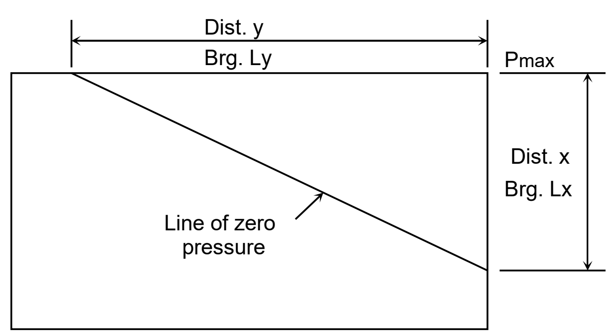
Case 2: For 2 Corners in Bearing (Dist. y > L and Dist. x <= B)



Case 3: For 2 Corners in Bearing (Dist. y <= L and Dist. x > B)



Case 4: For 1 Corner in Bearing (Dist. y <= L and Dist. x <= B)



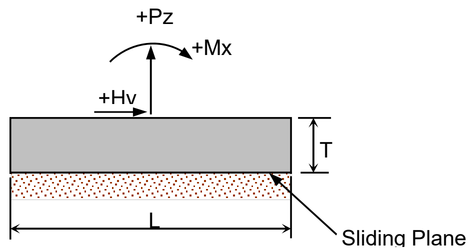
GATE TOWER STABILITY ANALYSIS

Job Name:	Springbank Off-Stream Storage Project	Number:	110773396		
Site:	Gate Tower	Originator:	ACG 7/2/2020	Checker:	CG
Load Case:	E3-13 Extreme Earthquake				

Input Data:

Footing Data:

Footing Length, L =	10.00	m
Footing Width, B =	6.40	m
Footing Thickness, T =	0.00	m
Coef. of Base Friction, μ =	0.51	
Ultimate Bearing, Pall =	1281.00	kPa

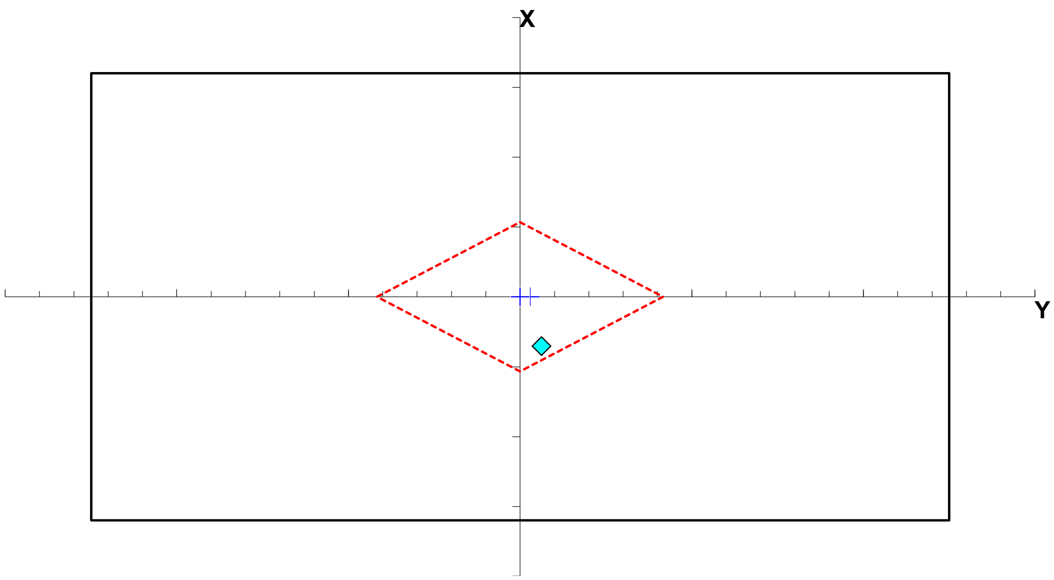


Nomenclature

Loading Data:

Direction of Seismic Load: COMBINED

	Uplift	Vertical Soil	Not Used	Not Used	Not Used	SAP2000 Reaction
Yp (m.) =	0.00	0.12				0.00
Xp (m.) =	0.00	0.00				0.00
Pz (kN) =	1128.96	-11583.42				-14862.16
Hy (kN) =	0.00	0.00				159.99
Hx (kN) =	0.00	0.00				339.39
My (kN-m) =	0.00	0.00				18030.97
Mx (kN-m) =	0.00	0.00				4937.65



FOOTING PLAN

Note: Is the "Kern" area of footing (When resultant of loads falls within "Kern", entire footing base is in bearing.)

Results:

Total Resultant Load and Eccentricities:

ΣPy =	-25316.62	kN
ey =	0.25	m (<= L/6)
ex =	-0.71	m (<= B/6)
ΣHy =	159.99	kN
ΣHx =	339.39	kN
H resultant =	375.20	kN
ΣMry =	84625.86	kN-m
ΣMoy =	21643.64	kN-m
ΣMrx =	130895.81	kN-m
ΣMox =	10582.45	kN-m

Sliding Check:

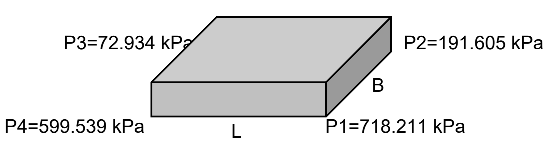
Frict =	12911.48	kN
FS(slid) =	34.412	

% Base Area in Compression:

Dist. y =	N.A.	m
Dist. x =	N.A.	m
Brg. Ly =	10.000	m
Brg. Lx =	6.400	m
%Brg. Area =	100.00	%
Biaxial Case =	N.A.	6*ex/L + 6*ez/B = 0.816

Gross Soil Bearing Corner Pressures:

P_1 =	718.211	kPa
P_2 =	191.605	kPa
P_3 =	72.934	kPa
P_4 =	599.539	kPa



CORNER PRESSURES

Summary of Results:

Sliding Check:

FS(slid) =	34.41	> 1	OK

Bearing Area:

%Brg. Area =	100.00%	> 1%	OK

Bearing Pressure Check:

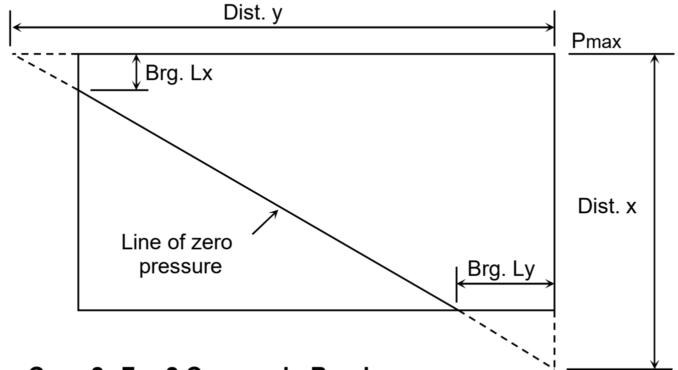
FS(brg) =	1.78	> 1.0	OK

Flotation Check:

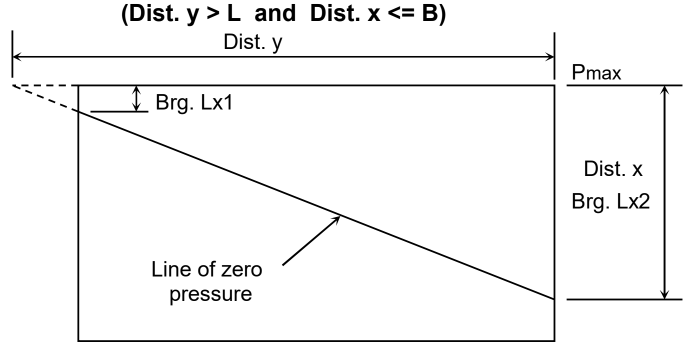
FS (float) =	23.42	> 1	OK

Nomenclature for Biaxial Eccentricity:

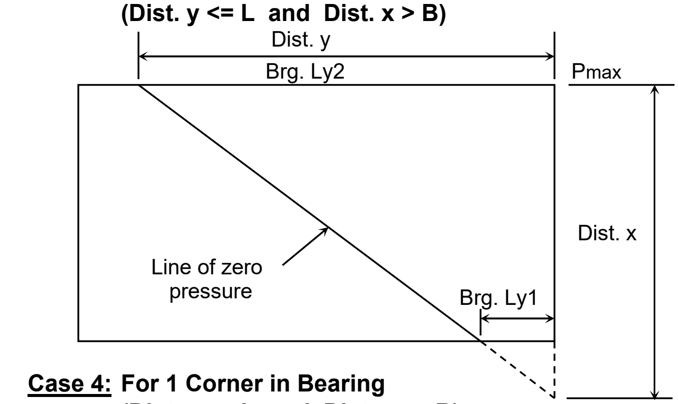
Case 1: For 3 Corners in Bearing
(Dist. y > L and Dist. x > B)



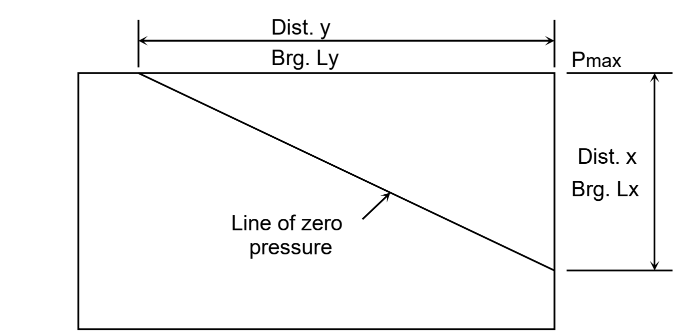
Case 2: For 2 Corners in Bearing
(Dist. y > L and Dist. x <= B)



Case 3: For 2 Corners in Bearing
(Dist. y <= L and Dist. x > B)



Case 4: For 1 Corner in Bearing
(Dist. y <= L and Dist. x <= B)

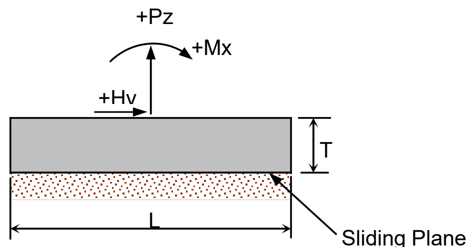


GATE TOWER STABILITY ANALYSIS					
Job Name:	Springbank Off-Stream Storage Project	Number:	110773396		
Site:	Gate Tower	Originator:	ACG	7/2/2020	Checker: CG
Load Case:	E3-14 Extreme Earthquake				

Input Data:

Footing Data:

Footing Length, L =	10.00	m
Footing Width, B =	6.40	m
Footing Thickness, T =	0.00	m
Coef. of Base Friction, μ =	0.51	
Ultimate Bearing, Pall =	1281.00	kPa

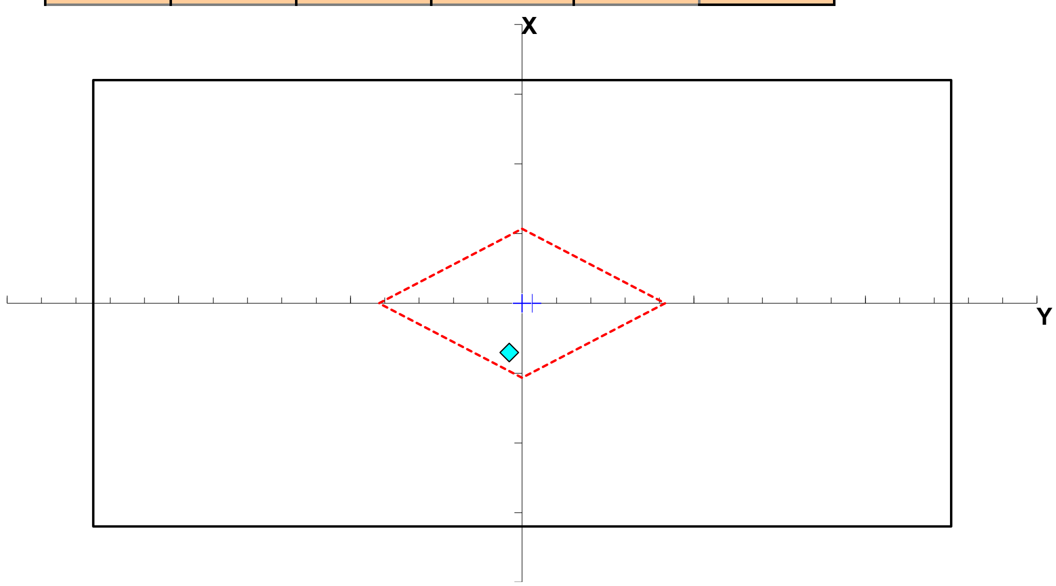


Nomenclature

Loading Data:

Direction of Seismic Load: COMBINED

	Uplift	Vertical Soil	Not Used	Not Used	Not Used	SAP2000 Reaction
Yp (m.) =	0.00	0.12				0.00
Xp (m.) =	0.00	0.00				0.00
Pz (kN) =	1128.96	-11583.42				-14862.12
Hy (kN) =	0.00	0.00				-144.84
Hx (kN) =	0.00	0.00				339.39
My (kN-m) =	0.00	0.00				18030.97
Mx (kN-m) =	0.00	0.00				-5012.75



FOOTING PLAN

Note: Is the "Kern" area of footing (When resultant of loads falls within "Kern", entire footing base is in bearing.)

Results:

Total Resultant Load and Eccentricities:

ΣPy =	-25316.58	kN
ey =	-0.15	m (<= L/6)
ex =	-0.71	m (<= B/6)
ΣHy =	-144.84	kN
ΣHx =	339.39	kN
H resultant =	369.00	kN
ΣMry =	84625.74	kN-m
ΣMoy =	21643.64	kN-m
ΣMrx =	133559.81	kN-m
ΣMox =	-10657.55	kN-m

Sliding Check:

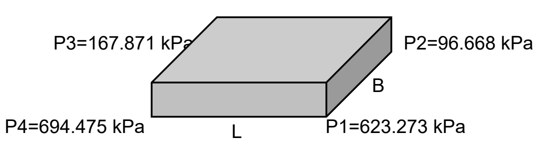
Frict =	12911.46	kN
FS(slid) =	34.990	

% Base Area in Compression:

Dist. y =	N.A.	m
Dist. x =	N.A.	m
Brg. Ly =	10.000	m
Brg. Lx =	6.400	m
%Brg. Area =	100.00	%
Biaxial Case =	N.A.	6*ex/L + 6*ez/B = 0.756

Gross Soil Bearing Corner Pressures:

P_1 =	623.273	kPa
P_2 =	96.668	kPa
P_3 =	167.871	kPa
P_4 =	694.475	kPa



CORNER PRESSURES

Summary of Results:

Sliding Check:

FS(slid) =	34.99	> 1	OK

Bearing Area:

%Brg. Area =	100.00%	> 1%	OK

Bearing Pressure Check:

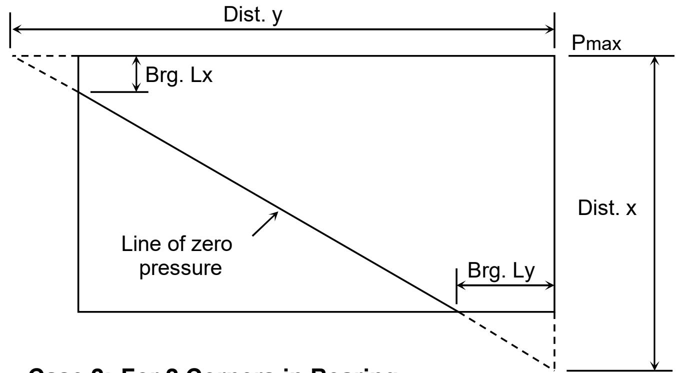
FS(brg) =	1.84	> 1.0	OK

Flotation Check:

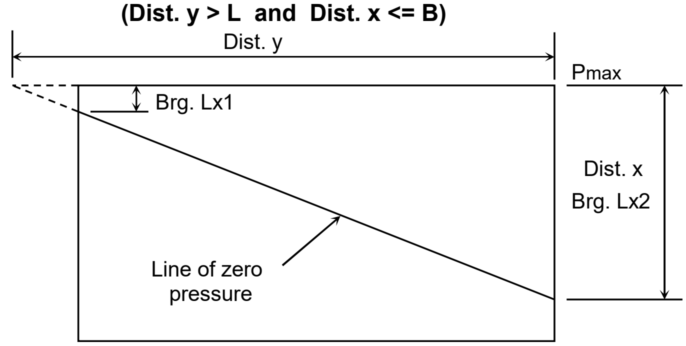
FS (float) =	23.42	> 1	OK

Nomenclature for Biaxial Eccentricity:

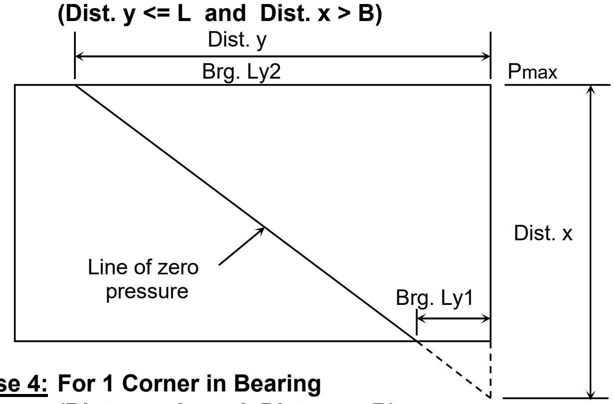
Case 1: For 3 Corners in Bearing (Dist. y > L and Dist. x > B)



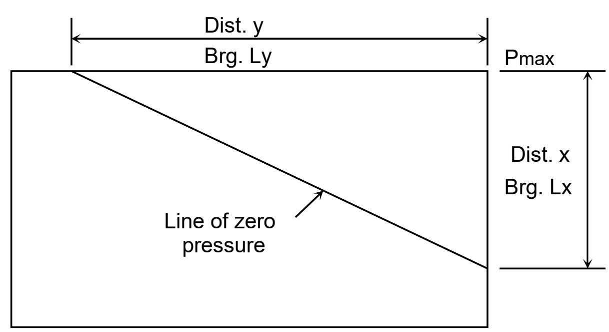
Case 2: For 2 Corners in Bearing (Dist. y > L and Dist. x <= B)



Case 3: For 2 Corners in Bearing (Dist. y <= L and Dist. x > B)



Case 4: For 1 Corner in Bearing (Dist. y <= L and Dist. x <= B)



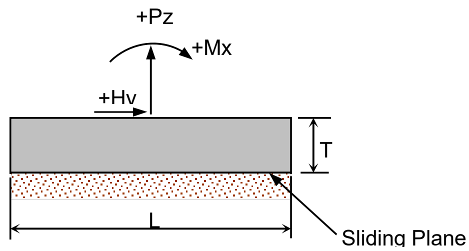
GATE TOWER STABILITY ANALYSIS

Job Name:	Springbank Off-Stream Storage Project	Number:	110773396		
Site:	Gate Tower	Originator:	ACG 7/2/2020	Checker:	CG
Load Case:	E3-15 Extreme Earthquake				

Input Data:

Footing Data:

Footing Length, L =	10.00	m
Footing Width, B =	6.40	m
Footing Thickness, T =	0.00	m
Coef. of Base Friction, μ =	0.51	
Ultimate Bearing, Pall =	1281.00	kPa

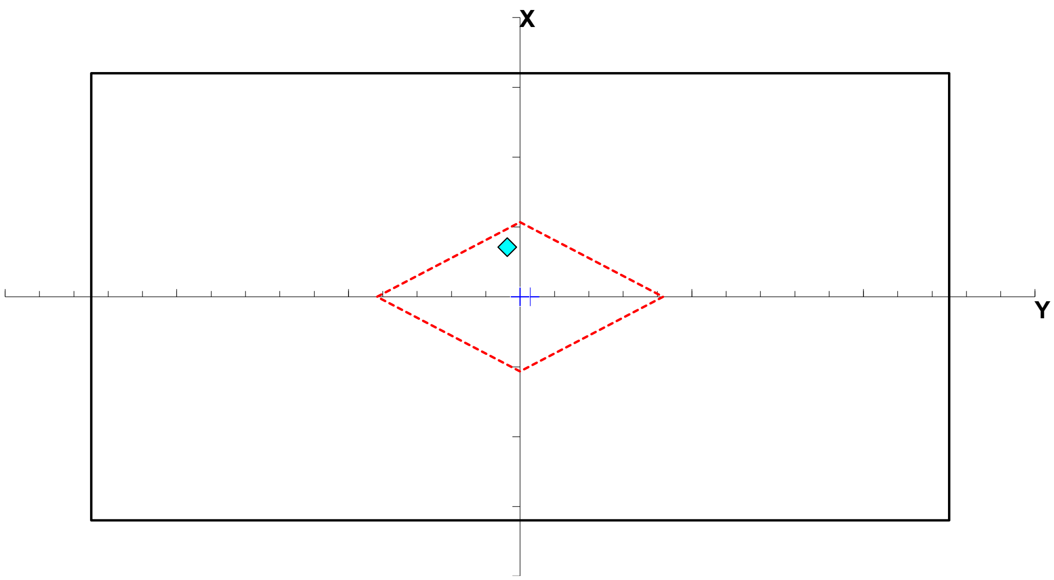


Nomenclature

Loading Data:

Direction of Seismic Load: COMBINED

	Uplift	Vertical Soil	Not Used	Not Used	Not Used	SAP2000 Reaction
Yp (m.) =	0.00	0.12				0.00
Xp (m.) =	0.00	0.00				0.00
Pz (kN) =	1128.96	-11583.42				-14862.12
Hy (kN) =	0.00	0.00				-144.84
Hx (kN) =	0.00	0.00				-339.39
My (kN-m) =	0.00	0.00				-18030.97
Mx (kN-m) =	0.00	0.00				-5012.75



FOOTING PLAN

Note: Is the "Kern" area of footing (When resultant of loads falls within "Kern", entire footing base is in bearing.)

Results:

Total Resultant Load and Eccentricities:

ΣPy =	-25316.58	kN
ey =	-0.15	m (<= L/6)
ex =	0.71	m (<= B/6)
ΣHy =	-144.84	kN
ΣHx =	-339.39	kN
H resultant =	369.00	kN
ΣMry =	84625.74	kN-m
ΣMoy =	-21643.64	kN-m
ΣMrx =	133559.81	kN-m
ΣMox =	-10657.55	kN-m

Sliding Check:

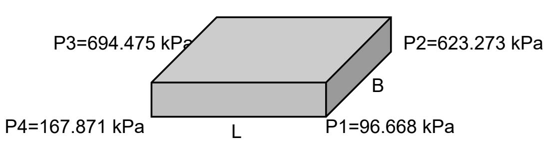
Frict =	12911.46	kN
FS(slid) =	34.990	

% Base Area in Compression:

Dist. y =	N.A.	m
Dist. x =	N.A.	m
Brg. Ly =	10.000	m
Brg. Lx =	6.400	m
%Brg. Area =	100.00	%
Biaxial Case =	N.A.	6*ex/L + 6*ez/B = 0.756

Gross Soil Bearing Corner Pressures:

P_1 =	96.668	kPa
P_2 =	623.273	kPa
P_3 =	694.475	kPa
P_4 =	167.871	kPa



CORNER PRESSURES

Summary of Results:

Sliding Check:

FS(slid) =	34.99	> 1	OK

Bearing Area:

%Brg. Area =	100.00%	> 1%	OK

Bearing Pressure Check:

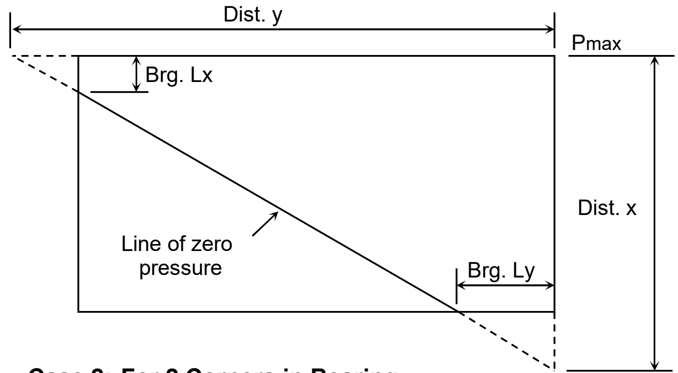
FS(brg) =	1.84	> 1.0	OK

Flotation Check:

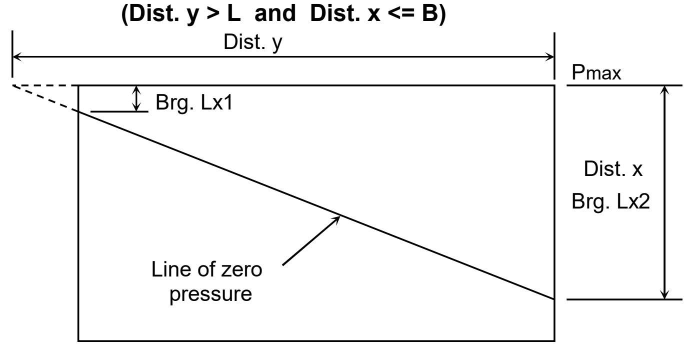
FS (float) =	23.42	> 1	OK

Nomenclature for Biaxial Eccentricity:

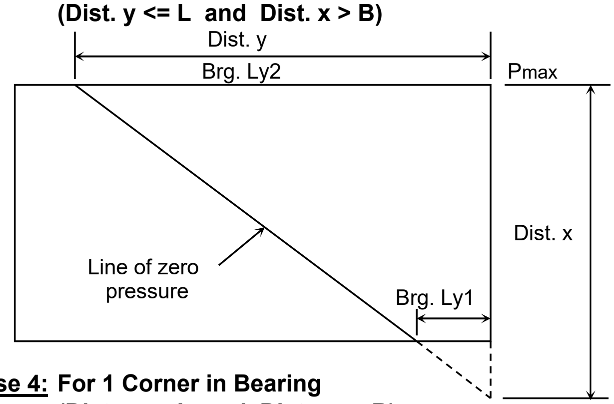
Case 1: For 3 Corners in Bearing
(Dist. y > L and Dist. x > B)



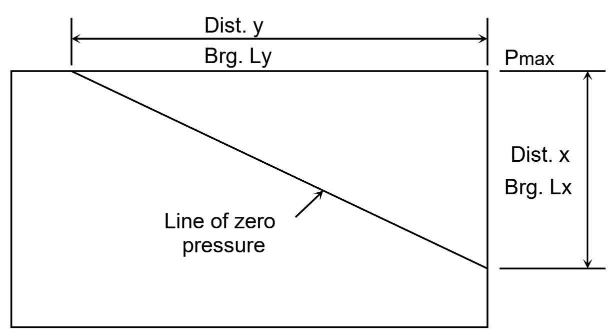
Case 2: For 2 Corners in Bearing
(Dist. y > L and Dist. x <= B)



Case 3: For 2 Corners in Bearing
(Dist. y <= L and Dist. x > B)



Case 4: For 1 Corner in Bearing
(Dist. y <= L and Dist. x <= B)



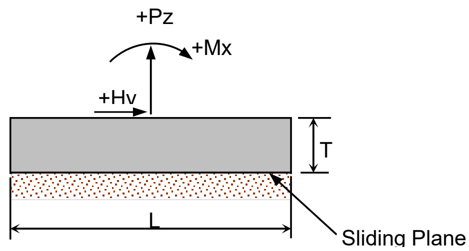
GATE TOWER STABILITY ANALYSIS

Job Name:	Springbank Off-Stream Storage Project	Number:	110773396		
Site:	Gate Tower	Originator:	ACG 7/2/2020	Checker:	CG
Load Case:	E3-16 Extreme Earthquake				

Input Data:

Footing Data:

Footing Length, L =	10.00	m
Footing Width, B =	6.40	m
Footing Thickness, T =	0.00	m
Coef. of Base Friction, μ =	0.51	
Ultimate Bearing, Pall =	1281.00	kPa

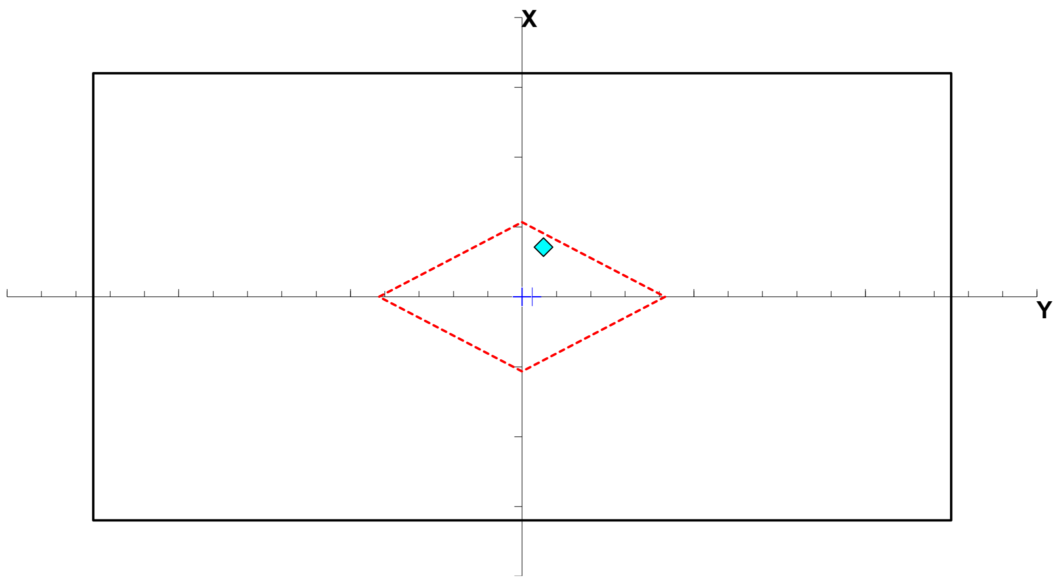


Nomenclature

Loading Data:

Direction of Seismic Load: COMBINED

	Uplift	Vertical Soil	Not Used	Not Used	Not Used	SAP2000 Reaction
Yp (m.) =	0.00	0.12				0.00
Xp (m.) =	0.00	0.00				0.00
Pz (kN) =	1128.96	-11583.42				-14862.16
Hy (kN) =	0.00	0.00				159.99
Hx (kN) =	0.00	0.00				-339.39
My (kN-m) =	0.00	0.00				-18030.97
Mx (kN-m) =	0.00	0.00				4937.65



FOOTING PLAN

Note: Is the "Kern" area of footing (When resultant of loads falls within "Kern", entire footing base is in bearing.)

Results:

Total Resultant Load and Eccentricities:

ΣPy =	-25316.62	kN
ey =	0.25	m (<= L/6)
ex =	0.71	m (<= B/6)
ΣHy =	159.99	kN
ΣHx =	-339.39	kN
H resultant =	375.20	kN
ΣMry =	84625.86	kN-m
ΣMoy =	-21643.64	kN-m
ΣMrx =	130895.81	kN-m
ΣMox =	10582.45	kN-m

Sliding Check:

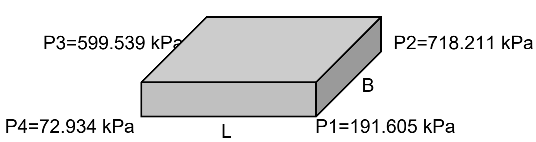
Frict =	12911.48	kN
FS(slid) =	34.412	

% Base Area in Compression:

Dist. y =	N.A.	m
Dist. x =	N.A.	m
Brg. Ly =	10.000	m
Brg. Lx =	6.400	m
%Brg. Area =	100.00	%
Biaxial Case =	N.A.	6*ex/L + 6*ez/B = 0.816

Gross Soil Bearing Corner Pressures:

P_1 =	191.605	kPa
P_2 =	718.211	kPa
P_3 =	599.539	kPa
P_4 =	72.934	kPa



CORNER PRESSURES

Summary of Results:

Sliding Check:

FS(slid) =	34.41	> 1	OK

Bearing Area:

%Brg. Area =	100.00%	> 1%	OK

Bearing Pressure Check:

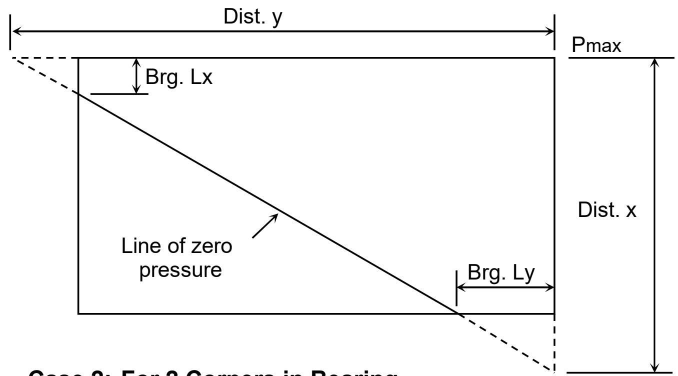
FS(brg) =	1.78	> 1.0	OK

Flotation Check:

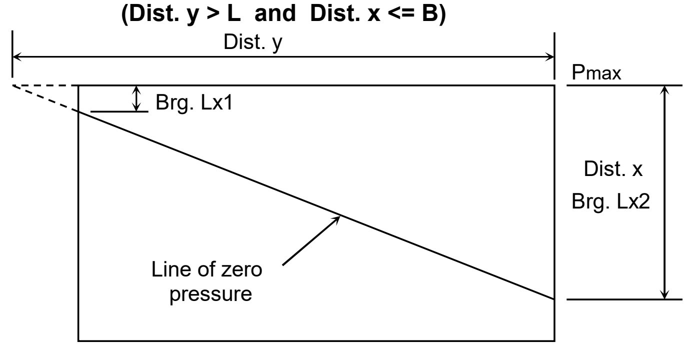
FS (float) =	23.42	> 1	OK

Nomenclature for Biaxial Eccentricity:

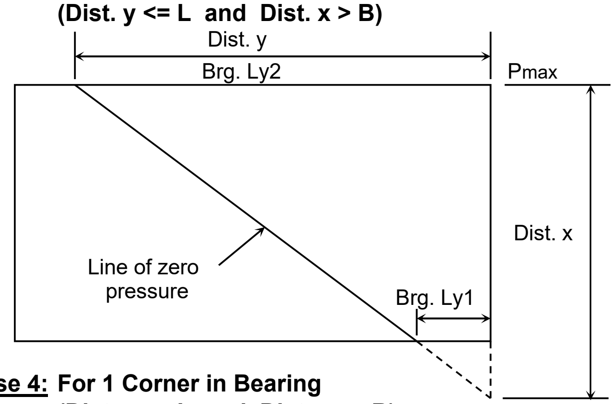
Case 1: For 3 Corners in Bearing
(Dist. y > L and Dist. x > B)



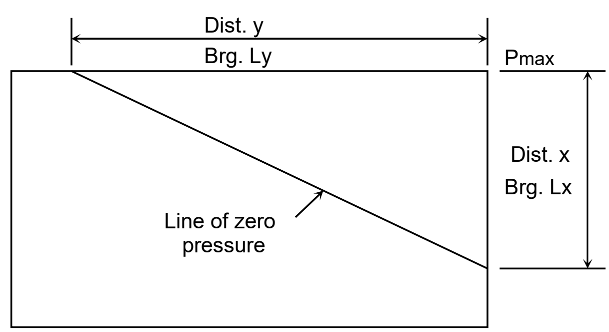
Case 2: For 2 Corners in Bearing
(Dist. y > L and Dist. x <= B)



Case 3: For 2 Corners in Bearing
(Dist. y <= L and Dist. x > B)



Case 4: For 1 Corner in Bearing
(Dist. y <= L and Dist. x <= B)



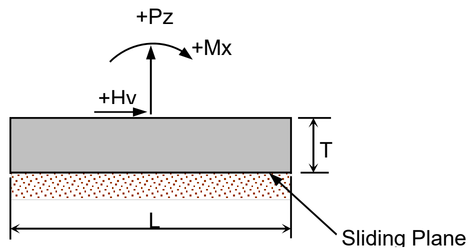
GATE TOWER STABILITY ANALYSIS

Job Name:	Springbank Off-Stream Storage Project	Number:	110773396		
Site:	Gate Tower	Originator:	ACG 7/2/2020	Checker:	CG
Load Case:	E3-17 Extreme Earthquake				

Input Data:

Footing Data:

Footing Length, L =	10.00	m
Footing Width, B =	6.40	m
Footing Thickness, T =	0.00	m
Coef. of Base Friction, μ =	0.51	
Ultimate Bearing, Pall =	1281.00	kPa

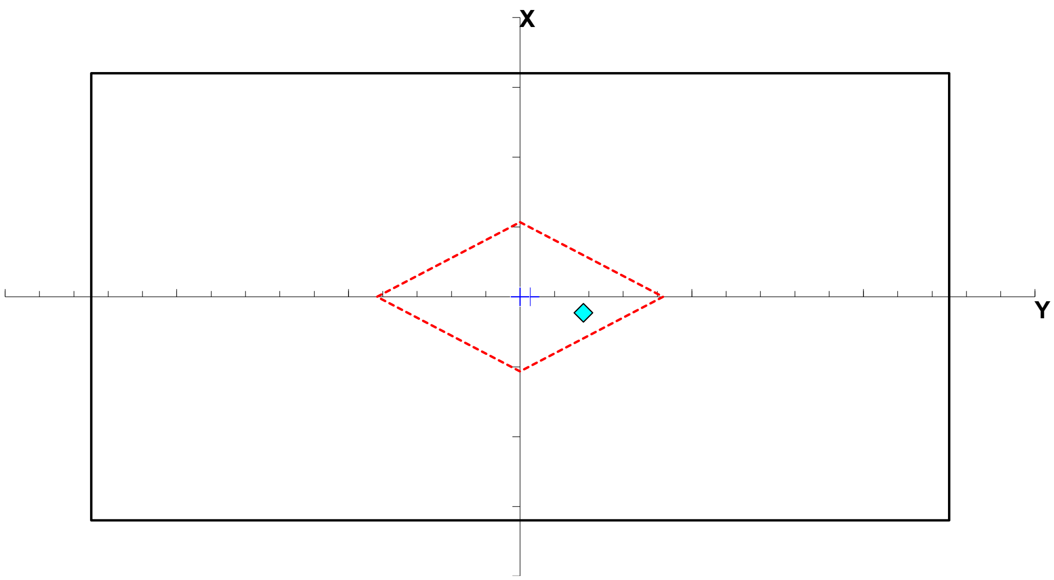


Nomenclature

Loading Data:

Direction of Seismic Load: COMBINED

	Uplift	Vertical Soil	Not Used	Not Used	Not Used	SAP2000 Reaction
Yp (m.) =	0.00	0.12				0.00
Xp (m.) =	0.00	0.00				0.00
Pz (kN) =	1128.96	-11583.42				-13558.12
Hy (kN) =	0.00	0.00				515.09
Hx (kN) =	0.00	0.00				101.82
My (kN-m) =	0.00	0.00				5409.29
Mx (kN-m) =	0.00	0.00				16549.45



FOOTING PLAN

Note: Is the "Kern" area of footing (When resultant of loads falls within "Kern", entire footing base is in bearing.)

Results:

Total Resultant Load and Eccentricities:

ΣPy =	-24012.58	kN
ey =	0.74	m (<= L/6)
ex =	-0.23	m (<= B/6)
ΣHy =	515.09	kN
ΣHx =	101.82	kN
H resultant =	525.06	kN
ΣMry =	80452.93	kN-m
ΣMoy =	9021.96	kN-m
ΣMrx =	124375.61	kN-m
ΣMox =	22194.25	kN-m

Sliding Check:

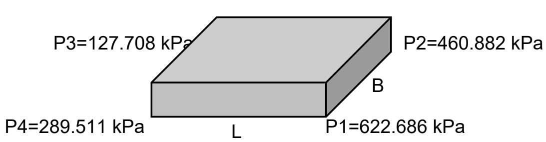
Frict =	12246.42	kN
FS(slid) =	23.324	

% Base Area in Compression:

Dist. y =	N.A.	m
Dist. x =	N.A.	m
Brg. Ly =	10.000	m
Brg. Lx =	6.400	m
%Brg. Area =	100.00	%
Biaxial Case =	N.A.	6*ex/L + 6*ez/B = 0.66

Gross Soil Bearing Corner Pressures:

P_1 =	622.686	kPa
P_2 =	460.882	kPa
P_3 =	127.708	kPa
P_4 =	289.511	kPa



CORNER PRESSURES

Summary of Results:

Sliding Check:

FS(slid) =	23.32	> 1	OK

Bearing Area:

%Brg. Area =	100.00%	> 1%	OK

Bearing Pressure Check:

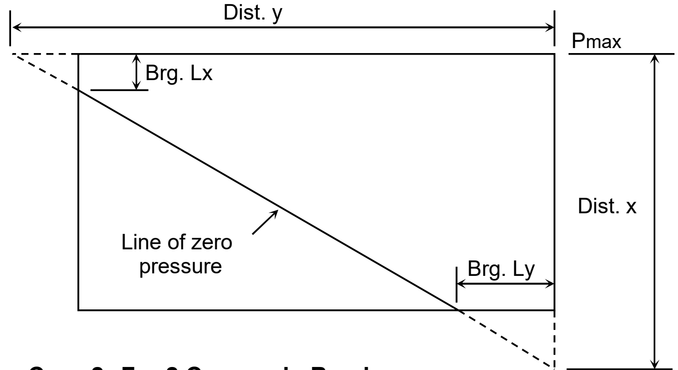
FS(brg) =	2.06	> 1.0	OK

Flotation Check:

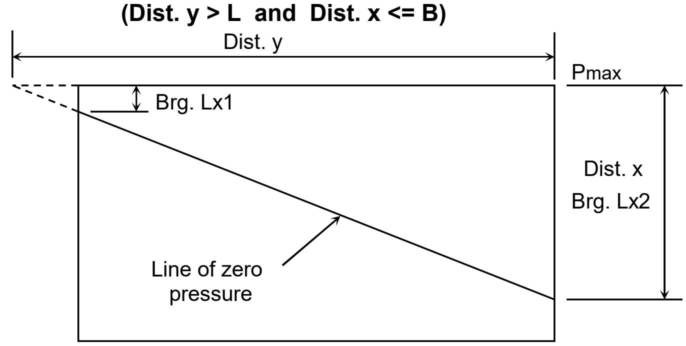
FS (float) =	22.27	> 1	OK

Nomenclature for Biaxial Eccentricity:

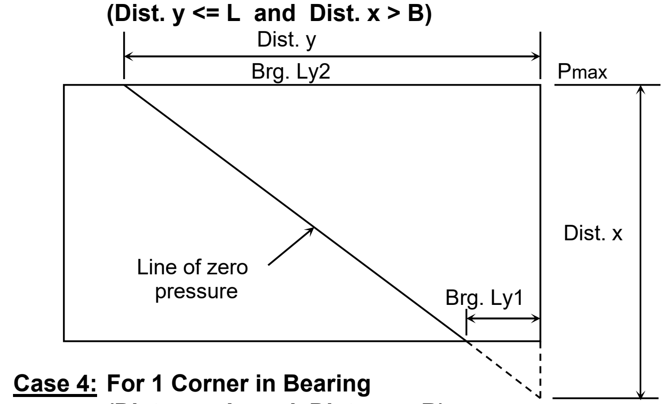
Case 1: For 3 Corners in Bearing
(Dist. y > L and Dist. x > B)



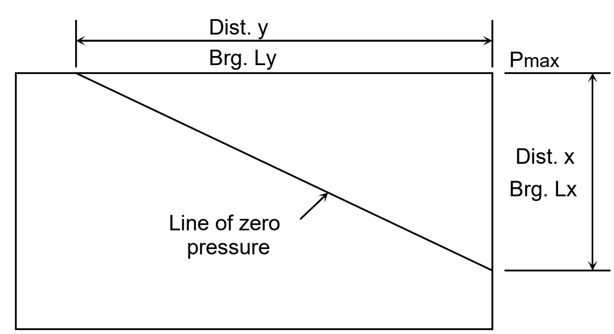
Case 2: For 2 Corners in Bearing
(Dist. y > L and Dist. x <= B)



Case 3: For 2 Corners in Bearing
(Dist. y <= L and Dist. x > B)



Case 4: For 1 Corner in Bearing
(Dist. y <= L and Dist. x <= B)



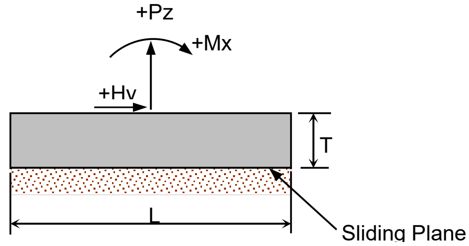
GATE TOWER STABILITY ANALYSIS

Job Name:	Springbank Off-Stream Storage Project	Number:	110773396
Site:	Gate Tower	Originator:	ACG 7/2/2020 Checker: CG
Load Case:	E3-18 Extreme Earthquake		

Input Data:

Footing Data:

Footing Length, L =	10.00	m
Footing Width, B =	6.40	m
Footing Thickness, T =	0.00	m
Coef. of Base Friction, μ =	0.51	
Ultimate Bearing, Pall =	1281.00	kPa

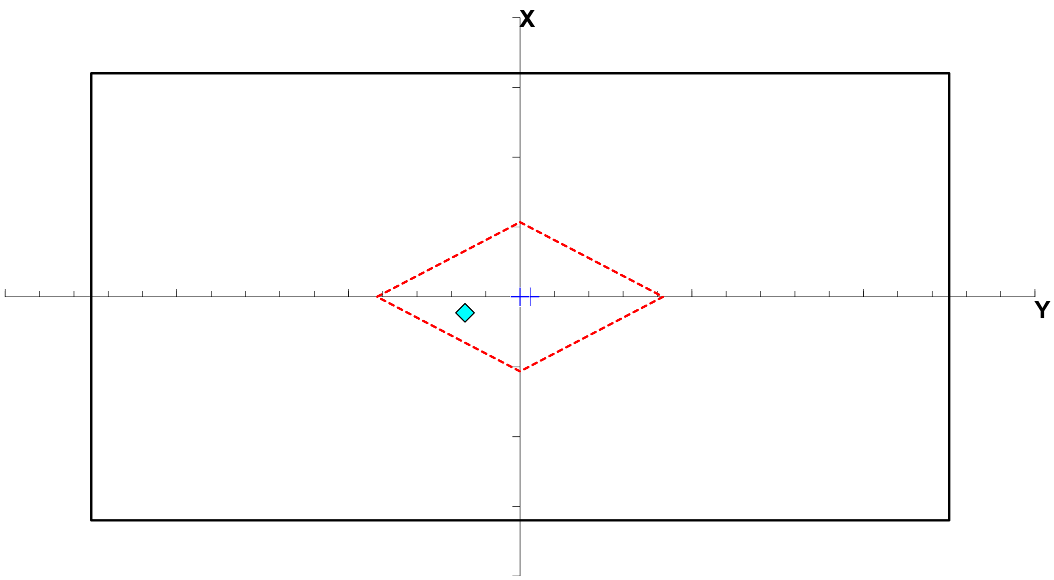


Nomenclature

Loading Data:

Direction of Seismic Load: COMBINED

	Uplift	Vertical Soil	Not Used	Not Used	Not Used	SAP2000 Reaction
Yp (m.) =	0.00	0.12				0.00
Xp (m.) =	0.00	0.00				0.00
Pz (kN) =	1128.96	-11583.42				-13558.00
Hy (kN) =	0.00	0.00				-501.01
Hx (kN) =	0.00	0.00				101.82
My (kN-m) =	0.00	0.00				5409.29
Mx (kN-m) =	0.00	0.00				-16618.57



FOOTING PLAN

Note: Is the "Kern" area of footing (When resultant of loads falls within "Kern", entire footing base is in bearing.)

Results:

Total Resultant Load and Eccentricities:

ΣPy =	-24012.46	kN
ey =	-0.64	m (<= L/6)
ex =	-0.23	m (<= B/6)
ΣHy =	-501.01	kN
ΣHx =	101.82	kN
H resultant =	511.25	kN
ΣMry =	80452.53	kN-m
ΣMoy =	9021.96	kN-m
ΣMrx =	127039.17	kN-m
ΣMox =	-22263.37	kN-m

Sliding Check:

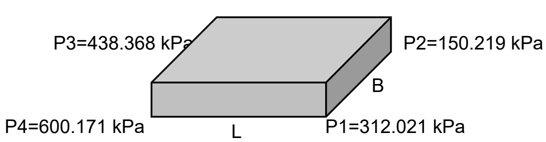
Frict =	12246.35	kN
FS(slid) =	23.954	

% Base Area in Compression:

Dist. y =	N.A.	m
Dist. x =	N.A.	m
Brg. Ly =	10.000	m
Brg. Lx =	6.400	m
%Brg. Area =	100.00	%
Biaxial Case =	N.A.	6*ex/L + 6*ez/B = 0.6

Gross Soil Bearing Corner Pressures:

P1 =	312.021	kPa
P2 =	150.219	kPa
P3 =	438.368	kPa
P4 =	600.171	kPa



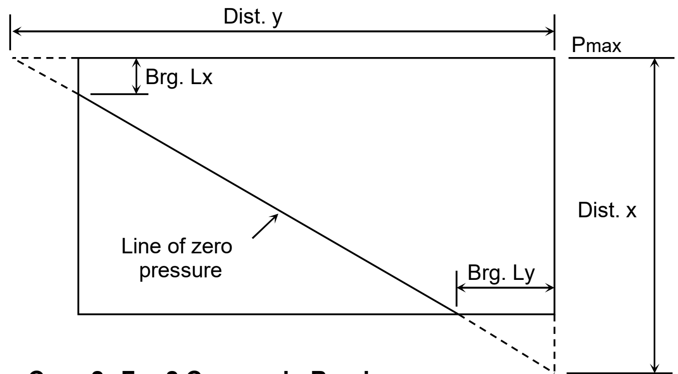
CORNER PRESSURES

Summary of Results:

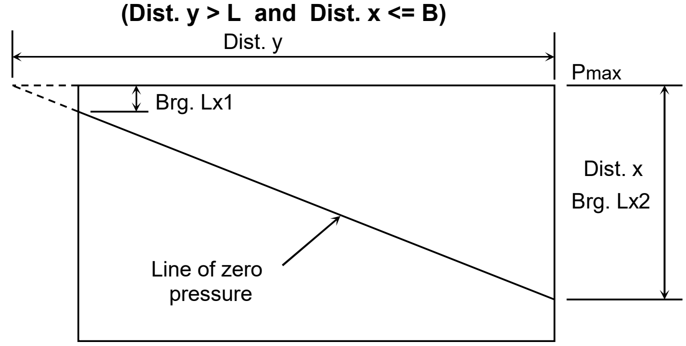
Sliding Check:			
FS(slid) =	**23.95**	> 1	OK
Bearing Area:			
%Brg. Area =	**100.00%**	> 1%	OK
Bearing Pressure Check:			
FS(brg) =	**2.13**	> 1.0	OK
Flotation Check:			
FS (float) =	**22.27**	> 1	OK

Nomenclature for Biaxial Eccentricity:

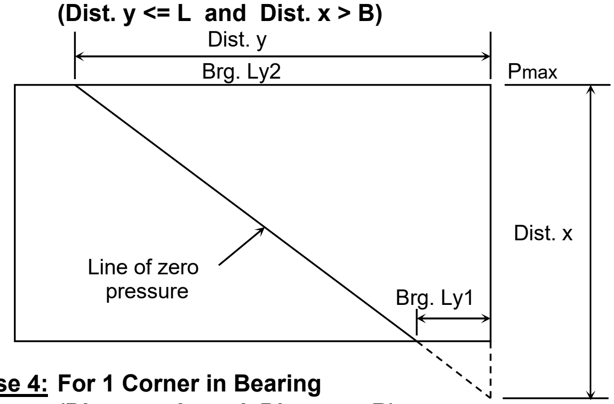
Case 1: For 3 Corners in Bearing (Dist. y > L and Dist. x > B)



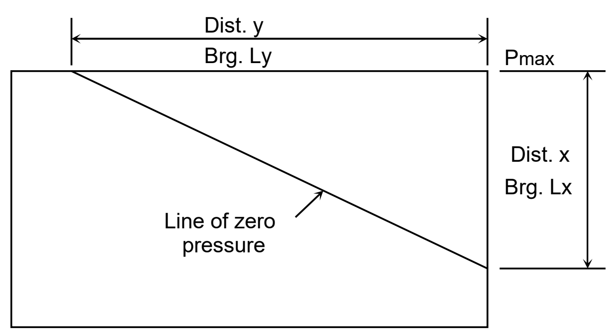
Case 2: For 2 Corners in Bearing (Dist. y > L and Dist. x <= B)



Case 3: For 2 Corners in Bearing (Dist. y <= L and Dist. x > B)



Case 4: For 1 Corner in Bearing (Dist. y <= L and Dist. x <= B)



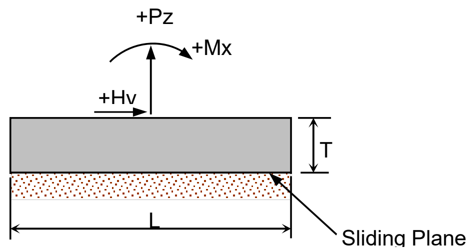
GATE TOWER STABILITY ANALYSIS

Job Name:	Springbank Off-Stream Storage Project	Number:	110773396
Site:	Gate Tower	Originator:	ACG 7/2/2020 Checker: CG
Load Case:	E3-19 Extreme Earthquake		

Input Data:

Footing Data:

Footing Length, L =	10.00	m
Footing Width, B =	6.40	m
Footing Thickness, T =	0.00	m
Coef. of Base Friction, μ =	0.51	
Ultimate Bearing, Pall =	1281.00	kPa

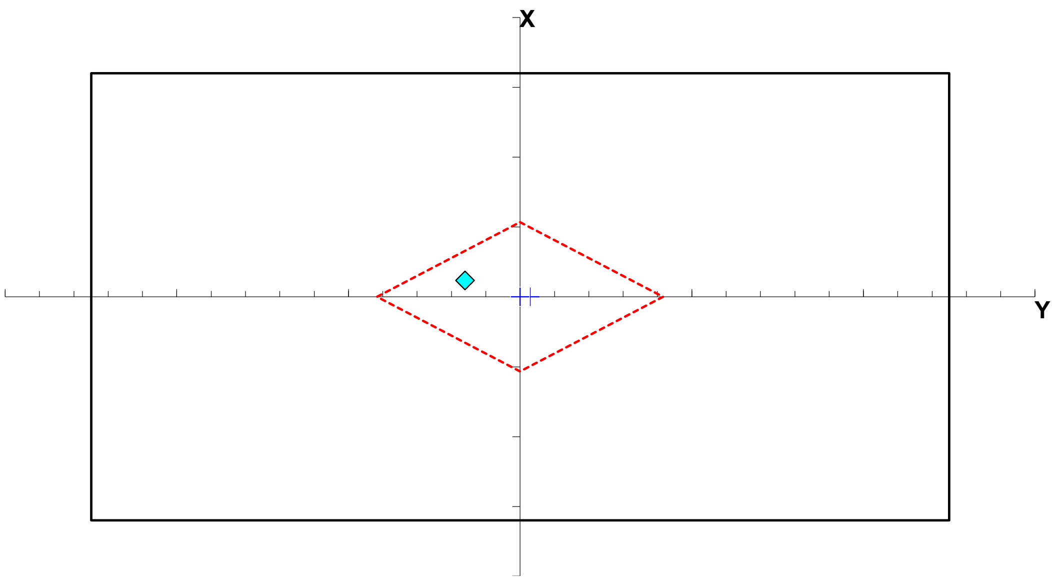


Nomenclature

Loading Data:

Direction of Seismic Load: COMBINED

	Uplift	Vertical Soil	Not Used	Not Used	Not Used	SAP2000 Reaction
Yp (m.) =	0.00	0.12				**0.00**
Xp (m.) =	0.00	0.00				0.00
Pz (kN) =	1128.96	-11583.42				**-13558.00**
Hy (kN) =	0.00	0.00				**-501.01**
Hx (kN) =	0.00	0.00				**-101.82**
My (kN-m) =	0.00	0.00				**-5409.29**
Mx (kN-m) =	0.00	0.00				**-16618.57**



FOOTING PLAN

Note: Is the "Kern" area of footing (When resultant of loads falls within "Kern", entire footing base is in bearing.)

Results:

Total Resultant Load and Eccentricities:

ΣPy =	-24012.46	kN
ey =	-0.64	m (<= L/6)
ex =	0.23	m (<= B/6)
ΣHy =	-501.01	kN
ΣHx =	-101.82	kN
H resultant =	511.25	kN
ΣMry =	80452.53	kN-m
ΣMoy =	-9021.96	kN-m
ΣMrx =	127039.17	kN-m
ΣMox =	-22263.37	kN-m

Sliding Check:

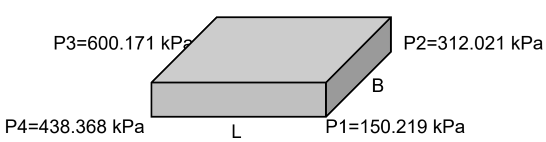
Frict =	12246.35	kN
FS(slid) =	23.954	

% Base Area in Compression:

Dist. y =	N.A.	m
Dist. x =	N.A.	m
Brg. Ly =	10.000	m
Brg. Lx =	6.400	m
%Brg. Area =	100.00	%
Biaxial Case =	N.A.	6*ex/L + 6*ez/B = 0.6

Gross Soil Bearing Corner Pressures:

P1 =	150.219	kPa
P2 =	312.021	kPa
P3 =	600.171	kPa
P4 =	438.368	kPa



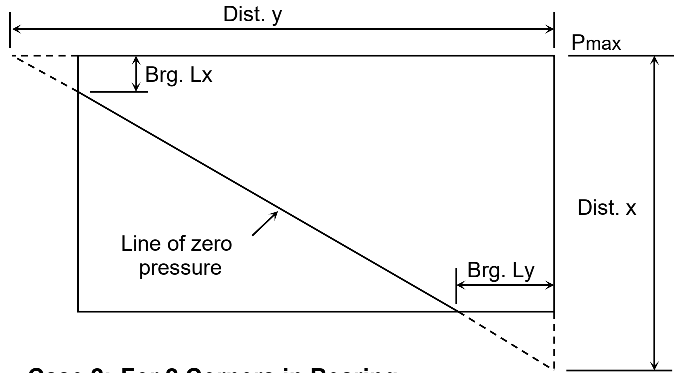
CORNER PRESSURES

Summary of Results:

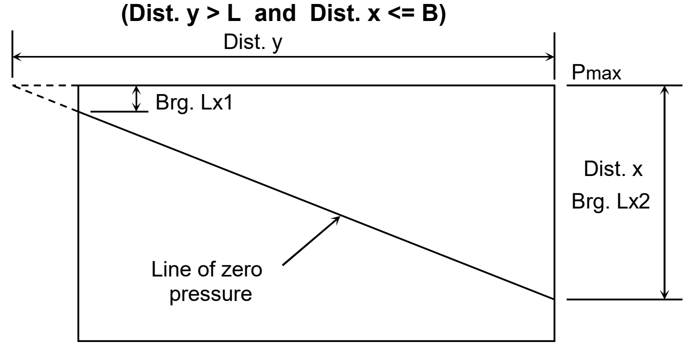
Sliding Check:			
FS(slid) =	23.95	> 1	OK
Bearing Area:			
%Brg. Area =	100.00%	> 1%	OK
Bearing Pressure Check:			
FS(brg) =	2.13	> 1.0	OK
Flotation Check:			
FS (float) =	22.27	> 1	OK

Nomenclature for Biaxial Eccentricity:

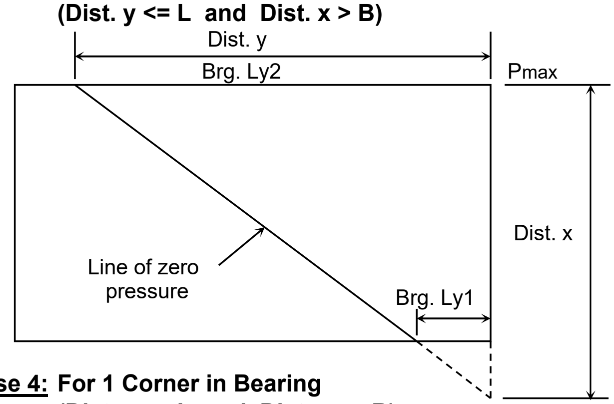
Case 1: For 3 Corners in Bearing
(Dist. y > L and Dist. x > B)



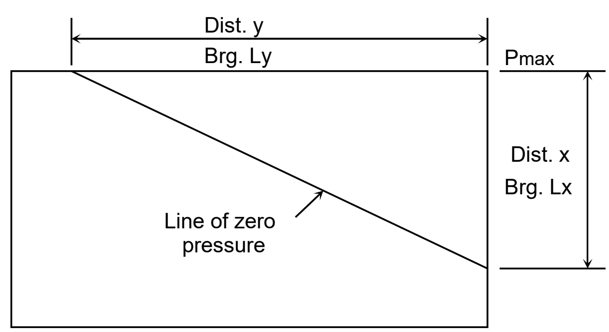
Case 2: For 2 Corners in Bearing
(Dist. y > L and Dist. x <= B)



Case 3: For 2 Corners in Bearing
(Dist. y <= L and Dist. x > B)



Case 4: For 1 Corner in Bearing
(Dist. y <= L and Dist. x <= B)



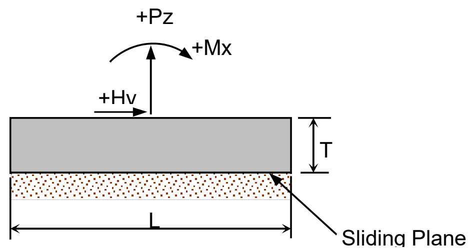
GATE TOWER STABILITY ANALYSIS

Job Name:	Springbank Off-Stream Storage Project	Number:	110773396		
Site:	Gate Tower	Originator:	ACG 7/2/2020	Checker:	CG
Load Case:	E3-20 Extreme Earthquake				

Input Data:

Footing Data:

Footing Length, L =	10.00	m
Footing Width, B =	6.40	m
Footing Thickness, T =	0.00	m
Coef. of Base Friction, μ =	0.51	
Ultimate Bearing, Pall =	1281.00	kPa

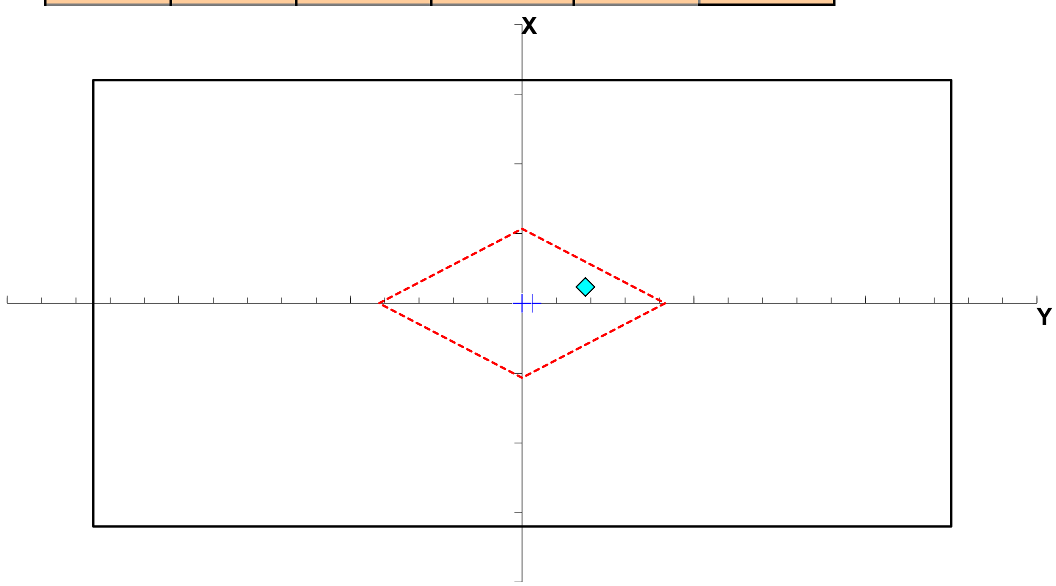


Nomenclature

Loading Data:

Direction of Seismic Load: COMBINED

	Uplift	Vertical Soil	Not Used	Not Used	Not Used	SAP2000 Reaction
Yp (m.) =	0.00	0.12				**0.00**
Xp (m.) =	0.00	0.00				0.00
Pz (kN) =	1128.96	-11583.42				**-13558.12**
Hy (kN) =	0.00	0.00				**515.09**
Hx (kN) =	0.00	0.00				**-101.82**
My (kN-m) =	0.00	0.00				**-5409.29**
Mx (kN-m) =	0.00	0.00				**16549.45**



FOOTING PLAN

Note: Is the "Kern" area of footing (When resultant of loads falls within "Kern", entire footing base is in bearing.)

Results:

Total Resultant Load and Eccentricities:

ΣPy =	-24012.58	kN
ey =	0.74	m (<= L/6)
ex =	0.23	m (<= B/6)
ΣHy =	515.09	kN
ΣHx =	-101.82	kN
H resultant =	525.06	kN
ΣMry =	80452.93	kN-m
ΣMoy =	-9021.96	kN-m
ΣMrx =	124375.61	kN-m
ΣMox =	22194.25	kN-m

Sliding Check:

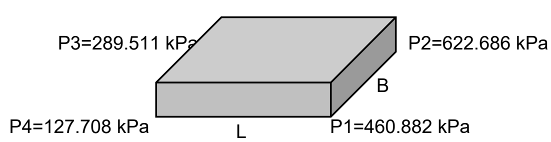
Frict =	12246.42	kN
FS(slid) =	23.324	

% Base Area in Compression:

Dist. y =	N.A.	m
Dist. x =	N.A.	m
Brg. Ly =	10.000	m
Brg. Lx =	6.400	m
%Brg. Area =	100.00	%
Biaxial Case =	N.A.	6*ex/L + 6*ez/B = 0.66

Gross Soil Bearing Corner Pressures:

P_1 =	460.882	kPa
P_2 =	622.686	kPa
P_3 =	289.511	kPa
P_4 =	127.708	kPa



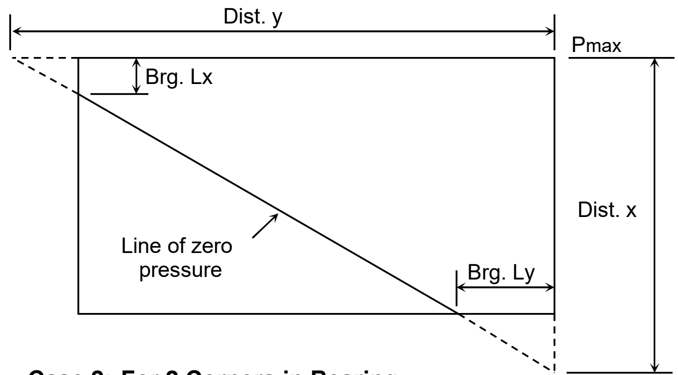
CORNER PRESSURES

Summary of Results:

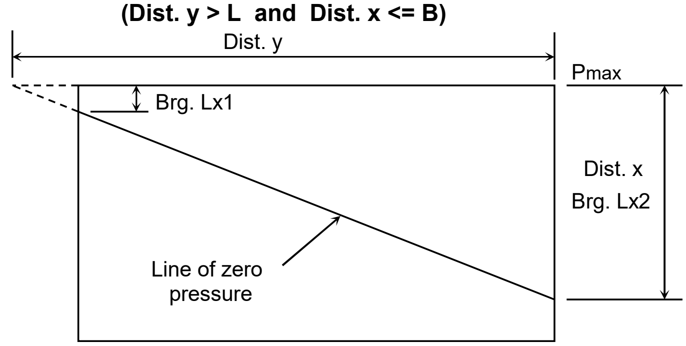
Sliding Check:			
FS(slid) =	23.32	> 1	OK
Bearing Area:			
%Brg. Area =	100.00%	> 1%	OK
Bearing Pressure Check:			
FS(brg) =	2.06	> 1.0	OK
Flotation Check:			
FS (float) =	22.27	> 1	OK

Nomenclature for Biaxial Eccentricity:

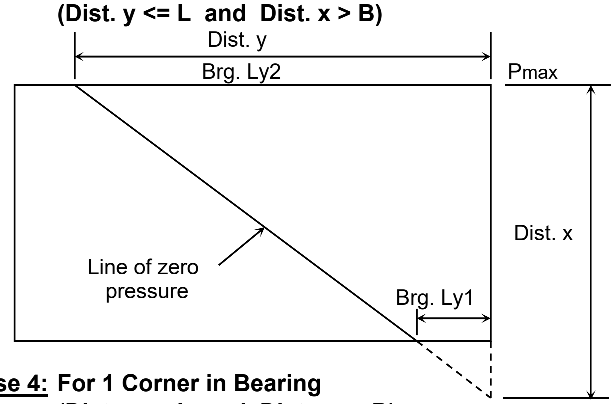
Case 1: For 3 Corners in Bearing
(Dist. y > L and Dist. x > B)



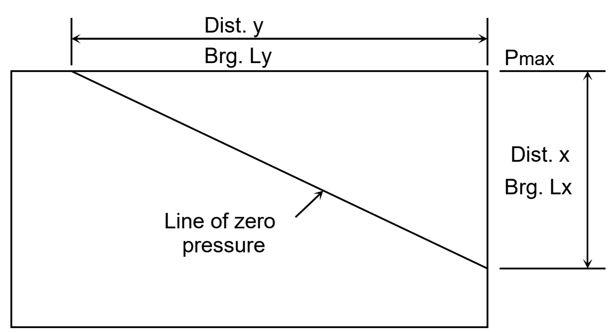
Case 2: For 2 Corners in Bearing
(Dist. y > L and Dist. x <= B)



Case 3: For 2 Corners in Bearing
(Dist. y <= L and Dist. x > B)



Case 4: For 1 Corner in Bearing
(Dist. y <= L and Dist. x <= B)



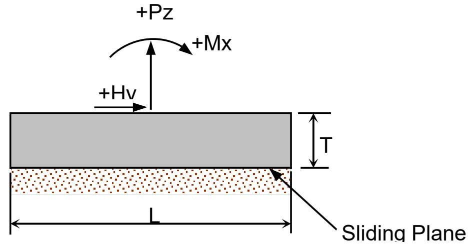
GATE TOWER STABILITY ANALYSIS

Job Name:	Springbank Off-Stream Storage Project	Number:	110773396
Site:	Gate Tower	Originator:	ACG 7/2/2020 Checker: CG
Load Case:	E3-21 Extreme Earthquake		

Input Data:

Footing Data:

Footing Length, L =	10.00	m
Footing Width, B =	6.40	m
Footing Thickness, T =	0.00	m
Coef. of Base Friction, μ =	0.51	
Ultimate Bearing, Pall =	1281.00	kPa

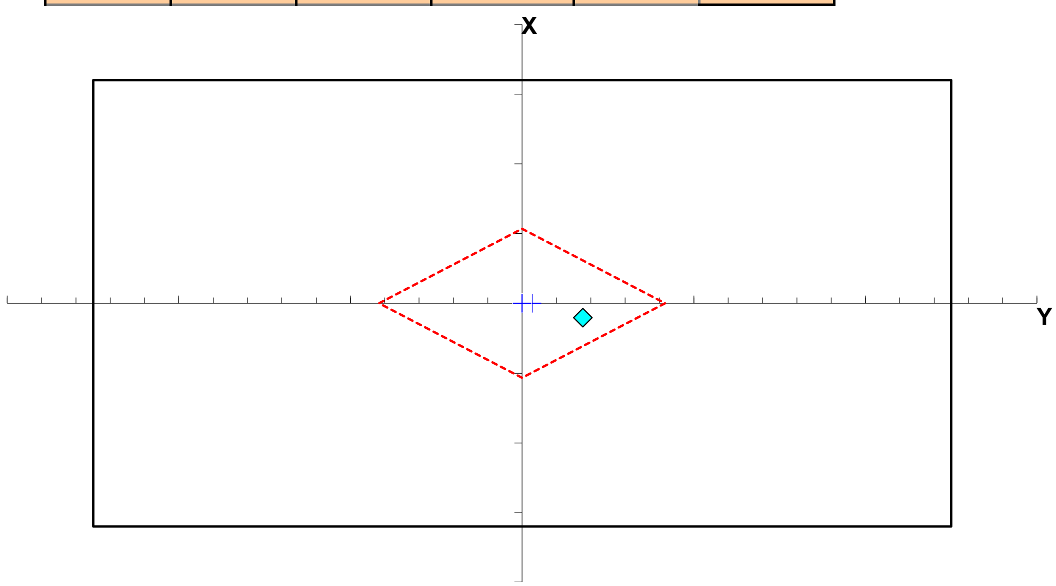


Nomenclature

Loading Data:

Direction of Seismic Load: COMBINED

	Uplift	Vertical Soil	Not Used	Not Used	Not Used	SAP2000 Reaction
Yp (m.) =	0.00	0.12				**0.00**
Xp (m.) =	0.00	0.00				0.00
Pz (kN) =	1128.96	-11583.42				**-14862.20**
Hy (kN) =	0.00	0.00				**515.62**
Hx (kN) =	0.00	0.00				**101.82**
My (kN-m) =	0.00	0.00				**5409.29**
Mx (kN-m) =	0.00	0.00				**16546.46**



FOOTING PLAN

Note: Is the "Kern" area of footing (When resultant of loads falls within "Kern", entire footing base is in bearing.)

Results:

Total Resultant Load and Eccentricities:

ΣPy =	-25316.66	kN
ey =	0.71	m (<= L/6)
ex =	-0.21	m (<= B/6)
ΣHy =	515.62	kN
ΣHx =	101.82	kN
H resultant =	525.58	kN
ΣMry =	84626.00	kN-m
ΣMoy =	9021.96	kN-m
ΣMrx =	130896.03	kN-m
ΣMox =	22191.26	kN-m

Sliding Check:

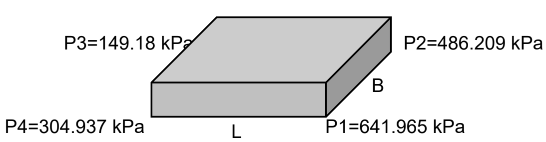
Frict =	12911.50	kN
FS(slid) =	24.566	

% Base Area in Compression:

Dist. y =	N.A.	m
Dist. x =	N.A.	m
Brg. Ly =	10.000	m
Brg. Lx =	6.400	m
%Brg. Area =	100.00	%
Biaxial Case =	N.A.	6*ex/L + 6*ez/B = 0.623

Gross Soil Bearing Corner Pressures:

P_1 =	641.965	kPa
P_2 =	486.209	kPa
P_3 =	149.180	kPa
P_4 =	304.937	kPa



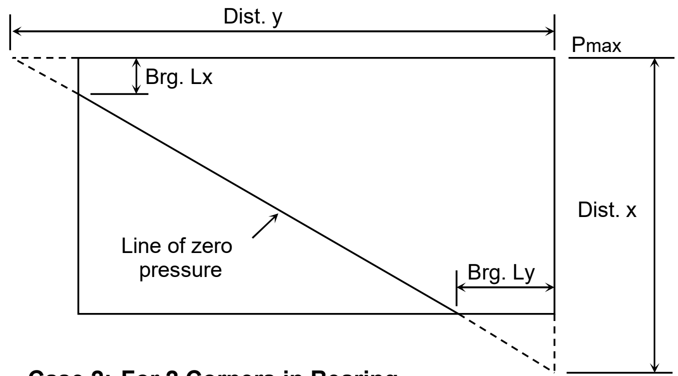
CORNER PRESSURES

Summary of Results:

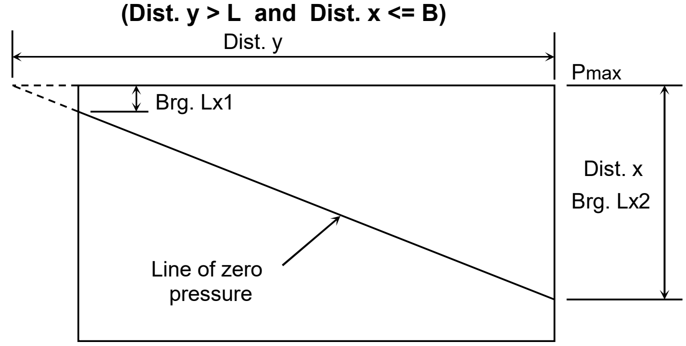
Sliding Check:			
FS(slid) =	24.57	> 1	OK
Bearing Area:			
%Brg. Area =	100.00%	> 1%	OK
Bearing Pressure Check:			
FS(brg) =	2.00	> 1.0	OK
Flotation Check:			
FS (float) =	23.42	> 1	OK

Nomenclature for Biaxial Eccentricity:

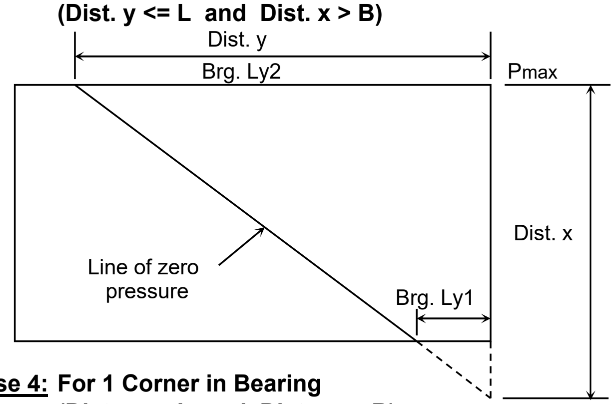
Case 1: For 3 Corners in Bearing
(Dist. y > L and Dist. x > B)



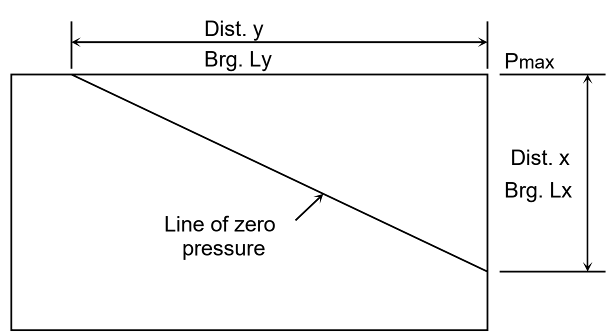
Case 2: For 2 Corners in Bearing
(Dist. y > L and Dist. x <= B)



Case 3: For 2 Corners in Bearing
(Dist. y <= L and Dist. x > B)



Case 4: For 1 Corner in Bearing
(Dist. y <= L and Dist. x <= B)



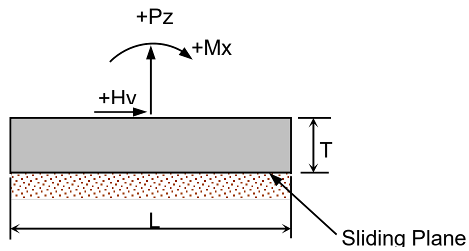
GATE TOWER STABILITY ANALYSIS

Job Name:	Springbank Off-Stream Storage Project	Number:	110773396
Site:	Gate Tower	Originator:	ACG 7/2/2020 Checker: CG
Load Case:	E3-22 Extreme Earthquake		

Input Data:

Footing Data:

Footing Length, L =	10.00	m
Footing Width, B =	6.40	m
Footing Thickness, T =	0.00	m
Coef. of Base Friction, μ =	0.51	
Ultimate Bearing, Pall =	1281.00	kPa

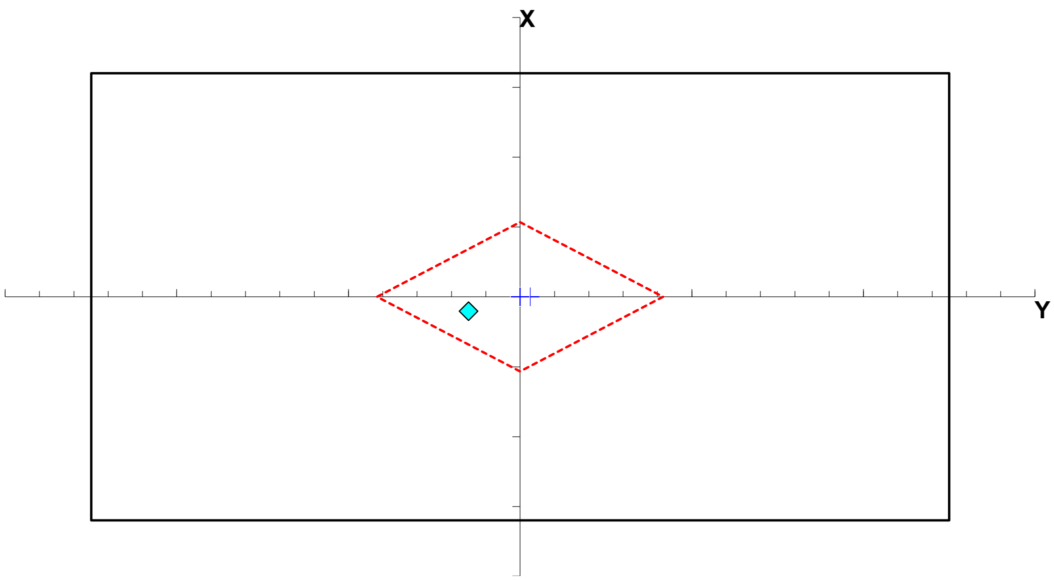


Nomenclature

Loading Data:

Direction of Seismic Load: COMBINED

	Uplift	Vertical Soil	Not Used	Not Used	Not Used	SAP2000 Reaction
Yp (m.) =	0.00	0.12				0.00
Xp (m.) =	0.00	0.00				0.00
Pz (kN) =	1128.96	-11583.42				-14862.08
Hy (kN) =	0.00	0.00				-500.48
Hx (kN) =	0.00	0.00				101.82
My (kN-m) =	0.00	0.00				5409.29
Mx (kN-m) =	0.00	0.00				-16621.56



FOOTING PLAN

Note: Is the "Kern" area of footing (When resultant of loads falls within "Kern", entire footing base is in bearing.)

Results:

Total Resultant Load and Eccentricities:

ΣPy =	-25316.54	kN
ey =	-0.60	m (<= L/6)
ex =	-0.21	m (<= B/6)
ΣHy =	-500.48	kN
ΣHx =	101.82	kN
H resultant =	510.73	kN
ΣMry =	84625.60	kN-m
ΣMoy =	9021.96	kN-m
ΣMrx =	133559.59	kN-m
ΣMox =	-22266.36	kN-m

Sliding Check:

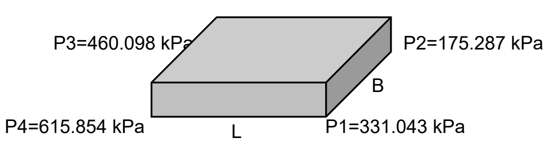
Frict =	12911.43	kN
FS(slid) =	25.280	

% Base Area in Compression:

Dist. y =	N.A.	m
Dist. x =	N.A.	m
Brg. Ly =	10.000	m
Brg. Lx =	6.400	m
%Brg. Area =	100.00	%
Biaxial Case =	N.A.	6*ex/L + 6*ez/B = 0.557

Gross Soil Bearing Corner Pressures:

P_1 =	331.043	kPa
P_2 =	175.287	kPa
P_3 =	460.098	kPa
P_4 =	615.854	kPa



CORNER PRESSURES

Summary of Results:

Sliding Check:

FS(slid) =	25.28	> 1	OK

Bearing Area:

%Brg. Area =	100.00%	> 1%	OK

Bearing Pressure Check:

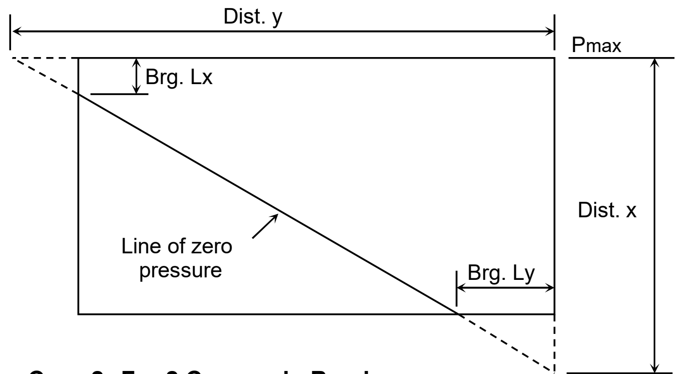
FS(brg) =	2.08	> 1.0	OK

Flotation Check:

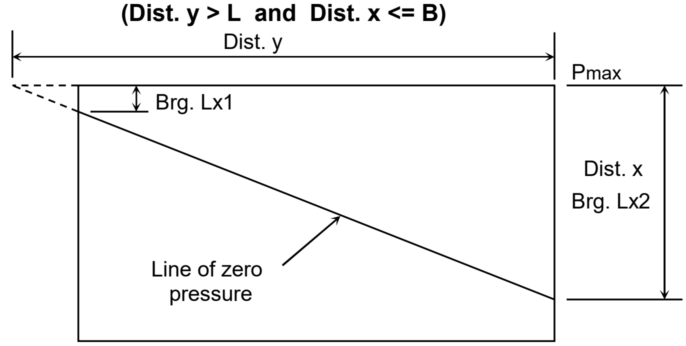
FS (float) =	23.42	> 1	OK

Nomenclature for Biaxial Eccentricity:

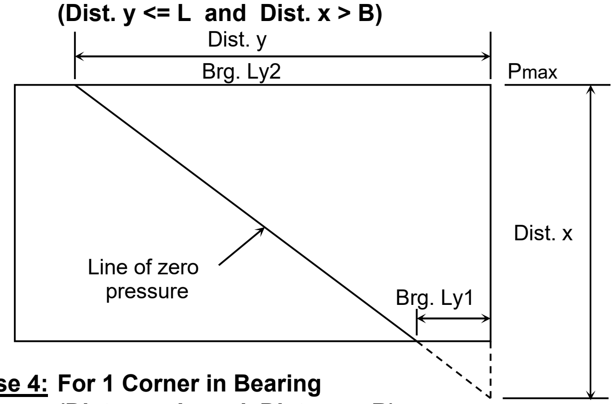
Case 1: For 3 Corners in Bearing
(Dist. y > L and Dist. x > B)



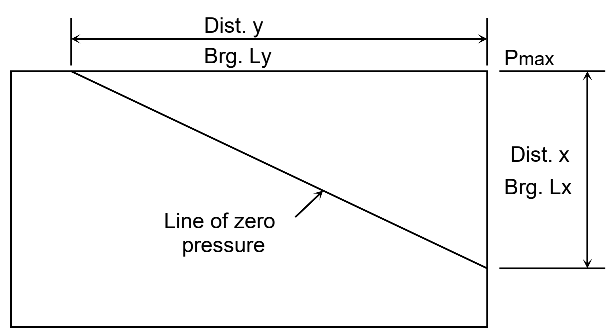
Case 2: For 2 Corners in Bearing
(Dist. y > L and Dist. x <= B)



Case 3: For 2 Corners in Bearing
(Dist. y <= L and Dist. x > B)



Case 4: For 1 Corner in Bearing
(Dist. y <= L and Dist. x <= B)



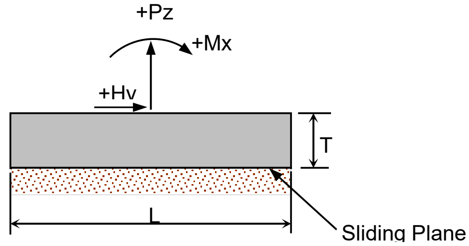
GATE TOWER STABILITY ANALYSIS

Job Name:	Springbank Off-Stream Storage Project	Number:	110773396
Site:	Gate Tower	Originator:	ACG 7/2/2020 Checker: CG
Load Case:	E3-23 Extreme Earthquake		

Input Data:

Footing Data:

Footing Length, L =	10.00	m
Footing Width, B =	6.40	m
Footing Thickness, T =	0.00	m
Coef. of Base Friction, μ =	0.51	
Ultimate Bearing, Pall =	1281.00	kPa

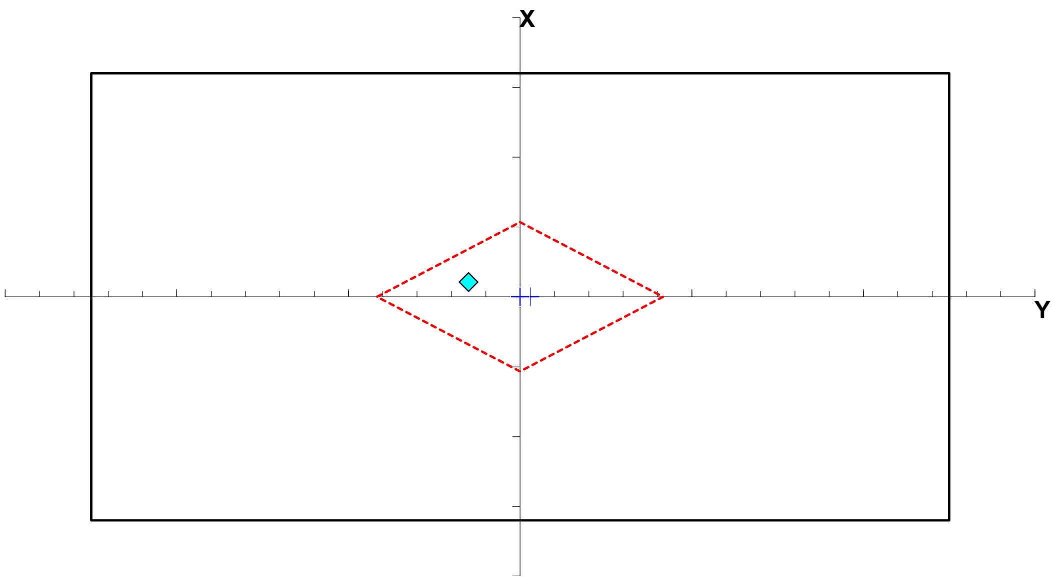


Nomenclature

Loading Data:

Direction of Seismic Load: COMBINED

	Uplift	Vertical Soil	Not Used	Not Used	Not Used	SAP2000 Reaction
Yp (m.) =	0.00	0.12				**0.00**
Xp (m.) =	0.00	0.00				0.00
Pz (kN) =	1128.96	-11583.42				**-14862.08**
Hy (kN) =	0.00	0.00				**-500.48**
Hx (kN) =	0.00	0.00				**-101.82**
My (kN-m) =	0.00	0.00				**-5409.29**
Mx (kN-m) =	0.00	0.00				**-16621.56**



FOOTING PLAN

Note: Is the "Kern" area of footing (When resultant of loads falls within "Kern", entire footing base is in bearing.)

Results:

Total Resultant Load and Eccentricities:

ΣPy =	-25316.54	kN
ey =	-0.60	m (<= L/6)
ex =	0.21	m (<= B/6)
ΣHy =	-500.48	kN
ΣHx =	-101.82	kN
H resultant =	510.73	kN
ΣMry =	84625.60	kN-m
ΣMoy =	-9021.96	kN-m
ΣMrx =	133559.59	kN-m
ΣMox =	-22266.36	kN-m

Sliding Check:

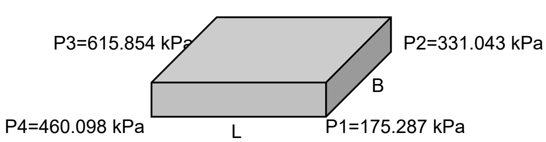
Frict =	12911.43	kN
FS(slid) =	25.280	

% Base Area in Compression:

Dist. y =	N.A.	m
Dist. x =	N.A.	m
Brg. Ly =	10.000	m
Brg. Lx =	6.400	m
%Brg. Area =	100.00	%
Biaxial Case =	N.A.	6*ex/L + 6*ez/B = 0.557

Gross Soil Bearing Corner Pressures:

P1 =	175.287	kPa
P2 =	331.043	kPa
P3 =	615.854	kPa
P4 =	460.098	kPa



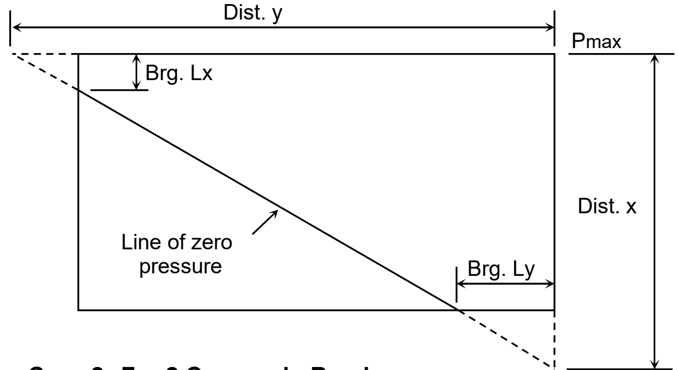
CORNER PRESSURES

Summary of Results:

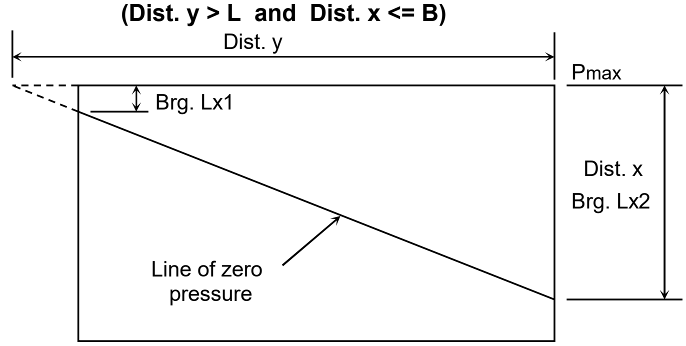
Sliding Check:			
FS(slid) =	25.28	> 1	OK
Bearing Area:			
%Brg. Area =	100.00%	> 1%	OK
Bearing Pressure Check:			
FS(brg) =	2.08	> 1.0	OK
Flotation Check:			
FS (float) =	23.42	> 1	OK

Nomenclature for Biaxial Eccentricity:

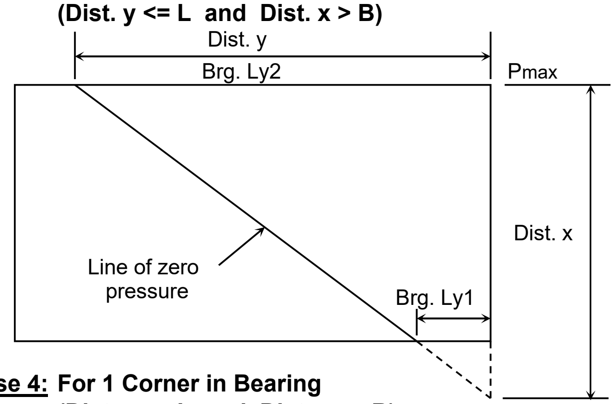
Case 1: **For 3 Corners in Bearing**
(Dist. y > L and Dist. x > B)



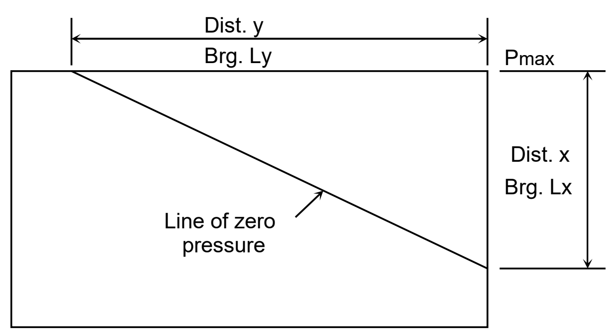
Case 2: **For 2 Corners in Bearing**
(Dist. y > L and Dist. x <= B)



Case 3: **For 2 Corners in Bearing**
(Dist. y <= L and Dist. x > B)



Case 4: **For 1 Corner in Bearing**
(Dist. y <= L and Dist. x <= B)



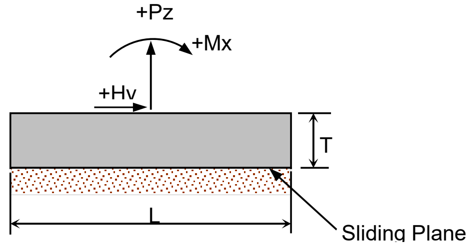
GATE TOWER STABILITY ANALYSIS

Job Name:	Springbank Off-Stream Storage Project	Number:	110773396			
Site:	Gate Tower	Originator:	ACG	7/2/2020	Checker:	CG
Load Case:	E3-24 Extreme Earthquake					

Input Data:

Footing Data:

Footing Length, L =	10.00	m
Footing Width, B =	6.40	m
Footing Thickness, T =	0.00	m
Coef. of Base Friction, μ =	0.51	
Ultimate Bearing, Pall =	1281.00	kPa

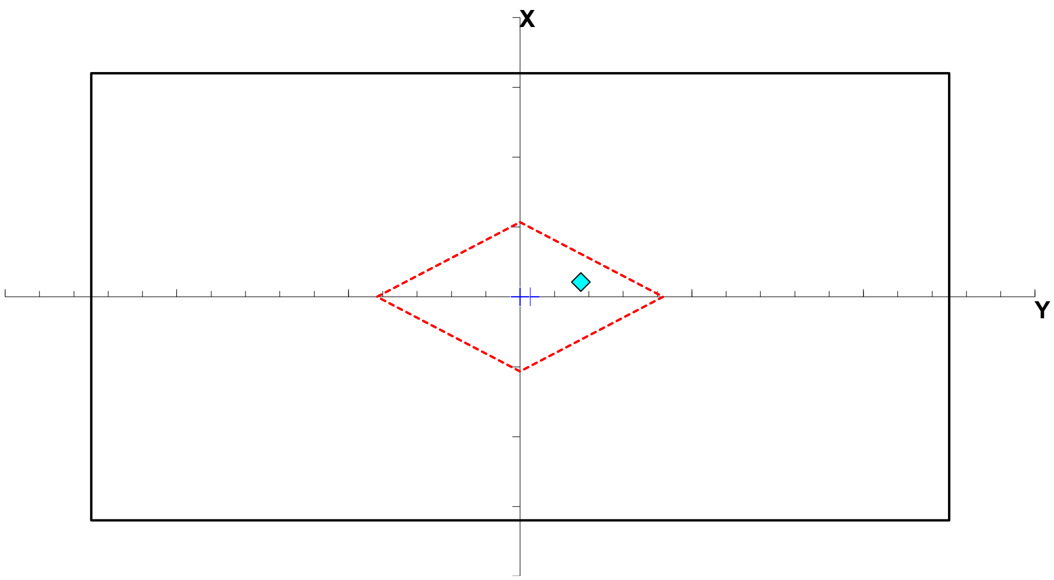


Nomenclature

Loading Data:

Direction of Seismic Load: COMBINED

	Uplift	Vertical Soil	Not Used	Not Used	Not Used	SAP2000 Reaction
Yp (m.) =	0.00	0.12				**0.00**
Xp (m.) =	0.00	0.00				0.00
Pz (kN) =	1128.96	-11583.42				**-14862.20**
Hy (kN) =	0.00	0.00				**515.62**
Hx (kN) =	0.00	0.00				**-101.82**
My (kN-m) =	0.00	0.00				**-5409.29**
Mx (kN-m) =	0.00	0.00				**16546.46**



FOOTING PLAN

Note: Is the "Kern" area of footing (When resultant of loads falls within "Kern", entire footing base is in bearing.)

Results:

Total Resultant Load and Eccentricities:

ΣPy =	-25316.66	kN
ey =	0.71	m (<= L/6)
ex =	0.21	m (<= B/6)
ΣHy =	515.62	kN
ΣHx =	-101.82	kN
H resultant =	525.58	kN
ΣMry =	84626.00	kN-m
ΣMoy =	-9021.96	kN-m
ΣMrx =	130896.03	kN-m
ΣMox =	22191.26	kN-m

Sliding Check:

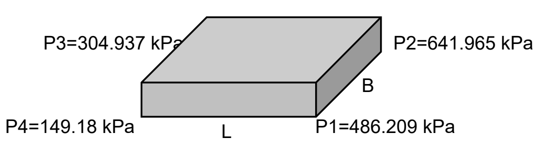
Frict =	12911.50	kN
FS(slid) =	24.566	

% Base Area in Compression:

Dist. y =	N.A.	m
Dist. x =	N.A.	m
Brg. Ly =	10.000	m
Brg. Lx =	6.400	m
%Brg. Area =	100.00	%
Biaxial Case =	N.A.	6*ex/L + 6*ez/B = 0.623

Gross Soil Bearing Corner Pressures:

P_1 =	486.209	kPa
P_2 =	641.965	kPa
P_3 =	304.937	kPa
P_4 =	149.180	kPa



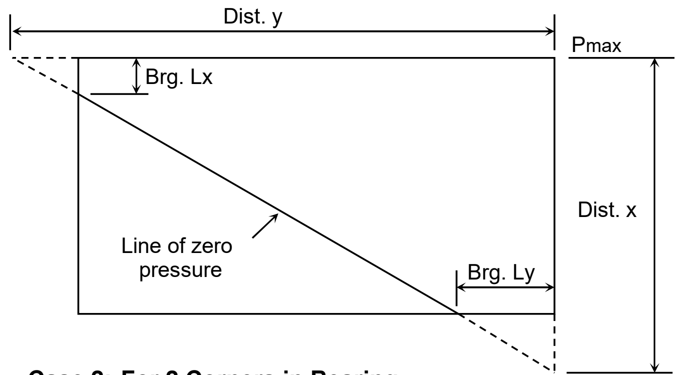
CORNER PRESSURES

Summary of Results:

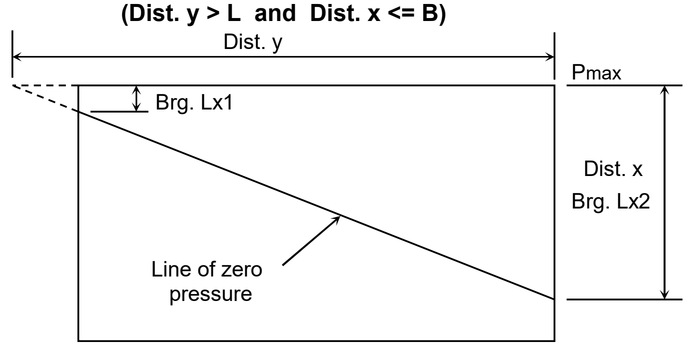
Sliding Check:			
FS(slid) =	24.57	> 1	OK
Bearing Area:			
%Brg. Area =	100.00%	> 1%	OK
Bearing Pressure Check:			
FS(brg) =	2.00	> 1.0	OK
Flotation Check:			
FS (float) =	23.42	> 1	OK

Nomenclature for Biaxial Eccentricity:

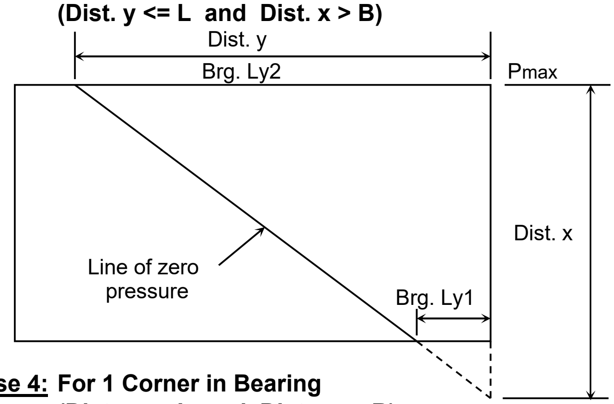
Case 1: For 3 Corners in Bearing (Dist. y > L and Dist. x > B)



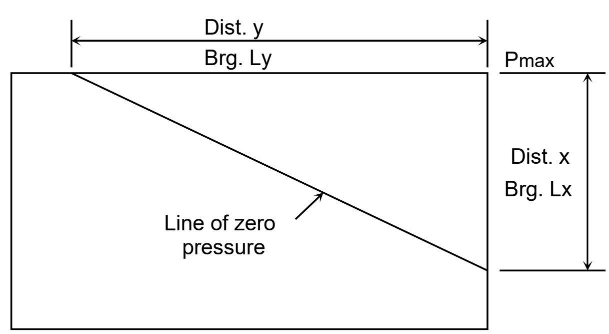
Case 2: For 2 Corners in Bearing (Dist. y > L and Dist. x <= B)



Case 3: For 2 Corners in Bearing (Dist. y <= L and Dist. x > B)



Case 4: For 1 Corner in Bearing (Dist. y <= L and Dist. x <= B)



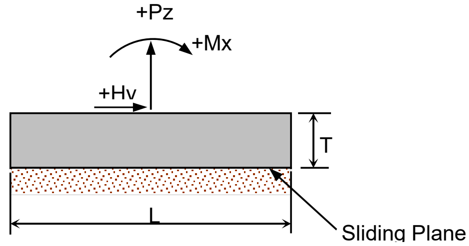
GATE TOWER STABILITY ANALYSIS

Job Name:	Springbank Off-Stream Storage Project	Number:	110773396		
Site:	Gate Tower	Originator:	ACG 7/2/2020	Checker:	CG
Load Case:	PE-1 Post-Earthquake				

Input Data:

Footing Data:

Footing Length, L =	10.00	m
Footing Width, B =	6.40	m
Footing Thickness, T =	0.00	m
Coef. of Base Friction, μ =	0.51	
Ultimate Bearing, Pall =	1281.00	kPa

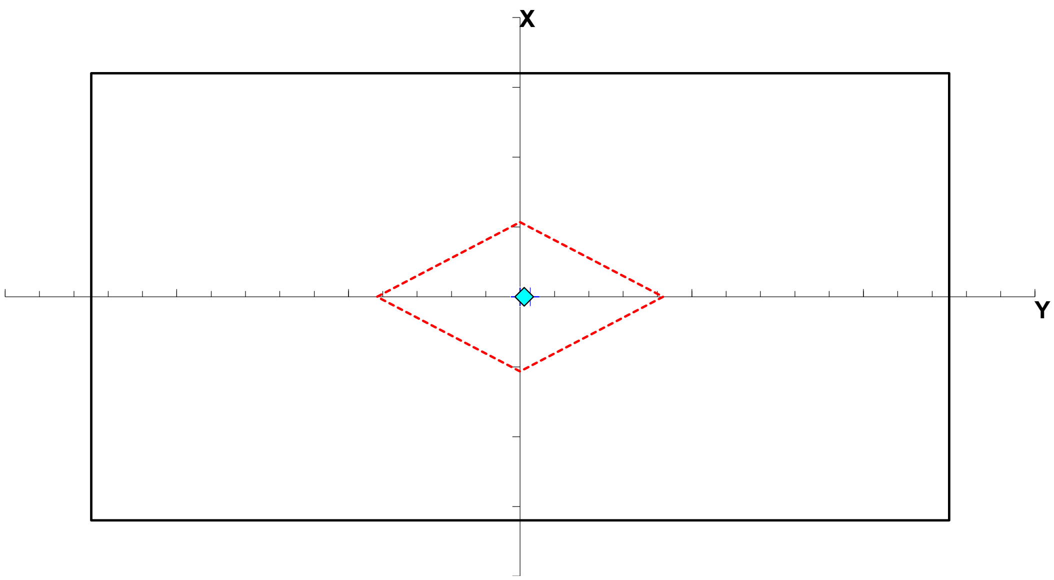


Nomenclature

Loading Data:

Direction of Seismic Load: X-DIRECTION

	Uplift	Vertical Soil	Not Used	Not Used	Not Used	SAP2000 Reaction
Yp (m.) =	0.00	0.12				0.00
Xp (m.) =	0.00	0.00				0.00
Pz (kN) =	1128.96	-11583.42				-14032.24
Hy (kN) =	0.00	0.00				6.24
Hx (kN) =	0.00	0.00				2.14
My (kN-m) =	0.00	0.00				-1.45
Mx (kN-m) =	0.00	0.00				-33.70



FOOTING PLAN

Note: Is the "Kern" area of footing (When resultant of loads falls within "Kern", entire footing base is in bearing.)

Results:

Total Resultant Load and Eccentricities:

ΣPy =	-24486.70	kN
ey =	0.05	m (<= L/6)
ex =	0.00	
ΣHy =	6.24	kN
ΣHx =	2.14	kN
H resultant =	6.59	kN
ΣMry =	N.A.	kN-m
ΣMoy =	N.A.	kN-m
ΣMrx =	126746.22	kN-m
ΣMox =	5611.11	kN-m

Sliding Check:

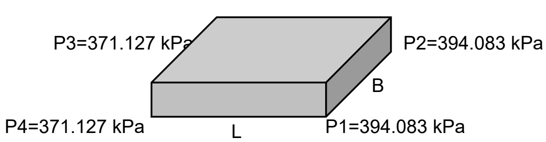
Frict =	12488.22	kN
FS(slid) =	1893.806	

% Base Area in Compression:

Dist. y =	N.A.	m
Dist. x =	N.A.	m
Brg. Ly =	10.000	m
Brg. Lx =	6.400	m
%Brg. Area =	100.00	%
Biaxial Case =	N.A.	

Gross Soil Bearing Corner Pressures:

P_1 =	394.083	kPa
P_2 =	394.083	kPa
P_3 =	371.127	kPa
P_4 =	371.127	kPa



CORNER PRESSURES

Summary of Results:

Sliding Check:

FS(slid) = **1893.81** > 1.1 OK

Bearing Area:

%Brg. Area = **100.00%** > 75% OK

Bearing Pressure Check:

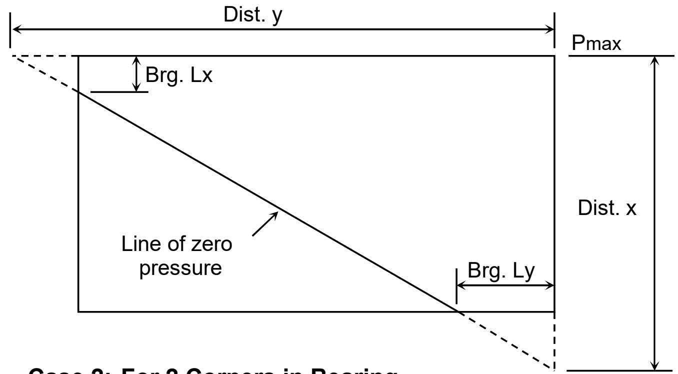
FS(brg) = **3.25** > 1.0 OK

Flotation Check:

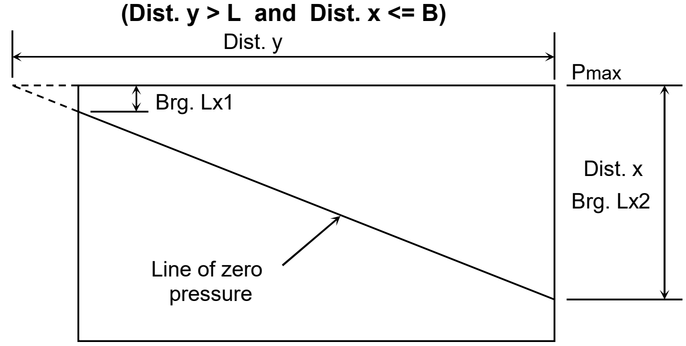
FS (float) = **22.69** > 1.1 OK

Nomenclature for Biaxial Eccentricity:

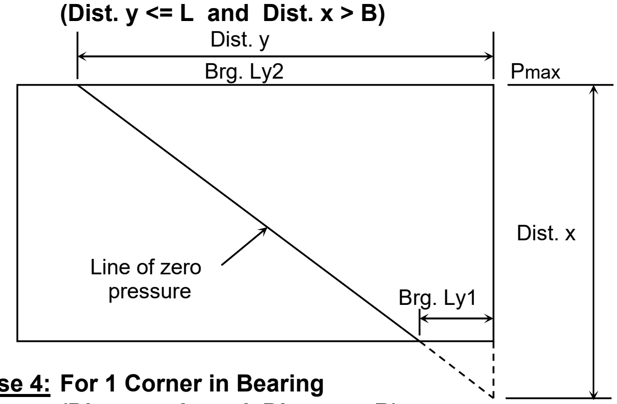
Case 1: For 3 Corners in Bearing (Dist. y > L and Dist. x > B)



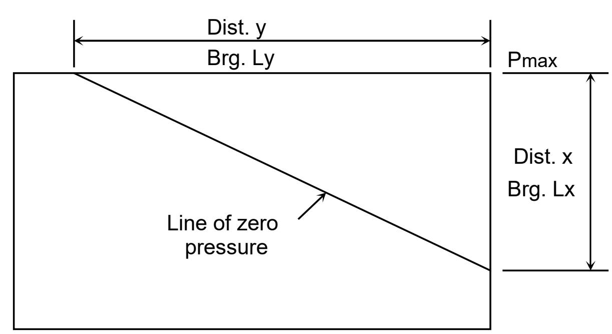
Case 2: For 2 Corners in Bearing (Dist. y > L and Dist. x <= B)



Case 3: For 2 Corners in Bearing (Dist. y <= L and Dist. x > B)



Case 4: For 1 Corner in Bearing (Dist. y <= L and Dist. x <= B)



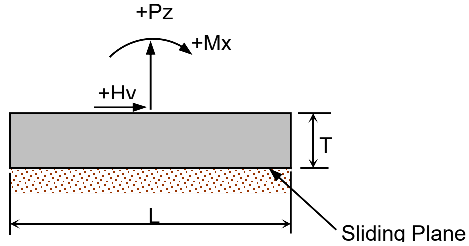
GATE TOWER STABILITY ANALYSIS

Job Name:	Springbank Off-Stream Storage Project	Number:	110773396
Site:	Gate Tower	Originator:	ACG 7/2/2020 Checker: CG
Load Case:	PE-2+ Post-Earthquake		

Input Data:

Footing Data:

Footing Length, L =	10.00	m
Footing Width, B =	6.40	m
Footing Thickness, T =	0.00	m
Coef. of Base Friction, μ =	0.51	
Ultimate Bearing, Pall =	1281.00	kPa

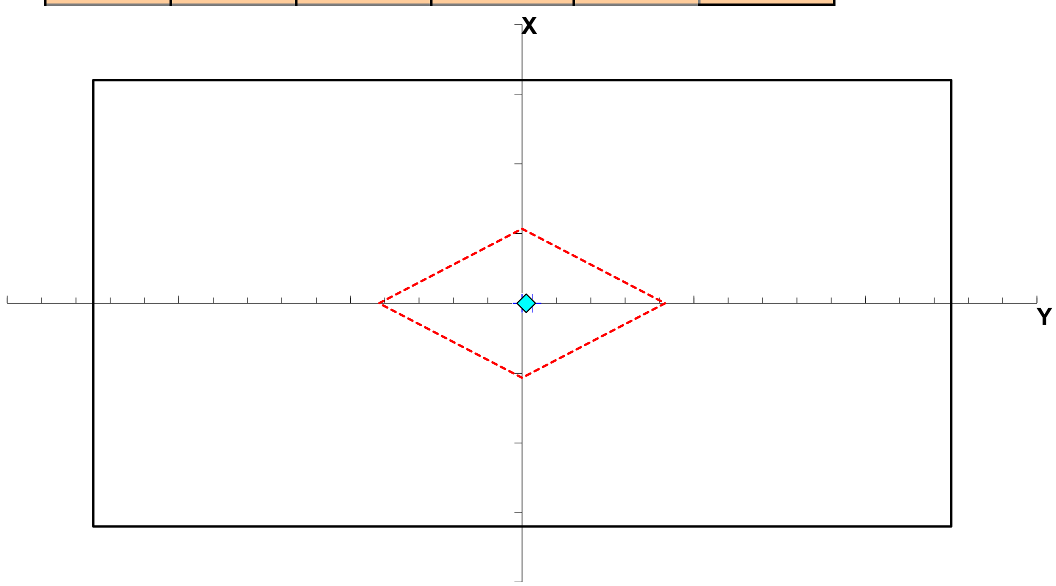


Nomenclature

Loading Data:

Direction of Seismic Load: Y-DIRECTION

	Uplift	Vertical Soil	Not Used	Not Used	Not Used	SAP2000 Reaction
Yp (m.) =	0.00	0.12				**0.00**
Xp (m.) =	0.00	0.00				0.00
Pz (kN) =	1128.96	-11583.42				**-14159.99**
Hy (kN) =	0.00	0.00				**4.99**
Hx (kN) =	0.00	0.00				**0.00**
My (kN-m) =	0.00	0.00				**0.00**
Mx (kN-m) =	0.00	0.00				**-30.72**



FOOTING PLAN

Note: Is the "Kern" area of footing (When resultant of loads falls within "Kern", entire footing base is in bearing.)

Results:

Total Resultant Load and Eccentricities:

ΣPy =	-24614.45	kN
ey =	0.05	m (<= L/6)
ex =	0.00	
ΣHy =	4.99	kN
ΣHx =	0.00	kN
H resultant =	4.99	kN
ΣMry =	N.A.	kN-m
ΣMoy =	N.A.	kN-m
ΣMrx =	127384.94	kN-m
ΣMox =	5614.08	kN-m

Sliding Check:

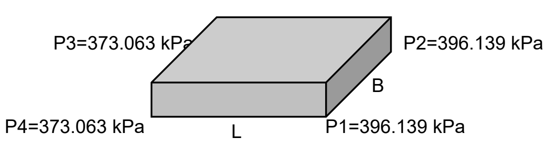
Frict =	12553.37	kN
FS(slid) =	2513.690	

% Base Area in Compression:

Dist. y =	N.A.	m
Dist. x =	N.A.	m
Brg. Ly =	10.000	m
Brg. Lx =	6.400	m
%Brg. Area =	100.00	%
Biaxial Case =	N.A.	

Gross Soil Bearing Corner Pressures:

P1 =	396.139	kPa
P2 =	396.139	kPa
P3 =	373.063	kPa
P4 =	373.063	kPa



CORNER PRESSURES

Summary of Results:

Sliding Check:

FS(slid) =	2513.69	> 1.1	OK

Bearing Area:

%Brg. Area =	100.00%	> 75%	OK

Bearing Pressure Check:

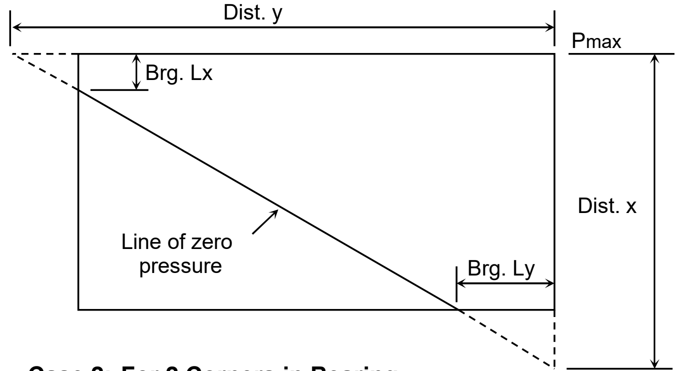
FS(brg) =	3.23	> 1.0	OK

Flotation Check:

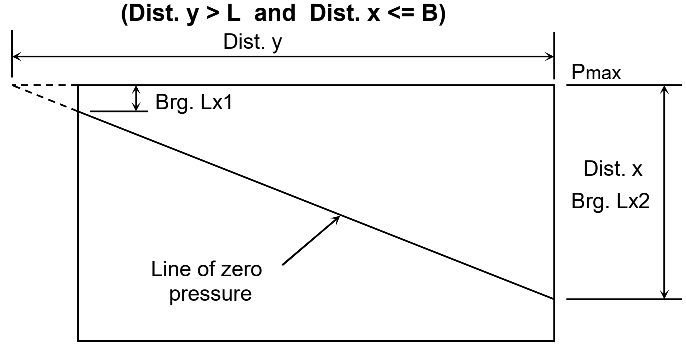
FS (float) =	22.80	> 1.1	OK

Nomenclature for Biaxial Eccentricity:

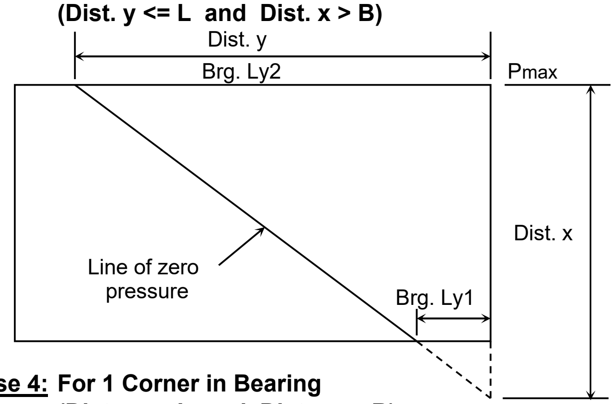
Case 1: For 3 Corners in Bearing
(Dist. y > L and Dist. x > B)



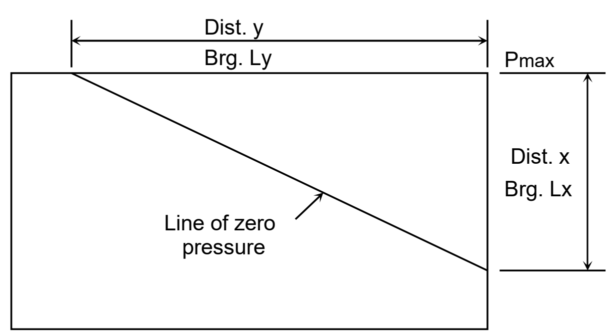
Case 2: For 2 Corners in Bearing
(Dist. y > L and Dist. x <= B)



Case 3: For 2 Corners in Bearing
(Dist. y <= L and Dist. x > B)



Case 4: For 1 Corner in Bearing
(Dist. y <= L and Dist. x <= B)



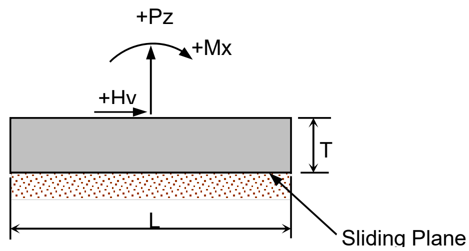
GATE TOWER STABILITY ANALYSIS

Job Name:	Springbank Off-Stream Storage Project	Number:	110773396		
Site:	Gate Tower	Originator:	ACG 7/2/2020	Checker:	CG
Load Case:	PE-2- Post-Earthquake				

Input Data:

Footing Data:

Footing Length, L =	10.00	m
Footing Width, B =	6.40	m
Footing Thickness, T =	0.00	m
Coef. of Base Friction, μ =	0.51	
Ultimate Bearing, Pall =	1281.00	kPa

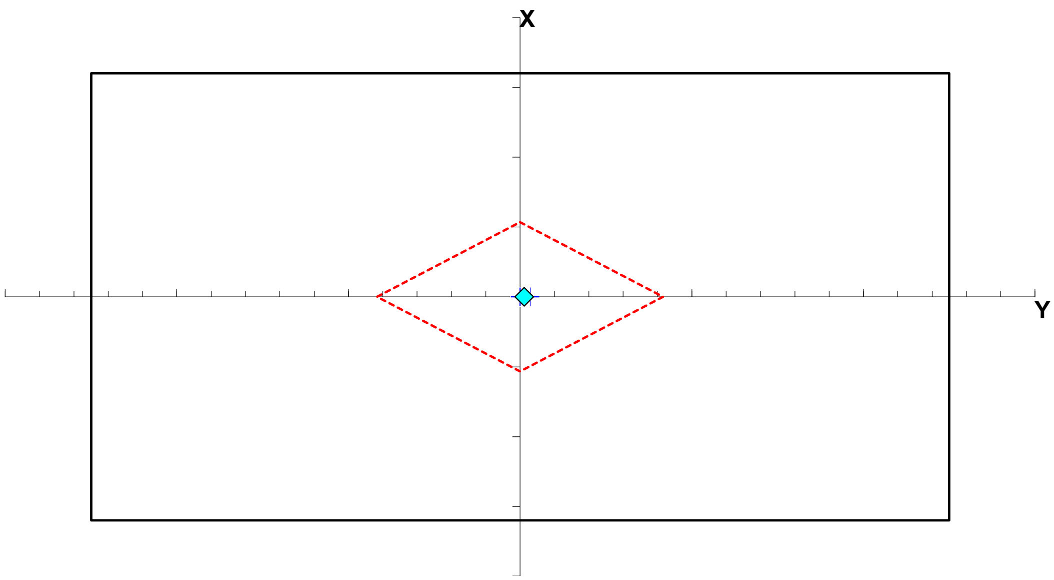


Nomenclature

Loading Data:

Direction of Seismic Load: Y-DIRECTION

	Uplift	Vertical Soil	Not Used	Not Used	Not Used	SAP2000 Reaction
Yp (m.) =	0.00	0.12				**0.00**
Xp (m.) =	0.00	0.00				0.00
Pz (kN) =	1128.96	-11583.42				**-14260.21**
Hy (kN) =	0.00	0.00				**9.62**
Hx (kN) =	0.00	0.00				**0.00**
My (kN-m) =	0.00	0.00				**0.00**
Mx (kN-m) =	0.00	0.00				**-41.39**



FOOTING PLAN

Note: Is the "Kern" area of footing (When resultant of loads falls within "Kern", entire footing base is in bearing.)

Results:

Total Resultant Load and Eccentricities:

ΣPy =	-24714.67	kN
ey =	0.05	m (<= L/6)
ex =	0.00	
ΣHy =	9.62	kN
ΣHx =	0.00	kN
H resultant =	9.62	kN
ΣMry =	N.A.	kN-m
ΣMoy =	N.A.	kN-m
ΣMrx =	127886.07	kN-m
ΣMox =	5603.41	kN-m

Sliding Check:

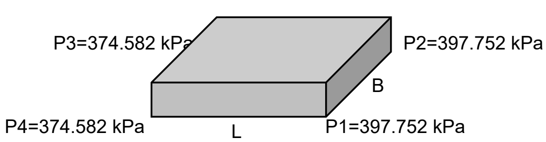
Frict =	12604.48	kN
FS(slid) =	1310.374	

% Base Area in Compression:

Dist. y =	N.A.	m
Dist. x =	N.A.	m
Brg. Ly =	10.000	m
Brg. Lx =	6.400	m
%Brg. Area =	100.00	%
Biaxial Case =	N.A.	

Gross Soil Bearing Corner Pressures:

P_1 =	397.752	kPa
P_2 =	397.752	kPa
P_3 =	374.582	kPa
P_4 =	374.582	kPa



CORNER PRESSURES

Summary of Results:

Sliding Check:

FS(slid) = **1310.37** > 1.1 OK

Bearing Area:

%Brg. Area = **100.00%** > 75% OK

Bearing Pressure Check:

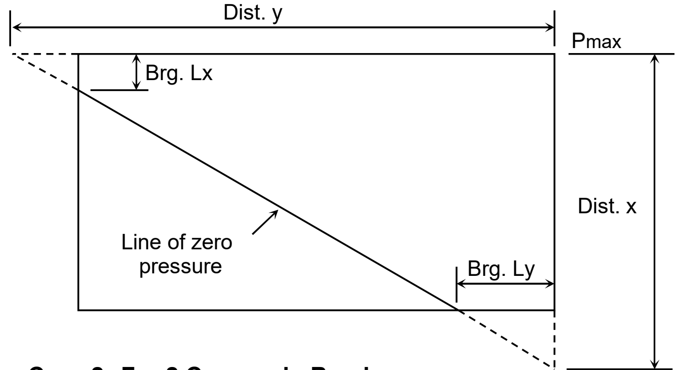
FS(brg) = **3.22** > 1.0 OK

Flotation Check:

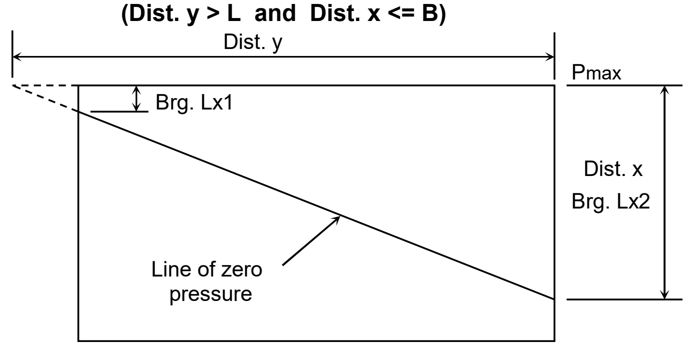
FS (float) = **22.89** > 1.1 OK

Nomenclature for Biaxial Eccentricity:

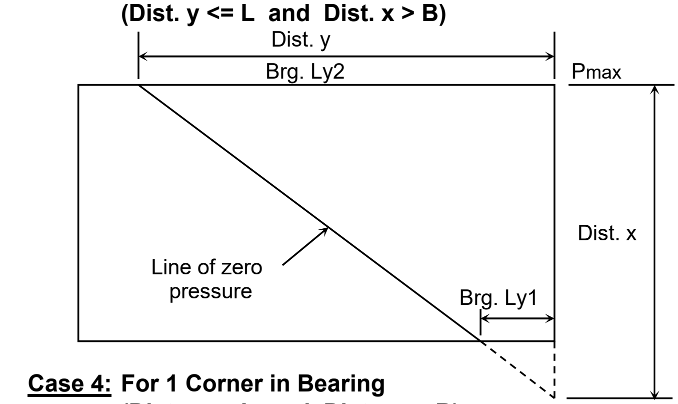
Case 1: For 3 Corners in Bearing (Dist. y > L and Dist. x > B)



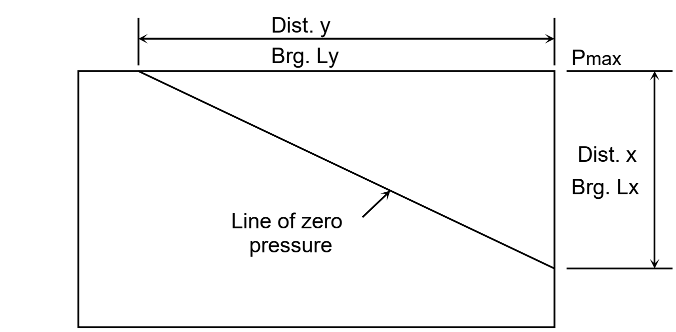
Case 2: For 2 Corners in Bearing (Dist. y > L and Dist. x <= B)



Case 3: For 2 Corners in Bearing (Dist. y <= L and Dist. x > B)



Case 4: For 1 Corner in Bearing (Dist. y <= L and Dist. x <= B)



APPENDIX E.5-3 CSU RIGID BASIN

Appendix E.5-3 – Rigid Stilling Basin Stability Calculations Springbank Off-Stream Storage/Alberta Transportation Table of Contents

Stantec

By:	PRS	Date:	10/29/19
Chk:	ACG	Date:	10/30/19
Subject:	**LLOW Rigid Stilling Basin Stability Analysis**		
Job Name:	**SR1**	Job No.:	**110773396**

LLOW Rigid Stilling Basin Stability Anaylsis Load Combinations, Requirements, and Results

References:

Alberta Transportation *Water Control Structures - Selected Design Guidelines* , 2004
CDA *Dam Safety Guidelines* , 2007
Springbank Off-Stream Storage Project - *Design Basis Memorandum (DBM)* , 2019

Required Stability Safety Factors

Classification	Resultant DBM Table 7	Bearing (kPa) AT WCS 8.4	Uplift DBM Table 7	Sliding DBM Table 7
Usual	MIDDLE THIRD	< 150 (Allowable)	1.5	1.5
Unusual	MIDDLE THIRD	< 150 (Allowable)	1.3	1.3
Extreme	MIDDLE HALF	< 150 (Allowable)	1.1	1.1

Stabilty Results

Condition	Classification	Resultant	Bearing (kPa)	Uplift	Sliding
1 Dry Condition	Usual	MIDDLE THIRD	93.8	N/A	2.5
2 10 Year Flow	Unusual	MIDDLE THIRD	75.0	4.3	1.5
3 Rapid Gate Closure	Unusual	MIDDLE THIRD	65.2	2.8	1.5
4 Const./ Maint.	Unusual	MIDDLE THIRD	88.2	N/A	1.9
5 Maximum Flow	Extreme	MIDDLE THIRD	71.4	3.3	1.4
6 Earthquake*	Extreme	MIDDLE THIRD	90.9	>10	1.0-1.9
7 Post-Earthquake**	Extreme	MIDDLE THIRD	Passes	Passes	Passes

* Per DBM Section 7.2, there is no stability acceptance criteria for the seismic load cases.
** Because the Resultant from the Earthquake load cases remains in the middle third of the structure, the Post-Earthquake condition of the structure will have the same results as the Pre-Earthquake condition.

Load Condition Descriptions:
(See load notation page 2)

1 Dry Condition
Ws + Wsoil + Fo (DEAD + EARTH)
Dry Fill
Empty Basin

2 10 Year Flow
Ws + Wsoil + Ww + Fo+ Fd + U (DEAD + EARTH + HYDRO + UPLIFT)
Saturated fill from 10 year flow head water to 10 year flow tailwater
Water in Basin @ 10 year flow surface height

3 Rapid Gate Closure
Ws + Wsoil + Fo + U (DEAD + EARTH + UPLIFT)
Saturated fill from maximum flow head water to maximum flow tailwater
Empty Basin

4 Construction/ Maintenance
Ws + Wsoil + Fo + Fs (DEAD + EARTH + SURCHARGE)
Dry Fill
Empty Basin
Construction Live Load or Surcharge

5 Max Flow
Ws + Wsoil + Ww + Fo + Fd + U (DEAD + EARTH + HYDRO + UPLIFT)
Saturated fill from maximum flow head water to maximum flow tailwater
Water in Basin @ max flow surface height

6 Earthquake
Ws + Wsoil + Fo + Qh + Qv (DEAD + EARTH + EQ)
Dry Fill
No Water in Basin
Earthquake Soil Loads:
6a : 1.0*kh +/- 0.0*kv
6b : 1.0*kh +/- 0.3*kv
6c : 0.3*kh +/- 1.0*kv

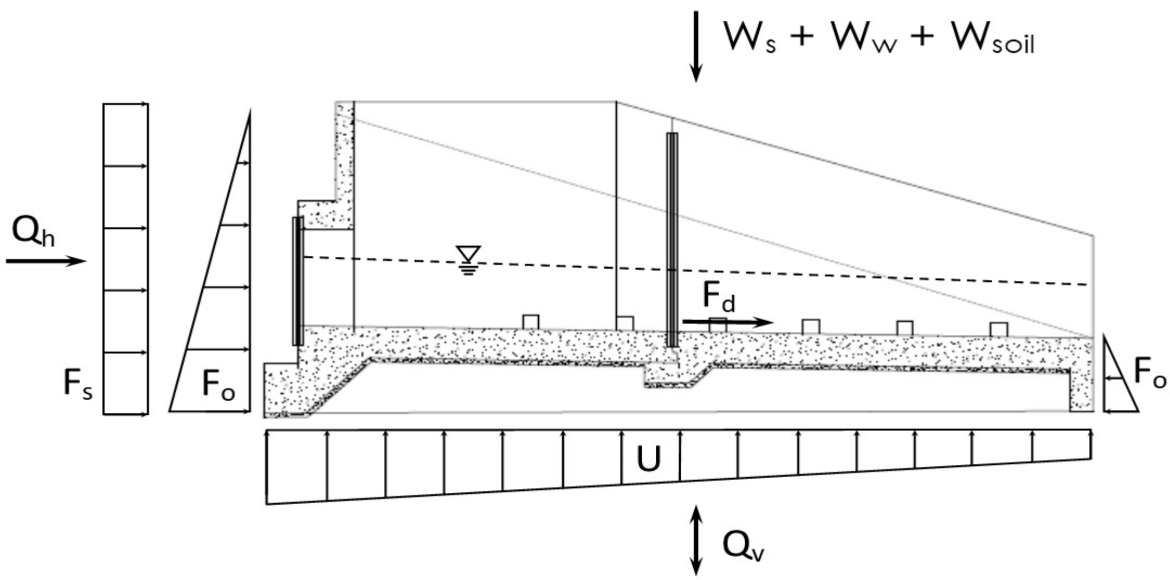
7 Post-Earthquake
Ws + Wsoil + Fo (DEAD + EARTH)
Dry Fill
Empty Basin
Bearing Area based on resultant location from Earthquake load case.

Stantec

By: PRS Date: 10/29/19
Chk: ACG Date: 10/30/19
Subject: LLOW Rigid Stilling Basin Stability Analysis
Job Name: SR1 Job No.: 110773396

Load Notation:

Ws-	Structure Weight	DEAD
Vsoil-	Vertical Soil Weight	EARTH
Ww-	Basin Water Weight	HYDRO
U-	Uplift	UPLIFT
Fo-	At-Rest Earth Load and Hydrostatic	EARTH, HYDRO
Fs-	Surcharge Load	SURCHARGE
Fd-	Dynamic Water Force	HYDRO
Qv-	Vertical Earthquake Load	EQ
Qh-	Horizontal Earthquake Load	EQ



Note: Figure above is a general representation, free body diagrams vary based on loading condition.

RIGID STILLING BASIN STABILITY ANALYSIS

References:

Alberta Transportation *Water Control Structures - Selected Design Guidelines*, 2004.
EM 1110-2-2100 *Stability Analysis of Concrete Structures*, 2005.
CDA *Dam Safety Guidelines*, 2007.
Springbank Off-Stream Storage Project - Design Basis Memorandum (DBM), 2019.

- Water elevation in basin is assumed to be linear from headwater elevation to tailwater elevation.
- Groundwater elevation is assumed to vary from the headwater elevation to the tailwater elevation.
- Soil elevation is assumed to be at top of wall at outlet and at top of slab elevation at end of basin.
- Slab slope is assumed to be level, except for uplift and lateral earth pressure.
- Forces perpendicular to the flow are assumed to not control for stability due to limited soil area, limited exposed wall surfaces, and passive soil pressure.
- By engineering judgment, the uplift difference due to the shallow slab slope (0.018) is negligible; thus will not affect the results as calculated herein.

INPUTS

General:

Wall Thickness: $t_w := 500\text{mm}$

Slab Overhang: $t_o := 500\text{mm}$

Slab Thickness: $t_s := 750\text{mm}$

Slope of Slab: $S_s := 0.018$

Surcharge Soil Height: $H_s := 1\text{m}$

Number of Baffle Blocks: $n_{bb} := 21$

Baffle Block Height: $H_{bb} := 350\text{mm}$

Baffle Block Width: $W_{bb} := 1440\text{mm}$

Drag Coefficient: $C_d := 2.00$

Water Velocity: $V := 8.02\,\frac{\text{m}}{\text{s}}$ (Rigid Stilling Basin Hydraulic Design)

Moist Soil Unit Weight: $\gamma_m := 20.0\,\frac{\text{kN}}{\text{m}^3}$ (Geotech. Memo 19-07-19 Properties for Embankment Shell)

Saturated Soil Unit Weight: $\gamma_s := 20.0\,\frac{\text{kN}}{\text{m}^3}$

At-Rest Soil Coefficient: $K_o := 0.59$

Passive Soil Coefficient: $K_p := 2.37$

Foundation Soil Friction Angle: $\phi_f := 24°$

Water Unit Weight: $\gamma_w := 9.81 \dfrac{kN}{m^3}$ (DBM Table 2)

Concrete Unit Weight: $\gamma_c := 23.5 \dfrac{kN}{m^3}$ (DBM Table 2)

Submerged Soil Unit Weight: $\gamma_{sub} := \gamma_s - \gamma_w = 10.19 \cdot \dfrac{kN}{m^3}$

Horizontal Seismic Coefficient: $K_h := \dfrac{2}{3} \cdot 0.28 = 0.19$ (Seismic Hazard Assessment - Springbank Off-Stream Dam and Reservoir Table 4)

For 3 Seismic Cases: $K_{h.a} := 1.0 \cdot K_h = 0.19$ $K_{h.b} := 1.0 \cdot K_h = 0.19$ $K_{h.c} := 0.3 \cdot K_h = 0.06$

Vertical Seismic Coefficient: $K_v := 0.56 \cdot K_h = 0.10$ (Seismic Hazard Assessment - Springbank Off-Stream Dam and Reservoir Table 5)

For 3 Seismic Cases: $K_{v.a} := 0.0 \cdot K_v = 0.00$ $K_{v.b} := 0.3 \cdot K_v = 0.03$ $K_{v.c} := 1.0 K_v = 0.10$

Allowable Bearing Pressure (Long Term): $q_{a.lt} := 150kPa$ (Geotech. Memo 19-07-19)

Allowable Bearing Pressure (Short Term): $q_{a.st} := 200kPa$ (Geotech. Memo 19-07-19)

Elevations:

At Outlet:

Top of Slab Elevation: $E_{slab} := 1183.120m$

Top of Wall Elevation: $E_{wall.1} := 1188.5m$

Top of Soil Elevation: $E_{s.1} := 1188.5m$

Headwater Elevation (10 Yr): $E_{w.1.un} := E_{slab} + 0.73m = 1183.85 \cdot m$

Headwater Elevation (max): $E_{w.1.e} := E_{slab} + 1.43m = 1184.55 \cdot m$

(From Hydraulic Design, assume low resistance in conduit for stability calculations)

At End of Basin:

Top of Wall Elevation: $E_{wall.2} := 1185.280m$

Top of Soil Elevation: $E_{s.2} := E_{slab} = 1183.12 \cdot m$

Tailwater Elevation (10 Yr): $E_{w.2.un} := E_{slab} + 0.63m = 1183.75 \cdot m$ (From Hydraulic Design)

Tailwater Elevation (max): $E_{w.2.e} := E_{slab} + 1.1m = 1184.22 \cdot m$

Structure Dimensions:

Internal Basin Width: $W_b := 10m$

Basin Slab Width: $W_{bs} := W_b + 2(t_o + t_w) = 12.00 \cdot m$

Conduit Width: $W_c := 2.4m$

Rectangular Basin Length: $L_b := 9m$

Basin Transition Extension Length: $L_e := 1.2m$

Basin and Extension Length: $L_{be} := L_b + L_e = 10.20 \cdot m$

Basin Transition Length: $L_t := 5.6m$

Chute Transition Length: $L_c := 1.2m$

Transition and Chute Length: $L_{tc} := L_t + L_c = 6.80 \cdot m$

End of Basin:

Cutoff Wall Height: $h_c := 1000mm$

Cutoff Wall Thickness: $t_c := 500mm$

Basin Wall Height: $h_e := E_{wall.2} - E_{slab} = 2.16 \cdot m$

End of Transition:

Transition Wall Height: $h_t := E_{wall.1} - E_{slab} = 5.38 \cdot m$

Transition Ledge Thickness: $t_{tl} := 500mm$

Transition Ledge Length: $L_{tl} := 1000mm$

Top of Soil Elevation: $E_{s.t} := E_{s.1} - \frac{E_{s.1} - E_{s.2}}{L_{tc} + L_{be}} \cdot L_{tc} = 1186.35 \cdot m$

Top of Water Elevation (10 Yr): $E_{w.t.un} := \frac{E_{w.2.un} - E_{w.1.un}}{L_{tc} + L_{be}} \cdot L_{tc} + E_{w.1.un} = 1183.81 \cdot m$

Top of Water Elevation (Max): $E_{w.t.e} := \frac{E_{w.2.e} - E_{w.1.e}}{L_{tc} + L_{be}} \cdot L_{tc} + E_{w.1.e} = 1184.42 \cdot m$

Wall Angle: $\theta := \operatorname{atan}\left[\frac{0.5 \cdot (W_b - W_c)}{L_{tc}}\right] = 29.20 \cdot °$

Diagonal Wall Length: $L_d := \frac{L_t}{\cos(\theta)} = 6.42 \cdot m$

At Outlet:

Conduit Wall Thickness: $t_{wc} := 700mm$

Outlet Wall Thickness: $t_{wo} := 1200mm$

Conduit Slab Thickness: $t_{sc} := 900mm$

Outlet Ledge Thickness: $t_{ol} := 1200mm$

Outlet Ledge Length, Top: $L_{ol.t} := 750mm$

Outlet Ledge Length, Base: $L_{ol.b} := 950mm$

Outlet Ledge Transition Length: $L_{olt} := 1350mm$ Assumed. Based on 1:1 slope.

Conduit Opening Height: $h_{oc} := 2.4m$

Header Wall Width: $W_{hw} := W_c + 2\left(\dfrac{t_w}{\cos(\theta)} + L_c \cdot \tan(\theta)\right) = 4.89 \cdot m$ $L_c = 1.20 \cdot m$

Header Wall Thickness: $t_h := 400mm$ $\theta = 29.20 \cdot deg$

Header Wall Height: $h_h := E_{wall.1} - \left(E_{slab} + h_{oc} + t_{wc}\right) = 2.28 \cdot m$

Chute Transition Slab Width: $W_{sc} := W_c + 2\left(\dfrac{t_o + t_w}{\cos(\theta)} + L_c \cdot \tan(\theta)\right) = 6.03 \cdot m$

RESULTANTS

Note: Resultant locations are referenced from the bottom of the slab at the end of the basin

Structure Weight:

Volume of Outlet Ledge: $V_{ol} := W_{sc} \cdot \left(L_{ol.b} \cdot t_{ol} + \frac{1}{2} L_{olt}^{2}\right) = 12.37 \cdot m^3$

Resultant Location of Outlet Ledge: $$R_{ol} := \frac{L_{ol.b} \cdot t_{ol} \left(\frac{L_{ol.b}}{2} + L_{olt}\right) + \frac{1}{2}\left(L_{olt}^{2}\right)\left(\frac{2}{3} L_{olt}\right)}{\left[\left(L_{ol.b} \cdot t_{ol}\right) + \frac{1}{2}\left(L_{olt}^{2}\right)\right]} + \left[L_{be} + L_{tc} + L_{ol.t} - \left(L_{ol.b} + L_{olt}\right)\right] = 16.86 \cdot m$$

Volume of Chute Slab: $V_{cs} := W_{sc} \cdot L_c \cdot t_s = 5.43 \cdot m^3$

Volume of Chute Walls: $V_{cw} := \left[W_{hw} \cdot \left(h_{oc} + t_{wc}\right) - \left[W_c \cdot 0.5 \cdot h_{oc} + 0.5 \cdot \pi \cdot \left(0.5 \cdot W_c\right)^2\right]\right] \cdot L_c = 12.01 \cdot m^3$

Chute Resultant Loc.: $R_{cs} := L_{be} + L_t + 0.5 \cdot L_c = 16.40 \cdot m$

Volume of Header Wall: $V_{hw} := h_h \cdot t_h \cdot W_{hw} = 4.46 \cdot m^3$

H.W. Resultant Loc.: $R_{hw} := L_{be} + L_t + 0.5 \cdot t_h = 16.00 \cdot m$

Volume of Transition Slab: $V_{ts} := 0.5 \cdot \left(W_{sc} + W_{bs}\right) \cdot L_t \cdot t_s = 37.87 \cdot m^3$

Trans. Slab Resultant Loc.: $R_{ts} := L_{be} + \frac{W_{bs} + 2 \cdot W_{sc}}{3\left(W_{sc} + W_{bs}\right)} L_t = 12.69 \cdot m$

Volume of Transition Walls: $V_{tw} := 2 \cdot h_t \cdot L_d \cdot t_w = 34.51 \cdot m^3$

Trans. Walls Resultant Loc.: $R_{tw} := L_{be} + 0.5 \cdot L_t = 13.00 \cdot m$

Volume of Transition Ledge: $V_{tl} := W_{bs} \cdot \left(L_{tl} \cdot t_{tl} + \frac{1}{2} t_{tl}^{2}\right) = 7.50 \cdot m^3$

Resultant Location of Transition Ledge: $$R_{tl} := \frac{L_{tl} \cdot t_{tl} \left(\frac{L_{tl}}{2} + t_{tl}\right) + \frac{1}{2}\left(t_{tl}^{2}\right)\left(\frac{2}{3} t_{tl}\right)}{L_{tl} \cdot t_{tl} + \frac{1}{2} t_{tl}^{2}} + \left[L_b + 700mm - \left(L_{tl} + t_{tl}\right)\right] = 9.07 \cdot m$$

Volume of Basin Slab: $V_{bs} := W_{bs} \cdot L_{be} \cdot t_s = 91.80 \cdot m^3$

Basin Slab Resultant Loc.: $R_{bs} := 0.5 \cdot L_{be} = 5.10 \cdot m$

Volume of Basin Walls: $V_{bw} := 2 \cdot \left[0.5 \cdot \left(h_t + h_e\right)\right] \cdot L_{be} \cdot t_w = 38.45 \cdot m^3$

Basin Walls Resultant Loc.: $R_{bw} := L_{be} - \frac{h_t + 2h_e}{3\left(h_e + h_t\right)} \cdot L_{be} = 5.83 \cdot m$

Baffle Blocks Volume: $V_{bb} := n_{bb} \cdot H_{bb}{}^2 \cdot W_{bb} = 3.70 \cdot m^3$

Baffle Blocks Resultant Loc.: $R_{bb} := \frac{(3 \cdot 12.025m + 4 \cdot 10.025m + 3 \cdot 8.025m + 4 \cdot 6.025m + 3 \cdot 4.025m + 4 \cdot 2.025m)}{n_{bb}} = 6.88 \cdot n$

Volume of Cutoff Wall: $V_c := h_c \cdot t_c \cdot W_{bs} = 6.00 \cdot m^3$

Cutoff Wall Resultant Loc.: $R_c := 0.5 \cdot t_c = 0.25 \cdot m$

Volume of Side Key: $V_k := 2h_c \cdot t_c \cdot \left(L_{be} + L_d\right) = 16.62 \cdot m^3$

Side Key Resultant Loc.: $R_k := \frac{\left(0.5L_t + L_{be}\right)L_d + \left(0.5L_{be}\right)L_{be}}{L_d + L_{be}} = 8.15 \cdot m$

Volume of Concrete: $V_{conc} := V_{cs} + V_{cw} + V_{hw} + V_{ts} + V_{tw} + V_{tl} \cdots + V_{bs} + V_{bw} + V_{bb} + V_c + V_{ol} + V_k$ $\boxed{V_{conc} = 270.72 \cdot m^3}$

Structure Weight Result. Loc.: $R_s := \frac{V_{ol} \cdot R_{ol} + \left(V_{cs} + V_{cw}\right) \cdot R_{cs} + V_{hw} \cdot R_{hw} + V_{ts} \cdot R_{ts} + V_{tw} \cdot R_{tw} \cdots + V_{tl} \cdot R_{tl} + V_{bs} \cdot R_{bs} + V_{bw} \cdot R_{bw} + V_{bb} \cdot R_{bb} + V_c \cdot R_c + V_k \cdot R_k}{V_{conc}}$ $\boxed{R_s = 8.93 \cdot m}$

Weight of Structure: $W_s := \gamma_c \cdot V_{conc}$ $\boxed{W_s = 6361.97 \cdot kN}$

Slab Centroid:

Length of Slab: $L_s := L_b + L_e + L_t + L_c + L_{ol.t} = 17.75 \cdot m$

Basin Slab and Extention Area: $A_{bs} := W_{bs} \cdot L_{be} = 122.40 \cdot m^2$

Transition Slab Area: $A_{ts} := \frac{1}{2}\left(W_{bs} + W_{sc}\right) \cdot L_t = 50.49 \cdot m^2$

Outlet Slab/Ledge Area: $A_{cs} := W_{sc} \cdot \left(L_c + L_{ol.t}\right) = 11.76 \cdot m^2$

Area of Slab: $A_s := A_{bs} + A_{ts} + A_{cs} = 184.65 \cdot m^2$

Slab Centroid Location: $C_s := \frac{A_{bs} \cdot \frac{L_{be}}{2} + A_{ts} \cdot \left[L_{be} + \frac{W_{bs} + 2W_{sc}}{3\left(W_{sc} + W_{bs}\right)} \cdot L_t\right] + A_{cs} \cdot \left(L_{be} + L_t + \frac{L_c + L_{ol.t}}{2}\right)}{A_s}$

$\boxed{C_s = 7.92 \cdot m}$

Vertical Soil Weight:

Note: Weight of Soil is the same for all load combinations because the moist and saturated soil unit weights as provided are equal

Volume of Soil on Chute Transition: $V_{o.s1} := h_h \cdot (L_c - t_h) \cdot W_{hw} = 8.91 \cdot m^3$

Volume of Soil on Conduit Ledge: $V_{o.s2} := \left[E_{s.1} - (E_{slab} - t_{sc})\right] \cdot (W_{sc} - W_c - 2 \cdot t_{wc}) \cdot L_{ol.t} = 10.51 \cdot m^3$

Volume of Soil on Slab Overhang: $V_{o.s3} := (E_{s.1} - E_{slab}) \cdot (W_{sc} - W_c - 2 \cdot t_{wc}) \cdot L_c = 14.41 \cdot m^3$

Total Volume of Soil on Outlet: $V_{o.s} := V_{o.s1} + V_{o.s2} + V_{o.s3} = 33.84 \cdot m^3$

Resultant Location of Outlet Soil:

$$R_{o.s} := \frac{\left[V_{o.s1} \cdot (L_{be} + L_{tc} - 400mm)\right] + \left[V_{o.s2} \cdot \left(L_{be} + L_{tc} + \frac{L_{ol.t}}{2}\right)\right] + \left[V_{o.s3} \cdot \left(L_{be} + L_{tc} - \frac{L_c}{2}\right)\right]}{V_{o.s}} = 16.76 \cdot m$$

Volume of Transition Soil: $V_{t.s} := 2 \cdot \left[0.5 \cdot (E_{s.1} + E_{s.t}) - E_{slab}\right] \cdot L_d \cdot t_o = 27.61 \cdot m^3$

Volume of Basin Soil: $V_{b.s} := 2 \cdot \left[0.5 \cdot (E_{s.t} + E_{s.2}) - E_{slab}\right] \cdot L_{be} \cdot t_o = 16.46 \cdot m^3$

Volume of Underslab Soil: $V_{u.s} := h_c \cdot \left[(W_{bs} - 2t_c) \cdot (L_{be} - t_c) + \left[\frac{1}{2}(W_{bs} + W_{hw}) - 2.t_c\right] \cdot L_t\right] - V_{tl} = 140.88 \cdot m^3$

Resultant of Underslab Soil: $R_{u.s} := R_s = 8.93 \cdot m$ (Approximate)

Transition Soil Resultant Loc.: $R_{t.s} := L_{be} + L_t - \frac{E_{s.1} + 2E_{s.t}}{3(E_{s.t} + E_{s.1})} \cdot L_t = 13.00 \cdot m$

Basin Soil Resultant Loc.: $R_{b.s} := \frac{2 \cdot L_{be}}{3} = 6.80 \cdot m$

Weight of Soil: $W_{soil} := \gamma_m \cdot (V_{o.s} + V_{t.s} + V_{b.s} + V_{u.s})$ $\boxed{W_{soil} = 4375.90 \cdot kN}$

Soil Weight Resultant Loc.: $R_{soil} := \frac{V_{o.s} \cdot R_{o.s} + V_{t.s} \cdot R_{t.s} + V_{b.s} \cdot R_{b.s} + V_{u.s} \cdot R_{u.s}}{\frac{W_{soil}}{\gamma_m}}$ $\boxed{R_{soil} = 10.49 \cdot m}$

Basin Water Weight (10 Year Flow):

Transition Effective Water Areas:

$$A_{tc.w} := \begin{bmatrix} \frac{1}{2}\left(W_b + W_c\right)L_{tc} \\ \frac{1}{2}W_c \cdot L_{tc} \\ \int_{0m}^{L_{tc}} \frac{1}{4}\frac{\left(W_b - W_c\right)}{L_{tc}}\left(2x - \frac{x^2}{L_{tc}}\right)dx \end{bmatrix} = \begin{pmatrix} 42.16 \\ 8.16 \\ 8.61 \end{pmatrix} \cdot m^2$$

Transition Water Depths:

$$E_{t.w.un} := \begin{pmatrix} E_{w.t.un} - E_{slab} \\ E_{w.1.un} - E_{w.t.un} \\ E_{w.1.un} - E_{w.t.un} \end{pmatrix} = \begin{pmatrix} 0.69 \\ 0.04 \\ 0.04 \end{pmatrix} \cdot m$$

Transition Water Volumes:

$$V_{t.w.un_i} := A_{tc.w_i} \cdot E_{t.w.un_i} \qquad V_{t.w.un} = \begin{pmatrix} 29.09 \\ 0.33 \\ 0.34 \end{pmatrix} \cdot m^3$$

Transition Water Resultant Locations:

$$R_{tc.w} := L_{be} + \begin{bmatrix} \frac{W_b + 2W_c}{3\left(W_c + W_b\right)} \cdot L_{tc} \\ \frac{2}{3}L_{tc} \\ L_{tc} - \frac{\int_{0m}^{L_{tc}} \frac{1}{4}\frac{\left(W_b - W_c\right)}{L_{tc}}\left(2x - \frac{x^2}{L_{tc}}\right)\cdot x\,dx}{\int_{0m}^{L_{tc}} \frac{1}{4}\frac{\left(W_b - W_c\right)}{L_{tc}}\left(2x - \frac{x^2}{L_{tc}}\right)dx} \end{bmatrix}$$

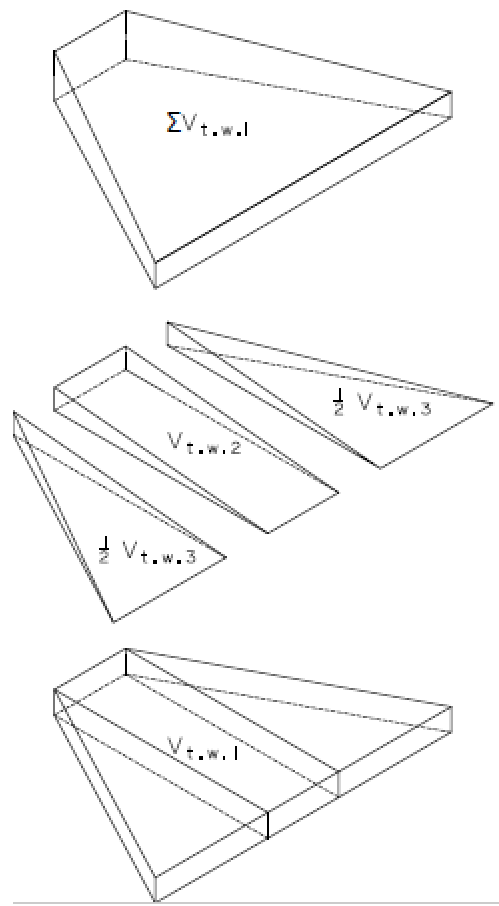


Figure: Transition Water Volumes

Transition Water Resultant: $R_{t.w} := \frac{\sum_i \left(V_{t.w.un_i} \cdot R_{tc.w_i}\right)}{\sum_i \left(V_{t.w.un_i}\right)} = 12.92 \cdot m$

Basin Water Result. Location: $R_{b.w} := L_{be} - \frac{E_{w.t.e} + 2E_{w.2.e}}{3\left(E_{w.2.e} + E_{w.t.e}\right)} L_{be} = 5.10 \cdot m$

Volume of Basin Water: $V_{b.w.un} := L_{be} \cdot W_b \cdot \left[0.5 \cdot \left(E_{w.t.un} + E_{w.2.un}\right) - E_{slab}\right] = 67.32 \cdot m^3$

Weight of Water 10 Year Flow: $W_{w.un} := \gamma_w \cdot \left[\sum_i \left(V_{t.w.un_i}\right) + V_{b.w.un}\right]$ $\boxed{W_{w.un} = 952.37 \cdot kN}$

Basin Water Weight (Max Flow):

Transition Water Depths: $E_{t.w.e} := \begin{pmatrix} E_{w.t.e} - E_{slab} \\ E_{w.1.e} - E_{w.t.e} \\ E_{w.1.e} - E_{w.t.e} \end{pmatrix} = \begin{pmatrix} 1.30 \\ 0.13 \\ 0.13 \end{pmatrix} \cdot m$

Transition Water Volumes: $V_{t.w.e_i} := A_{tc.w_i} \cdot E_{t.w.e_i}$ $\quad V_{t.w.e} = \begin{pmatrix} 54.72 \\ 1.08 \\ 1.14 \end{pmatrix} \cdot m^3$

Volume of Basin Water: $V_{b.w.e} := L_{be} \cdot W_b \cdot \left[0.5 \cdot \left(E_{w.t.e} + E_{w.2.e}\right) - E_{slab}\right] = 122.30 \cdot m^3$

Weight of Water Max Flow: $W_{w.e} := \gamma_w \cdot \left[\sum_i \left(V_{t.w.e_i}\right) + V_{b.w.e}\right]$ $\quad \boxed{W_{w.e} = 1758.30 \cdot kN}$

Water Resultant Location: $R_w := \dfrac{\sum_i \left(V_{t.w.e_i}\right) \cdot R_{t.w} + V_{b.w.e} \cdot R_{b.w}}{\dfrac{W_{w.e}}{\gamma_w}}$ $\quad \boxed{R_w = 7.59 \cdot m}$

Note: The water weight resultant locations varies slightly for the two load cases, but is negligible by inspection.

Uplift Force (10 Year Flow):

Uplift Head @ Outlet Ledge: $H_{u.ol.un} := E_{w.1.un} - \left(E_{slab} - t_{sc} - t_{ol}\right) = 2.83 \cdot m$

Outlet Ledge Uplift Area: $A_{ol.u} := W_{sc} \cdot \left(L_{ol.t} + L_c\right) = 11.76 \cdot m^2$

Outlet Ledge Uplift Force: $U_{ol.un} := \gamma_w \cdot H_{u.ol.un} \cdot A_{ol.u} = 326.57 \cdot kN$

Uplift Head @ Outlet: $H_{u.o.un} := E_{w.1.un} - \left(E_{slab} - t_s\right) = 1.48 \cdot m$

Uplift Head @ End of Basin: $H_{u.e.un} := E_{w.2.un} - \left(E_{slab} - t_s\right) = 1.38 \cdot m$

Uplift Head Slope: $H_{u.s.un} := \dfrac{H_{u.e.un} - H_{u.o.un}}{L_t + L_{be}} = -0.01$

Uplift Head @ End of Transition: $H_{u.t.un} := H_{u.o.un} + H_{u.s.un} \cdot L_t = 1.44 \cdot m$

Transition Effective Uplift Areas:

$$A_{t.u} := \begin{bmatrix} \frac{1}{2}\left(W_{bs} + W_{sc}\right) L_t \\ \frac{1}{2} W_{sc} \cdot L_t \\ \int_{0m}^{L_t} \frac{1}{4} \frac{\left(W_{bs} - W_{sc}\right)}{L_t} \left(2x - \frac{x^2}{L_t}\right) dx \end{bmatrix} = \begin{pmatrix} 50.49 \\ 16.89 \\ 5.57 \end{pmatrix} \cdot m^2$$

Transition Water Depths:

$$H_{u.tc} := \begin{pmatrix} H_{u.t.un} \\ H_{u.o.un} - H_{u.t.un} \\ H_{u.o.un} - H_{u.t.un} \end{pmatrix} = \begin{pmatrix} 1.44 \\ 0.04 \\ 0.04 \end{pmatrix} \cdot m$$

Transition Uplift Forces:

$$U_{t.un_i} := \gamma_w \cdot A_{t.u_i} \cdot H_{u.tc_i} \qquad U_{t.un} = \begin{pmatrix} 715.50 \\ 5.87 \\ 1.94 \end{pmatrix} \cdot kN \qquad \sum_i U_{t.un_i} = 723.31 \cdot kN$$

Transition Uplift Resultant Locations:

$$R_{u.tc} := L_{be} + \begin{bmatrix} \dfrac{W_{bs} + 2W_{sc}}{3(W_{sc} + W_{bs})} \cdot L_t \\ \dfrac{2}{3} L_t \\ L_t - \dfrac{\displaystyle\int_{0m}^{L_t} \frac{1}{4} \frac{(W_{bs} - W_{sc})}{L_t} \left(2x - \frac{x^2}{L_t}\right) x \, dx}{\displaystyle\int_{0m}^{L_t} \frac{1}{4} \frac{(W_{bs} - W_{sc})}{L_t} \left(2x - \frac{x^2}{L_t}\right) dx} \end{bmatrix}$$

Transition Uplift Resultant Location:

$$R_{t.u} := \frac{\displaystyle\sum_i \left(U_{t.un_i} \cdot R_{u.tc_i}\right)}{\displaystyle\sum_i \left(U_{t.un_i}\right)} = 12.70 \cdot m$$

Basin Uplift Force:

$$U_{b.un} := \gamma_w \cdot L_{be} \cdot W_{bs} \cdot \frac{1}{2}\left(H_{u.t.un} + H_{u.e.un}\right) = 1695.78 \cdot kN$$

Uplift Force Unusual Flow:

$$U_{un} := U_{ol.un} + \left(\sum_i U_{t.un_i}\right) + U_{b.un} \qquad \boxed{U_{un} = 2745.66 \cdot kN}$$

Horizontal Force From Uplift:

$$U_{un.h} := S_s \cdot \left[\left(\sum_i U_{t.un_i}\right) + U_{b.un}\right] \qquad \boxed{U_{un.h} = 43.54 \cdot kN}$$

Uplift Force (Max Flow):

Uplift Head @ Outlet Ledge: $H_{u.ol.e} := E_{w.1.e} - \left(E_{slab} - t_{sc} - t_{ol}\right) = 3.53 \cdot m$

Outlet Ledge Uplift Force: $U_{ol.e} := \gamma_w \cdot H_{u.ol.e} \cdot A_{ol.u} = 407.34 \cdot kN$

Uplift Head @ Outlet: $H_{u.o.e} := E_{w.1.e} - \left(E_{slab} - t_s\right) = 2.18 \cdot m$

Uplift Head @ End of Basin: $H_{u.e.e} := E_{w.2.e} - \left(E_{slab} - t_s\right) = 1.85 \cdot m$

Uplift Head Slope: $H_{u.s.e} := \dfrac{H_{u.e.e} - H_{u.o.e}}{L_t + L_{be}} = -0.02$

Uplift Head @ End of Transition: $H_{u.t.e} := H_{u.o.e} + H_{u.s.e} \cdot L_t = 2.06 \cdot m$

Transition Effective Uplift Areas:

$$A_{t.w} := \begin{bmatrix} \frac{1}{2}\left(W_{bs} + W_{sc}\right)L_t \\ \frac{1}{2} W_{sc} \cdot L_t \\ \displaystyle\int_{0m}^{L_t} \frac{1}{4} \cdot \frac{\left(W_{bs} - W_{sc}\right)}{L_t}\left(2x - \frac{x^2}{L_t}\right) dx \end{bmatrix} = \begin{pmatrix} 50.49 \\ 16.89 \\ 5.57 \end{pmatrix} \cdot m^2$$

Transition Water Depths:

$$H_{u.t} := \begin{pmatrix} H_{u.t.e} \\ H_{u.o.e} - H_{u.t.e} \\ H_{u.o.e} - H_{u.t.e} \end{pmatrix} = \begin{pmatrix} 2.06 \\ 0.12 \\ 0.12 \end{pmatrix} \cdot m$$

Transition Uplift Forces:

$$U_{t.e_i} := \gamma_w \cdot A_{t.w_i} \cdot H_{u.t_i} \qquad U_{t.e} = \begin{pmatrix} 1021.84 \\ 19.38 \\ 6.39 \end{pmatrix} \cdot kN \qquad \sum_i U_{t.e_i} = 1047.62 \cdot kN$$

Basin Uplift Force: $U_{b.e} := \gamma_w \cdot L_{be} \cdot W_{bs} \cdot \frac{1}{2}\left(H_{u.t.e} + H_{u.e.e}\right) = 2349.28 \cdot kN$

Basin Uplift Force React. Loc.: $R_{b.u} := L_{be} \cdot \dfrac{2H_{u.t.e} + H_{u.e.e}}{3 \cdot \left(H_{u.t.e} + H_{u.e.e}\right)} = 5.19 \cdot m$

Uplift Force Max Flow: $U_e := U_{ol.e} + \sum_i U_{t.e_i} + U_{b.e}$ $\boxed{U_e = 3804.24 \cdot kN}$

Horizontal Force From Uplift: $U_{e.h} := S_s \cdot \left(\sum_i U_{t.e_i} + U_{b.e}\right) = 61.14 \cdot kN$ $\boxed{U_{e.h} = 61.14 \cdot kN}$

Uplift Result. Loc.: $R_{up} := \dfrac{U_{ol.e} \cdot R_{cs} + \sum_i U_{t.e_i} \cdot R_{t.u} + U_{b.e} \cdot R_{b.u}}{U_e}$ $\boxed{R_{up} = 8.46 \cdot m}$

Note: Uplift resultant location is approximately the same (<1%) for both flow cases because uplift is linear for both

At-Rest Soil Force (Moist):

Headwall Soil Force:

$$F_{ha} := K_o \cdot \gamma_m \cdot \left(\frac{1}{2} \cdot h_h^{\,2} \cdot W_{hw}\right) = 149.88 \cdot kN$$

Transition Wall and Slab Soil Force:

$$F_{ta.u} := \frac{1}{2} \cdot K_o \cdot \gamma_m \cdot \left[0.5\left(E_{s.t} + E_{s.1}\right) - \left(E_{slab} - t_s\right)\right]^2 \cdot \left[\left(W_b + 2 \cdot t_w\right) - W_{hw}\right] = 921.29 \cdot kN$$

Outlet Soil Force:

$$F_{ol.u} := K_o \cdot \gamma_m \cdot \left[\left[W_{sc} - \left(W_c + 2t_{wc}\right)\right]\right] \cdot \left[h_h + \frac{1}{2}\left(t_{wc} + h_{oc} + t_{sc}\right)\right] \cdot \left(t_{wc} + h_{oc} + t_{sc}\right)\right] = 450.96 \cdot kN$$

Outlet Ledge Soil Force:

$$F_{ol2.u} := K_o \cdot \gamma_m \cdot W_{sc} \cdot \left(h_h + t_{wc} + h_{oc} + t_{sc} + \frac{t_{ol}}{2}\right) \cdot t_{ol} = 587.67 \cdot kN$$

Moist At-Rest Soil Force:

$$F_{a.u} := F_{ha} + F_{ta.u} + F_{ol.u} + F_{ol2.u} \qquad \boxed{F_{a.u} = 2109.79 \cdot kN}$$

At-Rest Soil Resultant Location:

$$R_a := \frac{\left[E_{wall.1} - \left(E_{slab} - t_s\right)\right]}{3} \qquad \boxed{R_a = 2.04 \cdot m}$$

At-Rest Soil Force (10 Year Flow):

Transition Wall Soil Force:

$$F_{ta.un} := \left[\left(W_b + 2 \cdot t_w\right) - W_{hw}\right] \cdot \left[\begin{array}{l} \frac{1}{2} \cdot K_o \cdot \gamma_s \cdot \left[0.5\left(E_{s.t} + E_{s.1}\right) - E_{w.1.un}\right]^2 \ldots \\ + K_o \cdot \gamma_s \cdot \left[0.5\left(E_{s.t} + E_{s.1}\right) - E_{w.1.un}\right] \cdot \left[E_{w.1.un} - \left(E_{slab} - t_s\right)\right] \ldots \\ + \frac{1}{2} \cdot K_o \cdot \gamma_{sub} \cdot \left[E_{w.1.un} - \left(E_{slab} - t_s\right)\right]^2 + \frac{1}{2} \cdot \gamma_w \cdot \left[E_{w.1.un} - \left(E_{slab} - t_s\right)\right]^2 \end{array}\right]$$

$$F_{ta.un} = 948.22 \cdot kN$$

Outlet Soil Force:

$$F_{ol.un} := \left[W_{sc} - \left(W_c + 2t_{wc}\right)\right] \cdot \left[\begin{array}{l} \frac{1}{2} K_o \cdot \gamma_s \cdot \left(E_{s.1} - h_h - E_{w.1.un}\right)^2 + K_o \cdot \gamma_m \cdot h_h \cdot \left(E_{s.1} - h_h - E_{w.1.un}\right) \ldots \\ + \frac{1}{2} K_o \cdot \gamma_{sub} \cdot \left[E_{w.1.un} - \left(E_{slab} - t_{sc}\right)\right]^2 \ldots \\ + K_o \cdot \gamma_s \cdot \left(E_{s.1} - E_{w.1.un}\right)\left[E_{w.1.un} - \left(E_{slab} - t_{sc}\right)\right] + \frac{1}{2} \gamma_w \cdot \left[E_{w.1.un} - \left(E_{slab} - t_{sc}\right)\right]^2 \end{array}\right]$$

$$F_{ol.un} = 462.88 \cdot kN$$

Outlet Ledge Soil Force:

$$F_{ol2.un} := W_{sc} \cdot \left[\begin{array}{l} \left[K_o \cdot \gamma_m \cdot \left(E_{s.1} - E_{w.1.un}\right) \cdot t_{ol}\right] + \left[K_o \cdot \gamma_{sub} \cdot \left[E_{w.1.un} - \left(E_{slab} - t_{sc}\right)\right] \cdot t_{ol}\right] \ldots \\ + \left(\frac{1}{2} K_o \cdot \gamma_{sub} \cdot t_{ol}^{\,2}\right) + \left[\gamma_w \cdot \left[E_{w.1.un} - \left(E_{slab} - t_{sc}\right)\right] \cdot t_{ol}\right] + \frac{1}{2} \cdot \gamma_w \cdot t_{ol}^{\,2} \end{array}\right]$$

$$F_{ol2.un} = 652.60 \cdot kN$$

10 Year Flow At-Rest Soil Force:

$$F_{a.un} := F_{ha} + F_{ta.un} + F_{ol.un} + F_{ol2.un} \qquad \boxed{F_{a.un} = 2213.58 \cdot kN}$$

At-Rest Soil Force (Max Flow):

Transition Wall Soil Force:

$$F_{ta.e} := \left[\left(W_b + 2 \cdot t_w\right) - W_{hw}\right] \cdot \left[\begin{array}{l} \frac{1}{2} \cdot K_o \cdot \gamma_s \cdot \left[0.5\left(E_{s.t} + E_{s.1}\right) - E_{w.1.e}\right]^2 \cdots \\ + K_o \cdot \gamma_s \cdot \left[0.5\left(E_{s.t} + E_{s.1}\right) - E_{w.1.e}\right] \cdot \left[E_{w.1.e} - \left(E_{slab} - t_s\right)\right] \cdots \\ + \frac{1}{2} \cdot K_o \cdot \gamma_{sub} \cdot \left[E_{w.1.e} - \left(E_{slab} - t_s\right)\right]^2 + \frac{1}{2} \cdot \gamma_w \cdot \left[E_{w.1.e} - \left(E_{slab} - t_s\right)\right]^2 \end{array}\right]$$

$$F_{ta.e} = 979.72 \cdot kN$$

Outlet Soil Force:

$$F_{ol.e} := \left[W_{sc} - \left(W_c + 2t_{wc}\right)\right] \cdot \left[\begin{array}{l} \frac{1}{2} K_o \cdot \gamma_s \cdot \left(E_{s.1} - h_h - E_{w.1.e}\right)^2 + K_o \cdot \gamma_m \cdot h_h \cdot \left(E_{s.1} - h_h - E_{w.1.e}\right) \cdots \\ + \frac{1}{2} K_o \cdot \gamma_{sub} \cdot \left[E_{w.1.e} - \left(E_{slab} - t_{sc}\right)\right]^2 \cdots \\ + K_o \cdot \gamma_s \cdot \left(E_{s.1} - E_{w.1.e}\right)\left[E_{w.1.e} - \left(E_{slab} - t_{sc}\right)\right] + \frac{1}{2} \gamma_w \cdot \left[E_{w.1.e} - \left(E_{slab} - t_{sc}\right)\right]^2 \end{array}\right]$$

$$F_{ol.e} = 475.33 \cdot kN$$

Outlet Ledge Soil Force:

$$F_{ol2.e} := W_{sc} \cdot \left[\begin{array}{l} \left[K_o \cdot \gamma_m \cdot \left(E_{s.1} - E_{w.1.e}\right) \cdot t_{ol}\right] + \left[K_o \cdot \gamma_{sub} \cdot \left[E_{w.1.e} - \left(E_{slab} - t_{sc}\right)\right] \cdot t_{ol}\right] \cdots \\ + \left(\frac{1}{2} K_o \cdot \gamma_{sub} \cdot t_{ol}^2\right) + \left[\gamma_w \cdot \left[E_{w.1.e} - \left(E_{slab} - t_{sc}\right)\right] \cdot t_{ol}\right] + \frac{1}{2} \cdot \gamma_w \cdot t_{ol}^2 \end{array}\right]$$

$$F_{ol2.e} = 672.98 \cdot kN$$

Max Flow At-Rest Soil Force: $F_{a.e} := F_{ha} + F_{ta.e} + F_{ol.e} + F_{ol2.e}$ $\boxed{F_{a.e} = 2277.90 \cdot kN}$

Resisting (At-Rest) Soil Force at End of Basin:

Note: Ignore water flow over soil at end of basin

Passive Soil Force at Cutoff: $F_p := 0.5K_o \gamma_m \cdot \left(t_s + h_c\right)^2 \cdot W_{bs}$ $\boxed{F_p = 216.82 \cdot kN}$

Passive Soil Resultant Location: $R_p := \frac{1}{3}\left(h_c + t_s\right)$ $\boxed{R_p = 0.58 \cdot m}$

Surcharge Force:

Surcharge Force:

$$F_{sur} := K_o \cdot \gamma_m \cdot H_s \cdot \left[\begin{array}{l} \left[0.5\left(E_{s.t} + E_{s.1}\right) - \left(E_{slab} - t_s\right)\right] \cdot \left[\left(W_b + 2t_w\right) - W_{hw}\right] + h_h \cdot W_{hw} \cdots \\ + \left[E_{s.1} - \left(E_{slab} - t_{sc}\right)\right] \cdot \left(W_{sc} - W_{hw}\right) + t_{ol} \cdot W_{sc} \end{array}\right]$$

$$\boxed{F_{sur} = 666.36 \cdot kN}$$

Surcharge Resultant Location: $R_{sur} := 0.5 \cdot \left[E_{s.1} - \left(E_{slab} - t_s\right)\right]$ $\boxed{R_{sur} = 3.07 \cdot m}$

Note: R_{sur} is slightly higher than the actual resultant due to varying soil height along the transition wall.

Dynamic Water Force:

Note: Water Velocity Based on Max Flow, but also use for 10 Year Flow

Total Drag Force: $F_d := 0.5 \cdot C_d \cdot \frac{\gamma_w}{g} \cdot n_{bb} \cdot H_{bb} \cdot W_{bb} \cdot V^2$ $\boxed{F_d = 681.00 \cdot kN}$

Drag Force Resultant Location: $R_d := 0.5 \cdot H_{bb} + t_s$ $\boxed{R_d = 0.93 \cdot m}$

Seismic Forces (Case a, K = 1.0*Kh + 0.0*Kv):

Horizontal Inertia Force: $Q_{h.i.a} := K_{h.a} \cdot W_s$ $\boxed{Q_{h.i.a} = 1187.57 \cdot kN}$

Vertical Inertia Force: $Q_{v.i.a} := K_{v.a} \cdot W_s$ $\boxed{Q_{v.i.a} = 0.00 \cdot kN}$

Horizontal Soil Force:

$$Q_{h.s.a} := K_{h.a} \cdot \gamma_m \cdot \begin{bmatrix} h_h^{\,2} \cdot (W_c + 2t_{wc}) + [E_{s.1} - (E_{slab} - t_{sc} - t_{ol})] \cdot t_{ol} \cdot (W_c + 2t_{wc}) \ldots \\ + [E_{s.1} - (E_{slab} - t_{sc} - t_{ol})]^2 \cdot [W_{hw} - (W_c + 2t_{wc})] \ldots \\ + [0.5(E_{s.t} + E_{s.1}) - (E_{slab} - t_s - h_c)]^2 \cdot (W_b + 2 \cdot t_w - W_{hw}) \ldots \\ + [E_{s.t} - [E_{slab} - 0.5(t_s + h_c)]] \cdot (t_s + h_c) \cdot 2 \cdot t_o + (t_s + h_c)^2 \cdot W_{bs} \end{bmatrix}$$

$\boxed{Q_{h.s.a} = 1428.57 \cdot kN}$

Vertical Inertia Force Resultant Location: $R_{q.v} := R_s = 8.93 \cdot m$ $\boxed{R_{q.v} = 8.93 \cdot m}$

Horiz. Inertia Force Resultant Location:

$$R_{q.h.i} := \frac{(V_{cs} + V_{ts} + V_{bs}) \cdot 0.5 \cdot t_s - V_c \cdot 0.5 \cdot h_c + V_{bw} \cdot \left[\frac{0.5 \cdot h_e^{\,2} + 0.5 \cdot (h_t - h_e) \cdot [h_e + 0.333 \cdot (h_t - h_e)]}{h_e + 0.5 \cdot (h_t - h_e)} + t_s\right] \ldots \\ + V_{tw} \cdot (t_s + 0.5 \cdot h_t) + V_{cw} \cdot [t_s + 0.5 \cdot (h_{oc} + t_{wc})] + V_{hw} \cdot (t_s + h_{oc} + t_{wc} + 0.5 \cdot h_h) + V_{bb} \cdot 0.5 \cdot H_{bb}}{V_{cs} + V_{ts} + V_{bs} + V_c + V_{bw} + V_{tw} + V_{cw} + V_{hw} + V_{bb}}$$

$\boxed{R_{q.h.i} = 1.38 \cdot m}$

Horiz. Soil Force Resultant Location: $R_{q.h.s} := 0.63 \cdot [E_{s.1} - (E_{slab} - t_s)] = 3.86 \cdot m$ $\boxed{R_{q.h.s} = 3.86 \cdot m}$

Notes: - Resultant location from Design Basis Memorandum
- Seismic resultant locations are the same for all seismic cases
- The Horizontal Soil Force Resultant Location is conservatively higher than the actual resultant location.

Seismic Forces (Case b, K = 1.0*Kh + 0.3*Kv):

Horizontal Inertia Force: $Q_{h.i.b} := K_{h.b} \cdot W_s$ $\boxed{Q_{h.i.b} = 1187.57 \cdot kN}$

Vertical Inertia Force: $Q_{v.i.b} := K_{v.b} \cdot W_s$ $\boxed{Q_{v.i.b} = 199.51 \cdot kN}$

Horizontal Soil Force:

$$Q_{h.s.b} := K_{h.b} \cdot \gamma_m \cdot \begin{bmatrix} h_h^{\,2} \cdot (W_c + 2t_{wc}) + \left[E_{s.1} - (E_{slab} - t_{sc} - t_{ol})\right] \cdot t_{ol} \cdot (W_c + 2t_{wc}) \ldots \\ + \left[E_{s.1} - (E_{slab} - t_{sc} - t_{ol})\right]^2 \cdot \left[W_{hw} - (W_c + 2t_{wc})\right] \ldots \\ + \left[0.5(E_{s.t} + E_{s.1}) - (E_{slab} - t_s - h_c)\right]^2 \cdot (W_b + 2 \cdot t_w - W_{hw}) \ldots \\ + \left[E_{s.t} - \left[E_{slab} - 0.5(t_s + h_c)\right]\right] \cdot (t_s + h_c) \cdot 2 \cdot t_o + (t_s + h_c)^2 \cdot W_{bs} \end{bmatrix}$$

$\boxed{Q_{h.s.b} = 1428.57 \cdot kN}$

Seismic Forces (Case c, K = 0.3*Kh + 1.0*Kv):

Horizontal Inertia Force: $Q_{h.i.c} := K_{h.c} \cdot W_s$ $\boxed{Q_{h.i.c} = 356.27 \cdot kN}$

Vertical Inertia Force: $Q_{v.i.c} := K_{v.c} \cdot W_s$ $\boxed{Q_{v.i.c} = 665.04 \cdot kN}$

Horizontal Soil Force:

$$Q_{h.s.c} := K_{h.c} \cdot \gamma_m \cdot \begin{bmatrix} h_h^{\,2} \cdot (W_c + 2t_{wc}) + \left[E_{s.1} - (E_{slab} - t_{sc} - t_{ol})\right] \cdot t_{ol} \cdot (W_c + 2t_{wc}) \ldots \\ + \left[E_{s.1} - (E_{slab} - t_{sc} - t_{ol})\right]^2 \cdot \left[W_{hw} - (W_c + 2t_{wc})\right] \ldots \\ + \left[0.5(E_{s.t} + E_{s.1}) - (E_{slab} - t_s - h_c)\right]^2 \cdot (W_b + 2 \cdot t_w - W_{hw}) \ldots \\ + \left[E_{s.t} - \left[E_{slab} - 0.5(t_s + h_c)\right]\right] \cdot (t_s + h_c) \cdot 2 \cdot t_o + (t_s + h_c)^2 \cdot W_{bs} \end{bmatrix}$$

$\boxed{Q_{h.s.c} = 428.57 \cdot kN}$

STABILITY ANALYSIS

	Usual	**Unusual**	**Extreme**
Resultant Location Required (DBM Table 7):	$R_{u.u} := 0.333$	$R_{u.un} := 0.333$	$R_e := 0.5$
Min. Bearing Factor of Safety (WCS 8.4):	$FS_b := 1.0$		
Min. Uplift Factor of Safety (DBM Table 7):	$FS_{u.u} := 1.5$	$FS_{u.un} := 1.3$	$FS_{u.e} := 1.1$
Min. Sliding Factor of Safety (DBM Table 7):	$FS_{s.u} := 1.5$	$FS_{s.un} := 1.3$	$FS_{s.e} := 1.1$

Note: "From DBM 7.2 "The seismic load cases are used to determine the post seismic condition of the structure. Thus there are no stability acceptance criteria for [these load cases]."

Load Case 1:
Dry Condition (Usual)

Resultant Location:

$$R_1 := \frac{W_s \cdot R_s + W_{soil} \cdot R_{soil} - F_{a.u} \cdot R_a - F_p \cdot R_p}{W_s + W_{soil}} = 9.15 \cdot m$$

Resultant Location Check:

$$R_{check.1} := \begin{cases} \text{"OK, MIDDLE THIRD"} & \text{if } C_s - R_{u.u} \cdot C_s \le R_1 \le C_s + R_{u.u} \cdot C_s \\ \text{"NG"} & \text{otherwise} \end{cases}$$

$R_{check.1} = \text{"OK, MIDDLE THIRD"}$

Resultant Force:

$$P_1 := W_s + W_{soil} = 10737.87 \cdot kN$$

Resultant Eccentricity:

$$e_1 := \left| R_1 - C_s \right| = 1.24 \cdot m$$

Bearing Pressure:

Note: this is a conservative approximation of the max. bearing pressure.

$$q_1 := \begin{cases} \dfrac{P_1}{A_s} + \dfrac{6P_1 \cdot e_1}{W_{sc} \cdot \left[2\left(L_s - C_s\right)\right]^2} & \text{if } e_1 \le \dfrac{2\left(L_s - C_s\right)}{6} \\ \dfrac{P_1}{\left[0.75 \cdot 2\left(L_s - C_s\right) - 1.5e_1\right] \cdot W_{sc}} & \text{otherwise} \end{cases} = 92.29 \cdot kPa$$

Bearing Pressure FS:

$$FS_{bp.1} := \frac{q_{a.lt}}{q_1}$$

$FS_{bp.1} = 1.6$

Bearing Pressure Check:

$$bp_{check.1} := \begin{cases} \text{"OK"} & \text{if } FS_{bp.1} \ge FS_b \\ \text{"NG"} & \text{otherwise} \end{cases}$$

$bp_{check.1} = \text{"OK"}$

Uplift FS:

$$FS_{u.1} := \text{"NA"}$$

$FS_{u.1} = \text{"NA"}$

Uplift Check:

$$u_{check.1} := \begin{cases} \text{"OK"} & \text{if } FS_{u.1} = \text{"NA"} \vee FS_{u.1} \ge FS_{u.u} \\ \text{"NG"} & \text{otherwise} \end{cases}$$

$u_{check.1} = \text{"OK"}$

Sliding FS:

$$FS_{s.1} := \frac{\left(W_s + W_{soil}\right) \cdot \tan\left(\phi_f\right)}{F_{a.u} - F_p}$$

$FS_{s.1} = 2.5$

Sliding Check:

$$s_{check.1} := \begin{cases} \text{"OK"} & \text{if } FS_{s.1} \ge FS_{s.u} \\ \text{"NG"} & \text{otherwise} \end{cases}$$

$s_{check.1} = \text{"OK"}$

Load Case 2:
10 Year Flow (Unusual)

Resultant Location: $R_2 := \dfrac{W_s \cdot R_s + W_{soil} \cdot R_{soil} + W_{w.un} \cdot R_w - F_{a.un} \cdot R_a - F_p \cdot R_p - F_d \cdot R_d - U_{un} \cdot R_{up}}{W_s + W_{soil} + W_{w.un} - U_{un}} = 9.11 \cdot m$

Resultant Location Check: $R_{check.2} := \begin{cases} \text{"OK, MIDDLE THIRD"} & \text{if } C_s - R_{u.un} \cdot C_s \le R_2 \le C_s + R_{u.un} \cdot C_s \\ \text{"NG"} & \text{otherwise} \end{cases}$

$\boxed{R_{check.2} = \text{"OK, MIDDLE THIRD"}}$

Resultant Force: $P_2 := W_s + W_{soil} + W_{w.un} - U_{un} = 8944.57 \cdot kN$

Resultant Eccentricity: $e_2 := \left|R_2 - C_s\right| = 1.19 \cdot m$

Bearing Pressure: $q_2 := \begin{cases} \dfrac{P_2}{A_s} + \dfrac{6P_2 \cdot e_2}{W_{sc} \cdot \left[2\left(L_s - C_s\right)\right]^2} & \text{if } e_2 \le \dfrac{2\left(L_s - C_s\right)}{6} \\ \dfrac{P_2}{\left[0.75 \cdot 2\left(L_s - C_s\right) - 1.5e_2\right] \cdot W_{sc}} & \text{otherwise} \end{cases} = 75.77 \cdot kPa$

Note: this is a conservative approximation of the max. bearing pressure.

Bearing Pressure FS: $FS_{bp.2} := \dfrac{q_{a.lt}}{q_2}$ $\boxed{FS_{bp.2} = 2.0}$

Bearing Pressure Check: $bp_{check.2} := \begin{cases} \text{"OK"} & \text{if } FS_{bp.2} \ge FS_b \\ \text{"NG"} & \text{otherwise} \end{cases}$ $\boxed{bp_{check.2} = \text{"OK"}}$

Uplift FS: $FS_{u.2} := \dfrac{W_s + W_{soil} + W_{w.un}}{U_{un}}$ $\boxed{FS_{u.2} = 4.3}$

Uplift Check: $u_{check.2} := \begin{cases} \text{"OK"} & \text{if } FS_{u.2} = \text{"NA"} \vee FS_{u.2} \ge FS_{u.un} \\ \text{"NG"} & \text{otherwise} \end{cases}$ $\boxed{u_{check.2} = \text{"OK"}}$

Sliding FS: $FS_{s.2} := \dfrac{\left(W_s + W_{soil} + W_{w.un} - U_{un}\right) \cdot \tan\left(\phi_f\right)}{F_{a.un} + F_d - F_p}$ $\boxed{FS_{s.2} = 1.5}$

Sliding Check: $s_{check.2} := \begin{cases} \text{"OK"} & \text{if } FS_{s.2} \ge FS_{s.un} \\ \text{"NG"} & \text{otherwise} \end{cases}$ $\boxed{s_{check.2} = \text{"OK"}}$

Load Case 3:
Rapid Gate Closure (Unusual)

Resultant Location:

$$R_3 := \frac{W_s \cdot R_s + W_{soil} \cdot R_{soil} - F_{a.e} \cdot R_a - F_p \cdot R_p - U_e \cdot R_{up}}{W_s + W_{soil} - U_e} = 9.49 \cdot m$$

Resultant Location Check:

$$R_{check.3} := \begin{cases} \text{"OK, MIDDLE THIRD"} & \text{if } C_s - R_{u.un} \cdot C_s \le R_3 \le C_s + R_{u.un} \cdot C_s \\ \text{"NG"} & \text{otherwise} \end{cases}$$

$$\boxed{R_{check.3} = \text{"OK, MIDDLE THIRD"}}$$

Resultant Force:

$$P_3 := W_s + W_{soil} - U_e = 6933.64 \cdot kN$$

Resultant Eccentricity:

$$e_3 := \left| R_3 - C_s \right| = 1.57 \cdot m$$

Bearing Pressure:

Note: this is a conservative approximation of the max. bearing pressure.

$$q_3 := \begin{cases} \dfrac{P_3}{A_s} + \dfrac{6P_3 \cdot e_3}{W_{sc} \cdot \left[2\left(L_s - C_s\right)\right]^2} & \text{if } e_3 \le \dfrac{2\left(L_s - C_s\right)}{6} \\ \dfrac{P_3}{\left[0.75 \cdot 2\left(L_s - C_s\right) - 1.5e_3\right] \cdot W_{sc}} & \text{otherwise} \end{cases} = 65.51 \cdot kPa$$

Bearing Pressure FS:

$$FS_{bp.3} := \frac{q_{a.lt}}{q_3} \qquad \boxed{FS_{bp.3} = 2.3}$$

Bearing Pressure Check:

$$bp_{check.3} := \begin{cases} \text{"OK"} & \text{if } FS_{bp.3} \ge FS_b \\ \text{"NG"} & \text{otherwise} \end{cases} \qquad \boxed{bp_{check.3} = \text{"OK"}}$$

Uplift FS:

$$FS_{u.3} := \frac{W_s + W_{soil}}{U_e} \qquad \boxed{FS_{u.3} = 2.8}$$

Uplift Check:

$$u_{check.3} := \begin{cases} \text{"OK"} & \text{if } FS_{u.3} = \text{"NA"} \vee FS_{u.3} \ge FS_{u.un} \\ \text{"NG"} & \text{otherwise} \end{cases} \qquad \boxed{u_{check.3} = \text{"OK"}}$$

Sliding FS:

$$FS_{s.3} := \frac{\left(W_s + W_{soil} - U_e\right) \cdot \tan\left(\phi_f\right)}{F_{a.e} - F_p} \qquad \boxed{FS_{s.3} = 1.5}$$

Sliding Check:

$$s_{check.3} := \begin{cases} \text{"OK"} & \text{if } FS_{s.3} \ge FS_{s.un} \\ \text{"NG"} & \text{otherwise} \end{cases} \qquad \boxed{s_{check.3} = \text{"OK"}}$$

Load Case 4:
Construction/Maintenance (Unusual)

Resultant Location:

$$R_4 := \frac{W_s \cdot R_s + W_{soil} \cdot R_{soil} - F_{a.u} \cdot R_a - F_p \cdot R_p - F_{sur} \cdot R_{sur}}{W_s + W_{soil}} = 8.96 \cdot m$$

Resultant Location Check:

$$R_{check.4} := \begin{vmatrix} \text{"OK, MIDDLE THIRD"} & \text{if } C_s - R_{u.un} \cdot C_s \le R_4 \le C_s + R_{u.un} \cdot C_s \\ \text{"NG"} & \text{otherwise} \end{vmatrix}$$

$$\boxed{R_{check.4} = \text{"OK, MIDDLE THIRD"}}$$

Resultant Force:

$$P_4 := W_s + W_{soil} = 10737.87 \cdot kN$$

Resultant Eccentricity:

$$e_4 := \left| R_4 - C_s \right| = 1.05 \cdot m$$

Bearing Pressure:

Note: this is a conservative approximation of the max. bearing pressure.

$$q_4 := \begin{vmatrix} \dfrac{P_4}{A_s} + \dfrac{6P_4 \cdot e_4}{W_{sc} \cdot \left[2\left(L_s - C_s\right)\right]^2} & \text{if } e_4 \le \dfrac{2\left(L_s - C_s\right)}{6} \\ \dfrac{P_4}{\left[0.75 \cdot 2\left(L_s - C_s\right) - 1.5e_4\right] \cdot W_{sc}} & \text{otherwise} \end{vmatrix} = 87.03 \cdot kPa$$

Bearing Pressure FS:

$$FS_{bp.4} := \frac{q_{a.lt}}{q_4} \qquad \boxed{FS_{bp.4} = 1.7}$$

Bearing Pressure Check:

$$bp_{check.4} := \begin{vmatrix} \text{"OK"} & \text{if } FS_{bp.4} \ge FS_b \\ \text{"NG"} & \text{otherwise} \end{vmatrix} \qquad \boxed{bp_{check.4} = \text{"OK"}}$$

Uplift FS:

$$FS_{u.4} := \text{"NA"} \qquad \boxed{FS_{u.4} = \text{"NA"}}$$

Uplift Check:

$$u_{check.4} := \begin{vmatrix} \text{"OK"} & \text{if } FS_{u.4} = \text{"NA"} \vee FS_{u.4} \ge FS_{u.un} \\ \text{"NG"} & \text{otherwise} \end{vmatrix} \qquad \boxed{u_{check.4} = \text{"OK"}}$$

Sliding FS:

$$FS_{s.4} := \frac{\left(W_s + W_{soil}\right) \cdot \tan\left(\phi_f\right)}{F_{a.u} + F_{sur} - F_p} \qquad \boxed{FS_{s.4} = 1.9}$$

Sliding Check:

$$s_{check.4} := \begin{vmatrix} \text{"OK"} & \text{if } FS_{s.4} \ge FS_{s.un} \\ \text{"NG"} & \text{otherwise} \end{vmatrix} \qquad \boxed{s_{check.4} = \text{"OK"}}$$

Load Case 5:
Maximum Flow (Extreme)

Resultant Location: $R_5 := \dfrac{W_s \cdot R_s + W_{soil} \cdot R_{soil} + W_{w.e} \cdot R_w - F_{a.e} \cdot R_a - F_p \cdot R_p - F_d \cdot R_d - U_e \cdot R_{up}}{W_s + W_{soil} + W_{w.e} - U_e} = 9.03 \cdot m$

Resultant Location Check: $R_{check.5} := \begin{cases} \text{"OK, MIDDLE HALF"} & \text{if } C_s - R_e \cdot C_s \le R_5 \le C_s + R_e \cdot C_s \\ \text{"OK, MIDDLE THIRD"} & \text{if } C_s - R_{u.un} \cdot C_s \le R_5 \le C_s + R_{u.un} \cdot C_s \\ \text{"NG"} & \text{otherwise} \end{cases}$

$\boxed{R_{check.5} = \text{"OK, MIDDLE THIRD"}}$

Resultant Force: $P_5 := W_s + W_{soil} + W_{w.e} - U_e = 8691.94 \cdot kN$

Resultant Eccentricity: $e_5 := |R_5 - C_s| = 1.11 \cdot m$

Bearing Pressure: $q_5 := \begin{cases} \dfrac{P_5}{A_s} + \dfrac{6P_5 \cdot e_5}{W_{sc} \cdot [2(L_s - C_s)]^2} & \text{if } e_5 \le \dfrac{2(L_s - C_s)}{6} \\ \dfrac{P_5}{[0.75 \cdot 2(L_s - C_s) - 1.5e_5] \cdot W_{sc}} & \text{otherwise} \end{cases} = 71.90 \cdot kPa$

Note: this is a conservative approximation of the max. bearing pressure.

Bearing Pressure FS: $FS_{bp.5} := \dfrac{q_{a.lt}}{q_5}$ $\boxed{FS_{bp.5} = 2.1}$

Bearing Pressure Check: $bp_{check.5} := \begin{cases} \text{"OK"} & \text{if } FS_{bp.5} \ge FS_b \\ \text{"NG"} & \text{otherwise} \end{cases}$ $\boxed{bp_{check.5} = \text{"OK"}}$

Uplift FS: $FS_{u.5} := \dfrac{W_s + W_{soil} + W_{w.e}}{U_e}$ $\boxed{FS_{u.5} = 3.3}$

Uplift Check: $u_{check.5} := \begin{cases} \text{"OK"} & \text{if } FS_{u.5} = \text{"NA"} \lor FS_{u.5} \ge FS_{u.e} \\ \text{"NG"} & \text{otherwise} \end{cases}$ $\boxed{u_{check.5} = \text{"OK"}}$

Sliding FS: $FS_{s.5} := \dfrac{(W_s + W_{soil} + W_{w.e} - U_e) \cdot \tan(\phi_f)}{F_{a.e} + F_d - F_p}$ $\boxed{FS_{s.5} = 1.4}$

Sliding Check: $s_{check.5} := \begin{cases} \text{"OK"} & \text{if } FS_{s.5} \ge FS_{s.e} \\ \text{"NG"} & \text{otherwise} \end{cases}$ $\boxed{s_{check.5} = \text{"OK"}}$

Load Case 6a:
Earthquake K = 1.0*Kh +/- 0.0*Kv (Extreme)

Resultant Location:

$$R_{6.a} := \frac{W_s \cdot R_s + W_{soil} \cdot R_{soil} - F_{a.e} \cdot R_a - F_p \cdot R_p \cdots + -Q_{v.i.a} \cdot R_{q.v} - Q_{h.i.a} \cdot R_{q.h.i} - Q_{h.s.a} \cdot R_{q.h.s}}{W_s + W_{soil} - Q_{v.i.a}} = 8.46 \cdot m$$

Resultant Location Check:

$$R_{check.6.a} := \begin{cases} \text{"OK, MIDDLE HALF"} & \text{if } C_s - R_e \cdot C_s \le R_{6.a} \le C_s + R_e \cdot C_s \\ \text{"OK, MIDDLE THIRD"} & \text{if } C_s - R_{u.un} \cdot C_s \le R_{6.a} \le C_s + R_{u.un} \cdot C_s \\ \text{"NG"} & \text{otherwise} \end{cases}$$

$$\boxed{R_{check.6.a} = \text{"OK, MIDDLE THIRD"}}$$

Resultant Force:

$$P_{6.a} := W_s + W_{soil} + Q_{v.i.a} = 10737.87 \cdot kN$$

Resultant Eccentricity:

$$e_{6.a} := \left| R_{6.a} - C_s \right| = 0.54 \cdot m$$

Bearing Pressure:

Note: this is a conservative approximation of the max. bearing pressure.

$$q_{6.a} := \begin{cases} \dfrac{P_{6.a}}{A_s} + \dfrac{6P_{6.a} \cdot e_{6.a}}{W_{sc} \cdot \left[2\left(L_s - C_s\right)\right]^2} & \text{if } e_{6.a} \le \dfrac{2\left(L_s - C_s\right)}{6} \\ \dfrac{P_{6.a}}{\left[0.75 \cdot 2\left(L_s - C_s\right) - 1.5e_{6.a}\right] \cdot W_{sc}} & \text{otherwise} \end{cases} = 73.00 \cdot kPa$$

Bearing Pressure FS:

$$FS_{bp.6.a} := \frac{q_{a.st}}{q_{6.a}} \qquad \boxed{FS_{bp.6.a} = 2.7}$$

Bearing Pressure Check:

$$bp_{check.6.a} := \begin{cases} \text{"OK"} & \text{if } FS_{bp.6.a} \ge FS_b \\ \text{"NG"} & \text{otherwise} \end{cases} \qquad \boxed{bp_{check.6.a} = \text{"OK"}}$$

Uplift FS:

$$FS_{u.6.a} := \text{"NA"} \qquad \boxed{FS_{u.6.a} = \text{"NA"}}$$

Sliding FS:

$$FS_{s.6.a} := \frac{\left(W_s + W_{soil} - Q_{v.i.a}\right) \cdot \tan\left(\phi_f\right)}{F_{a.u} + Q_{h.i.a} + Q_{h.s.a} - F_p} \qquad \boxed{FS_{s.6.a} = 1.1}$$

Load Case 6b:
Earthquake K = 1.0*Kh - 0.3*Kv (Extreme)

Resultant Location:

$$R_{6.b} := \frac{W_s \cdot R_s + W_{soil} \cdot R_{soil} - F_{a.e} \cdot R_a - F_p \cdot R_p \cdots + -Q_{v.i.b} \cdot R_{q.v} - Q_{h.i.b} \cdot R_{q.h.i} - Q_{h.s.b} \cdot R_{q.h.s}}{W_s + W_{soil} - Q_{v.i.b}} = 8.45 \cdot m$$

Resultant Location Check:

$$R_{check.6.b} := \begin{cases} \text{"OK, MIDDLE HALF"} & \text{if } C_s - R_e \cdot C_s \le R_{6.b} \le C_s + R_e \cdot C_s \\ \text{"OK, MIDDLE THIRD"} & \text{if } C_s - R_{u.un} \cdot C_s \le R_{6.b} \le C_s + R_{u.un} \cdot C_s \\ \text{"NG"} & \text{otherwise} \end{cases}$$

$$\boxed{R_{check.6.b} = \text{"OK, MIDDLE THIRD"}}$$

Resultant Force: $P_{6.b} := W_s + W_{soil} - Q_{v.i.b} = 10538.36 \cdot kN$

Resultant Eccentricity: $e_{6.b} := \left|R_{6.b} - C_s\right| = 0.53 \cdot m$

Bearing Pressure:

Note: this is a conservative approximation of the max. bearing pressure.

$$q_{6.b} := \begin{cases} \dfrac{P_{6.b}}{A_s} + \dfrac{6P_{6.b} \cdot e_{6.b}}{W_{sc} \cdot \left[2\left(L_s - C_s\right)\right]^2} & \text{if } e_{6.b} \le \dfrac{2\left(L_s - C_s\right)}{6} \\ \dfrac{P_{6.b}}{\left[0.75 \cdot 2\left(L_s - C_s\right) - 1.5e_{6.b}\right] \cdot W_{sc}} & \text{otherwise} \end{cases} = 71.40 \cdot kPa$$

Bearing Pressure FS: $FS_{bp.6.b} := \dfrac{q_{a.st}}{q_{6.b}}$ $\qquad \boxed{FS_{bp.6.b} = 2.8}$

Bearing Pressure Check:

$$bp_{check.6.b} := \begin{cases} \text{"OK"} & \text{if } FS_{bp.6.b} \ge FS_b \\ \text{"NG"} & \text{otherwise} \end{cases} \qquad \boxed{bp_{check.6.b} = \text{"OK"}}$$

Uplift FS: $FS_{u.6.b} := \dfrac{W_s + W_{soil}}{Q_{v.i.b}}$ $\qquad \boxed{FS_{u.6.b} = 53.8}$

Sliding FS: $FS_{s.6.b} := \dfrac{\left(W_s + W_{soil} - Q_{v.i.b}\right) \cdot \tan\left(\phi_f\right)}{F_{a.u} + Q_{h.i.b} + Q_{h.s.b} - F_p}$ $\qquad \boxed{FS_{s.6.b} = 1.0}$

Load Case 6b:
K = 1.0*Kh + 0.3*Kv (Extreme)

Resultant Location:

$$R_{6.b.n} := \frac{W_s \cdot R_s + W_{soil} \cdot R_{soil} - F_{a.e} \cdot R_a - F_p \cdot R_p \cdots + Q_{v.i.b} \cdot R_{q.v} - Q_{h.i.b} \cdot R_{q.h.i} - Q_{h.s.b} \cdot R_{q.h.s}}{W_s + W_{soil} + Q_{v.i.b}} = 8.47 \cdot m$$

Resultant Location Check:

$$R_{check.6.b.n} := \begin{cases} \text{"OK, MIDDLE HALF"} & \text{if } C_s - R_e \cdot C_s \le R_{6.b.n} \le C_s + R_e \cdot C_s \\ \text{"OK, MIDDLE THIRD"} & \text{if } C_s - R_{u.un} \cdot C_s \le R_{6.b.n} \le C_s + R_{u.un} \cdot C_s \\ \text{"NG"} & \text{otherwise} \end{cases}$$

$$\boxed{R_{check.6.b.n} = \text{"OK, MIDDLE THIRD"}}$$

Resultant Force:

$$P_{6.b.n} := W_s + W_{soil} + Q_{v.i.b} = 10937.38 \cdot kN$$

Resultant Eccentricity:

$$e_{6.b.n} := \left| R_{6.b.n} - C_s \right| = 0.55 \cdot m$$

Bearing Pressure:

Note: this is a conservative approximation of the max. bearing pressure.

$$q_{6.b.n} := \begin{cases} \dfrac{P_{6.b.n}}{A_s} + \dfrac{6P_{6.b.n} \cdot e_{6.b.n}}{W_{sc} \cdot \left[2\left(L_s - C_s\right)\right]^2} & \text{if } e_{6.b.n} \le \dfrac{2\left(L_s - C_s\right)}{6} \\ \dfrac{P_{6.b.n}}{\left[0.75 \cdot 2\left(L_s - C_s\right) - 1.5e_{6.b.n}\right] \cdot W_{sc}} & \text{otherwise} \end{cases} = 74.60 \cdot kPa$$

Bearing Pressure FS:

$$FS_{bp.6.b.n} := \frac{q_{a.st}}{q_{6.b.n}} \qquad \boxed{FS_{bp.6.b.n} = 2.7}$$

Bearing Pressure Check:

$$bp_{check.6.b.n} := \begin{cases} \text{"OK"} & \text{if } FS_{bp.6.b.n} \ge FS_b \\ \text{"NG"} & \text{otherwise} \end{cases} \qquad \boxed{bp_{check.6.b.n} = \text{"OK"}}$$

Uplift FS:

$$FS_{u.6.b.n} := \frac{W_s + W_{soil}}{Q_{v.i.b}} \qquad \boxed{FS_{u.6.b.n} = 53.8}$$

Sliding FS:

$$FS_{s.6.b.n} := \frac{\left(W_s + W_{soil} + Q_{v.i.b}\right) \cdot \tan\left(\phi_f\right)}{F_{a.u} + Q_{h.i.b} + Q_{h.s.b} - F_p} \qquad \boxed{FS_{s.6.b.n} = 1.1}$$

Load Case 6c:
Earthquake K = 0.3*Kh - 1.0*Kv (Extreme)

Resultant Location:

$$R_{6.c} := \frac{W_s \cdot R_s + W_{soil} \cdot R_{soil} - F_{a.e} \cdot R_a - F_p \cdot R_p \cdots + -Q_{v.i.c} \cdot R_{q.v} - Q_{h.i.c} \cdot R_{q.h.i} - Q_{h.s.c} \cdot R_{q.h.s}}{W_s + W_{soil} - Q_{v.i.c}} = 8.92 \cdot m$$

Resultant Location Check:

$$R_{check.6.c} := \begin{cases} \text{"OK, MIDDLE HALF"} & \text{if } C_s - R_e \cdot C_s \le R_{6.c} \le C_s + R_e \cdot C_s \\ \text{"OK, MIDDLE THIRD"} & \text{if } C_s - R_{u.un} \cdot C_s \le R_{6.c} \le C_s + R_{u.un} \cdot C_s \\ \text{"NG"} & \text{otherwise} \end{cases}$$

$$\boxed{R_{check.6.c} = \text{"OK, MIDDLE THIRD"}}$$

Resultant Force:

$$P_{6.c} := W_s + W_{soil} - Q_{v.i.c} = 10072.83 \cdot kN$$

Resultant Eccentricity:

$$e_{6.c} := \left| R_{6.c} - C_s \right| = 1.00 \cdot m$$

Bearing Pressure:

Note: this is a conservative approximation of the max. bearing pressure.

$$q_{6.c} := \begin{cases} \dfrac{P_{6.c}}{A_s} + \dfrac{6P_{6.c} \cdot e_{6.c}}{W_{sc} \cdot \left[2\left(L_s - C_s\right)\right]^2} & \text{if } e_{6.c} \le \dfrac{2\left(L_s - C_s\right)}{6} \\ \dfrac{P_{6.c}}{\left[0.75 \cdot 2\left(L_s - C_s\right) - 1.5e_{6.c}\right] \cdot W_{sc}} & \text{otherwise} \end{cases} = 80.55 \cdot kPa$$

Bearing Pressure FS:

$$FS_{bp.6.c} := \frac{q_{a.st}}{q_{6.c}} \qquad \boxed{FS_{bp.6.c} = 2.5}$$

Bearing Pressure Check:

$$bp_{check.6.c} := \begin{cases} \text{"OK"} & \text{if } FS_{bp.6.c} \ge FS_b \\ \text{"NG"} & \text{otherwise} \end{cases} \qquad \boxed{bp_{check.6.c} = \text{"OK"}}$$

Uplift FS:

$$FS_{u.6.c} := \frac{W_s + W_{soil}}{Q_{v.i.c}} \qquad \boxed{FS_{u.6.c} = 16.1}$$

Sliding FS:

$$FS_{s.6.c} := \frac{\left(W_s + W_{soil} - Q_{v.i.c}\right) \cdot \tan\left(\phi_f\right)}{F_{a.u} + Q_{h.i.c} + Q_{h.s.c} - F_p} \qquad \boxed{FS_{s.6.c} = 1.7}$$

Load Case 6c:
Earthquake K = 0.3*Kh + 1.0*Kv (Extreme)

Resultant Location:

$$R_{6.c.n} := \frac{W_s \cdot R_s + W_{soil} \cdot R_{soil} - F_{a.e} \cdot R_a - F_p \cdot R_p + Q_{v.i.c} \cdot R_{q.v} - Q_{h.i.c} \cdot R_{q.h.i} - Q_{h.s.c} \cdot R_{q.h.s}}{W_s + W_{soil} + Q_{v.i.c}} = 8.92 \cdot m$$

Resultant Location Check:

$$R_{check.6.c.n} := \begin{cases} \text{"OK, MIDDLE HALF"} & \text{if } C_s - R_e \cdot C_s \le R_{6.c.n} \le C_s + R_e \cdot C_s \\ \text{"OK, MIDDLE THIRD"} & \text{if } C_s - R_{u.un} \cdot C_s \le R_{6.c.n} \le C_s + R_{u.un} \cdot C_s \\ \text{"NG"} & \text{otherwise} \end{cases}$$

$$\boxed{R_{check.6.c.n} = \text{"OK, MIDDLE THIRD"}}$$

Resultant Force:

$$P_{6.c.n} := W_s + W_{soil} + Q_{v.i.c} = 11402.91 \cdot kN$$

Resultant Eccentricity:

$$e_{6.c.n} := \left| R_{6.c.n} - C_s \right| = 1.00 \cdot m$$

Bearing Pressure:

Note: this is a conservative approximation of the max. bearing pressure.

$$q_{6.c.n} := \begin{cases} \dfrac{P_{6.c.n}}{A_s} + \dfrac{6P_{6.c.n} \cdot e_{6.c.n}}{W_{sc} \cdot \left[2\left(L_s - C_s\right)\right]^2} & \text{if } e_{6.c.n} \le \dfrac{2\left(L_s - C_s\right)}{6} \\ \dfrac{P_{6.c.n}}{\left[0.75 \cdot 2\left(L_s - C_s\right) - 1.5e_{6.c.n}\right] \cdot W_{sc}} & \text{otherwise} \end{cases} = 91.21 \cdot kPa$$

Bearing Pressure FS:

$$FS_{bp.6.c.n} := \frac{q_{a.st}}{q_{6.c.n}} \qquad \boxed{FS_{bp.6.c.n} = 2.2}$$

Bearing Pressure Check:

$$bp_{check.6.c.n} := \begin{cases} \text{"OK"} & \text{if } FS_{bp.6.c.n} \ge FS_b \\ \text{"NG"} & \text{otherwise} \end{cases} \qquad \boxed{bp_{check.6.c.n} = \text{"OK"}}$$

Uplift FS:

$$FS_{u.6.c.n} := \frac{W_s + W_{soil}}{Q_{v.i.c}} \qquad \boxed{FS_{u.6.c.n} = 16.1}$$

Sliding FS:

$$FS_{s.6.c.n} := \frac{\left(W_s + W_{soil} + Q_{v.i.c}\right) \cdot \tan\left(\phi_f\right)}{F_{a.u} + Q_{h.i.c} + Q_{h.s.c} - F_p} \qquad \boxed{FS_{s.6.c.n} = 1.9}$$

Load Case 7:
Load Case 1, Post-Seismic Event

Load Case 7 Applicability Check:
If the resultant force location is within the middle 1/3 of the structure for all seismic load cases, Load Case 7 (LC 7) will pass.

$$\text{if}\left(R_{check.6.a} = \text{"OK, MIDDLE THIRD"}, \text{"LC 7 PASSES"}, \text{"CHECK LC7"}\right) = \text{"LC 7 PASSES"}$$

$$\text{if}\left(R_{check.6.b} = \text{"OK, MIDDLE THIRD"}, \text{"LC 7 PASSES"}, \text{"CHECK LC7"}\right) = \text{"LC 7 PASSES"}$$

$$\text{if}\left(R_{check.6.b.n} = \text{"OK, MIDDLE THIRD"}, \text{"LC 7 PASSES"}, \text{"CHECK LC7"}\right) = \text{"LC 7 PASSES"}$$

$$\text{if}\left(R_{check.6.c} = \text{"OK, MIDDLE THIRD"}, \text{"LC 7 PASSES"}, \text{"CHECK LC7"}\right) = \text{"LC 7 PASSES"}$$

$$\text{if}\left(R_{check.6.c.n} = \text{"OK, MIDDLE THIRD"}, \text{"LC 7 PASSES"}, \text{"CHECK LC7"}\right) = \text{"LC 7 PASSES"}$$

Results Summary:

Load Case 1: Dry Condition (Usual)	STABLE
Load Case 2: 10-Year Flow (Unusual)	STABLE
Load Case 3: Rapid Gate Closure (Unusual)	STABLE
Load Case 4: Construction/Maintenance (Unusual)	STABLE
Load Case 5: Maximum Flow (Extreme)	STABLE
Load Case 6: Seismic Cases (Extreme)	STABLE
Load Case 7: Dry Condition Post-Seismic (Extreme)	STABLE

Concrete Quantity:

Reinforced Concrete: $V_{conc} = 270.72 \cdot m^3$

Foundation Concrete: $V_{fdn.conc} := A_s \cdot 100mm = 18.47 \cdot m^3$

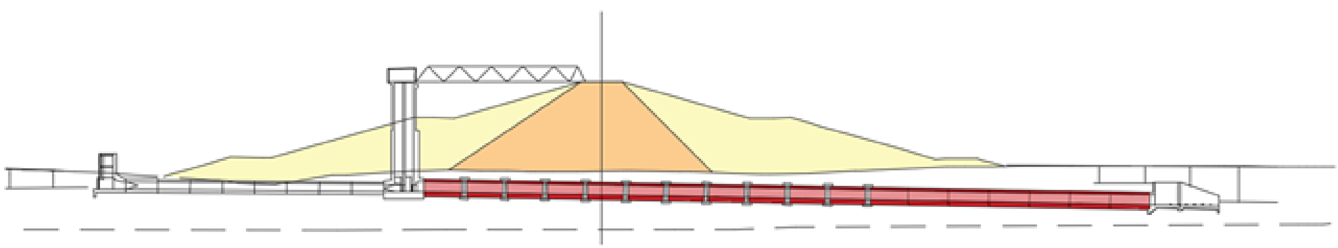
APPENDIX E.5-4 CONDUITS

Appendix B4 – LLOW Design Calculations

Springbank Off-Stream Storage/Alberta Transportation

Table of Contents

Gravity Conduit



USUAL LOAD CONDITION 1
U1

Stantec

TITLE: LLOW GRAVITY CONDUIT ANALYSIS – LOAD CONDITION U1

Author: E. Farfan
Project: SR-1
Project No.: 110773396
Date: 9/23/2019
Drawing: S-400

INTRODUCTION

This report provides an analysis of the forces acting on the walls of the Low-Level Outlet Works (LLOW) gravity conduit. The LLOW is a gated gravity drainage structure located within the banks of the Unnamed Creek and constructed through the embankment dam.

The LLOW conduit structure comprised of a cast-on-place reinforced concrete placed on an excavated channel that will be filled to the existing ground elevation. The walls of the excavation are far apart that the effects on the structure of the interaction between the native soil and the fill can be neglected in the analysis.

The acting forces on the LLOW gravity conduit are evaluated using a finite element model (FEM). The analysis validation is performed by comparing the resultant forces obtained with the FE analysis and results using the Direct Design method as described in ASCE 15-17.

The module Sigma/W from the computer program GeoStudio (2018) was used for the FE analysis.

OBJECTIVES

Determine the forces acting on the LLOW structure using an FE analysis and verify the results using the Direct Design method (ASCE 15-17).

GEOMETRY

The location of the cross-section selected to represent the highest overburden over the LLOW gravity conduit was located near the crest of the embankment on the downstream side from the embankment centerline as depicted in Figure 1.

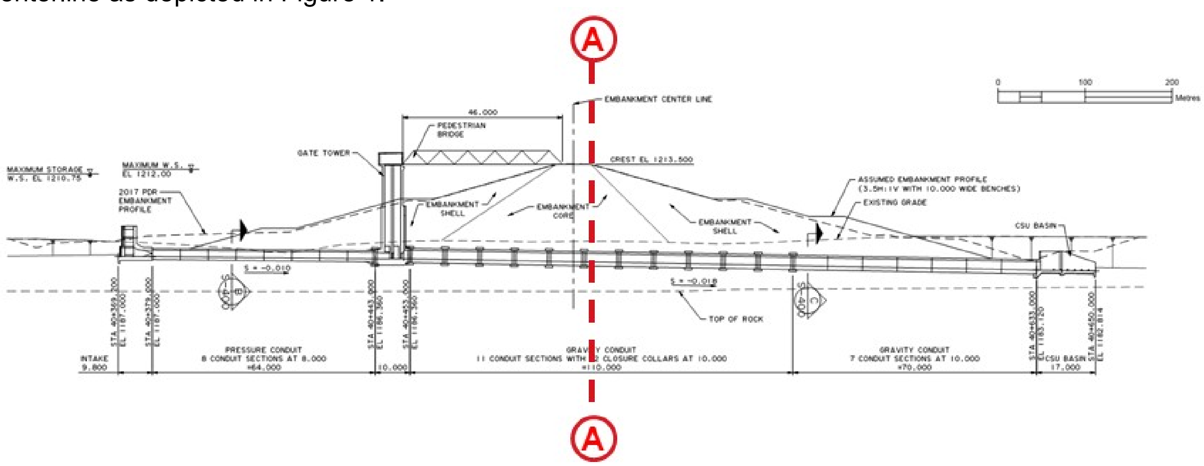


Figure 1. Location of the cross-section considered for the FE analysis.

The geometry of the LLOW gravity conduit is provided in Figure 2.

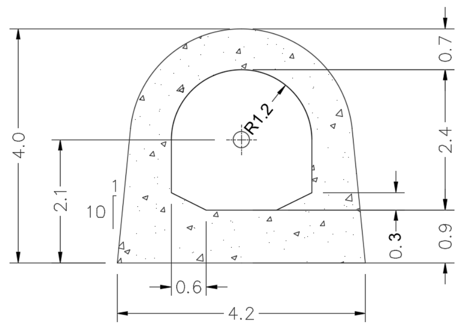


Figure 2. LLOW gravity conduit geometry (dimensions in meters).

Figure 3 shows the soil profile at section A-A.

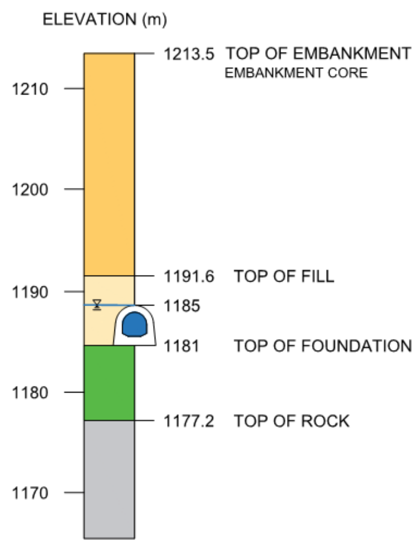


Figure 3. Soil profile at Section A-A.

MODEL DETAILS

The FE model (FEM) comprised of a region of 24.2m wide (or 5.8 times the structure size) and 36.6m in-depth (or 9 times the structure size). The region is discretized using a 1m global element size and a mix of quad and triangle unstructured mesh (see figure 4).

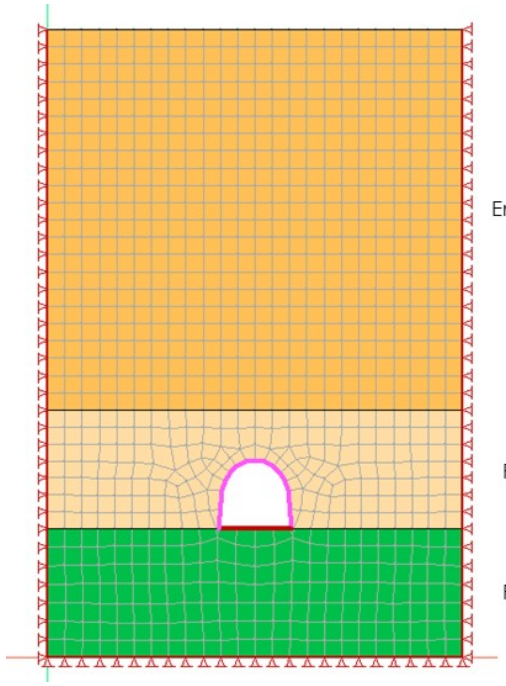


Figure 4. Mixed quad and triangle unstructured mesh (1m size element)

The discretization of the region resulted in 936 nodes and approximate 870 elements. The analysis is performed using a 2D model with 3 degrees of freedom at each node (displacement [x, y directions], and pore-water pressure). The model does not allow slip between the soil and the structural beams, this assumption results in higher stresses on the structure if slip was allowed to occur.

The groundwater table was set at the same elevation of the top of the conduit.

Material Data

Soil materials are modeled using elastic-plastic elements under drained conditions. Table 1 summarizes the soil parameters considered in the FEM.

Table 1. Soil parameters

Elevation (m)	*Depth (m)*	*Description*	*Unit weight (kN/m3)*	*c (kPa)*	*φ (deg)*	*E (MPa)*	*μ*
1213.5	0.0	Embankment Core	20	0	28	17	0.35
1185.0	28.5	Fill	20	0	24	10	0.35
1181.0	4.0	Foundation	18	0	27	17	0.35
1177.2	3.8	Rock	Uncompressible				

The conduit was modeled using structural beams. Table 2 summarizes the parameters used to model the conduit walls. The modulus of elasticity was calculated using a block of concrete with compressive strength equal to 30 MPa.

Table 2. Gravity conduit model parameters

Location	*Ec (MPa)*	*A (m^2)*	*Ixx (m^4)*
Top Section	24647.5	0.70	0.029
Bottom Section	24647.5	0.90	0.061

LOADS

Only the effect of gravity as a body load was considered in the analysis.

CONSTRAINS

The model was constrained from lateral movement on the side boundaries and axial movement at the bottom boundary (see figure 4).

RESULTS

The results of the FEA are presented in Figure 5 and summarized in Table 3. Figure 5 shows the diagrams for the moment, shear and axial forces respectively.

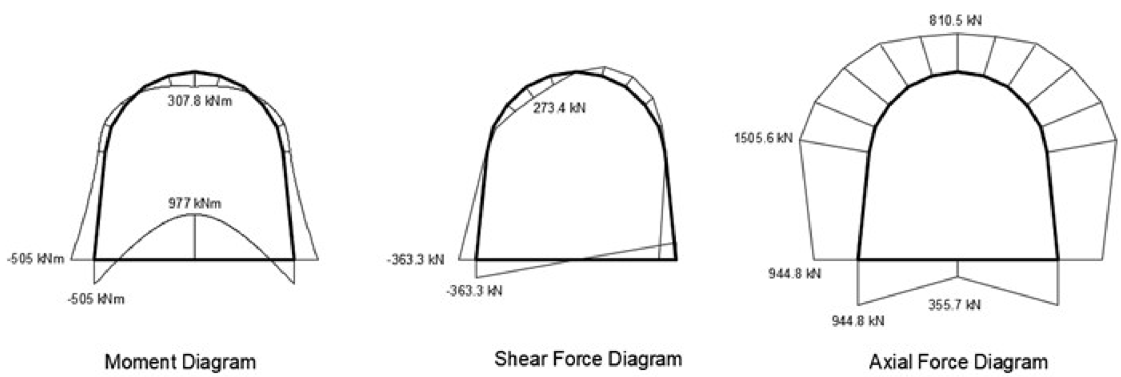


Figure 5. Moment, Shear and axial forces diagrams.

Table 3. Summary of resultant forces.

Location	*Max. Moment (kNm)*	*Max. Shear Force (kN)*	*Max. Axial Force (kN)*
Top Section	307.8	363.3	1505.6
Bottom Section	977.0	363.3	944.8

FEA RESULTS VALIDATION

Calculations of the forces acting on the gravity conduit due to the embankment surcharge using the Direct Design approach are presented in Attachment A.

The Direct Design method, also referred to as the Heger Pressure Distribution, provides a set of factors associated with a load distribution diagram to estimate the soil pressures acting on the conduit. The load factors are related to four types of installation. The type of installation has a significant effect on the loads carried by the conduit.

For this analysis, installation Type 1 is assumed. Type 1 installation comprises of 170 mm of bedding (Diameter/24) of compacted gravely-sand per specifications. The fill could range between the specified soil categories as long the minimum percentage of compaction is observed.

Figure 6 summarizes the comparison between the resultant forces from the FEM and the best estimated resultant forces from the Direct Design method.

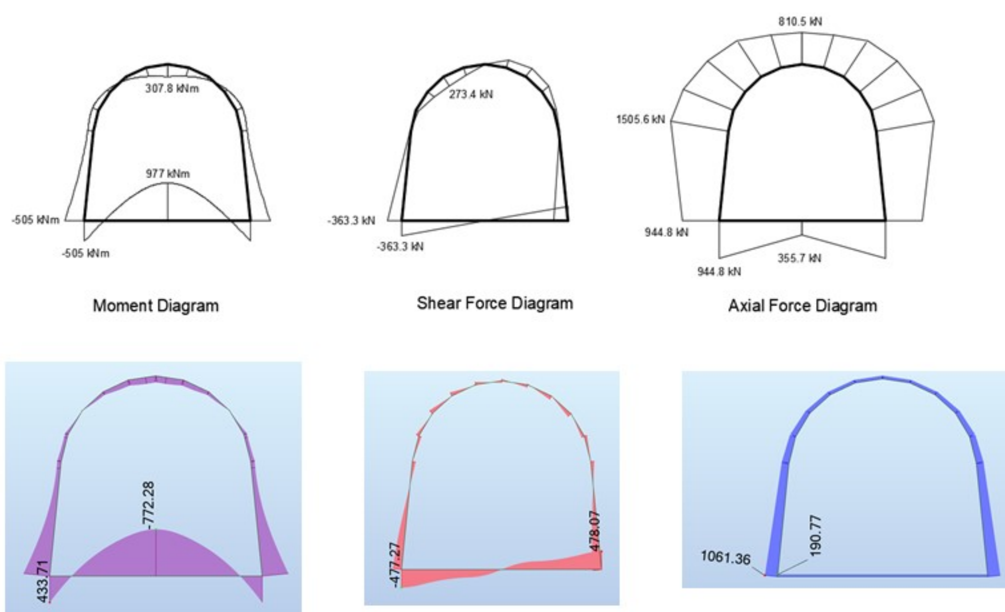


Figure 6. Comparison between FEM and Direct Design method.

CONCLUSIONS

The resultant forces on the gravity conduit calculated using the FEM (GeoStudio) are comparable with the resultant forces calculated using the Direct Design method.

REFERENCES

ASCE (2017). Standard practice for direct design of buried precast concrete pipe using standard installations (SIDD). ASCE/CI 15-17. 2017.

UMA (2008). Standard practice for the design and installation of rigid gravity sewer pipe in the city of Calgary. UMA Engineering Ltd. 0082-242-00.

USACE (1998). Engineering and design conduits, culverts, and pipes. U.S. Army Corps of Engineering. EM 110-2-2909. 31 March 1998. DC.

Moser, A. and Folkman, S. (2008). Buried pipe design. 3th edition. McGraw Hill. New York.

ACPA (2007). Concrete pipe design manual. American Concrete Pipe Association. www.concrete-pipe.org.

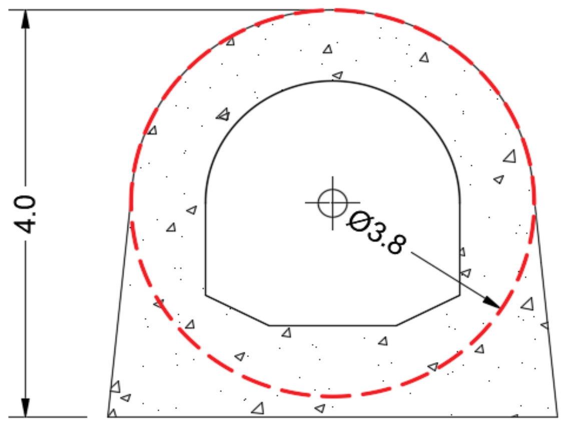
DIRECT DESIGN

Scope:

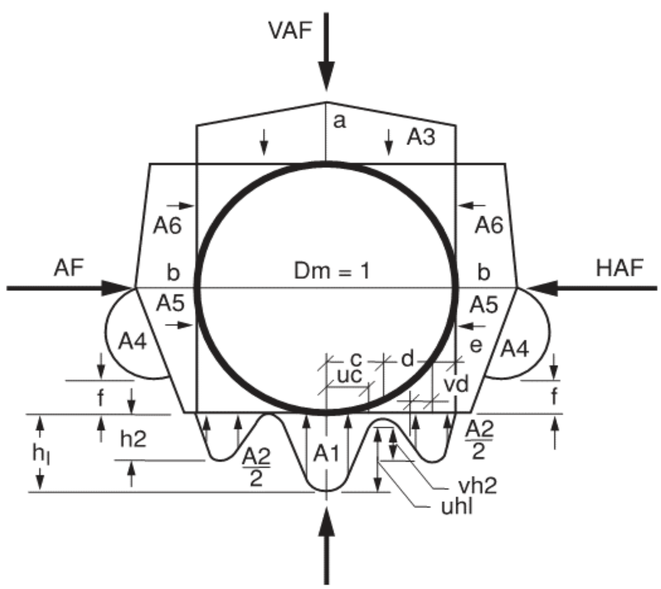
Calculate the soil pressures and forces actiong on the conduit using the direct method.

Geometry:

Equivalent diameter



Calculations:



Soil unit weight	w =	20	kN/m^3
Equivalent diameter	Do =	3.8	m
Overburden height	H=	28.5	m

Installation Type	VAF	HAF	A1	A2	A3	A4	A5	A6
1	1.35	0.45	0.62	0.73	1.35	0.19	0.08	0.18
2	1.40	0.40	0.85	0.55	1.40	0.15	0.08	0.17
3	1.40	0.37	1.05	0.35	1.40	0.10	0.10	0.17
4	4.45	0.30	1.45	0.00	1.45	0.00	0.11	0.19

Installation Type	a	b	c	e	f	u	v
1	1.40	0.40	0.18	0.08	0.05	0.80	0.80
2	1.45	0.40	0.19	0.10	0.05	0.82	0.70
3	1.45	0.36	0.20	0.12	0.05	0.85	0.60
4	1.45	0.30	0.25	0.00		0.90	-

$$PL = w\,(H + \frac{Do\,(4-\pi)}{8}\,Do)$$

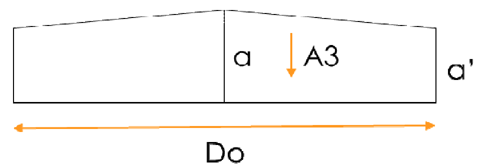
PL = 601.0 kN

Instalation Type 1

	Factor	Force
VAF	1.35	811.3 kN
HAF	0.45	270.4 kN
A1	0.62	372.6 kN
A2	0.73	438.7 kN
A3	1.35	811.3 kN
A4	0.19	114.2 kN
A5	0.08	48.1 kN
A6	0.18	108.2 kN
a	1.40	221.4 kN/m
b	0.40	63.3 kN/m
c	0.18	0.7 m
e	0.08	0.3 m
f	0.05	0.2 m
u	0.80	3.0 m
v	0.80	3.0 m
d	0.24	0.9 m
h1	2.87	454.0 kN/m
h2	1.85	292.5 kN/m
uc	0.144	0.55 m
vd	0.192	0.73 m

uh1	363.17 kN/m
vh2	234.03 kN/m

Equivalent Distributed Loads



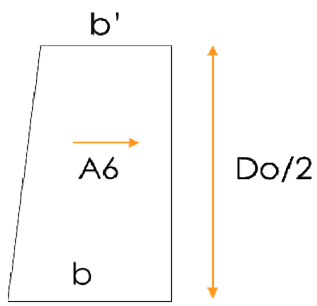
VAF 1.35

a = 1.35 PL/Do

$$\frac{(a+a')}{2}\frac{Do}{2}2 = 1.35\text{PL}$$

$$a' = 1.3\frac{PL}{Do}$$

a' = 205.6 kN/m



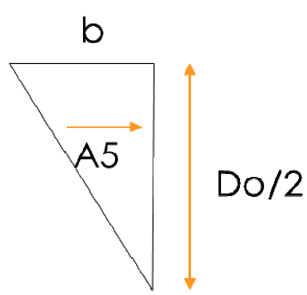
A6 = 0.18

b = 0.4 PL/Do

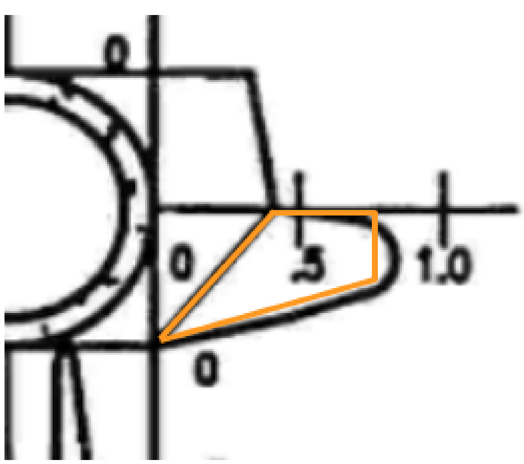
$$\frac{(b+b')}{2}\frac{Do}{2} = 0.18\text{PL}$$

$$b' = 0.32\frac{PL}{Do}$$

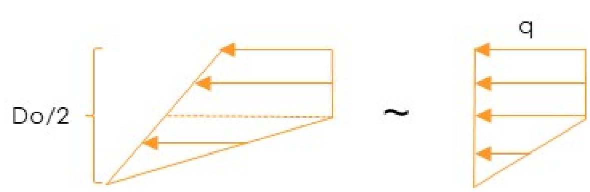
b' = 50.61 kN/m



b = 63.3 kN/m



A4 = 114.2 kN

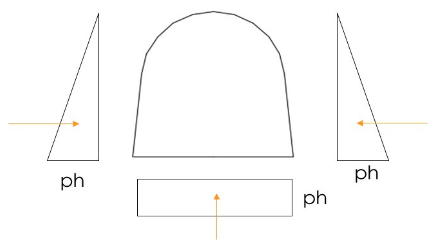


$$d' = Do/2$$

d'*q+1/2*q*d'=0.19*PL=A4

q= 80.34 kN/m

Water Pressure



Do =	3.8	m
γw =	9.81	kN/m3
ph =	37.3	kN/m

Resultant Forces

The structure was modeled using the FE computer program Robot (2019). Loads developed using the Direct Design method were superimposed to the frame comprised of beam elements that represented the conduit structure.
Since the FE model require supports to converge to a solution, two foundation scenarios are explored: Condition 1) consider elastic foundation under the bottom of the conduit structure; and Condition 2) consider an elastic support at the ends of the bottom section of the conduit structure.

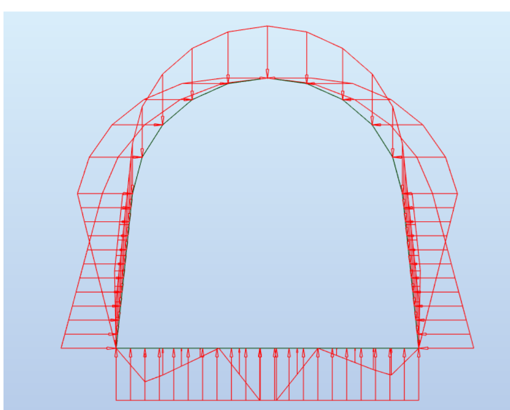
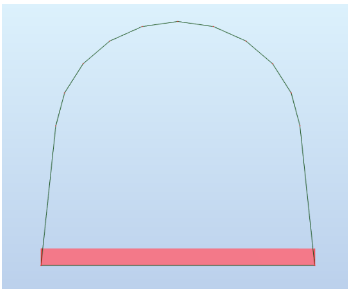


Figure 1 shows all the loads applied to the conduit structure. Loads were derived using the Direct Design method.

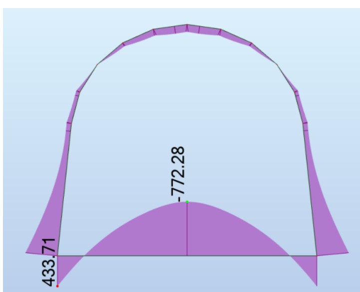
Loads acting on conduit structure

Condition 1.

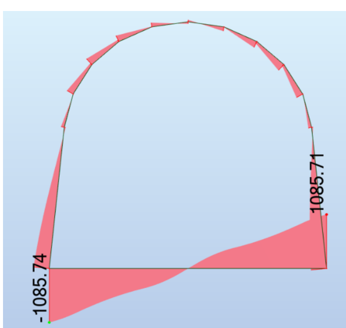
Elastic fundation



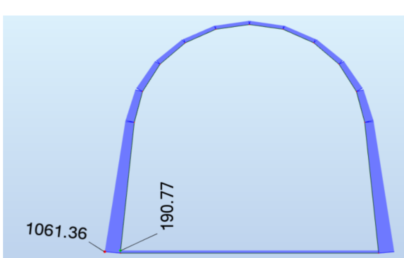
Moment Diagram



Shear Force Diagram

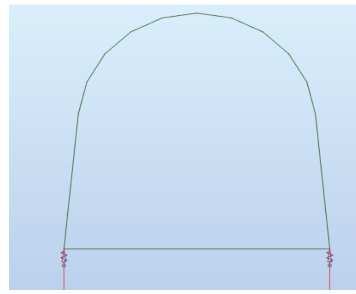


Axial Force Diagram

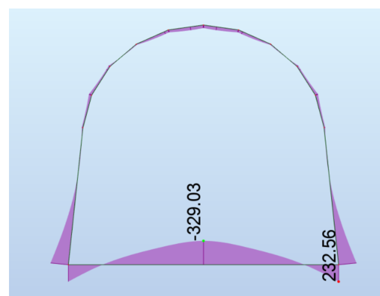


Condition 2.

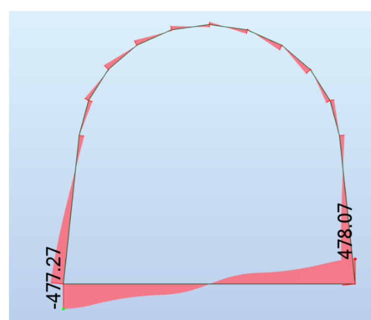
Elastic supports



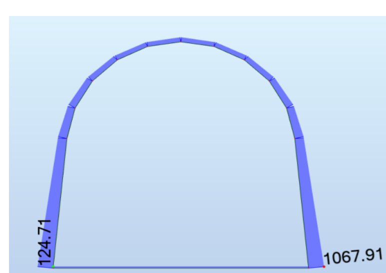
Moment Diagram



Shear Force Diagram

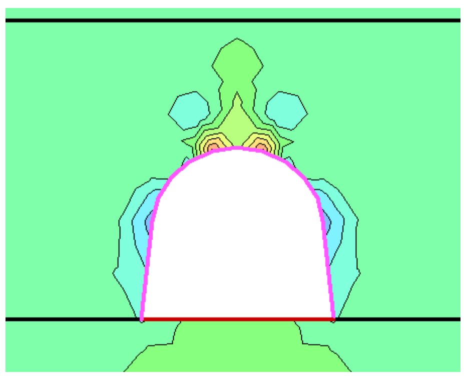


Axial Force Diagram



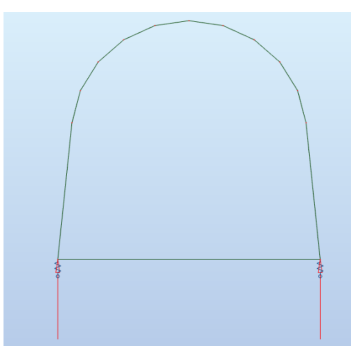
Discusion

The resultant shear forces and moments acting on the bottom of the conduit of the structure are susceptible to the foundation condition assumed for the analysis. According to the FEM developed with GeoStudio, the stresses under the bottom of the conduit structure are no homogeneous.

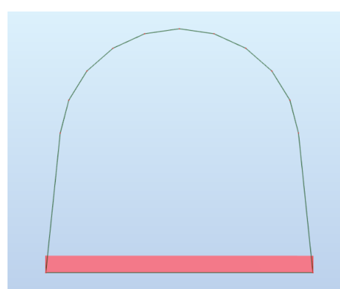


Total vertical stresses (from Geostudio FEM)

Assumed foundation conditions.



Elastic supports



Elastic fundation

DESIGN MOMENT ANALYSIS

Scope: Calculate the reinforcement required for the Gravity LLOW under the load case Usual Condition (U1).

Geometry:

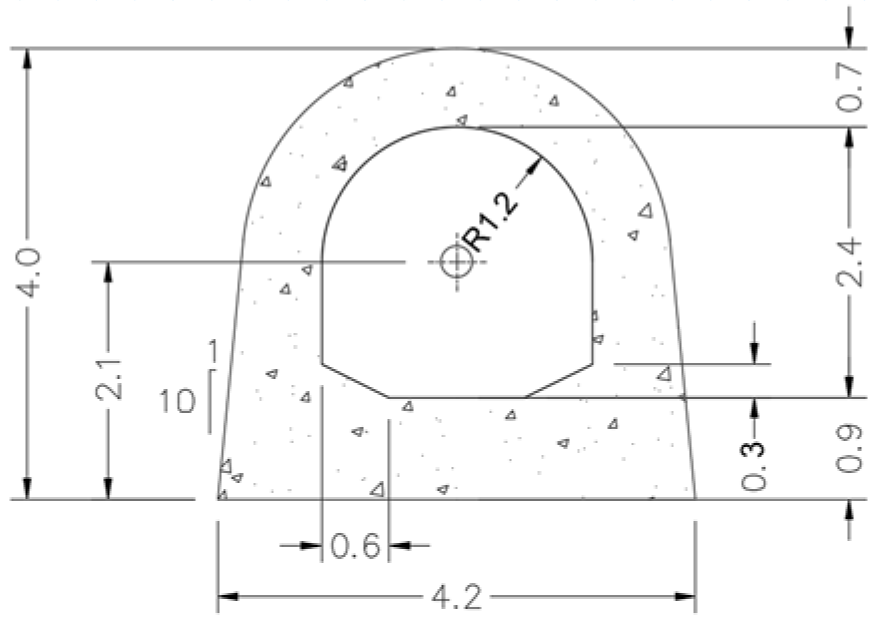


Figure 1. Cross section LLOW Gravity Conduit

Moment and Stress Demands:

Load Case U1

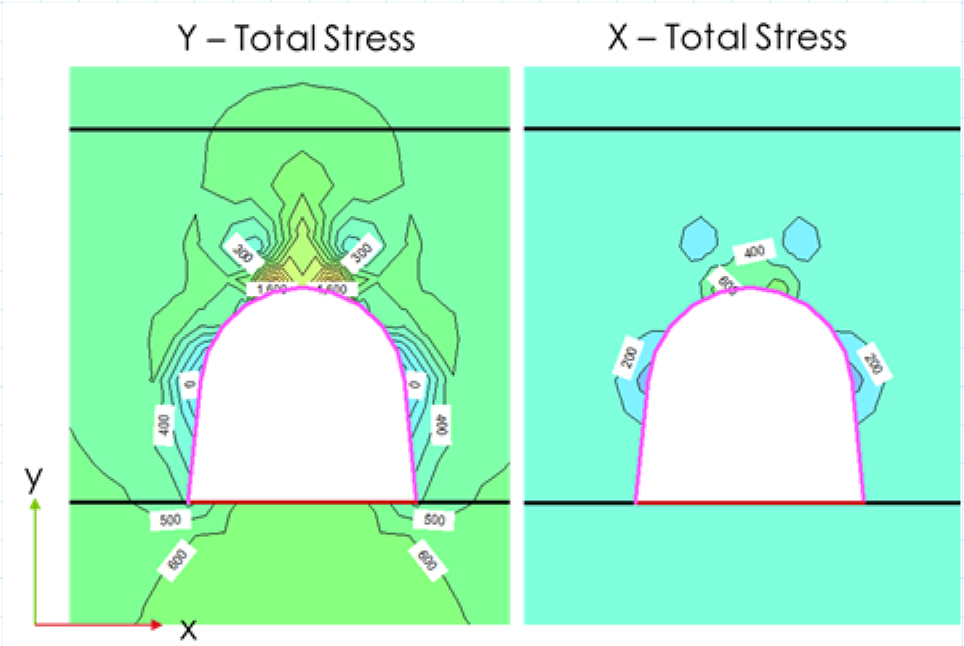
From the FE element Model

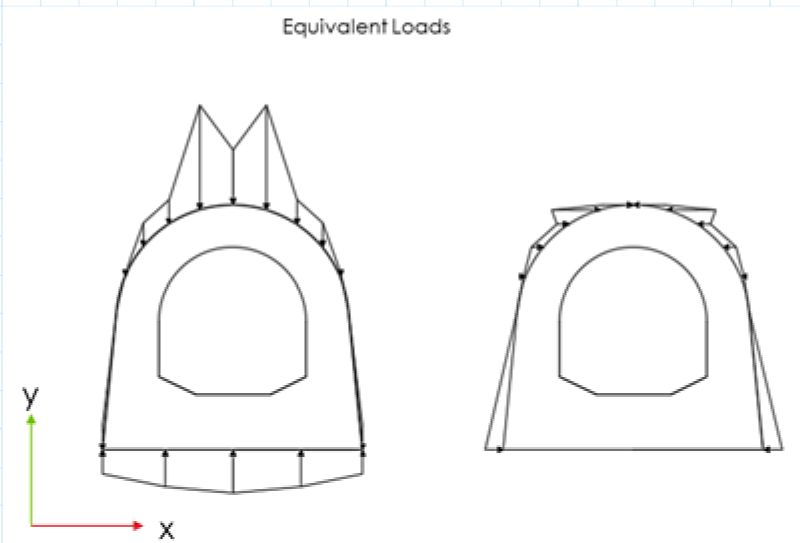
Bottom of Conduit:

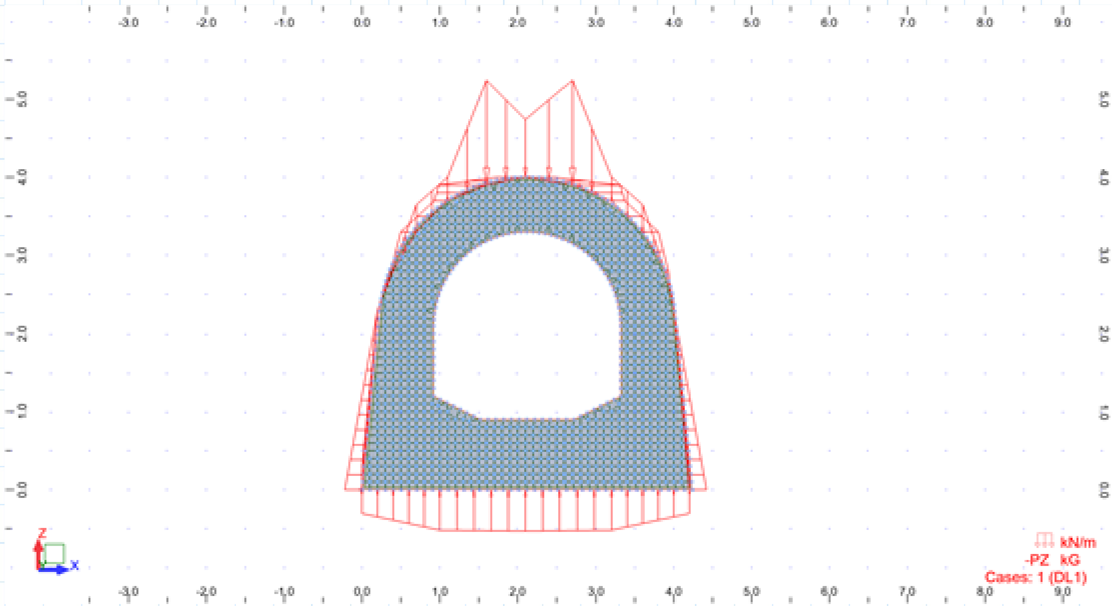
$$M_u := 977\ kN \cdot m$$

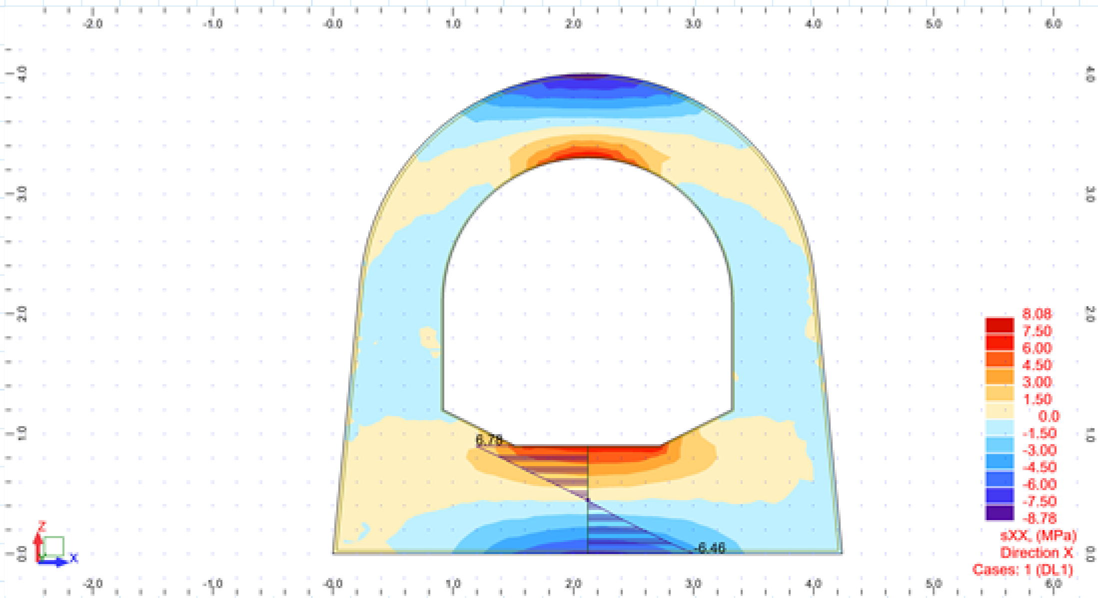
$$N_u := 355.7\ kN$$

Total Stressess results from GeoStudio






kN/m
-PZ kG
Cases: 1 (DL1)


6.78
-6.46
8.08
7.50
6.00
4.50
3.00
1.50
0.0
-1.50
-3.00
-4.50
-6.00
-7.50
-8.78
sXX, (MPa)
Direction X
Cases: 1 (DL1)

$h := 0.9\ m \qquad b := 1\ m$

$T := 6.48 \cdot MPa \qquad C := 6.03\ MPa$

$A := h \cdot b = 0.9\ m^2$

$I := \frac{1}{12} \cdot h^3 \cdot b = 0.061\ m^4$

$y := \frac{h}{2} = 0.450\ m$

$M := \frac{I}{y} \cdot T = 874.8\ kN \cdot m$

UNUSUAL LOAD CONDITION 1
UN1

TITLE: LLOW GRAVITY CONDUIT ANALYSIS – LOAD CONDITION UN1

Author: E. Farfan
Project: SR-1
Project No.: 110773396
Date: 10/23/2019
Drawing: S-400

INTRODUCTION

This report provides an analysis of the forces acting on the walls of the Low-Level Outlet Works (LLOW) gravity conduit. The LLOW is a gated gravity drainage structure located within the banks of the Unnamed Creek and constructed through the embankment dam.

The LLOW conduit structure comprised of a cast-on-place reinforced concrete placed on an excavated channel that will be filled to the existing ground elevation. The walls of the excavation are far apart that the effects on the structure of the interaction between the native soil and the fill can be neglected in the analysis.

The acting forces on the LLOW gravity conduit are evaluated using a finite element model (FEM). The module Sigma/W from the computer program GeoStudio (2018) was used for the FE analysis.

OBJECTIVES

Determine the forces acting on the LLOW structure using an FE analysis.

GEOMETRY

The location of the cross-section selected to represent the highest overburden over the LLOW gravity conduit was located near the crest of the embankment on the downstream side from the embankment centerline as depicted in Figure 1.

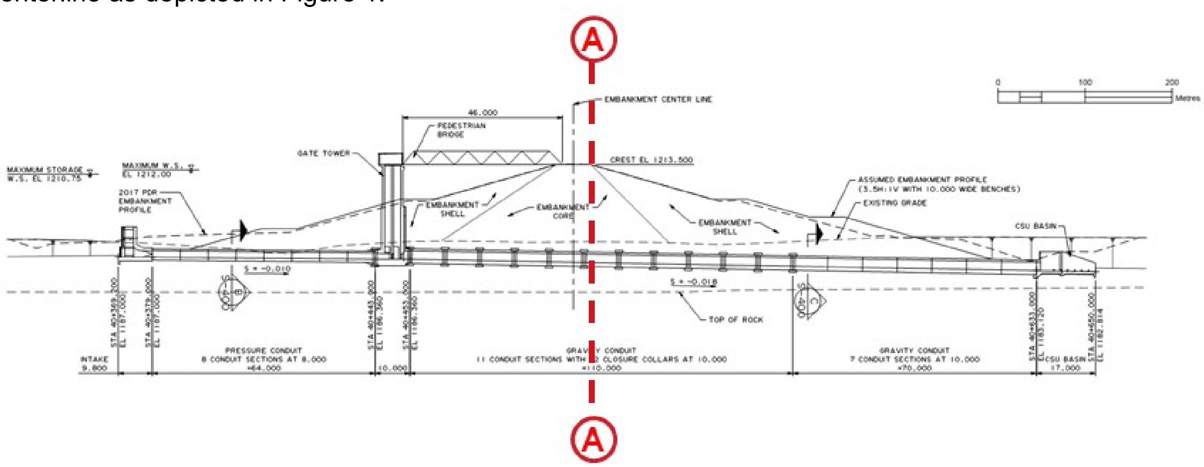


Figure 1. Location of the cross-section considered for the FE analysis.

The geometry of the LLOW gravity conduit is provided in Figure 2.

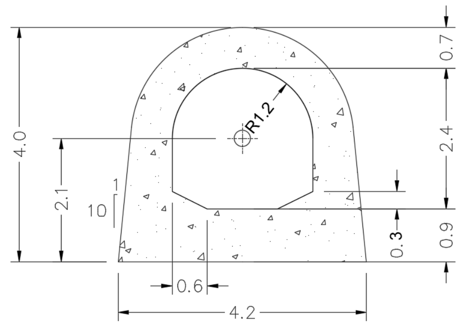


Figure 2. LLOW gravity conduit geometry (dimensions in meters).

Figure 3 shows the soil profile at section A-A.

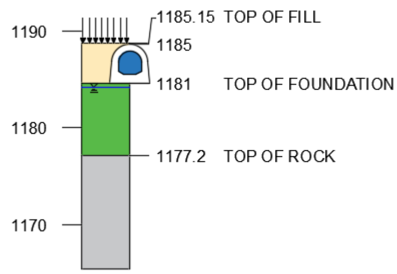


Figure 3. Soil profile at Section A-A.

MODEL DETAILS

The FE model (FEM) comprised of a region of 24.2m wide (or 5.8 times the structure size) and 11.7m in-depth (or 2.9 times the structure size). The region is discretized using a 1m global element size and a mix of quad and triangle unstructured mesh (see figure 4).

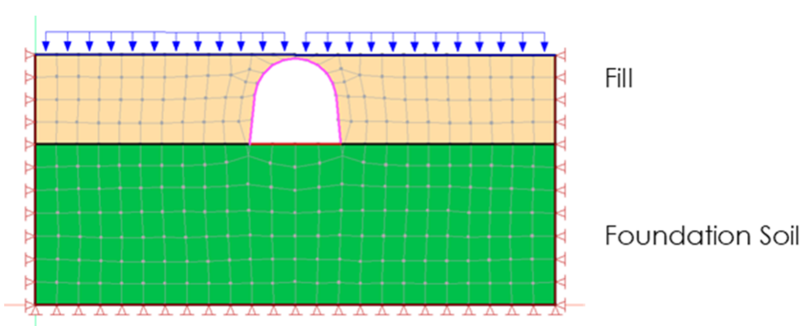


Figure 4. Mixed quad and triangle unstructured mesh (1m size element)

The discretization of the region resulted in 308 nodes and approximate 263 elements. The analysis is performed using a 2D model with 3 degrees of freedom at each node (displacement [x, y directions], and pore-water pressure). The model does not allow slip between the soil and the structural beams, this assumption results in higher stresses on the structure if slip was allowed to occur.

The groundwater table was set at the same elevation of the top of the conduit.

Material Data

Soil materials are modeled using elastic-plastic elements under drained conditions. Table 1 summarizes the soil parameters considered in the FEM.

Table 1. Soil parameters

Elevation (m)	*Depth (m)*	*Description*	*Unit weight (kN/m3)*	*c (kPa)*	*φ (deg)*	*E (MPa)*	*μ*
1185.15	28.5	Fill	20	0	24	10	0.35
1181.0	4.0	Foundation	18	0	27	17	0.35
1177.2	3.8	Rock	Uncompressible				

The conduit was modeled using structural beams. Table 2 summarizes the parameters used to model the conduit walls. The modulus of elasticity was calculated using a block of concrete with compressive strength equal to 30 MPa.

Table 2. Gravity conduit model parameters

Location	*Ec (MPa)*	*A (m^2)*	*Ixx (m^4)*
Top Section	24647.5	0.70	0.029
Bottom Section	24647.5	0.90	0.061

LOADS

The effect of gravity as a body load and a traffic load (15 kPa) were considered in the analysis.

CONSTRAINS

The model was constrained from lateral movement on the side boundaries and axial movement at the bottom boundary (see figure 4).

RESULTS

The results of the FEA are presented in Figure 5 and summarized in Table 3. Figure 5 shows the diagrams for the moment, shear and axial forces respectively.

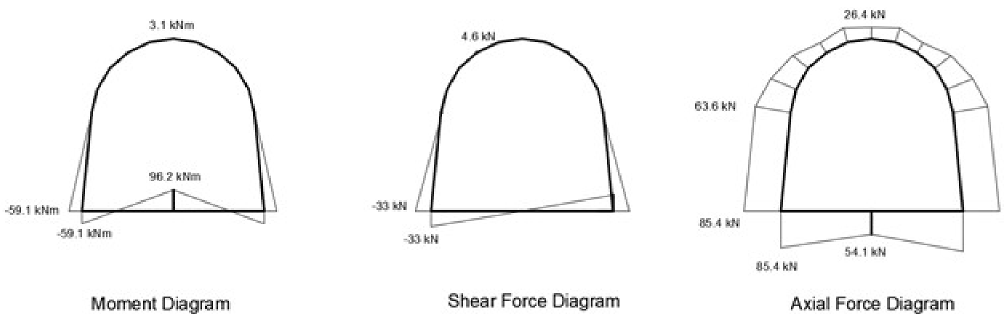


Figure 5. Moment, Shear and axial forces diagrams.

Table 3. Summary of resultant forces.

Location	*Max. Moment (kNm)*	*Max. Shear Force (kN)*	*Max. Axial Force (kN)*
Top Section	3.1	4.6	26.4
Bottom Section	96.2	33.0	85.4

Applicability of the methodology used in this analysis is presented in the calculations for the load condition U1.

REFERENCES

ASCE (2017). Standard practice for direct design of buried precast concrete pipe using standard installations (SIDD). ASCE/CI 15-17. 2017.

UMA (2008). Standard practice for the design and installation of rigid gravity sewer pipe in the city of Calgary. UMA Engineering Ltd. 0082-242-00.

USACE (1998). Engineering and design conduits, culverts, and pipes. U.S. Army Corps of Engineering. EM 110-2-2909. 31 March 1998. DC.

Moser, A. and Folkman, S. (2008). Buried pipe design. 3th edition. McGraw Hill. New York.

ACPA (2007). Concrete pipe design manual. American Concrete Pipe Association. www.concrete-pipe.org.

EXTREME LOAD CONDITION 1
E1

Scope: Evaluate the seismic effects on the LLOW Gravity Conduit under the load case Extreme Load Condition (E1).

Geometry:

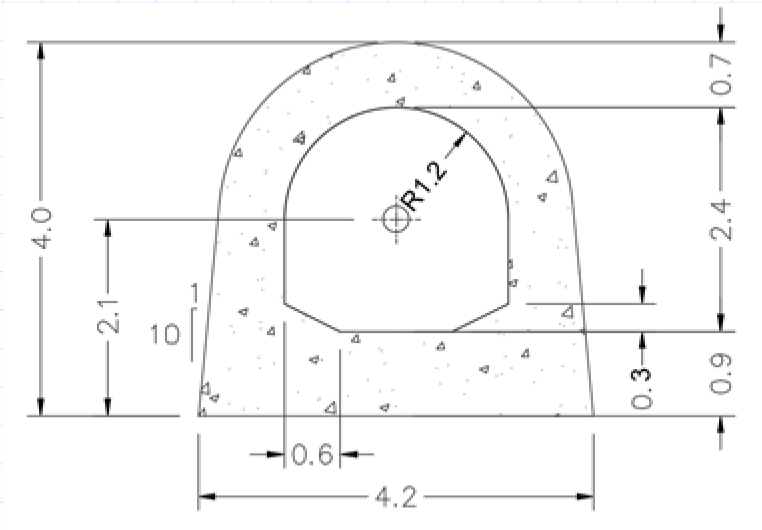


Figure 1. Cross section LLOW Gravity Conduit

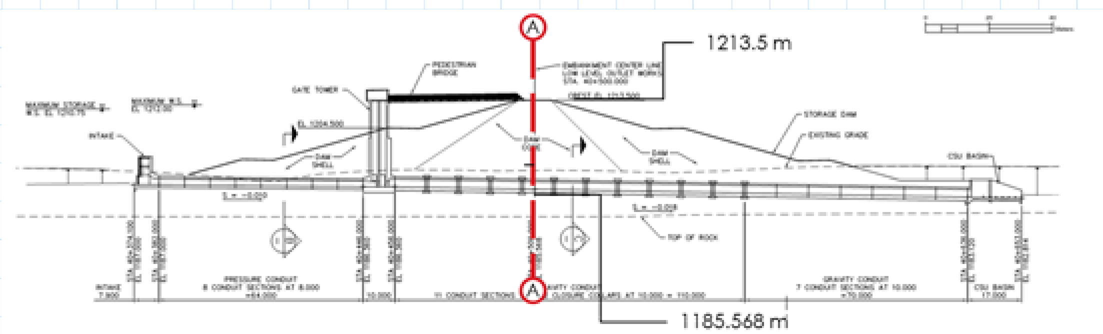


Figure 2. Embankment Corssection and LLOW Conduit Profile

Elevations:

Top of Embankment $EL_{emb} := 1213.5\ m$

Bottom of Conduit $EL := 1185.568\ m$

Loads:

Peak Ground Acceleration $PGA := 0.26$

Calculations:

$\gamma_s := 20 \ \frac{kN}{m^3}$ Soil unit weight

$D := 4 \ m$ Conduit Diameter

Top of Counduit

$z_1 := EL_{emb} - EL - D = 23.932 \ m$ Soil Height

$\sigma_{v1} := z_1 \cdot \gamma_s = 478.64 \ kPa$ Total Stress

$R_{d1} := 1.174 - 0.00814 \cdot \frac{z_1}{ft} = 0.535$

$\tau_{max1} := PGA \cdot \sigma_{v1} \cdot R_{d1} = 66.563 \ kPa$

Bottom of Counduit

$z_2 := EL_{emb} - EL = 27.932 \ m$ Soil Height

$\sigma_{v2} := z_2 \cdot \gamma_s = 558.64 \ kPa$ Total Stress

$R_{d2} := 1.174 - 0.00814 \cdot \frac{z_2}{ft} = 0.428$ Depth-dependent stress reduction factor

$\tau_{max2} := PGA \cdot \sigma_{v2} \cdot R_{d2} = 62.172 \ kPa$ Maximum earthquake-induced stress

Ground shear modulus

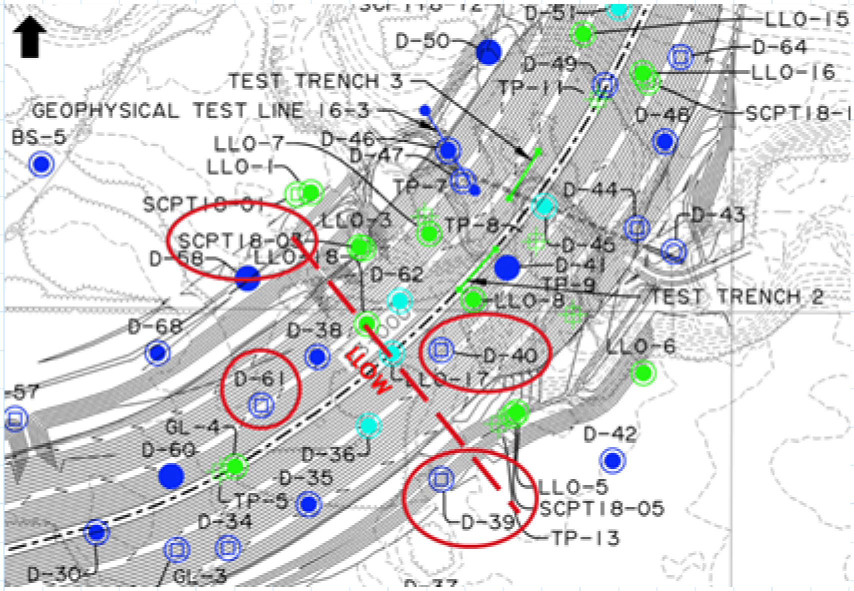


Figure 3. Selected CPT Test Locations

CPT Data

$q_{t1} := 25\ bar = 2.5\ MPa$ CPT D-39

$q_{t2} := 60\ bar = 6\ MPa$ CPT D-40

$q_{t3} := 30\ bar = 3\ MPa$ CPT D-61

$q_{t4} := 25\ bar = 2.5\ MPa$ SCPT18-03

$$q_t := \frac{q_{t1} + q_{t2} + q_{t3} + q_{t4}}{4} = 3.5\ MPa$$ Average CPT tip resistance

$$\sigma'_v := \frac{\sigma_{v1} + \sigma_{v2}}{2} = 518.64\ kPa$$ Average Effective Stress

$$G_{max} := 1634\ kPa \cdot \left(\frac{q_t}{kPa}\right)^{0.250} \cdot \left(\frac{\sigma'_v}{kPa}\right)^{0.375} = 131.022\ MPa$$ Maximum shear modulus

$G_m := 0.9 \cdot G_{max} = 117.92\ MPa$ Effective, strain-compatible shear modulus of the ground surrounding the conduit. (small strain factor 0.9)

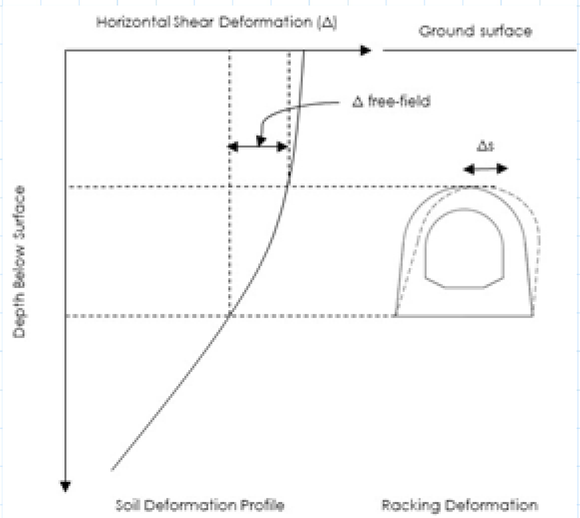
$\gamma_{max1} := \frac{\tau_{max1}}{G_m} = 5.645 \cdot 10^{-4}$ Top of Conduit

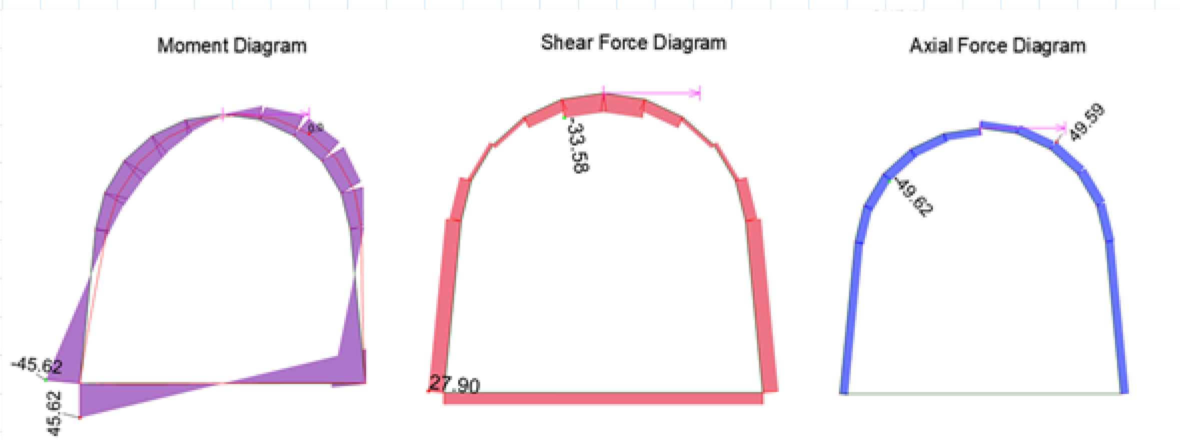
$\gamma_{max2} := \frac{\tau_{max2}}{G_m} = 5.272 \cdot 10^{-4}$ Bottom of Conduit

$\Delta_{free\_field1} := D \cdot \gamma_{max1} = 0.226\ cm$ Top of Conduit

$\Delta_{free\_field2} := D \cdot \gamma_{max2} = 0.211\ cm$ Bottom of Conduit

$$\Delta_{free\_field} := \Delta_{free\_field1} - \Delta_{free\_field2} = 0.015\ cm$$



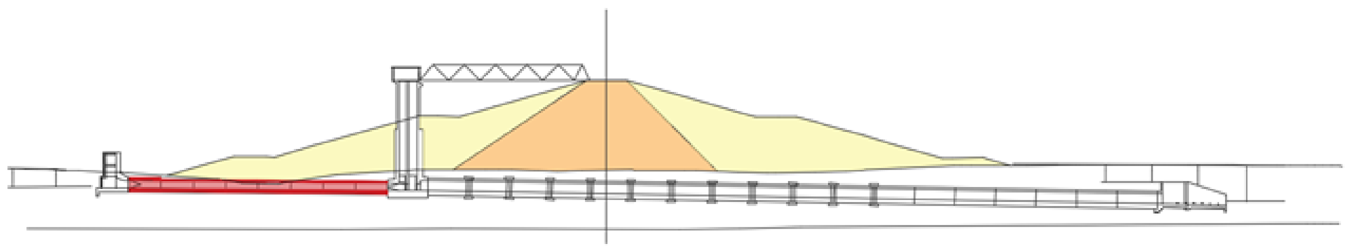


References:

Anderson D., Martin, G., and Lam, I. (2008). Seismic Analysis and Design of Retaining Walls, Buried Structures, Slopes and Embankments. NCHRP Report 611. Transportations Research Board. Whashington D.C.

Look, B. (2007). Handbook of Geotechnical Investigation and Design Tables. Taylor & Francis. New York.

Pressure Conduit



USUAL LOAD CONDITION 1
U1

Stantec

TITLE: LLOW PRESSURE CONDUIT ANALYSIS – LOAD CONDITION U1

Author: E. Farfan
Project: SR-1
Project No.: 110773396
Date: 9/27/2019
Drawing: S-400

INTRODUCTION

This report provides an analysis of the forces acting on the walls of the Low-Level Outlet Works (LLOW) gravity conduit. The LLOW is a gated gravity drainage structure located within the banks of the Unnamed Creek and constructed through the embankment dam.

The LLOW conduit structure comprised of a cast-on-place reinforced concrete placed on an excavated channel that will be filled to the existing ground elevation. The walls of the excavation are far apart that the effects on the structure of the interaction between the native soil and the fill can be neglected in the analysis.

The acting forces on the LLOW gravity conduit are evaluated using a finite element model (FEM). The analysis validation is performed by comparing the resultant forces obtained with the FE analysis and results using the Direct Design method as described in ASCE 15-17.

The module Sigma/W from the computer program GeoStudio (2018) was used for the FE analysis.

OBJECTIVES

Determine the forces acting on the LLOW structure using an FE analysis and verify the results using the Direct Design method (ASCE 15-17).

GEOMETRY

The location of the cross-section selected to represent the highest overburden over the LLOW gravity conduit was located near the crest of the embankment on the downstream side from the embankment centerline as depicted in Figure 1.

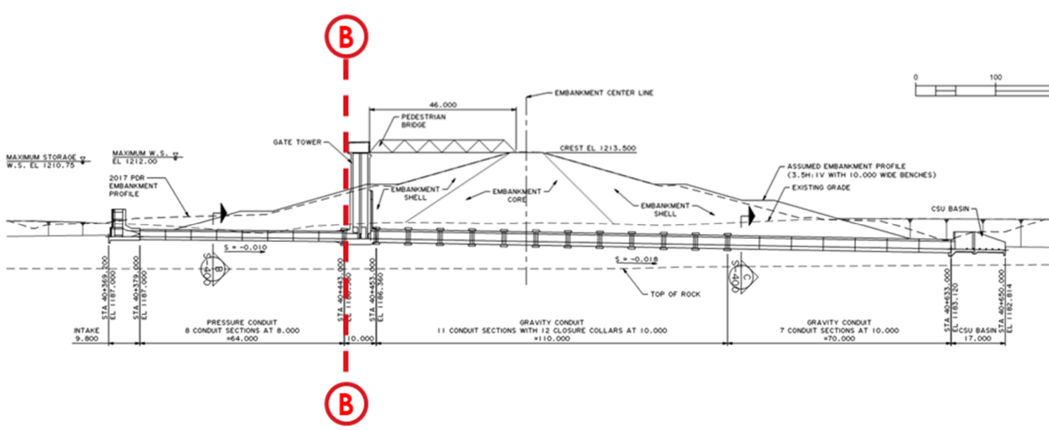


Figure 1. Location of the cross-section considered for the FE analysis.

The geometry of the LLOW gravity conduit is provided in Figure 2.

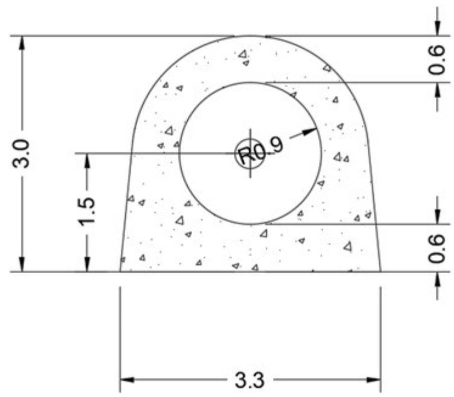


Figure 2. LLOW gravity conduit geometry (dimensions in meters).

Figure 3 shows the soil profile at section A-A.

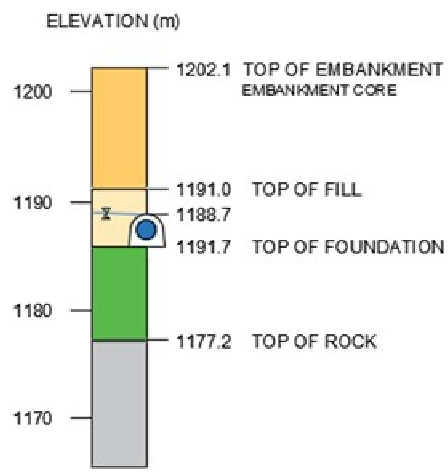


Figure 3. Soil profile at Section A-A.

MODEL DETAILS

The FE model (FEM) comprised of a region of 24.2m wide (or 5.8 times the structure size) and 36.6m in-depth (or 9 times the structure size). The region is discretized using a 1m global element size and a mix of quad and triangle unstructured mesh (see figure 4).

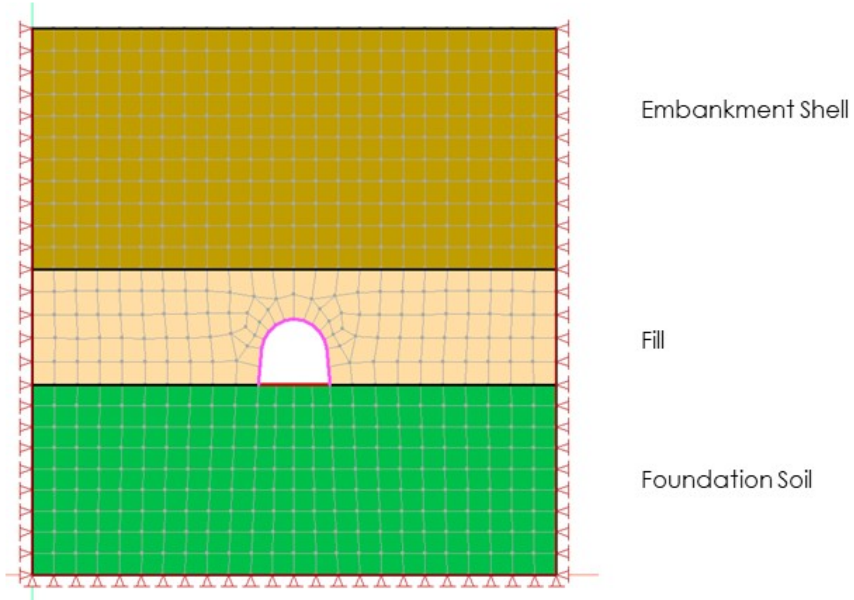


Figure 4. Mixed quad and triangle unstructured mesh (1m size element)

The discretization of the region resulted in 936 nodes and approximate 870 elements. The analysis is performed using a 2D model with 3 degrees of freedom at each node (displacement [x, y directions], and pore-water pressure). The model does not allow slip between the soil and the structural beams, this assumption results in higher stresses on the structure if slip was allowed to occur.

The groundwater table was set at the same elevation of the top of the conduit.

Material Data

Soil materials are modeled using elastic-plastic elements under drained conditions. Table 1 summarizes the soil parameters considered in the FEM.

Table 1. Soil parameters

Elevation (m)	*Depth (m)*	*Description*	*Unit weight (kN/m3)*	*c (kPa)*	*φ (deg)*	*E (MPa)*	*μ*
1213.5	0.0	Embankment Shell	20	0	24	10	0.35
1185.0	28.5	Fill	20	0	24	10	0.35
1181.0	4.0	Foundation	18	0	27	17	0.35
1177.2	3.8	Rock	Uncompressible				

The conduit was modeled using structural beams. Table 2 summarizes the parameters used to model the conduit walls. The modulus of elasticity was calculated using a block of concrete with compressive strength equal to 30 MPa.

Table 2. Gravity conduit model parameters

Location	Ec (MPa)	A (m^2)	Ixx (m^4)
Top Section	24647.5	0.60	0.018
Bottom Section	24647.5	0.60	0.018

LOADS

Only the effect of gravity as a body load was considered in the analysis.

CONSTRAINS

The model was constrained from lateral movement on the side boundaries and axial movement at the bottom boundary (see figure 4).

RESULTS

The results of the FEA are presented in Figure 5 and summarized in Table 3. Figure 5 shows the diagrams for the moment, shear and axial forces respectively.

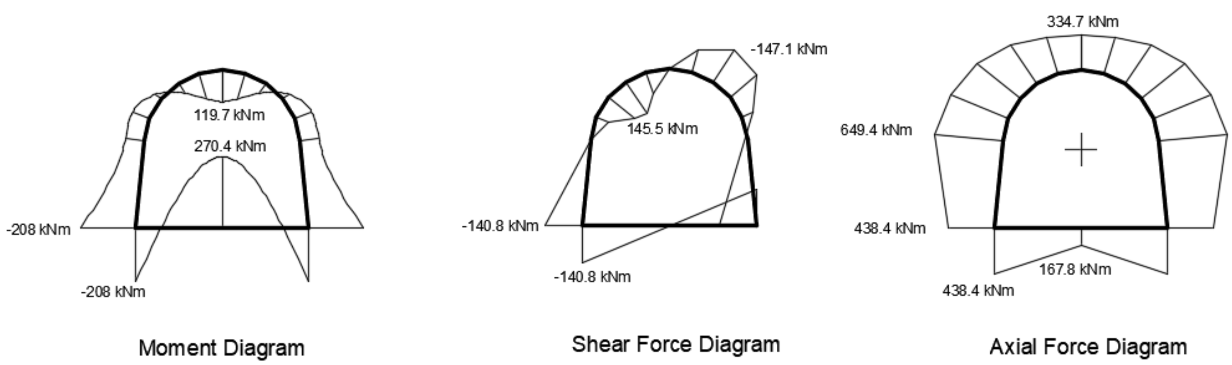


Figure 5. Moment, Shear and axial forces diagrams.

Stantec

Table 3. Summary of resultant forces.

Location	Max. Moment (kNm)	Max. Shear Force (kN)	Max. Axial Force (kN)
Top Section	119.7	145.5	649.4
Bottom Section	270.4	140.8	438.4

FEA RESULTS VALIDATION

Calculations of the forces acting on the gravity conduit due to the embankment surcharge using the Direct Design approach are presented in Attachment A.

The Direct Design method, also referred to as the Heger Pressure Distribution, provides a set of factors associated with a load distribution diagram to estimate the soil pressures acting on the conduit. The load factors are related to four types of installation. The type of installation has a significant effect on the loads carried by the conduit.

For this analysis, installation Type 1 is assumed. Type 1 installation comprises of 170 mm of bedding (Diameter/24) of compacted gravely-sand per specifications. The fill could range between the specified soil categories as long the minimum percentage of compaction is observed.

Figure 6 summarizes the comparison between the resultant forces from the FEM and the best estimated resultant forces from the Direct Design method.

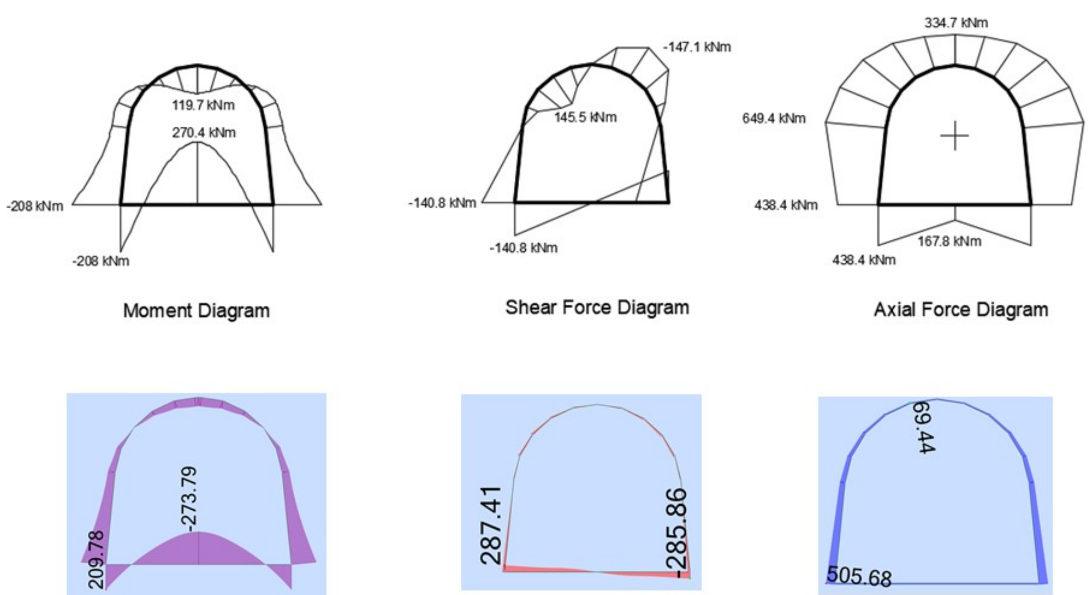


Figure 6. Comparison between FEM and Direct Design method.

CONCLUSIONS

The resultant forces on the gravity conduit calculated using the FEM (GeoStudio) are comparable with the resultant forces calculated using the Direct Design method.

REFERENCES

ASCE (2017). Standard practice for direct design of buried precast concrete pipe using standard installations (SIDD). ASCE/CI 15-17. 2017.

UMA (2008). Standard practice for the design and installation of rigid gravity sewer pipe in the city of Calgary. UMA Engineering Ltd. 0082-242-00.

USACE (1998). Engineering and design conduits, culverts, and pipes. U.S. Army Corps of Engineering. EM 110-2-2909. 31 March 1998. DC.

Moser, A. and Folkman, S. (2008). Buried pipe design. 3th edition. McGraw Hill. New York.

ACPA (2007). Concrete pipe design manual. American Concrete Pipe Association. www.concrete-pipe.org.

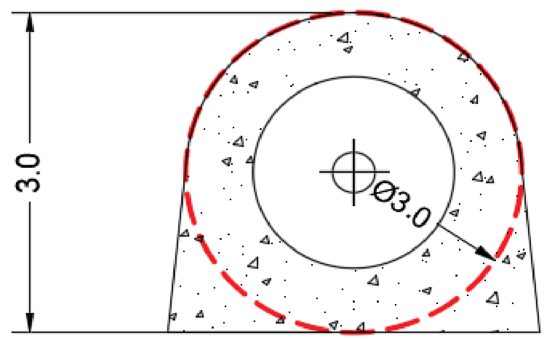
Project: SR1: LLOW	Cal.: Direct Design
Project No:	Project No:110773396
made by: EF	Date: 9/27/2019
ckd by:	

Scope:

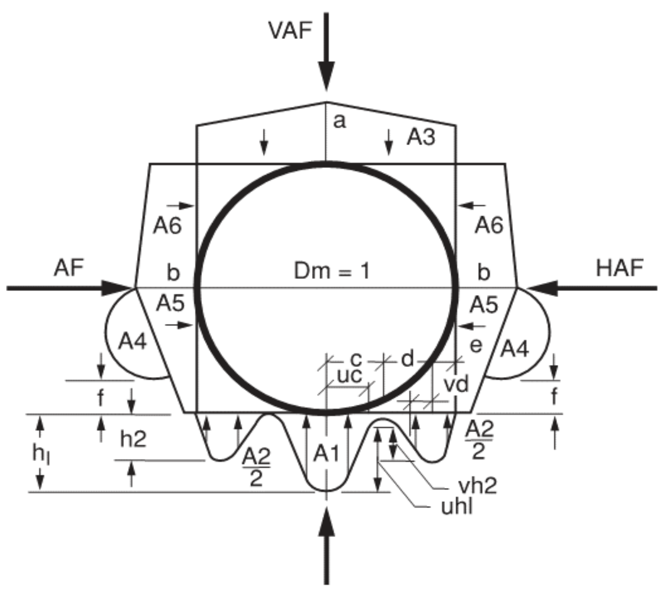
Calculate the soil pressures and forces actiong on the conduit using the direct method.

Geometry:

Equivalent diameter



Calculations:



Soil unit weight	w =	20	kN/m^3
Equivalent diameter	Do =	3	m
Overburden height	H=	13.4	m

Installation Type	VAF	HAF	A1	A2	A3	A4	A5	A6
1	1.35	0.45	0.62	0.73	1.35	0.19	0.08	0.18
2	1.40	0.40	0.85	0.55	1.40	0.15	0.08	0.17
3	1.40	0.37	1.05	0.35	1.40	0.10	0.10	0.17
4	4.45	0.30	1.45	0.00	1.45	0.00	0.11	0.19

Installation Type	a	b	c	e	f	u	v
1	1.40	0.40	0.18	0.08	0.05	0.80	0.80
2	1.45	0.40	0.19	0.10	0.05	0.82	0.70
3	1.45	0.36	0.20	0.12	0.05	0.85	0.60
4	1.45	0.30	0.25	0.00		0.90	-

$$PL = w\,(H + \frac{Do\,(4-\pi)}{8}\,Do)$$

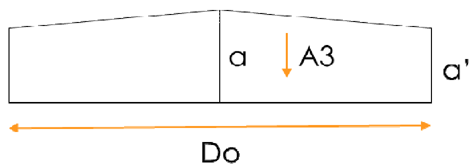
PL = 287.3 kN

Instalation Type 1

	Factor	Force
VAF	1.40	402.2 kN
HAF	0.40	114.9 kN
A1	0.85	244.2 kN
A2	0.55	158.0 kN
A3	1.40	402.2 kN
A4	0.15	43.1 kN
A5	0.08	23.0 kN
A6	0.17	48.8 kN
a	1.45	138.9 kN/m
b	0.40	38.3 kN/m
c	0.19	0.6 m
e	0.10	0.3 m
f	0.05	0.2 m
u	0.82	2.5 m
v	0.70	2.1 m
d	0.21	0.6 m
h1	3.69	353.1 kN/m
h2	1.48	141.9 kN/m
uc	0.1558	0.47 m
vd	0.147	0.44 m

uh1	289.56 kN/m
vh2	99.30 kN/m

Equivalent Distributed Loads



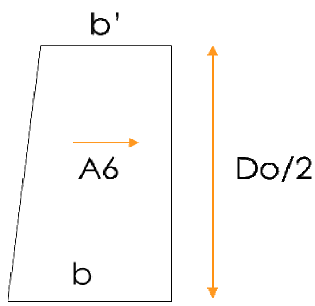
VAF 1.40

a = 1.45 PL/Do

$$\frac{(a+a')}{2}\frac{Do}{2}2 = 1.4\text{PL}$$

$$a' = 1.35\frac{PL}{Do}$$

a' =	129.3	kN/m



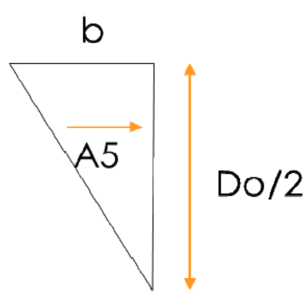
A6 = 0.17

b = 0.4 PL/Do

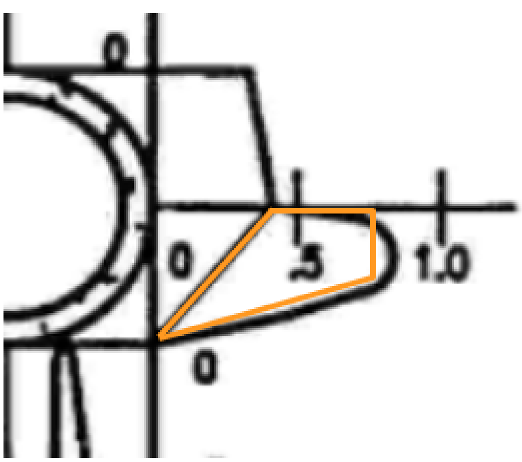
$$\frac{(b+b')}{2}\frac{Do}{2} = 0.17\text{PL}$$

$$b' = 0.28\frac{PL}{Do}$$

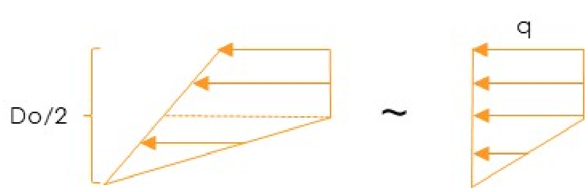
b' =	26.82	kN/m



b = 38.3 kN/m



A4 = 43.1 kN

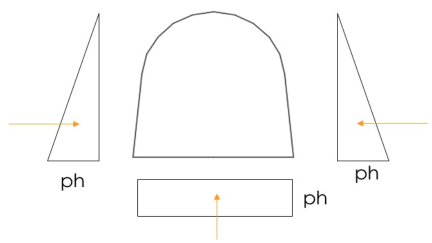


$$d' = Do/2$$

d'*q+1/2*q*d'=0.15*PL=A4

q=	28.73	kN/m

Water Pressure



Do =	3	m
γw =	9.81	kN/m3
ph =	29.4	kN/m

Resultant Forces

The structure was modeled using the FE computer program Robot (2019). Loads developed using the Direct Design method were superimposed to the frame comprised of beam elements that represented the conduit structure.
Since the FE model require supports to converge to a solution, two foundation scenarios are explored: Condition 1) consider elastic foundation under the bottom of the conduit structure; and Condition 2) consider an elastic support at the ends of the bottom section of the conduit structure.

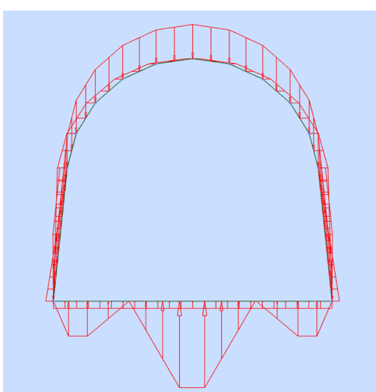
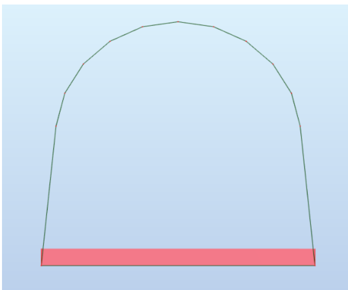


Figure 1 shows all the loads applied to the conduit structure. Loads were derived using the Direct Design method.

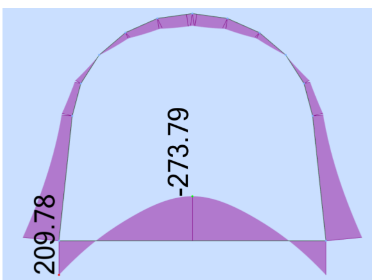
Loads acting on conduit structure

Condition 1.

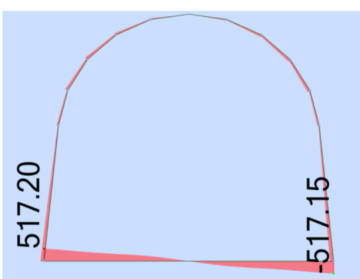
Elastic fundation



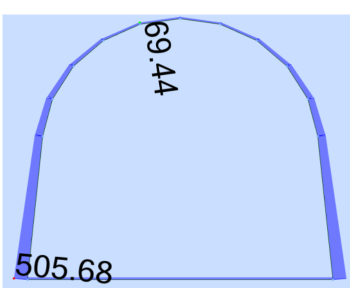
Moment Diagram



Shear Force Diagram

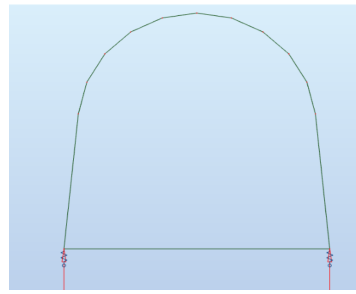


Axial Force Diagram

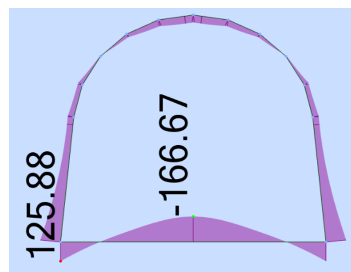


Condition 2.

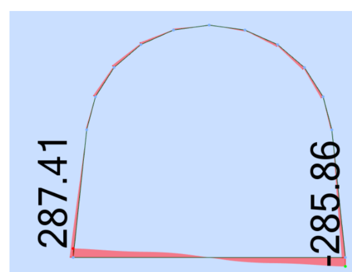
Elastic supports



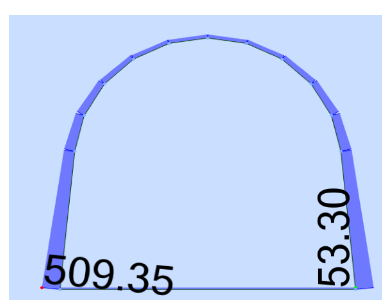
Moment Diagram



Shear Force Diagram

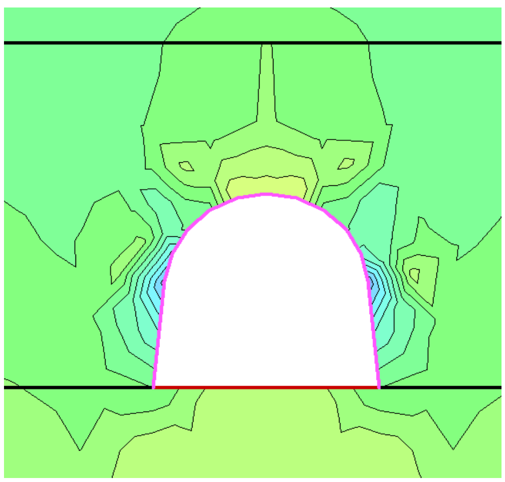


Axial Force Diagram



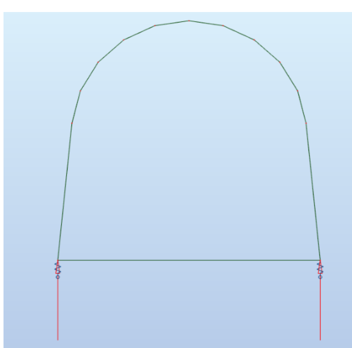
Discusion

The resultant shear forces and moments acting on the bottom of the conduit of the structure are susceptible to the foundation condition assumed for the analysis. According to the FEM developed with GeoStudio, the stresses under the bottom of the conduit structure are no homogeneous.

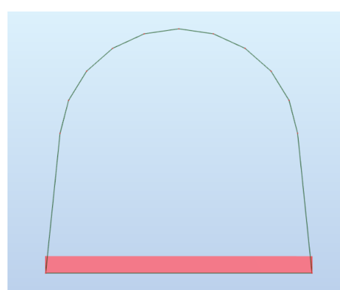


Total vertical stresses (from Geostudio FEM)

Assumed foundation conditions.



Elastic supports



Elastic fundation

UNUSUAL LOAD CONDITION 1
UN1

Stantec

TITLE: LLOW PRESSURE CONDUIT ANALYSIS – LOAD CONDITION UN1

Author: E. Farfan
Project: SR-1
Project No.: 110773396
Date: 9/27/2019
Drawing: S-400

INTRODUCTION

This report provides an analysis of the forces acting on the walls of the Low-Level Outlet Works (LLOW) gravity conduit. The LLOW is a gated gravity drainage structure located within the banks of the Unnamed Creek and constructed through the embankment dam.

The LLOW conduit structure comprised of a cast-on-place reinforced concrete placed on an excavated channel that will be filled to the existing ground elevation. The walls of the excavation are far apart that the effects on the structure of the interaction between the native soil and the fill can be neglected in the analysis.

The acting forces on the LLOW gravity conduit are evaluated using a finite element model (FEM). The module Sigma/W from the computer program GeoStudio (2018) was used for the FE analysis.

OBJECTIVES

Determine the forces acting on the LLOW structure using an FE analysis.

GEOMETRY

The location of the cross-section selected to represent the highest overburden over the LLOW gravity conduit was located near the crest of the embankment on the downstream side from the embankment centerline as depicted in Figure 1.

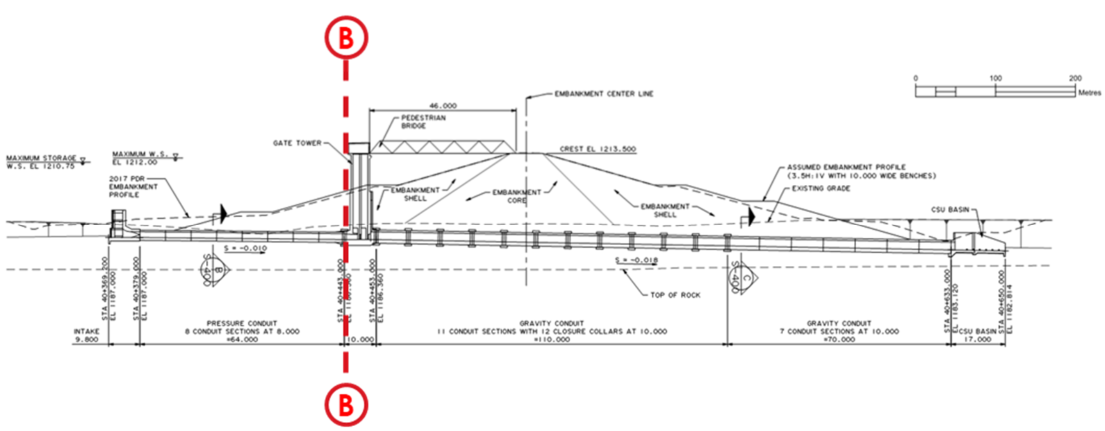


Figure 1. Location of the cross-section considered for the FE analysis.

The geometry of the LLOW gravity conduit is provided in Figure 2.

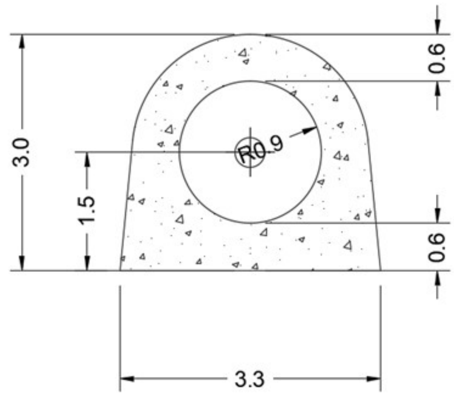


Figure 2. LLOW gravity conduit geometry (dimensions in meters).

Figure 3 shows the soil profile at section A-A.

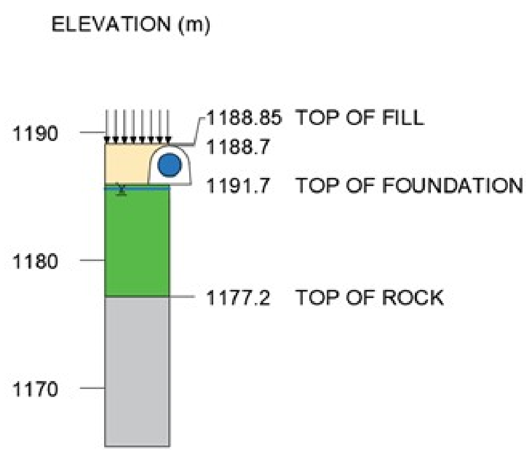


Figure 3. Soil profile at Section A-A.

MODEL DETAILS

The FE model (FEM) comprised of a region of 24.2m wide (or 5.8 times the structure size) and 36.6m in-depth (or 4 times the structure size). The region is discretized using a 1m global element size and a mix of quad and triangle unstructured mesh (see figure 4).

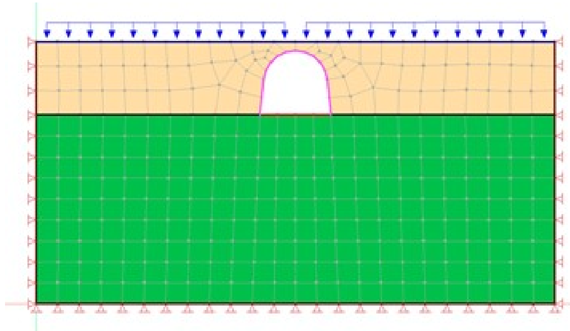


Figure 4. Mixed quad and triangle unstructured mesh (1m size element)

The discretization of the region resulted in 338 nodes and approximate 287 elements. The analysis is performed using a 2D model with 3 degrees of freedom at each node (displacement [x, y directions], and pore-water pressure). The model does not allow slip between the soil and the structural beams, this assumption results in higher stresses on the structure if slip was allowed to occur.

Groundwater table was set at the same elevation of the top of the conduit.

Material Data

Soil materials are modeled using elastic-plastic elements under drained conditions. Table 1 summarizes the soil parameters considered in the FEM.

Table 1. Soil parameters

Elevation (m)	*Depth (m)*	*Description*	*Unit weight (kN/m3)*	*c (kPa)*	*φ (deg)*	*E (MPa)*	*μ*
1188.85	28.5	Fill	20	0	24	10	0.35
1181.0	4.0	Foundation	18	0	27	17	0.35
1177.2	3.8	Rock	Uncompressible				

The conduit was modeled using structural beams. Table 2 summarizes the parameters used to model the conduit walls. The modulus of elasticity was calculated using a block of concrete with compressive strength equal to 30 MPa.

Table 2. Gravity conduit model parameters

Location	*Ec (MPa)*	*A (m^2)*	*Ixx (m^4)*
Top Section	24647.5	0.60	0.018
Bottom Section	24647.5	0.60	0.018

LOADS

The effect of gravity as a body load and a traffic load (15 kPa) were considered in the analysis.

CONSTRAINS

The model was constrained from lateral movement on the side boundaries and axial movement at the bottom boundary (see figure 4).

RESULTS

Results of the FEA are presented in Figure 5 and summarized in Table 3. Figure 5 shows the diagrams for the moment, shear and axial forces respectively.

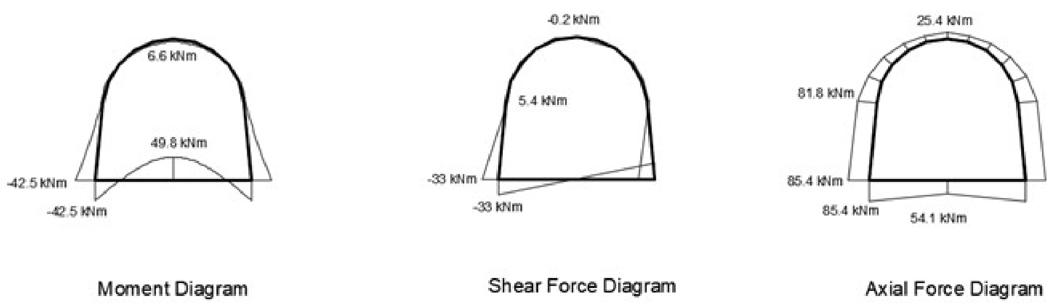


Figure 5. Moment, Shear and axial forces diagrams.

Table 3. Summary of resultant forces.

Location	*Max. Moment (kNm)*	*Max. Shear Force (kN)*	*Max. Axial Force (kN)*
Top Section	6.6	0.2	24.4
Bottom Section	49.8	33.0	85.4

Stantec

Applicability of the methodology used in this analysis is presented in the calculations for the load condition U1.

REFERENCES

ASCE (2017). Standard practice for direct design of buried precast concrete pipe using standard installations (SIDD). ASCE/CI 15-17. 2017.

UMA (2008). Standard practice for the design and installation of rigid gravity sewer pipe in the city of Calgary. UMA Engineering Ltd. 0082-242-00.

USACE (1998). Engineering and design conduits, culverts, and pipes. U.S. Army Corps of Engineering. EM 110-2-2909. 31 March 1998. DC.

Moser, A. and Folkman, S. (2008). Buried pipe design. 3th edition. McGraw Hill. New York.

ACPA (2007). Concrete pipe design manual. American Concrete Pipe Association. www.concrete-pipe.org.

UNUSUAL LOAD CONDITION 2
UN2

Scope: Calculate the factor of safety against uplift per unit length (1m) of the two sections that comprise the LLOW Pressure Conduit

Geometry:

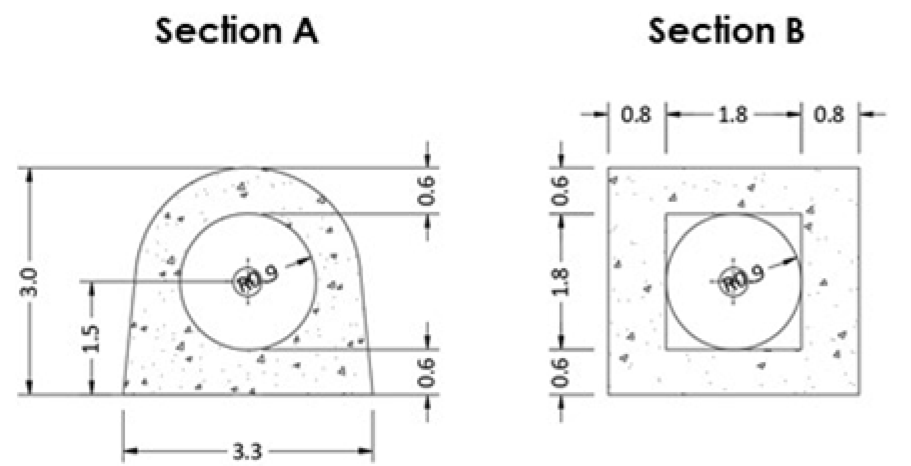


Figure 1. Cross section LLOW Pressure Conduit

Calculations:

Section A

$A_A := 5.738\ m^2$ Effective cross section area

$A_{AT} := 8.282\ m^2$ Cross section structure

Opening $A_{opA} := A_{AT} - A_A = 2.544\ m^2$

Section B

$A_B := 6.96\ m^2$ Effective cross section area

$A_{BT} := 10.2\ m^2$ Cross section structure

Opening $A_{opB} := A_{BT} - A_B = 3.24\ m^2$

$\gamma_c := 23.5\ \frac{kN}{m^3}$ Unit weight of concrete

$\gamma_w := 9.81\ \frac{kN}{m^3}$ Unit weight of water

Factor of Safety

Section A $FS := \frac{A_A \cdot \gamma_c + A_{opA} \cdot \gamma_w}{A_{AT} \cdot \gamma_w} = 1.967$

Section B $FS := \frac{A_B \cdot \gamma_c + A_{opB} \cdot \gamma_w}{A_{BT} \cdot \gamma_w} = 1.95$

UNUSUAL LOAD CONDITION 3
UN3

Scope: Calculate the factor of safety against uplift per unit length (1m) of the two sections that comprise the LLOW Pressure Conduit

Geometry:

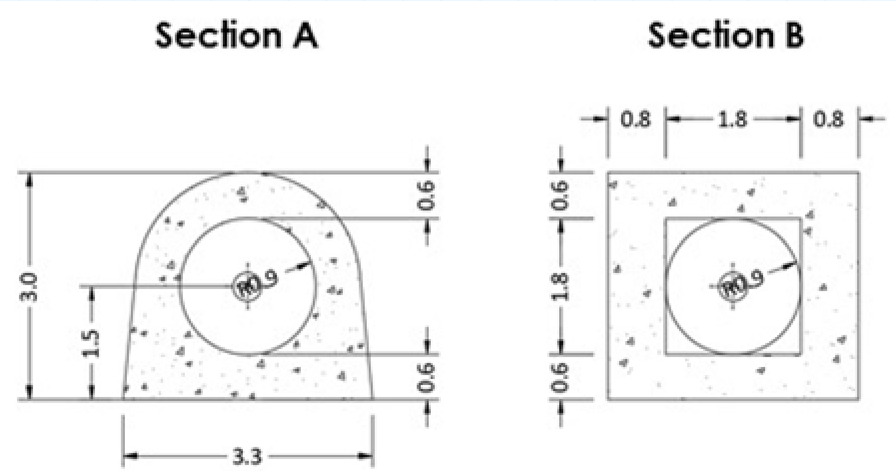


Figure 1. Cross section LLOW Pressure Conduit

Calculations:

Section A

$A_A := 5.738\ m^2$ Effective cross section area

$A_{AT} := 8.282\ m^2$ Cross section structure

Section B

$A_B := 6.96\ m^2$ Effective cross section area

$A_{BT} := 10.2\ m^2$ Cross section structure

$\gamma_c := 23.5 \ \dfrac{kN}{m^3}$ Unit weight of concrete

$\gamma_w := 9.81 \ \dfrac{kN}{m^3}$ Unit weight of water

Factor of Safety

Section A $FS := \dfrac{A_A \cdot \gamma_c}{A_{AT} \cdot \gamma_w} = 1.66$

Section B $FS := \dfrac{A_B \cdot \gamma_c}{A_{BT} \cdot \gamma_w} = 1.63$

EXTREME LOAD CONDITION 1
E1

Scope: Evaluate the seismic effects on the LLOW Pressure Conduit under the load case Extreme Load Condition (E1).

Geometry:

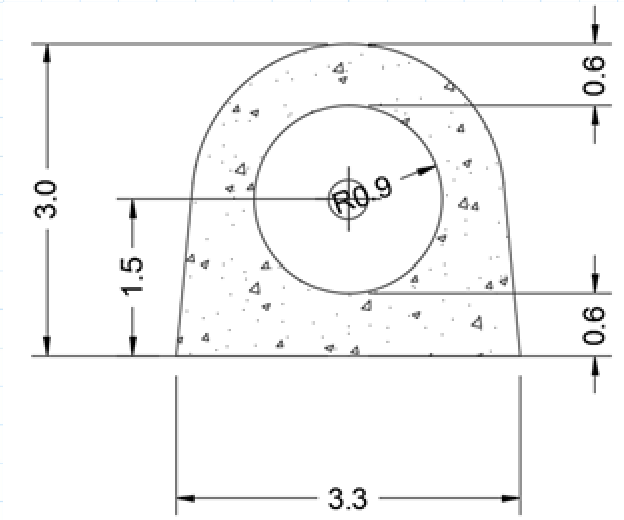


Figure 1. Cross section LLOW Pressure Conduit

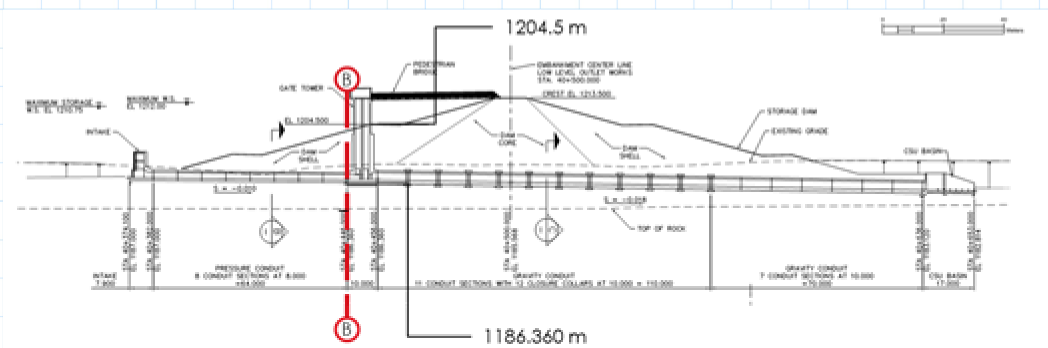


Figure 2. Embankment Corssection and LLOW Conduit Profile

Elevations:

Top of Embankment $EL_{emb} := 1204.5\ m$

Bottom of Conduit $EL := 1186.360\ m$

Loads:

Peak Ground Acceleration $PGA := 0.26$

Calculations:

$\gamma_s := 20 \frac{kN}{m^3}$ Soil unit weight

$D := 4\ m$ Conduit Diameter

Top of Counduit

$z_1 := EL_{emb} - EL - D = 14.14\ m$ Soil Height

$\sigma_{v1} := z_1 \cdot \gamma_s = 282.8\ kPa$ Total Stress

$R_{d1} := 1.174 - 0.00814 \cdot \frac{z_1}{ft} = 0.796$

$\tau_{max1} := PGA \cdot \sigma_{v1} \cdot R_{d1} = 58.556\ kPa$

Bottom of Counduit

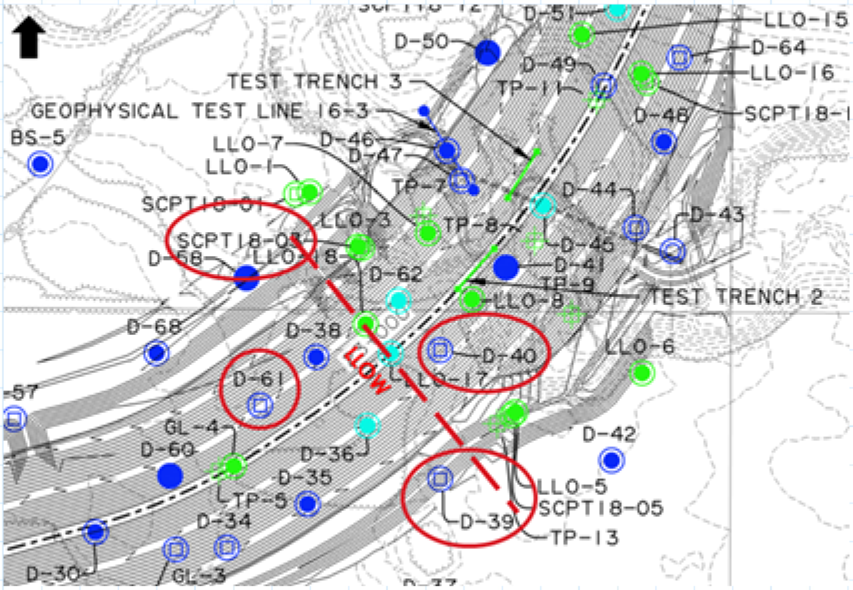
$z_2 := EL_{emb} - EL = 18.14\ m$ Soil Height

$\sigma_{v2} := z_2 \cdot \gamma_s = 362.8\ kPa$ Total Stress

$R_{d2} := 1.174 - 0.00814 \cdot \frac{z_2}{ft} = 0.69$ Depth-dependent stress reduction factor

$\tau_{max2} := PGA \cdot \sigma_{v2} \cdot R_{d2} = 65.044\ kPa$ Maximum earthquake-induced stress

Ground shear modulus



CPT Data

$q_{t1} := 25\ bar = 2.5\ MPa$ CPT D-39

$q_{t2} := 60\ bar = 6\ MPa$ CPT D-40

$q_{t3} := 30\ bar = 3\ MPa$ CPT D-61

$q_{t4} := 25\ bar = 2.5\ MPa$ SCPT18-03

$$q_t := \frac{q_{t1} + q_{t2} + q_{t3} + q_{t4}}{4} = 3.5\ MPa$$ Average CPT tip resistance

$$\sigma'_v := \frac{\sigma_{v1} + \sigma_{v2}}{2} = 322.8\ kPa$$ Average Effective Stress

$$G_{max} := 1634\ kPa \cdot \left(\frac{q_t}{kPa}\right)^{0.250} \cdot \left(\frac{\sigma'_v}{kPa}\right)^{0.375} = 109.678\ MPa$$ Maximum shear modulus

$G_m := 0.9 \cdot G_{max} = 98.71\ MPa$ Effective, strain-compatible shear modulus of the ground surrounding the conduit. (small strain factor 0.9)

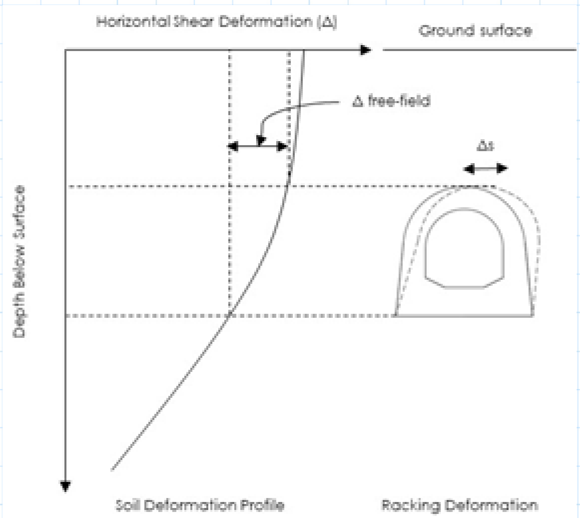
$$\gamma_{max1} := \frac{\tau_{max1}}{G_m} = 5.932 \cdot 10^{-4}$$ Top of Conduit

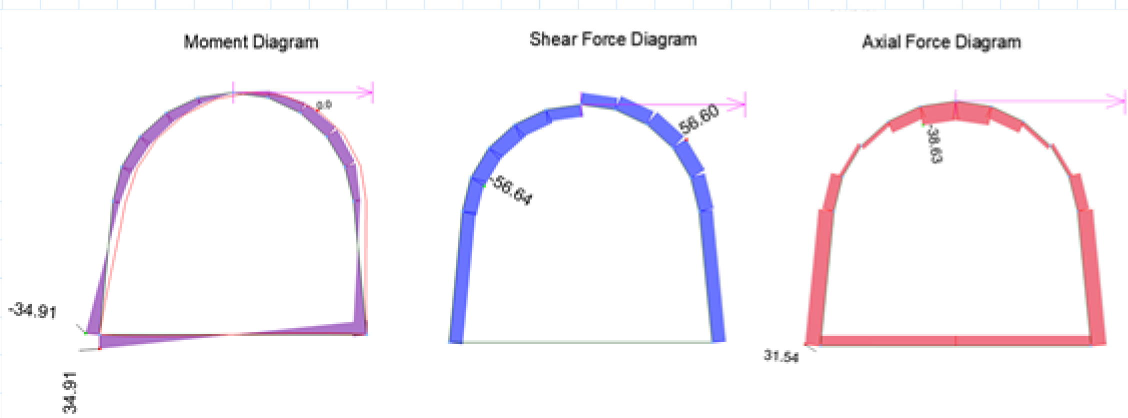
$$\gamma_{max2} := \frac{\tau_{max2}}{G_m} = 6.589 \cdot 10^{-4}$$ Bottom of Conduit

$$\Delta_{free\_field1} := D \cdot \gamma_{max1} = 0.237\ cm$$ Top of Conduit

$$\Delta_{free\_field2} := D \cdot \gamma_{max2} = 0.264\ cm$$ Bottom of Conduit

$$\Delta_{free\_field} := \Delta_{free\_field1} - \Delta_{free\_field2} = -0.026\ cm$$





APPENDIX E.5-5 PROJECT DRAWINGS

Refer to Preliminary Design Report – Appendix A for drawings.

Springbank Off-Stream Storage Project Structural Design Report

Debris Deflection Barrier

Prepared for:

Alberta Transportation
3rd Floor – Twin Atria Building
4999 – 98 Avenue
Edmonton, AB T6B 2X3

Prepared by:

Stantec Consulting Ltd
Calgary, AB

Project Number 110773396

September 25, 2020

Table of Contents

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

1.0 INTRODUCTION

1.1 PURPOSE

This Structural Design Report (SDR) describes stability assessment, structural analyses and design of the Debris Deflection Barrier (DDB), which is part of the Springbank Off-stream Storage Project (SR1). The SDR consolidates and documents the design philosophy, relevant criteria, primary design parameters, and reference source of data used for design. The Debris Deflection Barrier was sized to meet stability requirements and major structural members were designed for conformance with structural criteria.

1.2 PROJECT OVERVIEW

SR1 is a flood diversion system comprised of a diversion structure, a diversion channel and off-stream dry storage reservoir (no permanent pool). When in operation, SR1 will divert and temporarily store excess flood water from the Elbow River and release it back into the river system in a controlled manner. SR1 will work in tandem with the downstream Glenmore Reservoir to limit flood flows downstream of Glenmore to less than 170 m^3/s for up to SR1's design event - the 2013 flood or its equivalent.

Elements of the project are:

- Diversion Structure on the Elbow River consisting of, from left to right when looking downstream, gated Diversion Inlet structure leading to a Diversion Channel, gated Service Spillway located on the Elbow River, adjacent Auxiliary Spillway and a Floodplain Berm. A Debris Deflection Barrier is in the headwater of the Diversion Structure to protect the Diversion Inlet from flood debris.

- Diversion Channel leading from the Elbow River at the Diversion Inlet to the Off-stream Storage Reservoir with an Emergency Spillway along the channel and Channel Outlet at end of the channel.

- Off-stream Storage Dam with Low-Level Outlet Works.

1.3 DESIGN OBJECTIVES

The primary objective of the DDB is to reduce the risks that large debris pose to the operation of the Diversion Inlet gates during a flood event, and to the bridge piers and other structures in the Diversion Channel. The alignment of the barrier, parallel to the river, promotes the passage of debris through the Service Spillway and downstream into the Elbow River.

The structure will normally be in a dry condition except during flood events. After flood events, debris removal from the Debris Deflection Barrier and Service Spillway will be needed. After each event, the DDB may be damaged as the debris impacts the structure and repairs may be needed to restore any damaged portions of the frame. The DBB can be envisioned as a large trash rack as with trash racks maintenance is key. The DDB is a secondary system and is not the primary flood control structure.

1.4 GENERAL ARRANGEMENT

The DDB consists of a steel framed post and horizontal beam system bearing on a concrete foundation. The concrete foundation bears on the rock subgrade and incorporates a tension component using drilled shafts. The structure is 165-m-long with a variable height concrete foundation wall surmounted by a 5.75-metre-tall steel frame. The structure is divided into 10.0 m panels consisting of four vertical posts, a horizontal cross brace at the top and six or seven horizontal pipes mounted to the steel vertical members. The horizontal members of the frame are comprised of hollow steel structural piping spaced 750 mm apart.

The concrete foundation wall forms the left bank of the Elbow River and extends from rock to the 1:2 -year water surface. This ranges from Elevation 1211.5 m at the Service Spillway upstream to Elevation 1212.0 at the left Elbow River abutment. The top of the frame is set to Elevation 1217.25 m: the Probable Maximum Flood in the Elbow River assuming no diversion.

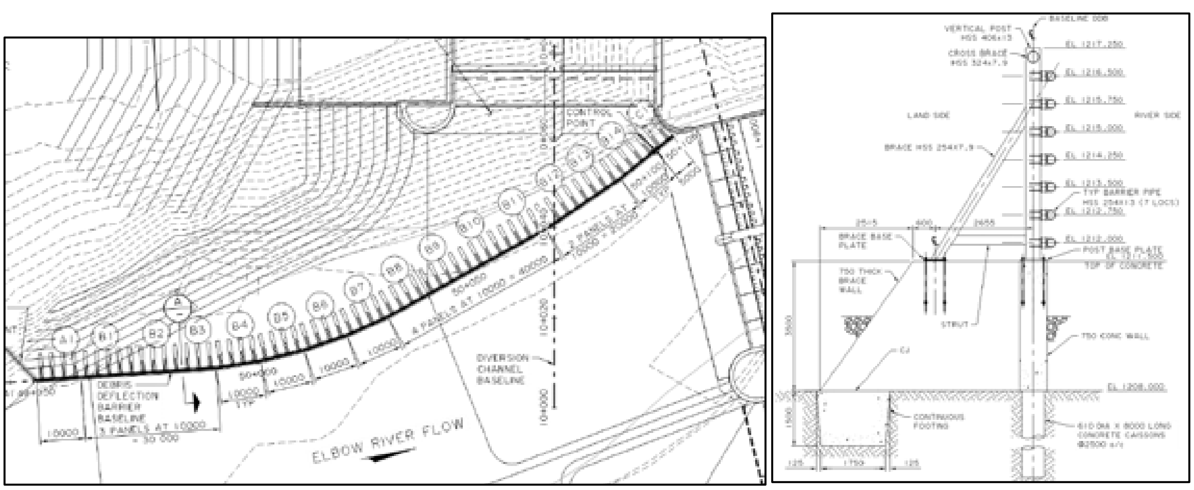


Figure 1. Plan and Section of Debris Deflection Barrier

1.5 BASIS FOR STRUCTURE LAYOUT

The DDB layout is based on physical hydraulic model studies and computational hydrotechnical evaluations to establish overall geometry and layout angles. The orientation was selected based on physical hydraulic modelling results. The loading was assessed by computational fluid dynamic (CFD) modelling and debris assessment. The foundation was designed in such way with a goal to reduce uplift while providing rigidity to the structure with the connection between the drilled shafts and the footings. The space between the rack steel pipes was selected based on CFD modelling. The rack spaces permit water to flow through the barrier while still having a barrier to limit passage of large debris before entering the Diversion Channel. The spacing between the vertical posts was determined to be 2.5 metres based on preliminary element sizing, layout, buildability and to avoid side by side posts at module ends.

2.0 CODES AND STANDARDS

In accordance with "terms of reference" for this project, the design complies with current Alberta Transportation (AT) Design Standards and current AT Design and Construction Bulletins. By reference in AT Standards, Canadian Dam Association (CDA) Dam Safety Guidelines and Technical Bulletin Nos. 1 through 9 provided primary guidance for design of the project including the hydraulic structures. Other recognized industry standards referenced in the AT/CDA Guidelines were used to supplement aspects of the design that the AT/CDA Guidelines do not address. Such references include the US Army Corps of Engineers (USACE) Engineering Manuals and US Bureau of Reclamation (USBR) Design Standards. In case of conflicting criteria, AT provisions were used unless a "more stringent" requirement was deemed appropriate based on engineering judgement.

Where referenced by AT and CDA, the Alberta Building Code (ABC) was used to obtain certain design loads (wind, snow, live, vehicle), and develop load combinations associated with strength and serviceability. ABC provisions were used primarily for evaluation of individual elements based on wind and snow loading. Otherwise loading was based on physical model testing, CFD modelling, and the debris assessment report.

The following codes, guidelines, and standards were identified for use on this project:

2.1 PROJECT STANDARDS

- Alberta Government, Terms of Reference (TOR0015997) for "Flood Mitigation Works, Springbank Off-Stream Storage Project (SR1) (WAC0078983), Addendum No. 2," August 1, 2014.
- AT's "Engineering Consultant Guidelines for Highway Bridge and Water Projects, Volume 1- Design & Tender" - 2011.
- AT's "Engineering Consultant Guidelines for Highway Bridge and Water Projects, Volume 2- Design & Tender" - 2011.
- AT's Civil Works Master Specifications for Construction of Provincial Water Management Projects.

2.2 DAM DESIGN AND SAFETY

- Province of Alberta Water Act – Water (Ministerial) Regulation - Regulation 205/98 (consolidated up to 185/2015).
- AT's "Water Control Structures Selected Design Guidelines" – Nov. 2004
- Canadian Dam Association Dam Safety Guidelines (CDA) 2007 with 2013 Revisions.
- CDA – Technical Bulletins:
    1. Inundation, Consequences, and Classification for Dam Safety, 2007
    2. Surveillance of Dam Facilities, 2007
    3. Flow Control Equipment for Dam Safety, 2007
    4. Retracted & Replaced by "Guidelines for Public Safety Around Dams," 2011
    5. Dam Safety Analysis and Assessment, 2007
    6. Hydrotechnical Considerations for Dam Safety, 2007
    7. Seismic Hazard Considerations for Dam Safety, 2007
    8. Geotechnical Considerations for Dam Safety, 2007
    9. Structural Considerations for Dam Safety, 2007
- USACE - Stability Analysis of Concrete Structures - EM 1110-2-2100, December 2005
- USACE – Earthquake Design and Evaluation of Concrete Hydraulic Structures - EM 1110-2-6053, 1 May 2007
- USACE - Gravity Dam Design - EM 1110-2-2200, June 1995
- USACE – Retaining and Flood Walls – EM 1110-2-2502, 29 September 1989

- USBR – Design Standards No. 14, Appurtenant Structures for Dams (Spillways and Outlet Works) Design Standards, Chapters 1 to 3, August 2014
- USBR – Design of Small Dams, 3rd Edition, 1987
- FEMA – Best Practices Technical Manuals

2.3 BUILDING CODE & PERSONNEL SAFETY

- Alberta Building Code (ABC) 2014
- National Building Code of Canada (NBCC) 2015
- Alberta Occupational Health and Safety Code (OHS code).

2.4 STRUCTURAL ANALYSIS, DESIGN AND MATERIAL SPECIFICATIONS

- Concrete Materials and Methods of Concrete Construction, CSA A23.1-14 & A23.2 -14
- Design of Concrete Structures, CSA A23.3-14
- Design of Steel Structures, CSA S16-14
- Welded Steel Construction, CSA W59-13
- Canadian Foundation Engineering Manual, Canadian Geotechnical Society – 4th Ed., 2006
- Canadian Highway Bridge Design Code
- Alberta Transportation Bridge Design Criteria
- Reinforcing Steel Institute of Canada, Standards Practice Manual

3.0 PROJECT DATA

3.1 LOCATION

The project is located in the Springbank area of Rocky View County, Alberta, Canada, southwest of the City of Calgary in Township 24 (Range 04/03, W5M).

Latitude	51.050504 N
Longitude	114.401436 W
Elevation	1180 to 1220 m

3.2 FOUNDATION PARAMETERS

Site characterization is based on geologic assessment of the project site, exploratory borings, laboratory testing of project samples, and geotechnical engineering judgment. The Debris Deflection Barrier will bear on bedrock of the Brazeau Formation in the bed of the Elbow River. At this location, the Brazeau Formation consists of thin beds of steeply dipping, highly weathered and fractured claystone, mudstone, shale and sandstone. The bedrock conditions for use in design were established from a site-specific geotechnical exploration and the associated laboratory testing. The following foundation parameters, derived from Brazeau formation data, are described in the PDR, Appendix D - Geotechnical Assessment Report, Section 5.7.

Bedrock Unit Weight	25.6 kN/m^3	
Bedrock Friction Angle (Rock/Rock Interface) (φ)	26 Deg.	
Concrete/Rock Interface Friction Angle (φ)	26 Deg.	
Cross Bed Friction Angle (φ) – Passive Wedge	24 Deg.	
Ultimate Bearing Capacity (σ_{ult})	1915 kPa	
Allowable Bearing Capacity – Usual	1270 kPa	(σ_{ult}/1.5 $_{SF}$)
Allowable Bearing Capacity – Unusual	1470 kPa	(σ_{ult}/1.3 $_{SF}$)
Allowable Bearing Capacity – Extreme	1740 kPa	(σ_{ult}/1.1 $_{SF}$)

Cohesion: In accordance with CDA Guidelines Technical Bulletin No. 7 (Geotechnical) and Technical Bulletin No. 8 (Structural), cohesion was not included in the sliding stability analysis, and acceptance criteria is based on sliding factors for friction only resistance.

The foundation structure elements (caissons and spread footings) were configured based on the design parameters and the applied structure loading discussed later. A full description of the design process of the foundation elements is presented in PDR, Appendix D - Geotechnical Assessment Report, Section 10.5.

3.3 HYDROTECHNICAL PARAMETERS

Table 1 provides a summary of the hydrotechnical parameters used in the design.

Table 1. Elbow River Water Levels

Load Case	U/S Water Level (m)	D/S Water Level (m)
Usual Load Cases (Normal)		
U1 – Normal pool elevation (Sunny Day)	1211.5	1211.5
U2 – 1:100 Year Flood (760 m^3/s) with Log Impact Load	1215.8	1215.8
Unusual Load Cases		
UN1 – FoR (1240 m^3/s) with Vehicle Impact Load	1215.8	1215.8
UN2 – 1:100 Year Flood (760 m^3/s) with 33% Blocked	1216.05	1215.8
Extreme Load Cases		
E1 – 1:100 Year Flood (760 m^3/s) with 70% Blocked	1216.5	1215.8
E2 – Sunny Day with Seismic	1211.5	1211.5

3.4 CLIMATE DATA

3.4.1 Snow

Snow Load data for this project was obtained from Environment Canada and Alberta Building Code.

- Ground snow load, snow component (S_s) =1.7 kPa
- Ground snow load, rain component (S_r) =0.1 kPa
- Snow load, Importance factor (I_s) =1.25

3.4.2 Frost Considerations

Frost depth was determined in accordance with Alberta Building Code and is shown in PDR, Appendix D - Geotechnical Assessment Report.

- Minimum design frost depth of 2.0 m
- Non-frost susceptible backfill - Gravel and clean sands

3.4.3 Temperature Variations

Monthly temperature data for use in the evaluation was obtained from the Calgary International Airport records, which is considered representative of typical temperature ranges at the project site.

3.4.4 Wind

A wind load of 0.48 kPa was determined for use at the site based on the Alberta Building Code.

4.0 CONSTRUCTION MATERIALS

4.1 CONCRETE AND CONCRETE ACCESSORIES

- **Structural Concrete – Class A1**
  General use reinforced concrete where thermal control and volume change are not a concern.
  Minimum Compressive Strength: 30 MPa @ 28 days
  Mixture defined in Section 03300 – Concrete, AT Civil Works Specifications.

- **Foundation Concrete - Class F**
  15 MPa @ 28 days, (AT Civil Works Specifications)
  For use in foundation preparation such as mud mats and low strength fill.

- **Grout**
  Premixed structural non-shrink grout for equipment bases.

- **Preformed Expansion Joint Filler**
  ASTM D1752, Type I, Closed-cell sponge rubber.

- **Bond Breaker**
  Bituminous paint conforming to CGSB 37.2-88.

4.2 METALS

- **Steel Reinforcement - CAN/CSA-G30.18, Grade 400W deformed bars**
- **Structural Steel - CSA-G40.21, Grade 300W or 350W – Hot-dipped Galvanized**
- **Stainless Steel - ASTM A276**
- **Weathering Steel – ASTM A588, A242, A847, and A709-50W**
- **Miscellaneous Metals (ladders, handrails) - Galvanized steel**

4.3 EARTHWORK MATERIALS

The Debris Deflection Barrier will be constructed on the existing rock foundation. Soil backfill parameters are based on terminology in AT's Civil Works Master Specification 02330 – Earthwork Materials and described in the PDR, Appendix D - Geotechnical Assessment Report.

Design values for specified material include:

Impervious Fill

Unit Weight (-)	21 kN/m^3
Internal Friction Angle (-)	18 deg

Granular Fill

Unit Weight (-)	21 kN/m^3
Internal Friction Angle (-)	34 deg

Glacial Till

Unit Weight (-)	20 kN/m^3
Internal Friction Angle (-)	27 deg

Rock Fill

Unit Weight (-)	22 kN/m^3
Internal Friction Angle (-)	20 deg

Siltation (Equivalent Fluid)

Unit Weight Vertical (-)	19 kN/m^3
Unit Weight Horizontal (-)	13 kN/m^3

5.0 STRUCTURAL ANALYSIS APPROACH

For the purposes of analysis and structural design, the Debris Deflection Barrier was divided into a steel frame, and reinforced concrete base walls and foundation. Each component of the structure was evaluated, as applicable, for global stability, strength, and serviceability. Each element or member of the DDB was assessed for applicable imposed loads to which they may be subject per the governing code criteria.

Strength evaluation was used to verify size of critical components such as structural steel framing components, concrete walls, footing and caissons. Strength evaluation of individual concrete elements and members was performed to verify member sizes and reinforcement requirements in accordance with CSA A23.3-14 and as supplemented using CSA "Structural Design of Wastewater Treatment Plants 2018 for revisions addressing service load conditions, shrinkage and temperature reinforcement and crack control. Strength evaluations provided design values for sizing concrete reinforcement and joint doweling. A combination of Excel spreadsheets and SAP2000 software was used to generate shear and moment values for strength design of components. A three-dimensional finite element method (FEM) model consisting of steel framing elements and spring foundation loads was created to design the components. The FEM was supplemented with Excel calculations.

Serviceability includes limiting deflections, reducing crack potential, providing thermal stress relief, and incorporating measures to mitigate alkali-aggregate reaction (AAR). A combination of Excel spreadsheets, or commercial software were used to evaluate deflection and thermal effects. Finite Element Models (FEMs) were used to validate manual calculations, identify potential stress concentrations, and assess additional serviceability concerns such as localized deflection, need for thermal stress relief, and stress redistribution not captured in manual calculations. Design detailing and material specification were used to mitigate concrete cracking and AAR potential.

5.1 DESIGN TOOLS AND SOFTWARE

- Microsoft Excel - 2010 - version: 14.0.7166.5000
- Mathcad 15.0 - 2013 - version: MC15_M030_20131216
- SAP2000 Advanced -2019- version 21.0.2

6.0 LOADS

6.1 DEAD LOADS (D)

Permanent loads on the structure include structure weight and water. Unit weights for principal materials are included in Table 2.

Table 2. Dead Load and Unit Weights

Material	Unit Weight	Source
Water	9.81 kN/m^3	CSA S6-14, Table 3.4
Reinforced Concrete	23.5 kN/m^3	AT WCS Design Guide 4.2
Steel	77.0 kN/m^3	AT WCS Design Guide 4.2

6.2 HYDROSTATIC LOADS (H)

Both horizontal and vertical components of water load were based on the water surface elevation for the load condition considered. Upstream and downstream water surface elevations are described in Hydrotechnical Parameters, Section 3.3. The water surface elevations were considered to be hydrostatic pressures without kinematic effects. Headwater was considered the water surface elevation at the upstream face of the structure. Tailwater was considered the water surface elevation downstream of the DDB and upstream of the Diversion Inlet.

6.3 UPLIFT PRESSURE (U)

Uplift pressures were considered in the cross bedding failure plane as well as under the concrete walls depending on the stability section under review.

6.4 EARTH PRESSURE (E)

Soil loads include both vertical and horizontal forces due to backfill, sediment, and siltation. Since backfill does not vary from upstream to downstream, earth pressure was not considered for this structure except where scour was considered on upstream or downstream side of the DDB.

Vertical force associated with soil mass above the structure was included as dead load based on vertical projection of footing or structure below the soil. Soil mass was based on moist unit weight for material above waterline and buoyant unit weight for material below the waterline. Vertical force associated with water above the structure was calculated separate from the soil mass.

Horizontal force associate with soil were based on at-rest condition represented by the empirical relationship:

$K_o = 1 - \sin\theta$ where: K_o = At-rest lateral pressure coefficient(*)
θ = Soil friction angle

**In accordance with EM 1110-2-2100 and EM 1110-2-2502 to use At-Rest Coefficient (K_o)*

6.5 LIVE LOADS (V)

Live loads associated with occupancy, vehicles and equipment surcharges were considered insignificant compared to other transient loads and were not considered for the DDB.

6.6 HYDRODYNAMIC LOADS (HD)

The DDB alignment is oriented approximately parallel to the Elbow River to promote passage of debris downstream of the structure and through the Service Spillway. In addition, the physical model testing demonstrated that "flushing" debris from in front of the DDB through operation of the Service Spillway gates may be possible. However, the design of the DDB considered the possibility of debris to accumulate in front of the structure and the potential for loading on the structure from the drag forces acting upon the accumulation and transferred to the superstructure.

Drag force on the woody debris accumulations on the face of the rack was determined using the procedures described in the US Department of Transportation Federal Highway Administration's "Debris Control Structures – Evaluation and Countermeasures – Hydraulic Engineering Circular No. 9".

The drag force equation is sensitive to the drag coefficient which in-turn is sensitive to both blockage ratio and Froude Number. Because hydraulic and debris accumulation conditions in the backwater can be highly variable during operation, an envelope approach to the drag coefficients was employed in the design calculations by selecting combinations of blockage ratios and Froude numbers that could plausibly be present during operations. Table 3 provides the resultant drag coefficients from these combinations.

Drag force applied by water passing through the structure were considered in the design. For the "clean" barrier, drag from the structural members is computed using the Computational Fluid Dynamics (CFD) model results discussed in later sections. For debris blockage scenarios, the structure drag forces are assumed to be included with the debris drag force calculations. Table 3 shows the drag forces applied for each load case.

Table 3. Hydrodynamic and Drag Forces

Load Case	Hydrodynamic	Drag Force from Underside of Mat	Drag Force from Clogging
Usual Load Cases:			
U1	None	None	None
U2	1.0 KN/m	None	None
Unusual Load Cases:			
UN1	1.0 KN/m	None	None
UN2	None	66 kN/m acting on a 1.5 m band centered 0.75 m below the modeled water surface	Upper Rack = 2.1 kN/m Bottom Rack = 4.9 kN/m
Extreme Load Cases:			
E1	None	66 kN/m acting on a 1.5 m band centered 0.75 m below the modeled water surface	Upper Rack = 1.95 kN/m Bottom Rack = 4.55 kN/m
E2	None	None	None

6.7 DEBRIS AND IMPACT LOADS (IM)

Woody debris in transport can impact the DDB when the project is diverting floods. The impact forces were computed using the methods described in "Maximum Impact Force of Woody Debris on Floodplain Structures" (USACE 2002), specifically the one-degree of freedom model derived in that document.

The CFD model results suggest a velocity of approximately 3 m/s against the face of the rack when the project is diverting 600 m^3/s from a total flow on the Elbow River of 760 m3/s. Assuming an approach angle that is perpendicular to the barrier rack; and that the alignment of the design log is such that its butt-end contacts the rack first, the computed impact from the design log is 146 kN. This load is assumed to act on a single horizontal tube for Load Case U2.

The same one-degree of freedom model was used to estimate the impact forces from a heavy object entrained in the flow. A one-ton class truck was selected as surrogate for this object. Based on published base curb weight for a Ford F-350, the vehicle was assumed to have a weight of approximately 3084 kg (6800 lbs). The vehicle velocity was estimated at 3 m/s using the hydraulic model results which produces an impact force of 258 kN. This load was assumed to act on 3 of the horizontal tubes for the Load Case UN1. The debris and impact loading for the various load conditions is summarized in Table 4.

Table 4. Impact Forces

Load Case	Impact Force (IM)
Usual Load Cases (Normal)	
U1	None
U2	146 KN
Unusual Load Cases	
UN1	258 KN
UN2	None
Extreme Load Cases	
E1	None
E2	None

6.8 ICE LOAD(I)

Three types of ice load to consider for the DDB design include Static Ice Load (I_s), Dynamic Ice Loading (I_d), and Ice Accretion Load (I_v).

- **Static Ice Load (I_s)** is a result of water surface freezing with application of horizontal load as an ice sheet expands and confinement increases. Static Ice Loading has the potential to occur at low flow conditions. Static ice loading is applied in Usual Load Cases that address winter operating conditions.

- **Dynamic Ice Loading (I_d)** is a result of moving ice floe impacting the structure. Dynamic Ice Loading was not considered as a design load case because the Diversion Structure does not have a permanent pool.

- **Ice Accretion Load (I_v)** occurs when ice bonds to the structure and must be broken as water level rises. Ice Accretion Load associated with water level rise was not considered for the Diversion Structures including the DDB due to small order of magnitude relative to hydrostatic loading and low probability of occurring simultaneous with spring and summer flooding.

Frost Heave. Vertical ice loading associated with "frost heave" was considered. The structures are normally in a dewatered or low-water state with freeze/thaw action tending to open rock joints and concrete/rock interface and subject the structure to increased uplift potential. To minimize frost heave loading potential and remove this condition from the analysis, foundation interfaces were located below the identified frost depth of 2.0 m for this site and drainage provided to reduce the formation of ice in the foundation.

6.9 SEISMIC – EARTHQUAKE LOADS (Q)

The seismic classification for the Debris Deflection Barrier is based on Stantec's *Seismic Hazard Assessment - Springbank Off-Stream Dam and Reservoir Report* dated November 28, 2016. Since the hazard classification for this structure is Extreme (Off-stream Storage Dam) or High (Diversion Structure), the seismic parameters are based on an Earthquake Design Ground Motion (EDGM) with an Annual Exceedance Probability (AEP) of 1/10,000 resulting in Peak Ground Acceleration (PGA) of 0.26 g for horizontal application and PGA of 0.15 for vertical application.

This project site is situated in an area of low to moderate seismic activity. Consequently, CDA Guidelines, Section 6.5 allow for the seismic stability analysis of concrete gravity structures to be completed using a pseudo-static approach (coefficient method). This method applies a seismic force to a rigid body with the objective of determining sliding and overturning response of the structure. Since the pseudo-static method does not recognize the oscillatory nature of seismic loads, accepted practice is to perform the stability calculations using sustained acceleration values equivalent to 2/3 of the peak acceleration values.

When performing concrete stress analyses, the objective is to determine the tensile crack length induced by the inertia forces applied to the structure, so peak acceleration is used to calculate seismic coefficients. This approach assumes an instantaneous acceleration spike can induce cracking but is not sustained long enough to develop significant displacement along the crack plane. If no significant displacement occurs, the dynamic stability is maintained.

6.9.1 Seismic Effects on Concrete Mass

The horizontal force required to accelerate the concrete mass is calculated as:

$Q_h = k_h \times W$ where:

Q_h = Horizontal seismic load (kN)
k_h = Horizontal seismic coefficient
W = Structure mass (kg)
PGA = Peak ground acceleration= 0.26g

For Stability Analysis (Table 5): k_h = 2/3 x 0.26 = 0.17
For Member Analysis (Table 6): k_h = 1.0 x 0.26 = 0.26

The vertical force required to accelerate the concrete mass is calculated as:

$Q_v = k_v \times W$ where:

Q_v = Vertical seismic load (kN)
k_v = Horizontal seismic coefficient = 0.56*k_h
W = Structure mass (kg)

For Stability Analysis (Table 5): k_v = 2/3 x (0.56*k_h) = 0.10
For Member Analysis (Table 6): k_v = 1.0 x (0.56*k_h) = 0.15

Since an earthquake produces oscillating forces, the peak horizontal PGA and vertical PGA cannot occur at the same time. To account for this in the stability calculations, three separate combinations of vertical and horizontal seismic combinations were considered, but only the maximum value was reported. The three combinations of vertical and horizontal seismic load are as follows:

Table 5. Stability Analysis – Seismic Coefficients

Seismic Combination	Horizontal	Vertical
100% Horiz., No Vert.	1.0*k_h = 0.17	-
100% Horiz., 30% Vert.	1.0*k_h = 0.17	0.3*k_v = 0.03
30% Horiz., 100% Vert.	0.3*k_h = 0.05	1.0*k_v = 0.10

Table 6. Stress Analysis – Seismic Coefficients

Seismic Combination	Horizontal	Vertical
100% Horiz., No Vert.	1.0*k_h = 0.26	-
100% Horiz., 30% Vert Horiz.	1.0*k_h = 0.26	0.3*k_v = 0.05
30% Horiz., 100% Vert.	0.3*k_h = 0.08	1.0*k_v = 0.15

6.9.2 Seismic Effects on Water (H_E)

Using a pseudo-static method, hydrodynamic effects on water were approximated by using the Westergaard method to calculate the seismic water force (H_E). The calculated hydrodynamic force is additive to the hydrostatic water pressure force. The distribution is parabolic with the line of action for the force H_E at 0.4h above the base of the water column. Detailed explanation of method can be found in Section 4-7.e, EM 1110-2-2100.

$$H_E = \left(\frac{7}{12}\right) * k_{h/v} * \gamma_w * h^2$$

where:
H_E = Seismic water force (kN)
$k_{h/v}$ = horizontal/vertical seismic coefficient
γ_w= unit weight of water (kN/m³)
h = depth of water (m)

Note: The Westergaard method assumes an infinite waterbody length in the horizontal direction, which is a reasonable simplifying assumption for most conditions. For the unique case where seismic acceleration of water in the cross-stream direction is considered to evaluate divider walls and training walls, the Westergaard method will conservatively overestimate the hydrodynamic force.

6.9.3 Seismic Effect on Soils

Dynamic soil pressures and associated forces were analyzed assuming non-yielding backfills and an elastic response using the Wood's method. As referenced in Section 5-5.a.1, EM 1110-2-2100, and verified by project specific calculation (Appendix D), this method can be expected to have dynamic soil pressures greater than those predicted by the Mononobe-Okabe method for yielding backfills.

The use of Wood's method is considered reasonable and was used for analysis of fill around the concrete foundation structure that has relatively low backfills (<4 m). The use of Wood's method may be overly conservative for taller retaining walls with height ranging from 4 m to 13 m with backfill consisting of granular fills and/or glacial till materials.

Wood's Method for Non-yielding Backfill: This method applies the effective peak ground acceleration coefficient (k_h) to the soil mass to calculate a lateral seismic force representing dynamic soil pressure effects. The lateral seismic force is assumed to act at a distance of 0.63h above the base of the wall and must be added to the lateral inertial forces, and if water is present, hydrodynamic seismic forces. Calculation of lateral seismic force of soil is as follows:

$Q_E = y * h^2 * k_h$ where: Q_E = Lateral seismic force of soil
Y = unit weight of soil (weighted average of Y_{sat} and y_b)
h^2 = height of backfill
k_h = horizontal seismic coefficient

6.10 CLIMATIC CONDITIONS

6.10.1 Snow Loads (S)

Snow loads were considered insignificant compared to hydrostatic loads and were not considered for the DDB.

6.10.2 Thermal Loads (T)

Thermal effects and measures, such as placement of expansion/contraction joints in concrete structures, to relieve thermal loads will be addressed during Final Design.

6.10.3 Wind (W)

Wind loads were applied to the DDB on load combination U1 only. The loads applied were based on the climate data shown in Section 3.4.

7.0 STABILITY ANALYSIS

The Debris Deflection Barrier was analyzed for stability for loading conditions in accordance with AT WCS, CDA Guidelines and CSA standards.

7.1 METHODOLOGY

The structural analysis of the DDB was completed based on a strength evaluation and design. Since the structure is supported by a continuous footing and caissons, a rigid body method was not used in the analysis.

All forces applied to the structure were computed and analyzed depending on the load case using a three-dimensional structural analysis model. The foundation was then designed to resist the force resultant at the foundation/rock interface.

7.2 LOAD CONDITIONS

The load combinations considered were coordinated with the Stantec Hydraulics group and are described in Table 7. The different load factors are also represented.

Table 7. Load Combinations

Usual Load Cases:		
U1	Normal pool (Sunny day)	1.25D+1.5H+1.5W+1.25E
U2	1:100 Year, 760 m^3/s	1.25D+1.5H+1.5HD+1.25E+1.5IM
Unusual Load Cases:		
UN1	1:250 Year, 1240 m^3/s	1.25D+1.5H+1.5HD+1.25E+1.5IM
UN2	1:100 Year, 760 m^3/s	1.25D+1.5H+1.5HD+1.25E
Extreme Load Cases:		
E1	1:100 Year, 760 m^3/s	1.25D+1.5H+1.5HD+1.25E
E2	Sunny day with seismic	1.25D+1.5H+1.25E+1.0Q
Notes:		
D	Dead Load: Weight of concrete and water	
H	Hydrostatic Load: See each load case for headwater and tailwater conditions	
HD	Hydrodynamic Loads: Not applicable for this analysis	
E	Earth/Sediment/Silt Loads: Includes horizontal and vertical loads	
IM	Impact Load: Debris carried by flow, applied 150 mm below top of wall	
Q	Seismic Loads: Design Earthquake load – evaluation to consider simultaneous horizontal and vertical components for three combinations	
W	Wind Loads: Used for Strength Analysis only – Not Applicable to Stability	

7.3 SUMMARY OF STABILITY ANALYSES

The structural analysis resultants based on strength evaluation were used to perform a static stability assessment rather than using the rigid body method (conventional gravity method). Refer to Section 8.0 for a summary of the structural analysis.

Table 8 shows a summary of the forces applied to the structure and the safety factors used for the foundation structure design. The summation of the vertical forces was compensated by the vertical resistance of the caissons and footing, resulting in a structure that is stable against floatation. The summation of the horizontal forces is compensated by the horizontal resistance provided by the bedrock in which the foundation will be installed in and it results in a structure that is stable for sliding.

This analysis is comparable to the stability analysis and the safety factors shown are a result of the design of the foundation to resist the forces applied to the structure. The safety factors are higher than CDA values since the design of the foundation was done using a strength evaluation method. The stability requirements of CDA, as used for gravity dam structures, were used as a guide, as they are not applicable to the DDB since it is not a dam,

Table 8. Stability Summary

Load Comb.	Σ Vert. Forces (KN)	Σ Horiz. Forces (KN)	Σ Moments (KN*m)	Minimum Required Floatation FS	Floatation SF Calc.	Minimum Required Sliding FS	Sliding FS Calc.
U1	1177	148	-8	1.5	3.75	1.5	3.93
U2	1430	-77	-10	1.5	3.09	1.5	7.60
UN1	1498	150	-19	1.3	2.95	1.3	3.88
UN2	1390	-224	-12	1.3	3.17	1.3	2.60
E1	1739	-320	-15	1.1	2.54	1.1	1.83
E2	1020	191	-6.6	1.1	4.33	1.1	3.04

8.0 STRENGTH EVALUATION AND DESIGN

Strength evaluation of individual elements or members of the structure was used to verify member sizes based on application of factored loads as described in ABC with some adjustments for more severe conditions or loads not included in the ABC.

Reinforced concrete design of the foundation structure was performed according to Design of Concrete Structures, CSA A23.3-14 with the additional requirements of CSA's SEED Document – *Structural Design of Wastewater Treatment Plants-2018* that addresses service load conditions, water tightness, shrinkage and temperature reinforcement, and crack control. The SEED Document contains references to ACI 350M-06 for modifying CSA A23.3-14.

Structural steel design was performed according to Design of Steel Structures, CSA S16-14, and codes for welding, materials, and other pertinent references.

In general, structural analysis and design was performed using SAP2000 and Excel spreadsheets. The Three-Dimensional Finite Element Model (FEM) was used to evaluate multiple load combinations, identify stress concentrations, and generate shear and moment values for design of individual elements. The FEM was supplemented with manual calculations to verify/validate model results and where necessary, refine the analysis of individual elements. Based on model output, a combination of manual calculation and commercial software were used for strength design. Additional elements evaluated as part of strength design included joint detailing, equipment anchorage, and embedded parts.

The structural design calculations for the concrete foundation and steel framing can be found in Appendix E.6-2.

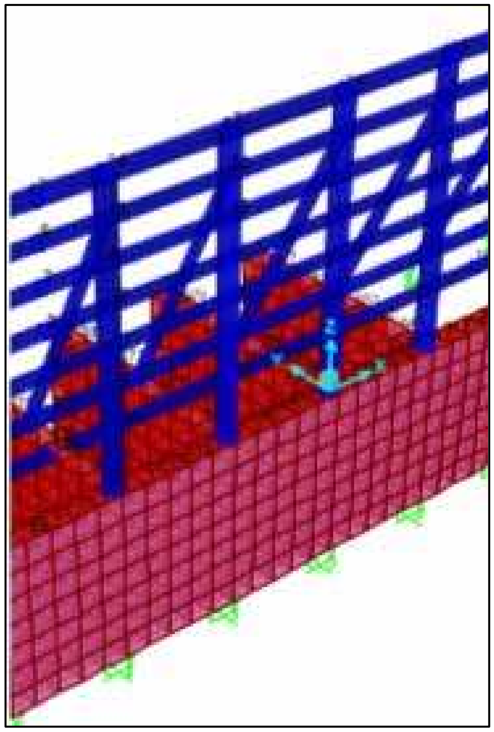


Figure 2. SAP2000 Model Frame of Barrier

9.0 SERVICEABILITY

Serviceability concerns with the Debris Deflection Barrier foundation relate primarily to concrete durability including limiting deflections, reducing crack potential, providing thermal stress relief, and incorporating measures to mitigate alkali-aggregate reaction (AAR) and other chemical attack. The same manual calculations, commercial software, or 3-D FEM used for strength evaluation were used to evaluate deflection and thermal growth, while design detailing and material specification were used to mitigate cracking and chemical attack.

Serviceability concerns with the Debris Deflection Barrier steel superstructure relate primarily to steel longevity, and ability to maintain and service the DDB, particularly following a flood evert. Steel longevity considerations include paint or galvanizing coatings for wet and dry conditions, sealing of internal chambers to eliminate oxygen, or the use of weathering steel for the members. The maintenance and servicing of the DDB was addressed by using modular construction with standardized parts and fabrication using exposed connections for ease in replacement if damaged.

10.0 CONSTRUCTION CONSIDERATIONS

Construction specifications and details for the Debris Deflection Barrier will be furthered during Final Design. The following construction considerations are noted:

- Dewatering of excavated areas will be required to sufficiently enable construction of the Debris Deflection Barrier. The services of a specialist dewatering contractor may be needed.

- Excavation will be to competent bedrock. All soil, including alluvium, talus and other unconsolidated deposits should be removed to expose unweathered or slightly weathered bedrock. Excavation should be performed by mechanical means only; blasting will not be permitted.

- Foundation preparation will require special care in cleaning and preparation of concrete/rock interface. Care must be taken during excavation of the foundation to identify unsuitable rock conditions or weak bedding planes that could impact stability. Loose material and rock overhangs will need to be removed. Small voids will be filled with dental concrete.

- Shear keys are required to maintain adequate sliding stability. Care should be taken during excavation of the shear key trenches to identify unsuitable rock conditions or weak beading planes that could compromise capacity of the shear key.

- Concrete placement will require sequencing for construction of upstream intermediate walls between piles.

- Fill placement and compaction methods must be reviewed and monitored to ensure wall movement does not occur during construction.

- Construction sequencing will be required to ensure the Debris Deflection Barrier is fully functional before a tie-in with the Diversion Channel is made.

11.0 REFERENCES

CDA, 2013: Canadian Dam Safety Guidelines 2007 – Revised 2013

ABC, 2014: Alberta Building Code 2014

USACE, 2016: EM 1110-2-2104 Strength Design for Reinforced Concrete Hydraulic Structures.

CSA S16-14: Design of Steel Structures

CSA A23.3: Design of Concrete Structures

Memo Reference: Debris Deflection Barrier – Flood Debris Characterization and Loading Conditions

APPENDIX E.6-1 DEBRIS BARRIER DRAWINGS

Refer to Preliminary Design Report - Appendix A for drawings.

APPENDIX E.6-2 DEBRIS BARRIER CALCULATIONS

Springbank Off-Stream Storage Project Structural Calculations

Debris Barrier

Prepared for:
Alberta Transportation
3rd Floor – Twin Atria Building
4999 – 98 Avenue
Edmonton, AB T6B 2X3

Prepared by:
Stantec Consulting Ltd
Calgary, AB

Project Number 110773396

November 27, 2019

Table 1 - Load Cases

Load Case	Debris	U/S (m)	D/S(m)	Impact Force (IM)	Hydro dynamic	Drag Force from Underside of Mat	Drag Force from Clogging	Discussion
Usual Load Cases (Normal)								
U1 – Normal pool (Sunny Day)	None	1211.50	1211.50	0	0	0	0	No water level difference
U2 – 1:100 Yr, 760 cms	Single Log Debris Impact	1215.80	1215.80	146 kN	1.0 KN/m	0	0	No water level difference, temporary loads
Unusual Load Cases								
UN1 – 1:250 Yr, 1240 cms	Vehicle Debris Impact	TBD	TBD	258 kN	1.0 KN/m	0	0	
UN2 – 1:100, Yr, 760 cms	Small to Medium Debris Mat	1216.05	1215.80	0	0	66 kN/m acting on a 1.5 m band centered 0.75 m below the modeled water surface	Upper Rack = 2.1 Kn/m Bottom Rack = 4.9 KN/m	33% blocked with 140 m wide continuous floating mat
Extreme Load Cases								
E1 – 1:100 Yr, 760 cms	Large Debris Matt	1216.5	1215.8	0	0	66 kN/m acting on a 1.5 m band centered 0.75 m below the modeled water surface	Upper Rack = 1.95 KN/m Bottom Rack = 4.55 KN/m	70% blocked with 140 m wide continuous floating mat
E2 – Sunny Day with Seismic	None	1211.5	1211.5	0	0	0	0	

Based on table 1, the Usual Condition includes two load cases:

U1: Sunny Day with Wind Load

- Water Surface Elevation: 1211.5 m
- Wind Load: 0.48 kPa per Alberta Building Code (2014);

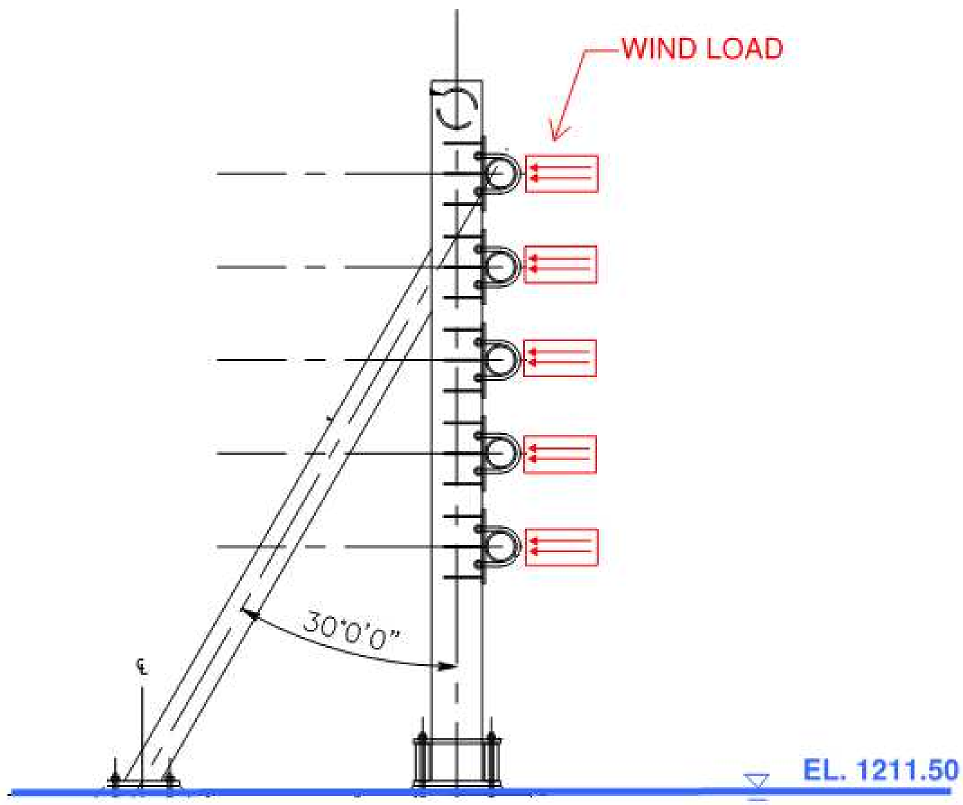


Figure 1 – Usual Load Case – No Flood with Wind

U2: 1:100 Year Flood Event with an Impact Load:

- Water Surface Elevation: U/S 1215.8 m, D/S 1215.8m
- Log Impact:
  - Design Log: 16m x 0.44m; Density = 900 KG/m³
  - Velocity: 3 metres per second

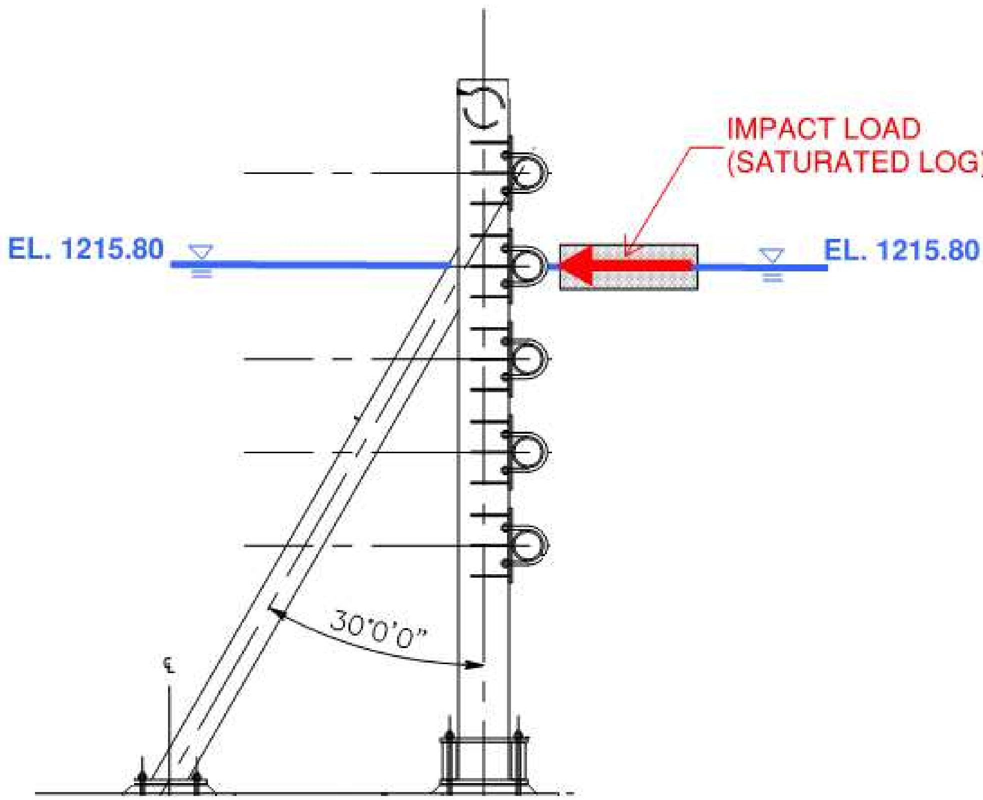


Figure 2 – Usual Load Case – 1:100 Year Flood with Log Impact

For the Unusual Condition, the primary load cases include:

UN1: 1:250 Year Flood Event with an Impact Load:

- Water Surface Elevation: TBD
- Vehicle Impact:
  - Design Vehicle: 3085 kg
  - Velocity: 3 metres per second

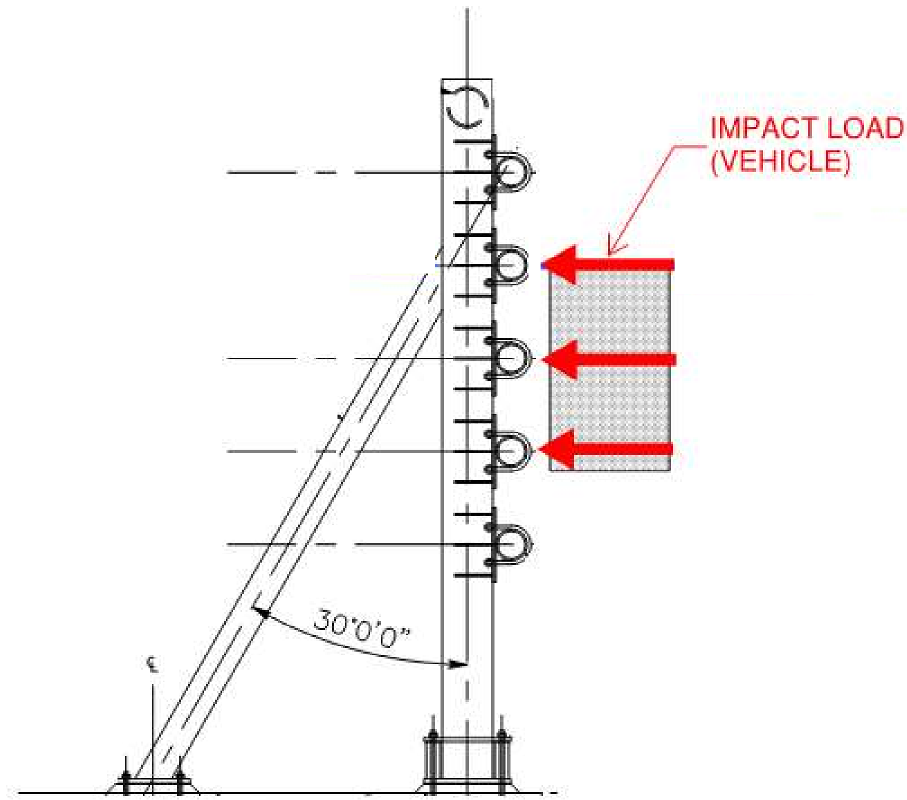


Figure 3 – Unusual Load Case – 1:250 Year Flood with Vehicle Impact

UN2: 1:100 Year Flood Event with 33% Debris Blockage:

- Water Surface Elevation: U/S 1216.05 m, D/S 1215.80 m
- Debris Blockage: 33%
- Floating Debris Mat Length: 140 m

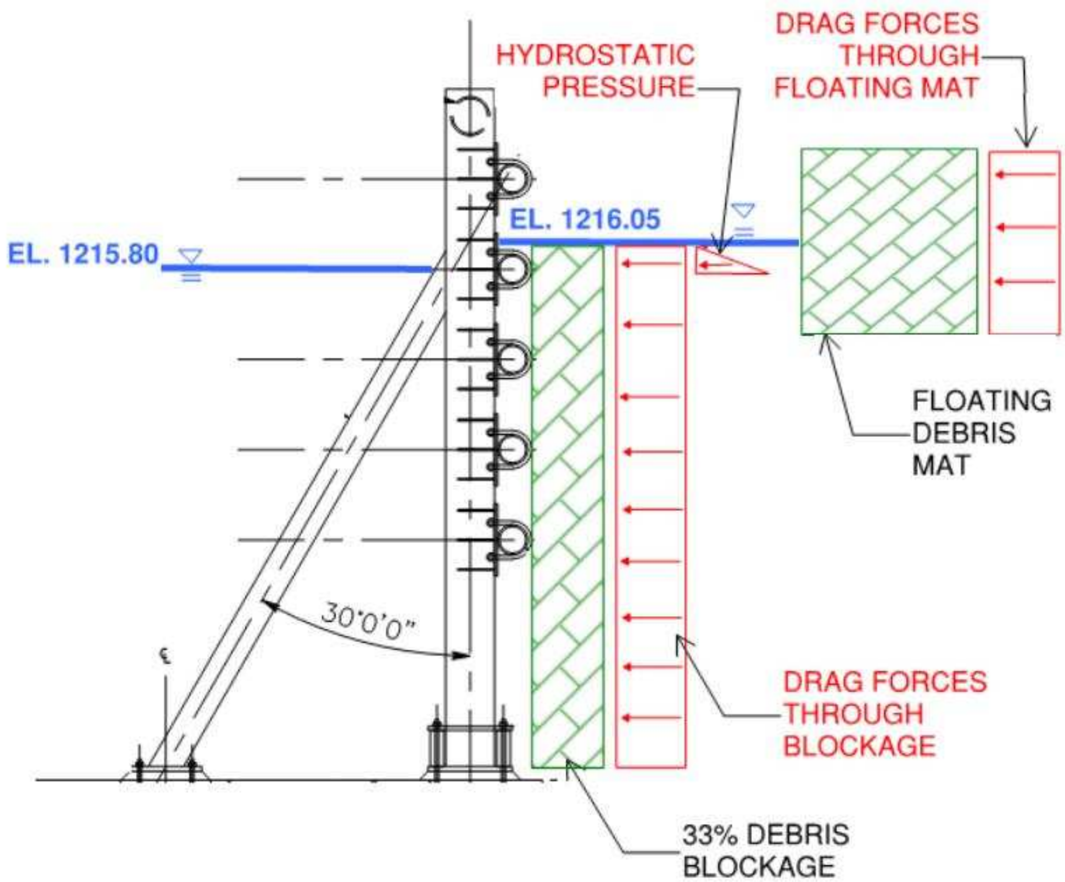


Figure 4 – Unusual Load Case – 1:100 Year Flood with 33% Debris Blockage

For the Extreme Load Case, the following condition was evaluated:

E1: 1:100 Year Flood Event with 70% Debris Blockage:

- Water Surface Elevation: U/S 1216.05 m, D/S 1215.80 m
- Debris Blockage: 70%
- Floating Debris Mat Length: 140 m

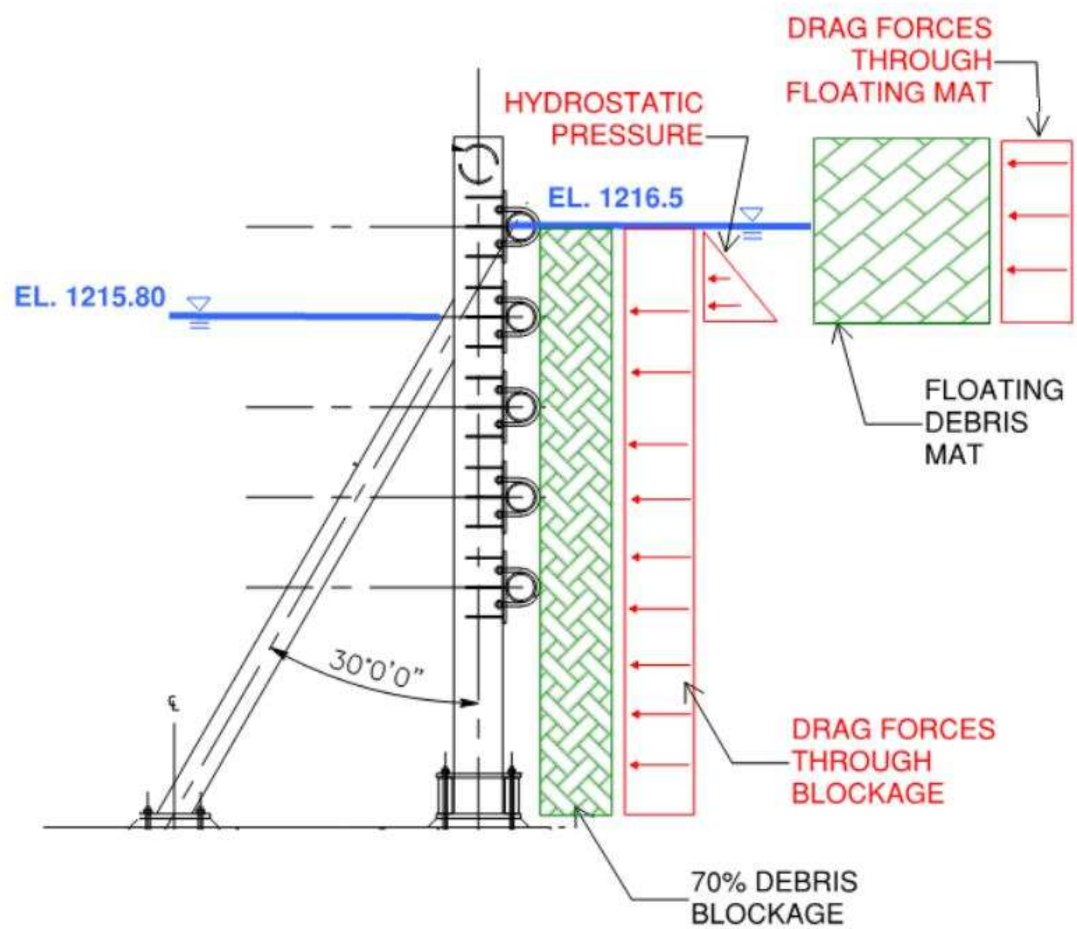


Figure 5 – Unusual Load Case – 1:100 Year Flood with 70% Debris Blockage

Table 2. Load Factors and Combinations for Structural Analysis

Load Case	Dead (D)	Hydro static (Hs)	Hydro dynamic (Hs or drag)	Wind (W)	Debris (IM)	Seismic (EQ)
Usual Load Cases (Normal)						
U1	1.25	1.5	0	1.5	0	0
U2	1.25	1.5	1.5	0	0	0
U3a	1.25	1.5	1.5	0	1.5	0
Unusual Load Cases						
UN1	1.25	1.5	1.5	0	0	0
UN2	1.25	1.5	1.5	0	1.5	0
UN3	1.25	1.5	1.5	0	1.25	0
Extreme Load Cases						
E1	1.25	1.25	0	0	0	1.0
E2	1.25	1.25	1.05	0	1.25	0

The above noted loading cases are based on EM 1110-2-2400 “Structural design and Evaluation of Outlet Works” and ETL 1110-2-584 “Design of Hydraulic Steel Structures”.

Project:	SR-1 Debris Barrier	Date Printed:		11/1/2019 14:04
Number:	110773396	Page	1 of	1
Revision #:	3			
Completed by:	JH	Date Completed:	10/15/2019	
Reviewed by:	BEF	Date Reviewed:	10/29/2019	

SR-1 Debris Barrier Dead load calc

Support A

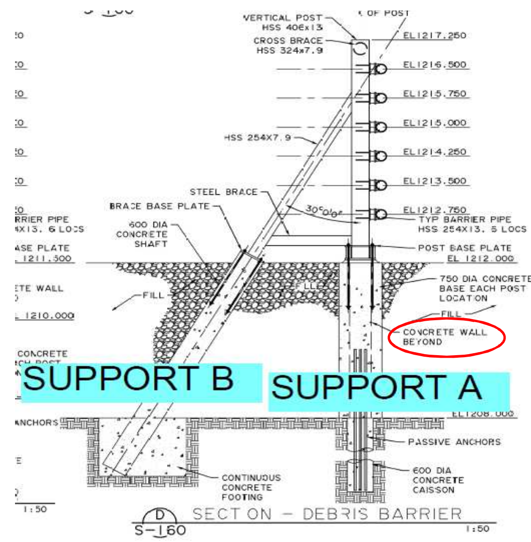
Conc wall parallel to struc		Conc pilaster		Conc wall perp to struc	
thickness (m)	0.5	thickness (m)	0.75	thickness (m)	0.5
height (m)	4	height (m)	4	height (m)	4
length (m)	1.75	length (m)		length (m)	1.9
volume (m^3)	3.5	volume (m^3)	1.77	volume (m^3)	3.80

Total volume Support A	9.07	m^3
Total dead load concrete Support A	218	KN
Dead Load from steel structure (SAP2000)	24	KN
Total dead load Support A	242	KN

Support B

Conc wall parallel to struc		Conc pilaster		Conc wall perp to struc	
thickness (m)	0	thickness (m)	0.6	thickness (m)	0.5
height (m)	0	height (m)	4	height (m)	4
length (m)	0	length (m)		length (m)	1.9
volume (m^3)	0	volume (m^3)	1.13	volume (m^3)	3.80

Total volume Support B	4.93	m^3
Total dead load concrete Support B	118	KN
Dead Load from steel structure (SAP2000)	1.6	KN
Total dead load Support B	120	KN



Project:	Debris Barrier		Date Printed:		11/1/2019 13:59
Number:	110773396		Page	1 of	2
Completed by:	JH	Date Completed:	6/20/2018		
Reviewed by:	BEF	Date Reviewed:	10/29/2019		

Vertical Post CALCULATION -using NBCC - no ice

Figure I-25: Chimneys, Cylinders, and Tanks HSS406

Total force=F= C_f x q x C_g x C_e x A A=dxh= 2334500 mm^2

d=	406	mm	(A-A)	Slenderness h/d =	14.16
h=	5750	mm		$d\sqrt{qC_e}$=	266.85
q=	0.48			For Ce (exposure factor):	Open terrain, only scattered bldgs,
Ce=	0.900				
Iw=	1				
Cg=	2.5	(2.5 for external pressure 4.1.7.1.6)			

If $d\sqrt{qCe}$ > 0.167: yes

Cross Section and roughness: Smooth and rough (surface sharp edges)

Cf to use= 1.2

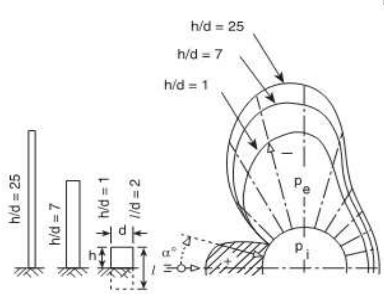
F= 3.03 kN

F= 1.30 kPa

Ww(s)= 0.526 kN/m

Commentary I

TOTAL FORCE $F = I_w \cdot C_f \cdot q \cdot C_g \cdot C_e \cdot A$, where $A = d \cdot h$



C_f : FORCE COEFFICIENT FOR $d\sqrt{qC_e} > 0.167$

Slenderness h/d = →	25	7	1
Cross section and roughness	C_f	C_f	C_f
Moderately smooth, (metal, timber, concrete)	0.7	0.6	0.5
Rough surface (rounded ribs h = 2%d)	0.9	0.8	0.7
Very rough surface (sharp ribs h = 8%d)	1.2	1.0	0.8
Smooth and rough surface sharp edges	1.4	1.2	1.0

C_p : EXTERNAL PRESS. COEFF. FOR $d\sqrt{qC_e} > 0.167$ and moderately smooth surface

h/d	l/d	α=	0°	15°	30°	45°	60°	75°	90°	105°	120°	135°	150°	165°	180°
25	50	C_p	+1.0	+0.8	+0.1	−0.9	−1.9	−2.5	−2.6	−1.9	−0.9	−0.7	−0.6	−0.6	−0.6
7	14	C_p	+1.0	+0.8	+0.1	−0.8	−1.7	−1.6	−2.2	−1.7	−0.8	−0.6	−0.5	−0.5	−0.5
1	2	C_p	+1.0	+0.8	+0.1	−0.7	−1.2	−1.6	−1.7	−1.2	−0.7	−0.5	−0.4	−0.4	−0.4

$\Delta p = p_i - p_e$ $p_i = C_{pi} \cdot q \cdot C_g \cdot C_e$ $p_e = C_p \cdot q \cdot C_g \cdot C_e$

Stack fully operating C_{pi} = +0.1; Stack throttled C_{pi} = −0.8

EG00932C

Figure I-25
Cylinders, chimneys and tanks

Project:	Debris Barrier		Date Printed:		11/1/2019 13:59
Number:	110773396		Page	2 of	2
Completed by:	JH	Date Completed:	6/20/2018		
Reviewed by:	BEF	Date Reviewed:	10/29/2019		

Horizontal Member CALCULATION -using NBCC - no ice

Figure I-25: Chimneys, Cylinders, and Tanks HSS 273

Total force=F= C_f x q x C_g x C_e x A   A=dxh= 1569750 mm^2

d=	273 mm	(A-A)	Slenderness h/d =	21.06
h=	5750 mm		$d\sqrt{qC_e}$=	179.43
q=	0.48		For Ce (exposure factor):	Open terrain, only scattered bldgs, t
Ce=	0.900			
Iw=	1			
Cg=	2.5	(2.5 for external pressure 4.1.7.1.6)		

If d√qCe > 0.167: yes

Cross Section and roughness: Smooth and rough (surface sharp edges)

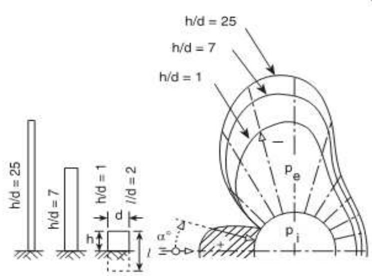
Cf to use= 1.2

F= 2.03 kN
F= 1.30 kPa

Ww(s)= 0.354 kN/m

Commentary I

TOTAL FORCE $F = I_w \cdot C_f \cdot q \cdot C_g \cdot C_e \cdot A$, where $A = d \cdot h$



C_f : FORCE COEFFICIENT FOR $d\sqrt{qC_e} > 0.167$

Slenderness h/d = →	25	7	1
Cross section and roughness	C_f	C_f	C_f
Moderately smooth, (metal, timber, concrete)	0.7	0.6	0.5
Rough surface (rounded ribs h = 2%d)	0.9	0.8	0.7
Very rough surface (sharp ribs h = 8%d)	1.2	1.0	0.8
Smooth and rough surface sharp edges	1.4	1.2	1.0

C_p : EXTERNAL PRESS. COEFF. FOR $d\sqrt{qC_e} > 0.167$ and moderately smooth surface

h/d	l/d	α=	0°	15°	30°	45°	60°	75°	90°	105°	120°	135°	150°	165°	180°
25	50	C_p	+1.0	+0.8	+0.1	−0.9	−1.9	−2.5	−2.6	−1.9	−0.9	−0.7	−0.6	−0.6	−0.6
7	14	C_p	+1.0	+0.8	+0.1	−0.8	−1.7	−1.6	−2.2	−1.7	−0.8	−0.6	−0.5	−0.5	−0.5
1	2	C_p	+1.0	+0.8	+0.1	−0.7	−1.2	−1.6	−1.7	−1.2	−0.7	−0.5	−0.4	−0.4	−0.4

$\Delta p = p_i - p_e$ $p_i = C_{pi} \cdot q \cdot C_g \cdot C_e$ $p_e = C_p \cdot q \cdot C_g \cdot C_e$

Stack fully operating $C_{pi} = +0.1$; Stack throttled $C_{pi} = -0.8$

EG00932C

Figure I-25
Cylinders, chimneys and tanks

Project:	Debris Barrier	Date Printed:	11/1/2019 13:56
Number:	110773396	Page	1 of 5
Completed by:	JH	Date Completed:	10/23/2018
Reviewed by:	BEF	Date Reviewed:	10/29/2019

Water Pressure Calculator - UN2 previous UN3 U/S

Base Elevation	1211.5	m	Head (z)	4.55	m
Water Elevation	1216.05	m	Width	1	m
Unit Weight of Water	9.81	KN/m^3	z/3=	1.52	m
Water pressure (P_{wh})=	101.5458	KN/m			
H_w=	101.5458	KN			

$$P_{wh} = \gamma_w \frac{z_1^2}{2}$$ acting at $z_1/3$ in KN/m

Where γ_w = unit weight of water = 9.81 KN/m^3

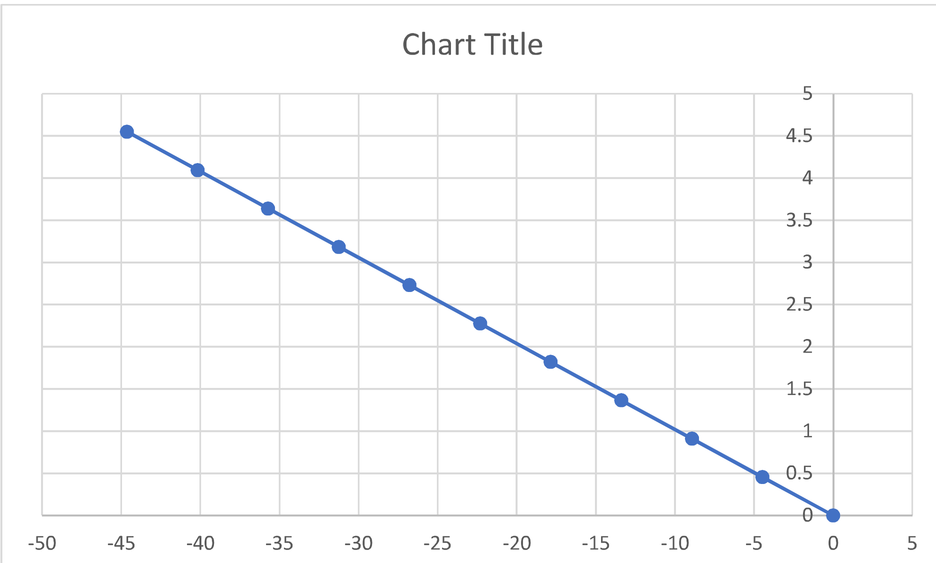
y (m)	diff (m)	P(Kpa)	b1 (KN)	b2 (KN)	P (KN)
0	0.455	44.6355	42.40372	0	9.65
0.455	0.455	40.17195	37.94017	42.40372	18.28
0.91	0.455	35.7084	33.47662	37.94017	16.25
1.365	0.455	31.24485	29.01307	33.47662	14.22
1.82	0.455	26.7813	24.54952	29.01307	12.19
2.275	0.455	22.31775	20.08597	24.54952	10.15
2.73	0.455	17.8542	15.62242	20.08597	8.12
3.185	0.455	13.39065	11.15887	15.62242	6.09
3.64	0.455	8.9271	6.695325	11.15887	4.06
4.095	0.455	4.46355	2.231775	6.695325	2.03
4.55	0.455	-8.7E-15	0	2.231775	0.25

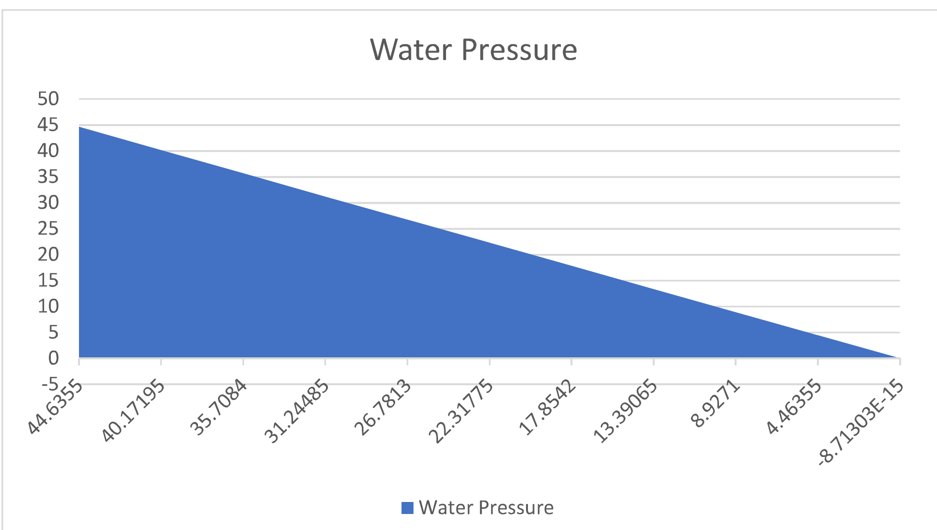
y (m)	P(Kpa)
4.55	-44.6355
4.095	-40.1719
3.64	-35.7084
3.185	-31.2448
2.73	-26.7813
2.275	-22.3177
1.82	-17.8542
1.365	-13.3906
0.91	-8.9271
0.455	-4.46355
0	8.71E-15

elevation (m)	diff y (m)	P(Kpa)	b1 (KN)	b2 (KN)	P (KN)	Elev (m)
0	1.25	44.6355	38.50425	44.6355	51.96	1211.5
1.25	0.75	32.373	28.69425	38.50425	33.60	1212.75
2	0.75	25.0155	21.33675	28.69425	18.76	1213.5
2.75	0.75	17.658	13.97925	21.33675	13.24	1214.25
3.5	0.75	10.3005	6.62175	13.97925	7.73	1215
4.25	0.75	2.943	-0.73575	6.62175	1.74	1215.75
5	0.75	-4.4145	-8.09325	-0.73575	-3.31	1216.5
5.75	0.75	-11.772	-15.4508	-8.09325	-8.83	1217.25
6.5	0.75	-19.1295	-22.8083	-15.4508	-14.35	1218
7.25	0.75	-26.487	-30.1658	-22.8083	-19.87	1218.75
8	0.75	-33.8445	-37.5233	-30.1658	-25.38	1219.5
8.75	0.75	-41.202	0	-37.5233	-7.04	1220.25

Project:	Debris Barrier		Date Printed:	11/1/2019 13:56
Number:	110773396		Page	2 of 10
Completed by:	JH	Date Completed:	10/23/2018	
Reviewed by:	BEF	Date Reviewed:	10/29/2019	

Water Pressure Calculator - UN2 previous UN3 U/S





Project:	Debris Barrier	Date Printed:		11/1/2019 13:56
Number:	110773396	Page	3 of	10
Completed by:	JH	Date Completed:	10/23/2018	
Reviewed by:	BEF	Date Reviewed:	10/29/2019	

Water Pressure Calculator - UN2 previous UN3 D/S

Base Elevation	1211.5	m	Head (z)	4.3	m
Water Elevation	1215.8	m	Width	1	m
Unit Weight of Water	9.81	KN/m^3	z/3=	1.43	m
Water pressure (P_{wh})=	90.69345	KN/m			
H_w=	90.69345	KN			

$$P_{wh} = \gamma_w \frac{z_1^2}{2}$$ acting at $z_1/3$ in KN/m

Where γ_w = unit weight of water = 9.81 KN/m^3

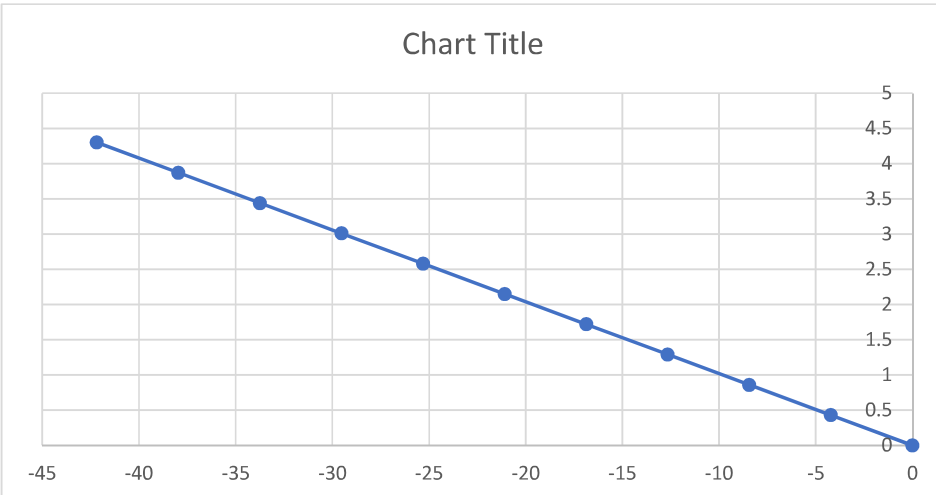
y (m)	diff (m)	P(Kpa)	b1 (KN)	b2 (KN)	P (KN)
0	0.43	42.183	40.07385	0	8.62
0.43	0.43	37.9647	35.85555	40.07385	16.32
0.86	0.43	33.7464	31.63725	35.85555	14.51
1.29	0.43	29.5281	27.41895	31.63725	12.70
1.72	0.43	25.3098	23.20065	27.41895	10.88
2.15	0.43	21.0915	18.98235	23.20065	9.07
2.58	0.43	16.8732	14.76405	18.98235	7.26
3.01	0.43	12.6549	10.54575	14.76405	5.44
3.44	0.43	8.4366	6.32745	10.54575	3.63
3.87	0.43	4.2183	2.10915	6.32745	1.81
4.3	0.43	8.71E-15	0	2.10915	0.23

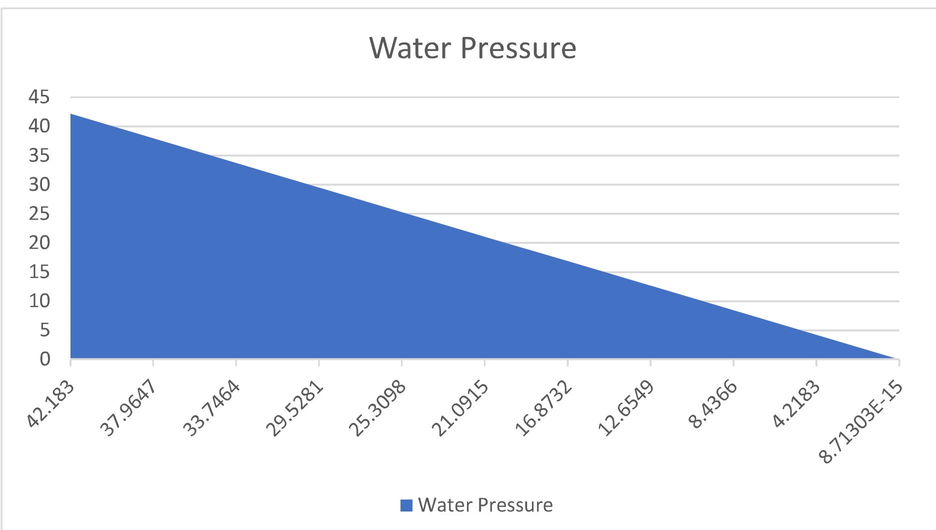
y (m)	P(Kpa)
4.3	-42.183
3.87	-37.9647
3.44	-33.7464
3.01	-29.5281
2.58	-25.3098
2.15	-21.0915
1.72	-16.8732
1.29	-12.6549
0.86	-8.4366
0.43	-4.2183
0	-8.7E-15

y (m)	diff (m)	P(Kpa)	b1 (KN)	b2 (KN)	P (KN)	Elev (m)
0	1.25	42.183	36.05175	42.183	48.90	1211.5
1.25	0.75	29.9205	26.24175	36.05175	31.15	1212.75
2	0.75	22.563	18.88425	26.24175	16.92	1213.5
2.75	0.75	15.2055	11.52675	18.88425	11.40	1214.25
3.5	0.75	7.848	4.16925	11.52675	5.89	1215
4.25	0.75	0.4905	-3.18825	4.16925	0.83	1215.75
5	0.75	-6.867	-10.5458	-3.18825	-5.15	1216.5
5.75	0.75	-14.2245	-17.9033	-10.5458	-10.67	1217.25
6.5	0.75	-21.582	-25.2608	-17.9033	-16.19	1218
7.25	0.75	-28.9395	-32.6183	-25.2608	-21.70	1218.75
8	0.75	-36.297	-39.9758	-32.6183	-27.22	1219.5
8.75	0.75	-43.6545	0	-39.9758	-7.50	1220.25

Project:	Debris Barrier		Date Printed:		11/1/2019 13:56
Number:	110773396		Page	4 of	10
Completed by:	JH	Date Completed:	10/23/2018		
Reviewed by:	BEF	Date Reviewed:	10/29/2019		

Water Pressure Calculator - UN2 previous UN3 D/S





Project:	Debris Barrier	Date Printed:		11/1/2019 13:56
Number:	110773396	Page	5 of	10
Completed by:	JH	Date Completed:	10/23/2018	
Reviewed by:	BEF	Date Reviewed:	10/29/2019	

Water Pressure Calculator - E1 - previous E2 U/S

Base Elevation	1211.5	m	Head (z)	5	m
Water Elevation	1216.5	m	Width	1	m
Unit Weight of Water	9.81	KN/m^3	z/3=	1.67	m
Water pressure (P_{wh})=	122.625	KN/m			
H_w=	122.625	KN			

$$P_{wh} = \gamma_w \frac{z_1^2}{2}$$ acting at $z_1/3$ in KN/m

Where γ_w = unit weight of water = 9.81 KN/m^3

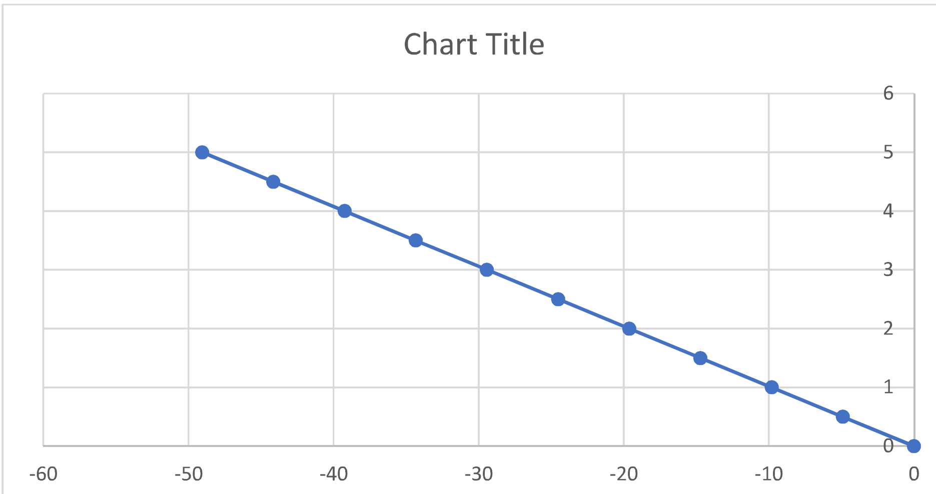
y (m)	diff (m)	P(Kpa)	b1 (KN)	b2 (KN)	P (KN)
0	0.5	49.05	46.5975	0	11.65
0.5	0.5	44.145	41.6925	46.5975	22.07
1	0.5	39.24	36.7875	41.6925	19.62
1.5	0.5	34.335	31.8825	36.7875	17.17
2	0.5	29.43	26.9775	31.8825	14.72
2.5	0.5	24.525	22.0725	26.9775	12.26
3	0.5	19.62	17.1675	22.0725	9.81
3.5	0.5	14.715	12.2625	17.1675	7.36
4	0.5	9.81	7.3575	12.2625	4.91
4.5	0.5	4.905	2.4525	7.3575	2.45
5	0.5	0	0	2.4525	0.31

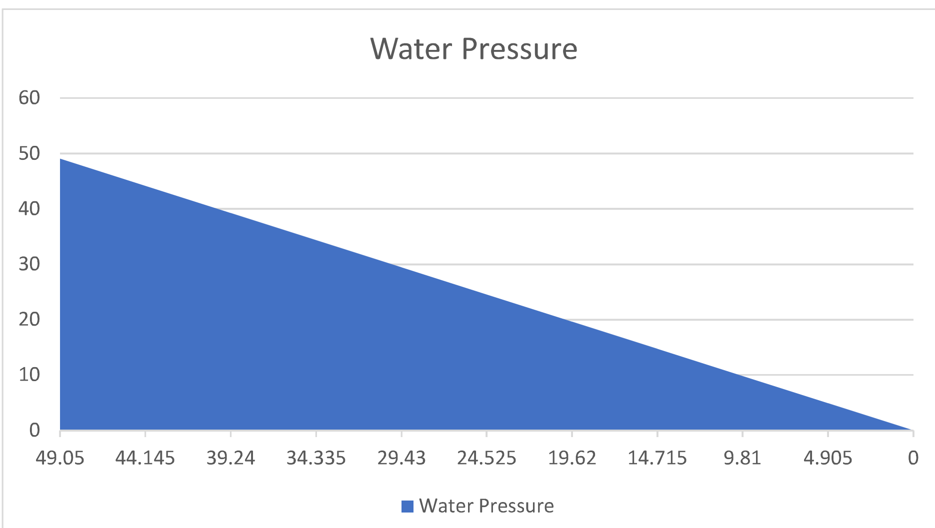
y (m)	P(Kpa)
5	-49.05
4.5	-44.145
4	-39.24
3.5	-34.335
3	-29.43
2.5	-24.525
2	-19.62
1.5	-14.715
1	-9.81
0.5	-4.905
0	0

y (m)	diff (m)	P(Kpa)	b1 (KN)	b2 (KN)	P (KN)	Elev (m)
0	1.25	49.05	42.91875	49.05	57.48	1211.5
1.25	0.75	36.7875	33.10875	42.91875	38.01	1212.75
2	0.75	29.43	25.75125	33.10875	22.07	1213.5
2.75	0.75	22.0725	18.39375	25.75125	16.55	1214.25
3.5	0.75	14.715	11.03625	18.39375	11.04	1215
4.25	0.75	7.3575	3.67875	11.03625	4.14	1215.75
5	0.75	0	0	3.67875	0.69	1216.5
5.75	0.75	-7.3575	-11.0363	-3.67875	-5.52	1217.25
6.5	0.75	-14.715	-18.3938	-11.0363	-11.04	1218
7.25	0.75	-22.0725	-25.7513	-18.3938	-16.55	1218.75
8	0.75	-29.43	-33.1088	-25.7513	-22.07	1219.5
8.75	0.75	-36.7875	0	-33.1088	-6.21	1220.25

Project:	Debris Barrier		Date Printed:	11/1/2019 13:56
Number:	110773396		Page	6 of 10
Completed by:	JH	Date Completed:	10/23/2018	
Reviewed by:	BEF	Date Reviewed:	10/29/2019	

Water Pressure Calculator - E1 - previous E2 U/S





Project:	Debris Barrier	Date Printed:	11/1/2019 13:56	
Number:	110773396	Page	7 of	10
Completed by:	JH	Date Completed:	10/23/2018	
Reviewed by:	BEF	Date Reviewed:	10/29/2019	

Water Pressure Calculator E1 - previous E2 D/S

Base Elevation	1211.5	m	Head (z)	4.3	m
Water Elevation	1215.8	m	Width	1	m
Unit Weight of Water	9.81	KN/m^3	z/3=	1.43	m
Water pressure (P_{wh})=	90.69345	KN/m			
H_w=	90.69345	KN			

$$P_{wh} = \gamma_w \frac{z_1^2}{2}$$ acting at $z_1/3$ in KN/m

Where γ_w = unit weight of water = 9.81 KN/m^3

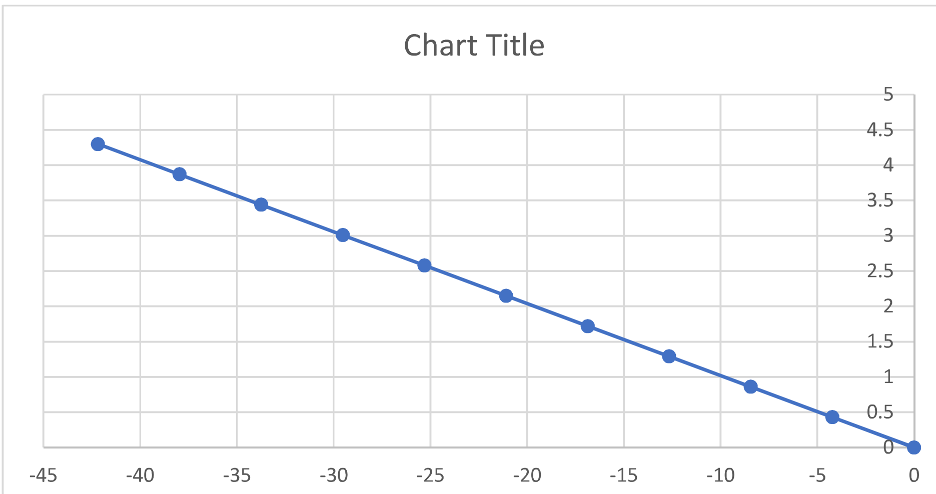
y (m)	P(Kpa)
4.3	-42.183
3.87	-37.9647
3.44	-33.7464
3.01	-29.5281
2.58	-25.3098
2.15	-21.0915
1.72	-16.8732
1.29	-12.6549
0.86	-8.4366
0.43	-4.2183
0	-8.7E-15

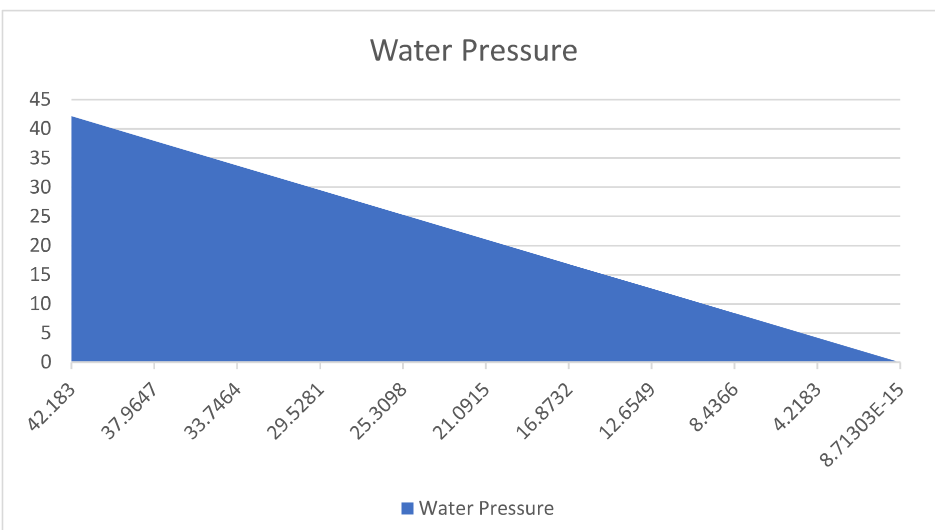
y (m)	diff (m)	P(Kpa)	b1 (KN)	b2 (KN)	P (KN)
0	0.43	42.183	40.07385	0	8.62
0.43	0.43	37.9647	35.85555	40.07385	16.32
0.86	0.43	33.7464	31.63725	35.85555	14.51
1.29	0.43	29.5281	27.41895	31.63725	12.70
1.72	0.43	25.3098	23.20065	27.41895	10.88
2.15	0.43	21.0915	18.98235	23.20065	9.07
2.58	0.43	16.8732	14.76405	18.98235	7.26
3.01	0.43	12.6549	10.54575	14.76405	5.44
3.44	0.43	8.4366	6.32745	10.54575	3.63
3.87	0.43	4.2183	2.10915	6.32745	1.81
4.3	0.43	8.71E-15	0	2.10915	0.23

y (m)	diff (m)	P(Kpa)	b1 (KN)	b2 (KN)	P (KN)	Elev (m)
0	1.25	42.183	36.05175	42.183	48.90	1211.5
1.25	0.75	29.9205	26.24175	36.05175	31.15	1212.75
2	0.75	22.563	18.88425	26.24175	16.92	1213.5
2.75	0.75	15.2055	11.52675	18.88425	11.40	1214.25
3.5	0.75	7.848	4.16925	11.52675	5.89	1215
4.25	0.75	0.4905	-3.18825	4.16925	0.83	1215.75
5	0.75	-6.867	-10.5458	-3.18825	-5.15	1216.5
5.75	0.75	-14.2245	-17.9033	-10.5458	-10.67	1217.25
6.5	0.75	-21.582	-25.2608	-17.9033	-16.19	1218
7.25	0.75	-28.9395	-32.6183	-25.2608	-21.70	1218.75
8	0.75	-36.297	-39.9758	-32.6183	-27.22	1219.5
8.75	0.75	-43.6545	0	-39.9758	-7.50	1220.25

Project:	Debris Barrier		Date Printed:		11/1/2019 13:56
Number:	110773396		Page	8 of	10
Completed by:	JH	Date Completed:	10/23/2018		
Reviewed by:	BEF	Date Reviewed:	10/29/2019		

Water Pressure Calculator E1 - previous E2 D/S





Project:	Debris Barrier	Date Printed:	11/1/2019 13:56	
Number:	110773396	Page	9 of	10
Completed by:	JH	Date Completed:	10/23/2018	
Reviewed by:	BEF	Date Reviewed:	10/29/2019	

E2

Earthquake calc for steel

Total weight of steel (per estimate)	21250 Kg		Weight per horiz component	1.80425379 kN/10 m
Total weight of steel (per estimate)	208.391 KN		Horiz EQ load per horiz component	0.30672314 KN/m
Total length	165 m			
Weight per m	1.26298 kN/m			
Weight per block	12.6298 kN/10 m			

Earthquake calc for concrete

EARTHQUAKE COEFF's:

Structure width (m) 6.375

HORIZONTAL COEFF. 0.17 m

VERTICAL COEFF. 0.03 m

Unit Weight of Concrete 24 KN/m^3

Conc wall parallel to struc		Conc pilaster Sup A		Conc wall perp to struc		Conc pilaster Sup B	
thickness (m)	0.5	thickness (m)	0.75	thickness (m)	0.5	thickness (m)	0.6
height (m)	3.5	height (m)	3.5	height (m)	3.5	height (m)	3.5
length (m)	1.75			length (m)	6.375		

ITEM NO.	DESCRIPTION	ELEVATION	DIMENSIONS (m)			SHAPE	AREA	WEIGHT	CENTROIDS	MOM ARM	MOMENT	HORIZ. Equake	HOR. EQ Load	HOR. EQ Load	CENTROIDS	MOM ARM	MOMENT	CONCRETE
		T/O PIER	X	Y	Z	FACTOR	m^2	KN	X DIST (m)	X (m)	CONC. (KNm)	LOAD (KN)	per m (KN/m)	per y m (KN/m2)	Y DIST (m)	Y (m)	EQ (KNm)	QUANTITIES
1	Wall Parallel	Pos. Concre	0.5	3.5	2.5	1	1.75	105	0.25	6.13	643	18	7	2	1.75	1.75	31	4.4
2	Wall Perp.	Pos. Concre	6.375	3.5	0.5	1	22.3125	268	3.19	3.19	853	46	7	2	1.75	1.75	80	11.2
3	Pilaster A	Pos. Concre	0.75	3.5	1	3.14	2.625	37	0.38	6.00	223	6	6	2	1.75	1.75	11	8.2
4	Pilaster B	Pos. Concre	0.6	3.5	1	3.14	2.1	24	4.00	2.38	56	4	4	1	1.75	1.75	7	6.6
						Σ		434			1776	74					129	30.4
						Σ		19.0										

HORIZONTAL FORCES (EQUAKE) = 74	kN
VERTICAL FORCES = 434	kN
VERTICAL FORCES (due to Eq) = 7	kN
RESISTING MOMENT (due to Conc) = 1776	kN-m
OVER TURNING MOMENT (due to Eq) = 31	kN-m
RESISTING MOMENT (due to Eq 'RMEQ') = 0	kN-m
TOTAL VOLUME CONCRETE = 30	m³

applied as an area load (0.5m down) onto parrallel wall and perpendicular wall

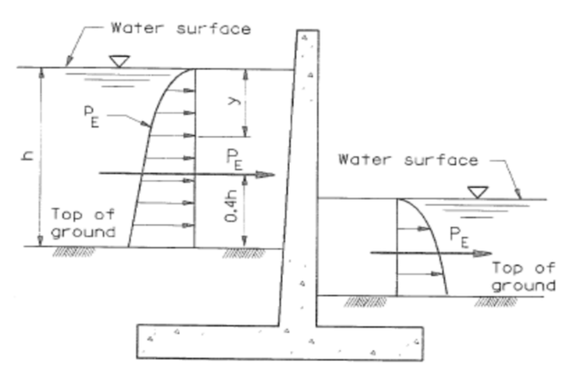


Figure 3-39. Hydrodynamic forces for freestanding water

Theory:
Using Earthquake formula: *(From Design of small dams)*
Pe = C λ w h (Increase in water pressure) Force = Ve = 0.726*Pe*y
C = Cm /2 (y/h (2- y/h) + sqrt(y/h(2-y/h))) = Moment = Me = 0.299 Pe y^2 = 0.4118 Ve y
(Dimensional coeff. giving distribution and magnitudes of pressures.)
λ = Earthquake intensity (ratio to acc due to gravity)
w = unit wt of water
Cm = (for verical faces) = 0.728 (refer charts)
Hence, C = 0.728 for y /h = 1 (overturning point at bottom of reservoir)

Project:	Debris Barrier		Date Printed:		11/1/2019 13:56
Number:	110773396		Page	10 of	10
Completed by:	JH	Date Completed:	10/23/2018		
Reviewed by:	BEF	Date Reviewed:	10/29/2019		

E2

Earthquake calc for water

Same level for U/S and D/S

Base Elevation	1208	m	h=	3.5 m
Water Elevation	1211.5	m		

c=	0.728			width=	2.5	m
λ=	0.17			Ve=	26.99367571	KN
w=	9.81	KN/m3		Me=	**38.9059848**	KNm
h=	3.5	m				
Pe=	**4.2492996**	KN/m				

Horizontal Load per y m 1.21 KN/m^2

applied as an area load (0.5m down) onto parrallel wall

Earthquake calc for soil

Unit Weight of Gravel 14 KN/m^3

Both sides the same, no load applied

ITEM NO.	DESCRIPTION	ELEVATION T/O PIER	DIMENSIONS (m) X	Y	Z	SHAPE FACTOR	AREA m^2	WEIGHT KN	CENTROIDS X DIST (m)	MOM ARM X (m)	MOMENT CONC. (KNm)	HORIZ. Equake LOAD (KN)	HOR. EQ Load per m (KN/m)	HOR. EQ Load per y m (KN/m2)	CENTROIDS Y DIST (m)	MOM ARM Y (m)	MOMENT EQ (KNm)	CONCRETE QUANTITIES
1	Soil	Pos. Concre	1	2	2.5	1	2	70	0.50	5.88	411	12	4.76	2.38	1.00	1.00	12	5.0

CONCRETE WALL CALCULATION

Project #:	110773396	Date Printed:	
Project Name:	SR-1 Debris Barrier	11/1/2019 14:03	
Type:	Wall design		
Location:	Full load on one side	Completed by:	JH
Span:	2.5 m	Date Completed:	9/4/2019
		Reviewed by:	BEF
		Date Reviewed:	10/29/2019

fc' = 35 MPa fy = 400 MPa
width (b) = 1000 mm depth (h) = 500 mm
conc cover= 75 mm

Load Calculation

Loading:		
Soil	22	kPa
Lat. Coef	0.7	
q	15.4	kPa
height of the wall	4.00	m
P = qh	61.60	KN/m
P' = Ph/2	123.2	KN
P'xh	492.80	KNm
factored	739.20	KNm/m

Moment coeficient = 0.123
Mf= 227.30 kNm

Mr = ϕs x fy x As x d = 342.13 kNm Mr>Mf ok (FIRST LOOK)

			# of Bars	Design.	Top/Bot	
ϕs =	0.85					
As =	2500 mm2	Reinf=	5	25	T/B	Spacing bars
d=	402.5 mm	Stirrups=	2	10		200

d= depth of beam - cover - stirrup bar diameter - half reinf bar diameter

α1 = 0.85-0.0015xfc' = 0.7975 ≥ 0.67
β1 = 0.97-0.0025xfc' = 0.8825 ≥ 0.67

$a = \dfrac{\phi s \times fy \times As}{\alpha \times fc' \times b \times \phi c} =$ 0.046849702 m 46.85 mm

ϕc = 0.65

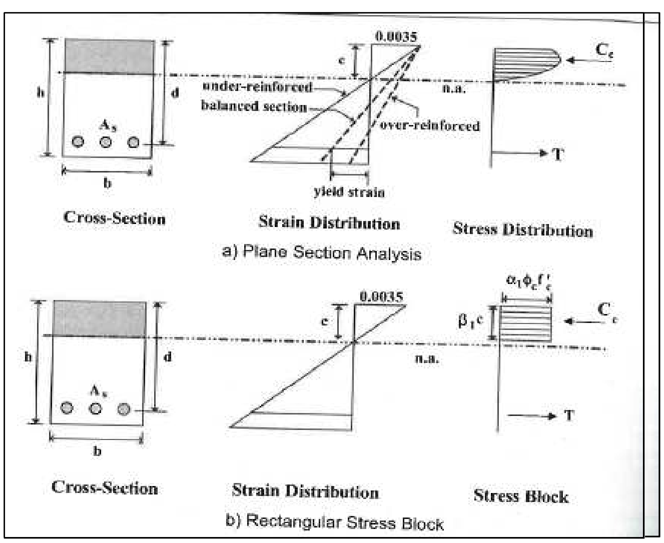
c = a/β1 = 0.053087 m = 53.09 mm

$\dfrac{\varepsilon s=}{349.412519} \quad \dfrac{0.0035}{53.0875}$

εs= 0.02304
εy= 0.002
εs>εy ok

Mr = ϕs*fy*As*(d - a/2)=
Mr = 342.11 kNm
Mr>Mf ok

%Utilization= 0.66443
Mcr= fr * I / (yt) = 2.6E+08 Nmm
Mcr= 264.11 kNm
fr = 0.6*λ*fc' = 3.54965 MPa
I = 1E+10 mm4
yt = 140 mm
1.2 Mcr= 316.93 kNm
Mr≥1.2Mcr ok



SHEAR CALCULATION

Vc = ϕc*β*λ*√fc'*b*d = 278.60 kN   **Vr total=** Vc + Vs = 454.50 kN

Vc=	0.65	0.18	1	5.91608	2.5	402.5

β = 0.18   Simplified method - clause 11.3.6.3
θ = 35   **Vf =** 111.00 kN
λ = 1 (normal density concrete)

Vr>Vf ok

Vs = ϕs x fy x Av x dv x cot θ / S = 175.90 kN   clause 11.3.5

Av = 200 mm2   Av = area of steel (stirrup)   %Utilization= 0.24
dv = 362.25 mm   dv = 0.9d or 0.72h (greater of)
S_{stirup}= 200 mm

CHECKS

Vr max < 5 x Vc ok
Vr max = 0.25*ϕc*fc'*b*dv = 2060.30 kN   ok
clause 11.3.3
S max = 0.7*dv= 253.575 mm   the smaller of
600 mm   (11.3.8.1)
If Vf > 0.125*λ*ϕc*fc'*b*dv, then Smax= Smax/2   clause 11.3.8.2

S max = 253.575 mm   ok

Spacing between reinf bars
S≥1.4ϕb 35
S≥1.4ϕagg 0
S≥30 mm 30
ϕagg = 20 mm
S (btw bs)= 35 mm

Av min = 0.06*√fc'*b*S / fy= 177.48 mm2   ok

As min = 0.2*√fc'*b*h= 591.61 mm2   ok
As = 2500 mm2

Width (fit. in bm) = 180 mm   NOT OK

beam exterior or int? ext
Cracking z=fs*(dc*A)^1/3= 0.00 N/mm   ok   (25000N/mm for ext)
(30000N/mm for int)
fs=0.6fy= 0 MPa   A=S*2dc= 1575 m2
dc = cover+ϕstirrup+1/2ϕb= 22.5 mm

License #2010*1NRDSQ492PZEHHT

Springbank Off-Stream Storage Project

Project Number: 110773396

Prepared for

Alberta Transportation

SAP2000 Analysis Report

Prepared by

Stantec Consulting Ltd.

Model Name: Debris Barrier Model

30 October 2019

Contents

List of Figures

List of Tables

1. Model geometry

This section provides model geometry information, including items such as joint coordinates, joint restraints, and element connectivity.

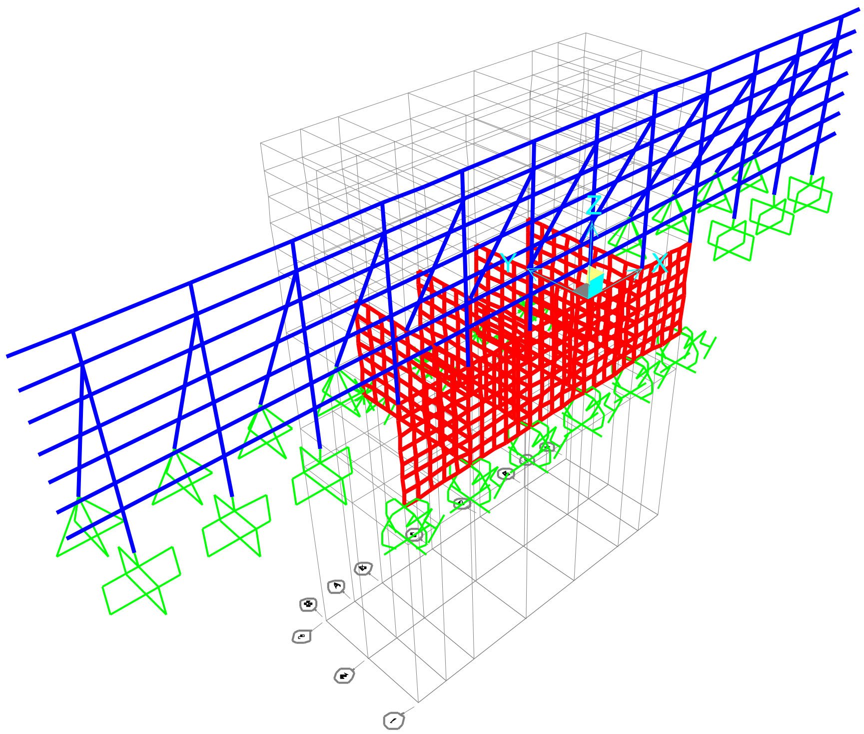


Figure 1: Finite element model

1.1. Joint coordinates

Table 1: Joint Coordinates

Table 1: Joint Coordinates

Joint	CoordSys	CoordType	GlobalX	GlobalY	GlobalZ
			m	m	m
1	GLOBAL	Cartesian	-5.	2.532	0.
2	GLOBAL	Cartesian	-6.25	0.	4.25
3	GLOBAL	Cartesian	-6.25	0.	3.5
4	GLOBAL	Cartesian	-6.25	0.	2.75
5	GLOBAL	Cartesian	-2.5	2.532	0.
6	GLOBAL	Cartesian	-6.25	0.	5.
7	GLOBAL	Cartesian	-6.25	0.	5.75
8	GLOBAL	Cartesian	-5.	0.	0.
9	GLOBAL	Cartesian	-5.	0.	4.25
10	GLOBAL	Cartesian	-5.	0.	3.5

Table 1: Joint Coordinates

Joint	CoordSys	CoordType	GlobalX	GlobalY	GlobalZ
			m	m	m
11	GLOBAL	Cartesian	-5.	0.	2.75
12	GLOBAL	Cartesian	-5.	0.	2.
13	GLOBAL	Cartesian	-5.	0.	5.
14	GLOBAL	Cartesian	-5.	0.	5.75
15	GLOBAL	Cartesian	-2.5	0.	0.
16	GLOBAL	Cartesian	-2.5	0.	2.
17	GLOBAL	Cartesian	-2.5	0.	3.5
18	GLOBAL	Cartesian	-2.5	0.	2.75
19	GLOBAL	Cartesian	-2.5	0.	4.25
20	GLOBAL	Cartesian	-2.5	0.	5.
21	GLOBAL	Cartesian	-2.5	0.	5.75
22	GLOBAL	Cartesian	0.	0.	0.
23	GLOBAL	Cartesian	0.	0.	4.25
24	GLOBAL	Cartesian	0.	0.	3.5
25	GLOBAL	Cartesian	0.	0.	2.75
26	GLOBAL	Cartesian	0.	0.	2.
27	GLOBAL	Cartesian	0.	0.	5.
28	GLOBAL	Cartesian	0.	0.	5.75
29	GLOBAL	Cartesian	2.5	0.	0.
30	GLOBAL	Cartesian	2.5	0.	2.
31	GLOBAL	Cartesian	2.5	0.	2.75
32	GLOBAL	Cartesian	2.5	0.	3.5
33	GLOBAL	Cartesian	2.5	0.	4.25
34	GLOBAL	Cartesian	2.5	0.	5.
35	GLOBAL	Cartesian	2.5	0.	5.75
36	GLOBAL	Cartesian	0.	2.532	0.
37	GLOBAL	Cartesian	-6.25	0.	2.
38	GLOBAL	Cartesian	3.75	0.	4.25
39	GLOBAL	Cartesian	3.75	0.	3.5
40	GLOBAL	Cartesian	3.75	0.	2.75
41	GLOBAL	Cartesian	3.75	0.	5.
42	GLOBAL	Cartesian	2.5	2.532	0.
43	GLOBAL	Cartesian	3.75	0.	2.
44	GLOBAL	Cartesian	3.75	0.	5.75
45	GLOBAL	Cartesian	5.	0.	0.
46	GLOBAL	Cartesian	5.	0.	5.
47	GLOBAL	Cartesian	5.	0.	5.75
48	GLOBAL	Cartesian	7.5	0.	0.
49	GLOBAL	Cartesian	7.5	0.	5.
50	GLOBAL	Cartesian	7.5	0.	5.75
51	GLOBAL	Cartesian	10.	0.	0.
52	GLOBAL	Cartesian	10.	0.	5.
53	GLOBAL	Cartesian	10.	0.	5.75
54	GLOBAL	Cartesian	12.5	0.	0.
55	GLOBAL	Cartesian	12.5	0.	5.
56	GLOBAL	Cartesian	12.5	0.	5.75
57	GLOBAL	Cartesian	13.75	0.	5.75
58	GLOBAL	Cartesian	5.	2.532	0.
59	GLOBAL	Cartesian	7.5	2.532	0.
60	GLOBAL	Cartesian	10.	2.532	0.
61	GLOBAL	Cartesian	12.5	2.532	0.
62	GLOBAL	Cartesian	13.75	0.	5.
63	GLOBAL	Cartesian	13.75	0.	4.25
64	GLOBAL	Cartesian	13.75	0.	3.5

Table 1: Joint Coordinates

Joint	CoordSys	CoordType	GlobalX	GlobalY	GlobalZ
			m	m	m
65	GLOBAL	Cartesian	13.75	0.	2.75
66	GLOBAL	Cartesian	13.75	0.	2.
67	GLOBAL	Cartesian	5.	0.	4.25
68	GLOBAL	Cartesian	5.	0.	3.5
69	GLOBAL	Cartesian	5.	0.	2.75
70	GLOBAL	Cartesian	5.	0.	2.
71	GLOBAL	Cartesian	7.5	0.	2.
72	GLOBAL	Cartesian	7.5	0.	3.5
73	GLOBAL	Cartesian	7.5	0.	2.75
74	GLOBAL	Cartesian	7.5	0.	4.25
75	GLOBAL	Cartesian	10.	0.	4.25
76	GLOBAL	Cartesian	10.	0.	3.5
77	GLOBAL	Cartesian	10.	0.	2.75
78	GLOBAL	Cartesian	10.	0.	2.
79	GLOBAL	Cartesian	12.5	0.	2.
80	GLOBAL	Cartesian	12.5	0.	2.75
81	GLOBAL	Cartesian	12.5	0.	3.5
82	GLOBAL	Cartesian	12.5	0.	4.25
83	GLOBAL	Cartesian	-16.25	0.	5.75
84	GLOBAL	Cartesian	-15.	0.	0.
85	GLOBAL	Cartesian	-15.	0.	5.
86	GLOBAL	Cartesian	-15.	0.	5.75
87	GLOBAL	Cartesian	-12.5	0.	0.
88	GLOBAL	Cartesian	-12.5	0.	5.
89	GLOBAL	Cartesian	-12.5	0.	5.75
90	GLOBAL	Cartesian	-10.	0.	0.
91	GLOBAL	Cartesian	-10.	0.	5.
92	GLOBAL	Cartesian	-10.	0.	5.75
93	GLOBAL	Cartesian	-7.5	0.	0.
94	GLOBAL	Cartesian	-7.5	0.	5.
95	GLOBAL	Cartesian	-7.5	0.	5.75
96	GLOBAL	Cartesian	-15.	2.532	0.
97	GLOBAL	Cartesian	-12.5	2.532	0.
98	GLOBAL	Cartesian	-10.	2.532	0.
99	GLOBAL	Cartesian	-7.5	2.532	0.
100	GLOBAL	Cartesian	-16.25	0.	5.
101	GLOBAL	Cartesian	-16.25	0.	4.25
102	GLOBAL	Cartesian	-16.25	0.	3.5
103	GLOBAL	Cartesian	-16.25	0.	2.75
104	GLOBAL	Cartesian	-16.25	0.	2.
105	GLOBAL	Cartesian	-15.	0.	4.25
106	GLOBAL	Cartesian	-15.	0.	3.5
107	GLOBAL	Cartesian	-15.	0.	2.75
108	GLOBAL	Cartesian	-15.	0.	2.
109	GLOBAL	Cartesian	-12.5	0.	2.
110	GLOBAL	Cartesian	-12.5	0.	3.5
111	GLOBAL	Cartesian	-12.5	0.	2.75
112	GLOBAL	Cartesian	-12.5	0.	4.25
113	GLOBAL	Cartesian	-10.	0.	4.25
114	GLOBAL	Cartesian	-10.	0.	3.5
115	GLOBAL	Cartesian	-10.	0.	2.75
116	GLOBAL	Cartesian	-10.	0.	2.
117	GLOBAL	Cartesian	-7.5	0.	2.
118	GLOBAL	Cartesian	-7.5	0.	2.75

Table 1: Joint Coordinates

Joint	CoordSys	CoordType	GlobalX	GlobalY	GlobalZ
			m	m	m
119	GLOBAL	Cartesian	-7.5	0.	3.5
120	GLOBAL	Cartesian	-7.5	0.	4.25
121	GLOBAL	Cartesian	-6.25	0.	1.25
122	GLOBAL	Cartesian	3.75	0.	1.25
123	GLOBAL	Cartesian	13.75	0.	1.25
124	GLOBAL	Cartesian	5.	0.	-3.5
125	GLOBAL	Cartesian	-7.5	0.	-3.5
126	GLOBAL	Cartesian	-16.25	0.	1.25
127	GLOBAL	Cartesian	-15.	0.	1.25
128	GLOBAL	Cartesian	-12.5	0.	1.25
129	GLOBAL	Cartesian	-10.	0.	1.25
130	GLOBAL	Cartesian	-5.	0.	1.25
131	GLOBAL	Cartesian	-2.5	0.	1.25
132	GLOBAL	Cartesian	0.	0.	1.25
133	GLOBAL	Cartesian	2.5	0.	1.25
134	GLOBAL	Cartesian	5.	0.	1.25
135	GLOBAL	Cartesian	-5.	4.875	-3.576E-07
136	GLOBAL	Cartesian	-5.	4.875	-3.5
137	GLOBAL	Cartesian	-5.	1.192E-07	-3.5
138	GLOBAL	Cartesian	-2.5	4.875	2.384E-07
139	GLOBAL	Cartesian	-2.5	4.875	-3.5
140	GLOBAL	Cartesian	-2.5	0.	-3.5
141	GLOBAL	Cartesian	0.	4.875	2.384E-07
142	GLOBAL	Cartesian	0.	4.875	-3.5
143	GLOBAL	Cartesian	0.	0.	-3.5
144	GLOBAL	Cartesian	2.5	4.875	2.384E-07
145	GLOBAL	Cartesian	2.5	4.875	-3.5
146	GLOBAL	Cartesian	2.5	0.	-3.5
147	GLOBAL	Cartesian	7.5	0.	1.25
148	GLOBAL	Cartesian	10.	0.	1.25
149	GLOBAL	Cartesian	12.5	0.	1.25
150	GLOBAL	Cartesian	-7.5	0.	1.25
153	GLOBAL	Cartesian	-7.	0.	0.
154	GLOBAL	Cartesian	-7.	3.406E-09	-0.5
155	GLOBAL	Cartesian	-7.5	0.	-0.5
156	GLOBAL	Cartesian	-7.	6.812E-09	-1.
157	GLOBAL	Cartesian	-7.5	0.	-1.
158	GLOBAL	Cartesian	-7.	1.022E-08	-1.5
159	GLOBAL	Cartesian	-7.5	0.	-1.5
160	GLOBAL	Cartesian	-7.	1.362E-08	-2.
161	GLOBAL	Cartesian	-7.5	0.	-2.
162	GLOBAL	Cartesian	-7.	1.703E-08	-2.5
163	GLOBAL	Cartesian	-7.5	0.	-2.5
164	GLOBAL	Cartesian	-7.	2.044E-08	-3.
165	GLOBAL	Cartesian	-7.5	0.	-3.
166	GLOBAL	Cartesian	-7.	2.384E-08	-3.5
167	GLOBAL	Cartesian	-6.5	0.	0.
168	GLOBAL	Cartesian	-6.5	6.812E-09	-0.5
169	GLOBAL	Cartesian	-6.5	1.362E-08	-1.
170	GLOBAL	Cartesian	-6.5	2.044E-08	-1.5
171	GLOBAL	Cartesian	-6.5	2.725E-08	-2.
172	GLOBAL	Cartesian	-6.5	3.406E-08	-2.5
173	GLOBAL	Cartesian	-6.5	4.087E-08	-3.
174	GLOBAL	Cartesian	-6.5	4.768E-08	-3.5

Table 1: Joint Coordinates

Joint	CoordSys	CoordType	GlobalX	GlobalY	GlobalZ
			m	m	m
175	GLOBAL	Cartesian	-6.	0.	0.
176	GLOBAL	Cartesian	-6.	1.022E-08	-0.5
177	GLOBAL	Cartesian	-6.	2.044E-08	-1.
178	GLOBAL	Cartesian	-6.	3.065E-08	-1.5
179	GLOBAL	Cartesian	-6.	4.087E-08	-2.
180	GLOBAL	Cartesian	-6.	5.109E-08	-2.5
181	GLOBAL	Cartesian	-6.	6.131E-08	-3.
182	GLOBAL	Cartesian	-6.	7.153E-08	-3.5
183	GLOBAL	Cartesian	-5.5	0.	0.
184	GLOBAL	Cartesian	-5.5	1.362E-08	-0.5
185	GLOBAL	Cartesian	-5.5	2.725E-08	-1.
186	GLOBAL	Cartesian	-5.5	4.087E-08	-1.5
187	GLOBAL	Cartesian	-5.5	5.450E-08	-2.
188	GLOBAL	Cartesian	-5.5	6.812E-08	-2.5
189	GLOBAL	Cartesian	-5.5	8.174E-08	-3.
190	GLOBAL	Cartesian	-5.5	9.537E-08	-3.5
191	GLOBAL	Cartesian	-5.	1.703E-08	-0.5
192	GLOBAL	Cartesian	-5.	3.406E-08	-1.
193	GLOBAL	Cartesian	-5.	5.109E-08	-1.5
194	GLOBAL	Cartesian	-5.	6.812E-08	-2.
195	GLOBAL	Cartesian	-5.	8.515E-08	-2.5
196	GLOBAL	Cartesian	-5.	1.022E-07	-3.
197	GLOBAL	Cartesian	-4.5	0.	0.
198	GLOBAL	Cartesian	-4.5	1.362E-08	-0.5
199	GLOBAL	Cartesian	-4.5	2.725E-08	-1.
200	GLOBAL	Cartesian	-4.5	4.087E-08	-1.5
201	GLOBAL	Cartesian	-4.5	5.450E-08	-2.
202	GLOBAL	Cartesian	-4.5	6.812E-08	-2.5
203	GLOBAL	Cartesian	-4.5	8.174E-08	-3.
204	GLOBAL	Cartesian	-4.5	9.537E-08	-3.5
205	GLOBAL	Cartesian	-4.	0.	0.
206	GLOBAL	Cartesian	-4.	1.022E-08	-0.5
207	GLOBAL	Cartesian	-4.	2.044E-08	-1.
208	GLOBAL	Cartesian	-4.	3.065E-08	-1.5
209	GLOBAL	Cartesian	-4.	4.087E-08	-2.
210	GLOBAL	Cartesian	-4.	5.109E-08	-2.5
211	GLOBAL	Cartesian	-4.	6.131E-08	-3.
212	GLOBAL	Cartesian	-4.	7.153E-08	-3.5
213	GLOBAL	Cartesian	-3.5	0.	0.
214	GLOBAL	Cartesian	-3.5	6.812E-09	-0.5
215	GLOBAL	Cartesian	-3.5	1.362E-08	-1.
216	GLOBAL	Cartesian	-3.5	2.044E-08	-1.5
217	GLOBAL	Cartesian	-3.5	2.725E-08	-2.
218	GLOBAL	Cartesian	-3.5	3.406E-08	-2.5
219	GLOBAL	Cartesian	-3.5	4.087E-08	-3.
220	GLOBAL	Cartesian	-3.5	4.768E-08	-3.5
221	GLOBAL	Cartesian	-3.	0.	0.
222	GLOBAL	Cartesian	-3.	3.406E-09	-0.5
223	GLOBAL	Cartesian	-3.	6.812E-09	-1.
224	GLOBAL	Cartesian	-3.	1.022E-08	-1.5
225	GLOBAL	Cartesian	-3.	1.362E-08	-2.
226	GLOBAL	Cartesian	-3.	1.703E-08	-2.5
227	GLOBAL	Cartesian	-3.	2.044E-08	-3.
228	GLOBAL	Cartesian	-3.	2.384E-08	-3.5

Table 1: Joint Coordinates

Joint	CoordSys	CoordType	GlobalX	GlobalY	GlobalZ
			m	m	m
229	GLOBAL	Cartesian	-2.5	0.	-0.5
230	GLOBAL	Cartesian	-2.5	0.	-1.
231	GLOBAL	Cartesian	-2.5	0.	-1.5
232	GLOBAL	Cartesian	-2.5	0.	-2.
233	GLOBAL	Cartesian	-2.5	0.	-2.5
234	GLOBAL	Cartesian	-2.5	0.	-3.
235	GLOBAL	Cartesian	-2.	0.	0.
236	GLOBAL	Cartesian	-2.	0.	-0.5
237	GLOBAL	Cartesian	-2.	0.	-1.
238	GLOBAL	Cartesian	-2.	0.	-1.5
239	GLOBAL	Cartesian	-2.	0.	-2.
240	GLOBAL	Cartesian	-2.	0.	-2.5
241	GLOBAL	Cartesian	-2.	0.	-3.
242	GLOBAL	Cartesian	-2.	0.	-3.5
243	GLOBAL	Cartesian	-1.5	0.	0.
244	GLOBAL	Cartesian	-1.5	0.	-0.5
245	GLOBAL	Cartesian	-1.5	0.	-1.
246	GLOBAL	Cartesian	-1.5	0.	-1.5
247	GLOBAL	Cartesian	-1.5	0.	-2.
248	GLOBAL	Cartesian	-1.5	0.	-2.5
249	GLOBAL	Cartesian	-1.5	0.	-3.
250	GLOBAL	Cartesian	-1.5	0.	-3.5
251	GLOBAL	Cartesian	-1.	0.	0.
252	GLOBAL	Cartesian	-1.	0.	-0.5
253	GLOBAL	Cartesian	-1.	0.	-1.
254	GLOBAL	Cartesian	-1.	0.	-1.5
255	GLOBAL	Cartesian	-1.	0.	-2.
256	GLOBAL	Cartesian	-1.	0.	-2.5
257	GLOBAL	Cartesian	-1.	0.	-3.
258	GLOBAL	Cartesian	-1.	0.	-3.5
259	GLOBAL	Cartesian	-0.5	0.	0.
260	GLOBAL	Cartesian	-0.5	0.	-0.5
261	GLOBAL	Cartesian	-0.5	0.	-1.
262	GLOBAL	Cartesian	-0.5	0.	-1.5
263	GLOBAL	Cartesian	-0.5	0.	-2.
264	GLOBAL	Cartesian	-0.5	0.	-2.5
265	GLOBAL	Cartesian	-0.5	0.	-3.
266	GLOBAL	Cartesian	-0.5	0.	-3.5
267	GLOBAL	Cartesian	0.	0.	-0.5
268	GLOBAL	Cartesian	0.	0.	-1.
269	GLOBAL	Cartesian	0.	0.	-1.5
270	GLOBAL	Cartesian	0.	0.	-2.
271	GLOBAL	Cartesian	0.	0.	-2.5
272	GLOBAL	Cartesian	0.	0.	-3.
273	GLOBAL	Cartesian	0.5	0.	0.
274	GLOBAL	Cartesian	0.5	0.	-0.5
275	GLOBAL	Cartesian	0.5	0.	-1.
276	GLOBAL	Cartesian	0.5	0.	-1.5
277	GLOBAL	Cartesian	0.5	0.	-2.
278	GLOBAL	Cartesian	0.5	0.	-2.5
279	GLOBAL	Cartesian	0.5	0.	-3.
280	GLOBAL	Cartesian	0.5	0.	-3.5
281	GLOBAL	Cartesian	1.	0.	0.
282	GLOBAL	Cartesian	1.	0.	-0.5

Table 1: Joint Coordinates

Joint	CoordSys	CoordType	GlobalX	GlobalY	GlobalZ
			m	m	m
283	GLOBAL	Cartesian	1.	0.	-1.
284	GLOBAL	Cartesian	1.	0.	-1.5
285	GLOBAL	Cartesian	1.	0.	-2.
286	GLOBAL	Cartesian	1.	0.	-2.5
287	GLOBAL	Cartesian	1.	0.	-3.
288	GLOBAL	Cartesian	1.	0.	-3.5
289	GLOBAL	Cartesian	1.5	0.	0.
290	GLOBAL	Cartesian	1.5	0.	-0.5
291	GLOBAL	Cartesian	1.5	0.	-1.
292	GLOBAL	Cartesian	1.5	0.	-1.5
293	GLOBAL	Cartesian	1.5	0.	-2.
294	GLOBAL	Cartesian	1.5	0.	-2.5
295	GLOBAL	Cartesian	1.5	0.	-3.
296	GLOBAL	Cartesian	1.5	0.	-3.5
297	GLOBAL	Cartesian	2.	0.	0.
298	GLOBAL	Cartesian	2.	0.	-0.5
299	GLOBAL	Cartesian	2.	0.	-1.
300	GLOBAL	Cartesian	2.	0.	-1.5
301	GLOBAL	Cartesian	2.	0.	-2.
302	GLOBAL	Cartesian	2.	0.	-2.5
303	GLOBAL	Cartesian	2.	0.	-3.
304	GLOBAL	Cartesian	2.	0.	-3.5
305	GLOBAL	Cartesian	2.5	0.	-0.5
306	GLOBAL	Cartesian	2.5	0.	-1.
307	GLOBAL	Cartesian	2.5	0.	-1.5
308	GLOBAL	Cartesian	2.5	0.	-2.
309	GLOBAL	Cartesian	2.5	0.	-2.5
310	GLOBAL	Cartesian	2.5	0.	-3.
311	GLOBAL	Cartesian	3.	0.	0.
312	GLOBAL	Cartesian	3.	0.	-0.5
313	GLOBAL	Cartesian	3.	0.	-1.
314	GLOBAL	Cartesian	3.	0.	-1.5
315	GLOBAL	Cartesian	3.	0.	-2.
316	GLOBAL	Cartesian	3.	0.	-2.5
317	GLOBAL	Cartesian	3.	0.	-3.
318	GLOBAL	Cartesian	3.	0.	-3.5
319	GLOBAL	Cartesian	3.5	0.	0.
320	GLOBAL	Cartesian	3.5	0.	-0.5
321	GLOBAL	Cartesian	3.5	0.	-1.
322	GLOBAL	Cartesian	3.5	0.	-1.5
323	GLOBAL	Cartesian	3.5	0.	-2.
324	GLOBAL	Cartesian	3.5	0.	-2.5
325	GLOBAL	Cartesian	3.5	0.	-3.
326	GLOBAL	Cartesian	3.5	0.	-3.5
327	GLOBAL	Cartesian	4.	0.	0.
328	GLOBAL	Cartesian	4.	0.	-0.5
329	GLOBAL	Cartesian	4.	0.	-1.
330	GLOBAL	Cartesian	4.	0.	-1.5
331	GLOBAL	Cartesian	4.	0.	-2.
332	GLOBAL	Cartesian	4.	0.	-2.5
333	GLOBAL	Cartesian	4.	0.	-3.
334	GLOBAL	Cartesian	4.	0.	-3.5
335	GLOBAL	Cartesian	4.5	0.	0.
336	GLOBAL	Cartesian	4.5	0.	-0.5

Table 1: Joint Coordinates

Joint	CoordSys	CoordType	GlobalX	GlobalY	GlobalZ
			m	m	m
337	GLOBAL	Cartesian	4.5	0.	-1.
338	GLOBAL	Cartesian	4.5	0.	-1.5
339	GLOBAL	Cartesian	4.5	0.	-2.
340	GLOBAL	Cartesian	4.5	0.	-2.5
341	GLOBAL	Cartesian	4.5	0.	-3.
342	GLOBAL	Cartesian	4.5	0.	-3.5
343	GLOBAL	Cartesian	5.	0.	-0.5
344	GLOBAL	Cartesian	5.	0.	-1.
345	GLOBAL	Cartesian	5.	0.	-1.5
346	GLOBAL	Cartesian	5.	0.	-2.
347	GLOBAL	Cartesian	5.	0.	-2.5
348	GLOBAL	Cartesian	5.	0.	-3.
350	GLOBAL	Cartesian	-5.	2.532	-0.5
351	GLOBAL	Cartesian	-5.	2.532	-1.
352	GLOBAL	Cartesian	-5.	2.532	-1.5
353	GLOBAL	Cartesian	-5.	2.532	-2.
354	GLOBAL	Cartesian	-5.	2.532	-2.5
355	GLOBAL	Cartesian	-5.	2.532	-3.
356	GLOBAL	Cartesian	-5.	2.532	-3.5
357	GLOBAL	Cartesian	-5.	4.875	-0.5
358	GLOBAL	Cartesian	-5.	4.875	-1.
359	GLOBAL	Cartesian	-5.	4.875	-1.5
360	GLOBAL	Cartesian	-5.	4.875	-2.
361	GLOBAL	Cartesian	-5.	4.875	-2.5
362	GLOBAL	Cartesian	-5.	4.875	-3.
364	GLOBAL	Cartesian	-2.5	2.532	-0.5
365	GLOBAL	Cartesian	-2.5	2.532	-1.
366	GLOBAL	Cartesian	-2.5	2.532	-1.5
367	GLOBAL	Cartesian	-2.5	2.532	-2.
368	GLOBAL	Cartesian	-2.5	2.532	-2.5
369	GLOBAL	Cartesian	-2.5	2.532	-3.
370	GLOBAL	Cartesian	-2.5	2.532	-3.5
371	GLOBAL	Cartesian	-2.5	4.875	-0.5
372	GLOBAL	Cartesian	-2.5	4.875	-1.
373	GLOBAL	Cartesian	-2.5	4.875	-1.5
374	GLOBAL	Cartesian	-2.5	4.875	-2.
375	GLOBAL	Cartesian	-2.5	4.875	-2.5
376	GLOBAL	Cartesian	-2.5	4.875	-3.
378	GLOBAL	Cartesian	0.	2.532	-0.5
379	GLOBAL	Cartesian	0.	2.532	-1.
380	GLOBAL	Cartesian	0.	2.532	-1.5
381	GLOBAL	Cartesian	0.	2.532	-2.
382	GLOBAL	Cartesian	0.	2.532	-2.5
383	GLOBAL	Cartesian	0.	2.532	-3.
384	GLOBAL	Cartesian	0.	2.532	-3.5
385	GLOBAL	Cartesian	0.	4.875	-0.5
386	GLOBAL	Cartesian	0.	4.875	-1.
387	GLOBAL	Cartesian	0.	4.875	-1.5
388	GLOBAL	Cartesian	0.	4.875	-2.
389	GLOBAL	Cartesian	0.	4.875	-2.5
390	GLOBAL	Cartesian	0.	4.875	-3.
392	GLOBAL	Cartesian	2.5	2.532	-0.5
393	GLOBAL	Cartesian	2.5	2.532	-1.
394	GLOBAL	Cartesian	2.5	2.532	-1.5

Table 1: Joint Coordinates

Joint	CoordSys	CoordType	GlobalX	GlobalY	GlobalZ
			m	m	m
395	GLOBAL	Cartesian	2.5	2.532	-2.
396	GLOBAL	Cartesian	2.5	2.532	-2.5
397	GLOBAL	Cartesian	2.5	2.532	-3.
398	GLOBAL	Cartesian	2.5	2.532	-3.5
399	GLOBAL	Cartesian	2.5	4.875	-0.5
400	GLOBAL	Cartesian	2.5	4.875	-1.
401	GLOBAL	Cartesian	2.5	4.875	-1.5
402	GLOBAL	Cartesian	2.5	4.875	-2.
403	GLOBAL	Cartesian	2.5	4.875	-2.5
404	GLOBAL	Cartesian	2.5	4.875	-3.
405	GLOBAL	Cartesian	-5.	0.633	0.
406	GLOBAL	Cartesian	-5.	0.633	-0.5
407	GLOBAL	Cartesian	-5.	1.266	0.
408	GLOBAL	Cartesian	-5.	1.266	-0.5
409	GLOBAL	Cartesian	-5.	1.899	0.
410	GLOBAL	Cartesian	-5.	1.899	-0.5
411	GLOBAL	Cartesian	-5.	0.633	-1.
412	GLOBAL	Cartesian	-5.	1.266	-1.
413	GLOBAL	Cartesian	-5.	1.899	-1.
414	GLOBAL	Cartesian	-5.	0.633	-1.5
415	GLOBAL	Cartesian	-5.	1.266	-1.5
416	GLOBAL	Cartesian	-5.	1.899	-1.5
417	GLOBAL	Cartesian	-5.	0.633	-2.
418	GLOBAL	Cartesian	-5.	1.266	-2.
419	GLOBAL	Cartesian	-5.	1.899	-2.
420	GLOBAL	Cartesian	-5.	0.633	-2.5
421	GLOBAL	Cartesian	-5.	1.266	-2.5
422	GLOBAL	Cartesian	-5.	1.899	-2.5
423	GLOBAL	Cartesian	-5.	0.633	-3.
424	GLOBAL	Cartesian	-5.	1.266	-3.
425	GLOBAL	Cartesian	-5.	1.899	-3.
426	GLOBAL	Cartesian	-5.	0.633	-3.5
427	GLOBAL	Cartesian	-5.	1.266	-3.5
428	GLOBAL	Cartesian	-5.	1.899	-3.5
429	GLOBAL	Cartesian	-5.	3.11775	-8.941E-08
430	GLOBAL	Cartesian	-5.	3.11775	-0.5
431	GLOBAL	Cartesian	-5.	3.7035	-1.788E-07
432	GLOBAL	Cartesian	-5.	3.7035	-0.5
433	GLOBAL	Cartesian	-5.	4.28925	-2.682E-07
434	GLOBAL	Cartesian	-5.	4.28925	-0.5
435	GLOBAL	Cartesian	-5.	3.11775	-1.
436	GLOBAL	Cartesian	-5.	3.7035	-1.
437	GLOBAL	Cartesian	-5.	4.28925	-1.
438	GLOBAL	Cartesian	-5.	3.11775	-1.5
439	GLOBAL	Cartesian	-5.	3.7035	-1.5
440	GLOBAL	Cartesian	-5.	4.28925	-1.5
441	GLOBAL	Cartesian	-5.	3.11775	-2.
442	GLOBAL	Cartesian	-5.	3.7035	-2.
443	GLOBAL	Cartesian	-5.	4.28925	-2.
444	GLOBAL	Cartesian	-5.	3.11775	-2.5
445	GLOBAL	Cartesian	-5.	3.7035	-2.5
446	GLOBAL	Cartesian	-5.	4.28925	-2.5
447	GLOBAL	Cartesian	-5.	3.11775	-3.
448	GLOBAL	Cartesian	-5.	3.7035	-3.

Table 1: Joint Coordinates

Joint	CoordSys	CoordType	GlobalX	GlobalY	GlobalZ
			m	m	m
449	GLOBAL	Cartesian	-5.	4.28925	-3.
450	GLOBAL	Cartesian	-5.	3.11775	-3.5
451	GLOBAL	Cartesian	-5.	3.7035	-3.5
452	GLOBAL	Cartesian	-5.	4.28925	-3.5
453	GLOBAL	Cartesian	-2.5	0.633	0.
454	GLOBAL	Cartesian	-2.5	0.633	-0.5
455	GLOBAL	Cartesian	-2.5	1.266	0.
456	GLOBAL	Cartesian	-2.5	1.266	-0.5
457	GLOBAL	Cartesian	-2.5	1.899	0.
458	GLOBAL	Cartesian	-2.5	1.899	-0.5
459	GLOBAL	Cartesian	-2.5	0.633	-1.
460	GLOBAL	Cartesian	-2.5	1.266	-1.
461	GLOBAL	Cartesian	-2.5	1.899	-1.
462	GLOBAL	Cartesian	-2.5	0.633	-1.5
463	GLOBAL	Cartesian	-2.5	1.266	-1.5
464	GLOBAL	Cartesian	-2.5	1.899	-1.5
465	GLOBAL	Cartesian	-2.5	0.633	-2.
466	GLOBAL	Cartesian	-2.5	1.266	-2.
467	GLOBAL	Cartesian	-2.5	1.899	-2.
468	GLOBAL	Cartesian	-2.5	0.633	-2.5
469	GLOBAL	Cartesian	-2.5	1.266	-2.5
470	GLOBAL	Cartesian	-2.5	1.899	-2.5
471	GLOBAL	Cartesian	-2.5	0.633	-3.
472	GLOBAL	Cartesian	-2.5	1.266	-3.
473	GLOBAL	Cartesian	-2.5	1.899	-3.
474	GLOBAL	Cartesian	-2.5	0.633	-3.5
475	GLOBAL	Cartesian	-2.5	1.266	-3.5
476	GLOBAL	Cartesian	-2.5	1.899	-3.5
477	GLOBAL	Cartesian	-2.5	3.11775	5.960E-08
478	GLOBAL	Cartesian	-2.5	3.11775	-0.5
479	GLOBAL	Cartesian	-2.5	3.7035	1.192E-07
480	GLOBAL	Cartesian	-2.5	3.7035	-0.5
481	GLOBAL	Cartesian	-2.5	4.28925	1.788E-07
482	GLOBAL	Cartesian	-2.5	4.28925	-0.5
483	GLOBAL	Cartesian	-2.5	3.11775	-1.
484	GLOBAL	Cartesian	-2.5	3.7035	-1.
485	GLOBAL	Cartesian	-2.5	4.28925	-1.
486	GLOBAL	Cartesian	-2.5	3.11775	-1.5
487	GLOBAL	Cartesian	-2.5	3.7035	-1.5
488	GLOBAL	Cartesian	-2.5	4.28925	-1.5
489	GLOBAL	Cartesian	-2.5	3.11775	-2.
490	GLOBAL	Cartesian	-2.5	3.7035	-2.
491	GLOBAL	Cartesian	-2.5	4.28925	-2.
492	GLOBAL	Cartesian	-2.5	3.11775	-2.5
493	GLOBAL	Cartesian	-2.5	3.7035	-2.5
494	GLOBAL	Cartesian	-2.5	4.28925	-2.5
495	GLOBAL	Cartesian	-2.5	3.11775	-3.
496	GLOBAL	Cartesian	-2.5	3.7035	-3.
497	GLOBAL	Cartesian	-2.5	4.28925	-3.
498	GLOBAL	Cartesian	-2.5	3.11775	-3.5
499	GLOBAL	Cartesian	-2.5	3.7035	-3.5
500	GLOBAL	Cartesian	-2.5	4.28925	-3.5
501	GLOBAL	Cartesian	0.	0.633	0.
502	GLOBAL	Cartesian	0.	0.633	-0.5

Table 1: Joint Coordinates

Joint	CoordSys	CoordType	GlobalX	GlobalY	GlobalZ
			m	m	m
503	GLOBAL	Cartesian	0.	1.266	0.
504	GLOBAL	Cartesian	0.	1.266	-0.5
505	GLOBAL	Cartesian	0.	1.899	0.
506	GLOBAL	Cartesian	0.	1.899	-0.5
507	GLOBAL	Cartesian	0.	0.633	-1.
508	GLOBAL	Cartesian	0.	1.266	-1.
509	GLOBAL	Cartesian	0.	1.899	-1.
510	GLOBAL	Cartesian	0.	0.633	-1.5
511	GLOBAL	Cartesian	0.	1.266	-1.5
512	GLOBAL	Cartesian	0.	1.899	-1.5
513	GLOBAL	Cartesian	0.	0.633	-2.
514	GLOBAL	Cartesian	0.	1.266	-2.
515	GLOBAL	Cartesian	0.	1.899	-2.
516	GLOBAL	Cartesian	0.	0.633	-2.5
517	GLOBAL	Cartesian	0.	1.266	-2.5
518	GLOBAL	Cartesian	0.	1.899	-2.5
519	GLOBAL	Cartesian	0.	0.633	-3.
520	GLOBAL	Cartesian	0.	1.266	-3.
521	GLOBAL	Cartesian	0.	1.899	-3.
522	GLOBAL	Cartesian	0.	0.633	-3.5
523	GLOBAL	Cartesian	0.	1.266	-3.5
524	GLOBAL	Cartesian	0.	1.899	-3.5
525	GLOBAL	Cartesian	0.	3.11775	5.960E-08
526	GLOBAL	Cartesian	0.	3.11775	-0.5
527	GLOBAL	Cartesian	0.	3.7035	1.192E-07
528	GLOBAL	Cartesian	0.	3.7035	-0.5
529	GLOBAL	Cartesian	0.	4.28925	1.788E-07
530	GLOBAL	Cartesian	0.	4.28925	-0.5
531	GLOBAL	Cartesian	0.	3.11775	-1.
532	GLOBAL	Cartesian	0.	3.7035	-1.
533	GLOBAL	Cartesian	0.	4.28925	-1.
534	GLOBAL	Cartesian	0.	3.11775	-1.5
535	GLOBAL	Cartesian	0.	3.7035	-1.5
536	GLOBAL	Cartesian	0.	4.28925	-1.5
537	GLOBAL	Cartesian	0.	3.11775	-2.
538	GLOBAL	Cartesian	0.	3.7035	-2.
539	GLOBAL	Cartesian	0.	4.28925	-2.
540	GLOBAL	Cartesian	0.	3.11775	-2.5
541	GLOBAL	Cartesian	0.	3.7035	-2.5
542	GLOBAL	Cartesian	0.	4.28925	-2.5
543	GLOBAL	Cartesian	0.	3.11775	-3.
544	GLOBAL	Cartesian	0.	3.7035	-3.
545	GLOBAL	Cartesian	0.	4.28925	-3.
546	GLOBAL	Cartesian	0.	3.11775	-3.5
547	GLOBAL	Cartesian	0.	3.7035	-3.5
548	GLOBAL	Cartesian	0.	4.28925	-3.5
549	GLOBAL	Cartesian	2.5	0.633	0.
550	GLOBAL	Cartesian	2.5	0.633	-0.5
551	GLOBAL	Cartesian	2.5	1.266	0.
552	GLOBAL	Cartesian	2.5	1.266	-0.5
553	GLOBAL	Cartesian	2.5	1.899	0.
554	GLOBAL	Cartesian	2.5	1.899	-0.5
555	GLOBAL	Cartesian	2.5	0.633	-1.
556	GLOBAL	Cartesian	2.5	1.266	-1.

Table 1: Joint Coordinates

Joint	CoordSys	CoordType	GlobalX	GlobalY	GlobalZ
			m	m	m
557	GLOBAL	Cartesian	2.5	1.899	-1.
558	GLOBAL	Cartesian	2.5	0.633	-1.5
559	GLOBAL	Cartesian	2.5	1.266	-1.5
560	GLOBAL	Cartesian	2.5	1.899	-1.5
561	GLOBAL	Cartesian	2.5	0.633	-2.
562	GLOBAL	Cartesian	2.5	1.266	-2.
563	GLOBAL	Cartesian	2.5	1.899	-2.
564	GLOBAL	Cartesian	2.5	0.633	-2.5
565	GLOBAL	Cartesian	2.5	1.266	-2.5
566	GLOBAL	Cartesian	2.5	1.899	-2.5
567	GLOBAL	Cartesian	2.5	0.633	-3.
568	GLOBAL	Cartesian	2.5	1.266	-3.
569	GLOBAL	Cartesian	2.5	1.899	-3.
570	GLOBAL	Cartesian	2.5	0.633	-3.5
571	GLOBAL	Cartesian	2.5	1.266	-3.5
572	GLOBAL	Cartesian	2.5	1.899	-3.5
573	GLOBAL	Cartesian	2.5	3.11775	5.960E-08
574	GLOBAL	Cartesian	2.5	3.11775	-0.5
575	GLOBAL	Cartesian	2.5	3.7035	1.192E-07
576	GLOBAL	Cartesian	2.5	3.7035	-0.5
577	GLOBAL	Cartesian	2.5	4.28925	1.788E-07
578	GLOBAL	Cartesian	2.5	4.28925	-0.5
579	GLOBAL	Cartesian	2.5	3.11775	-1.
580	GLOBAL	Cartesian	2.5	3.7035	-1.
581	GLOBAL	Cartesian	2.5	4.28925	-1.
582	GLOBAL	Cartesian	2.5	3.11775	-1.5
583	GLOBAL	Cartesian	2.5	3.7035	-1.5
584	GLOBAL	Cartesian	2.5	4.28925	-1.5
585	GLOBAL	Cartesian	2.5	3.11775	-2.
586	GLOBAL	Cartesian	2.5	3.7035	-2.
587	GLOBAL	Cartesian	2.5	4.28925	-2.
588	GLOBAL	Cartesian	2.5	3.11775	-2.5
589	GLOBAL	Cartesian	2.5	3.7035	-2.5
590	GLOBAL	Cartesian	2.5	4.28925	-2.5
591	GLOBAL	Cartesian	2.5	3.11775	-3.
592	GLOBAL	Cartesian	2.5	3.7035	-3.
593	GLOBAL	Cartesian	2.5	4.28925	-3.
594	GLOBAL	Cartesian	2.5	3.11775	-3.5
595	GLOBAL	Cartesian	2.5	3.7035	-3.5
596	GLOBAL	Cartesian	2.5	4.28925	-3.5

1.2. Joint restraints

Table 2: Joint Restraint Assignments

Table 2: Joint Restraint Assignments

Joint	U1	U2	U3	R1	R2	R3
48	Yes	Yes	Yes	Yes	Yes	Yes
51	Yes	Yes	Yes	Yes	Yes	Yes
54	Yes	Yes	Yes	Yes	Yes	Yes

Table 2: Joint Restraint Assignments

Joint	U1	U2	U3	R1	R2	R3
58	Yes	Yes	Yes	No	No	No
59	Yes	Yes	Yes	No	No	No
60	Yes	Yes	Yes	No	No	No
61	Yes	Yes	Yes	No	No	No
84	Yes	Yes	Yes	Yes	Yes	Yes
87	Yes	Yes	Yes	Yes	Yes	Yes
90	Yes	Yes	Yes	Yes	Yes	Yes
96	Yes	Yes	Yes	No	No	No
97	Yes	Yes	Yes	No	No	No
98	Yes	Yes	Yes	No	No	No
99	Yes	Yes	Yes	No	No	No
124	No	No	Yes	No	No	No
125	No	No	Yes	No	No	No
136	No	No	Yes	Yes	Yes	Yes
137	No	No	Yes	No	No	No
139	No	No	Yes	Yes	Yes	Yes
140	No	No	Yes	No	No	No
142	No	No	Yes	Yes	Yes	Yes
143	No	No	Yes	No	No	No
145	No	No	Yes	Yes	Yes	Yes
146	No	No	Yes	No	No	No

1.3. Element connectivity

Table 3: Connectivity - Frame

Table 3: Connectivity - Frame

Frame	JointI	JointJ	Length m
1	13	1	5.60455
2	20	5	5.60455
3	27	36	5.60455
4	34	42	5.60455
5	47	45	5.75
6	48	50	5.75
7	14	8	5.75
8	51	53	5.75
9	54	56	5.75
10	44	47	1.25
11	43	66	10.
12	40	65	10.
13	15	21	5.75
14	39	64	10.
15	38	63	10.
16	41	62	10.
17	47	50	2.5
18	50	53	2.5
19	22	28	5.75
20	53	56	2.5
21	56	57	1.25
22	46	58	5.60455

Table 3: Connectivity - Frame

Frame	JointI	JointJ	Length
			m
23	49	59	5.60455
24	52	60	5.60455
25	29	35	5.75
26	55	61	5.60455
27	86	84	5.75
28	87	89	5.75
29	90	92	5.75
30	93	95	5.75
31	83	86	1.25
32	104	37	10.
33	103	4	10.
34	102	3	10.
35	101	2	10.
36	100	6	10.
37	86	89	2.5
38	89	92	2.5
39	92	95	2.5
40	95	7	1.25
41	85	96	5.60455
42	7	14	1.25
43	37	43	10.
44	4	40	10.
45	3	39	10.
46	2	38	10.
47	6	41	10.
48	14	21	2.5
49	88	97	5.60455
50	91	98	5.60455
51	94	99	5.60455
52	121	122	10.
54	21	28	2.5
60	28	35	2.5
61	122	123	10.
62	126	121	10.
66	35	44	1.25

Table 4: Frame Section Assignments

Table 4: Frame Section Assignments

Frame	AnalSect	DesignSect	MatProp
1	HSS254x8	HSS254x8	Default
2	HSS254x8	HSS254x8	Default
3	HSS254x8	HSS254x8	Default
4	HSS254x8	HSS254x8	Default
5	HSS406x16	HSS406x16	Default
6	HSS406x16	HSS406x16	Default
7	HSS406x16	HSS406x16	Default
8	HS406X13	HS406X13	Default
9	HS406X13	HS406X13	Default
10	HS324X13	HS324X13	Default
11	HS254x16	HS254x16	Default

Table 4: Frame Section Assignments

Frame	AnalSect	DesignSect	MatProp
12	HS254x16	HS254x16	Default
13	HSS406x16	HSS406x16	Default
14	HS254x16	HS254x16	Default
15	HS254x16	HS254x16	Default
16	HS254x16	HS254x16	Default
17	HS324X13	HS324X13	Default
18	HS324X13	HS324X13	Default
19	HS406X13	HS406X13	Default
20	HS324X13	HS324X13	Default
21	HS324X13	HS324X13	Default
22	HSS254x8	HSS254x8	Default
23	HSS254x8	HSS254x8	Default
24	HSS254x8	HSS254x8	Default
25	HS406X13	HS406X13	Default
26	HSS254x8	HSS254x8	Default
27	HSS406x16	HSS406x16	Default
28	HSS406x16	HSS406x16	Default
29	HS406X13	HS406X13	Default
30	HS406X13	HS406X13	Default
31	HS324X13	HS324X13	Default
32	HS254x16	HS254x16	Default
33	HS254x16	HS254x16	Default
34	HS254x16	HS254x16	Default
35	HS254x16	HS254x16	Default
36	HS254x16	HS254x16	Default
37	HS324X13	HS324X13	Default
38	HS324X13	HS324X13	Default
39	HS324X13	HS324X13	Default
40	HS324X13	HS324X13	Default
41	HSS254x8	HSS254x8	Default
42	HS324X13	HS324X13	Default
43	HS254x16	HS254x16	Default
44	HS254x16	HS254x16	Default
45	HS254x16	HS254x16	Default
46	HS254x16	HS254x16	Default
47	HS254x16	HS254x16	Default
48	HS324X13	HS324X13	Default
49	HSS254x8	HSS254x8	Default
50	HSS254x8	HSS254x8	Default
51	HSS254x8	HSS254x8	Default
52	HS254x16	HS254x16	Default
54	HS324X13	HS324X13	Default
60	HS324X13	HS324X13	Default
61	HS254x16	HS254x16	Default
62	HS254x16	HS254x16	Default
66	HS324X13	HS324X13	Default

Table 5: Frame Release Assignments 1 - General, Part 1 of 2

Table 5: Frame Release Assignments 1 - General, Part 1 of 2

Frame	PI	V2I	V3I	TI	M2I	M3I
1	No	No	No	No	No	No
2	No	No	No	No	No	No
3	No	No	No	No	No	No
4	No	No	No	No	No	No
10	No	No	No	No	Yes	Yes
21	No	No	No	No	No	No
22	No	No	No	No	Yes	Yes
23	No	No	No	No	Yes	Yes
24	No	No	No	No	Yes	Yes
26	No	No	No	No	Yes	Yes
31	No	No	No	No	Yes	Yes
40	No	No	No	No	No	No
41	No	No	No	No	Yes	Yes
42	No	No	No	No	Yes	Yes
49	No	No	No	No	Yes	Yes
50	No	No	No	No	Yes	Yes
51	No	No	No	No	Yes	Yes
66	No	No	No	No	No	No

Table 5: Frame Release Assignments 1 - General, Part 2 of 2

Table 5: Frame Release Assignments 1 - General, Part 2 of 2

Frame	PJ	V2J	V3J	TJ	M2J	M3J
1	No	No	No	No	Yes	Yes
2	No	No	No	No	Yes	Yes
3	No	No	No	No	Yes	Yes
4	No	No	No	No	Yes	Yes
10	No	No	No	No	No	No
21	No	No	No	No	Yes	Yes
22	No	No	No	No	No	No
23	No	No	No	No	No	No
24	No	No	No	No	No	No
26	No	No	No	No	No	No
31	No	No	No	No	No	No
40	No	No	No	No	Yes	Yes
41	No	No	No	No	No	No
42	No	No	No	No	No	No
49	No	No	No	No	No	No
50	No	No	No	No	No	No
51	No	No	No	No	No	No
66	No	No	No	No	Yes	Yes

Table 6: Connectivity - Area

Table 6: Connectivity - Area

Area	Joint1	Joint2	Joint3	Joint4
26	93	153	154	155
27	155	154	156	157

Table 6: Connectivity - Area

Area	Joint1	Joint2	Joint3	Joint4
28	157	156	158	159
29	159	158	160	161
30	161	160	162	163
31	163	162	164	165
32	165	164	166	125
33	153	167	168	154
34	154	168	169	156
35	156	169	170	158
36	158	170	171	160
37	160	171	172	162
38	162	172	173	164
39	164	173	174	166
40	167	175	176	168
41	168	176	177	169
42	169	177	178	170
43	170	178	179	171
44	171	179	180	172
45	172	180	181	173
46	173	181	182	174
47	175	183	184	176
48	176	184	185	177
49	177	185	186	178
50	178	186	187	179
51	179	187	188	180
52	180	188	189	181
53	181	189	190	182
54	183	8	191	184
55	184	191	192	185
56	185	192	193	186
57	186	193	194	187
58	187	194	195	188
59	188	195	196	189
60	189	196	137	190
61	8	197	198	191
62	191	198	199	192
63	192	199	200	193
64	193	200	201	194
65	194	201	202	195
66	195	202	203	196
67	196	203	204	137
68	197	205	206	198
69	198	206	207	199
70	199	207	208	200
71	200	208	209	201
72	201	209	210	202
73	202	210	211	203
74	203	211	212	204
75	205	213	214	206
76	206	214	215	207
77	207	215	216	208
78	208	216	217	209
79	209	217	218	210
80	210	218	219	211
81	211	219	220	212

Table 6: Connectivity - Area

Area	Joint1	Joint2	Joint3	Joint4
82	213	221	222	214
83	214	222	223	215
84	215	223	224	216
85	216	224	225	217
86	217	225	226	218
87	218	226	227	219
88	219	227	228	220
89	221	15	229	222
90	222	229	230	223
91	223	230	231	224
92	224	231	232	225
93	225	232	233	226
94	226	233	234	227
95	227	234	140	228
96	15	235	236	229
97	229	236	237	230
98	230	237	238	231
99	231	238	239	232
100	232	239	240	233
101	233	240	241	234
102	234	241	242	140
103	235	243	244	236
104	236	244	245	237
105	237	245	246	238
106	238	246	247	239
107	239	247	248	240
108	240	248	249	241
109	241	249	250	242
110	243	251	252	244
111	244	252	253	245
112	245	253	254	246
113	246	254	255	247
114	247	255	256	248
115	248	256	257	249
116	249	257	258	250
117	251	259	260	252
118	252	260	261	253
119	253	261	262	254
120	254	262	263	255
121	255	263	264	256
122	256	264	265	257
123	257	265	266	258
124	259	22	267	260
125	260	267	268	261
126	261	268	269	262
127	262	269	270	263
128	263	270	271	264
129	264	271	272	265
130	265	272	143	266
131	22	273	274	267
132	267	274	275	268
133	268	275	276	269
134	269	276	277	270
135	270	277	278	271

Table 6: Connectivity - Area

Area	Joint1	Joint2	Joint3	Joint4
136	271	278	279	272
137	272	279	280	143
138	273	281	282	274
139	274	282	283	275
140	275	283	284	276
141	276	284	285	277
142	277	285	286	278
143	278	286	287	279
144	279	287	288	280
145	281	289	290	282
146	282	290	291	283
147	283	291	292	284
148	284	292	293	285
149	285	293	294	286
150	286	294	295	287
151	287	295	296	288
152	289	297	298	290
153	290	298	299	291
154	291	299	300	292
155	292	300	301	293
156	293	301	302	294
157	294	302	303	295
158	295	303	304	296
159	297	29	305	298
160	298	305	306	299
161	299	306	307	300
162	300	307	308	301
163	301	308	309	302
164	302	309	310	303
165	303	310	146	304
166	29	311	312	305
167	305	312	313	306
168	306	313	314	307
169	307	314	315	308
170	308	315	316	309
171	309	316	317	310
172	310	317	318	146
173	311	319	320	312
174	312	320	321	313
175	313	321	322	314
176	314	322	323	315
177	315	323	324	316
178	316	324	325	317
179	317	325	326	318
180	319	327	328	320
181	320	328	329	321
182	321	329	330	322
183	322	330	331	323
184	323	331	332	324
185	324	332	333	325
186	325	333	334	326
187	327	335	336	328
188	328	336	337	329
189	329	337	338	330

Table 6: Connectivity - Area

Area	Joint1	Joint2	Joint3	Joint4
190	330	338	339	331
191	331	339	340	332
192	332	340	341	333
193	333	341	342	334
194	335	45	343	336
195	336	343	344	337
196	337	344	345	338
197	338	345	346	339
198	339	346	347	340
199	340	347	348	341
200	341	348	124	342
257	8	405	406	191
258	405	407	408	406
259	407	409	410	408
260	409	1	350	410
261	191	406	411	192
262	406	408	412	411
263	408	410	413	412
264	410	350	351	413
265	192	411	414	193
266	411	412	415	414
267	412	413	416	415
268	413	351	352	416
269	193	414	417	194
270	414	415	418	417
271	415	416	419	418
272	416	352	353	419
273	194	417	420	195
274	417	418	421	420
275	418	419	422	421
276	419	353	354	422
277	195	420	423	196
278	420	421	424	423
279	421	422	425	424
280	422	354	355	425
281	196	423	426	137
282	423	424	427	426
283	424	425	428	427
284	425	355	356	428
285	1	429	430	350
286	429	431	432	430
287	431	433	434	432
288	433	135	357	434
289	350	430	435	351
290	430	432	436	435
291	432	434	437	436
292	434	357	358	437
293	351	435	438	352
294	435	436	439	438
295	436	437	440	439
296	437	358	359	440
297	352	438	441	353
298	438	439	442	441
299	439	440	443	442

Table 6: Connectivity - Area

Area	Joint1	Joint2	Joint3	Joint4
300	440	359	360	443
301	353	441	444	354
302	441	442	445	444
303	442	443	446	445
304	443	360	361	446
305	354	444	447	355
306	444	445	448	447
307	445	446	449	448
308	446	361	362	449
309	355	447	450	356
310	447	448	451	450
311	448	449	452	451
312	449	362	136	452
313	15	453	454	229
314	453	455	456	454
315	455	457	458	456
316	457	5	364	458
317	229	454	459	230
318	454	456	460	459
319	456	458	461	460
320	458	364	365	461
321	230	459	462	231
322	459	460	463	462
323	460	461	464	463
324	461	365	366	464
325	231	462	465	232
326	462	463	466	465
327	463	464	467	466
328	464	366	367	467
329	232	465	468	233
330	465	466	469	468
331	466	467	470	469
332	467	367	368	470
333	233	468	471	234
334	468	469	472	471
335	469	470	473	472
336	470	368	369	473
337	234	471	474	140
338	471	472	475	474
339	472	473	476	475
340	473	369	370	476
341	5	477	478	364
342	477	479	480	478
343	479	481	482	480
344	481	138	371	482
345	364	478	483	365
346	478	480	484	483
347	480	482	485	484
348	482	371	372	485
349	365	483	486	366
350	483	484	487	486
351	484	485	488	487
352	485	372	373	488
353	366	486	489	367

Table 6: Connectivity - Area

Area	Joint1	Joint2	Joint3	Joint4
354	486	487	490	489
355	487	488	491	490
356	488	373	374	491
357	367	489	492	368
358	489	490	493	492
359	490	491	494	493
360	491	374	375	494
361	368	492	495	369
362	492	493	496	495
363	493	494	497	496
364	494	375	376	497
365	369	495	498	370
366	495	496	499	498
367	496	497	500	499
368	497	376	139	500
369	22	501	502	267
370	501	503	504	502
371	503	505	506	504
372	505	36	378	506
373	267	502	507	268
374	502	504	508	507
375	504	506	509	508
376	506	378	379	509
377	268	507	510	269
378	507	508	511	510
379	508	509	512	511
380	509	379	380	512
381	269	510	513	270
382	510	511	514	513
383	511	512	515	514
384	512	380	381	515
385	270	513	516	271
386	513	514	517	516
387	514	515	518	517
388	515	381	382	518
389	271	516	519	272
390	516	517	520	519
391	517	518	521	520
392	518	382	383	521
393	272	519	522	143
394	519	520	523	522
395	520	521	524	523
396	521	383	384	524
397	36	525	526	378
398	525	527	528	526
399	527	529	530	528
400	529	141	385	530
401	378	526	531	379
402	526	528	532	531
403	528	530	533	532
404	530	385	386	533
405	379	531	534	380
406	531	532	535	534
407	532	533	536	535

Table 6: Connectivity - Area

Area	Joint1	Joint2	Joint3	Joint4
408	533	386	387	536
409	380	534	537	381
410	534	535	538	537
411	535	536	539	538
412	536	387	388	539
413	381	537	540	382
414	537	538	541	540
415	538	539	542	541
416	539	388	389	542
417	382	540	543	383
418	540	541	544	543
419	541	542	545	544
420	542	389	390	545
421	383	543	546	384
422	543	544	547	546
423	544	545	548	547
424	545	390	142	548
425	29	549	550	305
426	549	551	552	550
427	551	553	554	552
428	553	42	392	554
429	305	550	555	306
430	550	552	556	555
431	552	554	557	556
432	554	392	393	557
433	306	555	558	307
434	555	556	559	558
435	556	557	560	559
436	557	393	394	560
437	307	558	561	308
438	558	559	562	561
439	559	560	563	562
440	560	394	395	563
441	308	561	564	309
442	561	562	565	564
443	562	563	566	565
444	563	395	396	566
445	309	564	567	310
446	564	565	568	567
447	565	566	569	568
448	566	396	397	569
449	310	567	570	146
450	567	568	571	570
451	568	569	572	571
452	569	397	398	572
453	42	573	574	392
454	573	575	576	574
455	575	577	578	576
456	577	144	399	578
457	392	574	579	393
458	574	576	580	579
459	576	578	581	580
460	578	399	400	581
461	393	579	582	394

Table 6: Connectivity - Area

Area	Joint1	Joint2	Joint3	Joint4
462	579	580	583	582
463	580	581	584	583
464	581	400	401	584
465	394	582	585	395
466	582	583	586	585
467	583	584	587	586
468	584	401	402	587
469	395	585	588	396
470	585	586	589	588
471	586	587	590	589
472	587	402	403	590
473	396	588	591	397
474	588	589	592	591
475	589	590	593	592
476	590	403	404	593
477	397	591	594	398
478	591	592	595	594
479	592	593	596	595
480	593	404	145	596

Table 7: Area Section Assignments

Table 7: Area Section Assignments

Area	Section	MatProp
26	Foundation wall parallel	Default
27	Foundation wall parallel	Default
28	Foundation wall parallel	Default
29	Foundation wall parallel	Default
30	Foundation wall parallel	Default
31	Foundation wall parallel	Default
32	Foundation wall parallel	Default
33	Foundation wall parallel	Default
34	Foundation wall parallel	Default
35	Foundation wall parallel	Default
36	Foundation wall parallel	Default
37	Foundation wall parallel	Default
38	Foundation wall parallel	Default
39	Foundation wall parallel	Default
40	Foundation wall parallel	Default

Table 7: Area Section Assignments

Area	Section	MatProp
41	Foundation wall parallel	Default
42	Foundation wall parallel	Default
43	Foundation wall parallel	Default
44	Foundation wall parallel	Default
45	Foundation wall parallel	Default
46	Foundation wall parallel	Default
47	Foundation wall parallel	Default
48	Foundation wall parallel	Default
49	Foundation wall parallel	Default
50	Foundation wall parallel	Default
51	Foundation wall parallel	Default
52	Foundation wall parallel	Default
53	Foundation wall parallel	Default
54	Foundation wall parallel	Default
55	Foundation wall parallel	Default
56	Foundation wall parallel	Default
57	Foundation wall parallel	Default
58	Foundation wall parallel	Default
59	Foundation wall parallel	Default
60	Foundation wall parallel	Default
61	Foundation wall parallel	Default
62	Foundation wall parallel	Default
63	Foundation wall parallel	Default
64	Foundation wall parallel	Default
65	Foundation wall parallel	Default
66	Foundation wall parallel	Default
67	Foundation wall parallel	Default
68	Foundation wall parallel	Default
69	Foundation wall parallel	Default
70	Foundation wall parallel	Default

Table 7: Area Section Assignments

Area	Section	MatProp
71	Foundation wall parallel	Default
72	Foundation wall parallel	Default
73	Foundation wall parallel	Default
74	Foundation wall parallel	Default
75	Foundation wall parallel	Default
76	Foundation wall parallel	Default
77	Foundation wall parallel	Default
78	Foundation wall parallel	Default
79	Foundation wall parallel	Default
80	Foundation wall parallel	Default
81	Foundation wall parallel	Default
82	Foundation wall parallel	Default
83	Foundation wall parallel	Default
84	Foundation wall parallel	Default
85	Foundation wall parallel	Default
86	Foundation wall parallel	Default
87	Foundation wall parallel	Default
88	Foundation wall parallel	Default
89	Foundation wall parallel	Default
90	Foundation wall parallel	Default
91	Foundation wall parallel	Default
92	Foundation wall parallel	Default
93	Foundation wall parallel	Default
94	Foundation wall parallel	Default
95	Foundation wall parallel	Default
96	Foundation wall parallel	Default
97	Foundation wall parallel	Default
98	Foundation wall parallel	Default
99	Foundation wall parallel	Default
100	Foundation wall parallel	Default

Table 7: Area Section Assignments

Area	Section	MatProp
101	Foundation wall parallel	Default
102	Foundation wall parallel	Default
103	Foundation wall parallel	Default
104	Foundation wall parallel	Default
105	Foundation wall parallel	Default
106	Foundation wall parallel	Default
107	Foundation wall parallel	Default
108	Foundation wall parallel	Default
109	Foundation wall parallel	Default
110	Foundation wall parallel	Default
111	Foundation wall parallel	Default
112	Foundation wall parallel	Default
113	Foundation wall parallel	Default
114	Foundation wall parallel	Default
115	Foundation wall parallel	Default
116	Foundation wall parallel	Default
117	Foundation wall parallel	Default
118	Foundation wall parallel	Default
119	Foundation wall parallel	Default
120	Foundation wall parallel	Default
121	Foundation wall parallel	Default
122	Foundation wall parallel	Default
123	Foundation wall parallel	Default
124	Foundation wall parallel	Default
125	Foundation wall parallel	Default
126	Foundation wall parallel	Default
127	Foundation wall parallel	Default
128	Foundation wall parallel	Default
129	Foundation wall parallel	Default
130	Foundation wall parallel	Default

Table 7: Area Section Assignments

Area	Section	MatProp
131	Foundation wall parallel	Default
132	Foundation wall parallel	Default
133	Foundation wall parallel	Default
134	Foundation wall parallel	Default
135	Foundation wall parallel	Default
136	Foundation wall parallel	Default
137	Foundation wall parallel	Default
138	Foundation wall parallel	Default
139	Foundation wall parallel	Default
140	Foundation wall parallel	Default
141	Foundation wall parallel	Default
142	Foundation wall parallel	Default
143	Foundation wall parallel	Default
144	Foundation wall parallel	Default
145	Foundation wall parallel	Default
146	Foundation wall parallel	Default
147	Foundation wall parallel	Default
148	Foundation wall parallel	Default
149	Foundation wall parallel	Default
150	Foundation wall parallel	Default
151	Foundation wall parallel	Default
152	Foundation wall parallel	Default
153	Foundation wall parallel	Default
154	Foundation wall parallel	Default
155	Foundation wall parallel	Default
156	Foundation wall parallel	Default
157	Foundation wall parallel	Default
158	Foundation wall parallel	Default
159	Foundation wall parallel	Default
160	Foundation wall parallel	Default

Table 7: Area Section Assignments

Area	Section	MatProp
161	Foundation wall parallel	Default
162	Foundation wall parallel	Default
163	Foundation wall parallel	Default
164	Foundation wall parallel	Default
165	Foundation wall parallel	Default
166	Foundation wall parallel	Default
167	Foundation wall parallel	Default
168	Foundation wall parallel	Default
169	Foundation wall parallel	Default
170	Foundation wall parallel	Default
171	Foundation wall parallel	Default
172	Foundation wall parallel	Default
173	Foundation wall parallel	Default
174	Foundation wall parallel	Default
175	Foundation wall parallel	Default
176	Foundation wall parallel	Default
177	Foundation wall parallel	Default
178	Foundation wall parallel	Default
179	Foundation wall parallel	Default
180	Foundation wall parallel	Default
181	Foundation wall parallel	Default
182	Foundation wall parallel	Default
183	Foundation wall parallel	Default
184	Foundation wall parallel	Default
185	Foundation wall parallel	Default
186	Foundation wall parallel	Default
187	Foundation wall parallel	Default
188	Foundation wall parallel	Default
189	Foundation wall parallel	Default
190	Foundation wall parallel	Default

Table 7: Area Section Assignments

Area	Section	MatProp
191	Foundation wall parallel	Default
192	Foundation wall parallel	Default
193	Foundation wall parallel	Default
194	Foundation wall parallel	Default
195	Foundation wall parallel	Default
196	Foundation wall parallel	Default
197	Foundation wall parallel	Default
198	Foundation wall parallel	Default
199	Foundation wall parallel	Default
200	Foundation wall parallel	Default
257	Foundation Wall Perpendicular	Default
258	Foundation Wall Perpendicular	Default
259	Foundation Wall Perpendicular	Default
260	Foundation Wall Perpendicular	Default
261	Foundation Wall Perpendicular	Default
262	Foundation Wall Perpendicular	Default
263	Foundation Wall Perpendicular	Default
264	Foundation Wall Perpendicular	Default
265	Foundation Wall Perpendicular	Default
266	Foundation Wall Perpendicular	Default
267	Foundation Wall Perpendicular	Default
268	Foundation Wall Perpendicular	Default
269	Foundation Wall Perpendicular	Default
270	Foundation Wall Perpendicular	Default
271	Foundation Wall Perpendicular	Default
272	Foundation Wall Perpendicular	Default
273	Foundation Wall Perpendicular	Default
274	Foundation Wall Perpendicular	Default
275	Foundation Wall Perpendicular	Default
276	Foundation Wall Perpendicular	Default

Table 7: Area Section Assignments

Area	Section	MatProp
277	Foundation Wall Perpendicular	Default
278	Foundation Wall Perpendicular	Default
279	Foundation Wall Perpendicular	Default
280	Foundation Wall Perpendicular	Default
281	Foundation Wall Perpendicular	Default
282	Foundation Wall Perpendicular	Default
283	Foundation Wall Perpendicular	Default
284	Foundation Wall Perpendicular	Default
285	Foundation Wall Perpendicular	Default
286	Foundation Wall Perpendicular	Default
287	Foundation Wall Perpendicular	Default
288	Foundation Wall Perpendicular	Default
289	Foundation Wall Perpendicular	Default
290	Foundation Wall Perpendicular	Default
291	Foundation Wall Perpendicular	Default
292	Foundation Wall Perpendicular	Default
293	Foundation Wall Perpendicular	Default
294	Foundation Wall Perpendicular	Default
295	Foundation Wall Perpendicular	Default
296	Foundation Wall Perpendicular	Default
297	Foundation Wall Perpendicular	Default
298	Foundation Wall Perpendicular	Default
299	Foundation Wall Perpendicular	Default
300	Foundation Wall Perpendicular	Default
301	Foundation Wall Perpendicular	Default
302	Foundation Wall Perpendicular	Default
303	Foundation Wall Perpendicular	Default
304	Foundation Wall Perpendicular	Default
305	Foundation Wall Perpendicular	Default
306	Foundation Wall Perpendicular	Default

Table 7: Area Section Assignments

Area	Section	MatProp
307	Foundation Wall Perpendicular	Default
308	Foundation Wall Perpendicular	Default
309	Foundation Wall Perpendicular	Default
310	Foundation Wall Perpendicular	Default
311	Foundation Wall Perpendicular	Default
312	Foundation Wall Perpendicular	Default
313	Foundation Wall Perpendicular	Default
314	Foundation Wall Perpendicular	Default
315	Foundation Wall Perpendicular	Default
316	Foundation Wall Perpendicular	Default
317	Foundation Wall Perpendicular	Default
318	Foundation Wall Perpendicular	Default
319	Foundation Wall Perpendicular	Default
320	Foundation Wall Perpendicular	Default
321	Foundation Wall Perpendicular	Default
322	Foundation Wall Perpendicular	Default
323	Foundation Wall Perpendicular	Default
324	Foundation Wall Perpendicular	Default
325	Foundation Wall Perpendicular	Default
326	Foundation Wall Perpendicular	Default
327	Foundation Wall Perpendicular	Default
328	Foundation Wall Perpendicular	Default
329	Foundation Wall Perpendicular	Default
330	Foundation Wall Perpendicular	Default
331	Foundation Wall Perpendicular	Default
332	Foundation Wall Perpendicular	Default
333	Foundation Wall Perpendicular	Default
334	Foundation Wall Perpendicular	Default
335	Foundation Wall Perpendicular	Default
336	Foundation Wall Perpendicular	Default

Table 7: Area Section Assignments

Area	Section	MatProp
337	Foundation Wall Perpendicular	Default
338	Foundation Wall Perpendicular	Default
339	Foundation Wall Perpendicular	Default
340	Foundation Wall Perpendicular	Default
341	Foundation Wall Perpendicular	Default
342	Foundation Wall Perpendicular	Default
343	Foundation Wall Perpendicular	Default
344	Foundation Wall Perpendicular	Default
345	Foundation Wall Perpendicular	Default
346	Foundation Wall Perpendicular	Default
347	Foundation Wall Perpendicular	Default
348	Foundation Wall Perpendicular	Default
349	Foundation Wall Perpendicular	Default
350	Foundation Wall Perpendicular	Default
351	Foundation Wall Perpendicular	Default
352	Foundation Wall Perpendicular	Default
353	Foundation Wall Perpendicular	Default
354	Foundation Wall Perpendicular	Default
355	Foundation Wall Perpendicular	Default
356	Foundation Wall Perpendicular	Default
357	Foundation Wall Perpendicular	Default
358	Foundation Wall Perpendicular	Default
359	Foundation Wall Perpendicular	Default
360	Foundation Wall Perpendicular	Default
361	Foundation Wall Perpendicular	Default
362	Foundation Wall Perpendicular	Default
363	Foundation Wall Perpendicular	Default
364	Foundation Wall Perpendicular	Default
365	Foundation Wall Perpendicular	Default
366	Foundation Wall Perpendicular	Default

Table 7: Area Section Assignments

Area	Section	MatProp
367	Foundation Wall Perpendicular	Default
368	Foundation Wall Perpendicular	Default
369	Foundation Wall Perpendicular	Default
370	Foundation Wall Perpendicular	Default
371	Foundation Wall Perpendicular	Default
372	Foundation Wall Perpendicular	Default
373	Foundation Wall Perpendicular	Default
374	Foundation Wall Perpendicular	Default
375	Foundation Wall Perpendicular	Default
376	Foundation Wall Perpendicular	Default
377	Foundation Wall Perpendicular	Default
378	Foundation Wall Perpendicular	Default
379	Foundation Wall Perpendicular	Default
380	Foundation Wall Perpendicular	Default
381	Foundation Wall Perpendicular	Default
382	Foundation Wall Perpendicular	Default
383	Foundation Wall Perpendicular	Default
384	Foundation Wall Perpendicular	Default
385	Foundation Wall Perpendicular	Default
386	Foundation Wall Perpendicular	Default
387	Foundation Wall Perpendicular	Default
388	Foundation Wall Perpendicular	Default
389	Foundation Wall Perpendicular	Default
390	Foundation Wall Perpendicular	Default
391	Foundation Wall Perpendicular	Default
392	Foundation Wall Perpendicular	Default
393	Foundation Wall Perpendicular	Default
394	Foundation Wall Perpendicular	Default
395	Foundation Wall Perpendicular	Default
396	Foundation Wall Perpendicular	Default

Table 7: Area Section Assignments

Area	Section	MatProp
397	Foundation Wall Perpendicular	Default
398	Foundation Wall Perpendicular	Default
399	Foundation Wall Perpendicular	Default
400	Foundation Wall Perpendicular	Default
401	Foundation Wall Perpendicular	Default
402	Foundation Wall Perpendicular	Default
403	Foundation Wall Perpendicular	Default
404	Foundation Wall Perpendicular	Default
405	Foundation Wall Perpendicular	Default
406	Foundation Wall Perpendicular	Default
407	Foundation Wall Perpendicular	Default
408	Foundation Wall Perpendicular	Default
409	Foundation Wall Perpendicular	Default
410	Foundation Wall Perpendicular	Default
411	Foundation Wall Perpendicular	Default
412	Foundation Wall Perpendicular	Default
413	Foundation Wall Perpendicular	Default
414	Foundation Wall Perpendicular	Default
415	Foundation Wall Perpendicular	Default
416	Foundation Wall Perpendicular	Default
417	Foundation Wall Perpendicular	Default
418	Foundation Wall Perpendicular	Default
419	Foundation Wall Perpendicular	Default
420	Foundation Wall Perpendicular	Default
421	Foundation Wall Perpendicular	Default
422	Foundation Wall Perpendicular	Default
423	Foundation Wall Perpendicular	Default
424	Foundation Wall Perpendicular	Default
425	Foundation Wall Perpendicular	Default
426	Foundation Wall Perpendicular	Default

Table 7: Area Section Assignments

Area	Section	MatProp
427	Foundation Wall Perpendicular	Default
428	Foundation Wall Perpendicular	Default
429	Foundation Wall Perpendicular	Default
430	Foundation Wall Perpendicular	Default
431	Foundation Wall Perpendicular	Default
432	Foundation Wall Perpendicular	Default
433	Foundation Wall Perpendicular	Default
434	Foundation Wall Perpendicular	Default
435	Foundation Wall Perpendicular	Default
436	Foundation Wall Perpendicular	Default
437	Foundation Wall Perpendicular	Default
438	Foundation Wall Perpendicular	Default
439	Foundation Wall Perpendicular	Default
440	Foundation Wall Perpendicular	Default
441	Foundation Wall Perpendicular	Default
442	Foundation Wall Perpendicular	Default
443	Foundation Wall Perpendicular	Default
444	Foundation Wall Perpendicular	Default
445	Foundation Wall Perpendicular	Default
446	Foundation Wall Perpendicular	Default
447	Foundation Wall Perpendicular	Default
448	Foundation Wall Perpendicular	Default
449	Foundation Wall Perpendicular	Default
450	Foundation Wall Perpendicular	Default
451	Foundation Wall Perpendicular	Default
452	Foundation Wall Perpendicular	Default
453	Foundation Wall Perpendicular	Default
454	Foundation Wall Perpendicular	Default
455	Foundation Wall Perpendicular	Default
456	Foundation Wall Perpendicular	Default

Table 7: Area Section Assignments

Area	Section	MatProp
457	Foundation Wall Perpendicular	Default
458	Foundation Wall Perpendicular	Default
459	Foundation Wall Perpendicular	Default
460	Foundation Wall Perpendicular	Default
461	Foundation Wall Perpendicular	Default
462	Foundation Wall Perpendicular	Default
463	Foundation Wall Perpendicular	Default
464	Foundation Wall Perpendicular	Default
465	Foundation Wall Perpendicular	Default
466	Foundation Wall Perpendicular	Default
467	Foundation Wall Perpendicular	Default
468	Foundation Wall Perpendicular	Default
469	Foundation Wall Perpendicular	Default
470	Foundation Wall Perpendicular	Default
471	Foundation Wall Perpendicular	Default
472	Foundation Wall Perpendicular	Default
473	Foundation Wall Perpendicular	Default
474	Foundation Wall Perpendicular	Default
475	Foundation Wall Perpendicular	Default
476	Foundation Wall Perpendicular	Default
477	Foundation Wall Perpendicular	Default
478	Foundation Wall Perpendicular	Default
479	Foundation Wall Perpendicular	Default
480	Foundation Wall Perpendicular	Default

2. Material properties

This section provides material property information for materials used in the model.

Table 8: Material Properties 02 - Basic Mechanical Properties

Table 8: Material Properties 02 - Basic Mechanical Properties

Material	UnitWeight	UnitMass	E1	G12	U12	A1
	KN/m3	KN-s2/m4	KN/m2	KN/m2		1/C
4000Psi	2.3563E+01	2.4028E+00	24855578.06	10356490.86	0.2	9.9000E-06
5000Psi	2.3563E+01	2.4028E+00	27789381.66	11578909.02	0.2	9.9000E-06
A615Gr40	7.6973E+01	7.8490E+00	199947978.8			1.1700E-05
A615Gr60	7.6973E+01	7.8490E+00	199947978.8			1.1700E-05
HSSFy317	7.6973E+01	7.8490E+00	199947978.8	76903068.77	0.3	1.1700E-05

Table 9: Material Properties 03a - Steel Data

Table 9: Material Properties 03a - Steel Data

Material	Fy	Fu	FinalSlope
	KN/m2	KN/m2	
HSSFy317	317000.	427000.	-0.1

Table 10: Material Properties 03b - Concrete Data

Table 10: Material Properties 03b - Concrete Data

Material	Fc	eFc	FinalSlope
	KN/m2	KN/m2	
4000Psi	27579.03	27579.03	-0.1
5000Psi	34473.79	34473.79	-0.1

Table 11: Material Properties 03e - Rebar Data

Table 11: Material Properties 03e - Rebar Data

Material	Fy	Fu	FinalSlope
	KN/m2	KN/m2	
A615Gr40	275790.32	413685.47	-0.1
A615Gr60	413685.47	620528.21	-0.1

3. Section properties

This section provides section property information for objects used in the model.

3.1. Frames

Table 12: Frame Section Properties 01 - General, Part 1 of 4

Table 12: Frame Section Properties 01 - General, Part 1 of 4

SectionName	Material	Shape	t3	tw	Area	TorsConst	I33	I22
			m	m	m2	m4	m4	m4
HS254x16	HSSFy317	Pipe	0.254	0.0159	0.011893	0.000169	0.000085	0.000085
HS324X13	HSSFy317	Pipe	0.324	0.013	0.012701	0.000308	0.000154	0.000154
HS406X13	HSSFy317	Pipe	0.406	0.013	0.01605	0.00062	0.00031	0.00031
HSS254x8	HSSFy317	Pipe	0.254	0.0079	0.006108	0.000093	0.000046	0.000046
HSS406x16	HSSFy317	Pipe	0.406	0.0159	0.019486	0.000743	0.000371	0.000371

Table 12: Frame Section Properties 01 - General, Part 2 of 4

Table 12: Frame Section Properties 01 - General, Part 2 of 4

SectionName	I23	AS2	AS3
	m4	m2	m2
HS254x16	0.	0.005964	0.005964
HS324X13	0.	0.006358	0.006358
HS406X13	0.	0.008031	0.008031
HSS254x8	0.	0.003056	0.003056
HSS406x16	0.	0.009754	0.009754

Table 12: Frame Section Properties 01 - General, Part 3 of 4

Table 12: Frame Section Properties 01 - General, Part 3 of 4

SectionName	S33	S22	Z33	Z22	R33	R22
	m3	m3	m3	m3	m	m
HS254x16	0.000667	0.000667	0.000903	0.000903	0.084369	0.084369
HS324X13	0.00095	0.00095	0.001258	0.001258	0.110051	0.110051
HS406X13	0.001528	0.001528	0.002009	0.002009	0.139022	0.139022
HSS254x8	0.000364	0.000364	0.000479	0.000479	0.087054	0.087054
HSS406x16	0.001829	0.001829	0.002421	0.002421	0.138036	0.138036

Table 12: Frame Section Properties 01 - General, Part 4 of 4

Table 12: Frame Section Properties 01 - General, Part 4 of 4

SectionName	AMod	A2Mod	A3Mod	JMod	I2Mod	I3Mod	MMod	WMod
HS254x16	1.	1.	1.	1.	1.	1.	1.	1.
HS324X13	1.	1.	1.	1.	1.	1.	1.	1.
HS406X13	1.	1.	1.	1.	1.	1.	1.	1.
HSS254x8	1.	1.	1.	1.	1.	1.	1.	1.
HSS406x16	1.	1.	1.	1.	1.	1.	1.	1.

3.2. Areas

Table 13: Area Section Properties, Part 1 of 3

Table 13: Area Section Properties, Part 1 of 3

Section	Material	AreaType	Type	DrillDOF	Thickness	BendThick	F11Mod
					m	m	
Foundation wall parallel	5000Psi	Shell	Shell-Thick	Yes	0.5	0.5	1.
Foundation Wall Perpendicular	5000Psi	Shell	Shell-Thick	Yes	0.5	0.5	1.

Table 13: Area Section Properties, Part 2 of 3

Table 13: Area Section Properties, Part 2 of 3

Section	F22Mod	F12Mod	M11Mod	M22Mod	M12Mod	V13Mod	V23Mod
Foundation wall parallel	1.	1.	1.	1.	1.	1.	1.
Foundation Wall Perpendicular	1.	1.	1.	1.	1.	1.	1.

Table 13: Area Section Properties, Part 3 of 3

Table 13: Area Section Properties, Part 3 of 3

Section	MMod	WMod
Foundation wall parallel	1.	1.
Foundation Wall Perpendicular	1.	1.

3.3. Solids

Table 14: Solid Property Definitions

Table 14: Solid Property Definitions

SolidProp	Material	MatAngleA	MatAngleB	MatAngleC
		Degrees	Degrees	Degrees
Solid1	4000Psi	0.	0.	0.

4. Load patterns

This section provides loading information as applied to the model.

4.1. Definitions

Table 15: Load Pattern Definitions

Table 15: Load Pattern Definitions

LoadPat	DesignType	SelfWtMult	AutoLoad
DEAD	Dead	1.	
WINDx	Wind	1.	None
ICE	Other	1.	
HYDRO DYNAMIC USUAL	Other	1.	
DRAG FORCE U/S MATT UNUSUAL	Other	1.	
DRAG FORCE CLOGGING UNUSUAL	Other	1.	
HYDRO STATIC U1	Other	1.	
DEBRIS IM USUAL MID1	Other	1.	
HYDRO DYNAMIC UNUSUAL	Other	1.	
DRAG FORCE U/S MATT EXTREME	Other	1.	
DRAG FORCE CLOGGING EXTREME	Other	1.	
DEBRIS IM UNUSUAL MID1	Other	1.	
DEBRIS IM EXTREME	Other	1.	
EARTHQUAKE	Other	1.	
HYDRO STATIC E1	Other	1.	
WINDy	Wind	1.	None
HYDRO STATIC U2	Other	1.	
HYDRO STATIC U3	Other	1.	
HYDRO STATIC UN1	Other	1.	
HYDRO STATIC UN2	Other	1.	
HYDRO STATIC E2	Other	1.	
DEBRIS IM USUAL VERT1	Other	1.	
DEBRIS IM UNUSUAL VERT1	Other	1.	
DEBRIS IM USUAL VERT2	Other	1.	
DEBRIS IM USUAL VERT3	Other	1.	
DEBRIS IM USUAL VERT4	Other	1.	
DEBRIS IM UNUSUAL VERT2	Other	1.	

Table 15: Load Pattern Definitions

LoadPat	DesignType	SelfWtMult	AutoLoad
DEBRIS IM UNUSUAL VERT3	Other	1.	
DEBRIS IM UNUSUAL VERT4	Other	1.	
DEBRIS IM UNUSUAL MID2	Other	1.	
DEBRIS IM UNUSUAL MID3	Other	1.	
DEBRIS IM UNUSUAL MID4	Other	1.	
DEBRIS IM UNUSUAL MID5	Other	1.	
DEBRIS IM USUAL MID2	Other	1.	
DEBRIS IM USUAL MID3	Other	1.	
DEBRIS IM USUAL MID4	Other	1.	
DEBRIS IM USUAL MID5	Other	1.	

5. Load cases

This section provides load case information.

5.1. Definitions

Table 16: Load Case Definitions, Part 1 of 2

Table 16: Load Case Definitions, Part 1 of 2

Case	Type	InitialCond	ModalCase	BaseCase	MassSource	DesActOpt
DEAD	LinStatic	Zero				Prog Det
MODAL	LinModal	Zero				Prog Det
WINDx	LinStatic	Zero				Prog Det
ICE	LinStatic	Zero				Prog Det
HYDRO DYNAMIC USUAL	LinStatic	Zero				Prog Det
DRAG FORCE UNDERSIDE MATT	LinStatic	Zero				Prog Det
DRAG FORCE CLOGGING	LinStatic	Zero				Prog Det
HYDRO STATIC U1	LinStatic	Zero				Prog Det
DEBRIS IM USUAL MID1	LinStatic	Zero				Prog Det
HYDRO DYNAMIC UNUSUAL	LinStatic	Zero				Prog Det

Table 16: Load Case Definitions, Part 1 of 2

Case	Type	InitialCond	ModalCase	BaseCase	MassSource	DesActOpt
DRAG FORCE U/S MATT EXTREME	LinStatic	Zero				Prog Det
DRAG FORCE CLOGGING EXTREME	LinStatic	Zero				Prog Det
DEBRIS IM UNUSUAL MID1	LinStatic	Zero				Prog Det
DEBRIS IM EXTREME	LinStatic	Zero				Prog Det
EARTHQUAKE	LinStatic	Zero				Prog Det
HYDRO STATIC E1	LinStatic	Zero				Prog Det
WINDy	LinStatic	Zero				Prog Det
HYDRO STATIC U2	LinStatic	Zero				Prog Det
HYDRO STATIC UN1	LinStatic	Zero				Prog Det
HYDRO STATIC UN2	LinStatic	Zero				Prog Det
HYDRO STATIC E2	LinStatic	Zero				Prog Det
DRAG MATT UN3	LinStatic	Zero				Prog Det
DRAG CLOG UN3	LinStatic	Zero				Prog Det
DEBRIS IM USUAL VERT1	LinStatic	Zero				Prog Det
DEBRIS IM UNUSUAL VERT1	LinStatic	Zero				Prog Det
DEBRIS IM USUAL VERT2	LinStatic	Zero				Prog Det
DEBRIS IM USUAL VERT3	LinStatic	Zero				Prog Det
DEBRIS IM USUAL VERT4	LinStatic	Zero				Prog Det
DEBRIS IM UNUSUAL VERT2	LinStatic	Zero				Prog Det
DEBRIS IM UNUSUAL VERT3	LinStatic	Zero				Prog Det
DEBRIS IM UNUSUAL VERT4	LinStatic	Zero				Prog Det
DEBRIS IM UNUSUAL MID2	LinStatic	Zero				Prog Det
DEBRIS IM UNUSUAL MID3	LinStatic	Zero				Prog Det
DEBRIS IM UNUSUAL MID4	LinStatic	Zero				Prog Det
DEBRIS IM UNUSUAL MID5	LinStatic	Zero				Prog Det
DEBRIS IM USUAL MID2	LinStatic	Zero				Prog Det
DEBRIS IM USUAL MID3	LinStatic	Zero				Prog Det
DEBRIS IM USUAL MID4	LinStatic	Zero				Prog Det

Table 16: Load Case Definitions, Part 1 of 2

Case	Type	InitialCond	ModalCase	BaseCase	MassSource	DesActOpt
DEBRIS IM USUAL MID5	LinStatic	Zero				Prog Det

Table 16: Load Case Definitions, Part 2 of 2

Table 16: Load Case Definitions, Part 2 of 2

Case	DesignAct
DEAD	Non-Composite
MODAL	Other
WINDx	Short-Term Composite
ICE	Other
HYDRO DYNAMIC USUAL	Other
DRAG FORCE UNDERSIDE MATT	Other
DRAG FORCE CLOGGING	Other
HYDRO STATIC U1	Other
DEBRIS IM USUAL MID1	Other
HYDRO DYNAMIC UNUSUAL	Other
DRAG FORCE U/S MATT EXTREME	Other
DRAG FORCE CLOGGING EXTREME	Other
DEBRIS IM UNUSUAL MID1	Other
DEBRIS IM EXTREME	Other
EARTHQUAKE	Other
HYDRO STATIC E1	Other
WINDy	Short-Term Composite
HYDRO STATIC U2	Other
HYDRO STATIC UN1	Other
HYDRO STATIC UN2	Other
HYDRO STATIC E2	Other
DRAG MATT UN3	Other
DRAG CLOG UN3	Other

Table 16: Load Case Definitions, Part 2 of 2

Case	DesignAct
DEBRIS IM USUAL VERT1	Other
DEBRIS IM UNUSUAL VERT1	Other
DEBRIS IM USUAL VERT2	Other
DEBRIS IM USUAL VERT3	Other
DEBRIS IM USUAL VERT4	Other
DEBRIS IM UNUSUAL VERT2	Other
DEBRIS IM UNUSUAL VERT3	Other
DEBRIS IM UNUSUAL VERT4	Other
DEBRIS IM UNUSUAL MID2	Other
DEBRIS IM UNUSUAL MID3	Other
DEBRIS IM UNUSUAL MID4	Other
DEBRIS IM UNUSUAL MID5	Other
DEBRIS IM USUAL MID2	Other
DEBRIS IM USUAL MID3	Other
DEBRIS IM USUAL MID4	Other
DEBRIS IM USUAL MID5	Other

5.2. Static case load assignments

Table 17: Case - Static 1 - Load Assignments

Table 17: Case - Static 1 - Load Assignments

Case	LoadType	LoadName	LoadSF
DEAD	Load pattern	DEAD	1.
WINDx	Load pattern	WINDx	1.
ICE	Load pattern	ICE	1.
HYDRO DYNAMIC USUAL	Load pattern	HYDRO DYNAMIC USUAL	1.
DRAG FORCE UNDERSIDE MATT	Load pattern	DRAG FORCE U/S MATT UNUSUAL	1.

Table 17: Case - Static 1 - Load Assignments

Case	LoadType	LoadName	LoadSF
DRAG FORCE CLOGGING	Load pattern	DRAG FORCE CLOGGING UNUSUAL	1.
HYDRO STATIC U1	Load pattern	HYDRO STATIC U1	1.
DEBRIS IM USUAL MID1	Load pattern	DEBRIS IM USUAL MID1	1.
HYDRO DYNAMIC UNUSUAL	Load pattern	HYDRO DYNAMIC UNUSUAL	1.
DRAG FORCE U/S MATT EXTREME	Load pattern	DRAG FORCE U/S MATT EXTREME	1.
DRAG FORCE CLOGGING EXTREME	Load pattern	DRAG FORCE CLOGGING EXTREME	1.
DEBRIS IM UNUSUAL MID1	Load pattern	DEBRIS IM UNUSUAL MID1	1.
DEBRIS IM EXTREME	Load pattern	DEBRIS IM EXTREME	1.
EARTHQUAKE	Load pattern	EARTHQUAKE	1.
HYDRO STATIC E1	Load pattern	HYDRO STATIC E2	1.
WINDy	Load pattern	WINDy	1.
HYDRO STATIC U2	Load pattern	HYDRO STATIC U3	1.
HYDRO STATIC UN1	Load pattern	HYDRO STATIC UN1	1.
HYDRO STATIC UN2	Load pattern	HYDRO STATIC UN2	1.
HYDRO STATIC E2	Load pattern	HYDRO STATIC E2	1.
DEBRIS IM USUAL VERT1	Load pattern	DEBRIS IM USUAL VERT1	1.
DEBRIS IM UNUSUAL VERT1	Load pattern	DEBRIS IM UNUSUAL VERT1	1.
DEBRIS IM USUAL VERT2	Load pattern	DEBRIS IM USUAL VERT2	1.
DEBRIS IM USUAL VERT3	Load pattern	DEBRIS IM USUAL VERT3	1.
DEBRIS IM USUAL VERT4	Load pattern	DEBRIS IM USUAL VERT4	1.
DEBRIS IM UNUSUAL VERT2	Load pattern	DEBRIS IM UNUSUAL VERT2	1.
DEBRIS IM UNUSUAL VERT3	Load pattern	DEBRIS IM UNUSUAL VERT3	1.
DEBRIS IM UNUSUAL VERT4	Load pattern	DEBRIS IM UNUSUAL VERT4	1.
DEBRIS IM UNUSUAL MID2	Load pattern	DEBRIS IM UNUSUAL MID2	1.
DEBRIS IM UNUSUAL MID3	Load pattern	DEBRIS IM UNUSUAL MID3	1.
DEBRIS IM UNUSUAL MID4	Load pattern	DEBRIS IM UNUSUAL MID4	1.
DEBRIS IM UNUSUAL MID5	Load pattern	DEBRIS IM UNUSUAL MID5	1.

Table 17: Case - Static 1 - Load Assignments

Case	LoadType	LoadName	LoadSF
DEBRIS IM USUAL MID2	Load pattern	DEBRIS IM USUAL MID2	1.
DEBRIS IM USUAL MID3	Load pattern	DEBRIS IM USUAL MID3	1.
DEBRIS IM USUAL MID4	Load pattern	DEBRIS IM USUAL MID4	1.
DEBRIS IM USUAL MID5	Load pattern	DEBRIS IM USUAL MID5	1.

5.3. Response spectrum case load assignments

Table 18: Function - Response Spectrum - User

Table 18: Function - Response Spectrum - User

Name	Period Sec	Accel	FuncDamp
UNIFRS	0.	1.	0.05
UNIFRS	1.	1.	

6. Load combinations

This section provides load combination information.

Table 19: Combination Definitions

Table 19: Combination Definitions

ComboName	ComboType	CaseName	ScaleFactor
U1x	Linear Add	DEAD	1.25
U1x		WINDx	1.5
U1x		HYDRO STATIC U1	1.5
U2 MID1	Linear Add	DEAD	1.25
U2 MID1		HYDRO DYNAMIC USUAL	1.5
U2 MID1		HYDRO STATIC U2	1.5
U2 MID1		DEBRIS IM USUAL MID1	1.5
UN1 MID1	Linear Add	DEAD	1.25
UN1 MID1		HYDRO DYNAMIC USUAL	1.5
UN1 MID1		HYDRO STATIC UN1	1.5
UN1 MID1		DEBRIS IM UNUSUAL MID1	1.5
UN2	Linear Add	DEAD	1.25

Table 19: Combination Definitions

ComboName	ComboType	CaseName	ScaleFactor
UN2		HYDRO DYNAMIC UNUSUAL	0.
UN2		HYDRO STATIC UN2	1.5
UN2		DRAG FORCE CLOGGING	1.5
UN2		DRAG FORCE UNDERSIDE MATT	1.5
E1	Linear Add	DEAD	1.25
E1		HYDRO STATIC E1	1.25
E1		DEBRIS IM EXTREME	1.25
E1		DRAG FORCE CLOGGING EXTREME	1.05
E1		DRAG FORCE U/S MATT EXTREME	1.05
E2	Linear Add	DEAD	1.25
E2		HYDRO STATIC E2	1.25
E2		EARTHQUAKE	1.
U1y	Linear Add	DEAD	1.25
U1y		WINDy	1.5
U1y		HYDRO STATIC U1	1.5
WIND45	Linear Add	WINDx	0.71
WIND45		WINDy	0.71
U145	Linear Add	DEAD	1.25
U145		WIND45	1.5
U145		HYDRO STATIC U1	1.5
U1x_NEG	Linear Add	DEAD	1.25
U1x_NEG		WINDx	-1.5
U1x_NEG		HYDRO STATIC U1	1.5
U1y_NEG	Linear Add	DEAD	1.25
U1y_NEG		WINDy	-1.5
U1y_NEG		HYDRO STATIC U1	1.5
U145_NEG	Linear Add	DEAD	1.25
U145_NEG		WIND45	-1.5
U145_NEG		HYDRO STATIC U1	1.5
U2 VERT1	Linear Add	DEAD	1.25
U2 VERT1		HYDRO DYNAMIC USUAL	1.5
U2 VERT1		HYDRO STATIC U2	1.5
U2 VERT1		DEBRIS IM USUAL VERT1	1.5
UN1 VERT1	Linear Add	DEAD	1.25
UN1 VERT1		HYDRO DYNAMIC USUAL	1.5

Table 19: Combination Definitions

ComboName	ComboType	CaseName	ScaleFactor
UN1 VERT1		HYDRO STATIC UN1	1.5
UN1 VERT1		DEBRIS IM UNUSUAL VERT1	1.5
U2 MID2	Linear Add	DEAD	1.25
U2 MID2		HYDRO DYNAMIC USUAL	1.5
U2 MID2		HYDRO STATIC U2	1.5
U2 MID2		DEBRIS IM USUAL MID2	1.5
U2 MID3	Linear Add	DEAD	1.25
U2 MID3		HYDRO DYNAMIC USUAL	1.5
U2 MID3		HYDRO STATIC U2	1.5
U2 MID3		DEBRIS IM USUAL MID3	1.5
U2 MID4	Linear Add	DEAD	1.25
U2 MID4		HYDRO DYNAMIC USUAL	1.5
U2 MID4		HYDRO STATIC U2	1.5
U2 MID4		DEBRIS IM USUAL MID4	1.5
U2 MID5	Linear Add	DEAD	1.25
U2 MID5		HYDRO DYNAMIC USUAL	1.5
U2 MID5		HYDRO STATIC U2	1.5
U2 MID5		DEBRIS IM USUAL MID5	1.5
UN1 MID2	Linear Add	DEAD	1.25
UN1 MID2		HYDRO DYNAMIC USUAL	1.5
UN1 MID2		HYDRO STATIC UN1	1.5
UN1 MID2		DEBRIS IM UNUSUAL MID2	1.5
UN1 MID3	Linear Add	DEAD	1.25
UN1 MID3		HYDRO DYNAMIC USUAL	1.5
UN1 MID3		HYDRO STATIC UN1	1.5
UN1 MID3		DEBRIS IM UNUSUAL MID3	1.5
UN1 MID4	Linear Add	DEAD	1.25
UN1 MID4		HYDRO DYNAMIC USUAL	1.5
UN1 MID4		HYDRO STATIC UN1	1.5

Table 19: Combination Definitions

ComboName	ComboType	CaseName	ScaleFactor
UN1 MID4		DEBRIS IM UNUSUAL MID4	1.5
UN1 MID5	Linear Add	DEAD	1.25
UN1 MID5		HYDRO DYNAMIC USUAL	1.5
UN1 MID5		HYDRO STATIC UN1	1.5
UN1 MID5		DEBRIS IM UNUSUAL MID5	1.5
U2 VERT2	Linear Add	DEAD	1.25
U2 VERT2		HYDRO DYNAMIC USUAL	1.5
U2 VERT2		HYDRO STATIC U2	1.5
U2 VERT2		DEBRIS IM USUAL VERT2	1.5
U2 VERT3	Linear Add	DEAD	1.25
U2 VERT3		HYDRO DYNAMIC USUAL	1.5
U2 VERT3		HYDRO STATIC U2	1.5
U2 VERT3		DEBRIS IM USUAL VERT3	1.5
U2 VERT4	Linear Add	DEAD	1.25
U2 VERT4		HYDRO DYNAMIC USUAL	1.5
U2 VERT4		HYDRO STATIC U2	1.5
U2 VERT4		DEBRIS IM USUAL VERT4	1.5
UN1 VERT2	Linear Add	DEAD	1.25
UN1 VERT2		HYDRO DYNAMIC USUAL	1.5
UN1 VERT2		HYDRO STATIC UN1	1.5
UN1 VERT2		DEBRIS IM UNUSUAL VERT2	1.5
UN1 VERT3	Linear Add	DEAD	1.25
UN1 VERT3		HYDRO DYNAMIC USUAL	1.5
UN1 VERT3		HYDRO STATIC UN1	1.5
UN1 VERT3		DEBRIS IM UNUSUAL VERT3	1.5
UN1 VERT4	Linear Add	DEAD	1.25
UN1 VERT4		HYDRO DYNAMIC USUAL	1.5
UN1 VERT4		HYDRO STATIC UN1	1.5

Table 19: Combination Definitions

ComboName	ComboType	CaseName	ScaleFactor
UN1 VERT4		DEBRIS IM UNUSUAL VERT4	1.5
E2-Service	Linear Add	DEAD	1.
E2-Service		HYDRO STATIC E2	1.
E2-Service		EARTHQUAKE	1.
E1-service	Linear Add	DEAD	1.
E1-service		HYDRO STATIC E1	1.
E1-service		DEBRIS IM EXTREME	1.
E1-service		DRAG FORCE CLOGGING EXTREME	1.
E1-service		DRAG FORCE U/S MATT EXTREME	1.
UN2-service	Linear Add	DEAD	1.
UN2-service		HYDRO DYNAMIC UNUSUAL	0.
UN2-service		HYDRO STATIC UN2	1.
UN2-service		DRAG FORCE CLOGGING	1.
UN2-service		DRAG FORCE UNDERSIDE MATT	1.
UN1-VERT1_service	Linear Add	DEAD	1.
UN1-VERT1_service		HYDRO DYNAMIC USUAL	1.
UN1-VERT1_service		HYDRO STATIC UN1	1.
UN1-VERT1_service		DEBRIS IM UNUSUAL VERT1	1.
DEAD_SERVICE	Linear Add	DEAD	1.

7. Design preferences

This section provides the design preferences for each type of design, which typically include material reduction factors, framing type, stress ratio limit, deflection limits, and other code specific items.

7.1. Steel design

Table 20: Preferences - Steel Design - CSA S16-14, Part 1 of 3

Table 20: Preferences - Steel Design - CSA S16-14, Part 1 of 3

THDesign	FrameType	PatLLF	SRatioLimit	MaxIter	AccRat	DuctFact	OverFact	PhiB
Envelopes	Type LD MRF	0.75	0.95	1	0.35	5.	1.5	0.9

Table 20: Preferences - Steel Design - CSA S16-14, Part 2 of 3

Table 20: Preferences - Steel Design - CSA S16-14, Part 2 of 3

PhiC	PhiT	PhiV	SlenderMod	SeisCode	SeisLoad	PlugWeld	CheckDefl	DLRat
0.9	0.9	0.9	Modify Geometry	Yes	Yes	Yes	No	120.

Table 20: Preferences - Steel Design - CSA S16-14, Part 3 of 3

Table 20: Preferences - Steel Design - CSA S16-14, Part 3 of 3

SDLAndLLRat	LLRat	TotalRat	NetRat
120.	360.	240.	240.

7.2. Concrete design

Table 21: Preferences - Concrete Design - ACI 318-14, Part 1 of 2

Table 21: Preferences - Concrete Design - ACI 318-14, Part 1 of 2

THDesign	NumCurves	NumPoints	MinEccen	PatLLF	UFLimit	SeisCat	Rho	Sds
Envelopes	24	11	Yes	0.75	0.95	D	1.	0.5

Table 21: Preferences - Concrete Design - ACI 318-14, Part 2 of 2

Table 21: Preferences - Concrete Design - ACI 318-14, Part 2 of 2

PhiT	PhiCTied	PhiCSpiral	PhiV	PhiVSeismic	PhiVJoint
0.9	0.65	0.75	0.75	0.6	0.85

7.3. *Aluminum design*

Table 22: Preferences - Aluminum Design - AA-ASD 2000

Table 22: Preferences - Aluminum Design - AA-ASD 2000

FrameType	SRatioLimit	LatFact	UseLatFact
Moment Frame	1.	1.333333	No

7.4. *Cold formed design*

Table 23: Preferences - Cold Formed Design - AISI-ASD96

Table 23: Preferences - Cold Formed Design - AISI-ASD96

FrameType	SRatioLimit	OmegaBS	OmegaBUS	OmegaBLTB	OmegaVS	OmegaVNS	OmegaT	OmegaC
Braced Frame	1.	1.67	1.67	1.67	1.67	1.5	1.67	1.8

8. Design overwrites

This section provides the design overwrites for each type of design, which are assigned to individual members of the structure.

8.1. *Steel design*

Table 24: Overwrites - Steel Design - CSA S16-14, Part 1 of 6

Table 24: Overwrites - Steel Design - CSA S16-14, Part 1 of 6

Frame	DesignSect	FrameType	Fy KN/m2	RLLF	AreaRatio	XLMajor
7	Program Determined	Program Determined	0.	0.	0.	0.
13	Program Determined	Program Determined	0.	0.	0.	0.
19	Program Determined	Program Determined	0.	0.	0.	0.
25	Program Determined	Program Determined	0.	0.	0.	0.
42	Program Determined	Program Determined	0.	0.	0.	0.
43	Program Determined	Program Determined	0.	0.	0.	0.
44	Program Determined	Program Determined	0.	0.	0.	0.
45	Program Determined	Program Determined	0.	0.	0.	0.
46	Program Determined	Program Determined	0.	0.	0.	0.
47	Program Determined	Program Determined	0.	0.	0.	0.
48	Program Determined	Program Determined	0.	0.	0.	0.
54	Program Determined	Program Determined	0.	0.	0.	0.
60	Program Determined	Program Determined	0.	0.	0.	0.
66	Program Determined	Program Determined	0.	0.	0.	0.
1	Program Determined	Program Determined	0.	0.	0.	0.
2	Program Determined	Program Determined	0.	0.	0.	0.
3	Program Determined	Program Determined	0.	0.	0.	0.

Table 24: Overwrites - Steel Design - CSA S16-14, Part 1 of 6

Frame	DesignSect	FrameType	Fy	RLLF	AreaRatio	XLMajor
			KN/m2			
4	Program Determined	Program Determined	0.	0.	0.	0.
5	Program Determined	Program Determined	0.	0.	0.	0.
5	Program Determined	Program Determined	0.	0.	0.	0.
6	Program Determined	Program Determined	0.	0.	0.	0.
6	Program Determined	Program Determined	0.	0.	0.	0.
8	Program Determined	Program Determined	0.	0.	0.	0.
8	Program Determined	Program Determined	0.	0.	0.	0.
9	Program Determined	Program Determined	0.	0.	0.	0.
9	Program Determined	Program Determined	0.	0.	0.	0.
10	Program Determined	Program Determined	0.	0.	0.	0.
10	Program Determined	Program Determined	0.	0.	0.	0.
11	Program Determined	Program Determined	0.	0.	0.	0.
11	Program Determined	Program Determined	0.	0.	0.	0.
12	Program Determined	Program Determined	0.	0.	0.	0.
12	Program Determined	Program Determined	0.	0.	0.	0.
14	Program Determined	Program Determined	0.	0.	0.	0.
14	Program Determined	Program Determined	0.	0.	0.	0.
15	Program Determined	Program Determined	0.	0.	0.	0.
15	Program Determined	Program Determined	0.	0.	0.	0.
16	Program Determined	Program Determined	0.	0.	0.	0.
16	Program Determined	Program Determined	0.	0.	0.	0.
17	Program Determined	Program Determined	0.	0.	0.	0.
17	Program Determined	Program Determined	0.	0.	0.	0.
18	Program Determined	Program Determined	0.	0.	0.	0.
18	Program Determined	Program Determined	0.	0.	0.	0.
20	Program Determined	Program Determined	0.	0.	0.	0.
20	Program Determined	Program Determined	0.	0.	0.	0.
21	Program Determined	Program Determined	0.	0.	0.	0.
21	Program Determined	Program Determined	0.	0.	0.	0.
22	Program Determined	Program Determined	0.	0.	0.	0.
22	Program Determined	Program Determined	0.	0.	0.	0.
23	Program Determined	Program Determined	0.	0.	0.	0.
23	Program Determined	Program Determined	0.	0.	0.	0.
24	Program Determined	Program Determined	0.	0.	0.	0.
24	Program Determined	Program Determined	0.	0.	0.	0.
26	Program Determined	Program Determined	0.	0.	0.	0.
26	Program Determined	Program Determined	0.	0.	0.	0.
27	Program Determined	Program Determined	0.	0.	0.	0.
27	Program Determined	Program Determined	0.	0.	0.	0.
28	Program Determined	Program Determined	0.	0.	0.	0.
28	Program Determined	Program Determined	0.	0.	0.	0.
29	Program Determined	Program Determined	0.	0.	0.	0.
29	Program Determined	Program Determined	0.	0.	0.	0.
30	Program Determined	Program Determined	0.	0.	0.	0.
30	Program Determined	Program Determined	0.	0.	0.	0.
31	Program Determined	Program Determined	0.	0.	0.	0.
31	Program Determined	Program Determined	0.	0.	0.	0.
32	Program Determined	Program Determined	0.	0.	0.	0.
32	Program Determined	Program Determined	0.	0.	0.	0.
33	Program Determined	Program Determined	0.	0.	0.	0.
33	Program Determined	Program Determined	0.	0.	0.	0.
34	Program Determined	Program Determined	0.	0.	0.	0.
34	Program Determined	Program Determined	0.	0.	0.	0.
35	Program Determined	Program Determined	0.	0.	0.	0.

Table 24: Overwrites - Steel Design - CSA S16-14, Part 1 of 6

Frame	DesignSect	FrameType	Fy KN/m2	RLLF	AreaRatio	XLMajor
35	Program Determined	Program Determined	0.	0.	0.	0.
36	Program Determined	Program Determined	0.	0.	0.	0.
36	Program Determined	Program Determined	0.	0.	0.	0.
37	Program Determined	Program Determined	0.	0.	0.	0.
37	Program Determined	Program Determined	0.	0.	0.	0.
38	Program Determined	Program Determined	0.	0.	0.	0.
38	Program Determined	Program Determined	0.	0.	0.	0.
39	Program Determined	Program Determined	0.	0.	0.	0.
39	Program Determined	Program Determined	0.	0.	0.	0.
40	Program Determined	Program Determined	0.	0.	0.	0.
40	Program Determined	Program Determined	0.	0.	0.	0.
41	Program Determined	Program Determined	0.	0.	0.	0.
41	Program Determined	Program Determined	0.	0.	0.	0.
49	Program Determined	Program Determined	0.	0.	0.	0.
49	Program Determined	Program Determined	0.	0.	0.	0.
50	Program Determined	Program Determined	0.	0.	0.	0.
50	Program Determined	Program Determined	0.	0.	0.	0.
51	Program Determined	Program Determined	0.	0.	0.	0.
51	Program Determined	Program Determined	0.	0.	0.	0.
52	Program Determined	Program Determined	0.	0.	0.	0.
52	Program Determined	Program Determined	0.	0.	0.	0.
61	Program Determined	Program Determined	0.	0.	0.	0.
61	Program Determined	Program Determined	0.	0.	0.	0.
62	Program Determined	Program Determined	0.	0.	0.	0.
62	Program Determined	Program Determined	0.	0.	0.	0.

Table 24: Overwrites - Steel Design - CSA S16-14, Part 2 of 6

Table 24: Overwrites - Steel Design - CSA S16-14, Part 2 of 6

Frame	XLMinor	XLLTB	XKMajor	XKMinor	XKLTB	Omega1Major	Omega1Minor
7	0.	0.	0.	0.	0.	0.	0.
13	0.	0.	0.	0.	0.	0.	0.
19	0.	0.	0.	0.	0.	0.	0.
25	0.	0.	0.	0.	0.	0.	0.
42	0.	0.	0.	0.	0.	0.	0.
43	0.	0.	0.	0.	0.	0.	0.
44	0.	0.	0.	0.	0.	0.	0.
45	0.	0.	0.	0.	0.	0.	0.
46	0.	0.	0.	0.	0.	0.	0.
47	0.	0.	0.	0.	0.	0.	0.
48	0.	0.	0.	0.	0.	0.	0.
54	0.	0.	0.	0.	0.	0.	0.
60	0.	0.	0.	0.	0.	0.	0.
66	0.	0.	0.	0.	0.	0.	0.
1	0.	0.	0.	0.	0.	0.	0.
2	0.	0.	0.	0.	0.	0.	0.
3	0.	0.	0.	0.	0.	0.	0.
4	0.	0.	0.	0.	0.	0.	0.
5	0.	0.	0.	0.	0.	0.	0.
5	0.	0.	0.	0.	0.	0.	0.
6	0.	0.	0.	0.	0.	0.	0.
6	0.	0.	0.	0.	0.	0.	0.

Table 24: Overwrites - Steel Design - CSA S16-14, Part 2 of 6

Frame	XLMinor	XLLTB	XKMajor	XKMinor	XKLTB	Omega1Major	Omega1Minor
8	0.	0.	0.	0.	0.	0.	0.
8	0.	0.	0.	0.	0.	0.	0.
9	0.	0.	0.	0.	0.	0.	0.
9	0.	0.	0.	0.	0.	0.	0.
10	0.	0.	0.	0.	0.	0.	0.
10	0.	0.	0.	0.	0.	0.	0.
11	0.	0.	0.	0.	0.	0.	0.
11	0.	0.	0.	0.	0.	0.	0.
12	0.	0.	0.	0.	0.	0.	0.
12	0.	0.	0.	0.	0.	0.	0.
14	0.	0.	0.	0.	0.	0.	0.
14	0.	0.	0.	0.	0.	0.	0.
15	0.	0.	0.	0.	0.	0.	0.
15	0.	0.	0.	0.	0.	0.	0.
16	0.	0.	0.	0.	0.	0.	0.
16	0.	0.	0.	0.	0.	0.	0.
17	0.	0.	0.	0.	0.	0.	0.
17	0.	0.	0.	0.	0.	0.	0.
18	0.	0.	0.	0.	0.	0.	0.
18	0.	0.	0.	0.	0.	0.	0.
20	0.	0.	0.	0.	0.	0.	0.
20	0.	0.	0.	0.	0.	0.	0.
21	0.	0.	0.	0.	0.	0.	0.
21	0.	0.	0.	0.	0.	0.	0.
22	0.	0.	0.	0.	0.	0.	0.
22	0.	0.	0.	0.	0.	0.	0.
23	0.	0.	0.	0.	0.	0.	0.
23	0.	0.	0.	0.	0.	0.	0.
24	0.	0.	0.	0.	0.	0.	0.
24	0.	0.	0.	0.	0.	0.	0.
26	0.	0.	0.	0.	0.	0.	0.
26	0.	0.	0.	0.	0.	0.	0.
27	0.	0.	0.	0.	0.	0.	0.
27	0.	0.	0.	0.	0.	0.	0.
28	0.	0.	0.	0.	0.	0.	0.
28	0.	0.	0.	0.	0.	0.	0.
29	0.	0.	0.	0.	0.	0.	0.
29	0.	0.	0.	0.	0.	0.	0.
30	0.	0.	0.	0.	0.	0.	0.
30	0.	0.	0.	0.	0.	0.	0.
31	0.	0.	0.	0.	0.	0.	0.
31	0.	0.	0.	0.	0.	0.	0.
32	0.	0.	0.	0.	0.	0.	0.
32	0.	0.	0.	0.	0.	0.	0.
33	0.	0.	0.	0.	0.	0.	0.
33	0.	0.	0.	0.	0.	0.	0.
34	0.	0.	0.	0.	0.	0.	0.
34	0.	0.	0.	0.	0.	0.	0.
35	0.	0.	0.	0.	0.	0.	0.
35	0.	0.	0.	0.	0.	0.	0.
36	0.	0.	0.	0.	0.	0.	0.
36	0.	0.	0.	0.	0.	0.	0.
37	0.	0.	0.	0.	0.	0.	0.

Table 24: Overwrites - Steel Design - CSA S16-14, Part 2 of 6

Frame	XLMinor	XLLTB	XKMajor	XKMinor	XKLTB	Omega1Major	Omega1Minor
37	0.	0.	0.	0.	0.	0.	0.
38	0.	0.	0.	0.	0.	0.	0.
38	0.	0.	0.	0.	0.	0.	0.
39	0.	0.	0.	0.	0.	0.	0.
39	0.	0.	0.	0.	0.	0.	0.
40	0.	0.	0.	0.	0.	0.	0.
40	0.	0.	0.	0.	0.	0.	0.
41	0.	0.	0.	0.	0.	0.	0.
41	0.	0.	0.	0.	0.	0.	0.
49	0.	0.	0.	0.	0.	0.	0.
49	0.	0.	0.	0.	0.	0.	0.
50	0.	0.	0.	0.	0.	0.	0.
50	0.	0.	0.	0.	0.	0.	0.
51	0.	0.	0.	0.	0.	0.	0.
51	0.	0.	0.	0.	0.	0.	0.
52	0.	0.	0.	0.	0.	0.	0.
52	0.	0.	0.	0.	0.	0.	0.
61	0.	0.	0.	0.	0.	0.	0.
61	0.	0.	0.	0.	0.	0.	0.
62	0.	0.	0.	0.	0.	0.	0.
62	0.	0.	0.	0.	0.	0.	0.

Table 24: Overwrites - Steel Design - CSA S16-14, Part 3 of 6

Table 24: Overwrites - Steel Design - CSA S16-14, Part 3 of 6

Frame	Omega2	U1Major	U1Minor	U2Major	U2Minor	NPower	Ry
7	0.	0.	0.	0.	0.	0.	0.
13	0.	0.	0.	0.	0.	0.	0.
19	0.	0.	0.	0.	0.	0.	0.
25	0.	0.	0.	0.	0.	0.	0.
42	0.	0.	0.	0.	0.	0.	0.
43	0.	0.	0.	0.	0.	0.	0.
44	0.	0.	0.	0.	0.	0.	0.
45	0.	0.	0.	0.	0.	0.	0.
46	0.	0.	0.	0.	0.	0.	0.
47	0.	0.	0.	0.	0.	0.	0.
48	0.	0.	0.	0.	0.	0.	0.
54	0.	0.	0.	0.	0.	0.	0.
60	0.	0.	0.	0.	0.	0.	0.
66	0.	0.	0.	0.	0.	0.	0.
1	0.	0.	0.	0.	0.	0.	0.
2	0.	0.	0.	0.	0.	0.	0.
3	0.	0.	0.	0.	0.	0.	0.
4	0.	0.	0.	0.	0.	0.	0.
5	0.	0.	0.	0.	0.	0.	0.
5	0.	0.	0.	0.	0.	0.	0.
6	0.	0.	0.	0.	0.	0.	0.
6	0.	0.	0.	0.	0.	0.	0.
8	0.	0.	0.	0.	0.	0.	0.
8	0.	0.	0.	0.	0.	0.	0.
9	0.	0.	0.	0.	0.	0.	0.
9	0.	0.	0.	0.	0.	0.	0.

Table 24: Overwrites - Steel Design - CSA S16-14, Part 3 of 6

Frame	Omega2	U1Major	U1Minor	U2Major	U2Minor	NPower	Ry
10	0.	0.	0.	0.	0.	0.	0.
10	0.	0.	0.	0.	0.	0.	0.
11	0.	0.	0.	0.	0.	0.	0.
11	0.	0.	0.	0.	0.	0.	0.
12	0.	0.	0.	0.	0.	0.	0.
12	0.	0.	0.	0.	0.	0.	0.
14	0.	0.	0.	0.	0.	0.	0.
14	0.	0.	0.	0.	0.	0.	0.
15	0.	0.	0.	0.	0.	0.	0.
15	0.	0.	0.	0.	0.	0.	0.
16	0.	0.	0.	0.	0.	0.	0.
16	0.	0.	0.	0.	0.	0.	0.
17	0.	0.	0.	0.	0.	0.	0.
17	0.	0.	0.	0.	0.	0.	0.
18	0.	0.	0.	0.	0.	0.	0.
18	0.	0.	0.	0.	0.	0.	0.
20	0.	0.	0.	0.	0.	0.	0.
20	0.	0.	0.	0.	0.	0.	0.
21	0.	0.	0.	0.	0.	0.	0.
21	0.	0.	0.	0.	0.	0.	0.
22	0.	0.	0.	0.	0.	0.	0.
22	0.	0.	0.	0.	0.	0.	0.
23	0.	0.	0.	0.	0.	0.	0.
23	0.	0.	0.	0.	0.	0.	0.
24	0.	0.	0.	0.	0.	0.	0.
24	0.	0.	0.	0.	0.	0.	0.
26	0.	0.	0.	0.	0.	0.	0.
26	0.	0.	0.	0.	0.	0.	0.
27	0.	0.	0.	0.	0.	0.	0.
27	0.	0.	0.	0.	0.	0.	0.
28	0.	0.	0.	0.	0.	0.	0.
28	0.	0.	0.	0.	0.	0.	0.
29	0.	0.	0.	0.	0.	0.	0.
29	0.	0.	0.	0.	0.	0.	0.
30	0.	0.	0.	0.	0.	0.	0.
30	0.	0.	0.	0.	0.	0.	0.
31	0.	0.	0.	0.	0.	0.	0.
31	0.	0.	0.	0.	0.	0.	0.
32	0.	0.	0.	0.	0.	0.	0.
32	0.	0.	0.	0.	0.	0.	0.
33	0.	0.	0.	0.	0.	0.	0.
33	0.	0.	0.	0.	0.	0.	0.
34	0.	0.	0.	0.	0.	0.	0.
34	0.	0.	0.	0.	0.	0.	0.
35	0.	0.	0.	0.	0.	0.	0.
35	0.	0.	0.	0.	0.	0.	0.
36	0.	0.	0.	0.	0.	0.	0.
36	0.	0.	0.	0.	0.	0.	0.
37	0.	0.	0.	0.	0.	0.	0.
37	0.	0.	0.	0.	0.	0.	0.
38	0.	0.	0.	0.	0.	0.	0.
38	0.	0.	0.	0.	0.	0.	0.
39	0.	0.	0.	0.	0.	0.	0.
39	0.	0.	0.	0.	0.	0.	0.

Table 24: Overwrites - Steel Design - CSA S16-14, Part 3 of 6

Frame	Omega2	U1Major	U1Minor	U2Major	U2Minor	NPower	Ry
40	0.	0.	0.	0.	0.	0.	0.
40	0.	0.	0.	0.	0.	0.	0.
41	0.	0.	0.	0.	0.	0.	0.
41	0.	0.	0.	0.	0.	0.	0.
49	0.	0.	0.	0.	0.	0.	0.
49	0.	0.	0.	0.	0.	0.	0.
50	0.	0.	0.	0.	0.	0.	0.
50	0.	0.	0.	0.	0.	0.	0.
51	0.	0.	0.	0.	0.	0.	0.
51	0.	0.	0.	0.	0.	0.	0.
52	0.	0.	0.	0.	0.	0.	0.
52	0.	0.	0.	0.	0.	0.	0.
61	0.	0.	0.	0.	0.	0.	0.
61	0.	0.	0.	0.	0.	0.	0.
62	0.	0.	0.	0.	0.	0.	0.
62	0.	0.	0.	0.	0.	0.	0.

Table 24: Overwrites - Steel Design - CSA S16-14, Part 4 of 6

Table 24: Overwrites - Steel Design - CSA S16-14, Part 4 of 6

Frame	Cr	Tr	Mr3	Mr2	Vr2	Vr3	CheckDefl
	KN	KN	KN-m	KN-m	KN	KN	
7	0.	0.	0.	0.	0.	0.	Program Determined
13	0.	0.	0.	0.	0.	0.	Program Determined
19	0.	0.	0.	0.	0.	0.	Program Determined
25	0.	0.	0.	0.	0.	0.	Program Determined
42	0.	0.	0.	0.	0.	0.	Program Determined
43	0.	0.	0.	0.	0.	0.	Program Determined
44	0.	0.	0.	0.	0.	0.	Program Determined
45	0.	0.	0.	0.	0.	0.	Program Determined
46	0.	0.	0.	0.	0.	0.	Program Determined
47	0.	0.	0.	0.	0.	0.	Program Determined
48	0.	0.	0.	0.	0.	0.	Program Determined
54	0.	0.	0.	0.	0.	0.	Program Determined
60	0.	0.	0.	0.	0.	0.	Program Determined
66	0.	0.	0.	0.	0.	0.	Program Determined
1	0.	0.	0.	0.	0.	0.	Program Determined
2	0.	0.	0.	0.	0.	0.	Program Determined
3	0.	0.	0.	0.	0.	0.	Program Determined

Table 24: Overwrites - Steel Design - CSA S16-14, Part 4 of 6

Frame	Cr	Tr	Mr3	Mr2	Vr2	Vr3	CheckDefl
	KN	KN	KN-m	KN-m	KN	KN	
4	0.	0.	0.	0.	0.	0.	Program Determined
5	0.	0.	0.	0.	0.	0.	Program Determined
5	0.	0.	0.	0.	0.	0.	Program Determined
6	0.	0.	0.	0.	0.	0.	Program Determined
6	0.	0.	0.	0.	0.	0.	Program Determined
8	0.	0.	0.	0.	0.	0.	Program Determined
8	0.	0.	0.	0.	0.	0.	Program Determined
9	0.	0.	0.	0.	0.	0.	Program Determined
9	0.	0.	0.	0.	0.	0.	Program Determined
10	0.	0.	0.	0.	0.	0.	Program Determined
10	0.	0.	0.	0.	0.	0.	Program Determined
11	0.	0.	0.	0.	0.	0.	Program Determined
11	0.	0.	0.	0.	0.	0.	Program Determined
12	0.	0.	0.	0.	0.	0.	Program Determined
12	0.	0.	0.	0.	0.	0.	Program Determined
14	0.	0.	0.	0.	0.	0.	Program Determined
14	0.	0.	0.	0.	0.	0.	Program Determined
15	0.	0.	0.	0.	0.	0.	Program Determined
15	0.	0.	0.	0.	0.	0.	Program Determined
16	0.	0.	0.	0.	0.	0.	Program Determined
16	0.	0.	0.	0.	0.	0.	Program Determined
17	0.	0.	0.	0.	0.	0.	Program Determined
17	0.	0.	0.	0.	0.	0.	Program Determined
18	0.	0.	0.	0.	0.	0.	Program Determined
18	0.	0.	0.	0.	0.	0.	Program Determined
20	0.	0.	0.	0.	0.	0.	Program Determined
20	0.	0.	0.	0.	0.	0.	Program Determined
21	0.	0.	0.	0.	0.	0.	Program Determined
21	0.	0.	0.	0.	0.	0.	Program Determined
22	0.	0.	0.	0.	0.	0.	Program Determined

Table 24: Overwrites - Steel Design - CSA S16-14, Part 4 of 6

Frame	Cr	Tr	Mr3	Mr2	Vr2	Vr3	CheckDefl
	KN	KN	KN-m	KN-m	KN	KN	
22	0.	0.	0.	0.	0.	0.	Program Determined
23	0.	0.	0.	0.	0.	0.	Program Determined
23	0.	0.	0.	0.	0.	0.	Program Determined
24	0.	0.	0.	0.	0.	0.	Program Determined
24	0.	0.	0.	0.	0.	0.	Program Determined
26	0.	0.	0.	0.	0.	0.	Program Determined
26	0.	0.	0.	0.	0.	0.	Program Determined
27	0.	0.	0.	0.	0.	0.	Program Determined
27	0.	0.	0.	0.	0.	0.	Program Determined
28	0.	0.	0.	0.	0.	0.	Program Determined
28	0.	0.	0.	0.	0.	0.	Program Determined
29	0.	0.	0.	0.	0.	0.	Program Determined
29	0.	0.	0.	0.	0.	0.	Program Determined
30	0.	0.	0.	0.	0.	0.	Program Determined
30	0.	0.	0.	0.	0.	0.	Program Determined
31	0.	0.	0.	0.	0.	0.	Program Determined
31	0.	0.	0.	0.	0.	0.	Program Determined
32	0.	0.	0.	0.	0.	0.	Program Determined
32	0.	0.	0.	0.	0.	0.	Program Determined
33	0.	0.	0.	0.	0.	0.	Program Determined
33	0.	0.	0.	0.	0.	0.	Program Determined
34	0.	0.	0.	0.	0.	0.	Program Determined
34	0.	0.	0.	0.	0.	0.	Program Determined
35	0.	0.	0.	0.	0.	0.	Program Determined
35	0.	0.	0.	0.	0.	0.	Program Determined
36	0.	0.	0.	0.	0.	0.	Program Determined
36	0.	0.	0.	0.	0.	0.	Program Determined
37	0.	0.	0.	0.	0.	0.	Program Determined
37	0.	0.	0.	0.	0.	0.	Program Determined
38	0.	0.	0.	0.	0.	0.	Program Determined

Table 24: Overwrites - Steel Design - CSA S16-14, Part 4 of 6

Frame	Cr	Tr	Mr3	Mr2	Vr2	Vr3	CheckDefl
	KN	KN	KN-m	KN-m	KN	KN	
38	0.	0.	0.	0.	0.	0.	Program Determined
39	0.	0.	0.	0.	0.	0.	Program Determined
39	0.	0.	0.	0.	0.	0.	Program Determined
40	0.	0.	0.	0.	0.	0.	Program Determined
40	0.	0.	0.	0.	0.	0.	Program Determined
41	0.	0.	0.	0.	0.	0.	Program Determined
41	0.	0.	0.	0.	0.	0.	Program Determined
49	0.	0.	0.	0.	0.	0.	Program Determined
49	0.	0.	0.	0.	0.	0.	Program Determined
50	0.	0.	0.	0.	0.	0.	Program Determined
50	0.	0.	0.	0.	0.	0.	Program Determined
51	0.	0.	0.	0.	0.	0.	Program Determined
51	0.	0.	0.	0.	0.	0.	Program Determined
52	0.	0.	0.	0.	0.	0.	Program Determined
52	0.	0.	0.	0.	0.	0.	Program Determined
61	0.	0.	0.	0.	0.	0.	Program Determined
61	0.	0.	0.	0.	0.	0.	Program Determined
62	0.	0.	0.	0.	0.	0.	Program Determined
62	0.	0.	0.	0.	0.	0.	Program Determined

Table 24: Overwrites - Steel Design - CSA S16-14, Part 5 of 6

Table 24: Overwrites - Steel Design - CSA S16-14, Part 5 of 6

Frame	DeflType	DLRat	SDLAndLLRat	LLRat	TotalRat	NetRat	DLAbs
							m
7	Program Determined	0.	0.	0.	0.	0.	0.
13	Program Determined	0.	0.	0.	0.	0.	0.
19	Program Determined	0.	0.	0.	0.	0.	0.
25	Program Determined	0.	0.	0.	0.	0.	0.
42	Program Determined	0.	0.	0.	0.	0.	0.
43	Program Determined	0.	0.	0.	0.	0.	0.
44	Program Determined	0.	0.	0.	0.	0.	0.
45	Program Determined	0.	0.	0.	0.	0.	0.
46	Program Determined	0.	0.	0.	0.	0.	0.
47	Program Determined	0.	0.	0.	0.	0.	0.
48	Program Determined	0.	0.	0.	0.	0.	0.
54	Program Determined	0.	0.	0.	0.	0.	0.

Table 24: Overwrites - Steel Design - CSA S16-14, Part 5 of 6

Frame	DeflType	DLRat	SDLAndLLRat	LLRat	TotalRat	NetRat	DLAbs
							m
60	Program Determined	0.	0.	0.	0.	0.	0.
66	Program Determined	0.	0.	0.	0.	0.	0.
1	Program Determined	0.	0.	0.	0.	0.	0.
2	Program Determined	0.	0.	0.	0.	0.	0.
3	Program Determined	0.	0.	0.	0.	0.	0.
4	Program Determined	0.	0.	0.	0.	0.	0.
5	Program Determined	0.	0.	0.	0.	0.	0.
5	Program Determined	0.	0.	0.	0.	0.	0.
6	Program Determined	0.	0.	0.	0.	0.	0.
6	Program Determined	0.	0.	0.	0.	0.	0.
8	Program Determined	0.	0.	0.	0.	0.	0.
8	Program Determined	0.	0.	0.	0.	0.	0.
9	Program Determined	0.	0.	0.	0.	0.	0.
9	Program Determined	0.	0.	0.	0.	0.	0.
10	Program Determined	0.	0.	0.	0.	0.	0.
10	Program Determined	0.	0.	0.	0.	0.	0.
11	Program Determined	0.	0.	0.	0.	0.	0.
11	Program Determined	0.	0.	0.	0.	0.	0.
12	Program Determined	0.	0.	0.	0.	0.	0.
12	Program Determined	0.	0.	0.	0.	0.	0.
14	Program Determined	0.	0.	0.	0.	0.	0.
14	Program Determined	0.	0.	0.	0.	0.	0.
15	Program Determined	0.	0.	0.	0.	0.	0.
15	Program Determined	0.	0.	0.	0.	0.	0.
16	Program Determined	0.	0.	0.	0.	0.	0.
16	Program Determined	0.	0.	0.	0.	0.	0.
17	Program Determined	0.	0.	0.	0.	0.	0.
17	Program Determined	0.	0.	0.	0.	0.	0.
18	Program Determined	0.	0.	0.	0.	0.	0.
18	Program Determined	0.	0.	0.	0.	0.	0.
20	Program Determined	0.	0.	0.	0.	0.	0.
20	Program Determined	0.	0.	0.	0.	0.	0.
21	Program Determined	0.	0.	0.	0.	0.	0.
21	Program Determined	0.	0.	0.	0.	0.	0.
22	Program Determined	0.	0.	0.	0.	0.	0.
22	Program Determined	0.	0.	0.	0.	0.	0.
23	Program Determined	0.	0.	0.	0.	0.	0.
23	Program Determined	0.	0.	0.	0.	0.	0.
24	Program Determined	0.	0.	0.	0.	0.	0.
24	Program Determined	0.	0.	0.	0.	0.	0.
26	Program Determined	0.	0.	0.	0.	0.	0.
26	Program Determined	0.	0.	0.	0.	0.	0.
27	Program Determined	0.	0.	0.	0.	0.	0.
27	Program Determined	0.	0.	0.	0.	0.	0.
28	Program Determined	0.	0.	0.	0.	0.	0.
28	Program Determined	0.	0.	0.	0.	0.	0.
29	Program Determined	0.	0.	0.	0.	0.	0.
29	Program Determined	0.	0.	0.	0.	0.	0.
30	Program Determined	0.	0.	0.	0.	0.	0.
30	Program Determined	0.	0.	0.	0.	0.	0.
31	Program Determined	0.	0.	0.	0.	0.	0.
31	Program Determined	0.	0.	0.	0.	0.	0.
32	Program Determined	0.	0.	0.	0.	0.	0.

Table 24: Overwrites - Steel Design - CSA S16-14, Part 5 of 6

Frame	DeflType	DLRat	SDLAndLLRat	LLRat	TotalRat	NetRat	DLAbs
							m
32	Program Determined	0.	0.	0.	0.	0.	0.
33	Program Determined	0.	0.	0.	0.	0.	0.
33	Program Determined	0.	0.	0.	0.	0.	0.
34	Program Determined	0.	0.	0.	0.	0.	0.
34	Program Determined	0.	0.	0.	0.	0.	0.
35	Program Determined	0.	0.	0.	0.	0.	0.
35	Program Determined	0.	0.	0.	0.	0.	0.
36	Program Determined	0.	0.	0.	0.	0.	0.
36	Program Determined	0.	0.	0.	0.	0.	0.
37	Program Determined	0.	0.	0.	0.	0.	0.
37	Program Determined	0.	0.	0.	0.	0.	0.
38	Program Determined	0.	0.	0.	0.	0.	0.
38	Program Determined	0.	0.	0.	0.	0.	0.
39	Program Determined	0.	0.	0.	0.	0.	0.
39	Program Determined	0.	0.	0.	0.	0.	0.
40	Program Determined	0.	0.	0.	0.	0.	0.
40	Program Determined	0.	0.	0.	0.	0.	0.
41	Program Determined	0.	0.	0.	0.	0.	0.
41	Program Determined	0.	0.	0.	0.	0.	0.
49	Program Determined	0.	0.	0.	0.	0.	0.
49	Program Determined	0.	0.	0.	0.	0.	0.
50	Program Determined	0.	0.	0.	0.	0.	0.
50	Program Determined	0.	0.	0.	0.	0.	0.
51	Program Determined	0.	0.	0.	0.	0.	0.
51	Program Determined	0.	0.	0.	0.	0.	0.
52	Program Determined	0.	0.	0.	0.	0.	0.
52	Program Determined	0.	0.	0.	0.	0.	0.
61	Program Determined	0.	0.	0.	0.	0.	0.
61	Program Determined	0.	0.	0.	0.	0.	0.
62	Program Determined	0.	0.	0.	0.	0.	0.
62	Program Determined	0.	0.	0.	0.	0.	0.

Table 24: Overwrites - Steel Design - CSA S16-14, Part 6 of 6

Table 24: Overwrites - Steel Design - CSA S16-14, Part 6 of 6

Frame	SDLAndLLAbs	LLAbs	TotalAbs	NetAbs	SpecCamber
	m	m	m	m	m
7	0.	0.	0.	0.	0.
13	0.	0.	0.	0.	0.
19	0.	0.	0.	0.	0.
25	0.	0.	0.	0.	0.
42	0.	0.	0.	0.	0.
43	0.	0.	0.	0.	0.
44	0.	0.	0.	0.	0.
45	0.	0.	0.	0.	0.
46	0.	0.	0.	0.	0.
47	0.	0.	0.	0.	0.
48	0.	0.	0.	0.	0.
54	0.	0.	0.	0.	0.
60	0.	0.	0.	0.	0.
66	0.	0.	0.	0.	0.
1	0.	0.	0.	0.	0.

Table 24: Overwrites - Steel Design - CSA S16-14, Part 6 of 6

Frame	SDLAndLLAbs	LLAbs	TotalAbs	NetAbs	SpecCamber
	m	m	m	m	m
2	0.	0.	0.	0.	0.
3	0.	0.	0.	0.	0.
4	0.	0.	0.	0.	0.
5	0.	0.	0.	0.	0.
5	0.	0.	0.	0.	0.
6	0.	0.	0.	0.	0.
6	0.	0.	0.	0.	0.
8	0.	0.	0.	0.	0.
8	0.	0.	0.	0.	0.
9	0.	0.	0.	0.	0.
9	0.	0.	0.	0.	0.
10	0.	0.	0.	0.	0.
10	0.	0.	0.	0.	0.
11	0.	0.	0.	0.	0.
11	0.	0.	0.	0.	0.
12	0.	0.	0.	0.	0.
12	0.	0.	0.	0.	0.
14	0.	0.	0.	0.	0.
14	0.	0.	0.	0.	0.
15	0.	0.	0.	0.	0.
15	0.	0.	0.	0.	0.
16	0.	0.	0.	0.	0.
16	0.	0.	0.	0.	0.
17	0.	0.	0.	0.	0.
17	0.	0.	0.	0.	0.
18	0.	0.	0.	0.	0.
18	0.	0.	0.	0.	0.
20	0.	0.	0.	0.	0.
20	0.	0.	0.	0.	0.
21	0.	0.	0.	0.	0.
21	0.	0.	0.	0.	0.
22	0.	0.	0.	0.	0.
22	0.	0.	0.	0.	0.
23	0.	0.	0.	0.	0.
23	0.	0.	0.	0.	0.
24	0.	0.	0.	0.	0.
24	0.	0.	0.	0.	0.
26	0.	0.	0.	0.	0.
26	0.	0.	0.	0.	0.
27	0.	0.	0.	0.	0.
27	0.	0.	0.	0.	0.
28	0.	0.	0.	0.	0.
28	0.	0.	0.	0.	0.
29	0.	0.	0.	0.	0.
29	0.	0.	0.	0.	0.
30	0.	0.	0.	0.	0.
30	0.	0.	0.	0.	0.
31	0.	0.	0.	0.	0.
31	0.	0.	0.	0.	0.
32	0.	0.	0.	0.	0.
32	0.	0.	0.	0.	0.
33	0.	0.	0.	0.	0.
33	0.	0.	0.	0.	0.

Table 24: Overwrites - Steel Design - CSA S16-14, Part 6 of 6

Frame	SDLAndLLAbs	LLAbs	TotalAbs	NetAbs	SpecCamber
	m	m	m	m	m
34	0.	0.	0.	0.	0.
34	0.	0.	0.	0.	0.
35	0.	0.	0.	0.	0.
35	0.	0.	0.	0.	0.
36	0.	0.	0.	0.	0.
36	0.	0.	0.	0.	0.
37	0.	0.	0.	0.	0.
37	0.	0.	0.	0.	0.
38	0.	0.	0.	0.	0.
38	0.	0.	0.	0.	0.
39	0.	0.	0.	0.	0.
39	0.	0.	0.	0.	0.
40	0.	0.	0.	0.	0.
40	0.	0.	0.	0.	0.
41	0.	0.	0.	0.	0.
41	0.	0.	0.	0.	0.
49	0.	0.	0.	0.	0.
49	0.	0.	0.	0.	0.
50	0.	0.	0.	0.	0.
50	0.	0.	0.	0.	0.
51	0.	0.	0.	0.	0.
51	0.	0.	0.	0.	0.
52	0.	0.	0.	0.	0.
52	0.	0.	0.	0.	0.
61	0.	0.	0.	0.	0.
61	0.	0.	0.	0.	0.
62	0.	0.	0.	0.	0.
62	0.	0.	0.	0.	0.

Table: Steel Design 1 - Summary Data - CSA S16-14, Part 1 of 2

Table: Steel Design 1 - Summary Data - CSA S16-14, Part 1 of 2

Frame	DesignSect	DesignType	Status	Ratio	RatioType
7	HSS406x16	Column	No Messages	0.395957	PMM
13	HSS406x16	Column	No Messages	0.396664	PMM
19	HS406X13	Column	No Messages	0.443595	PMM
25	HS406X13	Column	No Messages	0.445299	PMM
42	HS324X13	Beam	No Messages	0.144153	PMM
43	HS254x16	Beam	No Messages	0.032229	PMM
44	HS254x16	Beam	No Messages	0.051304	PMM
45	HS254x16	Beam	No Messages	0.120896	PMM
46	HS254x16	Beam	No Messages	0.117052	PMM
47	HS254x16	Beam	No Messages	0.616073	PMM
48	HS324X13	Beam	No Messages	0.177298	PMM
54	HS324X13	Beam	No Messages	0.182457	PMM
60	HS324X13	Beam	No Messages	0.179309	PMM
66	HS324X13	Beam	No Messages	0.139371	PMM
52	HS254x16	Beam	No Messages	0.057668	PMM

Table: Steel Design 1 - Summary Data - CSA S16-14, Part 2 of 2

Table: Steel Design 1 - Summary Data - CSA S16-14, Part 2 of 2

Frame	Combo	Location	ErrMsg	WarnMsg
		m		
7	UN2	5.75	No Messages	No Messages
13	UN2	0	No Messages	No Messages
19	UN2	0	No Messages	No Messages
25	UN2	0	No Messages	No Messages
42	UN1 VERT4	1.25	No Messages	No Messages
43	UN1 VERT3	6.25	No Messages	No Messages
44	UN1 VERT3	6.25	No Messages	No Messages
45	UN2	3.75	No Messages	No Messages
46	UN1 VERT3	6.25	No Messages	No Messages
47	UN1 MID5	10	No Messages	No Messages
48	UN1 VERT2	2.5	No Messages	No Messages
54	UN1 VERT3	2.5	No Messages	No Messages
60	UN1 VERT3	0	No Messages	No Messages
66	UN1 VERT1	0	No Messages	No Messages
52	UN2	1.25	No Messages	No Messages

Table: Steel Design 2 - PMM Details - CSA S16-14, Part 1 of 7

Table: Steel Design 2 - PMM Details - CSA S16-14, Part 1 of 7

Frame	DesignSect	DesignType	Status	Combo	Location	Pu
					m	KN
7	HSS406x16	Column	No Messages	UN2	5.75	233.209
13	HSS406x16	Column	No Messages	UN2	0	263.738
19	HS406X13	Column	No Messages	UN2	0	260.88
25	HS406X13	Column	No Messages	UN2	0	231.88
42	HS324X13	Beam	No Messages	UN1 VERT4	1.25	8.784
43	HS254x16	Beam	No Messages	UN1 VERT3	6.25	-0.854

Table: Steel Design 2 - PMM Details - CSA S16-14, Part 1 of 7

Frame	DesignSect	DesignType	Status	Combo	Location	Pu
					m	KN
44	HS254x16	Beam	No Messages	UN1 VERT3	6.25	-1.149
45	HS254x16	Beam	No Messages	UN2	3.75	-0.049
46	HS254x16	Beam	No Messages	UN1 VERT3	6.25	-1.888
47	HS254x16	Beam	No Messages	UN1 MID5	10	-7.833
48	HS324X13	Beam	No Messages	UN1 VERT2	2.5	7.477
54	HS324X13	Beam	No Messages	UN1 VERT3	2.5	8.123
60	HS324X13	Beam	No Messages	UN1 VERT3	0	9.286
66	HS324X13	Beam	No Messages	UN1 VERT1	0	8.916
52	HS254x16	Beam	No Messages	UN2	1.25	-5.274

Table: Steel Design 2 - PMM Details - CSA S16-14, Part 2 of 7

Table: Steel Design 2 - PMM Details - CSA S16-14, Part 2 of 7

Frame	MuMajor	MuMinor	VuMajor	VuMinor	Tu	Equation	TotalRatio
	KN-m	KN-m	KN	KN	KN-m		
7	-4.2081	-244.478	4.915	172.074	-2.0698	(13.9a)	0.395957
13	-0.4773	241.209	-0.324	159.771	2.068	(13.9a)	0.396664
19	0.3282	221.5526	0.374	148.591	1.8817	(13.9a)	0.443595
25	3.7162	226.1278	4.333	161.224	-1.1334	(13.9a)	0.445299
42	4.385	-50.6826	0.005506	41.484	0.9202	(13.9a)	0.144153
43	-4.8398	6.519	8.226	-0.547	-3.0583	(13.8.3c)	0.032229
44	-5.4634	11.7622	8.71	-3.58	-4.184	(13.8.3c)	0.051304
45	-2.1352	-31.0529	-6.085	-71.63	0.3244	(13.8.3c)	0.120896
46	-6.8047	28.9566	-9.718	14.941	5.2368	(13.8.3c)	0.117052
47	1.0901	157.0008	-1.582	-194.897	-0.1611	(13.8.3c)	0.616073
48	-8.7914	62.2808	11.104	-31.341	-1.2767	(13.9a)	0.177298
54	-10.6329	63.806	12.729	-33.99	-0.6667	(13.9a)	0.182457
60	-9.977	62.6516	-11.802	30.704	0.5801	(13.9a)	0.179309
66	2.0854	-49.0979	-1.845	-40.216	-1.3729	(13.9a)	0.139371
52	0.138	-13.7304	4.143	23.31	-2.2868	(13.8.3c)	0.057668

Table: Steel Design 2 - PMM Details - CSA S16-14, Part 3 of 7

Table: Steel Design 2 - PMM Details - CSA S16-14, Part 3 of 7

Frame	PRatio	MMajRatio	MMinRatio	SRLimit	CfOrCtDsgn	Cr	Tr
					KN	KN	KN
7	0.041949	0.006092	0.353955	0.95	233.209	4911.73	5559.359
13	0.04744	0.000691	0.349223	0.95	263.738	4911.73	5559.359
19	0.056971	0.000573	0.386623	0.95	260.88	4054.487	4579.178
25	0.050638	0.006485	0.394608	0.95	231.88	4054.487	4579.178
42	0.002424	0.012217	0.141202	0.95	8.784	3608.797	3623.726
43	0.000705	0.018792	0.025312	0.95	-0.854	1211.274	3393.19
44	0.000948	0.021213	0.04567	0.95	-1.149	1211.274	3393.19
45	0	0.008291	0.12057	0.95	-0.049	1211.274	3393.19
46	0.001559	0.026421	0.112431	0.95	-1.888	1211.274	3393.19
47	0.006467	0.004233	0.609592	0.95	-7.833	1211.274	3393.19
48	0.002063	0.024493	0.173514	0.95	7.477	3530.48	3623.726
54	0.002242	0.029623	0.177764	0.95	8.123	3530.48	3623.726
60	0.002563	0.027796	0.174547	0.95	9.286	3530.48	3623.726
66	0.00246	0.00581	0.136787	0.95	8.916	3608.797	3623.726
52	0.004354	0.000536	0.053312	0.95	-5.274	1211.274	3393.19

Table: Steel Design 2 - PMM Details - CSA S16-14, Part 4 of 7

Table: Steel Design 2 - PMM Details - CSA S16-14, Part 4 of 7

Frame	MfMajDsgn	MrMajor	U1Major	U2Major	XKMajor	XLMajor	Omega1Major
	KN-m	KN-m					
7	-4.2081	690.7028	1	1	2.342829	0.217391	1
13	-0.4773	690.7028	1	1	2.173304	0.217391	1
19	0.3282	573.0448	1	1	2.144902	0.217391	1
25	3.7162	573.0448	1	1	2.287671	0.217391	1
42	4.385	358.9375	1	1	1	1	1
43	-4.8398	257.5507	1.000032	1	1	0.25	1
44	-5.4634	257.5507	1.000043	1	1	0.25	1
45	-2.1352	257.5507	1.000002	1	1	0.25	1
46	-6.8047	257.5507	1.000071	1	1	0.25	1
47	1.0901	257.5507	1.000293	1	1	0.25	1
48	-8.7914	358.9375	1	1	1	1	1
54	-10.6329	358.9375	1	1	1	1	1
60	-9.977	358.9375	1	1	1	1	1
66	2.0854	358.9375	1	1	1	1	1
52	0.138	257.5507	1.000197	1	1	0.25	1

Table: Steel Design 2 - PMM Details - CSA S16-14, Part 5 of 7

Table: Steel Design 2 - PMM Details - CSA S16-14, Part 5 of 7

Frame	Omega2	MfMinDsgn	MrMinor	U1Minor	U2Minor	XKMinor	XLMinor
		KN-m	KN-m				
7	2.5	-244.478	690.7028	1	1	1	1
13	2.5	241.209	690.7028	1	1	1	1
19	2.5	221.5526	573.0448	1	1	1	1
25	2.5	226.1278	573.0448	1	1	1	1
42	1.355107	-50.6826	358.9375	1	1	1	1
43	1.222404	6.519	257.5507	1.000511	1	1	1
44	1.240197	11.7622	257.5507	1.000688	1	1	1
45	1.08876	-31.0529	257.5507	1.00003	1	1	1
46	1.277208	28.9566	257.5507	1.001131	1	1	1
47	1.071554	157.0008	257.5507	1.004711	1	1	1
48	2.5	62.2808	358.9375	1	1	1	1
54	2.5	63.806	358.9375	1	1	1	1
60	2.5	62.6516	358.9375	1	1	1	1
66	1.174298	-49.0979	358.9375	1	1	1	1
52	1.010414	-13.7304	257.5507	1.003167	1	1	1

Table: Steel Design 2 - PMM Details - CSA S16-14, Part 6 of 7

Table: Steel Design 2 - PMM Details - CSA S16-14, Part 6 of 7

Frame	Omega1Minor	Fy	E	Length	MajAxisAng	RLLF	SectClass
		KN/m2	KN/m2	m	Degrees		
7	1	317000	199947978.8	5.75	0	1	Class 1
13	1	317000	199947978.8	5.75	0	1	Class 1
19	1	317000	199947978.8	5.75	0	1	Class 1
25	1	317000	199947978.8	5.75	0	1	Class 1
42	1	317000	199947978.8	1.25	0	1	Class 1
43	1	317000	199947978.8	10	0	1	Class 1

Table: Steel Design 2 - PMM Details - CSA S16-14, Part 6 of 7

Frame	Omega1Minor	Fy	E	Length	MajAxisAng	RLLF	SectClass
		KN/m2	KN/m2	m	Degrees		
44	1	317000	199947978.8	10	0	1	Class 1
45	1	317000	199947978.8	10	0	1	Class 1
46	1	317000	199947978.8	10	0	1	Class 1
47	1	317000	199947978.8	10	0	1	Class 1
48	1	317000	199947978.8	2.5	0	1	Class 1
54	1	317000	199947978.8	2.5	0	1	Class 1
60	1	317000	199947978.8	2.5	0	1	Class 1
66	1	317000	199947978.8	1.25	0	1	Class 1
52	1	317000	199947978.8	10	0	1	Class 1

Table: Steel Design 2 - PMM Details - CSA S16-14, Part 7 of 7

Table: Steel Design 2 - PMM Details - CSA S16-14, Part 7 of 7

Frame	FramingType	ErrMsg	WarnMsg
7	Type LD Moment Resisting Frame	No Messages	No Messages
13	Type LD Moment Resisting Frame	No Messages	No Messages
19	Type LD Moment Resisting Frame	No Messages	No Messages
25	Type LD Moment Resisting Frame	No Messages	No Messages
42	Type LD Moment Resisting Frame	No Messages	No Messages
43	Type LD Moment Resisting Frame	No Messages	No Messages
44	Type LD Moment Resisting Frame	No Messages	No Messages
45	Type LD Moment Resisting Frame	No Messages	No Messages
46	Type LD Moment Resisting Frame	No Messages	No Messages
47	Type LD Moment Resisting Frame	No Messages	No Messages
48	Type LD Moment Resisting Frame	No Messages	No Messages
54	Type LD Moment Resisting Frame	No Messages	No Messages
60	Type LD Moment Resisting Frame	No Messages	No Messages
66	Type LD Moment Resisting Frame	No Messages	No Messages
52	Type LD Moment Resisting Frame	No Messages	No Messages

Table: Steel Design 3 - Shear Details - CSA S16-14, Part 1 of 4

Table: Steel Design 3 - Shear Details - CSA S16-14, Part 1 of 4

Frame	DesignSect	DesignType	Status	VMajorCombo	VMajorLoc	VMajorRatio
					m	
7	HSS406x16	Column	No Messages	UN1 VERT4	0	0.010422
13	HSS406x16	Column	No Messages	UN1 VERT3	5	0.007282
19	HS406X13	Column	No Messages	UN1 VERT4	5	0.009391

Table: Steel Design 3 - Shear Details - CSA S16-14, Part 1 of 4

Frame	DesignSect	DesignType	Status	VMajorCombo	VMajorLoc	VMajorRatio
					m	
25	HS406X13	Column	No Messages	UN1 VERT3	5	0.012275
42	HS324X13	Beam	No Messages	UN1 MID2	1.25	0.010298
43	HS254x16	Beam	No Messages	UN1 MID1	8.75	0.00813
44	HS254x16	Beam	No Messages	UN1 MID1	8.75	0.008803
45	HS254x16	Beam	No Messages	UN1 MID1	8.75	0.009488
46	HS254x16	Beam	No Messages	UN1 MID1	8.75	0.010098
47	HS254x16	Beam	No Messages	UN1 MID1	8.75	0.010269
48	HS324X13	Beam	No Messages	UN1 MID5	0	0.011065
54	HS324X13	Beam	No Messages	UN1 VERT3	2.5	0.010633
60	HS324X13	Beam	No Messages	UN1 MID1	2.5	0.011658
66	HS324X13	Beam	No Messages	UN1 VERT4	0	0.011528
52	HS254x16	Beam	No Messages	UN1 MID1	8.75	0.007483

Table: Steel Design 3 - Shear Details - CSA S16-14, Part 2 of 4

Table: Steel Design 3 - Shear Details - CSA S16-14, Part 2 of 4

Frame	VfMajDsgn	VrMajor	TuMajor	VMinorCombo	VMinorLoc	VMinorRatio	VfMinDsgn
	KN	KN	KN-m		m		KN
7	19.141	1836.619	0	UN2	0.75	0.108292	198.89
13	13.375	1836.619	0	UN2	5	0.111086	204.022
19	14.202	1512.231	0	UN2	5	0.132183	199.891
25	18.563	1512.231	0	UN2	5	0.128951	195.004
42	12.329	1197.222	0	UN1 VERT4	1.25	0.03465	41.484
43	9.131	1123.077	0	UN2	1.25	0.012886	14.472
44	9.886	1123.077	0	UN2	1.25	0.015935	17.897
45	10.656	1123.077	0	UN2	3.75	0.06378	71.63
46	11.341	1123.077	0	UN2	3.75	0.062253	69.915
47	11.533	1123.077	0	UN1 MID1	1.25	0.177511	199.358
48	13.247	1197.222	0	UN1 VERT2	0	0.02931	35.091
54	12.729	1197.222	0	UN1 VERT3	0	0.031523	37.74
60	13.957	1197.222	0	UN1 VERT3	2.5	0.028779	34.454
66	13.802	1197.222	0	UN1 VERT1	0	0.033591	40.216
52	8.404	1123.077	0	UN2	1.25	0.020756	23.31

Table: Steel Design 3 - Shear Details - CSA S16-14, Part 3 of 4

Table: Steel Design 3 - Shear Details - CSA S16-14, Part 3 of 4

Frame	VrMinor	TuMinor	SRLimit	RLLF	FramingType
	KN	KN-m			
7	1836.619	0	0.95	1	Type LD Moment Resisting Frame
13	1836.619	0	0.95	1	Type LD Moment Resisting Frame
19	1512.231	0	0.95	1	Type LD Moment Resisting Frame
25	1512.231	0	0.95	1	Type LD Moment Resisting Frame
42	1197.222	0	0.95	1	Type LD Moment Resisting Frame
43	1123.077	0	0.95	1	Type LD Moment Resisting Frame
44	1123.077	0	0.95	1	Type LD Moment Resisting Frame

Table: Steel Design 3 - Shear Details - CSA S16-14, Part 3 of 4

Frame	VrMinor KN	TuMinor KN-m	SRLimit	RLLF	FramingType
45	1123.077	0	0.95	1	Type LD Moment Resisting Frame
46	1123.077	0	0.95	1	Type LD Moment Resisting Frame
47	1123.077	0	0.95	1	Type LD Moment Resisting Frame
48	1197.222	0	0.95	1	Type LD Moment Resisting Frame
54	1197.222	0	0.95	1	Type LD Moment Resisting Frame
60	1197.222	0	0.95	1	Type LD Moment Resisting Frame
66	1197.222	0	0.95	1	Type LD Moment Resisting Frame
52	1123.077	0	0.95	1	Type LD Moment Resisting Frame

Table: Steel Design 3 - Shear Details - CSA S16-14, Part 4 of 4

Table: Steel Design 3 - Shear Details - CSA S16-14, Part 4 of 4

Frame	ErrMsg	WarnMsg
7	No Messages	No Messages
13	No Messages	No Messages
19	No Messages	No Messages
25	No Messages	No Messages
42	No Messages	No Messages
43	No Messages	No Messages
44	No Messages	No Messages
45	No Messages	No Messages
46	No Messages	No Messages
47	No Messages	No Messages
48	No Messages	No Messages
54	No Messages	No Messages
60	No Messages	No Messages
66	No Messages	No Messages
52	No Messages	No Messages

Table: Steel Design 7 - Beam Shear Forces - CSA S16-14

Table: Steel Design 7 - Beam Shear Forces - CSA S16-14

Frame	DesignSect	ComboLeft	VMajorLeft KN	ComboRight	VMajorRight KN
42	HS324X13	UN1 VERT4	-7.021	UN1 MID2	12.329
43	HS254x16	U1x	3.361	U1x_NEG	-3.168
44	HS254x16	UN1 VERT4	-3.621	U1x_NEG	-3.338
45	HS254x16	UN1 VERT4	-4.192	UN1 VERT1	3.364
46	HS254x16	UN1 VERT4	-4.709	UN1 VERT4	-4.038
47	HS254x16	UN1 VERT4	-4.907	UN1 VERT4	-4.679
48	HS324X13	UN1 MID5	-13.247	UN1 VERT2	11.104
54	HS324X13	UN1 VERT2	-11.043	UN1 VERT3	12.729
60	HS324X13	UN1 VERT3	-11.802	UN1 MID1	13.957
66	HS324X13	UN1 VERT4	-13.802	UN1 VERT4	-6.775
52	HS254x16	UN1 VERT4	-2.778	UN1 VERT1	2.522

Debris Barrier Project number:110773396 Date Printed: 11/1/2019 Page: 1 of 4
Completed by: JH Date completed: 10/24/2019 Reviewed by: BEF Date Reviewed: 10/29/2019

REACTION LOADS FROM SAP2000 MODEL - SUPPORT A

TABLE: Joint Reactions

Joint	OutputCase	F1	F2	F3	M1	M2	M3
Text	Text	KN	KN	KN	KN-m	KN-m	KN-m
137	U1x	0	67.758	1157.278	0	0	0
137	U2 MID1	0	-24.566	1109.842	0	0	0
137	UN1 MID1	0	58.177	1160.107	0	0	0
137	UN2	0	-105.272	638.688	0	0	0
137	E2	0	-16.76	892.558	0	0	0
137	E1	0	21.197	756.001	0	0	0
137	U1y	0	62.942	1126.759	0	0	0
137	WIND45	0	-1.402	326.241	0	0	0
137	U145	0	64.728	1286.76	0	0	0
137	U1x_NEG	0	65.905	437.516	0	0	0
137	U1y_NEG	0	70.72	468.036	0	0	0
137	U145_NEG	0	68.935	308.035	0	0	0
137	E3	0	-16.76	892.558	0	0	0
137	U2 VERT1	0	-29.892	1123.964	0	0	0
137	UN1 VERT1	0	48.766	1185.062	0	0	0
137	U2 MID2	0	-29.375	1155.374	0	0	0
137	U2 MID3	0	-20.18	1206.565	0	0	0
137	U2 MID4	0	-14.836	1163.248	0	0	0
137	U2 MID5	0	-24.507	1103.136	0	0	0
137	UN1 MID2	0	49.679	1240.568	0	0	0
137	UN1 MID3	0	65.926	1331.029	0	0	0
137	UN1 MID4	0	75.371	1254.482	0	0	0
137	UN1 MID5	0	58.28	1148.256	0	0	0
137	U2 VERT2	0	-25.339	1186.925	0	0	0
137	U2 VERT3	0	-16.166	1201.943	0	0	0
137	U2 VERT4	0	-17.423	1118.705	0	0	0
137	UN1 VERT2	0	56.81	1296.323	0	0	0
137	UN1 VERT3	0	73.021	1322.861	0	0	0
137	UN1 VERT4	0	70.799	1175.768	0	0	0
137	E3-Service	0	-23.176	720.388	0	0	0
137	E2-service	0	-23.176	720.388	0	0	0
137	UN2-service	0	-70.048	465.842	0	0	0
137	UN1-VERT1_service	0	32.644	830.092	0	0	0
137	DEAD_SERVICE	0	0.803	240.303	0	0	0
146	DEAD_SERVICE	0	0.787	239.74	0	0	0
140	U1x	0	68.098	1104.002	0	0	0

Debris Barrier Project number:110773396 Date Printed: 11/1/2019 Page: 2 of 4
Completed by: JH Date completed: 10/24/2019 Reviewed by: BEF Date Reviewed: 10/29/2019

140	U2 MID1	0	-22.107	1226.619	0	0	0
140	UN1 MID1	0	62.81	1350.882	0	0	0
140	UN2	0	-110.387	842.934	0	0	0
140	E2	0	-20.105	1045.846	0	0	0
140	E1	0	20.236	777.796	0	0	0
140	U1y	0	62.798	1083.465	0	0	0
140	WIND45	0	-1.384	319.585	0	0	0
140	U145	0	64.834	1235.522	0	0	0
140	U1x_NEG	0	65.722	408.285	0	0	0
140	U1y_NEG	0	71.022	428.822	0	0	0
140	U145_NEG	0	68.986	276.765	0	0	0
140	E3	0	-20.105	1045.846	0	0	0
140	U2 VERT1	0	-25.969	1203.896	0	0	0
140	UN1 VERT1	0	55.985	1310.728	0	0	0
140	U2 MID2	0	-29.5	1176.311	0	0	0
140	U2 MID3	0	-29.427	1165.687	0	0	0
140	U2 MID4	0	-22.23	1213.43	0	0	0
140	U2 MID5	0	-22.051	1226.317	0	0	0
140	UN1 MID2	0	49.745	1261.981	0	0	0
140	UN1 MID3	0	49.874	1243.207	0	0	0
140	UN1 MID4	0	62.594	1327.575	0	0	0
140	UN1 MID5	0	62.91	1350.348	0	0	0
140	U2 VERT2	0	-30.968	1159.788	0	0	0
140	U2 VERT3	0	-26.004	1186.343	0	0	0
140	U2 VERT4	0	-20.217	1232.325	0	0	0
140	UN1 VERT2	0	47.152	1232.784	0	0	0
140	UN1 VERT3	0	55.923	1279.709	0	0	0
140	UN1 VERT4	0	66.15	1360.965	0	0	0
140	E3-Service	0	-26.469	864.581	0	0	0
140	E2-service	0	-26.469	864.581	0	0	0
140	UN2-service	0	-73.45	600.689	0	0	0
140	UN1-VERT1_service	0	37.465	912.552	0	0	0
140	DEAD_SERVICE	0	0.849	232.401	0	0	0
146	DEAD_SERVICE	0	0.787	239.74	0	0	0
143	U1x	0	68.19	1101.433	0	0	0
143	U2 MID1	0	-21.9	1223.289	0	0	0
143	UN1 MID1	0	63.078	1348.237	0	0	0
143	UN2	0	-109.521	846.612	0	0	0
143	E2	0	-19.452	1047.776	0	0	0
143	E1	0	20.371	776.309	0	0	0
143	U1y	0	62.753	1079.324	0	0	0
143	WIND45	0	-1.299	319.254	0	0	0
143	U145	0	64.895	1232.019	0	0	0

143	U1x_NEG	0	65.497	404.845	0	0	0
143	U1y_NEG	0	70.933	426.954	0	0	0
143	U145_NEG	0	68.791	274.259	0	0	0
143	E3	0	-19.452	1047.776	0	0	0
143	U2 VERT1	0	-20.073	1229.351	0	0	0
143	UN1 VERT1	0	66.307	1358.95	0	0	0
143	U2 MID2	0	-22.092	1210.464	0	0	0
143	U2 MID3	0	-29.315	1163.291	0	0	0
143	U2 MID4	0	-29.382	1173.574	0	0	0
143	U2 MID5	0	-21.969	1223.367	0	0	0
143	UN1 MID2	0	62.74	1325.573	0	0	0
143	UN1 MID3	0	49.975	1242.212	0	0	0
143	UN1 MID4	0	49.857	1260.384	0	0	0
143	UN1 MID5	0	62.956	1348.374	0	0	0
143	U2 VERT2	0	-25.875	1183.569	0	0	0
143	U2 VERT3	0	-30.864	1157.507	0	0	0
143	U2 VERT4	0	-25.833	1200.695	0	0	0
143	UN1 VERT2	0	56.054	1278.046	0	0	0
143	UN1 VERT3	0	47.239	1231.992	0	0	0
143	UN1 VERT4	0	56.13	1308.31	0	0	0
143	E3-Service	0	-25.864	866.714	0	0	0
143	E2-service	0	-25.864	866.714	0	0	0
143	UN2-service	0	-72.874	602.975	0	0	0
143	UN1-VERT1_service	0	44.345	944.534	0	0	0
143	DEAD_SERVICE	0	0.841	231.403	0	0	0
146	U1x	0	68.039	1155.259	0	0	0
146	U2 MID1	0	-24.07	1100.625	0	0	0
146	UN1 MID1	0	58.694	1145.161	0	0	0
146	UN2	0	-103.629	643.366	0	0	0
146	E2	0	-15.604	896.179	0	0	0
146	E1	0	21.407	756.193	0	0	0
146	U1y	0	62.737	1124.254	0	0	0
146	WIND45	0	-1.131	325.939	0	0	0
146	U145	0	64.886	1284.364	0	0	0
146	U1x_NEG	0	65.127	435.65	0	0	0
146	U1y_NEG	0	70.43	466.654	0	0	0
146	U145_NEG	0	68.28	306.545	0	0	0
146	E3	0	-15.604	896.179	0	0	0
146	U2 VERT1	0	-17.063	1116.469	0	0	0
146	UN1 VERT1	0	71.077	1173.16	0	0	0
146	U2 MID2	0	-14.585	1162.057	0	0	0
146	U2 MID3	0	-19.991	1206.033	0	0	0

Debris Barrier Project number:110773396 Date Printed: 11/1/2019 Page: 4 of 4
Completed by: JH Date completed: 10/24/2019 Reviewed by: BEF Date Reviewed: 10/29/2019

146	U2 MID4	0	-29.102	1153.926	0	0	0
146	U2 MID5	0	-24.151	1107.684	0	0	0
146	UN1 MID2	0	75.455	1253.72	0	0	0
146	UN1 MID3	0	65.902	1331.431	0	0	0
146	UN1 MID4	0	49.802	1239.351	0	0	0
146	UN1 MID5	0	58.55	1157.636	0	0	0
146	U2 VERT2	0	-15.971	1201.546	0	0	0
146	U2 VERT3	0	-25.127	1185.841	0	0	0
146	U2 VERT4	0	-29.514	1122.216	0	0	0
146	UN1 VERT2	0	73.007	1323.501	0	0	0
146	UN1 VERT3	0	56.827	1295.749	0	0	0
146	UN1 VERT4	0	49.075	1183.316	0	0	0
146	E3-Service	0	-22.095	723.853	0	0	0
146	E2-service	0	-22.095	723.853	0	0	0
146	UN2-service	0	-68.955	468.867	0	0	0
146	UN1-VERT1_service	0	47.516	822.063	0	0	0
146	DEAD_SERVICE	0	0.787	239.74	0	0	0

	Factored Loads					
MIN	0	-110.387	231.403	0	0	0
MAX	0	75.455	1360.965	0	0	0

LOAD CASE MIN	U1x	UN2	DEAD_SERV	U1x	U1x	U1x
LOAD CASE MAX	U1x	UN1 MID2	UN1 VERT4	U1x	U1x	U1x
JOINT LOCATION MIN	137	140	143	137	137	137
JOINT LOCATION MAX	137	146	140	137	137	137

	Service Loads	
MIN	-73.45	465.842
MAX	47.516	944.534

LOAD CASE MIN	UN2-servic	UN1-VERT1_service
LOAD CASE MAX	UN1-VERT1	UN1-VERT1_service
JOINT LOCATION MIN	140	137
JOINT LOCATION MAX	146	143

Debris Barrier Project number:110773396 Date Printed: 11/1/2019 Page: 1 of 4
Completed by: JH Date completed: 10/24/2019 Reviewed by: BEF Date Reviewed: 10/29/2019

REACTION LOADS FROM SAP2000 MODEL - SUPPORT B

TABLE: Joint Reactions

Joint	OutputCase	F1	F2	F3	M1	M2	M3
Text	Text	KN	KN	KN	KN-m	KN-m	KN-m
136	U1x	0	137.418	301.736	-10.0468	1.9455	0.4624
136	U2 MID1	0	-70.049	794.619	-14.6108	-3.4923	2.6351
136	UN1 MID1	0	108.572	735.689	-17.8016	-2.3562	3.7465
136	UN2	0	-249.627	1154.416	-17.319	-7.0056	-8.5643
136	E2	0	-56.794	972.469	-18.627	-4.7313	-5.5752
136	E1	0	36.373	405.184	-9.5211	-0.5421	-1.7271
136	U1y	0	126.678	325.563	-10.2429	2.2917	-1.0125
136	WIND45	0	-6.601	154.44	-3.0936	-0.3818	0.377
136	U145	0	129.119	382.169	-11.5174	1.9492	-0.1078
136	U1x_NEG	0	140.623	-0.719	-3.7071	3.0982	-1.8089
136	U1y_NEG	0	151.363	-24.546	-3.511	2.7521	-0.334
136	U145_NEG	0	148.921	-81.151	-2.2365	3.0945	-1.2387
136	E3	0	-56.794	972.469	-18.627	-4.7313	-5.5752
136	U2 VERT1	0	-82.06	829.593	-15.0072	-1.9995	0.7767
136	UN1 VERT1	0	87.347	797.493	-18.5021	0.2818	0.4623
136	U2 MID2	0	-80.144	787.949	-14.2755	0.9957	-7.3016
136	U2 MID3	0	-58.493	679.396	-12.7213	2.8989	-15.8504
136	U2 MID4	0	-47.079	677.074	-12.9157	-0.5013	-8.0066
136	U2 MID5	0	-69.911	794.083	-14.5975	-3.6441	2.8475
136	UN1 MID2	0	90.733	723.903	-17.2091	5.5745	-13.8129
136	UN1 MID3	0	128.992	532.077	-14.4626	8.9378	-28.9197
136	UN1 MID4	0	149.164	527.974	-14.8062	2.9292	-15.0587
136	UN1 MID5	0	108.816	734.743	-17.778	-2.6245	4.1218
136	U2 VERT2	0	-70.289	722.362	-13.2645	2.7997	-14.0243
136	U2 VERT3	0	-49.671	663.892	-12.6255	1.559	-13.1671
136	U2 VERT4	0	-53.428	722.191	-13.6107	-2.52	-2.0517
136	UN1 VERT2	0	108.148	608.002	-15.4226	8.7624	-25.6928
136	UN1 VERT3	0	144.582	504.68	-14.2933	6.5701	-24.178
136	UN1 VERT4	0	137.943	607.701	-16.0342	-0.6381	-4.5357
136	E3-Service	0	-68.086	864.158	-16.0725	-4.3559	-5.5783
136	E2-service	0	-68.086	864.158	-16.0725	-4.3559	-5.5783
136	UN2-service	0	-166.529	786.339	-11.8984	-4.6662	-5.6907
136	UN1-VERT1_service	0	58.121	548.391	-12.6872	0.1921	0.3271
136	DEAD_SERVICE	0	-0.663	100.372	-2.1147	0.0253	0.1132
139	U1x	0	137.26	312.927	-10.2151	-0.6443	0.5681
139	U2 MID1	0	-62.673	683.131	-12.7184	-1.5138	4.0019
139	UN1 MID1	0	121.087	544.861	-14.542	-2.8916	6.9045

Debris Barrier Project number:110773396 Date Printed: 11/1/2019 Page: 2 of 4
Completed by: JH Date completed: 10/24/2019 Reviewed by: BEF Date Reviewed: 10/29/2019

139	UN2	0	-258.547	1109.832	-16.4114	0.1928	-1.9241
139	E2	0	-62.782	931.506	-17.8161	-0.0229	-1.3015
139	E1	0	34.305	396.5	-9.3225	0.0263	-0.637
139	U1y	0	125.563	335.368	-10.3701	-1.2E-05	-0.4773
139	WIND45	0	-6.549	154.884	-3.0995	-0.2659	0.3616
139	U145	0	128.506	392.864	-11.6678	-0.4401	0.2058
139	U1x_NEG	0	139.399	8.148	-3.8219	0.5618	-1.2412
139	U1y_NEG	0	151.096	-14.293	-3.6669	-0.0825	-0.1958
139	U145_NEG	0	148.153	-71.789	-2.3693	0.3576	-0.8789
139	E3	0	-62.782	931.506	-17.8161	-0.0229	-1.3015
139	U2 VERT1	0	-71.677	726.815	-13.3393	-2.8358	9.768
139	UN1 VERT1	0	105.176	622.056	-15.6391	-5.2278	17.0939
139	U2 MID2	0	-80.36	792.598	-14.384	-2.1961	7.357
139	U2 MID3	0	-80.2	794.525	-14.4153	2.5273	-8.6756
139	U2 MID4	0	-63.021	690.394	-12.8387	2.7153	-11.8839
139	U2 MID5	0	-62.543	682.624	-12.711	-1.4946	3.8644
139	UN1 MID2	0	89.832	738.303	-17.4854	-4.0974	12.8334
139	UN1 MID3	0	90.115	741.707	-17.5406	4.2493	-15.4982
139	UN1 MID4	0	120.472	557.696	-14.7546	4.5816	-21.1677
139	UN1 MID5	0	121.317	543.965	-14.5289	-2.8578	6.6615
139	U2 VERT2	0	-84.124	829.357	-14.9878	0.1368	-0.3788
139	U2 VERT3	0	-71.797	732.714	-13.4346	3.3922	-13.0865
139	U2 VERT4	0	-58.425	671.314	-12.5917	0.8554	-5.6033
139	UN1 VERT2	0	83.181	803.261	-18.5522	0.0252	-0.8367
139	UN1 VERT3	0	104.964	632.48	-15.8076	5.7778	-23.2929
139	UN1 VERT4	0	128.594	523.978	-14.3181	1.295	-10.0691
139	E3-Service	0	-74.022	827.538	-15.3395	0.0096	-1.3095
139	E2-service	0	-74.022	827.538	-15.3395	0.0096	-1.3095
139	UN2-service	0	-172.463	756.803	-11.2963	0.1311	-1.2836
139	UN1-VERT1_service	0	70.019	431.619	-10.7815	-3.4827	11.3951
139	DEAD_SERVICE	0	-0.59	101.49	-2.1323	0.0153	-0.0052
142	U1x	0	137.458	313.316	-10.2235	-0.5497	1.0354
142	U2 MID1	0	-62.191	681.684	-12.6921	1.4217	-3.4596
142	UN1 MID1	0	121.709	542.895	-14.5097	2.7672	-6.22
142	UN2	0	-256.503	1100.393	-16.2327	-0.5398	3.8448
142	E2	0	-61.229	924.008	-17.6664	-0.1895	2.6655
142	E1	0	34.636	394.814	-9.2818	-0.0253	0.8604
142	U1y	0	125.475	335.671	-10.3672	0.0408	0.3288
142	WIND45	0	-6.362	154.731	-3.0992	-0.3223	0.512
142	U145	0	128.644	393.142	-11.6704	-0.3974	0.9093
142	U1x_NEG	0	138.915	8.774	-3.8195	0.7218	-0.7529
142	U1y_NEG	0	150.898	-13.581	-3.6758	0.1313	-0.0462
142	U145_NEG	0	147.729	-71.052	-2.3727	0.5695	-0.6267

Debris Barrier Project number:110773396 Date Printed: 11/1/2019 Page: 3 of 4
Completed by: JH Date completed: 10/24/2019 Reviewed by: BEF Date Reviewed: 10/29/2019

142	E3	0	-61.229	924.008	-17.6664	-0.1895	2.6655
142	U2 VERT1	0	-58.083	670.193	-12.5693	-0.892	5.9273
142	UN1 VERT1	0	128.967	522.589	-14.2926	-1.3214	10.3678
142	U2 MID2	0	-62.684	688.751	-12.8053	-2.7251	12.1164
142	U2 MID3	0	-79.901	791.88	-14.3584	-2.5551	8.9076
142	U2 MID4	0	-80.064	791.047	-14.347	2.1127	-7.0058
142	U2 MID5	0	-62.347	682.191	-12.6987	1.4404	-3.6063
142	UN1 MID2	0	120.837	555.382	-14.7096	-4.5607	21.3047
142	UN1 MID3	0	90.413	737.625	-17.4541	-4.2603	15.6344
142	UN1 MID4	0	90.123	736.153	-17.434	3.9882	-12.4867
142	UN1 MID5	0	121.433	543.79	-14.5213	2.8003	-6.4793
142	U2 VERT2	0	-71.466	730.339	-13.3858	-3.3955	13.2784
142	U2 VERT3	0	-83.849	827.236	-14.9385	-0.1937	0.6713
142	U2 VERT4	0	-71.347	725.647	-13.3129	2.7369	-9.3543
142	UN1 VERT2	0	105.318	628.875	-15.7355	-5.7454	23.3581
142	UN1 VERT3	0	83.435	800.102	-18.4793	-0.0874	1.0798
142	UN1 VERT4	0	105.528	620.584	-15.6067	5.0912	-16.6366
142	E3-Service	0	-72.584	820.618	-15.2026	-0.2141	2.5847
142	E2-service	0	-72.584	820.618	-15.2026	-0.2141	2.5847
142	UN2-service	0	-171.103	750.529	-11.1773	-0.3613	2.5609
142	UN1-VERT1_service	0	85.877	365.326	-9.8839	-0.8824	6.9095
145	U1x	0	138.018	301.761	-10.0566	-3.0841	1.0693
145	U2 MID1	0	-68.902	790.941	-14.5489	3.5188	-2.4024
145	UN1 MID1	0	109.775	730.696	-17.7052	2.6345	-3.9207
145	UN2	0	-245.955	1145.841	-17.1993	7.0078	8.8245
145	E2	0	-54.221	966.706	-18.5386	4.7502	5.6054
145	E1	0	36.838	404.489	-9.5052	0.4985	1.7265
145	U1y	0	126.217	326.577	-10.2446	-2.2104	0.6348
145	WIND45	0	-6.006	153.804	-3.094	-0.2115	0.5408
145	U145	0	129.453	382.406	-11.5233	-2.7411	1.092
145	U1x_NEG	0	138.906	1.639	-3.7079	-1.7636	-0.5077
145	U1y_NEG	0	150.707	-23.177	-3.5199	-2.6373	-0.0732
145	U145_NEG	0	147.471	-79.006	-2.2412	-2.1066	-0.5304
145	E3	0	-54.221	966.706	-18.5386	4.7502	5.6054
145	U2 VERT1	0	-52.605	719.892	-13.5765	2.4191	2.3609
145	UN1 VERT1	0	138.574	605.145	-15.9868	0.6912	4.4967
145	U2 MID2	0	-46.512	675.828	-12.8976	0.4389	8.0911
145	U2 MID3	0	-58.062	678.509	-12.7078	-2.9359	15.8487
145	U2 MID4	0	-79.516	786.274	-14.2461	-1.0257	7.4045
145	U2 MID5	0	-69.093	791.596	-14.5638	3.3692	-2.208
145	UN1 MID2	0	149.341	527.277	-14.7872	-2.8081	14.6227
145	UN1 MID3	0	128.931	532.015	-14.4517	-8.7719	28.3313
145	UN1 MID4	0	91.02	722.451	-17.1701	-5.3963	13.4093

Debris Barrier Project number:110773396 Date Printed: 11/1/2019 Page: 4 of 4
Completed by: JH Date completed: 10/24/2019 Reviewed by: BEF Date Reviewed: 10/29/2019

145	UN1 MID5	0	109.439	731.854	-17.7314	2.3701	-3.5771
145	U2 VERT2	0	-49.232	663.082	-12.6141	-1.6087	13.1585
145	U2 VERT3	0	-69.799	721.15	-13.2436	-2.812	14.0345
145	U2 VERT4	0	-81.188	826.992	-14.9647	1.9058	-0.4582
145	UN1 VERT2	0	144.535	504.753	-14.2861	-6.4265	23.5773
145	UN1 VERT3	0	108.19	607.367	-15.3985	-8.5528	25.1254
145	UN1 VERT4	0	88.064	794.403	-18.44	-0.2159	-0.4851
145	E3-Service	0	-65.68	858.72	-15.9903	4.3767	5.6221
145	E2-service	0	-65.68	858.72	-15.9903	4.3767	5.6221
145	UN2-service	0	-164.086	780.642	-11.8187	4.6659	5.8635
145	UN1-VERT1_service	0	92.266	420.178	-11.0104	0.4548	2.9783
145	DEAD_SERVICE	0	-0.698	100.488	-2.1152	-0.0357	-0.117

	Factored Loads					
MIN	0	-258.547	-81.151	-18.627	-8.7719	-28.9197
MAX	0	151.363	1154.416	-2.1147	8.9378	28.3313
LOAD CASE MIN	U1x	UN2	U145_NEG	E2	UN1 MID3	UN1 MID3
LOAD CASE MAX	U1x	U1y_NEG	UN2	DEAD_SER	UN1 MID3	UN1 MID3
JOINT LOCATION MIN	136	139	136	136	145	136
JOINT LOCATION MAX	136	136	136	136	136	145

	Service Loads					
MIN		-172.463	365.326	-16.0725	-4.6662	-5.6907
MAX		92.266	864.158	-9.8839	4.6659	11.3951

LOAD CASE MIN		UN2-servic	UN1-VERT1_service
LOAD CASE MAX		UN1-VERT1	E2-service
JOINT LOCATION MIN		UN2-servic	UN1-VERT1_service
JOINT LOCATION MAX		UN1-VERT1	E2-service

Completed by: JH on 10/29/2019
Reviewed by: BEF on 10/29/2019

CONCLUSION

All calculations were based on the loading shown on the first part of this package.

Based on the calculations presented as well as the SAP2000 model results, the structure designed is able to sustain the loads included.

Stantec Consulting Ltd.

Jacqueline Caverzan Hunter P.Eng., B.Eng., C.E.T.
Structural Engineer
Phone: 204928 8693
jacqueline.hunter@stantec.com