Springbank Off-Stream Storage Project Preliminary Geotechnical Assessment Report

Volume 4 of 4

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

Prepared by:
Stantec Consulting Services Ltd
Calgary, Alberta

Project No. 110773396

December 8, 2020

Sign-off Sheet

This document entitled "Volume 4, Springbank Off-Stream Storage Project Preliminary Geotechnical Assessment Report," containing Attachments 5 - 14, 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)
Andrew Bayliss, P.Eng, Geotechnical Engineer

Prepared by ______________________________________
(signature)
Chris Jones, PE, Geotechnical Engineer

Prepared by ______________________________________
(signature)
Vince Severance, PE, Geotechnical Engineer

Reviewed by ______________________________________
(signature)
Hugo Aparicio, P.Eng, Geotechnical Engineer

Sign-off Sheet

Authenticated by ________________ 2020-12-09 ________________

(signature)

Dan Back P.Eng., Geotechnical Engineer

Stantec Consulting Ltd.
APEGA Permit Number P258

Validated by ________________ 2020-12-09 ________________

(signature)

Jeff Berg P.Eng., Senior Principal

Revision	Date	Description
0	September 25, 2020	Original Submittal
0-A	December 8, 2020	Re-Issued Rev. 0 to fix electronic display errors and remove Draft marks. No new content or revisions incorporated.

Stantec

ATTACHMENT 5
MATERIAL PROPERTIES DESIGN BASIS MEMO

Stantec

Memo

To:	Syed Abbas Alberta Transportation	From:	Hugo Aparicio/Dan Back Stantec
File:	110773396	Date:	November 20, 2019

Reference: Springbank Off –Stream Reservoir (SR1) – Updated Geotechnical Materials Properties Design Basis Memorandum - Selection of Soil Material Properties

1.0 INTRODUCTION

This document provides a summary of the process followed to select the geotechnical soil parameters to design the Diversion Channel and the earthen embankment Storage Dam. The parameter selection was based on the findings from the recently completed geotechnical and hydrogeological investigations performed at the project site.

1.1 PROJECT OVERVIEW

SR1 is comprised of three primary project components:

1. Diversion Structure with Floodplain Berm;
2. Diversion Channel; and
3. Off-Stream Storage Dam and Reservoir.

The Diversion Structure is located on the main channel and floodplain of the Elbow River upstream of Highway 22. The Floodplain Berm is located on the South floodplain of the Elbow River. The Floodplain Berm constrains flow within the Elbow River active channel and floodplain, and directs flow through the Diversion Structure.

Located on the north bank of the Elbow River, the Diversion Channel connects the Diversion Structure to the Off-stream Storage Reservoir and runs in a north easterly direction passing under Twp. Road 242 and Hwy 22 before discharging into the reservoir. The proposed channel bottom width is 24 m with 3H:1V side slopes. The side slopes are steepened to 2H:1V within the rock cut areas. Channel gradient varies from 0.1 percent to 0.2 percent. The maximum channel depth is 6.4 m. The total channel length is approximately 4,700 m.

The Off-steam Storage Dam and Reservoir are located between Hwy 1 and the Elbow River; and predominantly east of Hwy 22. The Dam Embankment is a zoned earthen structure approximately 4,000 m long with a maximum embankment height of 27 m. The Off-Stream Storage Dam and reservoir area outlets to the Elbow River via an unnamed tributary stream that currently runs through the land which the reservoir will occupy.

1.2 GENERAL SITE GEOLOGY

The SR1 Project Site is underlain by Upper Cretaceous to Tertiary bedrock deposited in the Alberta Foreland Basin and subsequently deformed by the Laromide Orogeny. More specifically, the project site is underlain by three bedrock formations: Brazeau, Coalspur and Paskapoo formations.

The Brazeau Formation subcrops beneath the western portion of the SR1 Project Site. It underlies the Floodplain Berm, Diversion Structure and Diversion Channel between approximate Stations 10+000 and 13+200 m. The dominant lithology is mudstone, siltstone and fine-grained sandstone. Coaly shale and coal beds are common.

The Coalspur Formation subcrops beneath the Diversion Channel between Stations 13+200 and 14+700 m, the Emergency Spillway, Diversion Channel Outlet, the west Dam abutment and western portion of the Dam footprint between approximate Stations 20+000 to Station 21+400 m. The Coalspur Formation consists of a sequence of inter-bedded mudstone, siltstone and fine-grained sandstone with subordinate coarser grained sandstone layers and channel lag deposits.

The Paskapoo Formation subcrops beneath the east dam abutment, the eastern portion of the dam footprint between approximate Stations 21+400 and 24+000 m, the LLOW and the Reservoir. The Paskapoo is comprised of an inter-bedded non-marine sandstone, siltstone and mudstone with minor amounts of bentonite and coal.

Generalized stratigraphy for the project site is shown in Figure 1.

Reference: Springbank Off –Stream Reservoir (SR1) – Updated Geotechnical Materials Properties Design Basis Memorandum

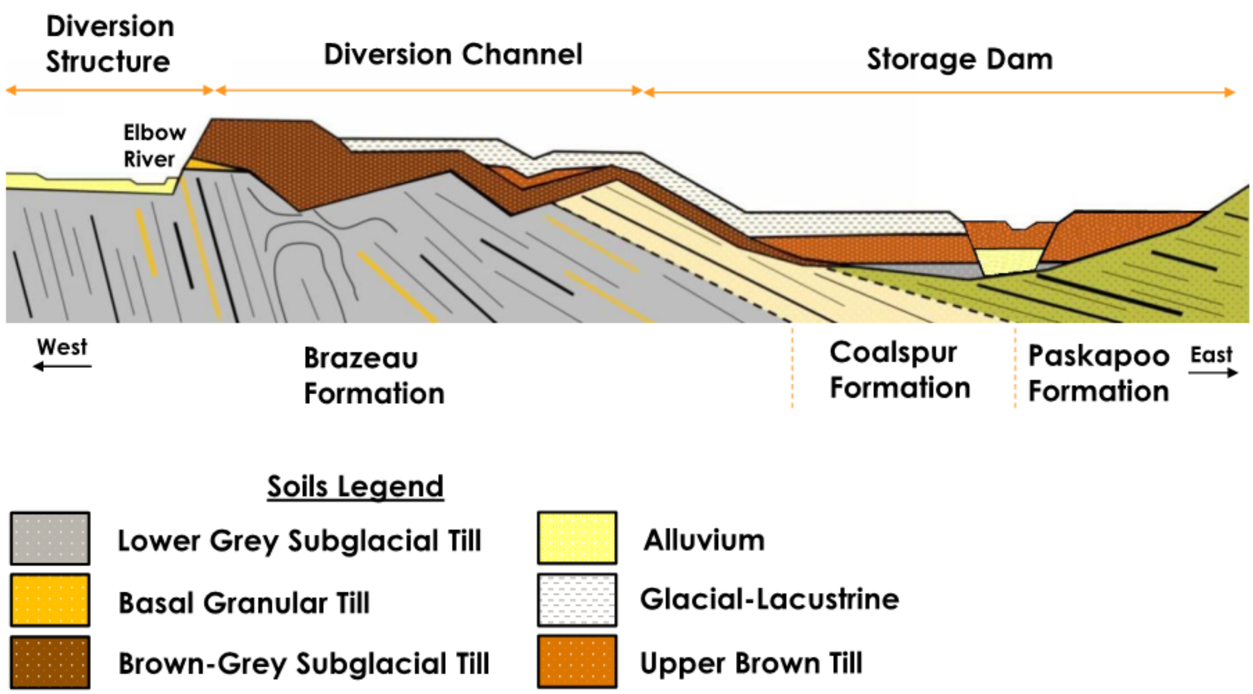


Figure 1. Generalized Site Stratigraphy

1.3 GENERAL SOIL CHARACTERIZATION

The soils characterized across the project site generally consist of alluvium, colluvium, and glaciogenic units. Alluvium was observed within the Elbow River valley along the Floodplain Berm alignment and diversion structure location and fluvial deposits were encountered within the valley of the Unnamed Creek along the Storage Dam alignment. Colluvium associated with landslides and eroded steep slopes was observed along the natural slopes of the Elbow River. Most of the soils across the Diversion Channel and Storage Dam alignments are glaciogenic soil units consisting of glacial lacustrine clays and silts of moderate to high plasticity and glacial till clays, silts, and sands of low plasticity.

The overall project site was divided into 13 different geographical zones for soil characterization purposes as discussed in Section 2.0 of this memo. The average soil thickness of the predominant glaciogenic soil units (lacustrine and till) was evaluated for each zone. This is presented in Figure 2 and Figure 3.

Reference: Springbank Off –Stream Reservoir (SR1) – Updated Geotechnical Materials Properties Design Basis Memorandum

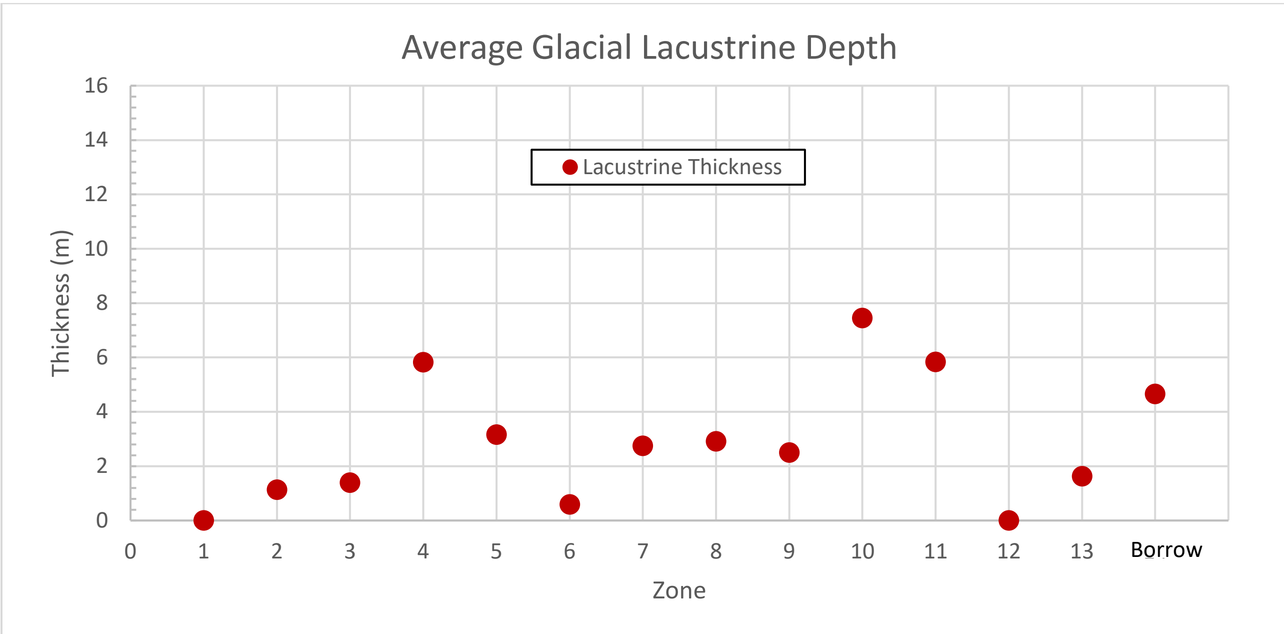


Figure 2. Average Soil Thickness – Glacial Lacustrine

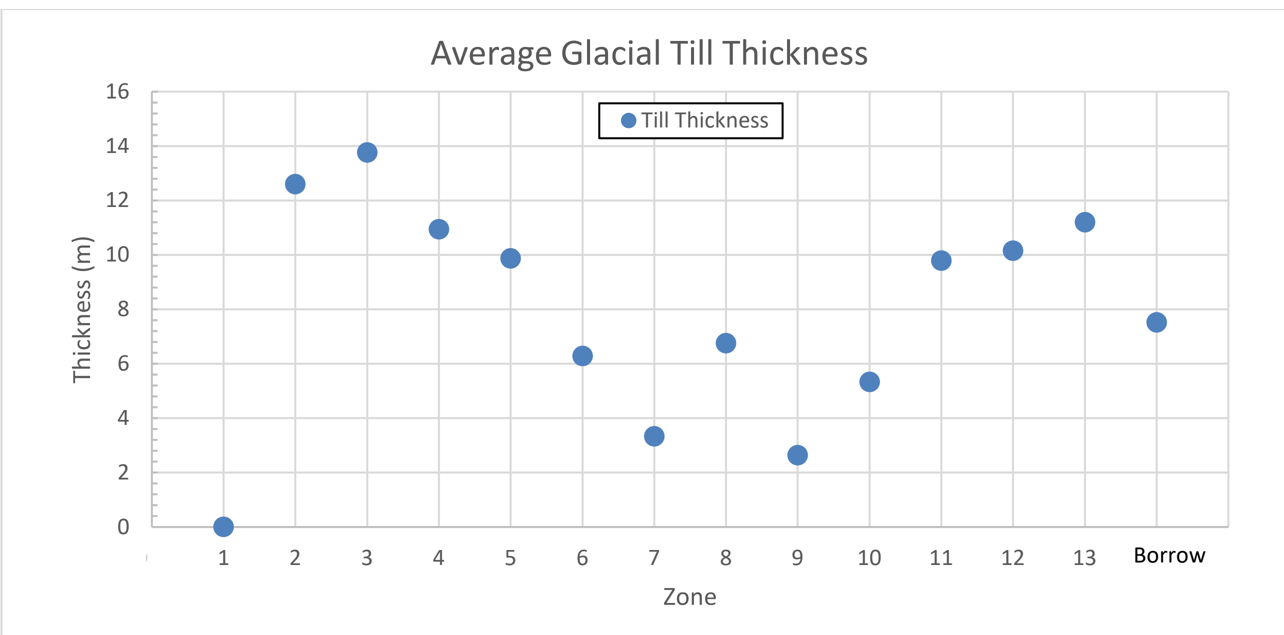


Figure 3. Average Soil Thickness – Glacial Till

2.0 EMBANKMENT AND FOUNDATION SOIL PROPERTIES

The initial field exploration was performed between March 21 and August 25, 2016. A total of 41 borings and 26 CPT soundings were completed within the footprint of the Storage Dam. In addition, 38 borings and 3 CPT soundings were completed along the Diversion Channel, five borings were completed at the potential borrow site, and 15 borings were drilled at the diversion structure/Floodplain Berm. The field activities consisted of advancing auger borings, sonic borings, and CPT borings. At certain locations, both CPT and auger borings were advanced near each other to calibrate CPT results. Boring logs, laboratory testing, and CPT data were reviewed to develop soil horizons and soil material properties. The field exploration information is included in Stantec's Geotechnical Investigation Report (Stantec 2016).

A supplemental field exploration was performed in 2018. The fieldwork was completed in two (2) mobilizations. The first mobilization was between April 21 and May 9, 2018. The first mobilization consisted of three (3) boreholes within the Elbow River (DB1 to DB3) for the proposed Debris Barrier and 11 boreholes and 6 Seismic Cone Penetration Test soundings within the dam footprint to assess proposed Low-Level Outlet alignment options. The second mobilization was between September 24 and October 31, 2018. The second mobilization consisted of four (4) boreholes to further characterize the glaciolacustrine and glacial till units within the dam footprint, two (2) boreholes to assess an alternate LLO alignment as requested by Alberta Environment and Parks (AEP), and 14 test pits and trenches throughout the dam footprint. Delays were encountered during the second mobilization fieldwork due to inclement weather which required demobilization of the test-pitting excavator on October 4, 2018 and re-mobilizing on October 29, 2018. The supplemental field exploration information is included in Stantec's Geotechnical Investigation Report (Stantec 2018). Data from the borings were used to characterize the subsurface materials along the Diversion Channel, Floodplain Berm, and dam sites. Soil samples from the Diversion Channel and borrow site boring locations were used to characterize the planned embankment materials, assuming the excavated soils will be used to construct the dam. These disturbed samples from the Diversion Channel were used to remold and test specimens in the laboratory to determine representative embankment properties.

The overall project site was divided into 13 different geographical zones for characterization purposes. The zone locations are shown on the plan view in Attachment 1. Borings and laboratory test results were organized by zone for the different soil types to determine soil parameters for use in the analyses. The footprints of the Floodplain Berm and Diversion Structure were designated as Zones 1 and 2, respectively. The footprint of the Diversion Channel was divided into six zones (Zones 3 through 8) and the footprint of the Storage Dam was divided into five zones (Zones 9 through 13). The Diversion Channel and borrow site borings were reviewed to determine characteristics for the material to be used to construct the Storage Dam. Below is a summary of the soil classifications determined within each of the 13 project zones.

As described by the general soil characterization described before, two predominant soils were encountered at the project site: glacial lacustrine and glacial till. The glacial lacustrine was typically encountered as olive brown to brown, medium to high-plastic, clay and silt. The glacial till was typically encountered as dark brown to grey, sandy, silty clay with variable gravel content.

Design soil parameters were selected for the seepage and stability analyses of the embankment dam and the Diversion Channel based on the laboratory test results and the field exploration data. Rock parameters were selected for Diversion Channel slope stability based on both laboratory test results and field observations of the rock mass.

2.1 SOIL CLASSIFICATIONS

Soil classifications were determined by the Unified Soil Classification System (USCS) (ASTM D2487) from laboratory testing consisting of Atterberg limits testing (ASTM D4318) and hydrometer grainsize analyses (ASTM D422). A summary of the USCS soil classifications determined for glacial lacustrine soil samples obtained in the different project zones is presented in Table 1.

Table 1. Summary of Glacial Lacustrine USCS Soil Classifications Grouped by Project Zone

Feature	Zone	Borings	Number of USCS Classifications	USCS Classifications
Floodplain Berm	1	FB3 thru FB7	0	No GL Soils
Diversion Structure	2	DS1 thru DS9	1	CL (1)
Diversion Channel	3	DC1 thru DC12	3	CH (2) CL (1)
	4	H10 thru H13	4	CH (1) CL (3)
	5	DC13 thru DC17	7	CH (7)
	6	H1 thru H4	1	CH (1)
	7	DC19 – DC24	8	CH (8)
	8	DC25 thru DC34	10	CH (8) CL (2)
Storage Dam	9	D1 thru D9	8	CH (7) CL (1)
	10	D10 thru D25	29	CH (26) CL (3)

Feature	Zone	Borings	Number of USCS Classifications	USCS Classifications
	11	D26 thru D40, D42, D57 thru D63 GL1 thru GL4 LLO01 thru LLO06, LLO17 thru LLO18	57	CH (22) CL (34) SC (1)
	12	D41 thru D50 LLO06 thru LLO07	0	No GL Soils
	13	D51 thru D52 LLO09 thru LLO16	4	CH (3) CL (1)
	Borrow	BS1 thru BS5	16	CH (6) CL (10)
	Geo Wells	GW1 thru GW11	16	CH (10) CL (6)
Total Site			164	CH (101) CL (62) SC (1)

Approximately 62 percent of the glacial lacustrine soil samples classified as CH (Clay of High plasticity) and 38 percent classified as CL (Clay of Low plasticity). The spatial distribution of glacial lacustrine CH and CL soil classifications is presented graphically in Figure 4.

Reference: Springbank Off –Stream Reservoir (SR1) – Updated Geotechnical Materials Properties Design Basis Memorandum

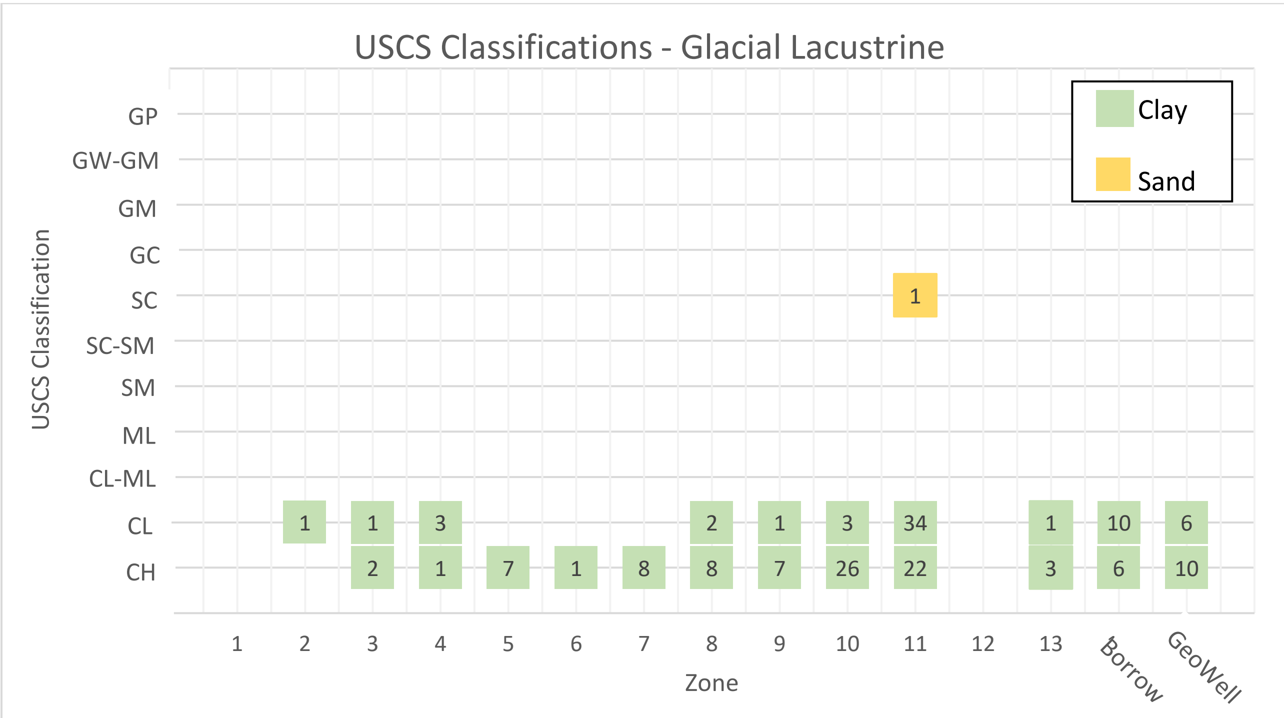


Figure 4. Spatial Distribution of Glacial Lacustrine USCS Soil Classifications

USCS soil classifications determined for glacial till soils from samples obtained from the different project zones are summarized in Table 2.

Table 2. Summary of Glacial Till USCS Soil Classifications Grouped by Project Zone

Feature	Zone	Borings	Number of USCS Classifications	USCS Classifications
Floodplain Berm	1	FB3 thru FB7	0	No GT Soils
Diversion Structure	2	DS1 thru DS9	9	CL (8) GM (1) *
Diversion Channel	3	DC1 thru DC12	42	CL (38) GM (2) * GC (1) * SC (1) *
	4	H10 thru H13	5	CL (5)
	5	DC13 thru DC17	12	CL (7) CL-ML (2) ML (1) SC-SM (1) SC (1)

Reference: Springbank Off –Stream Reservoir (SR1) – Updated Geotechnical Materials Properties Design Basis Memorandum

Feature	Zone	Borings	Number of USCS Classifications	USCS Classifications
	6	H1 thru H4	6	CL (4) ML (1) SC (1)
	7	DC19 – DC24	7	CL (4) CL-ML (2) SC (1)
	8	DC25 thru DC34	18	CL (15) CL-ML (2) GC (1) *
Storage Dam	9	D1 thru D9	8	CL (7) CL-ML (1)
	10	D10 thru D24	23	CL (21) CL-ML (1) GC (1) *
	11	D26 thru D40, D42, D57 thru D63 GL1 thru GL4 LLO01 thru LLO06, LLO17 thru LLO18	38	CL (32) CL-ML (1) ML (2) SC (1) GW (2) *
	12	D41 thru D50 LLO06 thru LLO07	24	CL (14) SC (1) SM (1) GC (2)* GW (2)* GW-GM (1)* GM (3)*
	13	D51 thru D52 LLO09 thru LLO16	6	CL (6)
	Borrow	BS1 thru BS5	14	CL (14)
	Geo Wells	GW1 thru GW11	15	CL (14) CL-ML (1)
Total Site			227	CL (189) CL-ML (10) ML (4) SC-SM (1) SC (6)* SM(1) GC (5)* GM (6)* GW-GM (1) GW(4)*

*Basal Sand/Gravel Till Layer

The spatial distribution of the glacial till USCS soil classifications is presented graphically in Figure 5.

Reference: Springbank Off –Stream Reservoir (SR1) – Updated Geotechnical Materials Properties Design Basis Memorandum

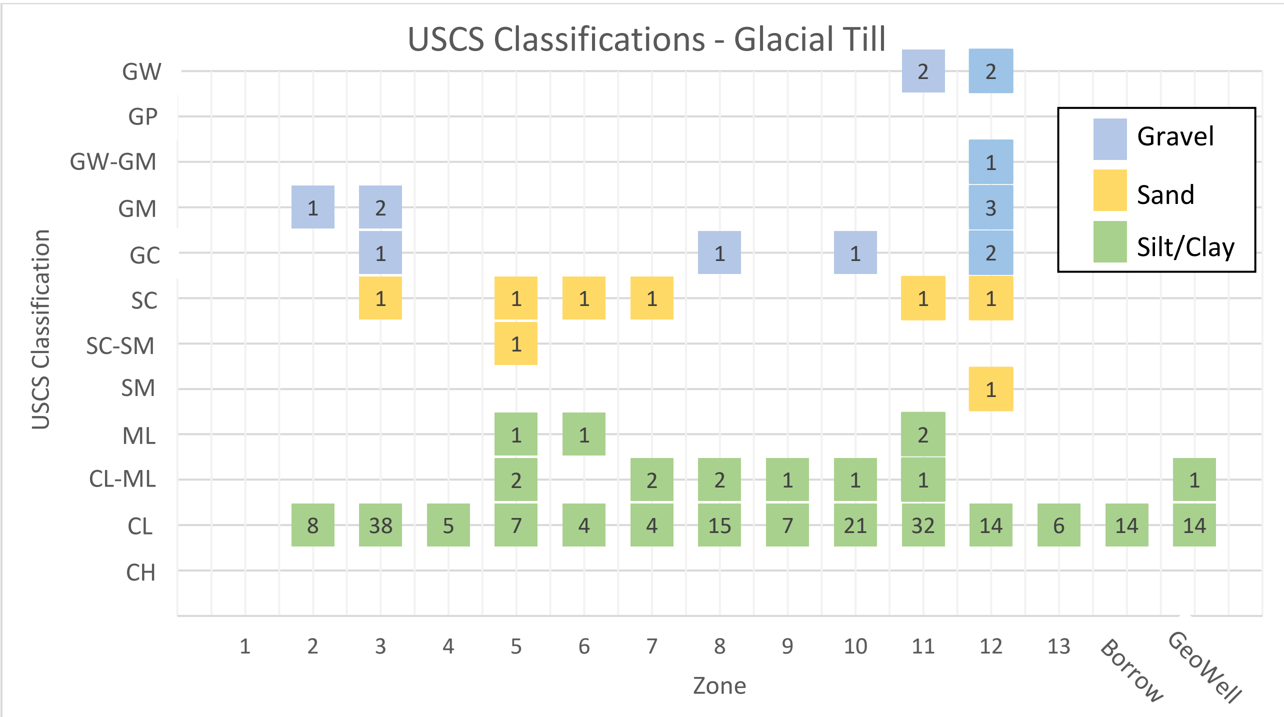


Figure 5. Spatial Distribution of Glacial Till USCS Soil Classifications

USCS soil classifications determined for alluvial soils encountered along the Floodplain Berm alignment are summarized in Table 3. The spatial distribution of the alluvial USCS soil classifications is presented graphically in Figure 6.

Table 3. Summary of Alluvial Soil USCS Soil Classifications

Feature	Zone	Borings	Number of USCS Classifications	USCS Classifications	
Floodplain Berm	1	FB3 thru FB7	4 (Alluvial)	GW-GM (2)	GP (2)

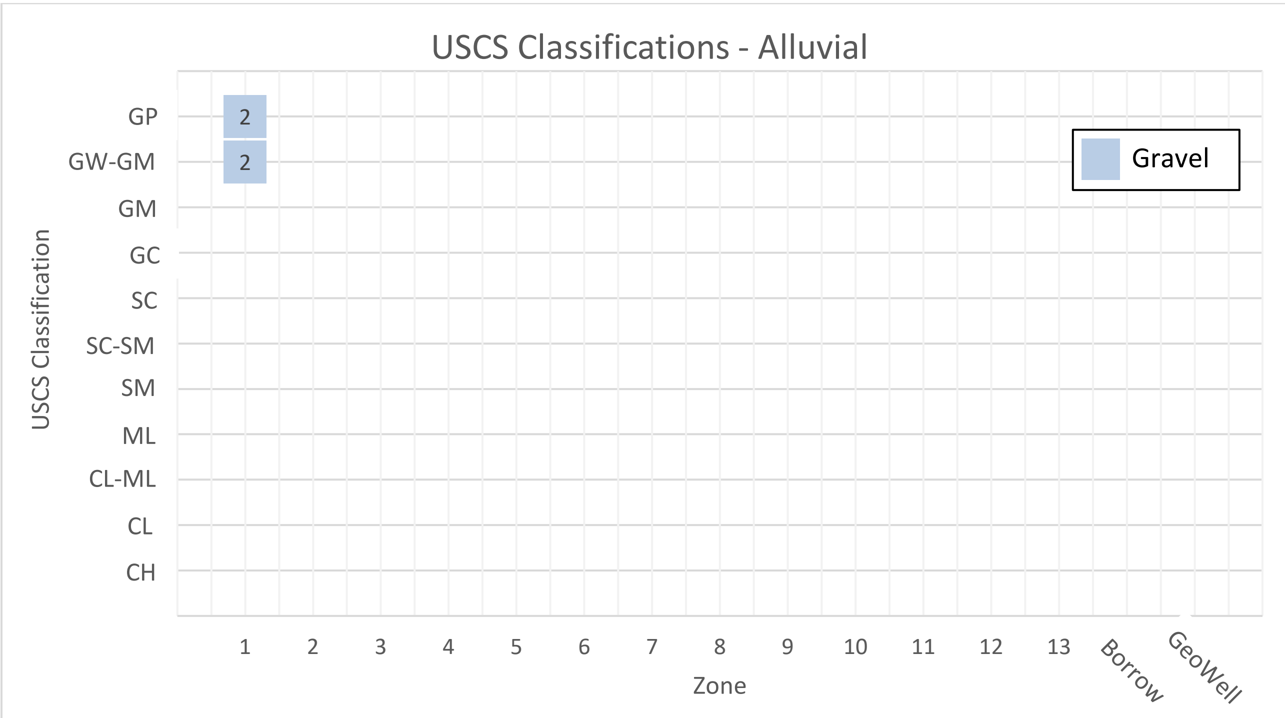


Figure 6. Spatial Distribution of Fluvial and Alluvial USCS Soil Classifications

The subsurface soils are comprised of glaciogenic units consisting mostly of glacial lacustrine and glacial till soils. The following is a detailed description of each soil unit and project location.

- Glacial lacustrine (GL), which is described as an olive green to brown, intermediate to high plasticity, lean to fat CLAY. Particle size distribution testing indicated that the GL is typically comprised of between 50 and 70 % clay sized particles and 30 to 50 % silt sized particles. The GL deposits within the first quarter section of the Drainage Channel (Zone 3) range from zero to 3 meters in thickness, and not present within half of the borings. In the remainder of the Diversion Channel (Zones 4 through 8), the GL ranged continuously from 2 to 5 meters in thickness with an exception along a ridge near Station 14+000 where no GL was present. The thickness of the GL typically ranges from 2 to 6 meters at the western end of the dam (from approximate Station 20+300 to 21+800) and toward the eastern end of the dam (from Station 22+700 to 23+200). In the center of the dam from Station 21+800 to Station 22+700, the GL is thicker, ranging from 8 to 15 meters in thickness. The GL is not present in the vicinity of the unnamed creek which crosses the dam site near Station 23+200. Isolated layers of GL are present east of the unnamed creek. Glacial till (GT), which is described as brown to grey, low to intermediate plasticity, lean CLAY with sand and gravel. There is large variability and inconsistency in the thickness of the GT layer. The thickness of the GT within the upstream half of the Diversion Channel (Zones 3 through 5) typically ranges from 9 to 20 meters. In the downstream half of the Diversion Channel (Zones 7 and 8), the GL ranges continuously from 2 to 9 meters. Within the Storage Dam footprint, the thickness ranges from 1 to 15 meters with the thickest layers generally in the center portion of the Storage Dam (from Station 22+100 to 23+000).

- Alluvial sand and gravely soils were encountered within the Floodplain Berm borings (FB3 through FB7). The fluvial sand was described as dense, dark brown to brown, silty sand. The fluvial gravel was described as very dense, brown, gray and black, well graded to poorly graded gravel with silt and sand. The thickness of the fluvial soils ranges from 3 to 4 meters along the Floodplain Berm alignment.

- Alluvial sand and gravel soils were encountered in the low-lying area of the unnamed creek near Station 23+200 of the Storage Dam. The alluvial sand was described as dense, brown, clayey sand with gravel and silty sand with gravel. The alluvial gravel was described as very dense, clayey and silty gravel with sand. The thickness of the alluvial soils ranges from 1 to 7 meters in the area of the unnamed creek.

2.2 UNIT WEIGHT

2.2.1 Data

Unit weight values were determined (ASTM D2167) for 88 undisturbed GT and GL samples. A summary of the insitu dry and moist unit weight values is presented in Figure 7 and 8. The spatial distribution of insitu moist unit weight values for both undisturbed GL and GT soil samples are summarized in Figure 9 and Figure 10, respectively.

Reference: Springbank Off –Stream Reservoir (SR1) – Updated Geotechnical Materials Properties Design Basis Memorandum

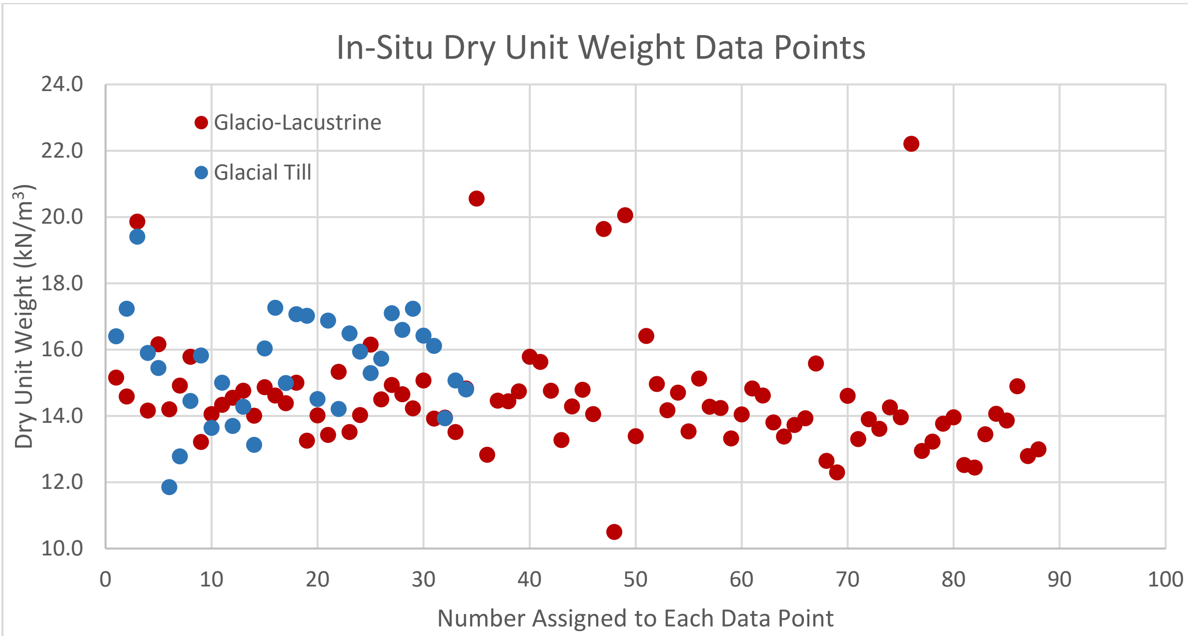


Figure 7. Project Wide Dry Unit Weight Values – GT and GL

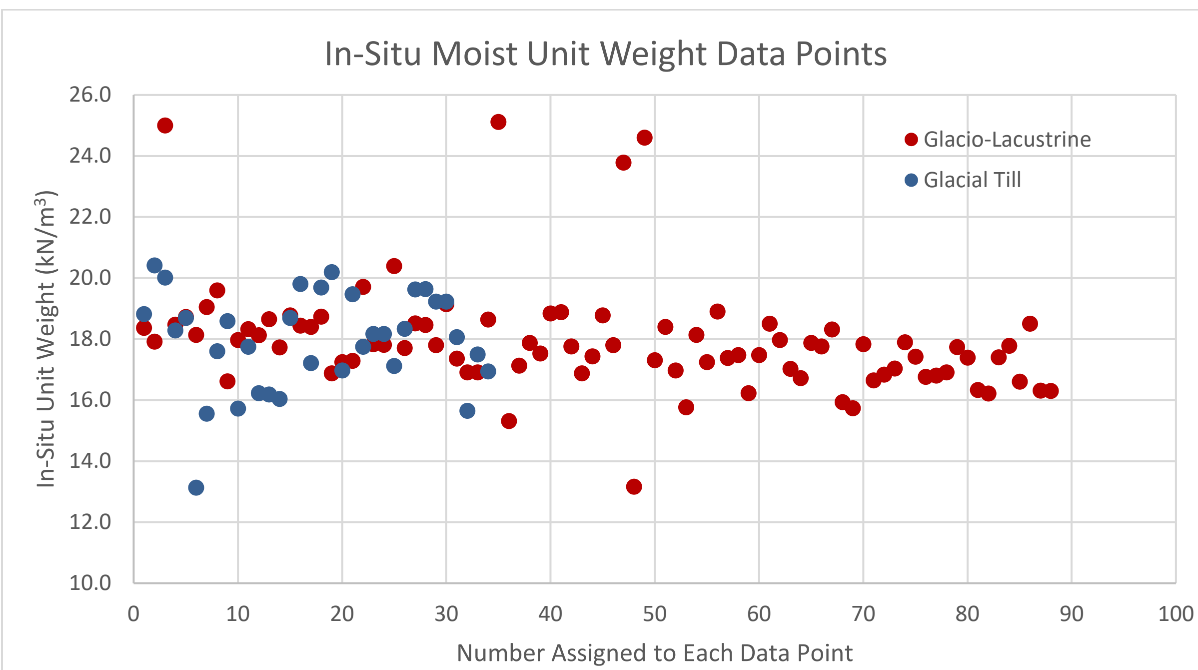


Figure 8. Project Wide In-Situ Unit Weight Values – GT and GL

Reference: Springbank Off –Stream Reservoir (SR1) – Updated Geotechnical Materials Properties Design Basis Memorandum

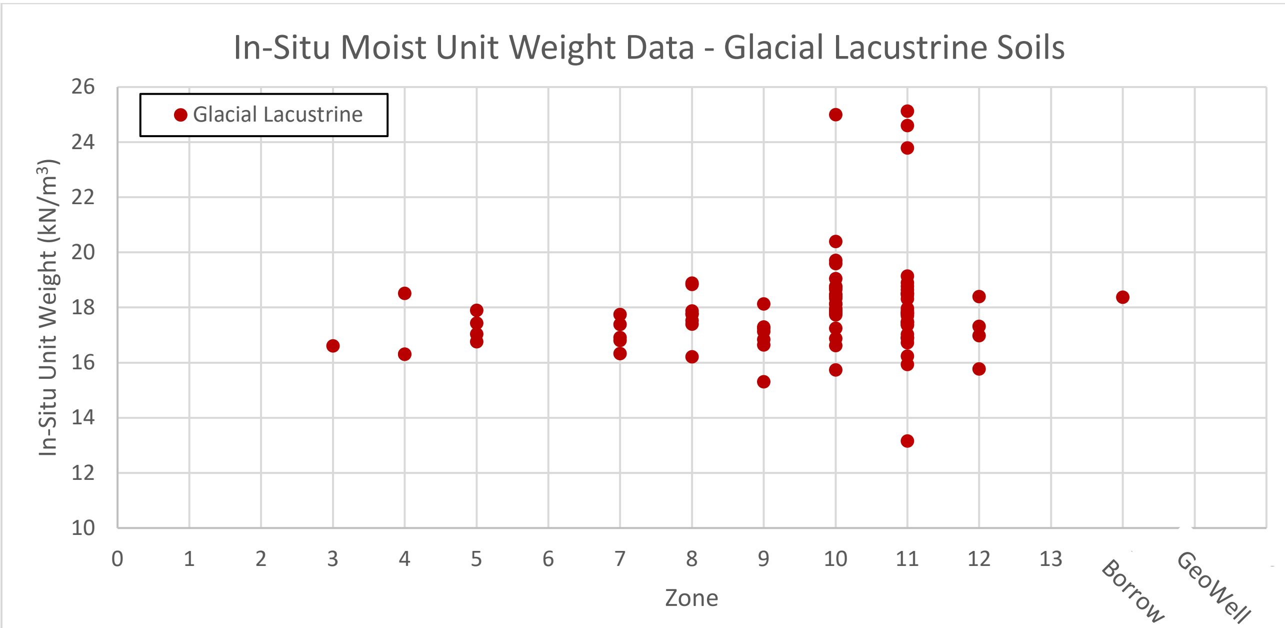


Figure 9. Spatial Distribution of Unit Weight Values – Glacial Lacustrine

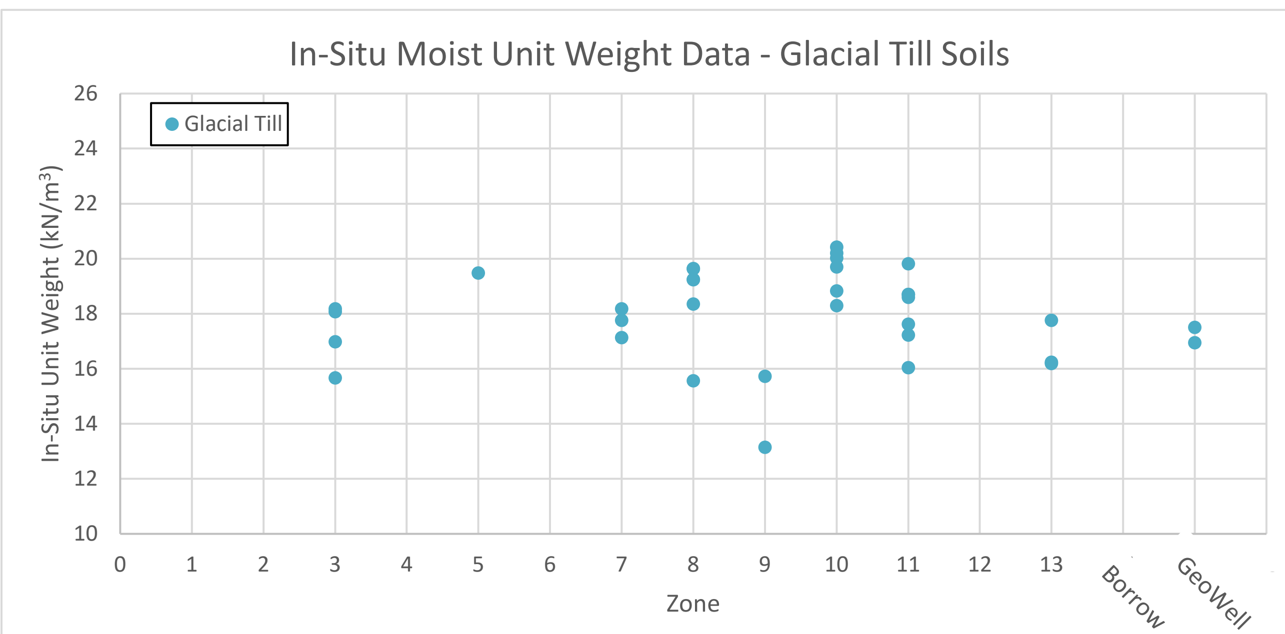


Figure 10. Spatial Distribution of Unit Weight Values – Glacial Till

Reference: Springbank Off –Stream Reservoir (SR1) – Updated Geotechnical Materials Properties Design Basis Memorandum

Standard Proctor moisture-density tests (ASTM D698) were performed on nine (9) disturbed GL bag samples and 24 disturbed GT samples. Maximum dry unit weight values obtained from standard Proctor tests are presented in Figure 11. Estimated embankment unit weight values for GL and GT samples compacted to 98 percent of standard proctor density are presented in Figure 12.

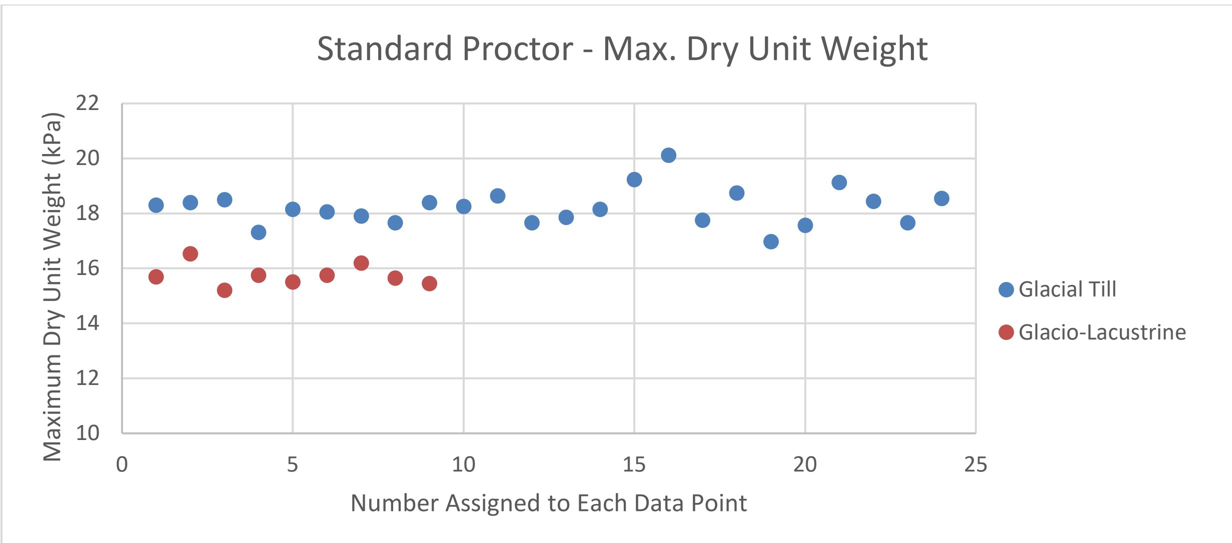


Figure 11. Standard Proctor – Maximum Dry Unit Weight

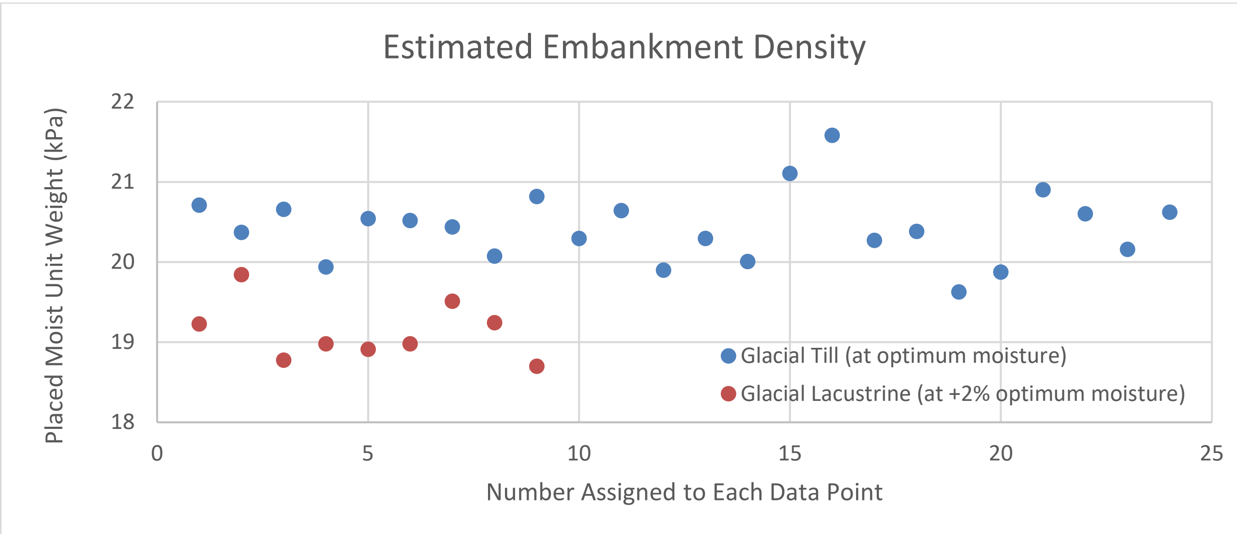


Figure 12. Estimated Embankment Density – 98% Proctor

2.2.2 Selected Parameters

Unit weights for in-situ soils were selected based on average results of laboratory testing and typical values from published sources. For the glacial lacustrine and glacial till soils, average laboratory unit weight test results were used to select the in-situ unit weight of 18 kN/m3 for both soils.

For the embankment sand drain and alluvial gravel material, typical values from Table 6 "Typical Values of Soil Index Properties" of NAVFAC DM 7.1 were selected. The embankment sand drain was assumed to be a relatively dense, clean uniform sand yielding a wet unit weight of approximately 21 kN/m3. The alluvial gravel was assumed to be a relatively dense, silty sand and gravel yielding a wet unit weight of approximately 22 kN/m3.

For the Storage Dam embankment materials, unit weights were selected using the moisture-density laboratory test results and specified compaction requirements. Assuming the material is placed to 98% maximum dry density at +2% optimum moisture for the glacial lacustrine soil and at optimum moisture for the glacial till soil, average wet densities from the results of the laboratory tests were calculated.

For weathered bedrock, the unit weight was assumed equal to the sand drain material. A summary of the selected unit weight values is presented in Table 4.

Table 4. Soil Density and Strength Parameters

Material Name	Unit Weight (kN/m^3)
Embankment Shell	20
Embankment Core	20
Sand Drain	21
Glacial Lacustrine	18
Glacial Till	18
Gravel	22
Weathered Bedrock	21

2.3 MOISTURE CONTENT

Project wide natural moisture content values from laboratory test results were reviewed. In-situ moisture content were reviewed and compared to optimum moisture content from the standard Proctor moisture-density lab testing. This data was reviewed for constructability purposes. Plots for glacial lacustrine and glacial till soil sample natural moisture content are included in Figure 13 and Figure 14.

Reference: Springbank Off –Stream Reservoir (SR1) – Updated Geotechnical Materials Properties Design Basis Memorandum

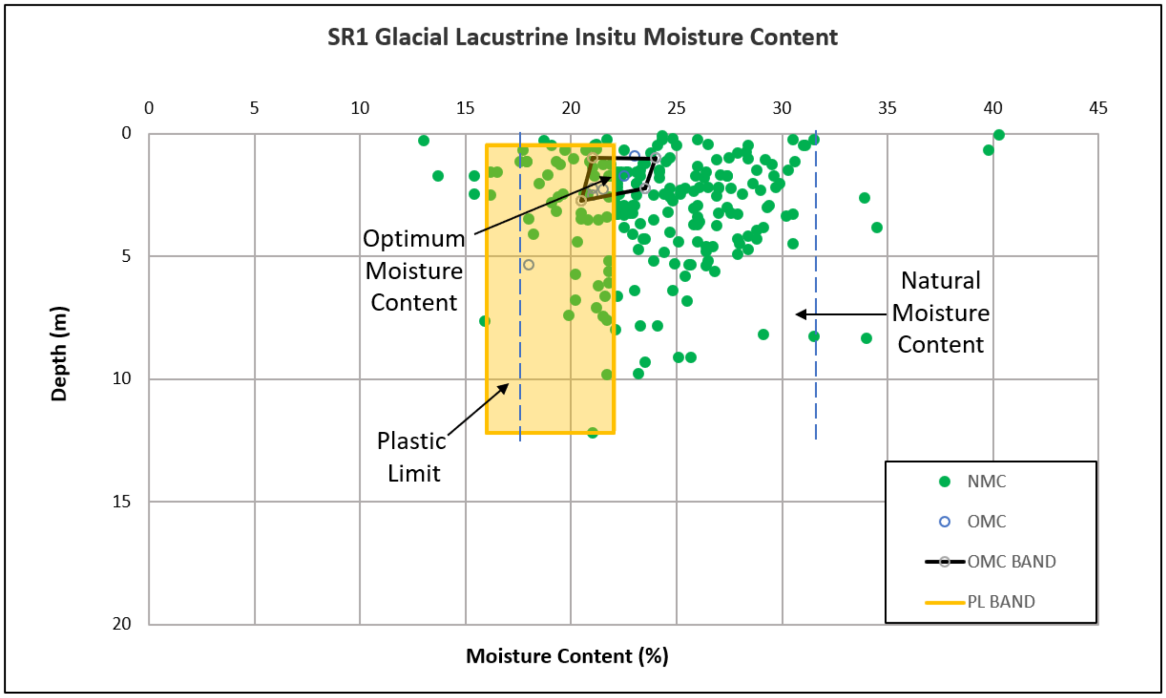


Figure 13. Glacial Lacustrine Natural Moisture Content

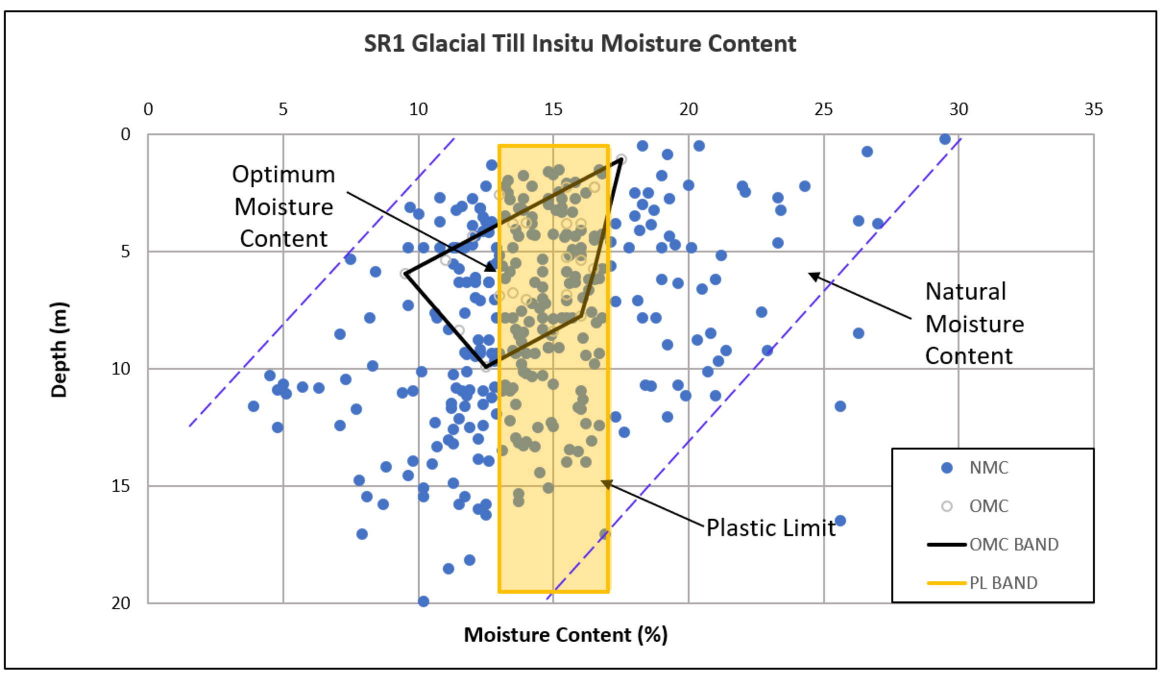


Figure 14. Glacial Till Natural Moisture Content

2.4 PERMEABILITY

2.4.1 Data

A total of 36 falling head permeability tests (ASTM D5084) were performed on undisturbed and remolded GL and GT soil samples. The test results were reviewed and summarized by zone and by soil type, and geometric means of the test results were calculated for each zone. Additionally, eight CPT field dissipation tests were reviewed to evaluate the horizontal hydraulic conductivity of the two predominant soil types.

The results of 17 falling head permeability tests performed on undisturbed and remolded GL soil samples are summarized in Table 5. The results of the four CPT field dissipation tests performed in GL are summarized in Table 6.

Table 5. Summary of Permeability Values from Laboratory Testing – Glacial Lacustrine

Zone	Sample Type	Number of Falling Head Permeability Tests	Geometric Mean k_v (m/sec)
5	Remolded	1	1.10E-10
7	Undisturbed	1	1.90E-10
8	Undisturbed	1	7.70E-10
10	Undisturbed	3	2.00E-10
11	Undisturbed	6	3.42E-10
12	Undisturbed	2	1.80E-10
Borrow	Remolded	2	7.14E-10
Geohydro Well	Undisturbed	1	3.20E-10
Total Site	Undisturbed	14	3.07E-10
	Remolded	3	5.12E-10

Table 6. Summary of CPT Pore Pressure Dissipation Tests – Glacial Lacustrine

Zone	Number of CPT Pore Pressure Dissipation Tests	Geometric Mean k_h (m/sec)
8	1	1.24E-9
11	3	1.46E-10
Total Site	4	2.49E-10

The range of permeability values obtained from undisturbed and remolded GL soil samples from different project zones is presented graphically in Figure 15 and Figure 16.

Reference: Springbank Off –Stream Reservoir (SR1) – Updated Geotechnical Materials Properties Design Basis Memorandum

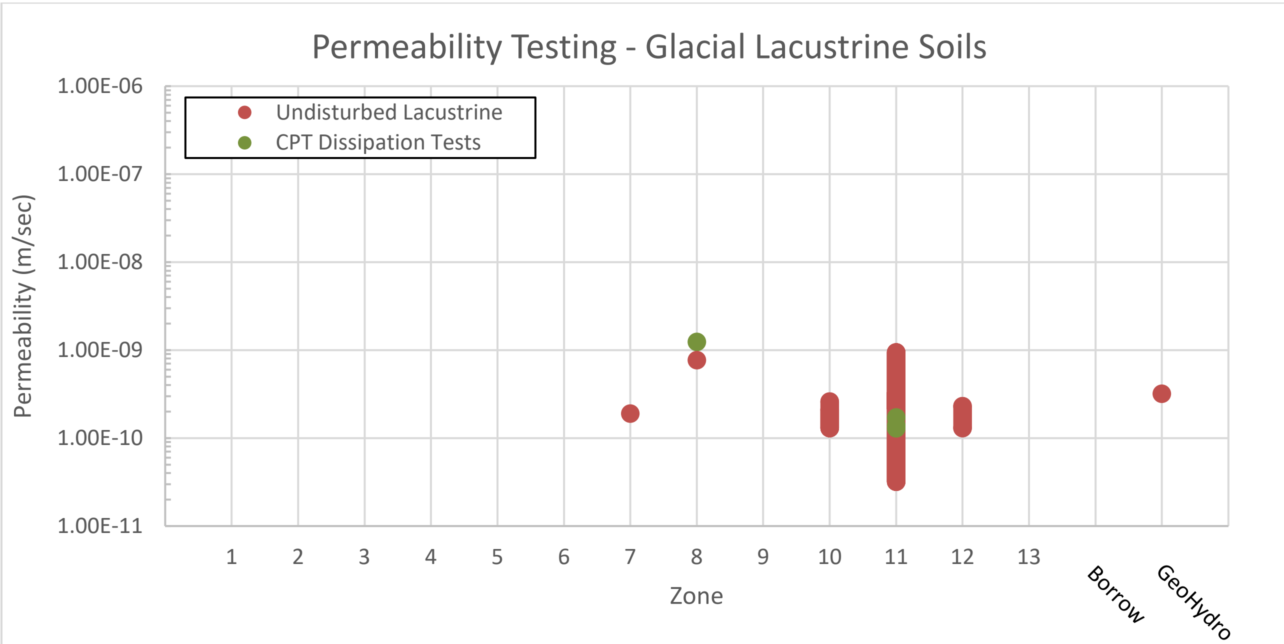


Figure 15. Spatial Distribution of Undisturbed Glacial Lacustrine Permeability Test Results

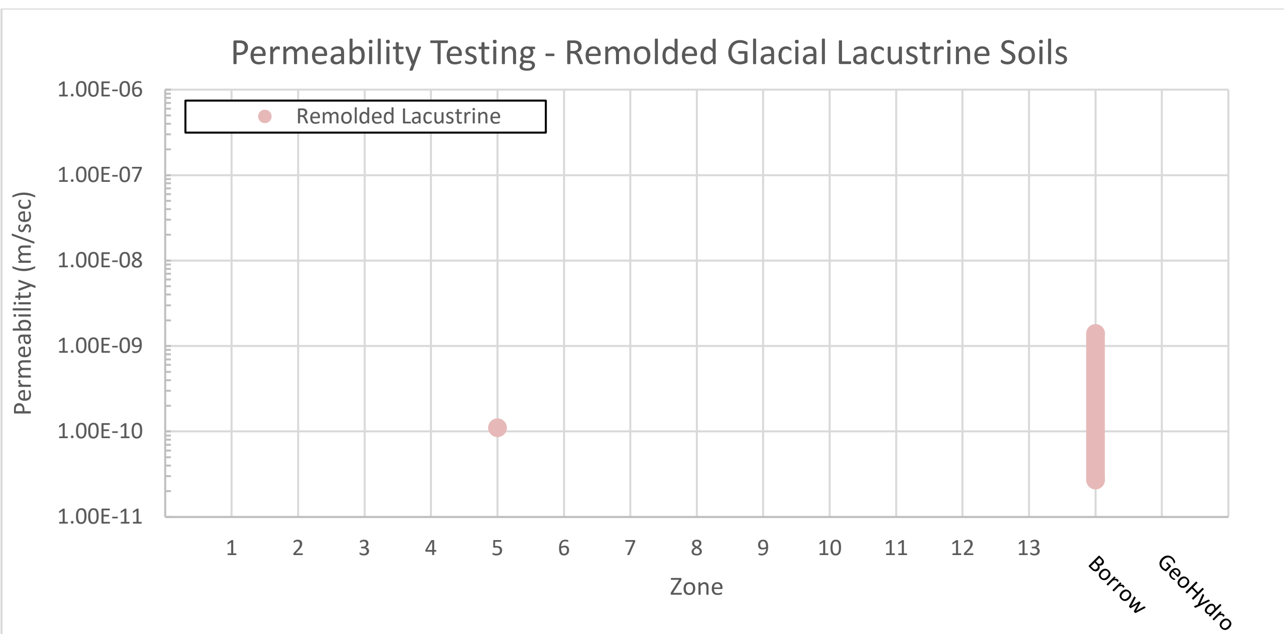


Figure 16. Spatial Distribution of Remolded Glacial Lacustrine Permeability Test Results

Reference: Springbank Off –Stream Reservoir (SR1) – Updated Geotechnical Materials Properties Design Basis Memorandum

The results of 19 falling head permeability tests performed on undisturbed and remolded GT soil samples are summarized in Table 7. The results of the four CPT field dissipation tests performed in GT soil are summarized in Table 68.

Table 7. Summary of Permeability Values from Laboratory Testing – Glacial Till

Zone	Sample Type	Number of Falling Head Permeability Tests	Geometric Mean k_v (m/sec)
3	Undisturbed	3	2.00E-10
	Remolded	4	1.17E-10
4	Remolded	2	4.42E-10
5	Remolded	1	1.50E-9
7	Undisturbed	1	7.70E-10
8	Remolded	1	8.90E-11
9	Undisturbed	1	3.50E-10
10	Undisturbed	1	4.50E-11
11	Remolded	2	6.05E-11
12	Remolded	1	5.10E-10
	Undisturbed	1	5.80E-11
Borrow	Remolded	1	1.00E-9
Total Site	Undisturbed	7	2.61E-10
	Remolded	12	3.81E-10

Table 8. Summary of CPT Pore Pressure Dissipation Tests – Glacial Till

Zone	Number of CPT Pore Pressure Dissipation Tests	Geometric Mean k_h (m/sec)
8	3	2.59E-8
11	1	3.03E-10
Total Site	4	8.51E-9

The range of permeability values obtained from undisturbed and remolded GT soil samples and CPT dissipation field tests from each project zone is presented graphically in Figure 17 and Figure 18.

Reference: Springbank Off –Stream Reservoir (SR1) – Updated Geotechnical Materials Properties Design Basis Memorandum

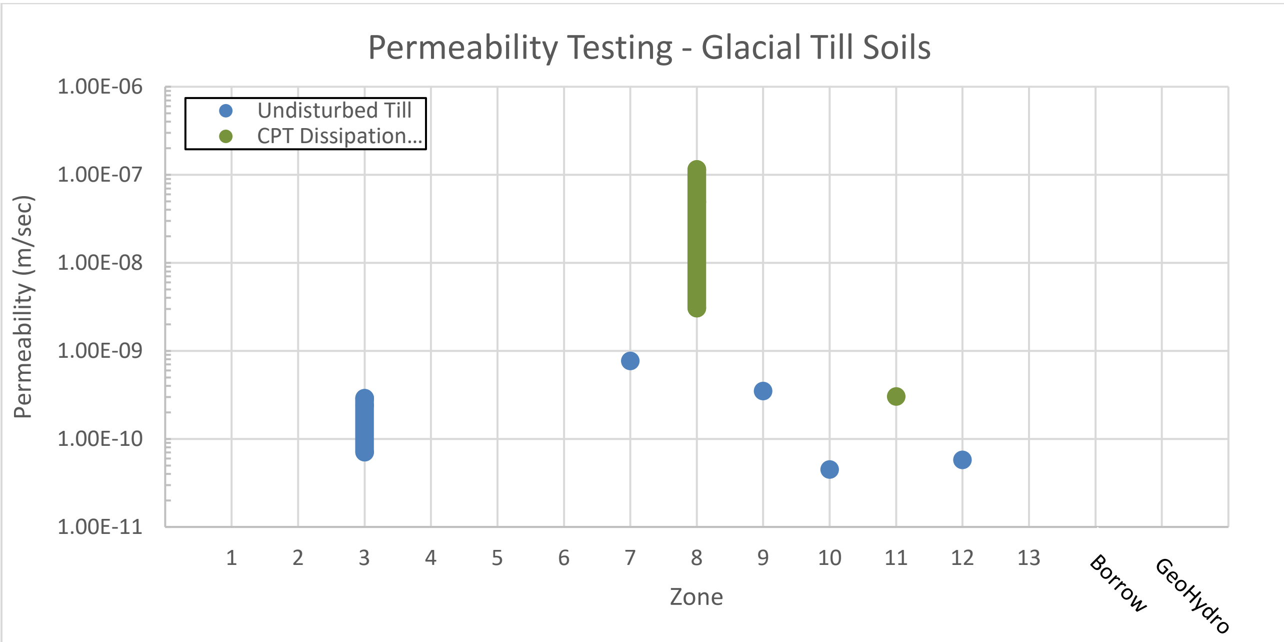


Figure 17. Spatial Distribution of Undisturbed Glacial Till Permeability Test Results

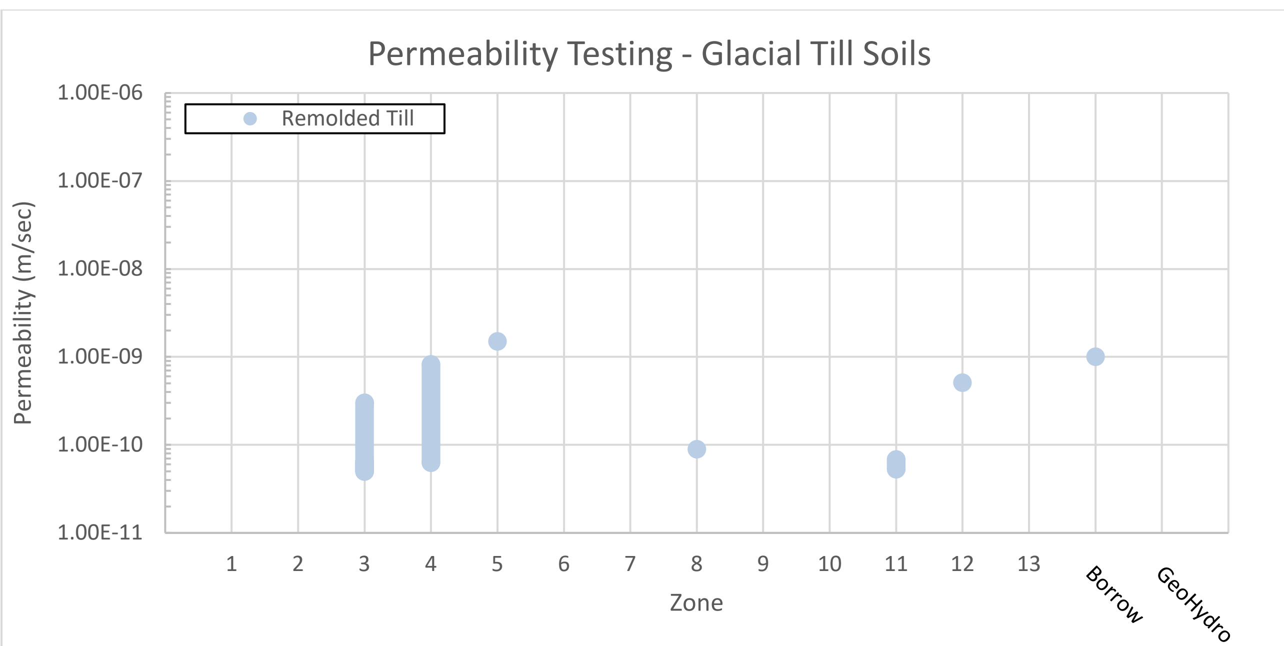


Figure 18. Spatial Distribution of Remolded Glacial Till Permeability Test Results

2.4.2 Selected Parameters

The laboratory falling head test results and the CPT data were used in selecting permeability values for seepage analyses. The permeability parameters selected for the analyses are presented in Table 9.

Table 9. Saturated Hydraulic Conductivity Parameters

Material Name	k_v (m/s)	k_h (m/s)	k_h/k_v
Embankment Shell	3.00E-10	3.00E-10	1.00
Core	3.00E-11	1.00E-10	3.33
Drain	1.00E-05	1.00E-05	1.00
Glacial Lacustrine	3.00E-11	1.00E-10	3.33
Glacial Till	3.00E-10	3.00E-10	1.00
Gravel	1.00E-06	1.00E-06	1.00
Weathered Bedrock	--	--	--

Vertical permeability parameters for the glacial till soil was selected by using the geometric mean of the laboratory test results for all samples obtained. These results are included in Section 2.4.1. CPT dissipation test data was reviewed for the glacial till to determine the horizontal permeability and horizontal to vertical ratio; however, there was a large variation in the four tests performed on glacial till soils. Based on the known depositional history of the glacial till, a horizontal to vertical ratio of one (1) was selected for glacial till.

For glacial lacustrine soil, the CPT dissipation test data had consistent results for the four tests performed, with a geometric mean of about 3.00E-10 m/s. The geometric mean from the falling head permeability tests conducted on undisturbed glacial lacustrine soil samples was also 3.00E-10 m/s. Based on the characteristics of the soil and its depositional history (lake deposits in horizontal seams), it did not seem appropriate to use a horizontal to vertical ratio of one (1) for the glacial lacustrine soil. Also, it was assumed the glacial lacustrine soil must have a lower permeability than the glacial till soil due to the sand and gravel content in the glacial till. Since a permeability of 3.00E-10 m/s was selected for glacial till, a horizontal permeability of 1.00E-10 m/s was selected for the glacial lacustrine. A horizontal to vertical ratio of 3.33 to 1 was used, following published data and typical values for lake deposits from Cedergren “Seepage, Drainage, and Flow Nets (1989)”. This resulted in vertical permeability of 3.00E-11 m/s.

Permeability tests conducted on remolded samples yielded similar results to those conducted on undisturbed soil samples. Because of this, the same values were selected for foundation soils and corresponding embankment soils.

Reference: Springbank Off –Stream Reservoir (SR1) – Updated Geotechnical Materials Properties Design Basis Memorandum

Typical values from Table 6 of Soil Mechanics in Engineering Practice (Terzaghi, 1967) for clean sands and gravel with silt and sand were used for the sand drain material and alluvial gravel, respectively.

2.5 DRAINED SHEAR STRENGTH

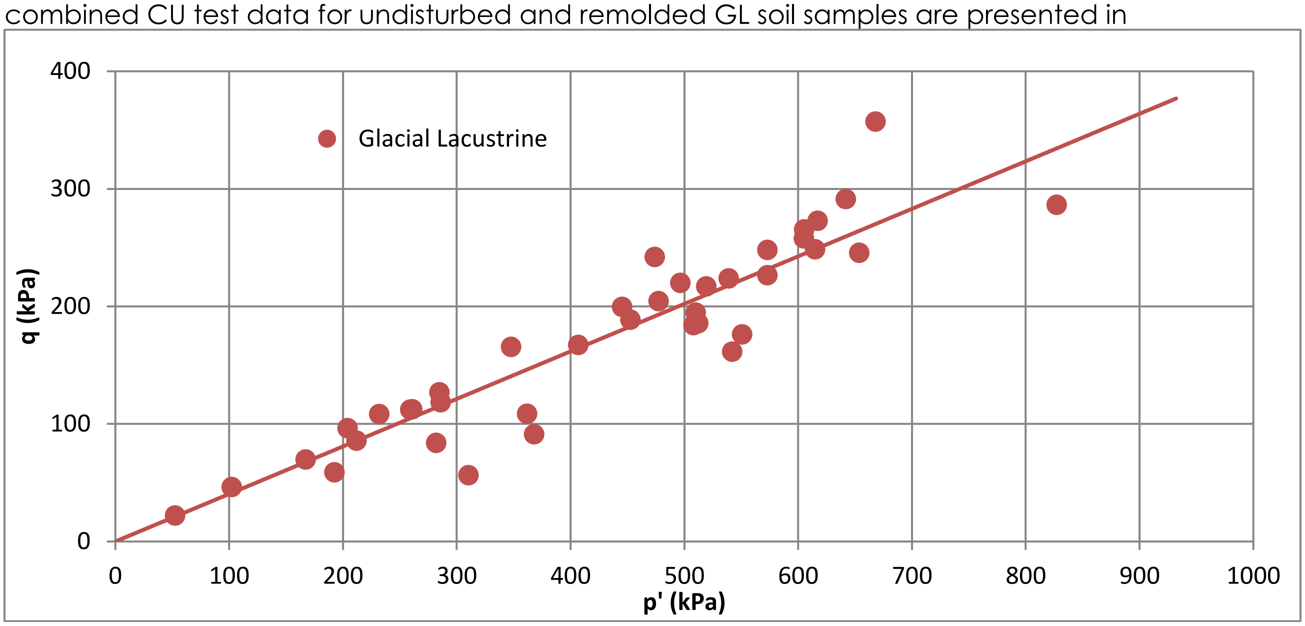
2.5.1 Data

A total of 83 consolidated undrained triaxial (ASTM D4767) tests were performed on undisturbed and remolded GL and GT soil samples. A summary of the soil types subjected to consolidated undrained (CU) triaxial testing are presented in Table 10.

Table 10. Summary of Consolidated Undrained (CU) Triaxial Tests

Test Type	Soil Type	Sample Type	Completed
CU Triaxial Tests	Glacial Lacustrine	Undisturbed	39
		Remolded	5
	Glacial Till	Undisturbed	22
		Remolded	17
	Total		83

The test results were reviewed and summarized by zone and by soil type, and best fit angle of friction values were calculated for each zone. The results of 44 CU triaxial tests performed on undisturbed and remolded GL soil samples are summarized in Table 11. The p-q plots of the combined CU test data for undisturbed and remolded GL soil samples are presented in



Reference: Springbank Off –Stream Reservoir (SR1) – Updated Geotechnical Materials Properties Design Basis Memorandum

Figure 19 and Figure 20, respectively. The range of best fit friction angles from single point CU tests performed on undisturbed and remolded GL soil samples from each project zone is presented graphically in Figure 21 and Figure 22, respectively.

Table 11. Summary of Average Drained Shear Strength Values for Stability Analysis – Glacial Lacustrine

Feature	Zone	Sample Type	Number of CU Triaxial Tests	Best Fit Friction Angle (°)
Diversion Channel	4	Undisturbed	1	17.3
		Remolded	1	27.9
	5	Undisturbed	2	2
	7	Undisturbed	1	25.1
	8	Undisturbed	3	25.2
		Remolded	1	21.6
Storage Dam	10	Undisturbed	13	22.8
	11	Undisturbed	16	24.5
		Remolded	1	25.1
	13	Undisturbed	2	29.5
	13	Remolded	2	24.5
	Borrow	Undisturbed	1	25.3
Total Site		Undisturbed	39	23.6
		Remolded	5	24.3

Reference: Springbank Off –Stream Reservoir (SR1) – Updated Geotechnical Materials Properties Design Basis Memorandum

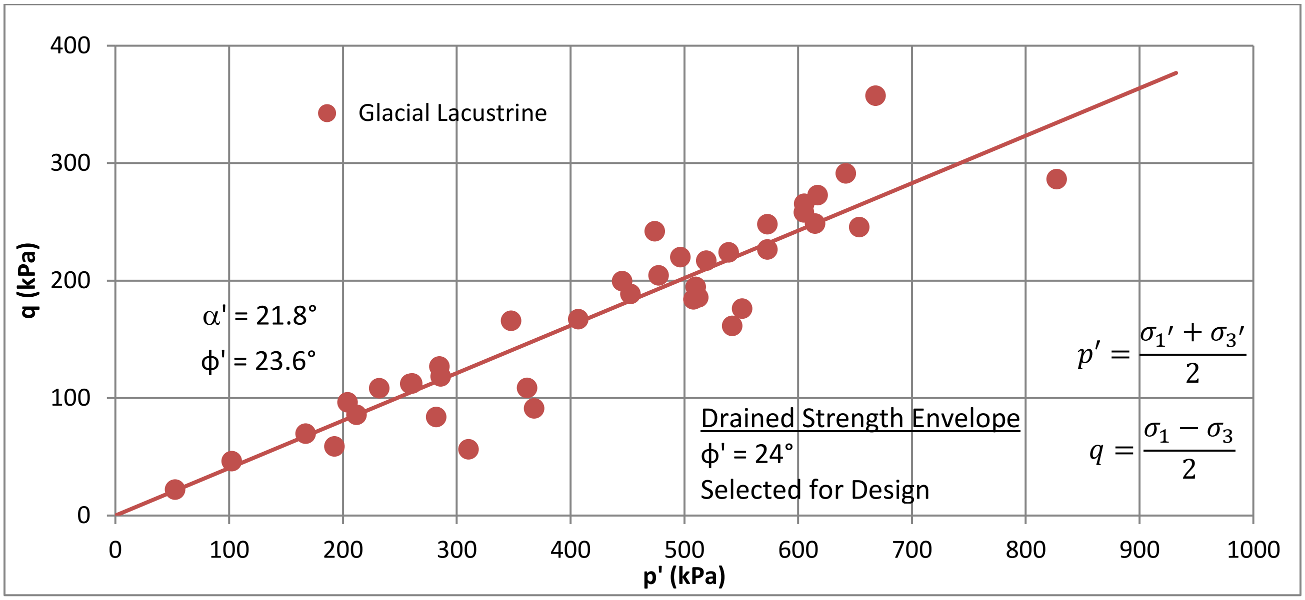


Figure 19. CU Triaxial Test Results - Undisturbed Glacial Lacustrine

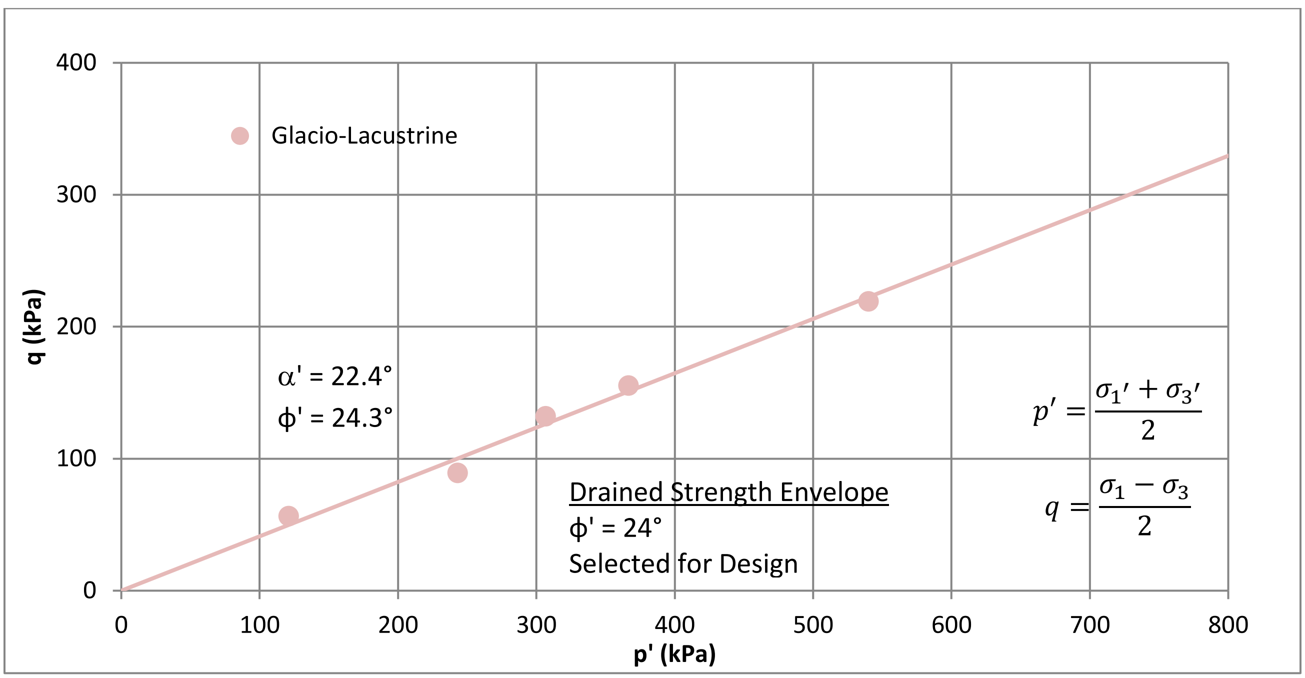


Figure 20. CU Triaxial Test Results – Remolded Glacial Lacustrine

CU triaxial tests performed on undisturbed glacial lacustrine specimens were typically performed until 20 percent axial strain was obtained. The CU test results typically produced a peak shear stress followed by a lower residual shear strength. Residual shear strengths either stabilized after 9 to 12 percent axial strain occurred or continued to decrease with additional strain.

Laboratory CU test results were reviewed to determine residual strength of the GL soil. The test results that clearly demonstrated a peak strength followed by a uniform residual strength yielded an average peak shear strength of 24 degrees and an average residual shear strength of 19 degrees after approximately 10 percent strain occurred.

Reference: Springbank Off –Stream Reservoir (SR1) – Updated Geotechnical Materials Properties Design Basis Memorandum

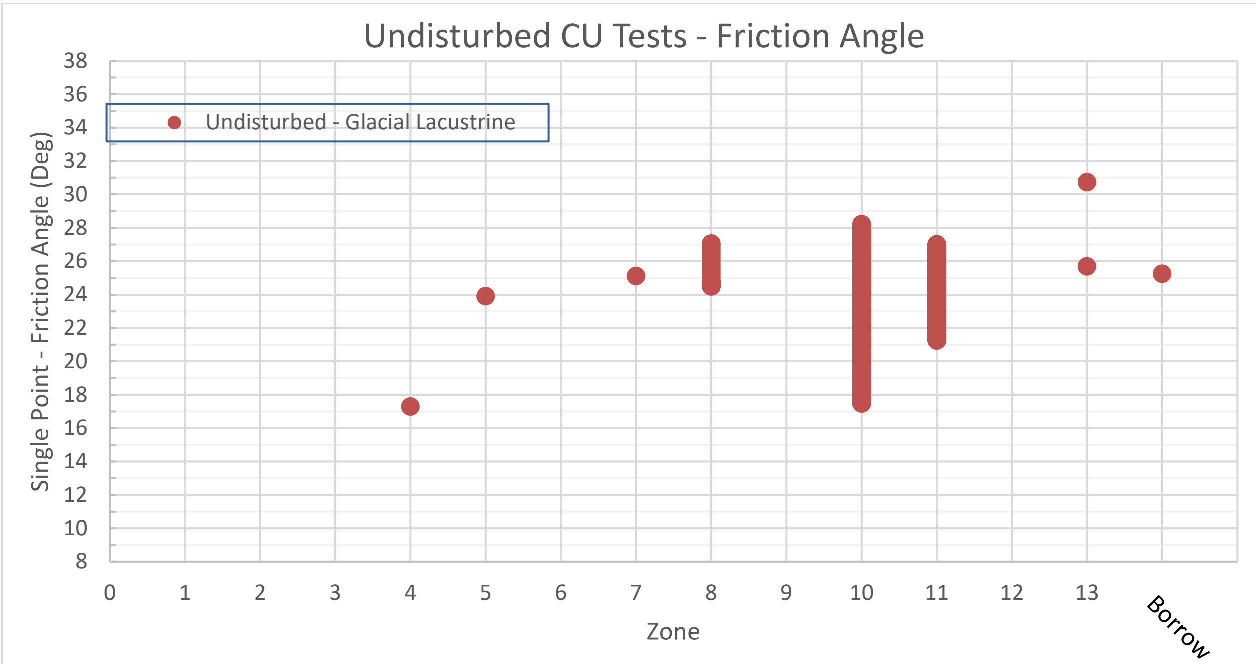


Figure 21. Spatial Distribution of CU Triaxial Test Results - Undisturbed Glacial Lacustrine

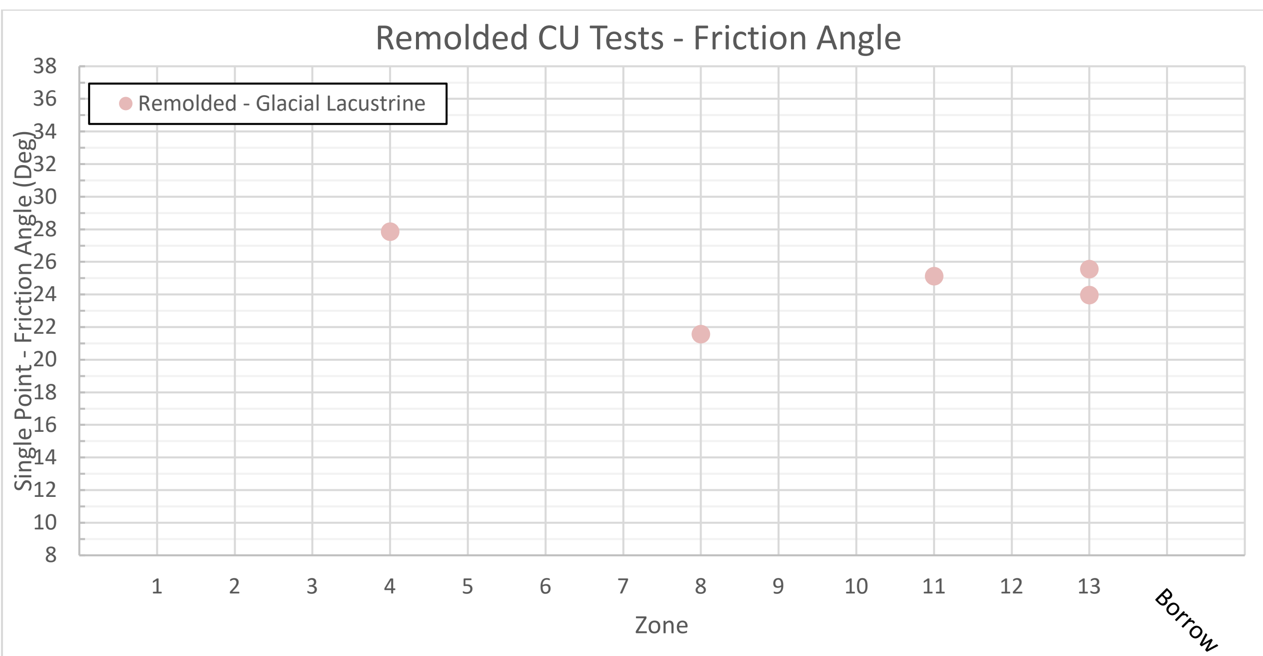


Figure 22. Spatial Distribution of CU Triaxial Test Results - Remolded Glacial Lacustrine

Reference: Springbank Off –Stream Reservoir (SR1) – Updated Geotechnical Materials Properties Design Basis Memorandum

The results of 39 consolidated undrained triaxial tests on undisturbed and remolded GT soil samples are summarized in Table 12. The p-q plots of the combined CU test data for undisturbed and remolded GT soil samples are presented in Figure 23 and Figure 24, respectively. The range of best fit friction angles from single point CU tests performed on undisturbed and remolded GT soil samples from each project zone is presented graphically in Figure 25 and Figure 26.

Table 12. Summary of Average Drained Shear Strength Values for Stability Analysis – Glacial Till

Feature	Zone	Sample Type	Number of CU Triaxial Tests	Best Fit Friction Angle (°)
Diversion Channel	3	Undisturbed	3	27.4
		Remolded	4	21.3
	4	Undisturbed	1	25.0
		Remolded	2	25.5
	6	Remolded	1	32.8
	7	Undisturbed	1	33.6
	8	Undisturbed	5	30.8
		Remolded	1	26.7
Storage Dam	9	Undisturbed	2	26.7
	10	Undisturbed	5	28.0
	11	Undisturbed	2	24.9
		Remolded	1	25.9
	12	Undisturbed	1	25.8
		Remolded	1	31.3
	13	Undisturbed	2	29.1
		Remolded	1	25.7
	Borrow	Remolded	6	28.4
Total Site		Undisturbed	22	27.5
		Remolded	17	27.7

Reference: Springbank Off –Stream Reservoir (SR1) – Updated Geotechnical Materials Properties Design Basis Memorandum

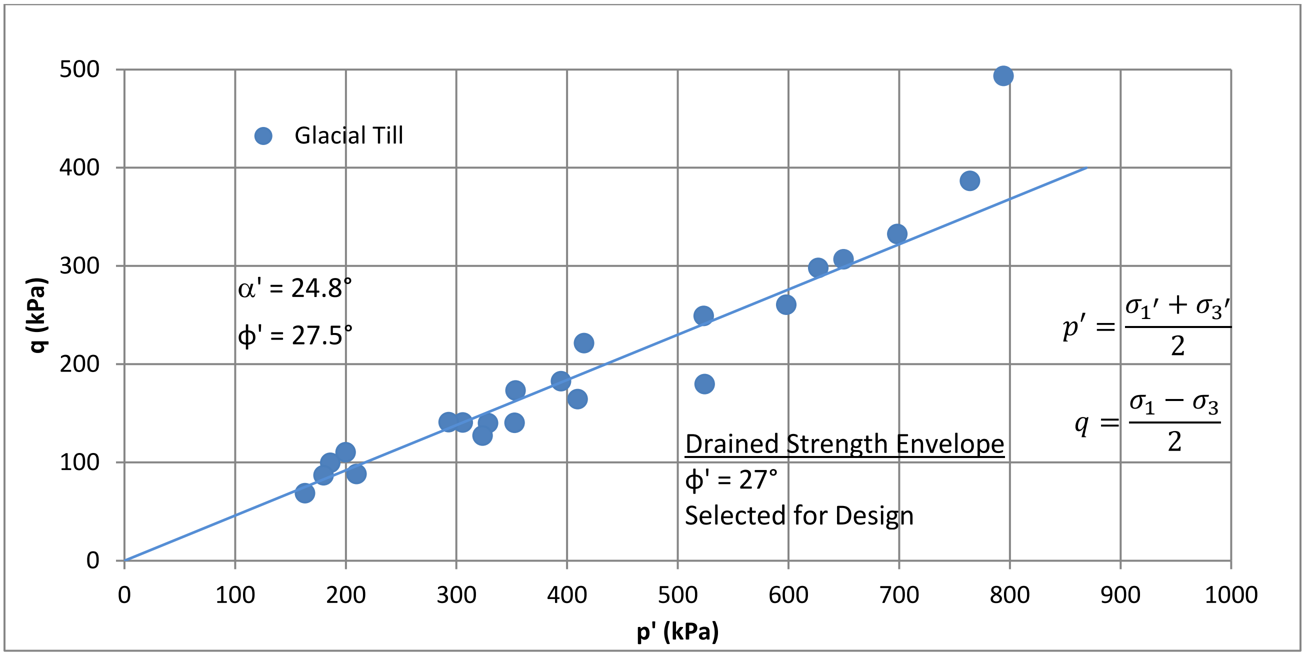


Figure 23. CU Triaxial Test Results - Undisturbed Glacial Till

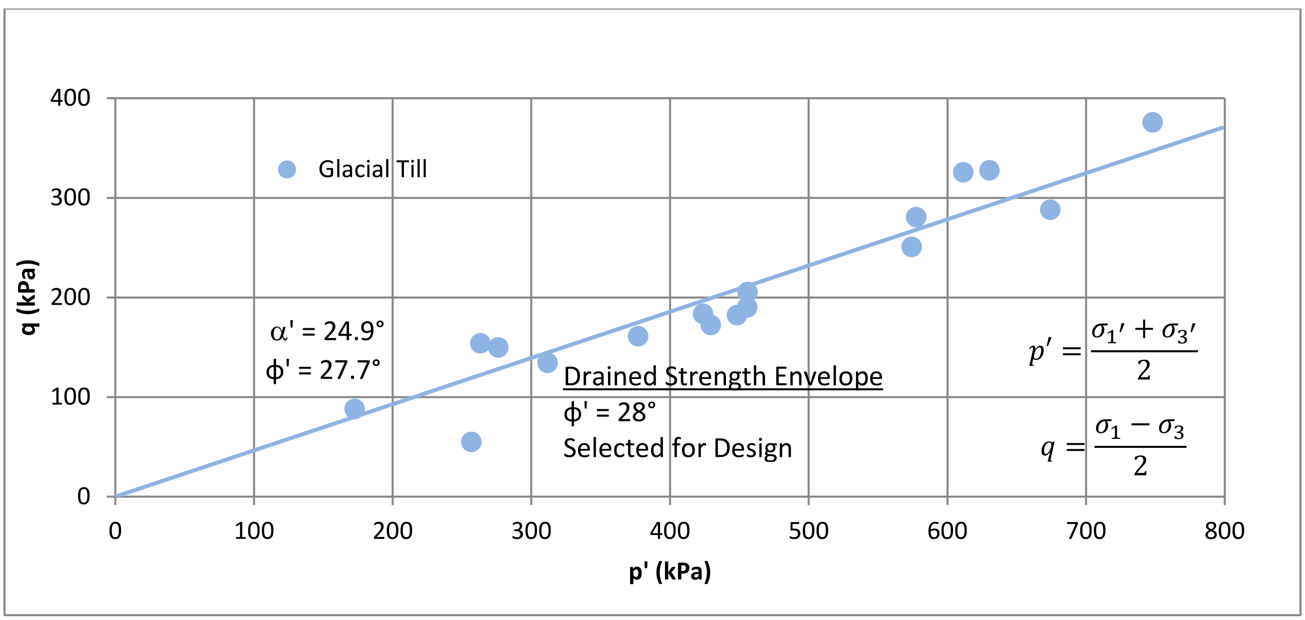


Figure 24. CU Triaxial Test Results - Remolded Glacial Till

Reference: Springbank Off –Stream Reservoir (SR1) – Updated Geotechnical Materials Properties Design Basis Memorandum

CU triaxial tests performed on undisturbed glacial till specimens were typically performed until 20 percent axial strain was obtained. The CU test results typically produced a peak shear stress followed by a lower residual shear strength. Residual shear strengths either stabilized after 7 to 15 percent axial strain occurred or began to increase or decrease with additional strain.

Laboratory CU test results were reviewed to determine residual strength of the GT soil. The test results that clearly demonstrated a peak strength followed by a uniform residual strength yielded an average peak shear strength of 27 degrees and an average residual shear strength of 25 degrees after approximately 10 percent strain occurred.

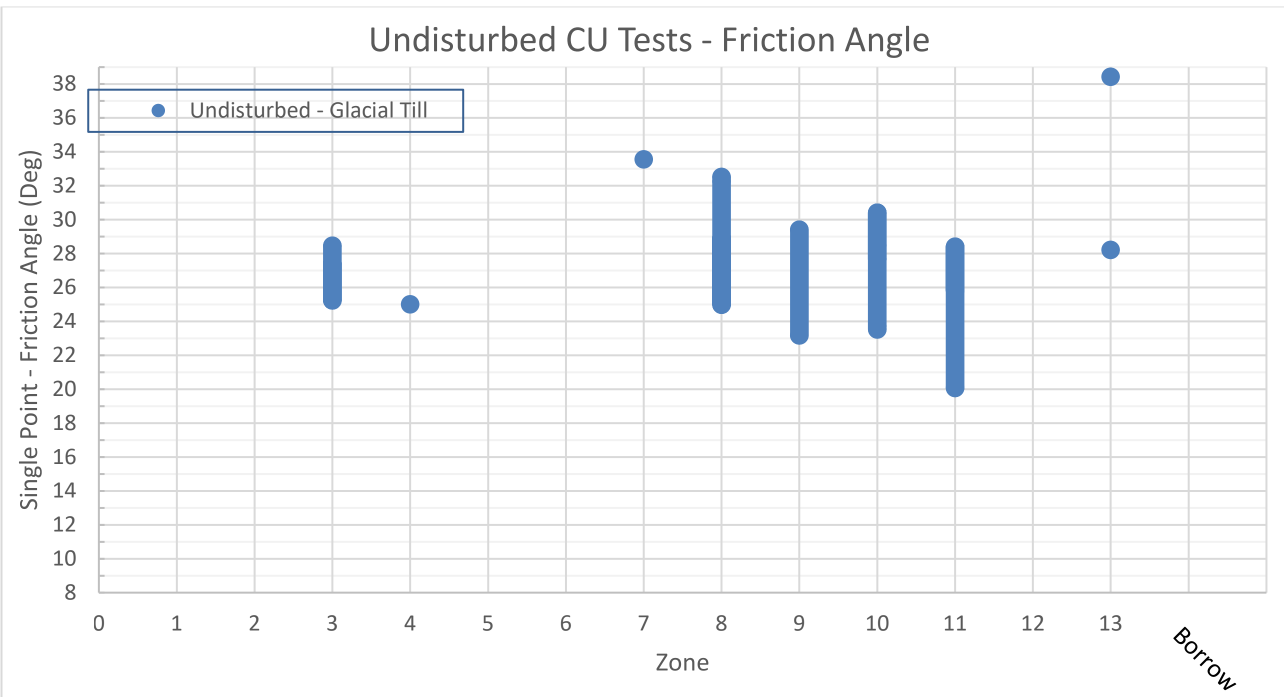


Figure 25. Spatial Distribution of CU Triaxial Test Results - Undisturbed Glacial Till

Reference: Springbank Off –Stream Reservoir (SR1) – Updated Geotechnical Materials Properties Design Basis Memorandum

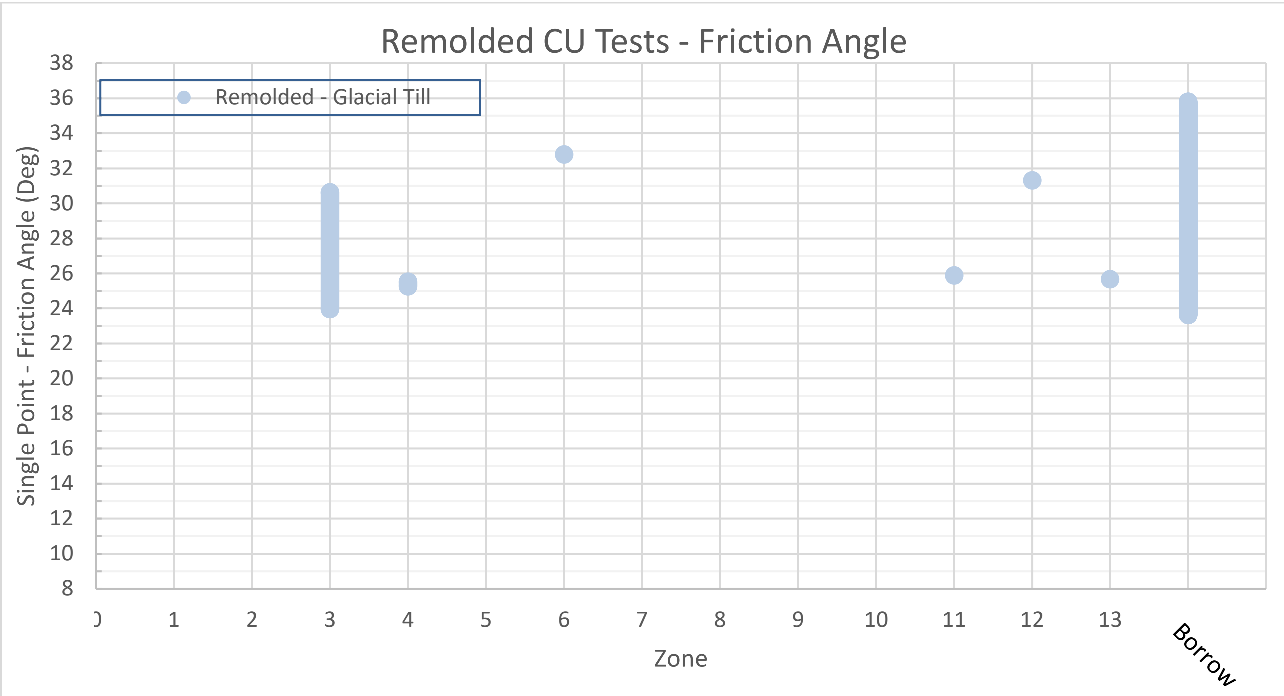


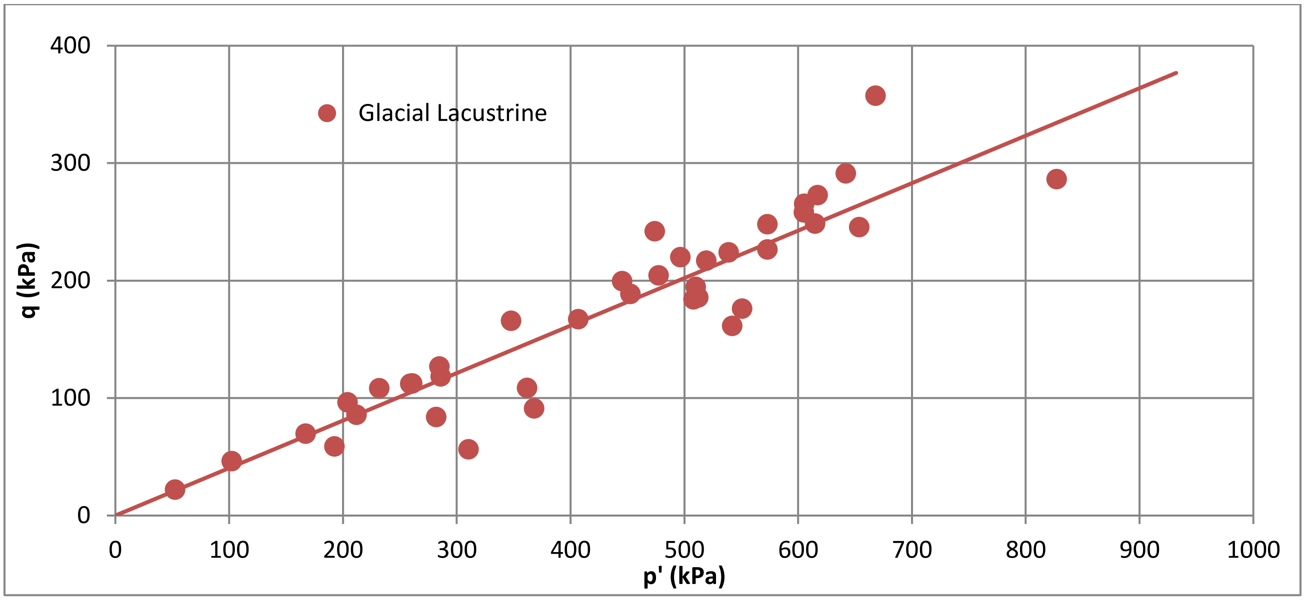
Figure 26. Spatial Distribution of CU Triaxial Test Results - Remolded Glacial Till

2.5.2 Selected Parameters

Consolidated undrained triaxial tests were conducted on both undisturbed and remolded soil samples. Strength parameters were generally selected by fitting a best-fit line through the p-q plot data points. Results of tests conducted on undisturbed samples were evaluated for the foundation soils and results of tests conducted on the remolded samples were evaluated for the embankment soils.

Test results were initially evaluated by geographic zone; however, upon review, it was noted that the test results were similar regardless of zone (Figure 21 and Figure 25). Therefore, strengths were selected by constructing a best-fit line through the data points. The p-q plots for tests conducted on undisturbed samples are presented in Figure 19 and Figure 23 for glacial lacustrine and glacial till, respectively.

Reference: Springbank Off –Stream Reservoir (SR1) – Updated Geotechnical Materials Properties Design Basis Memorandum



Tests conducted on remolded samples were reviewed for the embankment materials. Best-fit lines were constructed through the data points. The test results conducted on remolded glacial lacustrine and glacial till soil samples were nearly identical to those conducted on undisturbed samples. Plots of the test results on remolded glacial lacustrine and glacial till soil samples are included in Figure 20 and Figure 24, respectively.

For drained strengths for glacial lacustrine, glacial till, embankment shell, and embankment core materials, the friction angle was selected using the best-fit line. The best-fit line for both the glacial till and glacial lacustrine soils indicate a cohesion intercept of zero. This is consistent with what is expected for a normally to slightly overconsolidated clay.

In addition to the consolidated undrained triaxial test results yielding zero cohesion for the best fit line, published literature suggests no cohesion for drained strengths of normally consolidated clay. Overconsolidated clays will have cohesion; however, an envelope with cohesion greater than zero will overestimate strengths at low stress levels (shallow depths). Cohesion may be used for overconsolidated soils at great depths. The deeper glacial tills at the project site appear to be normally consolidated (Figure 42), so, in Stantec's opinion, no cohesion is warranted. Additionally, the CU test data obtained does not support cohesion.

The drained strength for the sand drain material and weathered bedrock were selected using correlations for coarse grained soils between dry unit weights and angle of internal friction (NAVFAC 1986). For the sand drain, assuming a dry unit weight of 18 kN/m^3 for a poorly graded sand, a friction angle of 33° was selected. For the alluvial gravel, assuming a dry unit weight of 20 kN/m^3 for a well graded gravel, a friction angle of 35° was selected. The weathered rock was assumed to be a well graded gravel with silt and sand. Assuming a dry unit weight of 20 kN/m³, a friction angle of 35° was selected. The drained strength parameters selected for the analyses are presented in Table 13.

Table 13. Selected Drained Soil Strength Parameters

Material Name	Drained Strength	
	Cohesion (kPa)	Friction Angle (degrees)
Embankment Shell (GL)	0	24
Embankment Core (GT)	0	28
Foundation Glacial Lacustrine	Variable c/p undrained strength	
Foundation Glacial Till	0	27
Sand Drain	0	33
Alluvial Gravel	0	35
Weathered Rock	0	35

2.6 UNDRAINED SHEAR STRENGTH

2.6.1 Data

2.6.1.1 UU Triaxial Tests

A total 11 unconsolidated undrained (UU) triaxial (ASTM D2850) tests were performed on undisturbed and remolded GL and GT soil samples. Summaries of the soil types subjected to triaxial testing are presented in Table 14.

Table 14. Summary of Unconsolidated Undrained (CU) Triaxial Tests

Test Type	Soil Type	Sample Type	Completed
UU Triaxial Tests	Glacial Lacustrine	Undisturbed	10
		Remolded	- - -
	Glacial Till	Undisturbed	- - -
		Remolded	1
	Total		11

The spatial distribution of undrained strengths from 11 unconsolidated undrained triaxial tests performed on undisturbed and remolded GL and GT soil samples are summarized in Figure 27.

Reference: Springbank Off –Stream Reservoir (SR1) – Updated Geotechnical Materials Properties Design Basis Memorandum

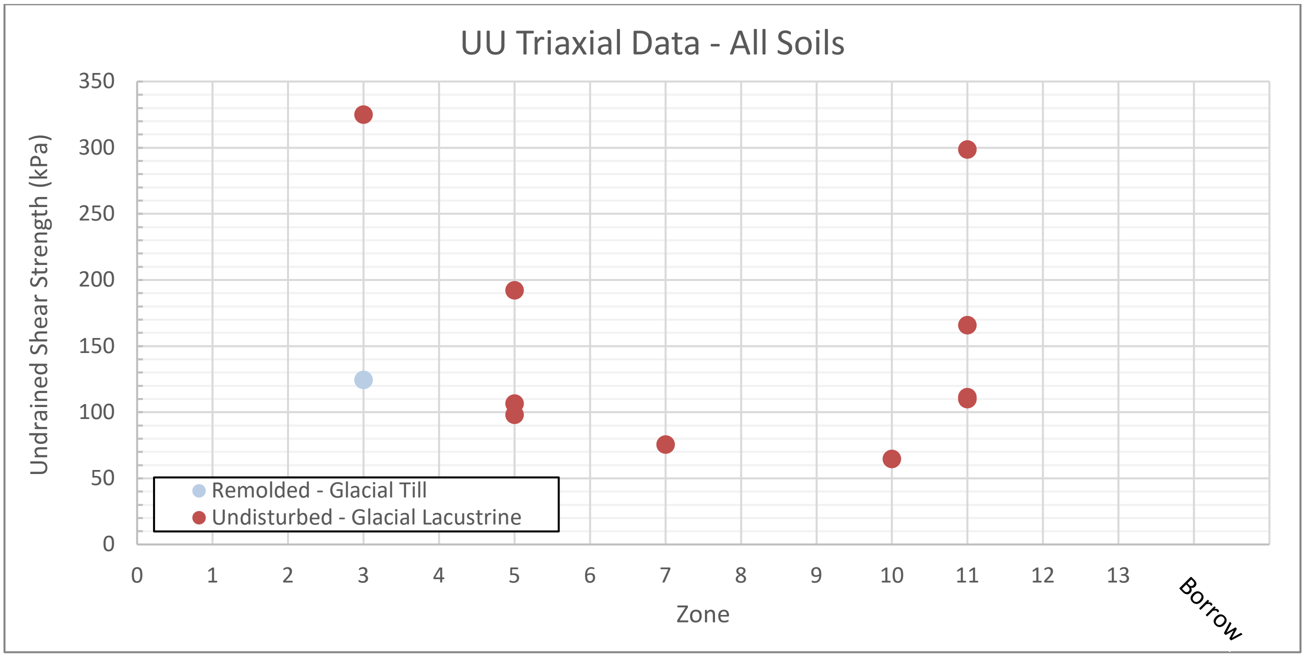


Figure 27. Spatial Distribution of Triaxial Undrained Strength Test Results

The UU test results were reviewed and summarized by zone and by soil type. The results of 10 UU triaxial tests performed on undisturbed and remolded GL soil samples are summarized in Table 15. One UU triaxial test performed on a remolded GT soil sample is summarized in Table 16.

Table 15. Summary of Average Undrained Shear Strength Values for Stability Analysis – Glacial Lacustrine

Feature	Zone	Sample Type	Number of UU Triaxial Results	Average Undrained Strength (kPa)
Diversion Channel	3	Undisturbed	1	325
	5	Undisturbed	3	132
	7	Undisturbed	1	76
	10	Undisturbed	1	65
	11	Undisturbed	4	171
Total Site		Undisturbed	10	155

Reference: Springbank Off –Stream Reservoir (SR1) – Updated Geotechnical Materials Properties Design Basis Memorandum

Table 16. Summary of Average Undrained Shear Strength Values for Stability Analysis – Glacial Till

Feature	Zone	Sample Type	Number of UU Triaxial Results	Average Undrained Strength (kPa)
Diversion Channel	3	Remolded	1	125

2.6.1.2 CPT Data

Undrained strength (S_u) from CPT data was calculated using a N_{kt} value of 15. Kleven (1981) showed that for normally consolidated marine clays, the cone factor N_{kt} varied between 11 and 19 with an average value of 15. Aas et al. (1986) correlated plasticity index to N_{kt}. The results indicate that N_{kt} increases with increasing plasticity, ranging from 8 to 16 for plasticity indexes from 3 to 50%. A large number of studies have been performed resulting in N_{kt} values between 15 and 20 (ESOPT 1974). Based on this information, an N_{kt} value of 15 was chosen for the glacial lacustrine and glacial till soils.

Soil horizon breaks were determined using nearby soil borings where available and SBT values from the CPT data. The data was summarized by soil type for all samples and by geographic zone. Project wide results of S_u versus depth for glacial lacustrine are included in Figure 28.

Reference: Springbank Off –Stream Reservoir (SR1) – Updated Geotechnical Materials Properties Design Basis Memorandum

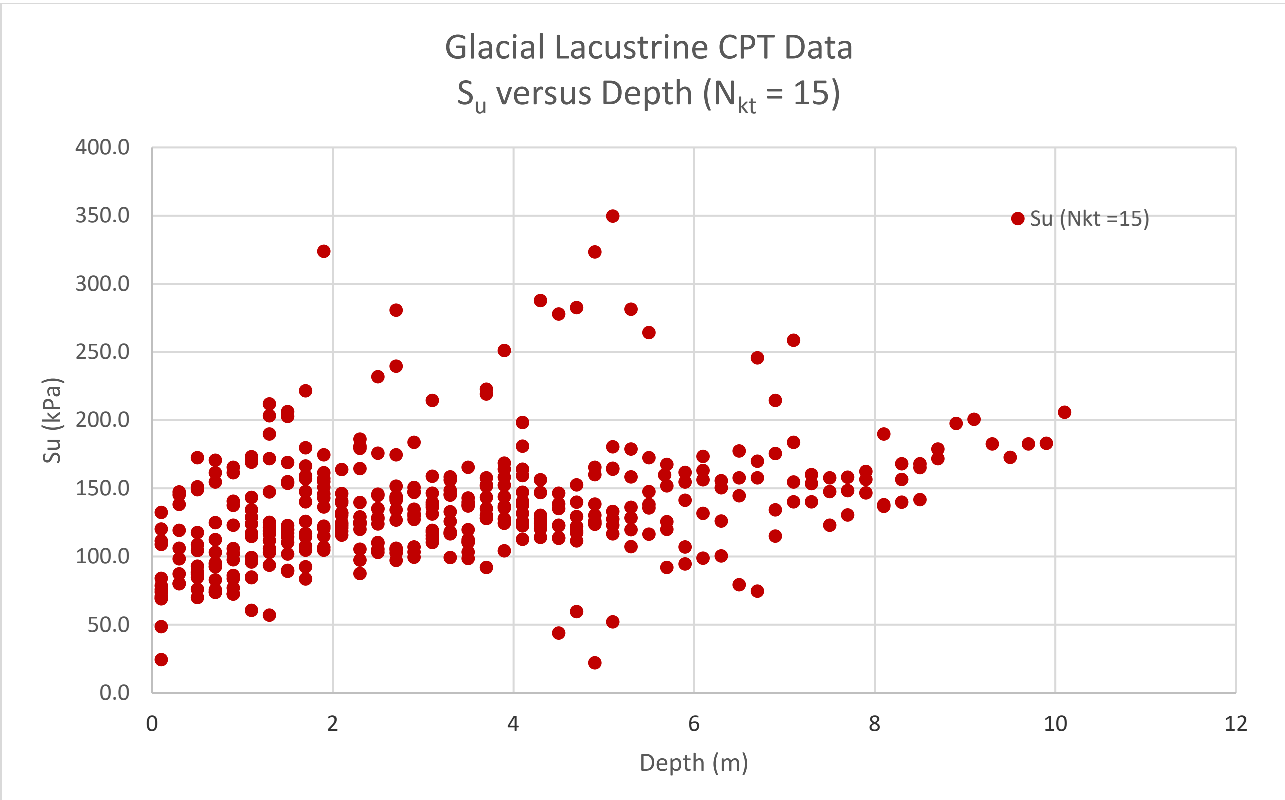


Figure 28. CPT Undrained Shear Strength versus Depth – Glacial Lacustrine – Project Wide

Project wide results of S_u versus depth for glacial till are included in Figure 29.

Reference: Springbank Off –Stream Reservoir (SR1) – Updated Geotechnical Materials Properties Design Basis Memorandum

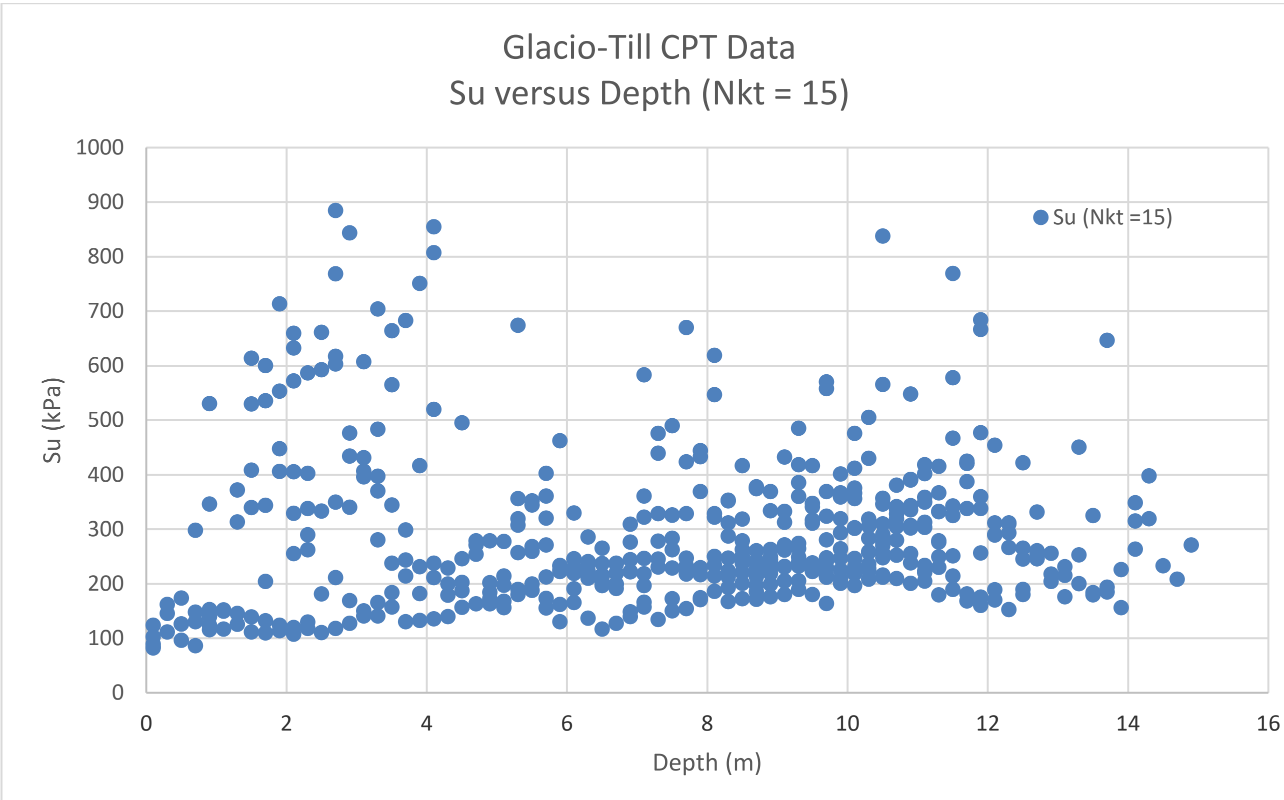


Figure 29. CPT Undrained Shear Strength versus Depth – Glacial Till – Project Wide

CPT soundings were advanced in Zone 8, Zone 9, Zone 11, and Zone 12. The range of undrained strength from the CPT soundings for glacial lacustrine soil by zone is included in Figure 30.

Reference: Springbank Off –Stream Reservoir (SR1) – Updated Geotechnical Materials Properties Design Basis Memorandum

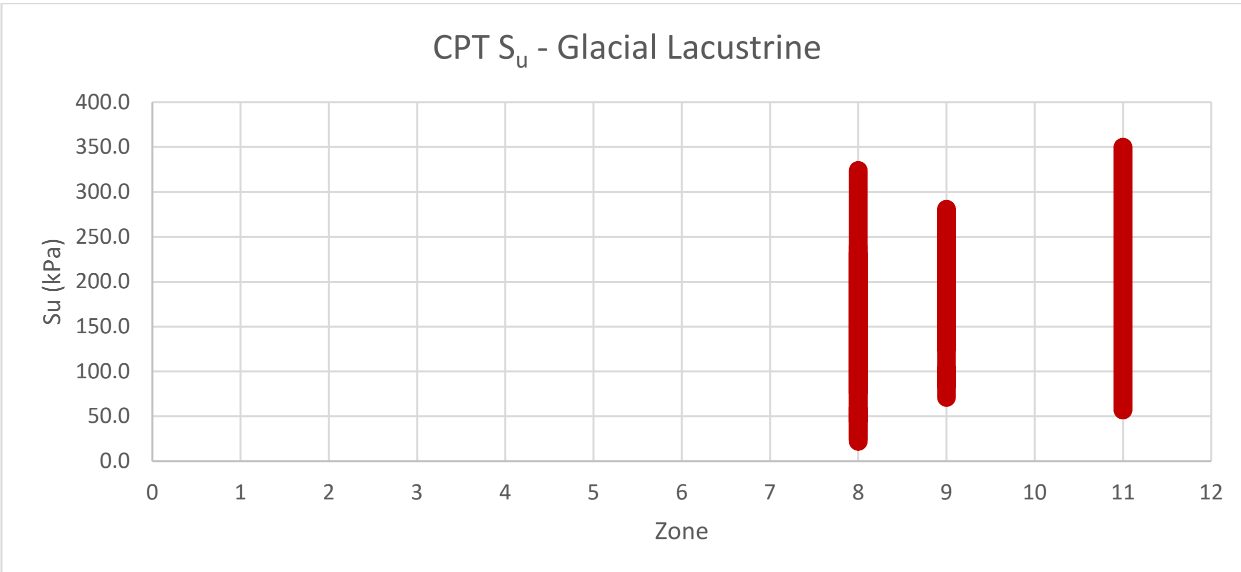


Figure 30. CPT Undrained Shear Strength – Glacial Lacustrine – By Zone

The range of undrained strength from the CPT soundings for glacial till soil by zone is included in Figure 31.

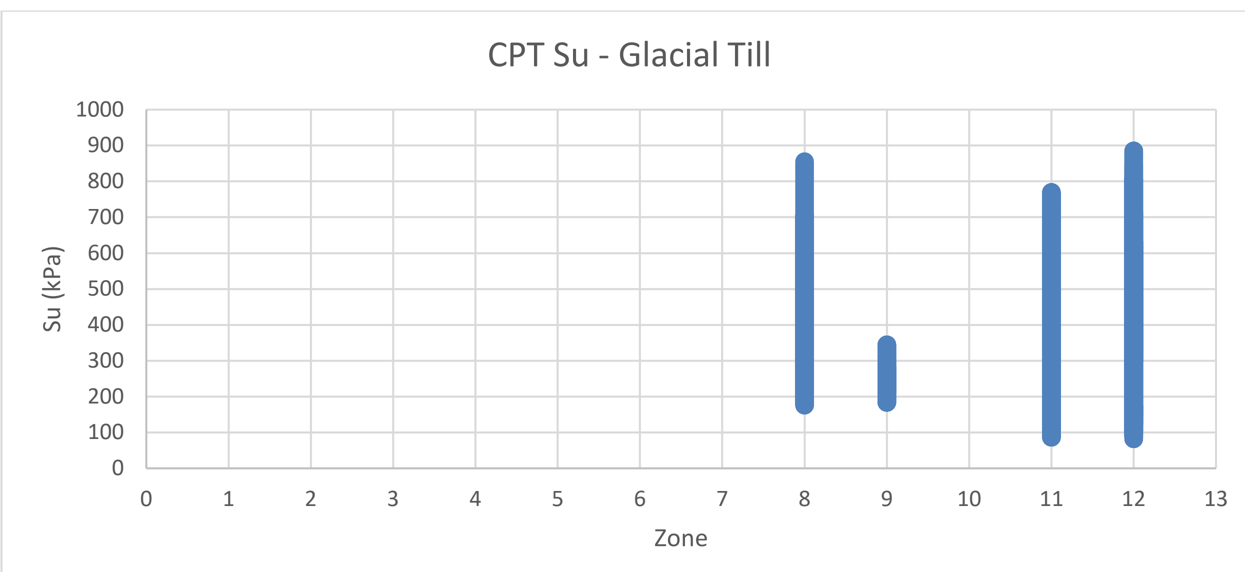


Figure 31. CPT Undrained Shear Strength – Glacial Till – By Zone

2.6.1.3 Undrained Strength Envelopes from CU Triaxial Tests

Using data from the CU tests, undrained strength envelopes were fit to plots of shear strength on the failure plane $(S_U)_{ff}$ versus specimen consolidation pressure (σ'_{con}) (FERC 2006; USBR 2011). The undrained strength envelope is represented by Mohr-Coulomb parameters (c and ϕ) as shown in Figure 32.

The undrained shear strength on the failure plane $(S_U)_{ff}$ was calculated for each CU test performed. In a triaxial compression test, failure develops on a plane that is oriented at (45˚ + ϕ'/2) above horizontal (Duncan et al. 2014). The shear stresses on the failure plane in a particular CU test can be determined using Mohr's circle and the equation shown in Figure 32.

Here, σ_{df} is the measured deviator stress at failure and ϕ'is the drained friction angle.

$$(S_u)_{ff} = \frac{\sigma_{df}}{2} \cos \phi' = c + \sigma'_{con} \tan \phi$$

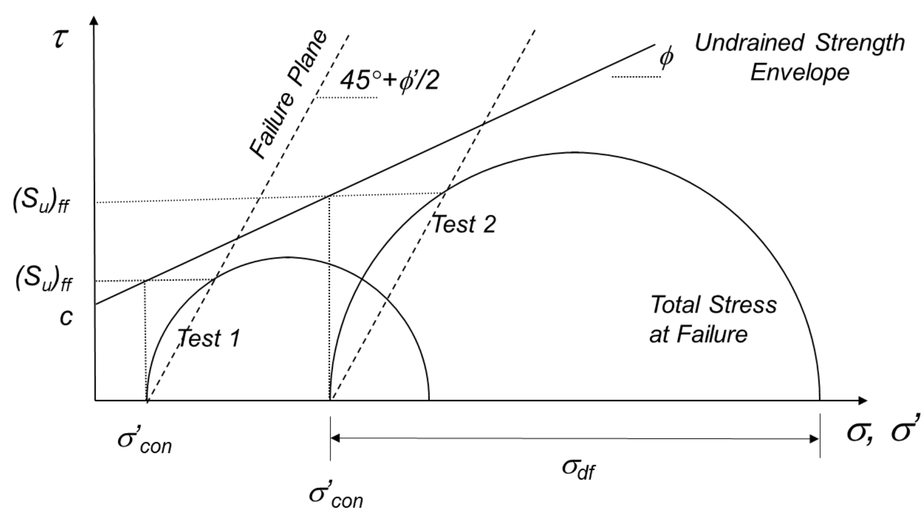


Figure 32 – Undrained Strength Envelope Representing the Failure Plane Shear Stresses Measured in CU Triaxial Tests

The results of $(S_U)_{ff}$ versus (σ'_{con}) for 39 CU tests performed on undisturbed Glacial Lacustrine specimens are included in Figure 33. An undrained strength envelope fit through the data results in c = 15 kPa and ϕ = 20˚. Likewise, the results from 22 CU tests performed on undisturbed Glacial Till specimens (Figure 34) indicate c = 60 kPa and ϕ = 19˚. The higher strength of the undisturbed Glacial Till likely reflects, in part, the higher preconsolidation pressures in this glacial material. The undrained

Reference: Springbank Off –Stream Reservoir (SR1) – Updated Geotechnical Materials Properties Design Basis Memorandum

cohesion and friction angle values shown in Figure 33 and Figure 34 were obtained by linear regression.

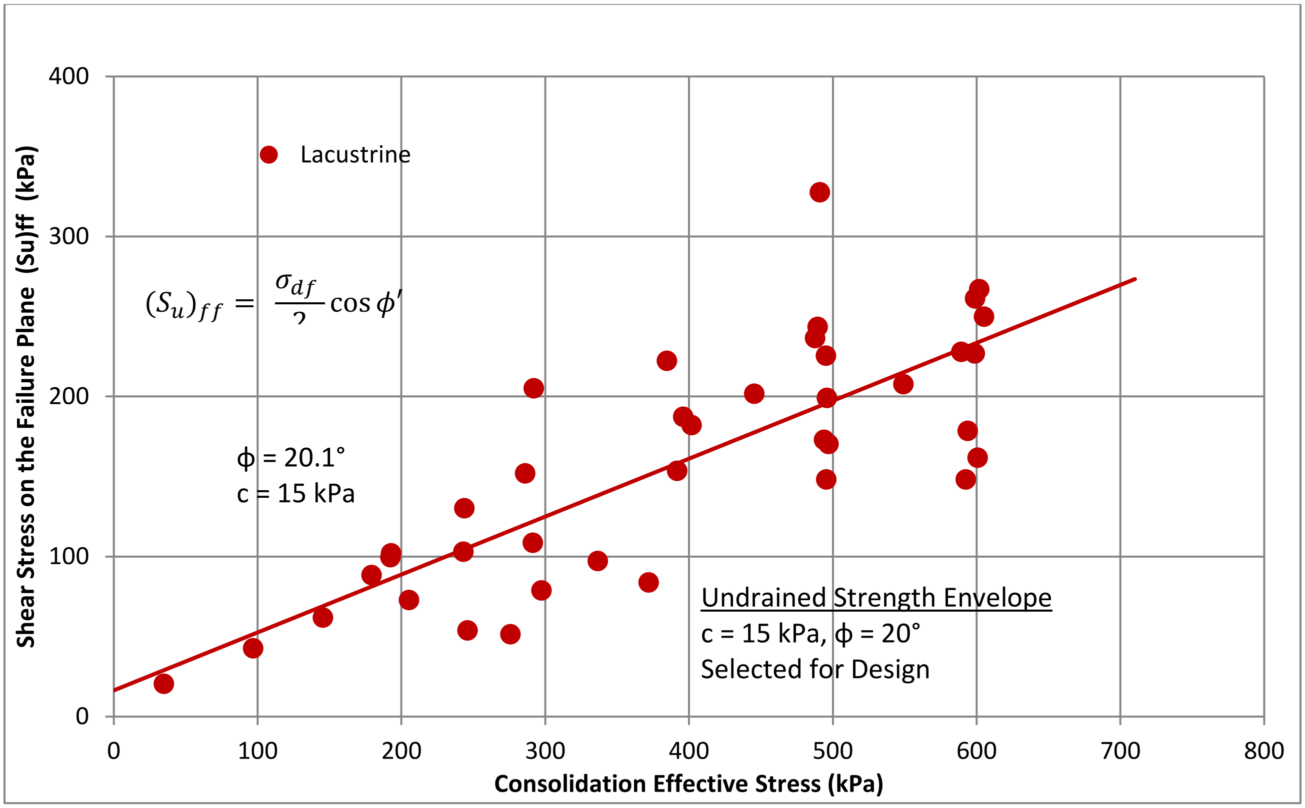


Figure 33. CU Triaxial Test Undrained Strength Envelope – Undisturbed Glacial Lacustrine

Reference: Springbank Off –Stream Reservoir (SR1) – Updated Geotechnical Materials Properties Design Basis Memorandum

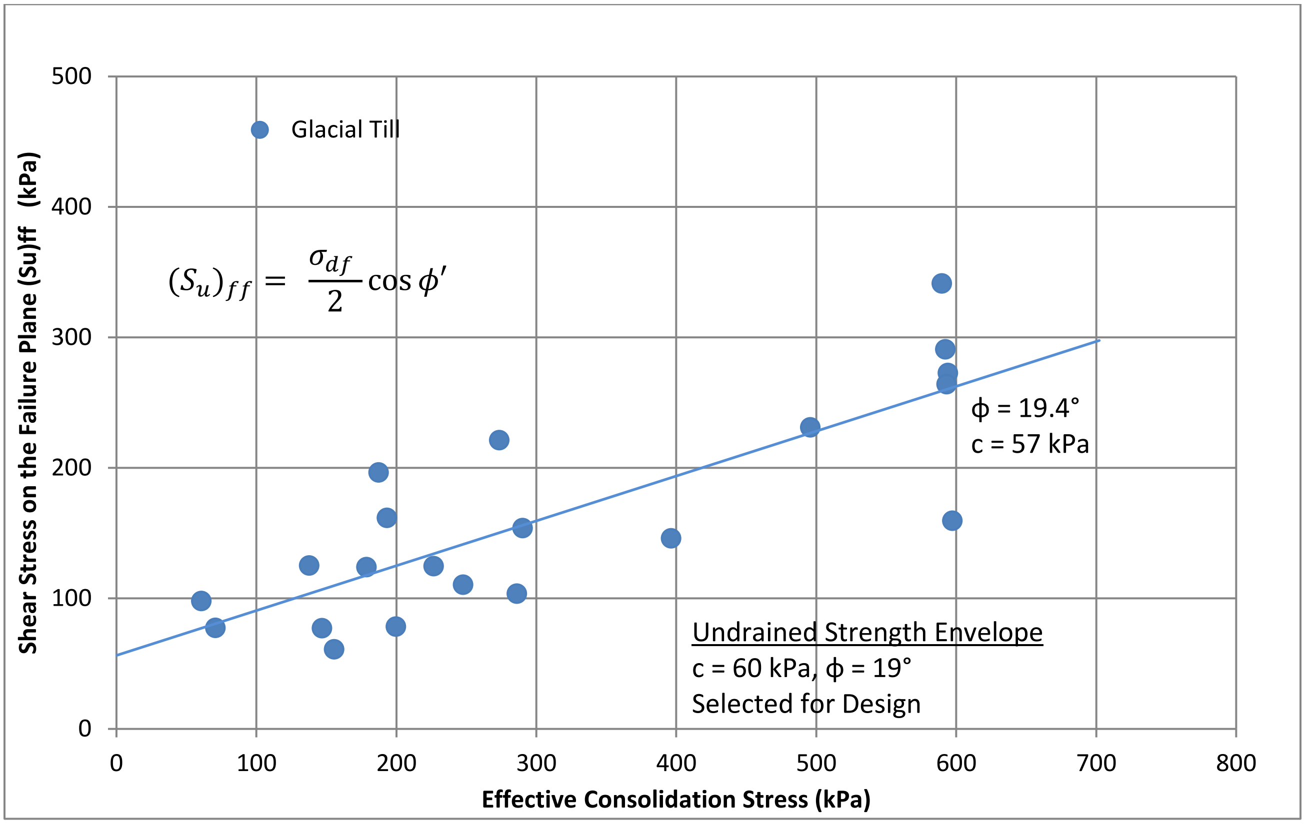


Figure 34. CU Triaxial Test Undrained Strength Envelope – Undisturbed Glacial Till

Results of $(S_U)_{ff}$ versus (σ'_{con}) for three CU tests performed on remolded Glacial Lacustrine samples and for 16 CU tests on remolded Glacial Till samples are plotted separately in Figures 35 and 36.

An undrained strength envelope fit through the remolded Glacial Lacustrine data in Figure 35 results in c = 25 kPa and ϕ = 15˚. Likewise, an undrained strength envelope fit through the remolded Glacial Till data in Figure 36 results in c = 80 kPa and ϕ = 19˚. The undrained cohesion and friction angle values shown in Figures 35 and 36 were obtained by linear regression.

During construction of the dam, these materials may be mixed to varying degrees within the embankment core and shell. However, depending on the sequence of construction and how the borrow pits are developed, there could be continuous zones of the compacted Glacial Lacustrine soil, which has a lower undrained strength.

Reference: Springbank Off –Stream Reservoir (SR1) – Updated Geotechnical Materials Properties Design Basis Memorandum

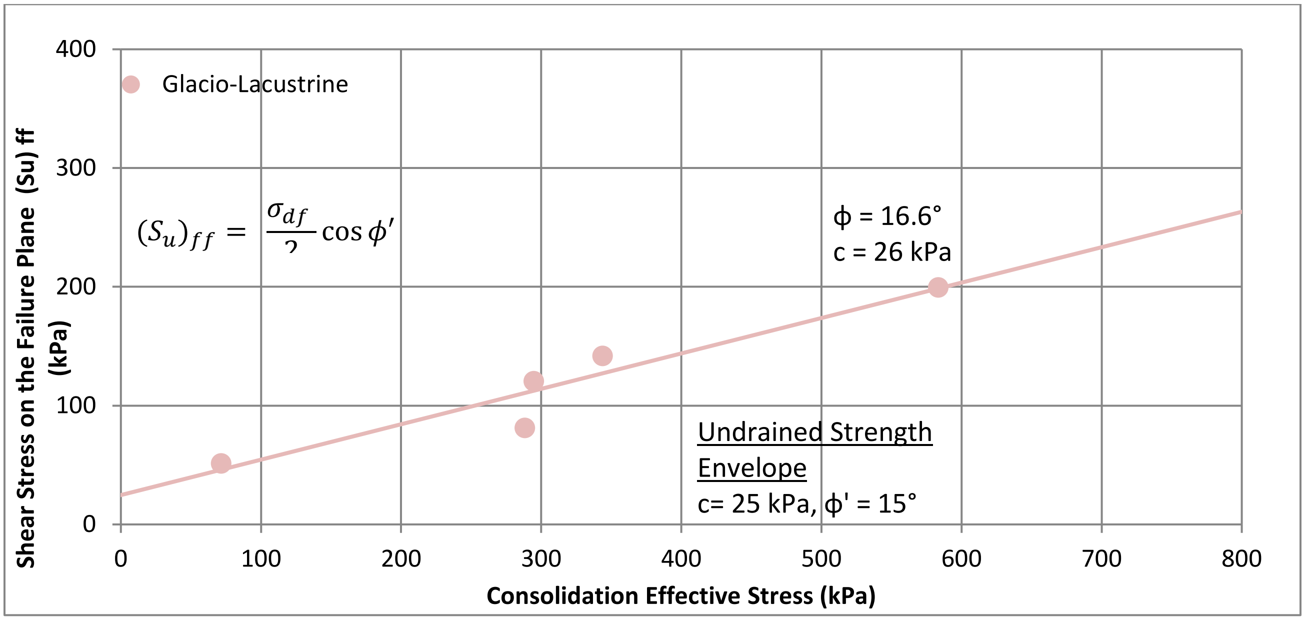


Figure 35. CU Triaxial Test Undrained Strength Envelope – Remolded Glacial Lacustrine

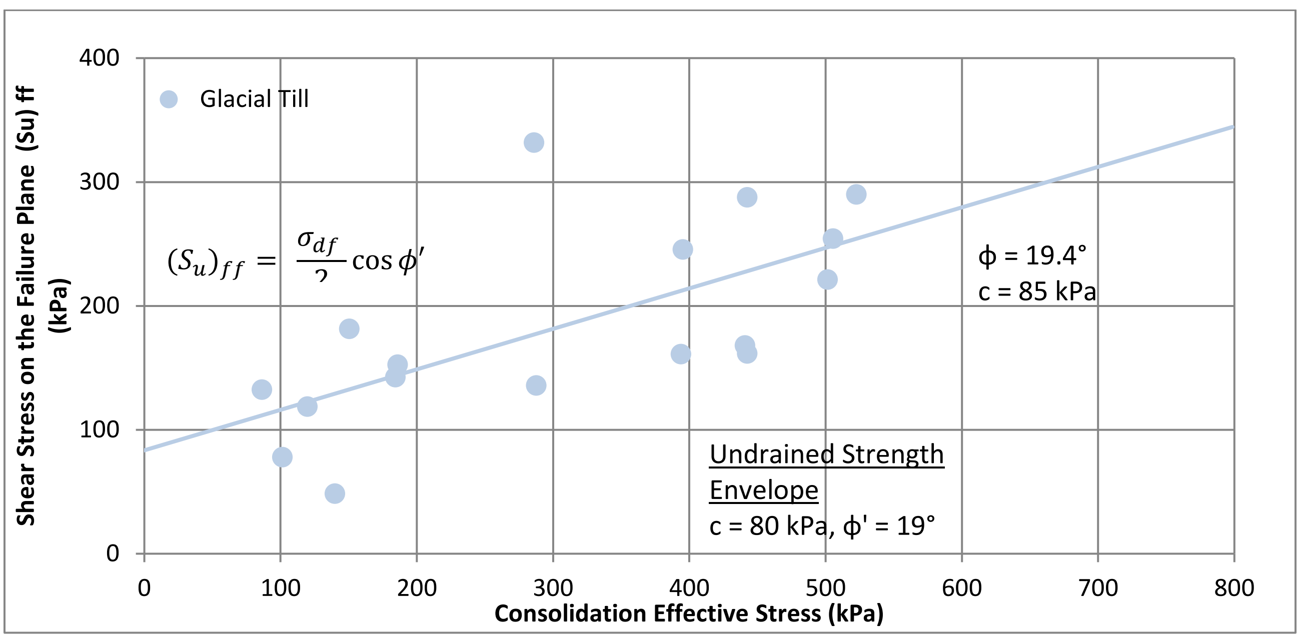


Figure 36. CU Triaxial Test Undrained Strength Envelope – Remolded Glacial Till

Reference: Springbank Off –Stream Reservoir (SR1) – Updated Geotechnical Materials Properties Design Basis Memorandum

2.6.1.4 Direct Simple Shear Testing

General – Direct simple shear (DSS) tests were performed to establish S_u/σ_v' (c/p) ratios appropriate for undrained analyses of the lacustrine clay layer. These tests were performed in accordance with ASTM D 6528-17. The four initial (June 2018 program) tests were performed at a shearing rate of five percent per hour. Subsequent tests were performed at a shearing rate of one percent per hour. The tests were performed by the TetraTech laboratory in Richmond, BC. While the 2016 tube samples were cut and evaluated prior to shipment to Vancouver, the other DSS samples were sent as intact Shelby tube samples.

Normally Consolidated Tests – The conditions within the glacial lacustrine clay layer under the embankment dam will vary with both applied load and pore pressure. To characterize possible behavior, variations in consolidation stress were utilized in the DSS tests to replicate the impact of stress history on the soil. To model the normally consolidated condition, samples were run at relatively high confining stresses. The initial program used stresses slightly higher than the measured preconsolidation pressures. Later OCR 1.0 tests were run at a confining stress of 500 kPa, well above observed preconsolidation pressures within the glacial lacustrine clay soil at the SR1 storage dam site.

OCR = 2.0 Tests – The glacial lacustrine clay typically exhibits some overconsolidation, varying from high OCR values near the surface to 2.0 or less at depths of four metres and greater. To replicate higher OCR conditions, the preconsolidation stress at each requested DSS test location was estimated from adjacent 1-D consolidation data and relative depths. As a companion to each normally consolidated test, a second DSS was performed using a consolidation stress equal to one half of the estimated preconsolidation stress.

Test Results – The main testing program began in late October 2018 and was completed during January 2019. The high consolidation stress tests began right away. The OCR 2.0 testing was initiated when 1-D consolidation tests in adjacent areas had been completed and analyzed to assign DSS test parameters.

As testing progressed, difficulties developed with the low confining stress (OCR 2.0) tests. Due to sample shear stiffness and generally low-end friction, the samples were partially sliding along the interface with the filter stones / platens, rather than yielding with shear deformation. These tests were performed with roughened, grooved porous metallic filter stones, but the friction was not enough to overcome the sample shear stiffness at the low normal pressure. The OCR 2.0 tests were then modified by first consolidating the samples to the full estimated preconsolidation stress and then unloading back to the specified consolidation for shearing. This “seated” the samples into the platen, but some slippage still occurred.

Ultimately replacement platens were utilized. These were made of the same roughened porous metallic material but had raised fins designed to penetrate into the sample ends. The raised fin platens improved the test results, producing higher shear resistance when tested on adjacent samples, but some slippage still occurred as the fins sheared through the base of the sample.

Overall, the DSS tests have not provided a full measure of the undrained shear strength of the Glacial Lacustrine clay. In most tests, the measured response partly represents the slipping resistance of the interface between the soil and the DSS end platens. Despite the slippage, these tests are considered meaningful as they provide a lower-bound of available shear strength. Table 17 below provides the basic results of the DSS testing.

Reference: Springbank Off –Stream Reservoir (SR1) – Updated Geotechnical Materials Properties Design Basis Memorandum

Table 17. Results of Direct Simple Shear Testing of Glacial Lacustrine Clay

Borehole	Sample	Depth (m)	$\sigma_{v'}$* (kPa)	$S_{u5\%}$ (kPa)	S_u/σ_v'	Test OCR**
LLO1	ST4	3.32	120	87	0.725	2.0
LLO1	ST4	3.34	270	85	0.315	1.0
LLO1	ST7	4.92	140	53	0.379	1.9
LLO1	ST7	4.94	300	82	0.273	1.0
D14	ST8	3.18	60	46	0.767	2.1
D14	ST8	3.22	500	140	0.280	1.0
D60	ST2	1.00	500	113	0.226	1.0
GL1A	ST2	1.30	45	49	1.089‡	2.0
GL1A	ST2	1.37	500	127	0.254	1.0
GL1A	ST5	2.69	55	57	1.036‡	2.0
GL1A	ST5	2.72	500	134	0.268	1.0
GL1A	ST8	3.88	66	85	1.288‡	2.0
GL1A	ST8	2.92	500	150	0.300	1.0
GL1A	ST11	5.24	77	98	1.273‡	2.0
GL1A	ST11	5.27	500	137	0.274	1.0
GL1A	ST14	6.67	112	88	0.786‡	2.0
GL1A	ST14	6.70	500	143	0.286	1.0
GL1A	ST17	8.03	132	96	0.727‡	2.0
GL1A	ST17	8.06	500	140	0.280	1.0
GL2	ST3	1.79	73	43	0.589	2.0
GL2	ST3	1.82	500	132	0.264	1.0
GL2	ST6	3.12	73	27	0.369	2.2
GL2	ST6	3.16	500	128	0.256	1.0
GL2	ST10	4.92	90	50	0.556‡	2.0
GL2	ST10	4.97	500	131	0.262	1.0
GL2	ST13	6.29	100	43	0.430	2.0
GL2	ST13	6.32	500	131	0.262	1.0
GL2	ST16	8.09	105	96	0.873‡	2.0
GL2	ST16	8.12	500	135	0.270	1.0
GL2	ST19	9.40	110	81	0.736‡	2.0
GL2	ST19	9.46	500	120	0.240	1.0
GL3A	ST5	3.08	68	52	0.765‡	2.0
GL3A	ST5	3.12	500	122	0.244	1.0
GL4	ST4	2.24	68	53	0.779‡	2.0
GL4	ST4	2.27	500	125	0.250	1.0
LLO17	ST4	2.10	68	31	0.456	2.0
LLO17	ST4	2.14	500	113	0.226	1.0

*Test consolidation stress applied during shearing. **σ_p' established from nearby 1-D consolidation testing. ‡Tests performed with raised rib platens.

OCR 1.0 tests: Count 19, Mean S_u/σ_v' = 0.265, Standard Deviation S_u/σ_v' = 0.0216
OCR 2.0 tests: Count 18, Mean S_u/σ_v' = 0.757, Standard Deviation S_u/σ_v' = 0.2701

The undrained strength ratio (S_u/σ_v') can be used to model the shear strength of a soil as a function of the effective vertical stress. The S_u/σ_v' value is dependent on the consolidation state of the soil where a constant value can be used for normally consolidated soils, and the ratio increases as OCR increases. A correlation between S_u/σ_v' and OCR was suggested by Ladd (1992) and is shown in **Equation 1**:

$$\frac{S_u}{\sigma_v'} = S * OCR^{0.8}$$ **Equation 1**

where:

S_u = Shear strength (assumes ϕ = 0)

σ_v' = Vertical effective pressure

S = Normally consolidated shear strength ratio

OCR = Overconsolidation Ratio

0.8 = empirical exponent

The results of the direct simple shear tests conducted on the undisturbed glacial lacustrine soil samples indicate an average S_u/σ_v' of 0.265 for normally consolidated soil samples, and an average S_u/σ_v' of 0.757 for soil samples with an OCR of 2. Refer to Figure 37 for a plot of all DSS results. Design strength ratios were selected as 0.265 and 0.757for OCR of 1.0 and 2.0, respectively.

A relationship is needed to calculate S_u/σ_v' for any OCR. This was accomplished by using the above values (selected from the DSS test results) and solving for the exponent in Equation 2. The resultant exponent was calculated as 1.5, somewhat higher the empirical value suggested by Ladd. The relationship used to calculate S_u/σ_v' for the stability analyses for the glacial lacustrine foundation soils is then:

$$\frac{S_u}{\sigma_v'} = 0.265 * OCR^{1.5}$$ **Equation 2**

This equation is depicted on the results of the direct simple shear tests shown in Figure 37 below. The selected equation results in 54% of the DSS test results above the S_u/σ_v' envelope.

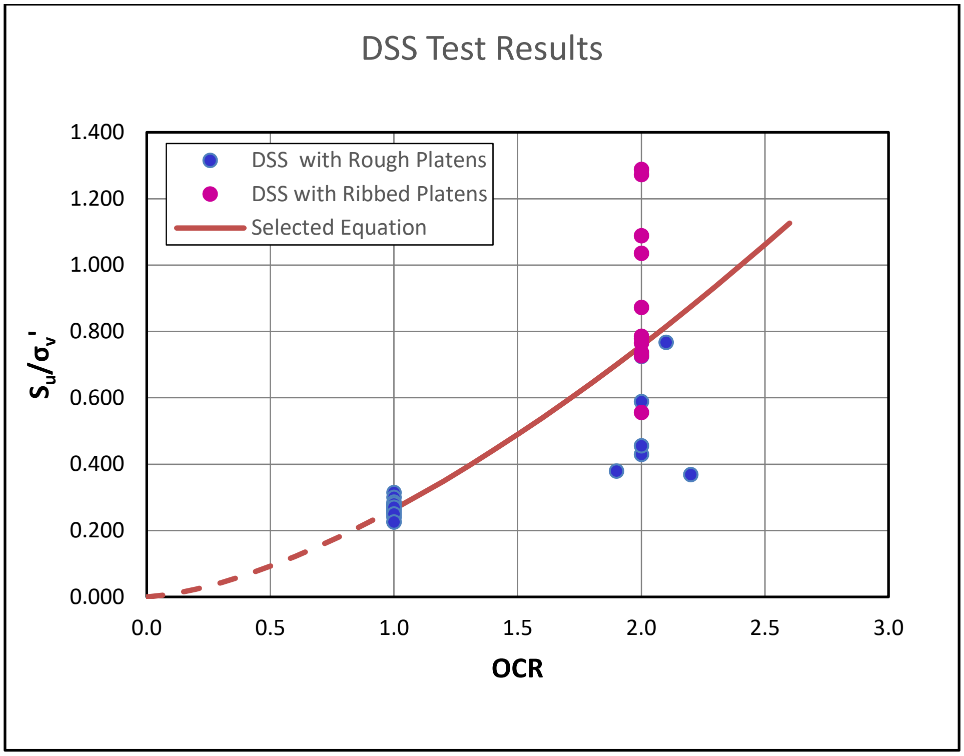


Figure 37. S_u/σ_v' versus OCR for the Glacial Lacustrine Foundation

2.6.2 SELECTED PARAMETERS

2.6.2.1 Undrained Strength for UU Tests and CPT Data

Undrained strength parameters for the glacial lacustrine and glacial till soils were initially selected using the results of the unconsolidated undrained laboratory testing.

For the glacial lacustrine soil, a preliminary undrained strength of 100 kPa was selected using the USACE two-thirds rule for the UU laboratory test results. CPT data was then evaluated. Using an Nkt value of 15, two-thirds of the CPT data points were above 120 kPa. Because the Nkt value was selected as a typical value and not based on site correlations, a value of 100 kPa was selected for the undrained shear strength of the glacial lacustrine soil. Approximately 80% of the CPT data points fall above this value. If an N_{kt} value of 18 could be justified, approximately two-thirds of the data points would fall above 100 kPa.

One unconsolidated undrained triaxial test was conducted on glacial till soil. This sample was obtained from DC1. No CPT borings were advanced near this boring, so a correlation between the UU test result and Nkt value was not performed. The result of the UU test was 125 kPa.

Undrained strength values from CPT data using an Nkt value of 15 were reviewed as shown on Figure 29. The CPT data for glacial till is more variable than glacial lacustrine. Approximately 95% of the CPT data points fall above 120 kPa. If an Nkt value of 26 could be supported, it would result in approximately two-thirds of the CPT data above the selected undrained shear strength of 120 kPa. Due to the large variability in CPT data for glacial till, the presence of many outliers, and the results of the UU test, an undrained strength of 120 kPa was selected for analysis.

The selected GL and GT undrained strength parameters from the UU tests and the CPT data are presented in Table 18. It is assumed that the sand? drain, gravel materials, and weathered bedrock are free-draining, and drained strength should be used for these materials in any undrained analyses.

Table 19. Selected Undrained Soil Strength Parameters from UU Tests and CPT Data

Material Name	Undrained Strength	
	Cohesion (kPa)	Friction Angle (degrees)
Embankment Shell	120	0
Embankment Core	100	0
Drain	0	33
Glacial Lacustrine	100	0
Glacial Till	120	0
Gravel	0	35
Weathered Bedrock	0	35

2.6.2.2 Strength Parameters from Undrained Strength Envelope Evaluation

The selected GL and GT undrained strength parameters from the undrained strength envelope evaluation are presented in Table 19.

Table 20. Selected Undrained Strength Parameters from Undrained Strength Envelope Evaluation

Material Name	Undrained Strength	
	Cohesion (kPa)	Friction Angle (degrees)
Remolded Glacial Lacustrine	25	15
Remolded Glacial Till	80	19
Embankment Shell/Core	40	17
Glacial Lacustrine	15	20
Glacial Till	60	19

2.6.2.3 Strength Parameters from Direct Simple Shear Testing

An S_u/σ_v' value of 0.23 is often used for normally consolidated clays; however, the direct simple shear and CU test results indicate a higher S_u/σ_v' value is appropriate for the glacial lacustrine soil. This is likely due to the glacial lacustrine having a higher silt content than the typical clay soil and some percentage of sand.

Direct simple shear test results were evaluated. However, these were conducted from soil samples with limited spatial distribution. There was some scatter in S_u/σ_v' value obtained from the thirty CU tests conducted at confining pressures resulting in normally consolidated conditions. Because of this, the thirtieth percentile value of 0.32 was selected as a reasonable value for the S_u/σ_v' from CU tests. This value from the CU tests correlates well with the 0.29 value obtained from the direct simple shear tests. An S_u/σ_v' value of 0.29 was selected for normally consolidated glacial lacustrine.

For glacial lacustrine with an OCR value of 2, the average results from the direct simple shear test was used to select the S_u/σ_v' value of 0.56. For OCR equal to 4, which is the average insitu OCR from consolidation testing, the equation $S_u/\sigma_v' = S * OCR^{0.8}$ was used to calculate a value of 0.87 using S = 0.29.

The soil parameters selected for use in the static stability analysis are included in Table 21. For the seismic stability, undrained strengths were reduced by 20 percent.

Table 21. Selected Soil Parameters from DSS Testing

Material	Unit Weight (kN/m³)	Bilinear Envelope: Drained Segment: Friction Angle (degrees)	Bilinear Envelope: Drained Segment: Cohesion (kPa)	Bilinear Envelope: Undrained Segment: Friction Angle (degrees)	Bilinear Envelope: Undrained Segment: Cohesion (kPa)	S_u/σ_v'
Sand Drain	21	33	0			
Glacial Lacustrine (OCR = 1)	18					0.29
Glacial Lacustrine (OCR = 2)	18					0.56
Glacial Lacustrine (OCR = 4)	18					0.87
Glacial Till	18	27	0	19	60	
Embankment	20	24	0	20	15	
Weathered Bedrock	21	35	0			

2.7 COMPRESSIBILITY OF SOILS

2.7.1 Laboratory Data

The pre-consolidation yield stress and over-consolidation ratio (OCR) for the glaciogenic deposits in Zones 9-11 (the dam footprint) have been estimated from 1D consolidation testing and CPT data.

Thirty-three (33) one-dimensional consolidation tests (ASTM D2435) were undertaken on undisturbed GL samples. The yield stress (commonly referred to as the pre-consolidation stress) was calculated using the Casagrande approach and used to derive the overconsolidation ratio (OCR), recompression index (C_r), and compression index (C_c) for each test. The data from the consolidation testing is presented in Table 22.

Table 22. Summary of Consolidation Test Results – Glacial Lacustrine

ID	Unit	Depth (m)	Pre-Consolidation Pressure (kPa)	In-situ Void Ratio	OCR	C_c	C_r
DC33	GL	3.00-3.60	190	0.894	3.2	0.25	0.09
DC34	GL	3.00-3.60	180	0.760	3.0	0.27	0.06
D2	GL	1.50-1.95	205	0.767	6.6	0.21	0.09
D12	GL	2.70-3.20	400	0.696	7.6	0.24	0.06
D14	GL	3.00-3.50	125	0.629	2.1	0.13	0.04
D14	GL	4.60-5.10	265	0.778	3.0	0.20	0.05
D14	GL	6.10-6.60	270	0.690	2.4	0.17	0.03
D16	GL	3.00-3.45	230	0.706	4.0	0.15	0.03
D20	GL	0.90-1.35	190	0.516	9.4	0.13	0.04
D20	GL	2.70-3.20	160	0.652	3.0	0.16	0.05
D20	GL	5.40-6.00	285	0.654	2.8	0.24	0.08
D20	GL	7.60-8.05	180	0.580	1.3	0.09	0.01
D28	GL	3.50-3.92	275	0.607	4.1	0.21	0.04
D30	GL	1.70-2.15	100	0.526	2.9	0.13	0.03
D30	GL	4.40-4.85	120	0.581	1.4	0.12	0.03
D36	GL	4.50-4.95	280	0.619	3.3	0.23	0.03
D51	GL	2.70-3.15	270	0.573	5.1	0.21	0.06
D59	GL	2.40-2.89	260	0.629	5.5	0.19	0.05
D60	GL	0.80-1.25	140	0.767	7.6	0.21	0.04

Reference: Springbank Off –Stream Reservoir (SR1) – Updated Geotechnical Materials Properties Design Basis Memorandum

D68	GL	4.40-4.85	160	0.448	1.9	0.12	0.02
LLO05	GL	3.00-3.45	120	0.573	2.1	0.11	0.03
LLO12	GL	3.00-3.45	115	0.713	2.0	0.16	0.05
LLO17	GL	2.25-2.70	145	0.728	3.3	0.19	0.06
GL1A	GL	1.50-1.95	95	0.692	3.1	0.12	0.03
GL1A	GL	4.05-4.50	200	0.525	2.6	0.16	0.04
GL1A	GL	5.40-8.85	160	0.552	1.6	0.12	0.03
GL1A	GL	7.20-7.65	240	0.532	1.8	0.12	0.02
GL2	GL	1.95-2.40	155	0.570	4.0	0.13	0.03
GL2	GL	5.10-5.55	190	0.636	2.0	0.16	0.04
GL2	GL	7.35-7.80	210	0.594	1.5	0.13	0.03
GL2	GL	8.25-8.70	155	0.658	1.0	0.17	0.04
GL3	GL	3.25-3.70	150	0.537	2.4	0.14	0.03
GL4	GL	2.40-2.85	145	0.854	3.1	0.19	0.06

Project wide results of pre-consolidation pressure versus depth and overconsolidation ratio versus depth for GL soils are included in Figure 38 and Figure 39. The spatial distribution of the Cr and Cc values obtained from 15 consolidation tests performed on undisturbed and remolded GL and GT soil samples are summarized in Figure 40.

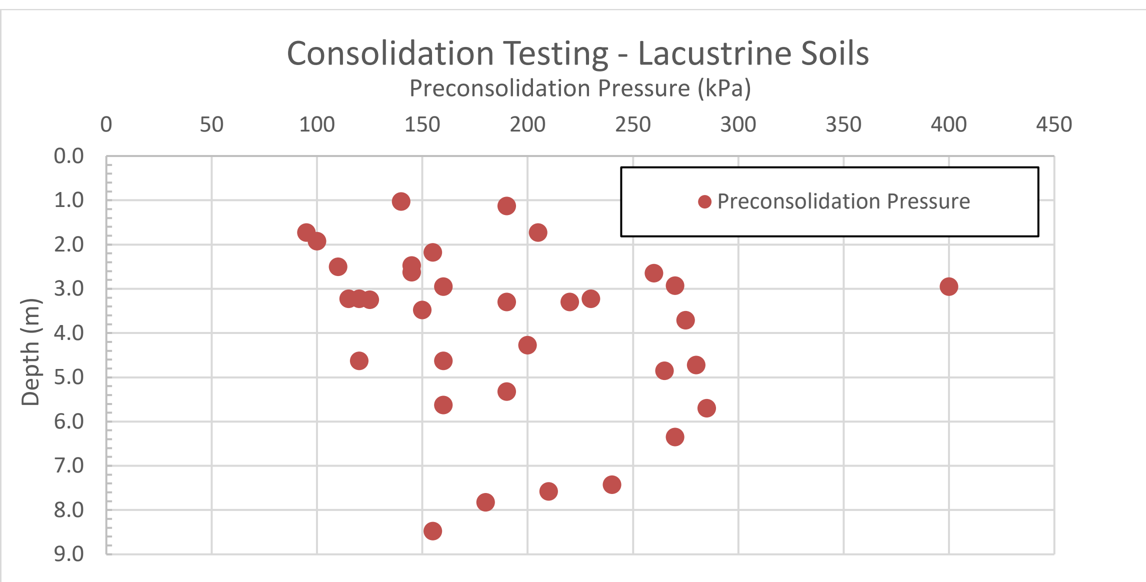


Figure 38. Pre-Consolidation Pressure Versus Depth - Glacial Lacustrine

Reference: Springbank Off –Stream Reservoir (SR1) – Updated Geotechnical Materials Properties Design Basis Memorandum

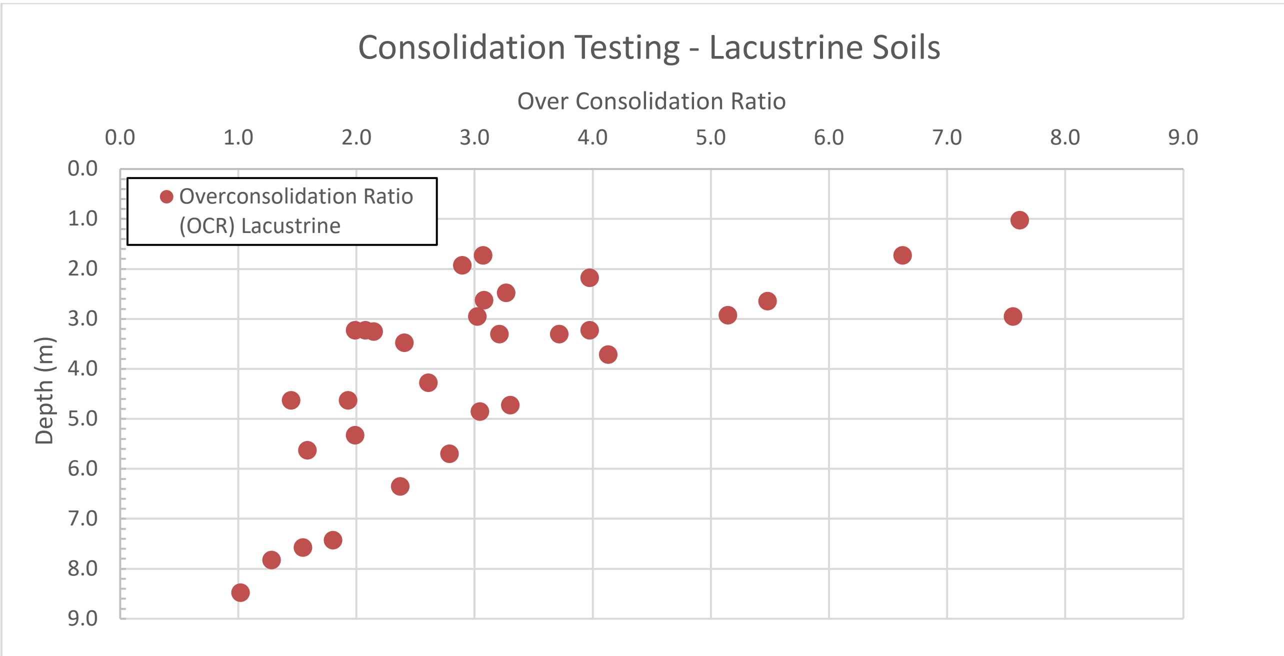


Figure 39. Over Consolidation Ratio with Depth - Glacial Lacustrine

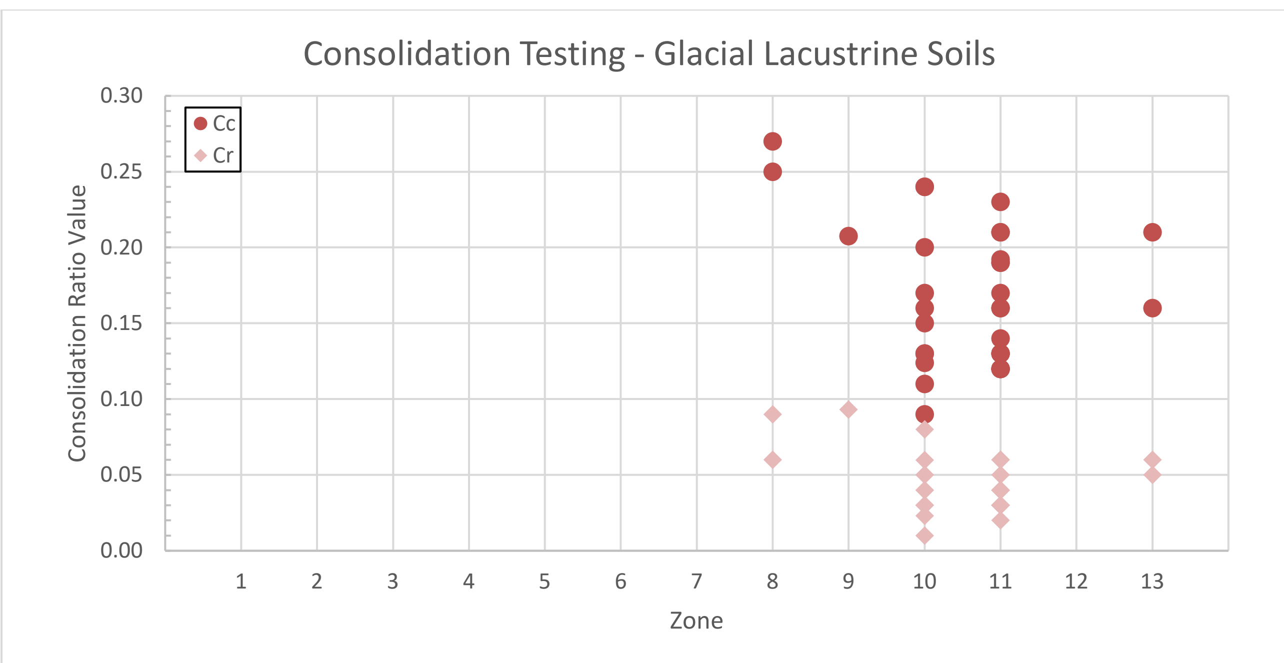


Figure 40. Spatial Distribution of Cr and Cc Values - Glacial Lacustrine

Reference: Springbank Off –Stream Reservoir (SR1) – Updated Geotechnical Materials Properties Design Basis Memorandum

Due to difficulty in obtaining undisturbed Shelby tube samples of glacial tills, only eleven one-dimensional consolidation tests were undertaken on undisturbed GT samples. The data from the consolidation testing is presented in Table 23.

Project wide results of pre-consolidation pressure versus depth and overconsolidation ratio versus depth for GT soils are included in Figure 41 and Figure 42. The spatial distribution of the C_r and C_c values obtained from the 13 consolidation tests performed on undisturbed GT soil samples are summarized in Figure 43.

Table 23. Summary of Consolidation Test Results – Glacial Till

ID	Unit	Depth (m)	Yield Stress (kPa)	In-situ Void Ratio	OCR	C_c	C_r
D8	GT	1.80-2.30	310	0.612	8.4	0.15	0.03
D11	GT	1.60-1.90	245	0.669	7.8	0.18	0.06
D62	GT	4.60-5.05	87	0.489	1.0	0.15	0.02
D68	GT	7.60-8.10	200	0.588	1.4	0.17	0.03
LLO08	GT	4.60-5.05	115	0.576	1.3	0.15	0.04
LLO12	GT	4.60-5.05	120	0.505	1.4	0.09	0.02
LLO12	GT	7.60-8.05	120	0.504	0.9	0.13	0.02
LLO17	GT	4.05-4.50	110	0.467	1.4	0.08	0.02
GL1A	GT	10.90-11.35	205	0.516	1.0	0.08	0.02
GL2	GT	10.5-10.95	135	0.482	0.7	0.08	0.02
GL2	GT	11.55-12.00	90	0.304	0.4	0.08	0.02

Reference: Springbank Off –Stream Reservoir (SR1) – Updated Geotechnical Materials Properties Design Basis Memorandum

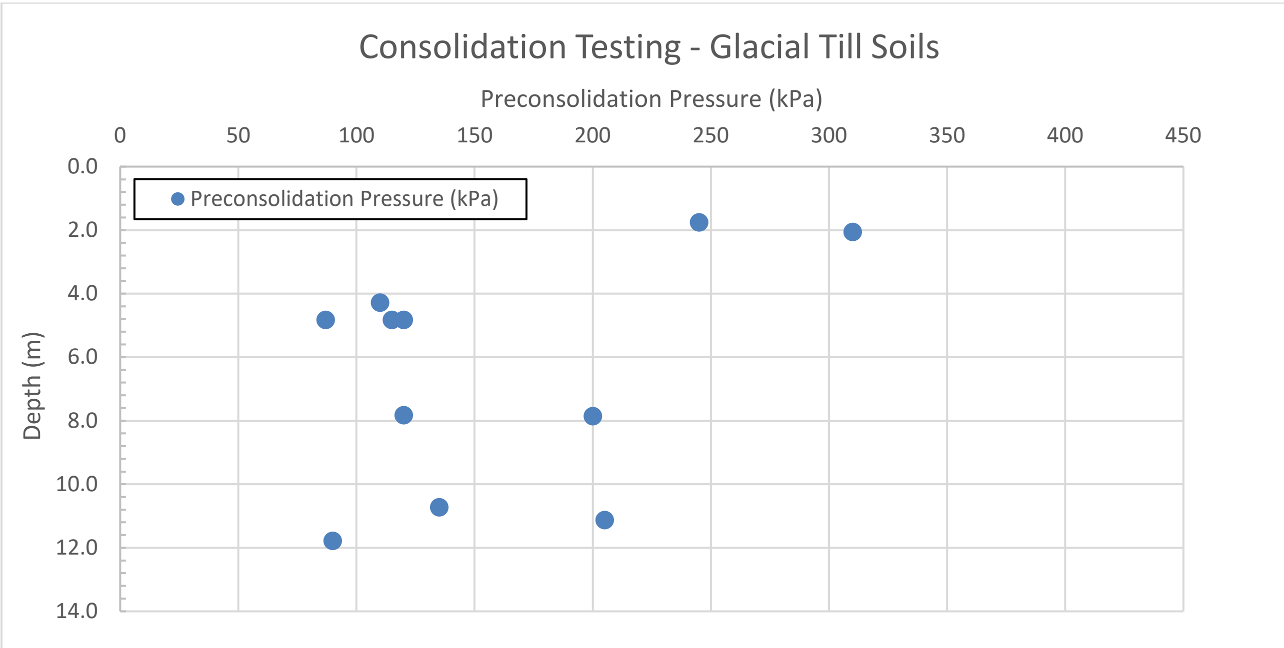


Figure 41. Pre-Consolidation Pressure Versus Depth - Glacial Till

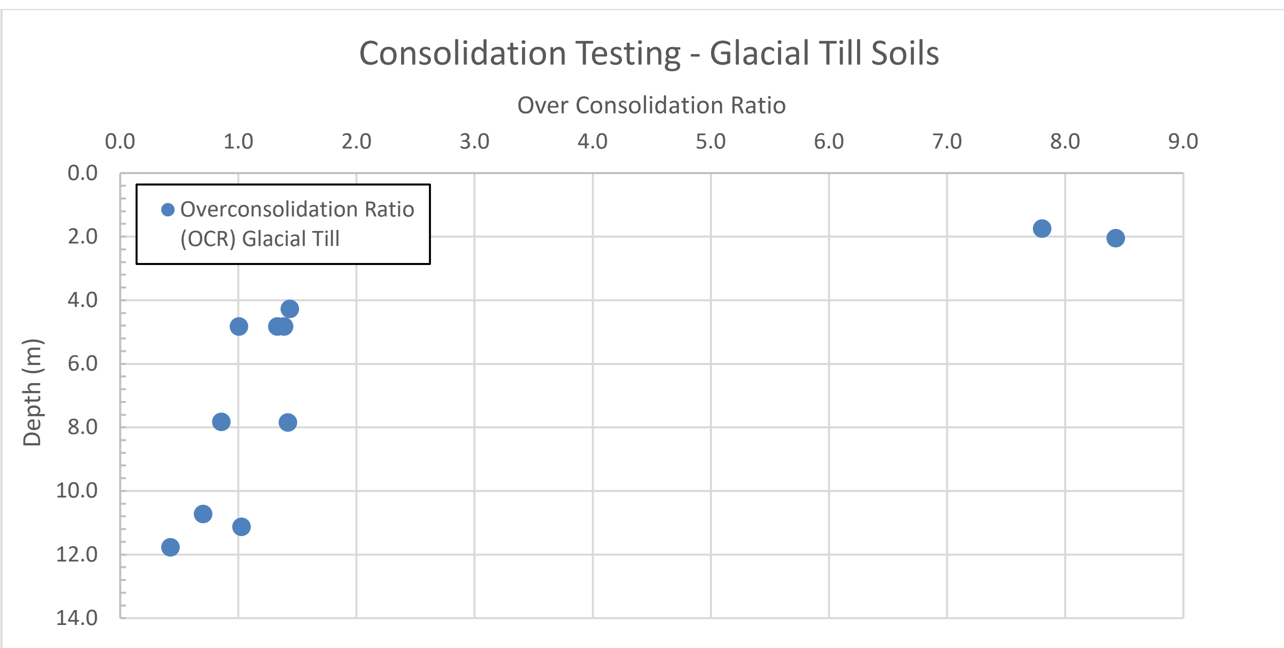


Figure 42. Over Consolidation Ratio Versus Depth - Glacial Till

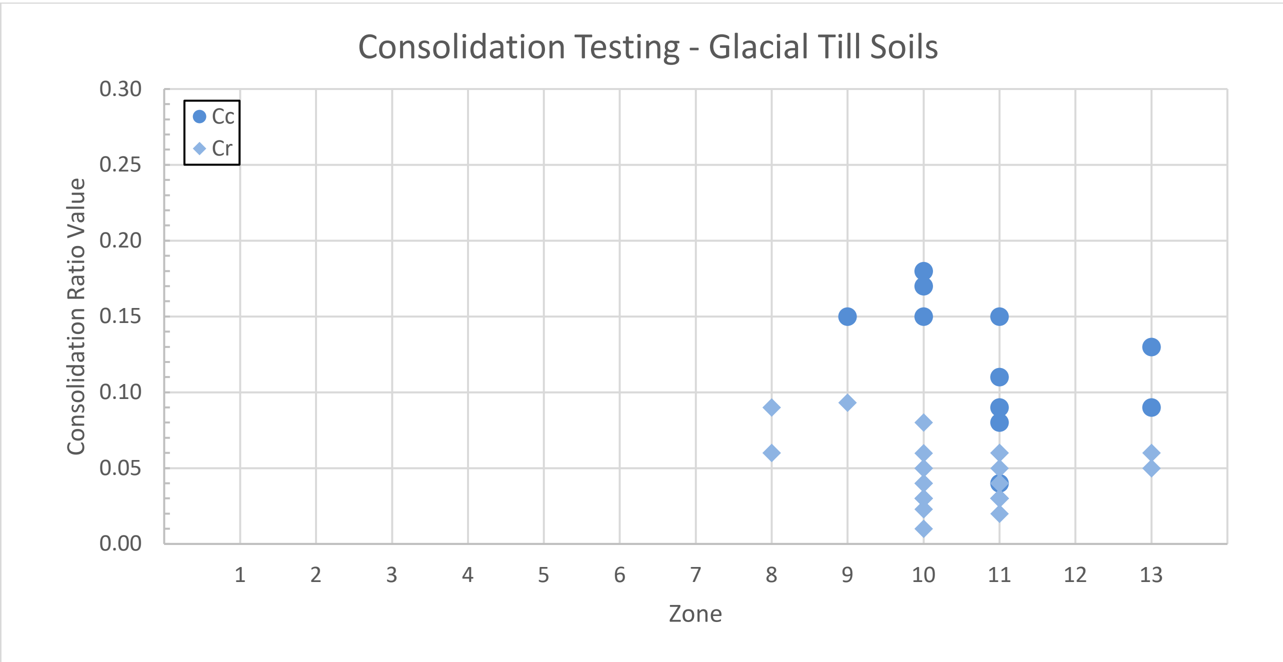


Figure 43. Spatial Distribution of Cc and Cr Consolidation Values - Glacial Till

2.7.2 Selected Parameters

Spatial consolidation test parameters of pre-consolidation pressure (Pc), Cc and Cr were used in the settlement analyses to calculate foundation soil settlement below the proposed embankment at specific embankment cross section locations. Settlement of the embankment core was estimated from an empirical settlement equation for earthfill clay core dams (Hunter and Fell, 2003).

3.0 BEDROCK PROPERTIES

A total of 97 rock core borings were completed at the SR1 Project site during the 2016 exploration. Boring logs, and associated laboratory testing are included in the Geotechnical Factual Report (Stantec 2016).

As discussed in Section 1.2 above, the project site is underlain by three primary bedrock formations; the Brazeau Formation, the Coalspur Formation and the Paskapoo Formation. The Diversion Channel passes over (and through) both the Brazeau and Coalspur formations. The Storage Dam lies largely over the Paskapoo Formation, with a small section of the western abutment over the Coalspur Formation. Since the deeper rock cutting occurs near the western (inlet) end of the Diversion Channel, the Brazeau Formation is most critical to understand rock cut stability.

3.1 DESCRIPTION OF BEDROCK FORMATIONS

For the Brazeau Formation, the dominant lithology is mudstone, siltstone and fine grained sandstone. Coaly shale and coal beds are common. Mudstone greenish-grey to dark grey, soft and generally weathered, siltstone, laminated, thin coal and coaly shale beds; numerous thin bentonites. Fractured throughout.

The Coalspur Formation is a sequence of inter-bedded mudstone, siltstone, fine grained sandstone with subordinate coarser grained sandstone layers and channel lag deposits, and coal; subordinate conglomerate and bentonite.

The Paskapoo Formation is comprised of an inter-bedded non-marine sandstone, siltstone and mudstone with minor amounts of bentonite and coal. Sandstone, pale grey, thick- to thin-bedded, commonly cross-stratified, Mudstone, gray to greenish-gray, with minor conglomerate, mollusc coquina, and coal.

3.2 BED AND JOINT ORIENTATION

The surficial geology at the SR1 Project Site – progressing west to east - exhibits a transition from steeply dipping (near vertical beds) to sub horizontal bedding. The Brazeau Formation at the western limit of the site, in addition to the transition from vertical to lesser dip angles, also contains significant local folding. In general the bedding alignment of the formations could be observed in outcrops along the Elbow River and along Highway 22. The variation of the bedding can be described as follows: Note that "OCxx" refers to Outcrop number as described in the Geotechnical Appendix of the Preliminary Design Report.

Brazeau Formation

- At Diversion Inlet (Diversion Channel Station 10+000) OC01 – Dip ENE at 75 to 85 degrees
- Near Diversion Channel Station 10+500 at OC04 – Dip SW at 20 to 45 degrees
- Near Diversion Channel Station 10+700 at OC05 – Dip NE at 30 to 70 degrees
- Shallow Syncline occurs at this location
- Near Diversion Channel Station 10+900 at OC05 – Dip SW at 25 to 64 degrees
- Near Diversion Channel Station 12+100 at OC08– Dip NE at 40 to 50 degrees
- Near Diversion Channel Station 12+300 at OC09 – Dip NE at 25 to 50 degrees
- Near Diversion Channel Station 12+500 at OC10 – Dip NE at 15 to 30 degrees
- Near Diversion Channel Station 12+900 at OC11 – Dip NE at 15 to 30 degrees

Coalspur Formation Begins

- Near Diversion Channel Station 13+400 at OC06&07 – Dip NE at 25 to 35 degrees

Paskapoo Formation Begins

- Near Storage Dam Station 22+200 at OC13 – Dip NE at 10 to 15 degrees

Each of the formations - but particularly the Brazeau Formation - are highly fractured, with multiple joint sets perpendicular to and parallel to the bedding orientation. Given the numerous different joints observed, detailed mapping of joints was not attempted.

3.3 UNCONFINED COMPRESSION TESTS

A total of 5 unconfined compression tests were completed on the samples retrieved. The results of UCS testing are summarized in Table 24. All tests were performed on Brazeau Formation samples. Refer to the Geotechnical Factual Report (Stantec 2016) for complete results of compression testing.

Table 24 Summary of Unconfined Compression Tests on Rock

Borehole	Depth (m)	Rock Material	Strain at Failure (%)	Compressive Strength (MPa)	Young's Modulus (GPa)	Poisson's Ratio
DS1	5.2	Sandstone	0.475	33.48	8.22	0.287
DS2	2.7	Mudstone	0.634	37.41	7.36	0.374
DS3	4.7	Mudstone	0.654	31.39	7.42	0.354
DS5	5.5	Mudstone	0.445	2.62	1.29	0.001
DS6	30.7	Shale	0.665	1.22	1.11	0.000

3.4 DIRECT SHEAR TESTS

A total of five (5) direct shear tests were completed on the samples retrieved. Each test consisted of three individual shears with all test sets performed one each at 70, 140 and 210 kPa normal stress. The results of shear testing are summarized in Table 25. All tests were performed on Brazeau Formation samples. Refer to the Geotechnical Factual Report (Stantec 2016) for complete results of shear testing.

Table 25 Summary of Direct Shear Testing on Rock

Boring	Depth (m)	Test Interface Type	Bedrock Type	Peak Friction Coefficient	Residual Friction Coefficient
DS10	3.89	Natural	Mudstone	0.83	0.79
DS1	3.35	Smooth Sawn	Mudstone / Siltstone	0.57	0.45
DS2	-	Smooth Sawn	Mudstone	0.50	0.41
DS6	33.49	Intact Sample	Mudstone	0.81	0.81
DS9	4.19	Smooth Sawn	Siltstone	0.83	0.80

3.5 PERMEABILITY TESTING

The results of packer testing and groundwater slug testing in the Paskapoo unit are summarized in Table 26 and Table 27, respectively. These indicate the in-situ hydraulic conductivity ranged between 6.5E-5 and 6.1E-8 m/s. This is comparable to a slightly permeable (widely to very widely spaced discontinuities) rock mass.

Table 26. Results of Packer Testing Based on Bedrock Type

Bedrock Type	Number of Tests	Minimum Permeability (m/s)	Maximum Permeability (m/s)	Average Permeability (m/s)
Mudstone	5	2.2E-7	4.3E-5	8.8E-6
Claystone	2	1.6E-7	2.3E-6	1.2E-6
Siltstone	5	4.2E-6	1.1E-7	1.6E-6
Sandstone	4	3.3E-7	2.8E-5	9.9E-6
Mixed	20	6.1E-8	6.5E-5	5.4E-6

Table 27. Results of Slug Test in Bedrock

ID	Ground Elevation (m)	Top of Screen (El. M)	Base of Screen (El. M)	K_r Hvorslev Method (m/s)	K_r KGS Method (m/s)
D51	1194.4	1165.4	1163.9	1.46E-5	-
GW1	1211.7	1199.5	1196.5	1.16E-6	2.33E-6
GW4	1204.3	1185.7	1182.6	8.77E-7	1.93E-6
GW6	1196.5	1177.6	1174.5	2.83E-9	3.84E-9

3.6 DENSITY / UNIT WEIGHT

Selected samples of the rock core obtained from the borings were measured for unit weight. A summary of the results is provided in Table 28. All selected samples are from the Brazeau Formation.

Table 28 Bedrock Measured Unit Weights

Boring	Depth (m)	Bedrock Type	Unit Weight (kN/m^3)
FB6	6.15	Sandstone, poor quality	25.1
DC6	25.37	Sandstone, fair quality	23.3
DC6	26.67	Sandstone, fair quality	23.8
DC7A	21.76	Siltstone, v. poor quality	30.0

3.7 BEDROCK STRENGTH PARAMETERS FOR MOHR-COULOMB EVALUATION

Following the submittal of the Draft Preliminary Design Report, bedrock materials were re-evaluated. In the preliminary design, the Hoek-Brown methodology was used to develop separate properties for the sandstone beds and other bedrock. On re-evaluation, it was determined that a simplified Hoek-Brown approach would be most appropriate. This approach developed the general rock mass characteristics with the sandstone included.

In order to use the Hoek-Brown criterion for estimating the strength of jointed rock masses, four properties of the rock mass need to be estimated. These include the following:

- Uniaxial compressive strength (UCS) of intact rock pieces
- Value of the Hoek Brown constant "m_i" for the intact rock pieces
- Value of the Geological Strength Index (GSI) for the rock mass
- Disturbance Factor (D)

The selection of these properties is described below.

UCS of Intact Rock Pieces

Five UCS tests were performed on samples of the Brazeau Formation. UCS tests were performed on mudstone, shale, and sandstone. The UCS for this formation varied from 1.22 Mpa to 37.41 Mpa for shale, mudstone, and sandstone samples. **A UCS of 3.0** was selected to represent the Brazeau Formation based on the range of tested values. The selected UCS value corresponds to a "very weak", highly weathered rock based on tables provided in Practical Rock Engineering (Hoek, 2006).

Hoek-Brown Constant "m_i"

The Hoek-Brown constant "m_i" was selected from a table provided in Practical Rock Engineering (Hoek, 2006) according to material type. The material type was selected as shale, in which a range of values of 6 +/- 2 is recommended. **An m_i value of 6** was selected based on the wide range of relatively low quality materials that form the Brazeau Formation.

Reference: Springbank Off –Stream Reservoir (SR1) – Updated Geotechnical Materials Properties Design Basis Memorandum

Geologic Strength Index (GSI)

The Geologic Strength Index (GSI) provides a number which, when combined with the intact rock properties, can be used for estimating the reduction in the rock mass strength for different geological conditions (Hoek, 2006). The GSI varies from 0 to 100 based on descriptive estimates of the rock structure and the surface quality of the rock.

The Brazeau Formation can be described by three GSI structure categories including very blocky, blocky/disturbed/seamy, and disintegrated. The Brazeau Formation can be described by three GSI surface condition categories including fair, poor, and very poor. Based on these descriptive categories, the GSI is estimated to range between 30 and 40. **A GSI value of 35** was selected.

Disturbance Factor (D)

The Disturbance Factor (D) is used to adjust the Hoek-Brown shear strength of the near surface rock mass due to excavation disturbance. The Disturbance Factor varies from 0 to 1.0, for no effect, and for maximum disturbance effect, respectively. This adjustment is only applied to the disturbed face of the rock mass, generally less than 1 to 2 m in thickness. For controlled blasting, or mechanical or hand excavation in poor quality rock masses (no blasting), D is taken as zero, and has no effect on the Hoek-Brown shear strength model. Based on the generally poor quality of the rock mass, and anticipated mechanical excavation or excellent quality controlled blasting, D is estimated equal to 0 (no effect on Hoek-Brown shear strength).

Note that the input parameters UCS and GSI have each increased slightly from the values provided in the Preliminary Design Report to account for the inclusion of the sandstone within the combined unit. The Disturbance Factor included previously (0.7) would only be applicable to the upper 1 to 2 m of the rock mass, so the value of 0.0, which is representative of the rest of the rock mass, has been selected for the re-evaluation.

The Geostudio software uses Hoek-Brown parameters to develop a shear-normal strength function. The generated function from Geostudio using the Hoek-Brown parameters discussed above is included in Figure 44.

Reference: Springbank Off –Stream Reservoir (SR1) – Updated Geotechnical Materials Properties Design Basis Memorandum

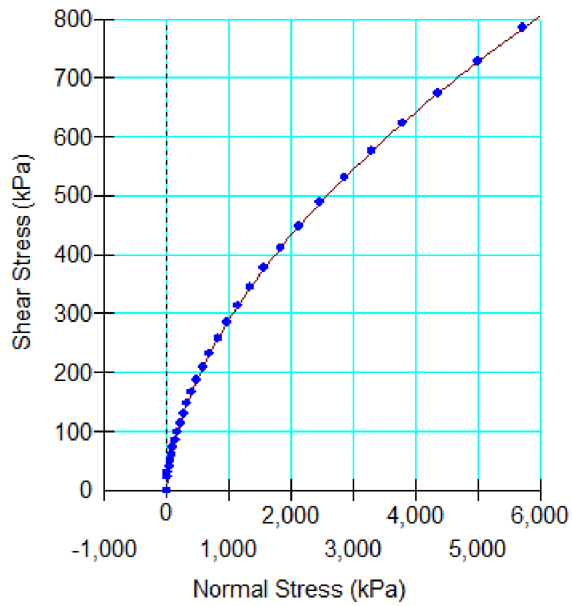


Figure 44. Shear-Normal Function using Hoek-Brown Parameters from Geostudio

3.8 BEDROCK STRENGTH ON BEDS & JOINTS FOR KINEMATIC WEDGE ANALYSES

The Brazeau Formation is characterized by numerous closely spaced bedding and joint planes with variable orientations. There does not appear to be predominant bedding or joint orientations with significant persistence that would tend to control stability of slopes through potential wedge, planar, or toppling type failures. In general, the size of the blocks created by the bedding and joints is anticipated to be relatively small in comparison within the size of the rock slope being analyzed. Accordingly, it is possible that there may be locations where unfavorable orientation of bedding and joints relative to a slope face may cause localized failures. However, it is anticipated that these failures will likely be relatively limited, both laterally and vertically. Therefore, it is believed that the overall strength of the Brazeau Formation is more appropriately characterized through analytical methods that model isotropic rock mass behavior such as the Hoek-Brown methodology (Hoek, 2006).

4.0 SUMMARY

The Geotechnical parameters selected in accordance with the discussions in Section 3 above were used to perform the analysis of the Diversion Channel excavated side slopes and the Storage Dam side slopes and foundation. Additional discussion of the use of these parameters in the analyses can be found in the respective Stability Analysis Memorandums for those elements.

STANTEC CONSULTING SERVICES INC.

Dan Back P. Eng., P.E.
Principal
Phone: (859) 422-3000
Fax: (859) 422-3100
Dan.Back@Stantec.com

Hugo Aparicio P. Eng., P.E.
Senior Principal
Phone: (859) 422-3037
Fax: (859) 422-3100
Hugo.Aparicio@Stantec.com

c. *John Montgomery*
John Menninger
Norm Fallu
Eric Monteith

ATTACHMENT 7
PSHA REPORT

Seismic Hazard Assessment – Springbank Off-Stream Dam and Reservoir

FINAL REPORT

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

Prepared by:
Stantec Consulting Ltd.
4730 Kingsway
Burnaby, BC V5H 0C6
Phone: (604) 436-3014
Fax: (604) 436-3752

Project No. 110773396

February 28, 2017

Rev.	Date	Description	Author	Reviewer	Approver
2	28-Feb-2017	Final Report	C. Longley	W. Quong	A. Bayliss
1	14-Feb-2017	Revised to Address Reviewer Comments	C. Longley	W. Quong	A. Bayliss
0	28-Nov-2016	Draft issued for review	C. Longley	W. Quong	A. Bayliss

Table of Contents

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

1.0 INTRODUCTION

Stantec Consulting Ltd. (Stantec) has completed a seismic hazard assessment for the Springbank Off-Stream Dam and Reservoir (SR1) project. The project is being developed by the Government of Alberta to divert and temporarily store floodwater from the Elbow River Basin. The project is located approximately 18 km west of Calgary, AB, and will include a diversion structure, a diversion channel and a maximum 27 m high dam.

The purpose of this seismic hazard assessment was to define ground motion parameters for use in seismic design of the proposed dam and associated appurtenant structures to satisfy the Canadian Dam Association (CDA) Dam Safety Guidelines (2007). The scope of work for this study consisted of the following:

- Review of geological, geotechnical and geophysical information for the project site, and review of historical seismicity within the project region;
- Development of a seismic source model reflective of the geological and tectonic setting of the project;
- Development of magnitude recurrence parameters to define the frequency of occurrence of earthquakes over a range of magnitudes for each seismic source;
- Selection of appropriate Ground Motion Prediction Equations (GMPEs) for use in estimation of earthquake ground motions;
- Probabilistic analysis to define the Earthquake Design Ground Motion (EDGM) with an Annual Exceedance Probability (AEP) of 1/10,000 at the SR1 site; and
- Selection of earthquake records for use in dynamic analysis of the proposed dam and associated appurtenant structures.

This report summarizes the geological and tectonic setting of the project, outlines our analysis methodology, provides recommended ground motion parameters for use in seismic design of the proposed dam and associated appurtenant structures, and provides appropriate earthquake records for use in dynamic analysis.

2.0 GEOLOGICAL AND TECTONIC SETTING

2.1 GEOLOGICAL SETTING

In support of the Environmental Impact Assessment (EIA) for the SR1 project, Stantec carried out a terrain assessment for project area. As indicated in our terrain assessment study, the project area is underlain by the Paleogene-aged sedimentary rocks of the Paskapoo Formation, consisting of mudstone and siltstone with lesser sandstone, conglomerate, coquina and coal (Prior et al., 2013).

Based on 1:50,000-scale mapping for the Calgary Urban Area (Moran, 1986), the project area is predominantly mapped as consisting of silt and clay glaciolacustrine deposits. However, a significant portion of the project area in mapped as Spy Hill drift overlying rocks from the Porcupine Hills formation. This material is a pebble-loam till overlying sandstone, siltstone and mudstone. Scattered bedrock outcrops and the fluvial sediments of the modern Elbow River constitute relatively minor coverage of the project area. Areas of glacial and modern fluvial sediments, characterized as silt overlying gravel possibly with minor sand, are subordinate in the project area and mapped in smaller units along the Elbow River; pebbly loamy till is mapped overlying bedrock in some areas (Moran, 1986).

The subsurface conditions encountered in the Stantec geotechnical investigation at the site were generally consistent with the published information on geology and surficial geology. At the diversion structure site, boreholes on the southeast side of the Elbow River indicated up to 2.1 m of overburden soil consisting of silty gravel with some sand and inferred cobbles. Boreholes on the northwest side of the river indicated overburden soil consisting of up to 11.7 m of stiff to hard clay, underlain by very dense sandy gravel to clayey gravel which extended to a maximum depth of 14.1 m. Bedrock underlying the overburden soils on both side of the river consisted of interbedded deposits of claystone, siltstone, mudstone, shale, and sandstone.

At the dam site, the overburden soils were found to consist primarily of stiff to hard clay to a depth of up to 20.1 m below the ground surface, with some zones of dense to very dense sand and gravel occurring mostly near the northeastern end of the dam footprint. Similarly to the diversion structure site, bedrock underlying the overburden soils consisted of interbedded deposits of claystone, siltstone, mudstone, shale, and sandstone.

Shear wave velocity measurements were obtained during the Stantec subsurface investigation by means of Seismic Cone Penetration Test (SCPT) and Multi-channel Analysis of Surface Waves (MASW) testing. Based on the measurements recorded in the SCPT and MASW tests, the lower bound values for shear wave velocity in the top 30 m below the ground surface (i.e., V_{s30}) were approximately 265 m/s at the dam site and 425 m/s at the diversion structure site.

2.2 TECTONIC SETTING

The SR1 project site is located near the eastern limit of the Cordilleran deformation belt, which is characterized by closely spaced, low displacement, north-northwest to south-southeast trending thrust faults. Notably, the Brazeau thrust fault is mapped as crossing the proposed diversion channel approximately 2 km west of the dam site. Based on our review of published literature, no information is available with respect to known active faults in the project region. However, we consider that because of its proximity to the dam site, the Brazeau thrust fault should be evaluated by a specialist in earthquake geology to confirm whether any evidence exists of activity within the Holocene epoch (i.e., approximately the last 10,000 years), which would impact our assessment. The current assessment implicitly assumes that this fault does not concentrate seismicity above that experienced by the surrounding areas.

The SR1 project site is situated in an area of low to moderate seismic activity. Historical seismicity near the project site is shown on Drawings 1 and 2 in **Appendix A**, which indicate the epicentral locations and magnitudes for recorded earthquakes in the project region. The locations and magnitudes of the recorded earthquakes are sourced from the Canadian Composite Seismicity Catalogue (CCSC11) for Western Canada (Macias-Carrasco et al., 2011), and the Alberta Geological Survey (AGS) database (Stern et al, 2016). The CCSC11 database includes records up to the end of 2010, and the AGS database includes records up to the end of 2015.

Induced seismicity is common in the foothills region of Alberta. Notable areas in which induced seismicity has been documented include the Crooked Lake Sequences (Schultz et al., 2015a) located approximately 30 km west of Fox Creek, the Brazeau River Cluster (Schultz et al., 2014) located approximately 150 km northwest of Calgary, the Rocky Mountain House Seismogenic Zone (Wetmiller, 1986) located approximately 100 km northwest of Calgary, and the Cardston Earthquake Swarm (Schultz et al., 2015b) located approximately 200 km southeast of Calgary. Induced seismicity in the foothills region has been linked to both hydraulic fracturing (i.e., “fracking”) and waste injection activities associated with oil and gas extraction (Atkinson et al., 2016).

3.0 SEISMIC DESIGN CRITERIA

The proposed SR1 dam will be classified as an extreme consequence dam in accordance with the Canadian Dam Association (CDA) Dam Safety Guidelines (2007). For an extreme consequence dam, these guidelines stipulate that the dam and associated appurtenant structures must be designed to resist an Earthquake Design Ground Motion (EDGM) with an Annual Exceedance Probability (AEP) of 1/10,000. The AEP level for the EDGM corresponds to the mean estimate of hazard.

EDGM parameters are to be described in terms of acceleration response spectra, peak ground motion parameters, magnitudes, distances and time histories. Deaggregation is required to identify the relative contributions of earthquakes with varying magnitudes and distances to seismic hazard, such that the most probable scenario events can be identified for use in time history selection and engineering design.

The CDA Dam Safety Guidelines (2007) note that because of differences in methodology for seismic safety evaluation and differences in performance criteria, seismic loads prescribed in building codes do not apply to dams and associated appurtenant structures. Moreover, the hazard estimates generated for the National Building Code of Canada (NBCC) are not site-specific, since little attention was paid to local factors or to uncertainty in the tectonic setting. Accordingly, to define the appropriate EDGM parameters for a specific site, a seismic hazard assessment must be conducted.

The CDA Dam Safety Guidelines (2007) state that seismic hazard is to be evaluated on the basis of current knowledge and standards, and should be based on both (i) local and regional geotectonic information; and (ii) a statistical analysis of historical earthquakes experienced in the region, taking into account all potential seismic sources capable of contributing significantly to seismic hazard at the site. In Canadian practice, seismic hazard is typically evaluated based on a probabilistic approach. As such, it is necessary to define seismic sources and to develop magnitude recurrence parameters for each source. Ground Motion Prediction Equations (GMPEs) should be selected to reflect the region and the types of seismic sources therein. Local subsurface conditions should also be taken into account in estimation of design ground motions.

Sources of uncertainty in the seismic hazard assessment include uncertainty in seismic source models, magnitude recurrence rates and GMPEs. These sources of uncertainty are to be assessed quantitatively to evaluate their impact on the estimated ground motions.

4.0 ANALYSIS METHODOLOGY

The Stantec evaluation consisted of a Probabilistic Seismic Hazard Assessment (PSHA) to define the Earthquake Design Ground Motion (EDGM) with an Annual Exceedance Probability (AEP) of 1/10,000 at the SR1 project site, located at latitude 51.048°, longitude -114.421°.

The PSHA included development of two alternative seismic source models. One model was regional in nature, incorporating clusters of induced earthquakes within broad areal sources. The other incorporated local sources reflecting the locations of past earthquake clusters. The robust approach was utilized, and seismic hazard was ultimately defined considering the higher of the values produced for the two alternative source models.

Magnitude recurrence parameters were estimated for each seismic source to define the rate of recurrence of earthquakes therein over a range of magnitudes. A key assumption in PSHA is that seismicity is uniformly distributed across each individual seismic source. Maximum magnitudes for each source were selected to reflect the information presented in Geological Survey of Canada (GSC) Open File 7576, which documents the 2015 National Building Code of Canada (NBCC) seismic hazard model. Published Ground Motion Prediction Equations (GMPEs) were utilized to relate earthquake characteristics to ground motions at the SR1 project site. The EDGM with an AEP of 1/10,000 was evaluated using EqHaz software (Assatourians and Atkinson, 2013). EqHaz software utilizes the method of Monte Carlo Simulation to generate a simulated earthquake catalogue, and computes the resulting earthquake motions using the specified GMPEs.

The probabilistic analysis included treatment of epistemic uncertainty using the "logic-tree" approach, whereby weighted sets of alternative input parameters and GMPEs are incorporated into the analysis to reflect incomplete knowledge of physical mechanisms, differences in expert opinions of modeling assumptions and extrapolation beyond observed ranges of data. Furthermore, the analysis included treatment of aleatory variability by incorporation of standard deviations in the GMPEs to reflect the inherent variability in prediction of future events.

4.1 SEISMIC SOURCE MODELS

As discussed above, our PSHA included development of two alternative seismic source models. The first model was regional in nature, incorporating clusters of induced earthquakes into broad areal sources based on an appreciation that the locations of induced earthquakes will vary spatially and temporally. The second model incorporated local sources reflecting past clusters of induced earthquakes to evaluate whether further activity in these same areas could significantly impact seismic hazard at the project site. For definition of seismic hazard at the project site, we utilized the robust approach, whereby the EDGM was defined considering the higher of the values from the two alternative source models. We also include recommendations on how to mitigate the potential for new induced seismicity clusters that could be initiated by future oil and gas activities in close proximity to the project site (see Section 5.4).

4.1.1 Regional Source Model

The regional source model developed in the Stantec assessment was modified from that developed by the GSC for the 2015 NBCC model. Namely, our analysis considered seismic sources within an approximately 300 km radius around the project site, in addition to the Cascadia Interface Source (CIS). Our analysis included modified versions of the Flathead Lake (FHLm), Rocky Mountain South (ROCSm), Southern British Columbia (SBCm) and Stable Cratonic Core (SCCm) areal source zones from the 2015 NBCC model. The Foothills zone in the 2015 NBCC model was not included as a distinct source in the Stantec model. Rather, portions thereof were assigned to the adjacent ROCSm and SCCm source zones to better reflect historical seismicity patterns in the project region.

Extensive work was completed by others for characterization of the CIS source in the 2015 NBCC model. Accordingly, no modifications were made to this source, with the exception of simplifying the interface geometry for compatibility with the EqHaz software capabilities.

The coordinates of the seismic sources included in the regional model are provided in Table 1. The regional seismic source model is also depicted on Drawing 1 in **Appendix A**.

Table 1. Coordinates of Seismic Source Boundaries (Regional Model)

FHLm		ROCSm		SBCm		SCCm		CIS	
Lat.	Long.	Lat.	Long.	Lat.	Long.	Lat.	Long.	Lat.	Long.
48.60°	-114.80°	54.00°	-116.40°	53.40°	-119.30°	48.00°	-111.00°	40.35°	-125.95°
48.60°	-114.00°	52.40°	-114.70°	52.80°	-118.00°	48.00°	-112.50°	41.00°	-126.17°
48.00°	-113.31°	48.00°	-112.50°	51.50°	-116.30°	52.40°	-114.70°	42.00°	-126.36°
47.00°	-112.20°	48.00°	-113.31°	50.40°	-115.60°	54.00°	-116.40°	43.00°	-126.40°
47.00°	-114.80°	48.60°	-114.00°	48.60°	-114.80°	54.00°	-111.00°	44.00°	-126.36°
-	-	48.60°	-114.80°	47.90°	-114.80°	-	-	44.80°	-126.28°
-	-	50.40°	-115.60°	47.90°	-119.00°	-	-	45.34°	-126.22°
-	-	51.50°	-116.30°	50.50°	-121.00°	-	-	46.00°	-126.10°
-	-	52.80°	-118.00°	51.50°	-121.00°	-	-	46.40°	-126.00°
-	-	53.40°	-119.30°	-	-	-	-	47.00°	-125.85°
-	-	54.00°	-118.80°	-	-	-	-	47.24°	-125.83°
-	-	-	-	-	-	-	-	47.36°	-125.87°
-	-	-	-	-	-	-	-	47.44°	-126.00°
-	-	-	-	-	-	-	-	47.89°	-127.00°
-	-	-	-	-	-	-	-	48.00°	-127.25°
-	-	-	-	-	-	-	-	48.34°	-128.00°

In the regional source model, clusters of induced seismicity were not defined as distinct seismic sources, but rather were considered to contribute to the broad areal sources in which they are situated. Such seismicity clusters are present at several locations within and near the boundaries of the ROCSm source zone. This approach demonstrates appreciation that induced seismicity may occur at any location where "fracking" or waste injection activities are carried out, and that locations of induced seismicity in the future will not necessary mirror those which have been observed in the past. However, it is acknowledged that this approach does not address the possibility of new clusters of activity near to the site. This issue is addressed in Section 5.4.

4.1.2 Local Source Model

The local source model included the seismic sources from the regional model, in addition to distinct sources for documented or suspected areas of induced seismicity. Namely, the local source model included areal sources for the previously noted Brazeau River Cluster (BRC), Cardston Earthquake Swarm (CES), Crooked Lake Sequences (CLS) and Rocky Mountain House Seismogenic Zone (RMH), in addition to an area approximately 30 km south of the project site (LOC) where clustering suggests the likelihood of induced seismicity.

The coordinates of the additional seismic sources included in the local model are provided in Table 2. The local seismic source model is also depicted on Drawing 2 in **Appendix A**.

Table 2. Coordinates of Boundaries for Additional Sources (Local Model)

BRC		CES		CLS		LOC		RMH	
Lat.	Long.	Lat.	Long.	Lat.	Long.	Lat.	Long.	Lat.	Long.
52.60°	-116.30°	48.90°	-113.00°	54.00°	-117.80°	50.80°	-114.20°	51.90°	-115.50°
52.90°	-116.30°	49.40°	-113.00°	54.80°	-117.80°	50.55°	-114.20°	52.40°	-115.50°
52.90°	-116.00°	49.40°	-112.30°	54.80°	-116.80°	50.55°	-114.40°	52.40°	-115.00°
52.60°	-116.00°	48.90°	-112.30°	54.00°	-116.80°	50.80°	-114.40°	51.90°	-115.00°

The local source model was considered for evaluation of whether further activity in areas of past "fracking" or waste injection could be expected to significantly impact seismic hazard at the project site. It should be noted that in the local source model, earthquakes occurring in distinct clusters within the ROCSm zone were not considered in estimation of magnitude recurrence parameters for the overall ROCSm zone.

4.2 MAGNITUDE RECURRENCE PARAMETERS

Magnitude recurrence parameters for areal seismic sources in the both the regional and local models were represented by truncated exponential relations, and magnitude recurrence parameters for the CIS source were represented using a characteristic relation. As previously noted, extensive work was completed by others for characterization of the CIS source in the

2015 NBCC model; therefore, no modifications to the magnitude recurrence parameters for this source were made in our study. Moreover, no changes were made to the magnitude recurrence parameters for the SCCm source, with the exception of scaling to the reduced source area.

For the FHLm, ROCSm, SBCm and induced earthquake cluster sources (i.e., BRC, CES, CLS, LOC and RMH), magnitude recurrence parameters were derived from historical earthquake data. Magnitude recurrence parameters for the FHLm, ROCSm and SBCm sources were estimated utilizing the Canadian Composite Seismicity Catalogue (CCSC11) for Western Canada (Macias-Carrasco et al., 2011), which contains earthquake data for events up to the end of the year 2010. The CCSC11 database can be found at www.seismotoolbox.ca (Atkinson et al.). Since rates of induced seismicity are constantly changing, magnitude recurrence parameters for the BRC, CES, CLS, LOC and RMH sources were estimated also using the Alberta Geological Survey (AGS) database (Stern et al., 2016), which contains earthquake data up to the end of the year 2015. All events in the CCSC11 database are presented in terms of moment magnitude, which is a measurement of earthquake magnitude in terms of seismic moment. Magnitudes for earthquakes in the AGS database were converted to moment magnitudes using the same factors used in the CCSC11 database.

The completeness windows considered for estimation of magnitude recurrence parameters in the FHLm, ROCSm and SBCm sources correspond to those utilized by the GSC for comparable zones in development of the 2010 NBCC model, as documented in GSC Open File 4459. The completeness windows considered for estimation of magnitude recurrence parameters for the BRC, CES, CLS, LOC and RMH sources were defined to reflect the period within which recurrence rates appear to be complete in the historical records. The completeness windows considered in our study are listed in Table 3.

Table 3. Completeness Windows for Seismic Source Zones

Year	Seismic Source							
	FHLm	**ROCSm**	**SBCm**	**BRC**	**CES**	**CLS**	**LOC**	**RMH**
2015	-	-	-	-	-	M2.0	-	-
1995	-	-	-	M2.9	-	-	-	-
1990	-	-	-	M3.5	-	-	-	-
1980	-	-	-	-	M3.5	-	-	-
1975	-	-	-	-	-	-	M2.7	M2.6
1966	-	M3.0	M3.0	-	-	-	-	-
1965	-	M3.3	M3.3	-	-	-	-	-
1960	M4.0	M4.3	M4.3	-	-	-	-	-
1940	M4.8	M4.8	M4.8	-	-	-	-	-
1917	M5.3	M5.3	M5.3	-	-	-	-	-
1899	M5.8	M5.8	M5.8	-	-	-	-	-

The trend of recurrence data reflecting the relative frequency of earthquake occurrence within each source zone as a function of magnitude was modeled as a Gutenberg-Richter relation, which is defined as follows:

$$Log\ N(M) = a - b*M$$

where "N(M)" is defined as the number of earthquakes per year of magnitude greater than "M", "M" is the moment magnitude, "a" is the y-intercept of the Gutenberg-Richter relation, and "b" is the slope of the relation.

Plots of the magnitude recurrence parameters for seismic sources in the regional model are presented in **Appendix B-1**, and plots of the magnitude recurrence parameters for seismic sources in the local model are presented in **Appendix B-2**. It should be noted that the value of "N_0" shown on the magnitude recurrence plots is equivalent to the value of $10^{\text{"}a\text{"}}$ with "a" as defined in the equation above, and the value of "Beta" is equivalent to the value of "b" in the equation above multiplied by the natural logarithm of 10.

Since the magnitude recurrence parameters for the SBCm source are well defined by historical records, the "best estimate" of the magnitude recurrence relation for the SBCm source was characterized by plotting a best-fit line through the historical data. For the FHLm, ROCSm and induced earthquake cluster sources (i.e., BRC, CES, CLS, LOC and RMH), best-fit lines through the historical data often produce unrealistically high "Beta" values, which could result in underestimation of the recurrence rates for large magnitude earthquakes, and thus underestimation of seismic hazard at the SR1 project site. As such, the magnitude recurrence parameters for these source zones were defined by taking a typical "Beta" value of 2.30 for the project region, extended through historical data for higher magnitude earthquakes within these sources.

The maximum magnitudes considered for earthquakes in each seismic source were based on those for the corresponding regions in GSC Open File 7576, which documents the 2015 NBCC seismic hazard model. The magnitude recurrence relations were truncated at the maximum magnitudes defined therein. Focal depths of 5 km were considered for all seismic sources, with the exception of the CIS source, for which the fault geometry was modeled to approximately match the geometry defined in GSC Open File 7576.

Treatment of epistemic uncertainty in the magnitude recurrence parameters for each seismic source was accomplished by development of upper and lower bound curves to the "best estimate" magnitude recurrence relations. The slopes and y-intercepts of the bounding curves were selected such that the upper and lower bounds widen at higher magnitudes. The widening bounds reflect the greater uncertainty in the magnitude recurrence relations at higher magnitudes, for which less earthquake data are available. The "best estimate", upper bound and lower bound magnitude recurrence relations were assigned weights of 0.68, 0.16 and 0.16, respectively, for the seismic hazard analysis.

Treatment of epistemic uncertainty in the values of maximum magnitude for each seismic source was accomplished by considering the "best estimate", upper bound and lower bound values of maximum magnitude and their corresponding weights in GSC Open File 7576. Namely, the "best estimate", upper bound and lower bound estimates of maximum magnitude for each source were assigned weights of 0.6, 0.1 and 0.3, respectively.

The full suite of input parameters defined for sources in the regional model, in addition to their associated weights, are presented in Table 4.

Table 4. List of Input Parameters for Seismic Sources (Regional Model)

Parameters		Scenario	Weight	Seismic Source				
				FHLm	**ROCSm**	**SBCm**	**SCCm**	**CIS**
Magnitude Recurrence Parameters	**Beta**	Upper	0.16	2.00	2.00	1.55	1.69	-5.0
	N_0			3,899	1,423	247	15	0.002*
	Beta	Best	0.68	2.30	2.30	1.75	2.00	-3.5
	N_0			9,589	2,593	369	40	0.002*
	Beta	Lower	0.16	2.60	2.60	1.95	2.26	-5.0
	N_0			23,585	4,725	550	94	0.002*
Maximum Magnitude		Upper	0.1	7.7	7.7	7.7	7.2	9.22
		Best	0.6	7.3	7.2	7.2	7.0	9.11
		Lower	0.3	7.2	7.0	7.0	6.8	9.02
Focal Depth		Best	1.0	5.0	5.0	5.0	5.0	N/A**

* N_0 value provided for the Cascadia Interface Source corresponds to number of characteristic earthquakes per year greater than M8.5

** The geometry of the CIS source was modeled directly; therefore, no specific focal depth was assumed for this source.

The full suite of input parameters defined for sources in the local model, in addition to their associated weights, are presented in Table 5.

Table 5. List of Input Parameters for Seismic Sources (Local Model)

Parameters		Scenario	Weight	Seismic Source									
				FHLm	**ROCSm**	**SBCm**	**BRC**	**CES**	**CLS**	**LOC**	**RMH**	**SCCm**	**CIS**
Magnitude Recurrence Parameters	**Beta**	Upper	0.16	2.00	2.00	1.55	2.00	2.00	2.00	2.00	2.00	1.69	-5.0
	N_0			3,899	565	247	223	291	13,630	50	858	15	0.002*
	Beta	Best	0.68	2.30	2.30	1.75	2.30	2.30	2.30	2.30	2.30	2.00	-3.5
	N_0			9,589	1,197	369	472	532	24,835	105	1,564	40	0.002*
	Beta	Lower	0.16	2.60	2.60	1.95	2.60	2.60	2.60	2.60	2.60	2.26	-5.0
	N_0			23,585	2,534	550	999	967	45,252	222	2,850	94	0.002*
Maximum Magnitude		Upper	0.1	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.2	9.22
		Best	0.6	7.3	7.2	7.2	7.2	7.2	7.2	7.2	7.2	7.0	9.11
		Lower	0.3	7.2	7.0	7.0	7.0	7.0	7.0	7.0	7.0	6.8	9.02
Focal Depth		Best	1.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	N/A**

* N_0 value provided for the Cascadia Interface Source corresponds to number of characteristic earthquakes per year greater than M8.5

** The geometry of the CIS source was modeled directly; therefore, no specific focal depth was assumed for this source.

4.3 GROUND MOTION PREDICTION EQUATIONS

Ground Motion Prediction Equations (GMPEs) are utilized to estimate the levels of ground motion that will occur at a site based on various factors, including earthquake magnitude, source-to-site distance, source characteristics and site characteristics. Three different source types were included our seismic hazard model: active crustal sources (FHLm, ROCSm, SBCm, BRC, CES, CLS, LOC, RMH), a stable cratonic source (SCCm) and a subduction interface source (CIS). Accordingly, our model incorporated appropriate GMPE suites for each of these source types. Details with respect to the selected GMPE suites are provided in the following sections.

4.3.1 Active Crustal Sources

For active crustal sources, Stantec considered the Next Generation Attenuation (NGA) West-2 GMPEs developed by Abrahamson et al. (2014), Boore et al. (2014), Campbell and Bozorgnia (2014) and Chiou and Youngs (2014). Namely, Stantec defined a "best estimate" GMPE model by weighting each of the four NGA West-2 GMPEs by a factor of 0.25. Similarly to the approach recommended by Atkinson and Adams (2013), Upper and lower bound alternatives were then defined by addition or subtraction of a logarithmic factor, "Delta", as defined below:

Delta (crustal) = min $(0.10+0.0007*R_{epi}, 0.3)$ *log(g) units*

Since the NGA West-2 GMPEs are defined based on nearest distance to the rupture surface (R_{rup}) or nearest distance to the surface projection of the fault (R_{jb}), it was necessary to convert these distance measurements to a form which can be applied for areal sources. For application of these GMPEs to our areal source zones, we converted distance measurements of R_{rup} or R_{jb} to equivalent measurements of hypocentral distance (R_{hypo}) or epicentral distance (R_{epi}), respectively, using the method by Goda et al. (2010). Where applicable, we subsequently converted R_{hypo} measurements to R_{epi} assuming a focal depth of 5 km for earthquakes occurring within the active crustal sources.

The GMPE models for our active crustal sources were defined for the site-specific ground conditions at the proposed diversion channel and dam sites. Specifically, the GMPE models were developed considering a representative shear wave velocity in the top 30 m (i.e., V_{s30}) of 425 m/s at the diversion structure site and 265 m/s at the dam site, as indicated in Seismic Cone Penetration Test (SCPT) and Multi-Channel Analysis of Surface Waves (MASW) testing in these areas. It should be noted that the V_{s30} value of 425 m/s is also applicable for the top of bedrock underlying the dam site, whereas the V_{s30} value of 265 m/s represents the surface of the soil deposits at this location.

4.3.2 Stable Cratonic Core

For the SCCm source, Stantec utilized the suite of GMPEs recommended by Atkinson and Adams (2013) for Eastern North America, which were utilized in the 2015 NBCC seismic hazard model to represent stable cratonic sources. This suite of GMPEs includes a "best estimate" comprising the geometric mean of the GMPEs by Pezeshk et al. (2011), Atkinson and Boore (2006), Atkinson (2008) as revised in Atkinson and Boore (2011), and two variations of Silva et al. (2002), each defined for or converted to a reference ground condition corresponding to the Site Class B/C boundary (i.e., V_{s30} = 760 m/s). Upper and lower bound alternatives were defined similarly to the approach described above for active crustal GMPEs. The reader is directed towards Atkinson and Adams (2013) for further details.

In the Stantec seismic hazard model, the ground motions for the SCCm source zone were initially computed for the Site Class B/C boundary (i.e., V_{s30} = 760 m/s) reference condition, then subsequently converted to the site-specific ground conditions using the approach described in the GMPE by Boore and Atkinson (2008).

4.3.3 Cascadia Interface Source

For the CIS source, Stantec utilized the suite of GMPEs recommended by Atkinson and Adams (2013) for interface events in the Cascadia region. Atkinson and Adams (2013) recommend a "best estimate" GMPE defined using the Atkinson and Macias (2009), Ghofrani & Atkinson (2013), Abrahamson et al. (2013) and Zhou et al. (2006) GMPEs, with weights of 0.5, 0.2, 0.2 and 0.1, respectively. Upper and lower bound alternatives were defined by Atkinson and Adams (2013) to approximately bound these four interface GMPE models. The upper and lower bound alternatives were defined by the addition or subtraction of a logarithmic factor, "Delta", as defined below:

$$Delta\ (interface) = min\ (0.15+0.0007*R_{cd},\ 0.35) \qquad log(g)\ units$$

In the Stantec seismic hazard model, the ground motions for the CIS source zone were initially computed for the Site Class B/C boundary (i.e., V_{s30} = 760 m/s) reference condition, then subsequently converted to the site-specific ground conditions using the approach in the GMPE by Boore and Atkinson (2008).

4.3.4 Treatment of Uncertainty in GMPEs

Treatment of epistemic uncertainty in the GMPEs discussed above was accomplished by the inclusion and weighting of the three alternative GMPEs for each source type. For each source type, the "best estimate", upper bound and lower bound GMPEs were assigned weights of 0.5, 0.25 and 0.25, respectively.

Treatment of aleatory variability was accomplished by incorporation of the applicable standard deviation values for the selected GMPEs, as listed in Table 6. No limit was placed on the number of standard deviations incorporated into the analysis.

Table 6. Standard Deviation Values for GMPEs

Parameter	Standard Deviation – log(g) units			
	Active Crustal		Stable Cratonic Core	Cascadia Interface
	V_{s30} = 425 m/s	V_{s30} = 265 m/s		
PGV	0.26	0.26	0.27	0.27
PGA	0.26	0.25	0.23	0.23
Sa(0.05s)	0.27	0.26	0.23	0.23
Sa(0.1s)	0.28	0.26	0.23	0.23
Sa(0.2s)	0.27	0.24	0.23	0.23
Sa(0.3s)	0.27	0.25	0.235	0.235
Sa(0.5s)	0.28	0.27	0.25	0.25
Sa(1.0s)	0.30	0.29	0.27	0.27
Sa(2.0s)	0.31	0.31	0.27	0.27
Sa(5.0s)	0.31	0.31	0.27	0.27
Sa(10.0s)	0.30	0.30	0.27	0.27

4.4 PROBABILISTIC ANALYSIS

The EDGM with an AEP of 1/10,000 was computed using EqHaz software (Assatourians and Atkinson, 2013). EqHaz software implements the method of Monte Carlo simulation to compute ground motions in three stages, as described below. EqHaz software has been validated by the software developer against other industry-standard software, EZ-FRISK and FRISK 88, for several sites in Western and Eastern Canada, as documented by Assatourians and Atkinson (2013).

1. **EqHaz1** (Stage 1) involves the creation of a simulated earthquake catalogue of a specified duration much longer than the return period for the earthquake of interest in the study. A simulated duration of 1,000,000 years was considered in the Stantec assessment. Simulated earthquakes of varying magnitudes are created at random locations across each seismic source throughout the specified duration, based on the magnitude recurrence parameters input for each source. EqHaz1 incorporates epistemic uncertainty in the input parameters using the "logic-tree" approach to incorporate the alternative sets of magnitude recurrence parameters and maximum magnitudes in addition to their associated weights.

2. **EqHaz2** (Stage 2) calculates the distances between the randomly selected earthquake locations and the site of interest, and computes the associated ground motions for each individual event in the simulated earthquake catalogue. EqHaz2 incorporates epistemic uncertainty in the GMPEs by inclusion of the "best estimate" and bounding curves in

addition to their associated weights. Furthermore, EqHaz2 incorporates aleatory variability implicitly by consideration of the standard deviations in the GMPEs.

3. **EqHaz3** (Stage 3) is utilized to process the results of the EqHaz2 calculations. Among the outputs are hazard curve data and sorted lists of ground motions from which the mean hazard probabilistic ground motions corresponding to EDGM can be obtained. In addition, deaggregation data is generated to facilitate interpretation of representative earthquake magnitudes and distances for different ground motion parameters.

Our probabilistic seismic hazard assessment incorporated the following two assumptions, which were reflected in our inputs to the EqHaz analysis software:

1. Consistent with the approach for the 2015 NBCC seismic hazard model, the contributions of earthquakes smaller than M4.8 were excluded, since earthquakes of smaller magnitudes are not considered to be of engineering concern (with the exception of induced events at very close epicentral distances, which are addressed in Section 5.4).

2. Hazard contributions from sources more than 300 km from the site, with the exception of those from the Cascadia Interface Source, were excluded because the hazard contributions beyond this cut-off distance are insignificant.

5.0 RESULTS AND RECOMMENDATIONS

5.1 EARTHQUAKE DESIGN GROUND MOTION

5.1.1 Horizontal EDGM Values

Based on the results of our analysis, the Peak Ground Acceleration (PGA), Peak Ground Velocity (PGV) and peak 5% damped spectral accelerations for the horizontal component of the Earthquake Design Ground Motion (EDGM) with an Annual Exceedance Probability (AEP) of 1/10,000 at the diversion structure and dam sites are presented in Table 7. The peak 5% damped spectral accelerations are also presented in Figure 1. Motions for intermediate periods may be estimated by means of linear interpolation between the values provided in Table 7. For all ground motion parameters, the regional source model was found to govern over the local source model in the robust approach.

EDGM values for the proposed diversion structure correspond to those for V_{s30} = 425 m/s, which represents a lower bound of the V_{s30} values obtained from Multi-channel Analysis of Surface Waves (MASW) tests in the vicinity of the diversion structure. EDGM values for the proposed dam correspond to those for V_{s30} = 265 m/s, which represents a lower bound of V_{s30} values from Seismic Cone Penetration Tests (SCPTs) and MASW tests in the vicinity of the dam. It should be noted that the EDGM values presented in Table 7 are reflective of those that would occur at the ground surface at the subject locations. If motions are input at the top of rock beneath the dam, it would be appropriate to consider the V_{s30} = 425 m/s values for the dam site.

Table 7. Horizontal EDGM Values for an AEP of 1/10,000 at the SR1 Project Site

Parameter	EDGM Values for an AEP of 1/10,000	
	Diversion Structure (V_{s30} = 425 m/s)	Dam (V_{s30} = 265 m/s)
PGV	17.5 cm/s	23.4 cm/s
PGA	0.26 g	0.28 g
Sa(0.05s)	0.34 g	0.33 g
Sa(0.1s)	0.54 g	0.47 g
Sa(0.2s)	0.63 g	0.64 g
Sa(0.3s)	0.54 g	0.69 g
Sa(0.5s)	0.35 g	0.52 g
Sa(1.0s)	0.18 g	0.26 g
Sa(2.0s)	0.072 g	0.11 g
Sa(5.0s)	0.022 g	0.034 g
Sa(10.0s)	0.0062 g	0.0087 g

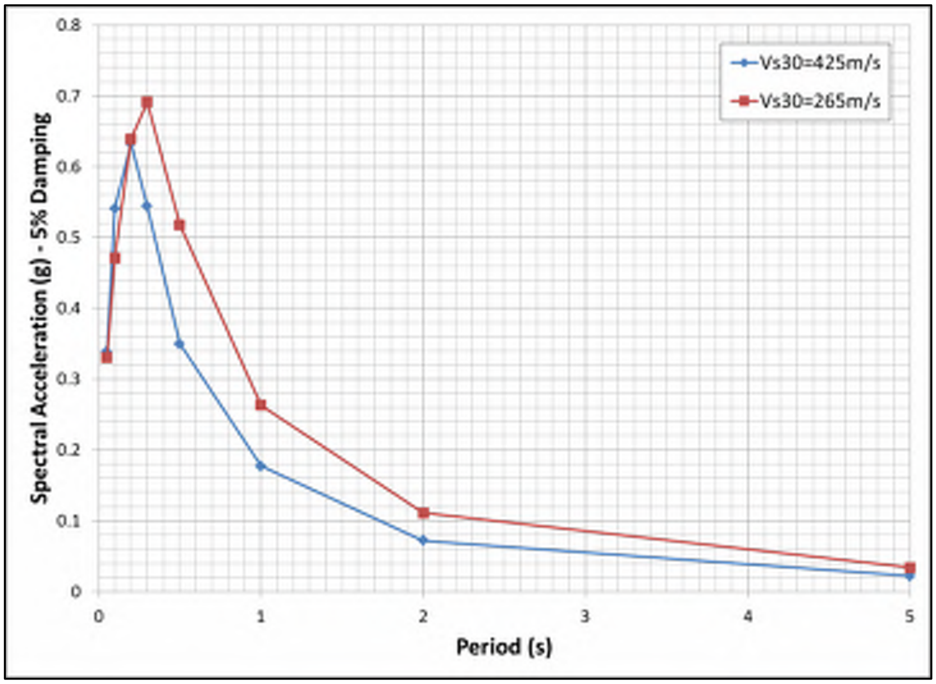


Figure 1. Horizontal EDGM Values for an AEP of 1/10,000 at the SR1 Site

In addition to the EDGM values for an AEP of 1/10,000, hazard curves are presented in **Appendix C** to indicate the AEP for a wide range of ground motion intensities. Hazard curves are provided only for the V_{s30} = 425 m/s site condition, since the shapes of the hazard curves for different site conditions are similar.

5.1.2 Vertical EDGM Values

To evaluate EDGM values with an AEP of 1/10,000 for the vertical component, Stantec considered the ratio of the Ground Motion Prediction Equation (GMPE) by Stewart et al. (2016) for the vertical component to the corresponding GMPE by Boore et al. (2014) for the horizontal component. The Vertical to Horizontal (V/H) ratios for PGA, PGV and spectral acceleration for periods of 2.0 s or less were computed from the ratio of the median motions predicted by these GMPEs for a magnitude of 6.0 and a distance of 20 km, which approximately correspond to the mean magnitude and distance values from the deaggregation data for the EDGM for these parameters (as discussed in Section 5.2). For spectral acceleration at periods of 5.0 and 10.0 s, the V/H ratios were computed from the ratio of the median motions predicted by these GMPEs for a magnitude of 7.25 and a distance of 250 km, which approximately correspond to the mean magnitude and distance values from the deaggregation data for the EDGM for these longer period motions (as discussed in Section 5.2).

The V/H ratios utilized to evaluate the EDGM value with an AEP of 1/10,000 at the SR1 project site are presented in Table 8. The resulting peak 5% damped spectral accelerations for the vertical component are presented in Figure 2.

Table 8. Ratio of Vertical to Horizontal Ground Motions

Parameter	Ratio of Vertical to Horizontal Ground Motions	
	Diversion Structure (V_{s30} = 425 m/s)	Dam (V_{s30} = 265 m/s)
PGV	0.41	0.39
PGA	0.56	0.56
Sa(0.05s)	0.86	0.94
Sa(0.1s)	0.72	0.81
Sa(0.2s)	0.47	0.50
Sa(0.3s)	0.41	0.40
Sa(0.5s)	0.40	0.36
Sa(1.0s)	0.42	0.37
Sa(2.0s)	0.51	0.43
Sa(5.0s)	0.58	0.48
Sa(10.0s)	0.91	0.76

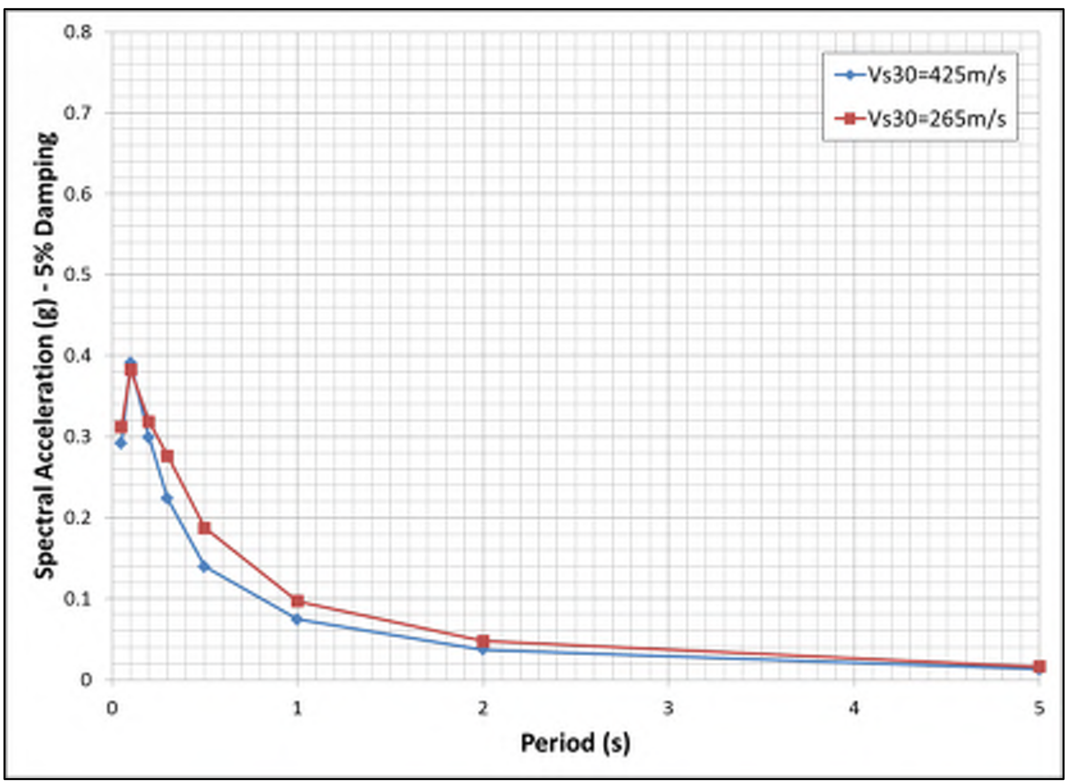


Figure 2. Vertical EDGM Values for an AEP of 1/10,000 at the SR1 Site

5.2 DEAGGREGATION OF SEISMIC HAZARD

Deaggregation data provides information to facilitate interpretation of which sources contribute significantly to seismic hazard at the site of interest. Table 9 indicates the percentage of the total seismic hazard for the EDGM with an AEP of 1/10,000 at the SR1 project site that is contributed by each seismic source. It should be noted that the hazard contributions from all seismic sources for a given period sum to 100%.

As indicated in Table 9, seismic hazard at the SR1 project site for all ground motion parameters is dominated by contributions from the ROCSm source zone, in which the SR1 project site is located. Contributions from the CIS source become significant for spectral accelerations at periods of 5.0 s and longer, and contributions from the SBCm source become significant for spectral acceleration at a period of 10.0 s. Contributions to seismic hazard from other sources in our model were found to be insignificant (i.e., were less than 10%) for all of the ground motion parameters evaluated.

Table 9. Hazard Contributions by Source to the EDGM for the SR1 Project Site

Parameter	Hazard Contribution by Seismic Source				
	FHLm	**ROCSm**	**SBCm**	**SCCm**	**CIS**
PGA	0%	100%	0%	0%	0%
PGV	0%	97%	2%	0%	1%
Sa(0.05s)	0%	98%	0%	2%	0%
Sa(0.1s)	0%	100%	0%	0%	0%
Sa(0.2s)	0%	100%	0%	0%	0%
Sa(0.3s)	0%	100%	0%	0%	0%
Sa(0.5s)	0%	99%	1%	0%	0%
Sa(1.0s)	0%	95%	5%	0%	0%
Sa(2.0s)	0%	92%	8%	0%	0%
Sa(5.0s)	2%	69%	6%	0%	23%
Sa(10.0s)	8%	52%	15%	5%	20%

Deaggregation data also provides information to facilitate interpretation of the characteristics of earthquakes (i.e., magnitudes and distances) which contribute significantly to seismic hazard at the site of interest. Magnitude-distance deaggregation plots for PGA, PGV and spectral acceleration for periods of 0.05 to 10.0 s are provided in **Appendix D**. In addition, the mean and mode magnitudes and distances for each ground motion parameter are listed in Table 10. The mean magnitude and distance values fall in the range M5.8 to M6.5 and 15 to 50 km, respectively, for ground motion parameters at periods of 2.0 s or less. For periods of 5.0 s or longer, the mean magnitudes and distances are in the order of M7.25 and 270 km, respectively.

Table 10. Deaggregation of Magnitude and Distance for the EDGM

Parameter	Mean		Mode	
	Magnitude	Distance (km)	Magnitude	Distance (km)
PGA	5.8	16	5.3	10
PGV	6.3	34	5.7	10
Sa(0.05s)	5.9	15	5.9	10
Sa(0.1s)	5.8	16	5.7	10
Sa(0.2s)	5.9	17	5.7	10
Sa(0.3s)	6.0	16	5.7	10
Sa(0.5s)	6.1	23	5.7	10
Sa(1.0s)	6.2	32	5.5	10
Sa(2.0s)	6.5	48	6.5	10
Sa(5.0s)	7.2	264	9.1	870
Sa(10.0s)	7.3	276	6.5	10

Based on the deaggregation data, we consider that a magnitude of 6.0 would be appropriate for use in liquefaction or slope displacement analyses for the proposed dam. Magnitude 6.0 corresponds to the typical mean (i.e., expected) magnitude value for ground motion parameters at the periods of greatest interest for the proposed dam and associated appurtenant structures.

5.3 EARTHQUAKE TIME HISTORIES

Stantec has selected a suite of linearly scaled earthquake records to approximately match the uniform hazard spectrum for an AEP of 1/10,000 over a period range of 0.05 to 2.0 s, which is expected to encompass the period range applicable for the proposed dam and associated appurtenant structures. Motions were selected to represent the soft rock conditions in the vicinity of the dam site, which typically fall within the rage of Site Class C (i.e., 360 m/s < V_{s30} < 760 m/s). Based on the deaggregation data obtained from our probabilistic analysis, Stantec considered the following magnitude and distance ranges in our earthquake record search:

- Moment magnitude between 5.0 and 6.5; and
- Joyner-Boore distances of 5 to 60 km.

Earthquakes of all mechanisms (i.e., strike-slip, reverse, normal, etc.) were included in our earthquake search. Preference was given to ground motions recorded at free-field instrument locations. In selection of representative earthquake records, Stantec limited the minimum and maximum linear scaling factors to 0.4 and 2.5, respectively.

In total, Stantec selected 11 sets of crustal earthquake records (i.e., three orthogonal components) from the Pacific Earthquake Engineering Research (PEER) Centre's Ground Motion Database to approximately match the target ground motion characteristics. The selected ground motion records are summarized in Table 11, and the unscaled records are included as an attachment to the pdf of this report.

Table 11. List of Selected Earthquake Motion Records

No.	RSN No.	Earthquake	M_w	Mechanism	R_{jb} (km)	V_{s30} (m/s)	Scaling Factor (Horizontal)	Scaling Factor (Vertical)
1	212	Livermore-01 (1980)	5.8	strike slip	23.9	403	1.65	1.67
2	246	Mammoth Lakes-06 (1980)	5.94	strike slip	41.8	371	1.87	2.02
3	321	Mammoth Lakes-11 (1983)	5.31	strike slip	7.1	382	2.29	2.16
4	548	Chalfant Valley-02 (1986)	6.19	strike slip	21.6	371	1.35	1.12
5	671	Whittier Narrows-01 (1987)	5.99	reverse-oblique	31.6	508	2.00	2.19
6	3605	Lazio-Abruzzo_ Italy (1984)	5.8	Normal	20.0	437	2.24	1.53
7	3859	Chi-Chi_ Taiwan-05 (1999)	6.2	Reverse	53.0	438	2.47	2.12
8	4139	Parkfield-02_ CA (2004)	6	strike slip	9.5	417	1.06	1.30
9	6057	Big Bear-01 (1992)	6.46	strike slip	26.2	362	1.93	1.81
10	6060	Big Bear-01 (1992)	6.46	strike slip	40.9	368	1.81	1.39
11	6878	Joshua Tree_ CA (1992)	6.1	strike slip	21.4	368	1.48	1.45

The mean value of magnitude for the selected earthquake records is 6.02, the mean value of distance (R_{jb}) is 27 km, and the mean value of V_{s30} is 402 m/s. The mean scaling factors applied to the ground motion records are 1.83 for the horizontal components and 1.70 for the vertical components. It should be noted that in addition to scaling for the purpose of matching the uniform hazard spectrum for an AEP of 1/10,000 over a period range of 0.05 to 2.0 s, scaling was also conducted to ensure that the average of the response spectra for the selected records was not less than 90% of the uniform hazard spectrum at any point within the period range of interest.

The geometric mean of the 5% damped acceleration response spectra for the horizontal components of each selected earthquake record set is plotted in Figure 3, along with the suite average and the "target" response spectrum, corresponding to the horizontal EDGM with an AEP of 1/10,000.

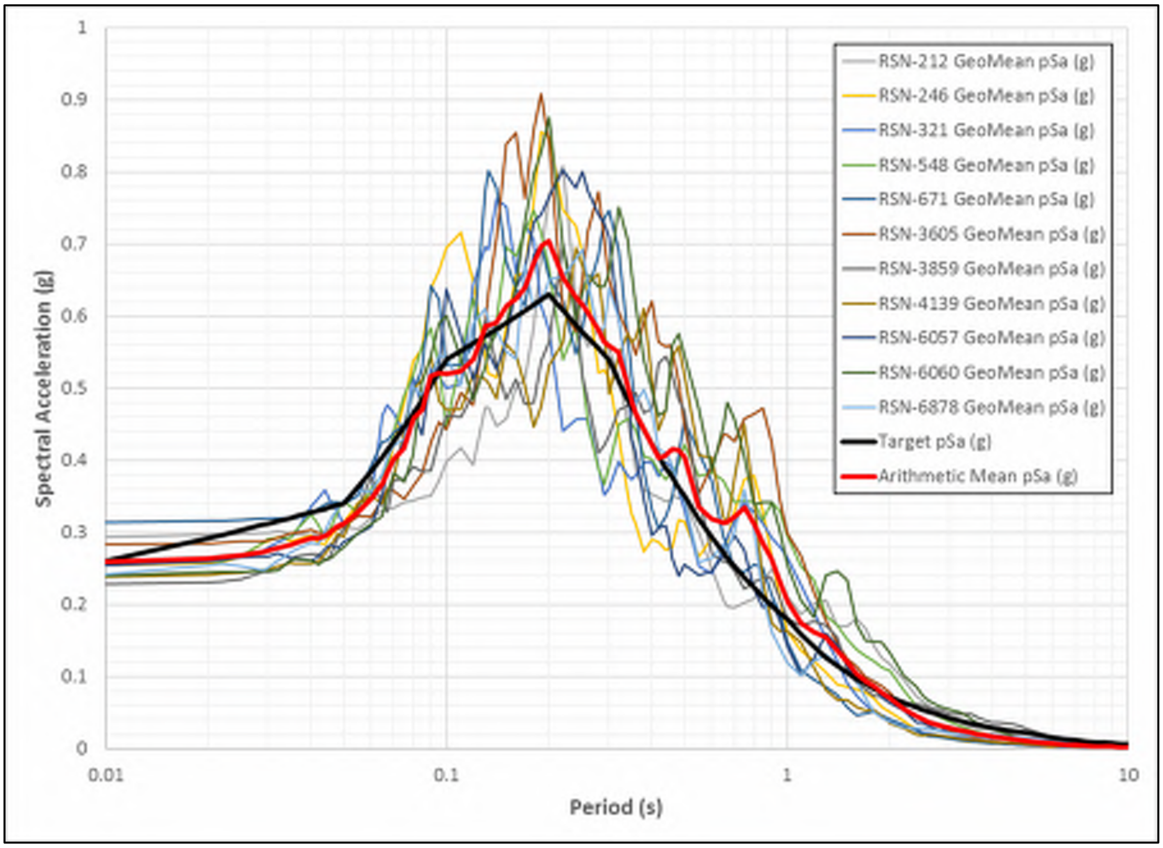


Figure 3. Geometric Mean of Horizontal Response Spectra for the Selected Earthquake Records (5% Damping)

The 5% damped vertical acceleration response spectra for the selected earthquake record sets are plotted in Figure 4, along with the suite average and the "target" response spectrum, corresponding to the vertical EDGM with an AEP of 1/10,000.

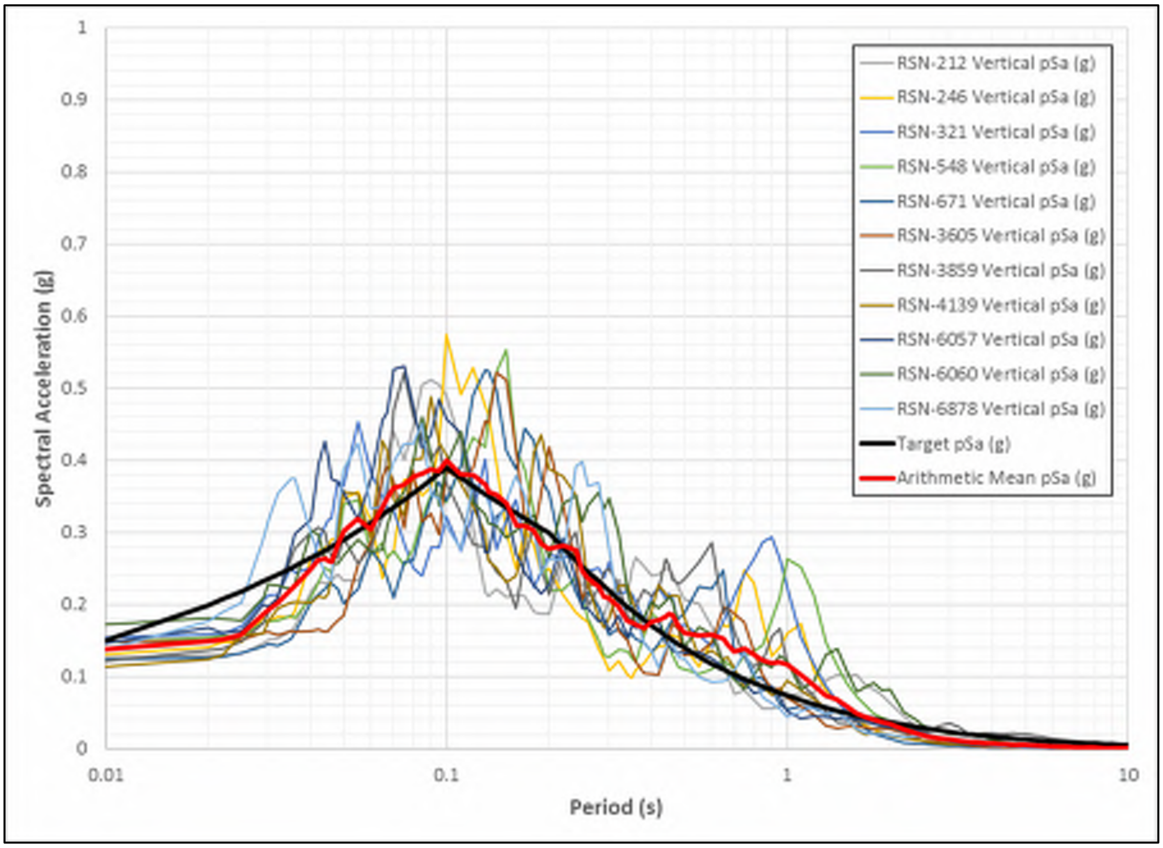


Figure 4. Vertical Response Spectra for the Selected Earthquake Records (5% Damping)

5.4 MANAGEMENT OF INDUCED SEISMICITY RISK

It should be recognized that although induced seismicity was incorporated into the Stantec seismic hazard model through inclusion of induced events in our regional and local source models, induced seismicity due to future "fracking" or waste injection in close proximity to the project site could substantially increase seismic hazard at the site. As such, we recommend that the owner take the following approach for managing risk associated with induced seismicity:

1. Obtain a 5 km exclusion zone for hydraulic fracturing and disposal wells around the extreme consequence facility to ensure no very near events are generated; and

2. Implement a real-time monitoring system to monitor activity of M>2 within 25 km of the facility, and develop a response plan in case earthquake rates become higher than those that are acceptable based on the design parameters or other considerations.

6.0 CLOSURE

This report was prepared for the exclusive use of Alberta Transportation and its agents for specific application to the Springbank Off-Stream Dam and Reservoir project. Any use of this report or the material contained herein by third parties, or for other than the intended purpose, should first be approved in writing by Stantec.

This seismic hazard assessment was completed by Chris Longley, M.Eng., P.Eng., and Wayne Quong, M.A.Sc., P.Eng., with consultation and review by Gail Atkinson, Ph.D., P.Geo. A letter documenting the review by Dr. Atkinson is provided in **Appendix E**.

We trust that this report meets your present requirements. If you have any questions or require additional information, please do not hesitate to contact the undersigned.

Respectfully,

STANTEC CONSULTING LTD.

Original signed by:

Chris Longley, M.Eng., P.Eng
Geotechnical Engineer
Phone: (604) 436-3014
Fax: (604) 436-3752
chris.longley@stantec.com

Original signed by:

Wayne Quong, M.A.Sc., P.Eng.
Senior Associate, Geotechnical
Phone: (604) 436-3014
Fax: (604) 436-3752
wayne.quong@stantec.com

7.0 REFERENCES

Abrahamson, N., et al. (2013). "B.C. Hydro Ground Motion Prediction Equations for 639 Subduction Earthquakes". *Earthquake Spectra*, submitted.

Abrahamson, N. et al. (2014). "Summary of the ASK14 ground motion relation for active crustal regions". *Earthquake Spectra*, Volume 30, No. 3, pages 1025–1055.

Adams, J. and Halchuk, S. (2003). "Fourth Generation Seismic Hazard Maps of Canada: Values for over 650 Canadian Localities intended for the 2005 National Building Code of Canada". Geological Survey of Canada – Open file 4459, 155p.

Assatourians, K. and Atkinson, G. (2013). "EqHaz – An Open Source Probabilistic Seismic Hazard Code Based on the Monte Carlo Simulation Approach". Seismological Research Letters, Volume 84, No 3, May/June 2013.

Atkinson, G. (2008). "Ground-motion prediction equations for eastern North America from a referenced empirical approach: implications for epistemic uncertainty". Bulletin of the Seismological Society of America 98, 1304-1318.

Atkinson, G. and Adams, J. (2013). "Ground motion prediction equations for application to the 2015 Canadian national seismic hazard maps". *Canadian Journal of Civil Engineering*, 2013, 40(10): 988-998, 10.1139/cjce-2012-0544

Atkinson, G. and Boore, D. (2006). "Earthquake Ground-Motion Prediction Equations for Eastern North America". *Bulletin of the Seismological Society of America*, December 2006. Volume 96, No. 6, pages 2181–2205.

Atkinson, G. and Boore, D. (2011). "Modifications to Existing Ground-Motion Prediction Equations in Light of New Data". *Bulletin of the Seismological Society of America*, June 2011. Volume 101, No. 3, pages 1121-1135.

Atkinson, G. and Macias, M. (2009). "Predicted Ground Motions for Great Interface Earthquakes in the Cascadia Subduction Zone". *Bulletin of the Seismological Society of America*, June 2009. Volume 99, No. 3, pages 1552-1578.

Atkinson, G. et al. (2016). "Hydraulic Fracturing and Seismicity in the Western Canada Sedimentary Basin". Seismological Research Letters, DOI: 10.1785/0220150263.

Boore, D. and Atkinson, G. (2008). "Ground-Motion Prediction Equations for the Average Horizontal Component of PGA, PGV and 5% Damped PSA at Spectral Periods between 0.01 s and 10.0 s". *Earthquake Spectra*, Volume 24, No. 1, pages 99-138.

Boore, D et al. (2014). "NGA-West2 equations for predicting PGA, PGV, and 5% damped PSA for shallow crustal earthquakes". *Earthquake Spectra*, Volume 30, No. 3, pages 1057–1085.

Campbell, K. and Bozorgnia, Y. (2014). "NGA-West2 ground motion model for the average horizontal components of PGA, PGV, and 5% damped linear acceleration response spectra". *Earthquake Spectra*, Volume 30, No. 3, pages 1087–1115.

Canadian Dam Association (2007). *Dam Safety Guidelines*.

Chiou, B. and Youngs, R. (2014). "Update of the Chiou and Youngs NGA model for the average horizontal component of peak ground motion and response spectra". *Earthquake Spectra*, Volume 30, No. 3, pages 1117–1153.

Ghofrani, H. and Atkinson, G. (2013). "Ground-motion prediction equations for interface earthquakes of M7 to 9 in Japan based on empirical data". *Bulleting of Earthquake Engineering*, submitted.

Goda, K. et al. (2010). "Impact of using updated seismic information on seismic hazard in western Canada". *Canadian Journal of Civil Engineering*, Volume 37: pages 562-575.

Halchuk, S. et al. (2014). "Fifth Generation Seismic Hazard Model Input Files as Proposed to Produce Values for the 2015 National Building Code of Canada". Geological Survey of Canada – Open File 7576.

Macias-Carrasco, M., Fereydouni, A., Goda, K., and Atkinson, G. 2011. Canadian Composite. Seismicity Catalogue (CCSC11) for Western Canada.

Moran, S.R. (1986). Surficial Geology of the Calgary Urban Area. Bulletin No. 53. Terrain Sciences Department, Alberta Research Council, Edmonton, Alberta, Canada.

Pettapiece, W. (1986). Physiographic Subdivisions of Alberta. Ottawa: Land Resource Centre, Research Branch. 1:1,500,000.

Pezeshk, S. et al. (2011). "Ground-motion prediction equations for eastern North America from a hybrid empirical method". *Bulletin of the Seismological Society of America*, in review.

Prior, G. et a. (2013). Bedrock geology of Alberta. Alberta Energy Regulator, AER/AGS Map 600. 1:1,000,000.

Schultz, R. et al. (2014). An investigation of seismicity clustered near the Cordel Field, west central Alberta, and its relation to a nearby disposal well. Journal of Geophysical Research, Solid Earth, 119, 3410–3423, doi:10.1002/2013JB010836.

Schultz, R. et al. (2015a). Hydraulic Fracturing and the Crooked Lake Sequences: Insights gleaned from regional seismic networks. Geophysical Research Letters, 42, doi:10.1002/2015GL063455.

Schultz, R. et al. (2015b). The Cardston Earthquake Swarm and Hydraulic Fracturing of the Exshaw Formation (Alberta Bakken Play). Bulletin of the Seismological Society of America, doi: 10.1785/0120150131.

Silva, W. et al. (2002). *Development of regional hard rock attenuation relations for central and eastern North America*, Technical Report, Pacific Engineering and Analysis, El Cerrito, CA. www.pacificengineering.org.

Stern, V. et al. (2016). Alberta earthquake catalogue, version 4.0 (GIS data, point features). Alberta Energy Regulator, AER/AGS Digital Dataset 2013-0017.

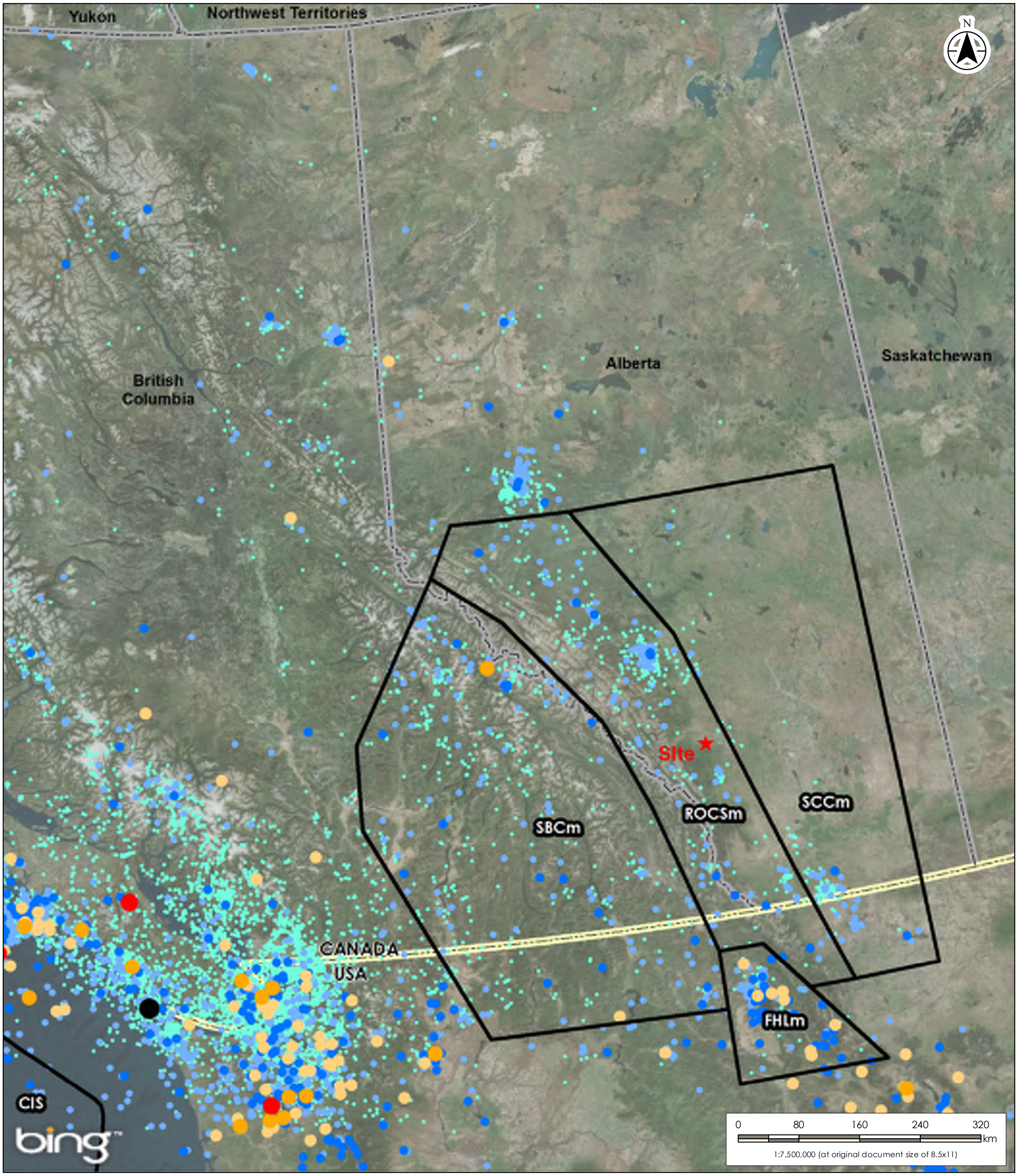
Stewart, J. et al. (2016). "NGA-West2 Equations for Predicting Vertical-Component PGA, PGV and 5%-Damped PSA from Shallow Crustal Earthquakes". Earthquake Spectra, Volume 32, No. 2, pages 1005-1031.

Wetmiller, R. (1986). "Earthquakes near Rocky Mountain House, Alberta, and their relationship to gas production facilities". *Canadian Journal of Earth Sciences*, Volume 23, No. 2, pages 172-181.

Zhao, J. et al. (2006). "Attenuation relations of strong ground motion in Japan using site classification based on predominant period". *Bulletin of the Seismological Society of America*, Vol. 96, pp. 898-913.

Appendix A DRAWINGS

S:\1232\projects\110773396\figures\discipline\Geotechnical\20161207_seismic_source_model\fig_110773396_001_seismic_source_model_regional.mxd   Revised: 2016-12-07 By: ssun



★ Project Location
International Boundary
Seismic Source

Earthquake Locations

- M<2.99
- M 3-3.99
- M 4-4.99
- M 5-5.99
- M 6-6.99
- M 7-7.99
- M>8

Stantec

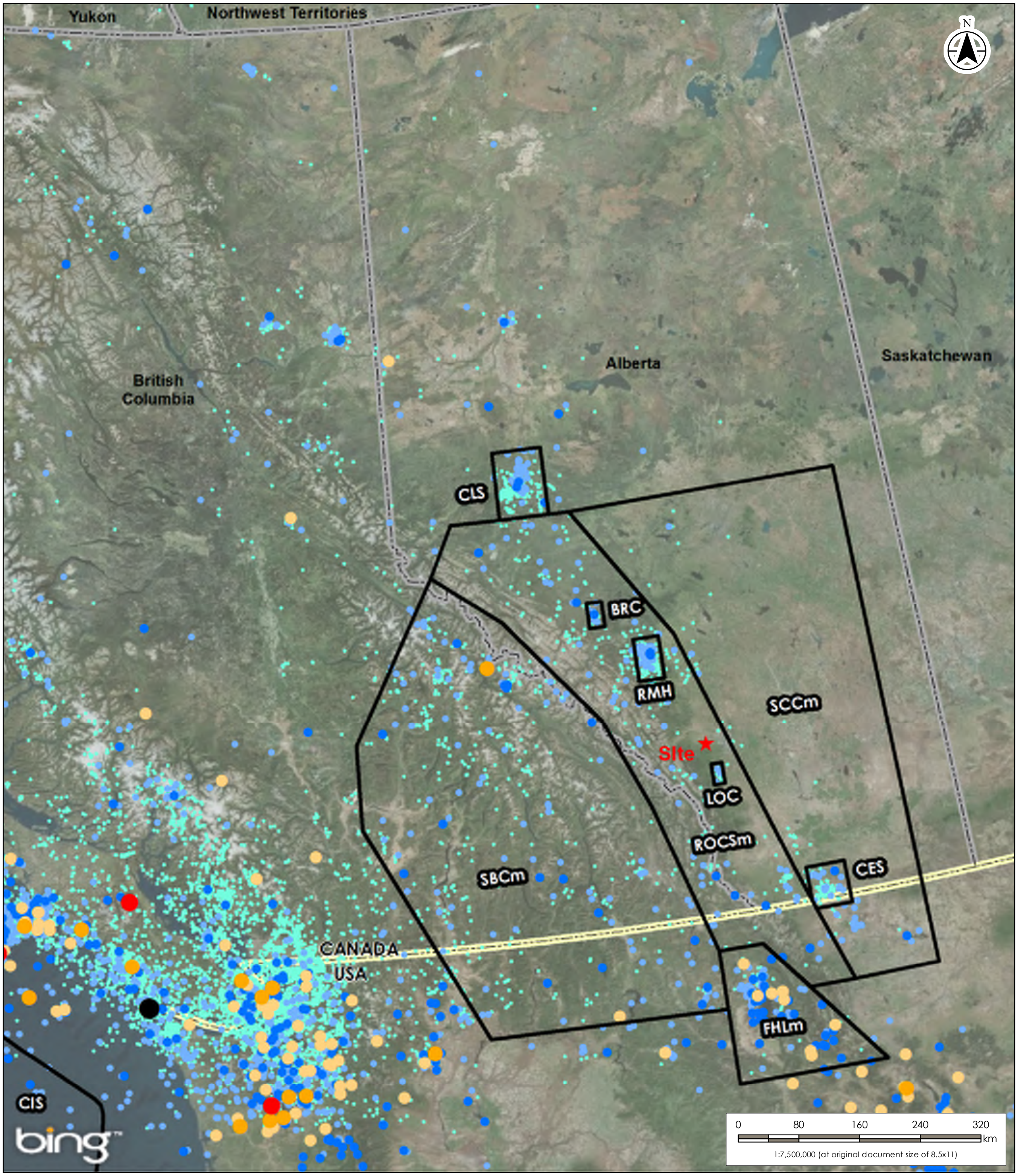
Project Location: West of Calgary, BC
110773396
Prepared by SS on 12/7/2016
Technical Review by CL

Client/Project
Alberta Transportation
Springbank Off-stream Reservoir
Seismic Hazard Assessment

Figure No.
1

Title
Seismic Source Model - Regional

S:\1232\projects\110773396\figures\discipline\Geotechnical\20161207_seismic_source_model\fig_110773396_002_seimic_source_model_local.mxd Revised: 2016-12-07 By: ssun



★ Project Location
International Boundary
Seismic Source

Earthquake Locations

- M<2.99
- M 3-3.99
- M 4-4.99
- M 5-5.99
- M 6-6.99
- M 7-7.99
- M>8

Stantec

Project Location: West of Calgary, BC
110773396
Prepared by SS on 12/7/2016
Technical Review by CL

Client/Project
Alberta Transportation
Springbank Off-stream Reservoir
Seismic Hazard Assessment

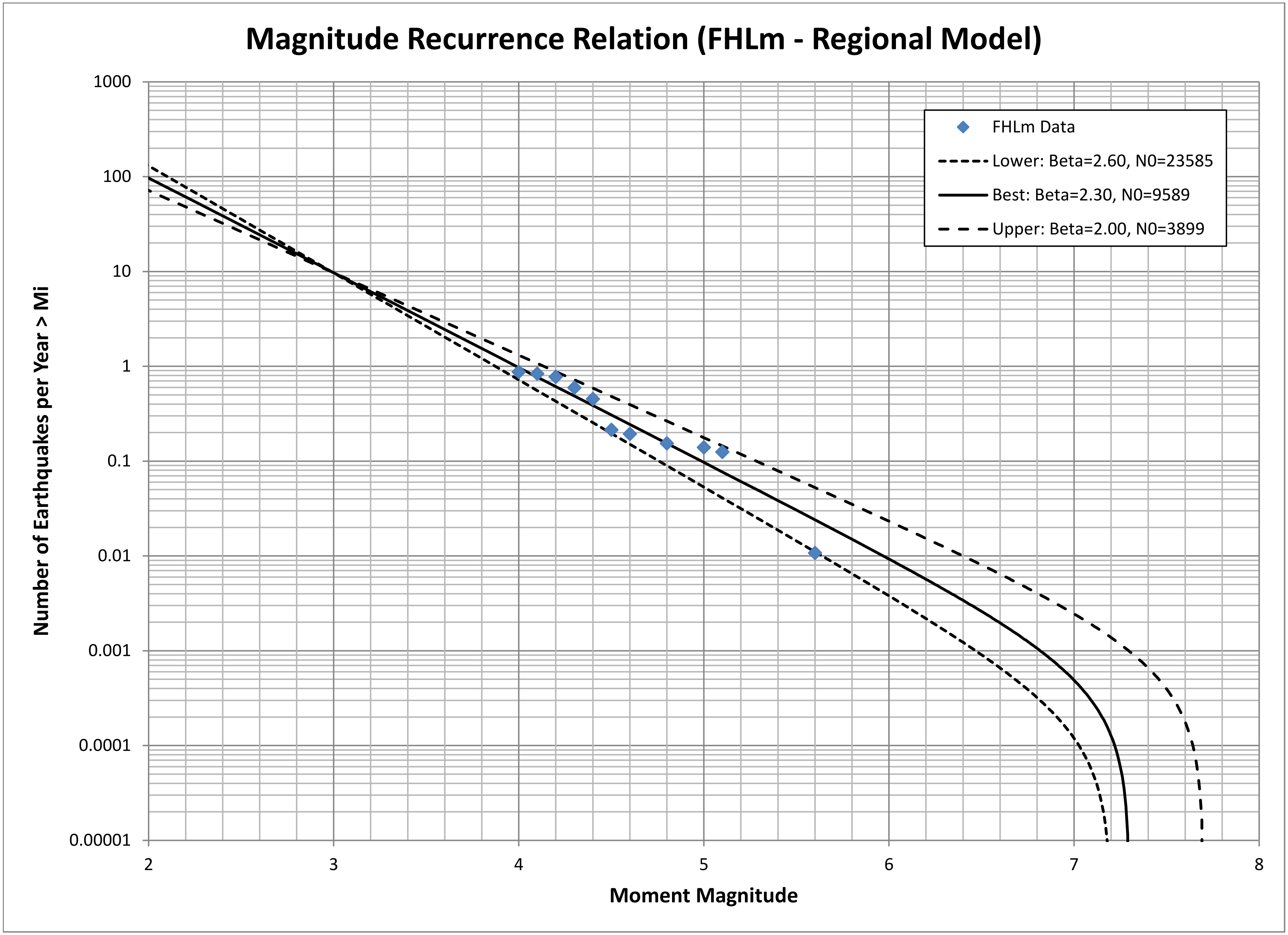
Figure No.
2

Title
Seismic Source Model - Local

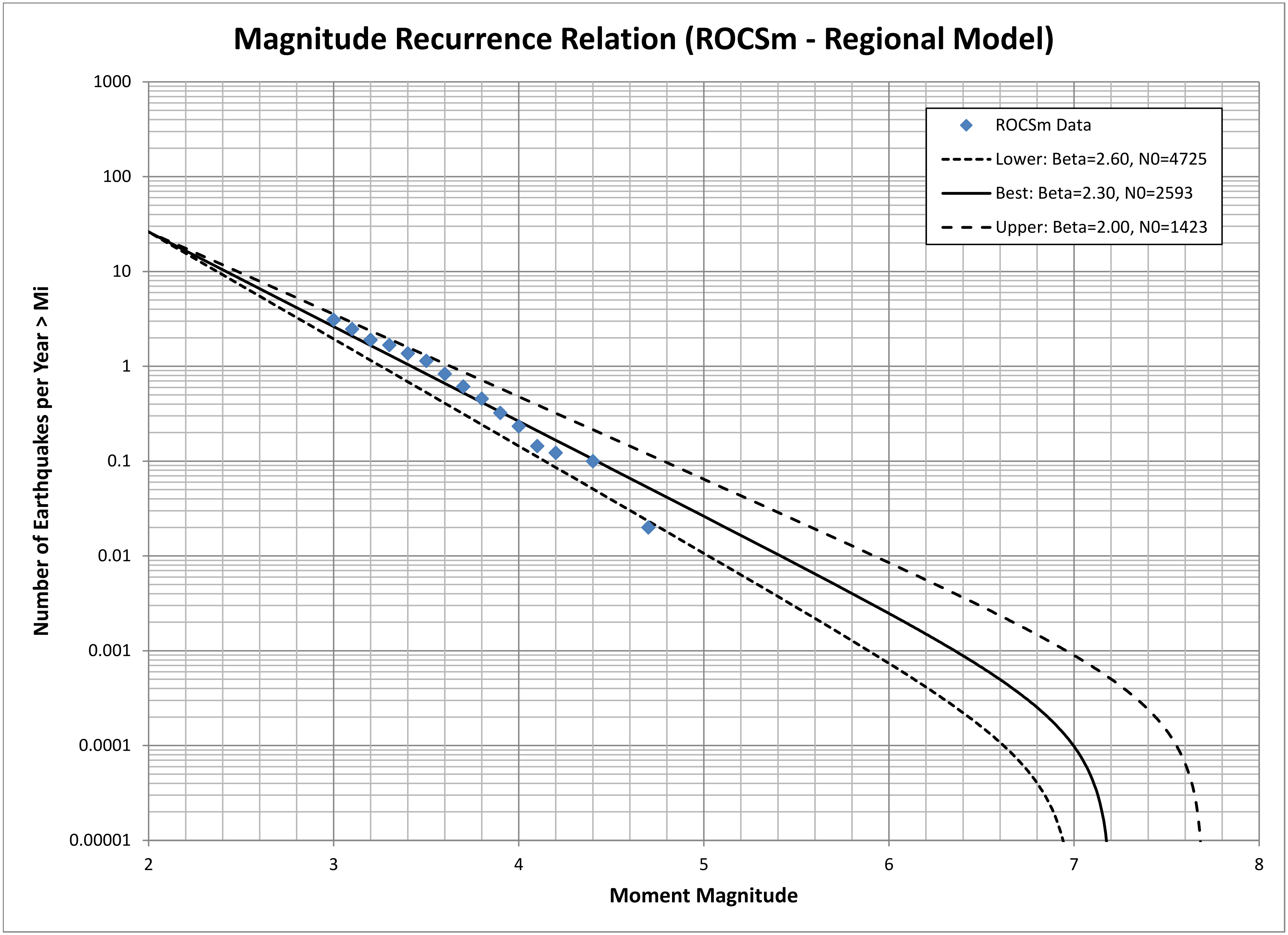
Page 01 of 01

Appendix B MAGNITUDE RECURRENCE RELATIONS

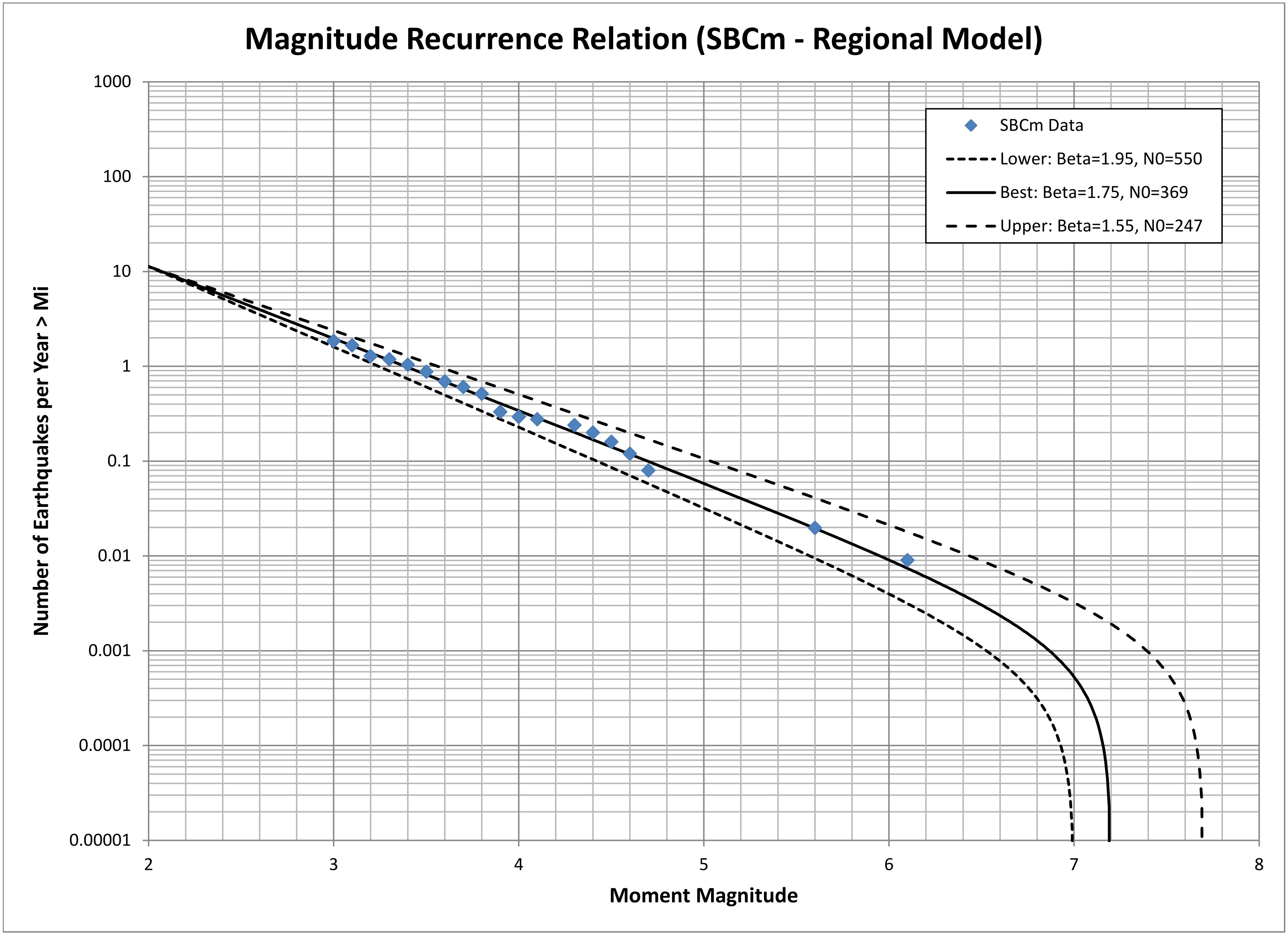
Appendix B-1 Magnitude Recurrence Parameters (Regional Model)

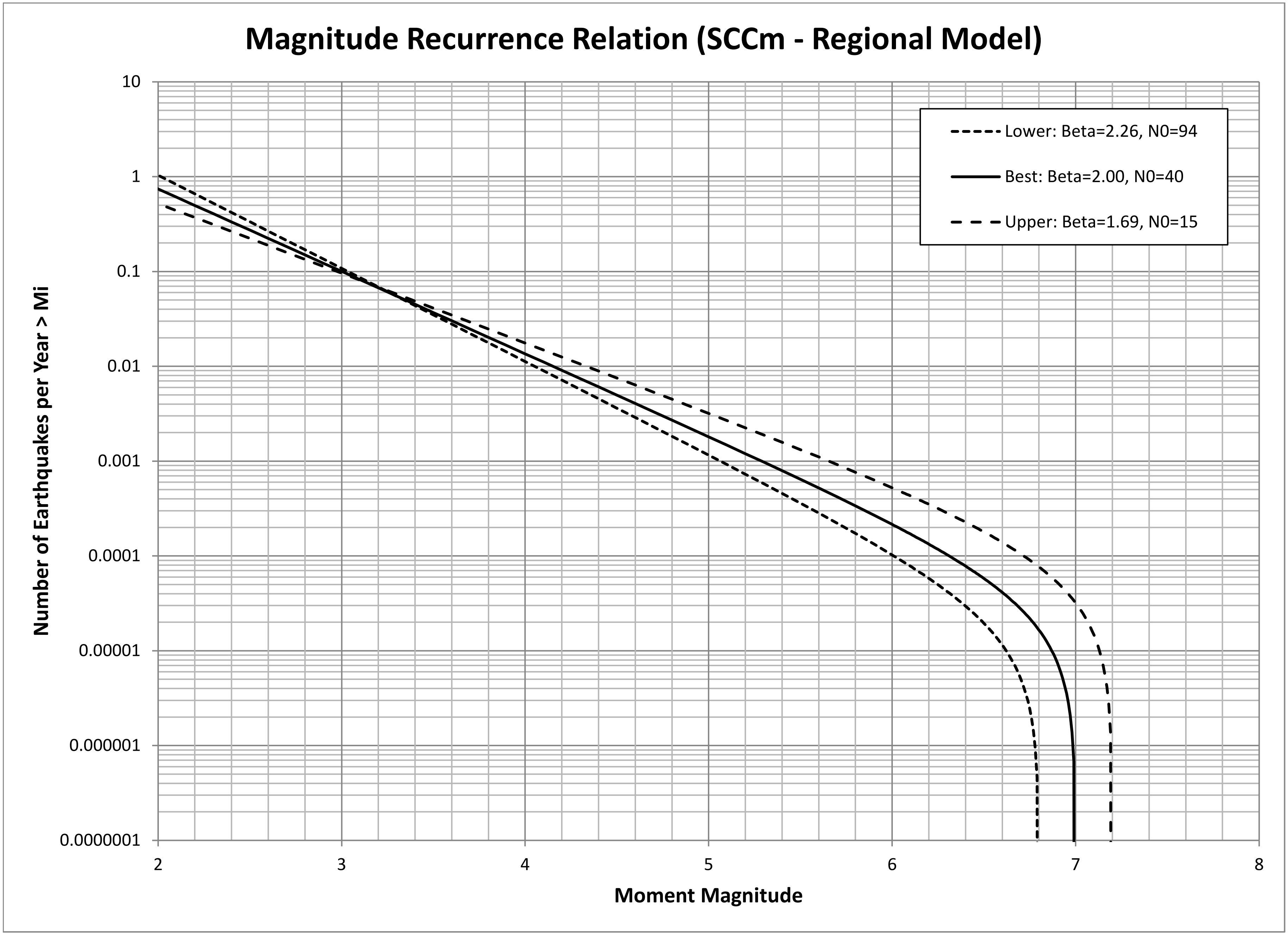


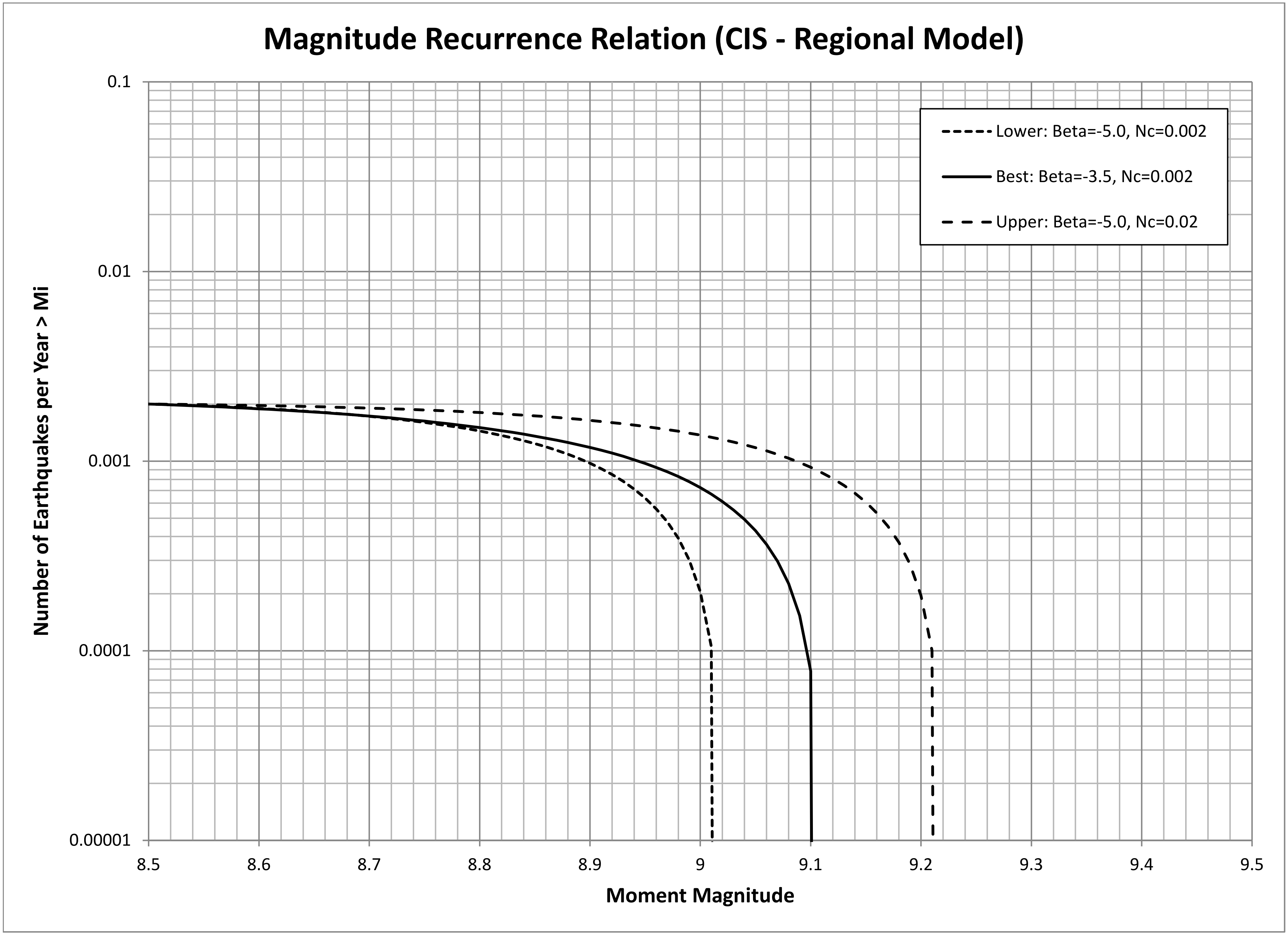
Magnitude Recurrence Relation (FHLm - Regional Model)
Number of Earthquakes per Year > Mi
1000
100
10
1
0.1
0.01
0.001
0.0001
0.00001
2
3
4
5
6
7
8
Moment Magnitude
FHLm Data
Lower: Beta=2.60, N0=23585
Best: Beta=2.30, N0=9589
Upper: Beta=2.00, N0=3899



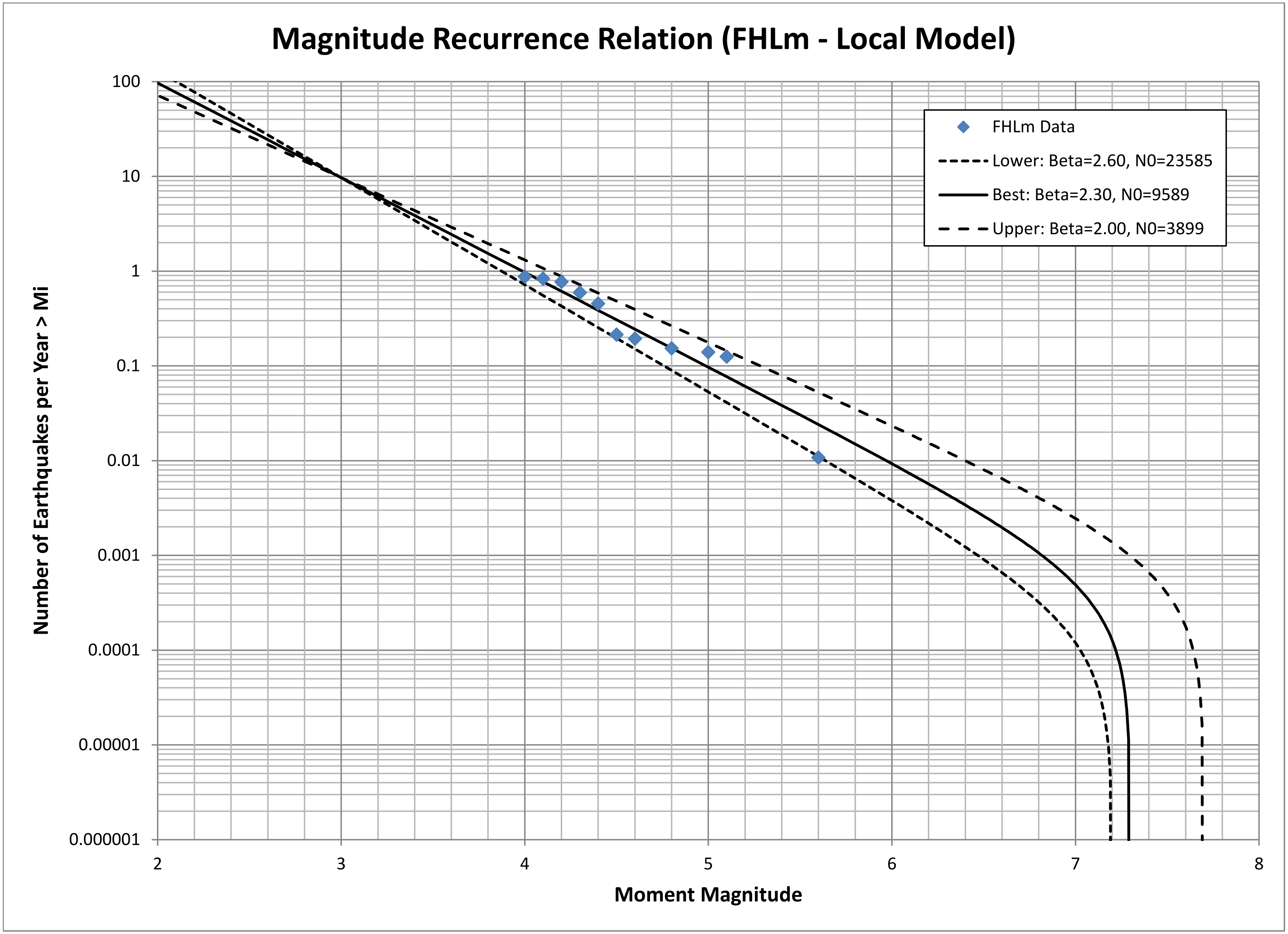
Magnitude Recurrence Relation (ROCSm - Regional Model)
Number of Earthquakes per Year > Mi
1000
100
10
1
0.1
0.01
0.001
0.0001
0.00001
2
3
4
5
6
7
8
Moment Magnitude
ROCSm Data
Lower: Beta=2.60, N0=4725
Best: Beta=2.30, N0=2593
Upper: Beta=2.00, N0=1423


Magnitude Recurrence Relation (SBCm - Regional Model)
Number of Earthquakes per Year > Mi
1000
100
10
1
0.1
0.01
0.001
0.0001
0.00001
2
3
4
5
6
7
8
Moment Magnitude
SBCm Data
Lower: Beta=1.95, N0=550
Best: Beta=1.75, N0=369
Upper: Beta=1.55, N0=247

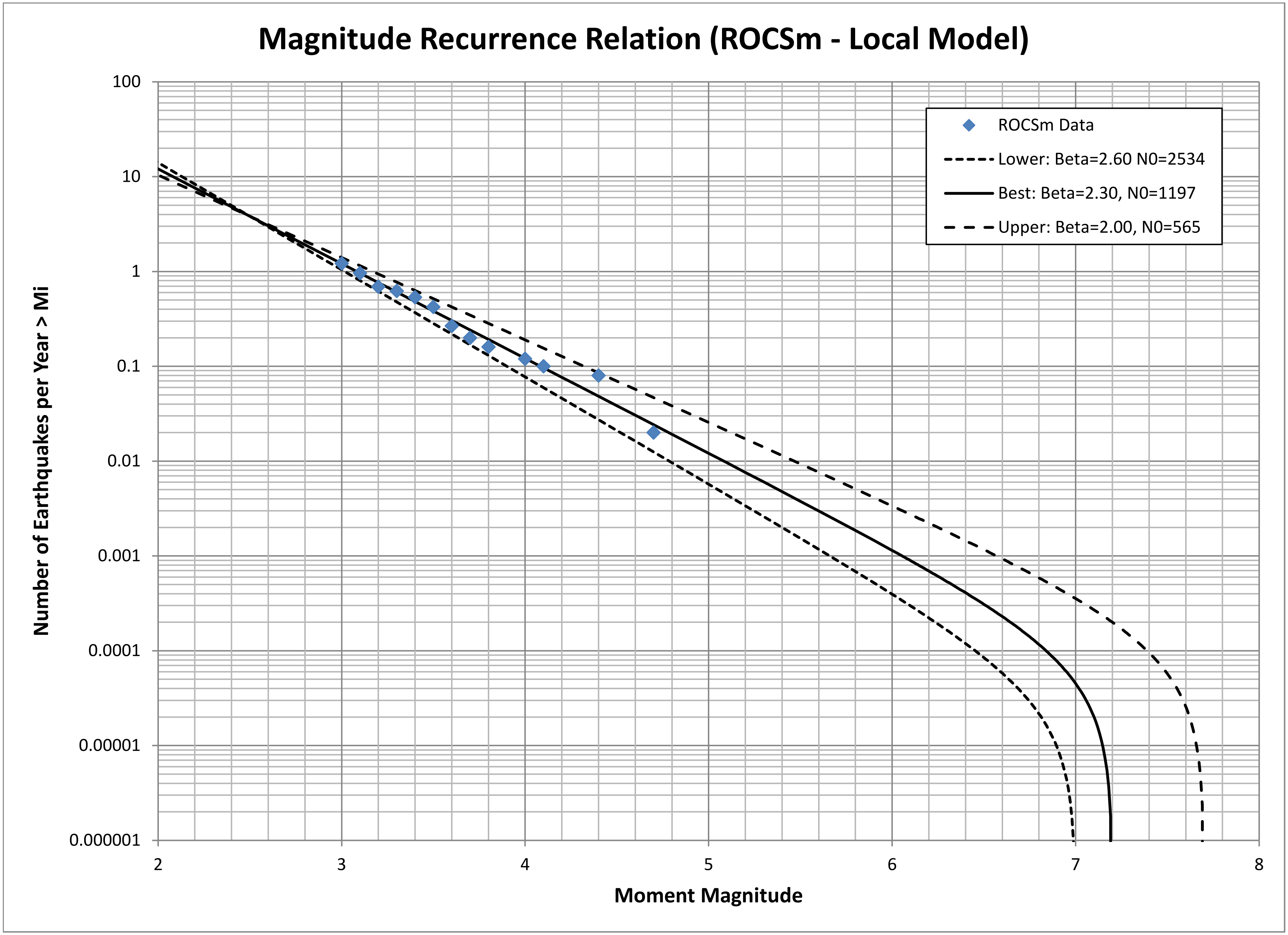

Magnitude Recurrence Relation (SCCm - Regional Model)
Number of Earthquakes per Year > Mi
10
1
0.1
0.01
0.001
0.0001
0.00001
0.000001
0.0000001
2
3
4
5
6
7
8
Moment Magnitude
Lower: Beta=2.26, N0=94
Best: Beta=2.00, N0=40
Upper: Beta=1.69, N0=15


Magnitude Recurrence Relation (CIS - Regional Model)
Lower: Beta=-5.0, Nc=0.002
Best: Beta=-3.5, Nc=0.002
Upper: Beta=-5.0, Nc=0.02
Number of Earthquakes per Year > Mi
0.1
0.01
0.001
0.0001
0.00001
8.5
8.6
8.7
8.8
8.9
9
9.1
9.2
9.3
9.4
9.5
Moment Magnitude

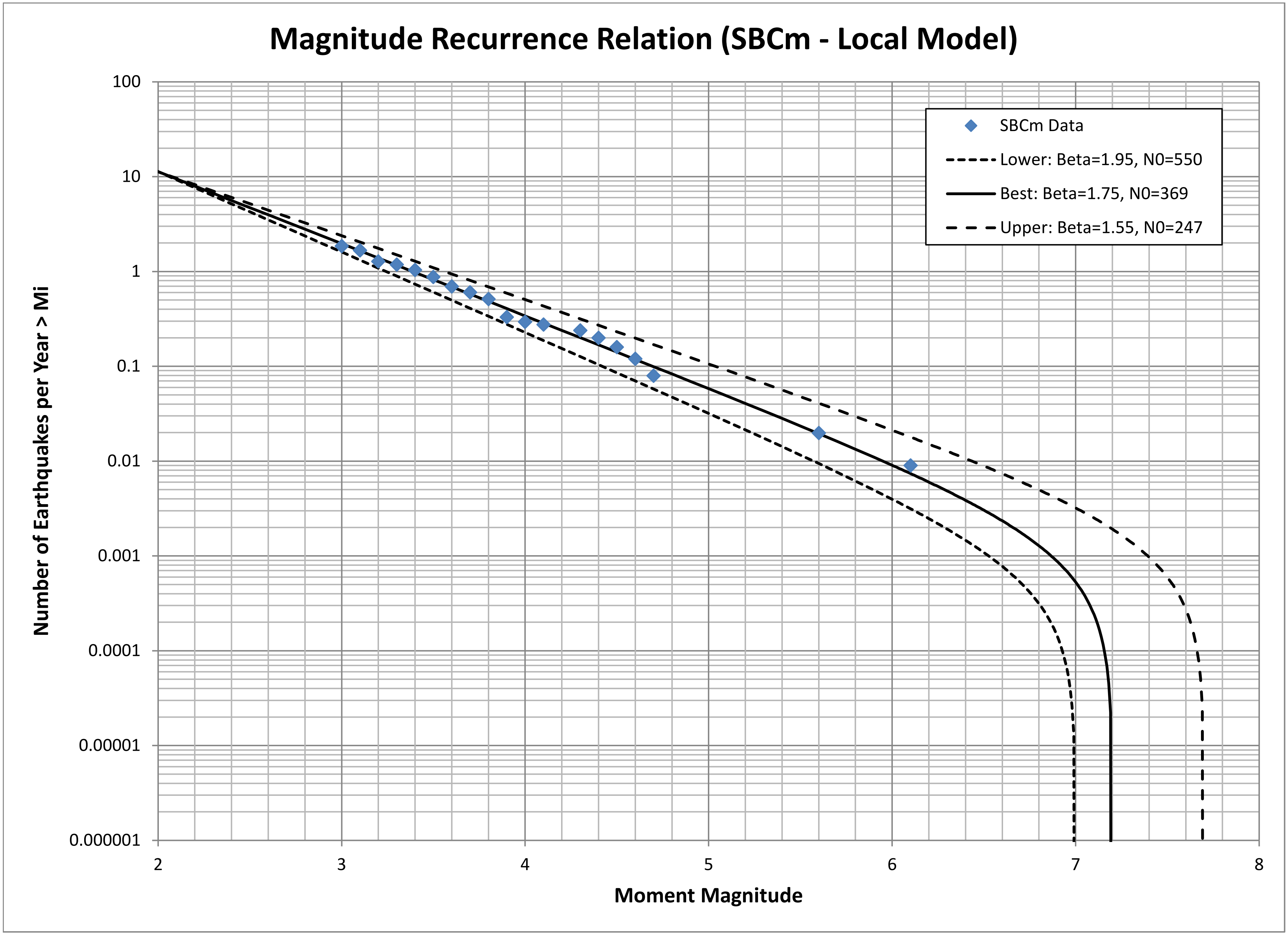
Appendix B-2 Magnitude Recurrence Parameters (Local Model)



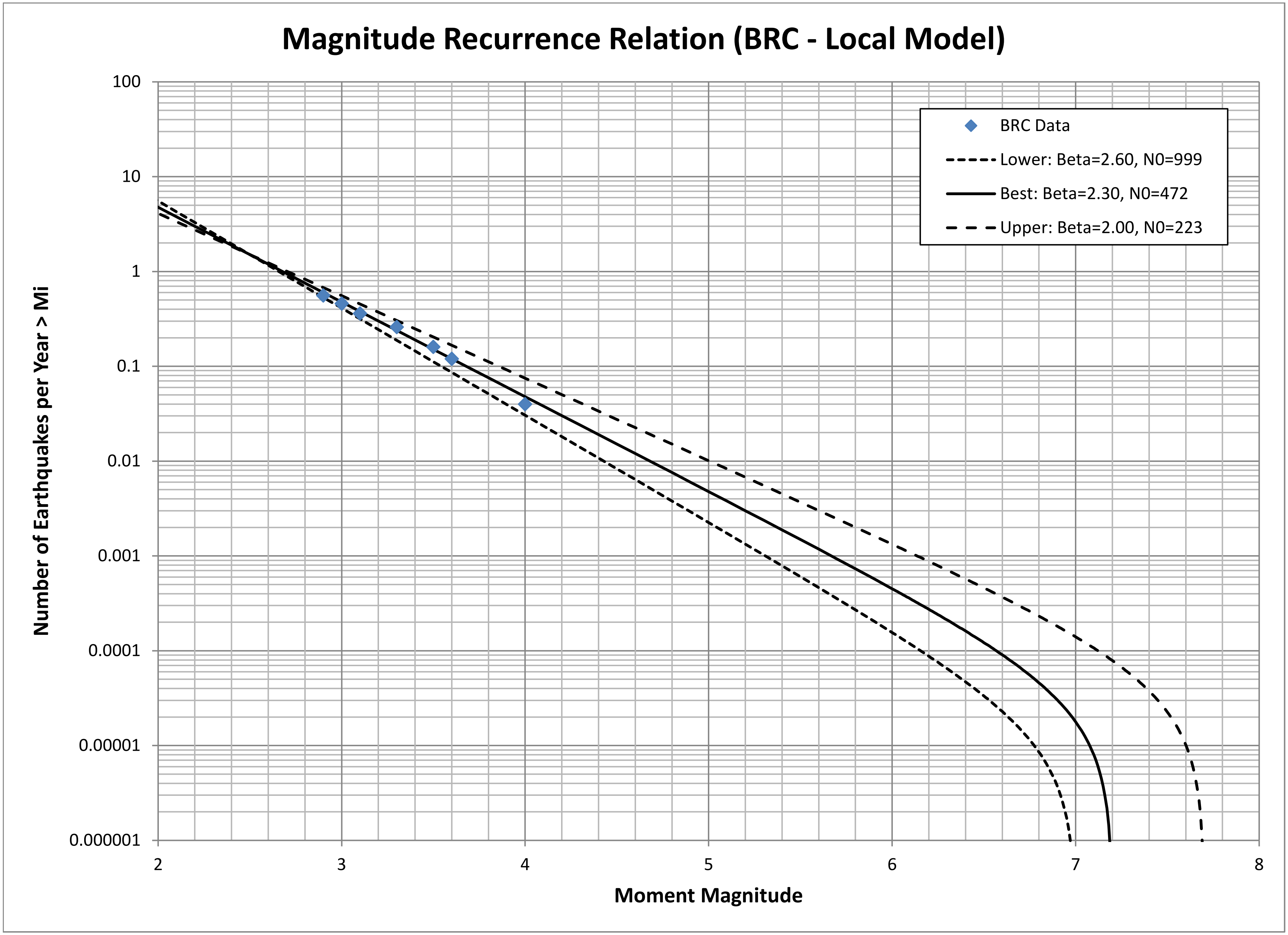
Magnitude Recurrence Relation (FHLm - Local Model)
Number of Earthquakes per Year > Mi
100
10
1
0.1
0.01
0.001
0.0001
0.00001
0.000001
2
3
4
5
6
7
8
Moment Magnitude
FHLm Data
Lower: Beta=2.60, N0=23585
Best: Beta=2.30, N0=9589
Upper: Beta=2.00, N0=3899



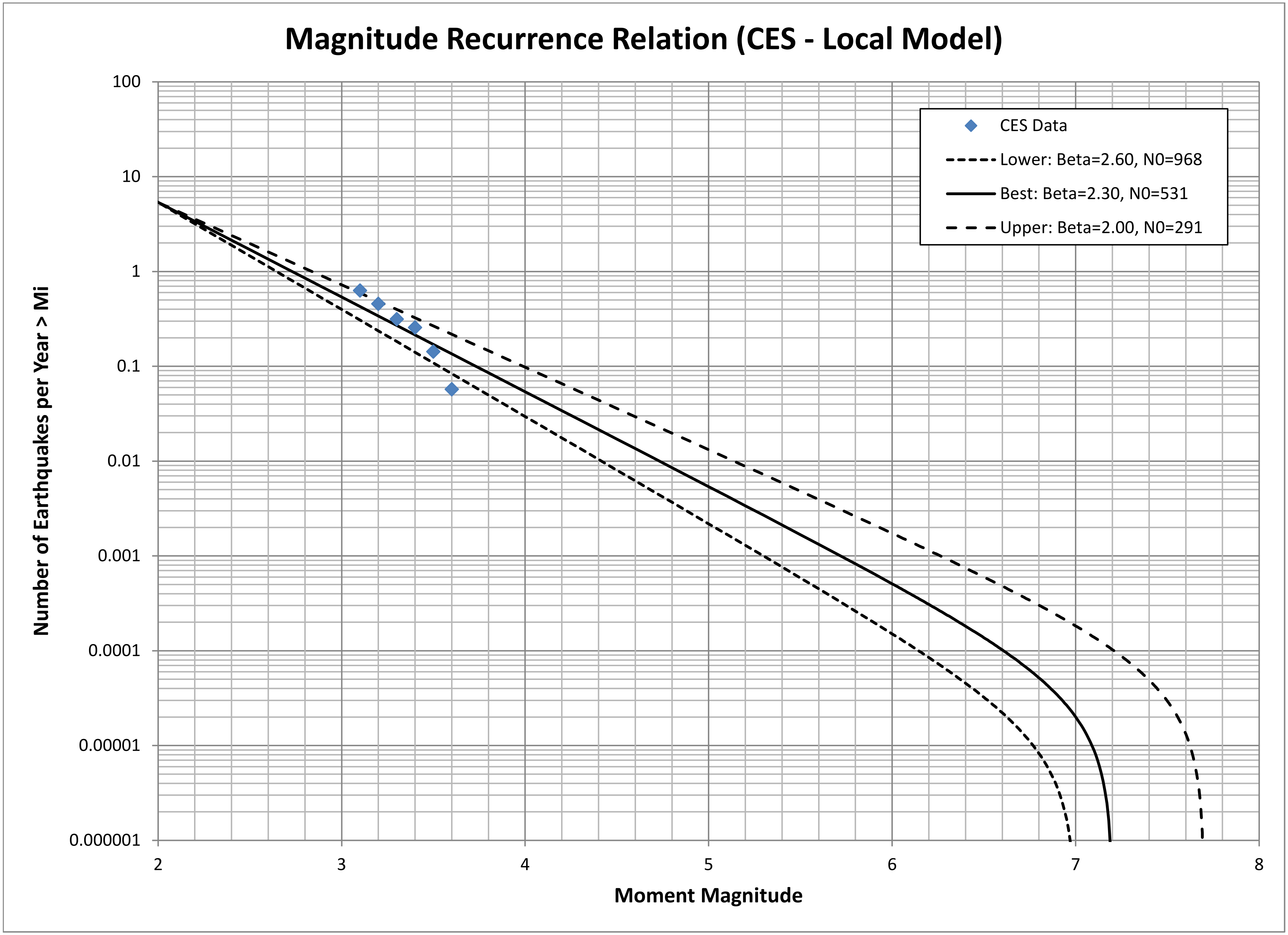
Magnitude Recurrence Relation (ROCSm - Local Model)
Number of Earthquakes per Year > Mi
100
10
1
0.1
0.01
0.001
0.0001
0.00001
0.000001
2
3
4
5
6
7
8
Moment Magnitude
ROCSm Data
Lower: Beta=2.60 N0=2534
Best: Beta=2.30, N0=1197
Upper: Beta=2.00, N0=565

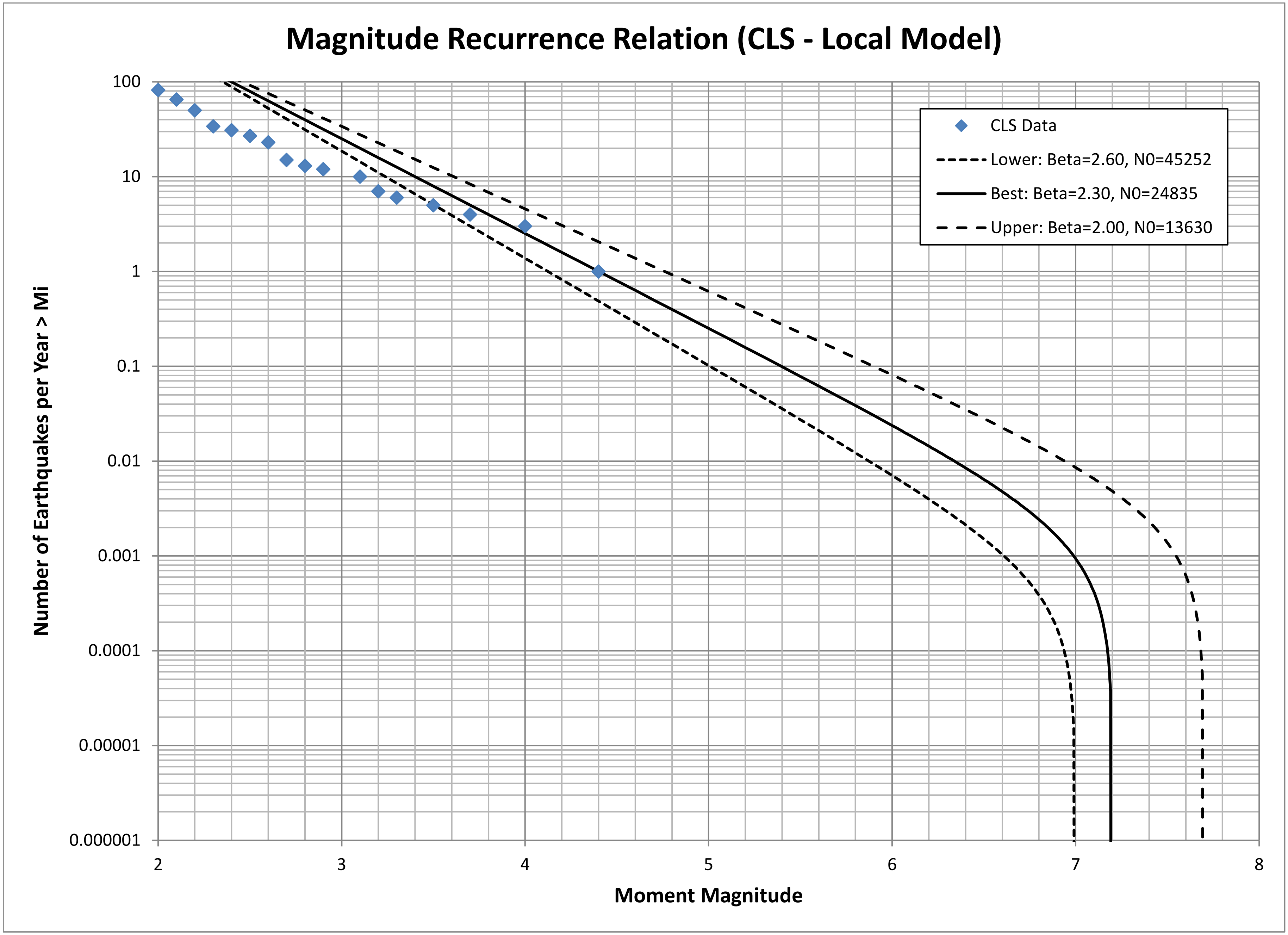


Magnitude Recurrence Relation (SBCm - Local Model)
Number of Earthquakes per Year > Mi
100
10
1
0.1
0.01
0.001
0.0001
0.00001
0.000001
2
3
4
5
6
7
8
Moment Magnitude
SBCm Data
Lower: Beta=1.95, N0=550
Best: Beta=1.75, N0=369
Upper: Beta=1.55, N0=247

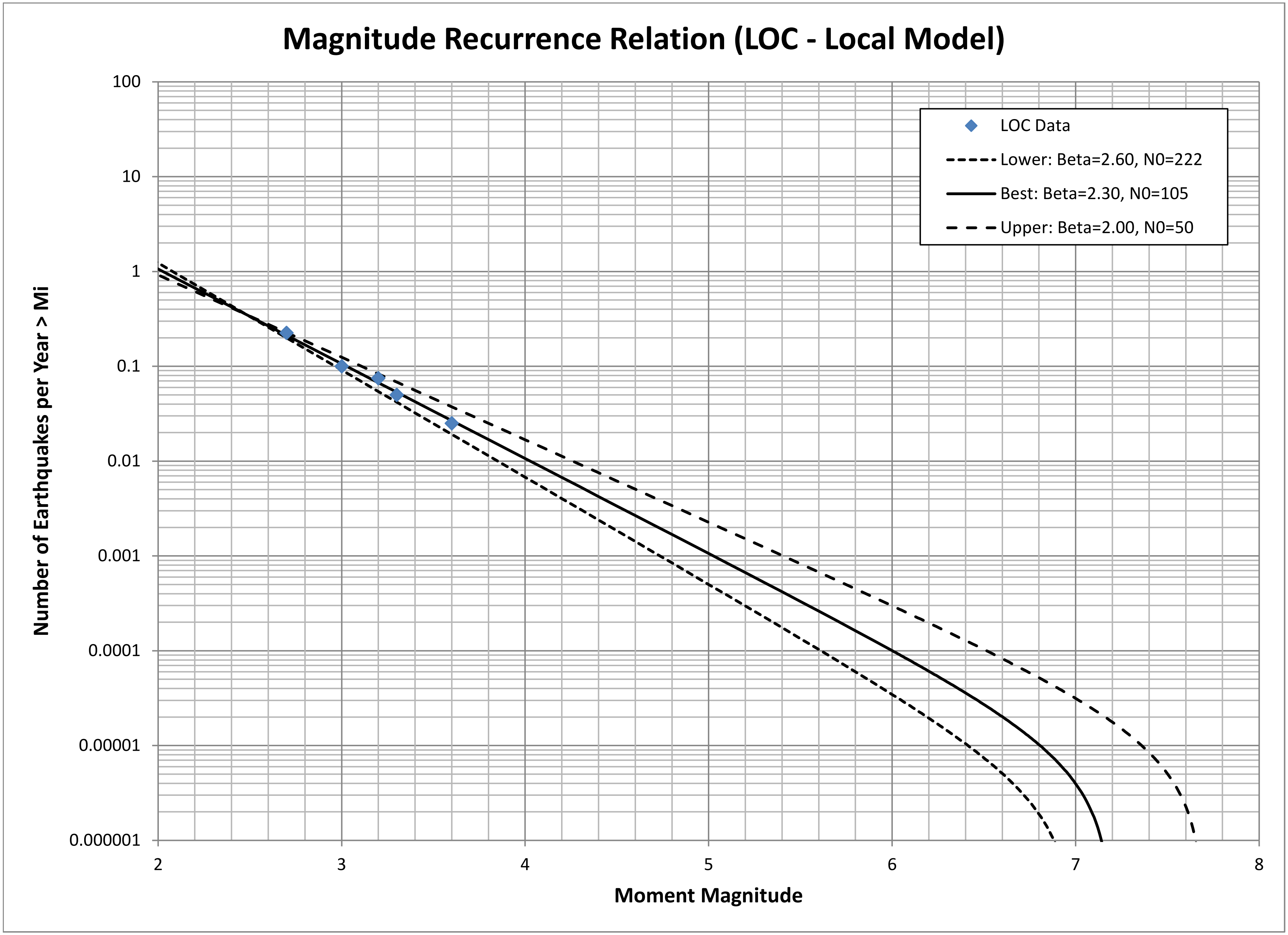


Magnitude Recurrence Relation (BRC - Local Model)
100
10
1
0.1
0.01
0.001
0.0001
0.00001
0.000001
Number of Earthquakes per Year > Mi
2
3
4
5
6
7
8
Moment Magnitude
BRC Data
Lower: Beta=2.60, N0=999
Best: Beta=2.30, N0=472
Upper: Beta=2.00, N0=223

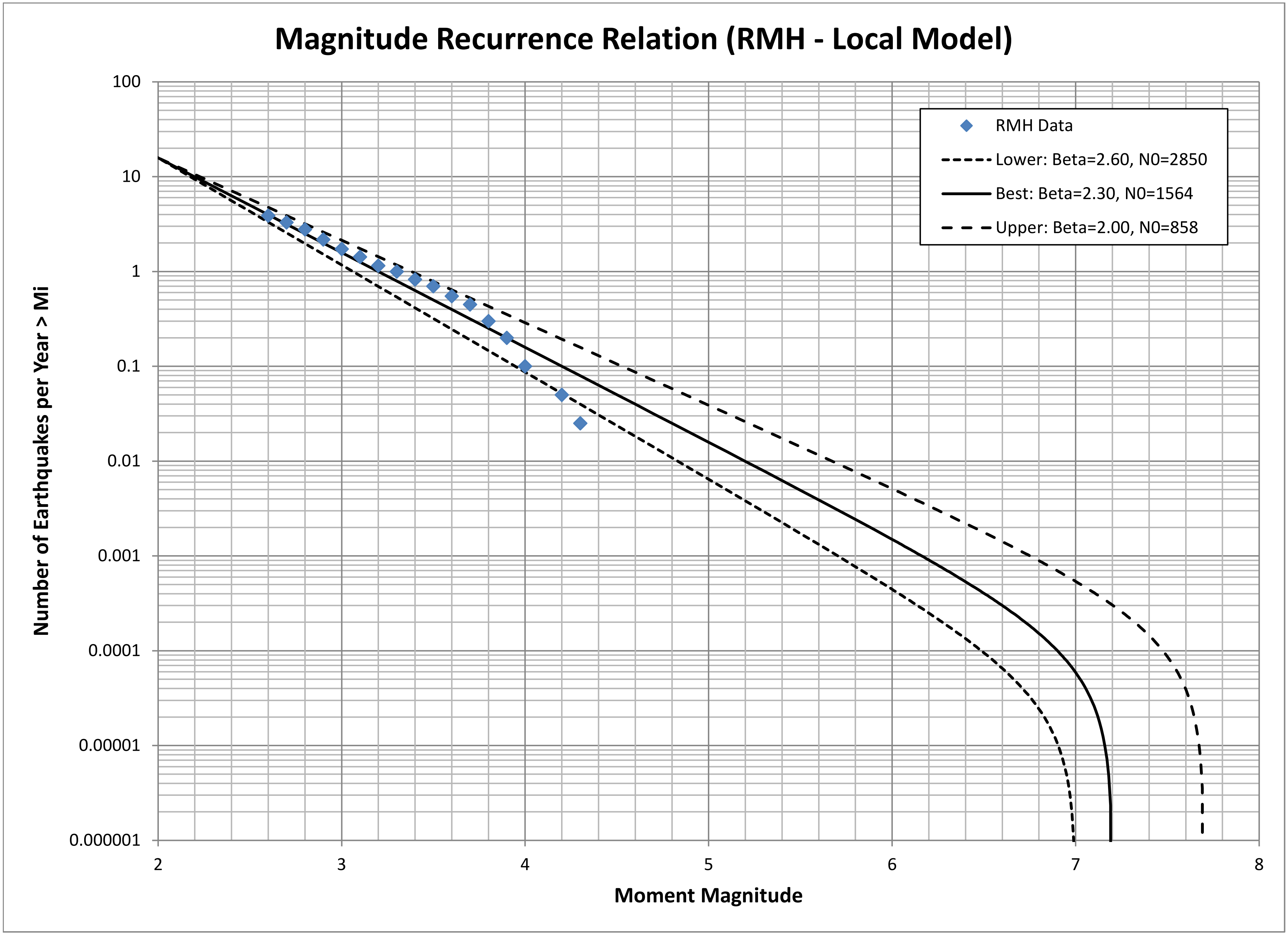

Magnitude Recurrence Relation (CES - Local Model)
Number of Earthquakes per Year > Mi
100
10
1
0.1
0.01
0.001
0.0001
0.00001
0.000001
2
3
4
5
6
7
8
Moment Magnitude
CES Data
Lower: Beta=2.60, N0=968
Best: Beta=2.30, N0=531
Upper: Beta=2.00, N0=291



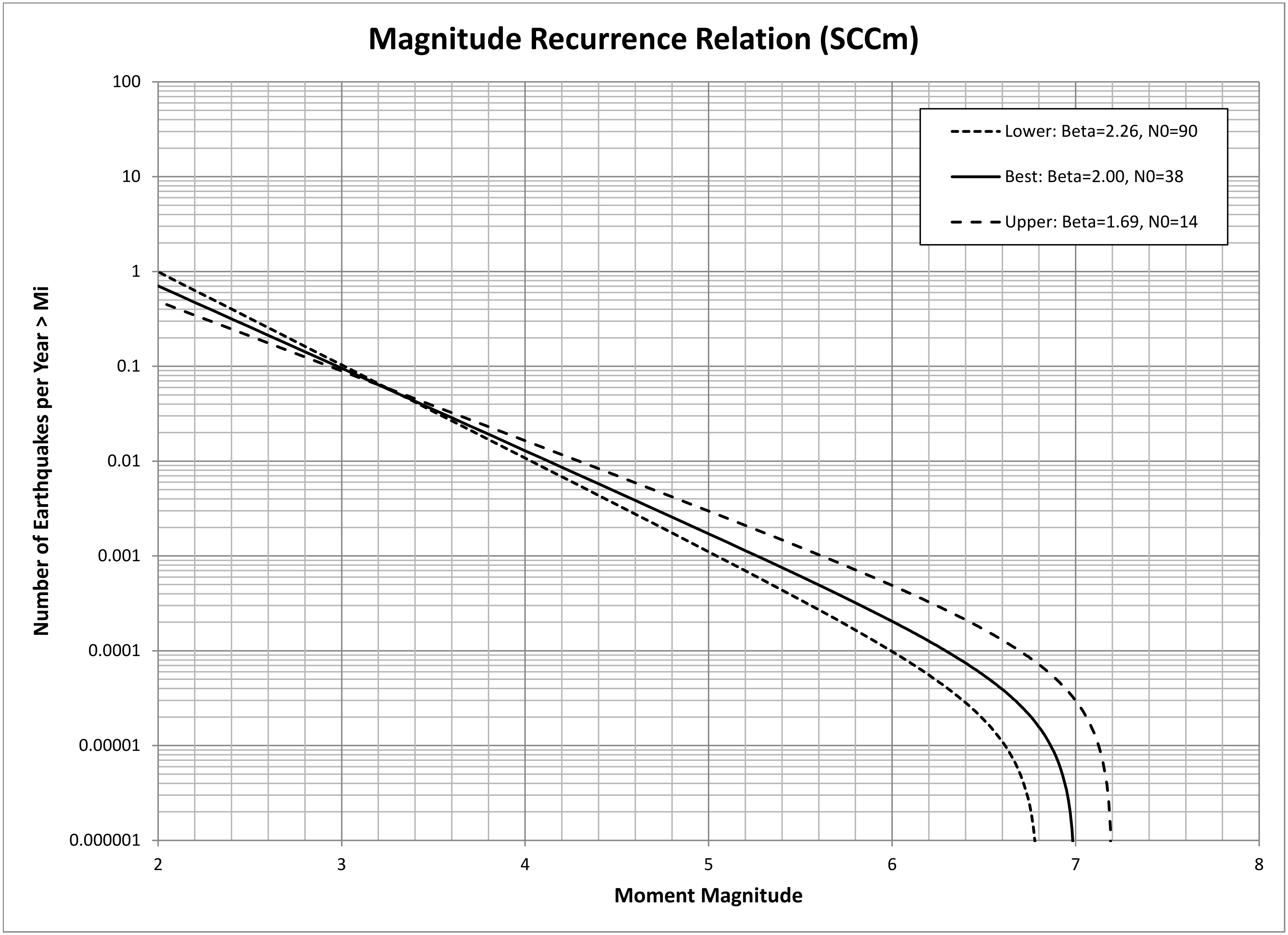
Magnitude Recurrence Relation (CLS - Local Model)
Number of Earthquakes per Year > Mi
Moment Magnitude
100
10
1
0.1
0.01
0.001
0.0001
0.00001
0.000001
2
3
4
5
6
7
8
CLS Data
Lower: Beta=2.60, N0=45252
Best: Beta=2.30, N0=24835
Upper: Beta=2.00, N0=13630



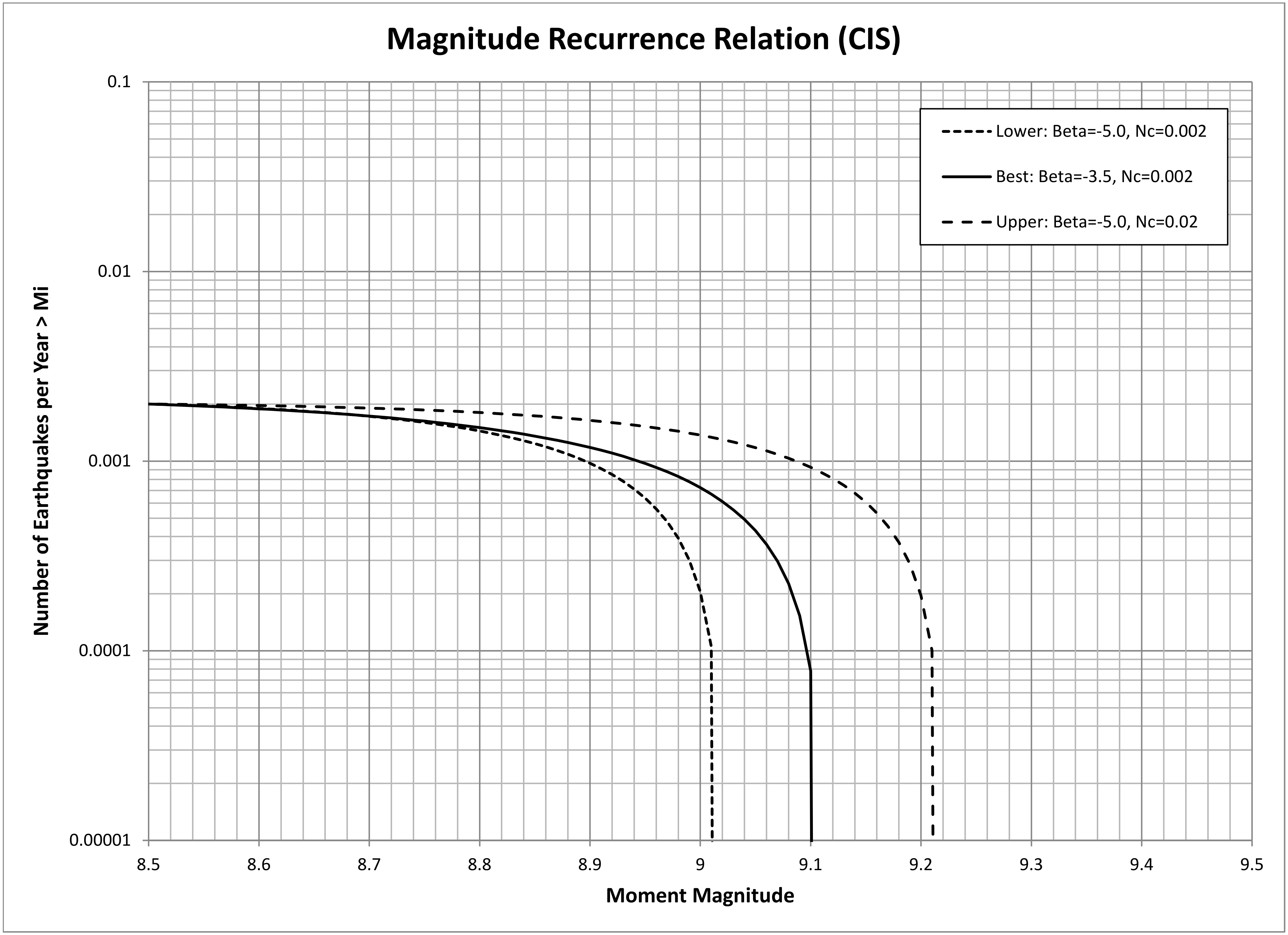
Magnitude Recurrence Relation (LOC - Local Model)
100
10
1
0.1
0.01
0.001
0.0001
0.00001
0.000001
Number of Earthquakes per Year > Mi
2
3
4
5
6
7
8
Moment Magnitude
LOC Data
Lower: Beta=2.60, N0=222
Best: Beta=2.30, N0=105
Upper: Beta=2.00, N0=50



Magnitude Recurrence Relation (RMH - Local Model)
Number of Earthquakes per Year > Mi
100
10
1
0.1
0.01
0.001
0.0001
0.00001
0.000001
2
3
4
5
6
7
8
Moment Magnitude
RMH Data
Lower: Beta=2.60, N0=2850
Best: Beta=2.30, N0=1564
Upper: Beta=2.00, N0=858

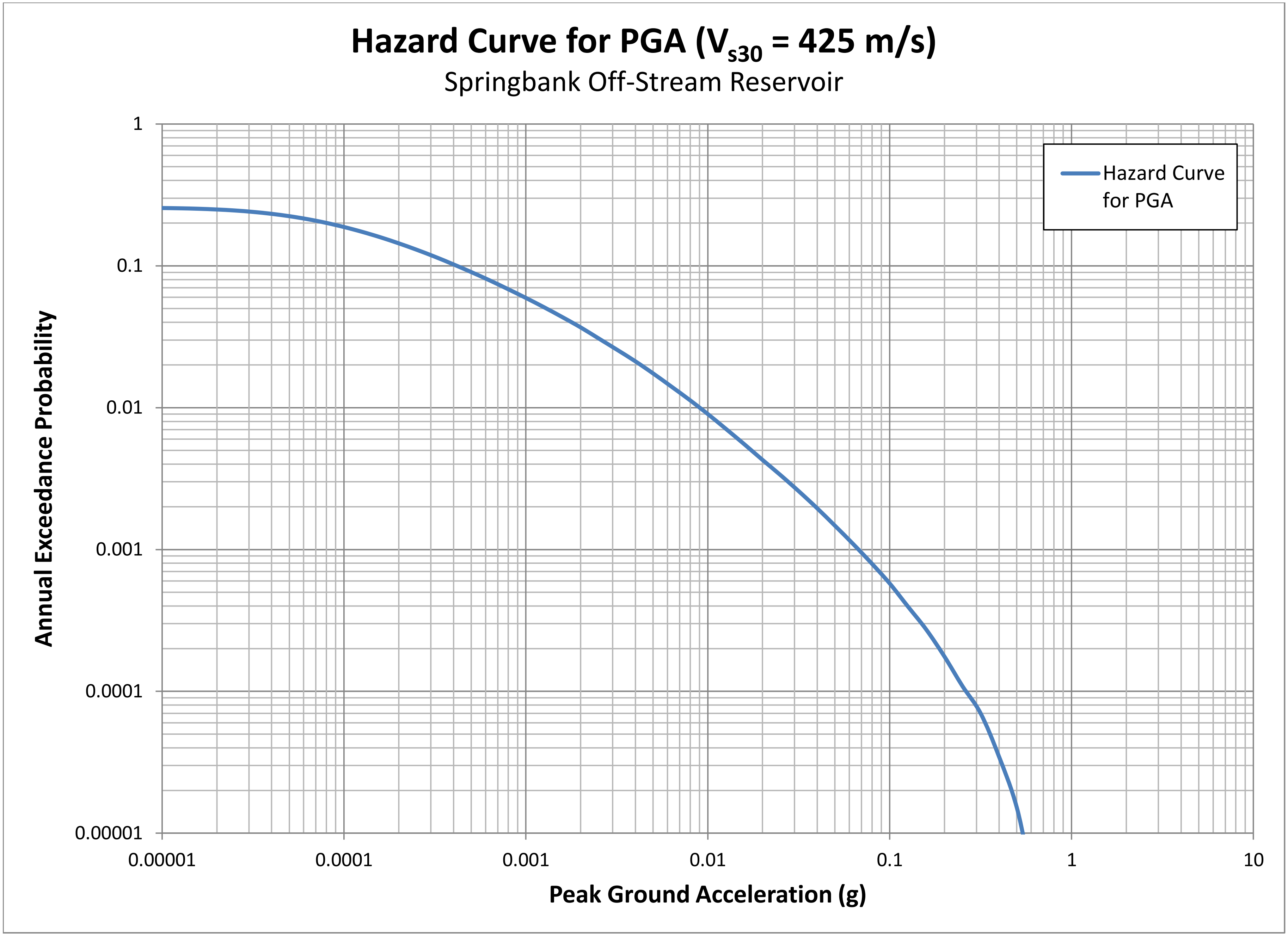


Magnitude Recurrence Relation (SCCm)
Lower: Beta=2.26, N0=90
Best: Beta=2.00, N0=38
Upper: Beta=1.69, N0=14
Number of Earthquakes per Year > Mi
100
10
1
0.1
0.01
0.001
0.0001
0.00001
0.000001
2
3
4
5
6
7
8
Moment Magnitude

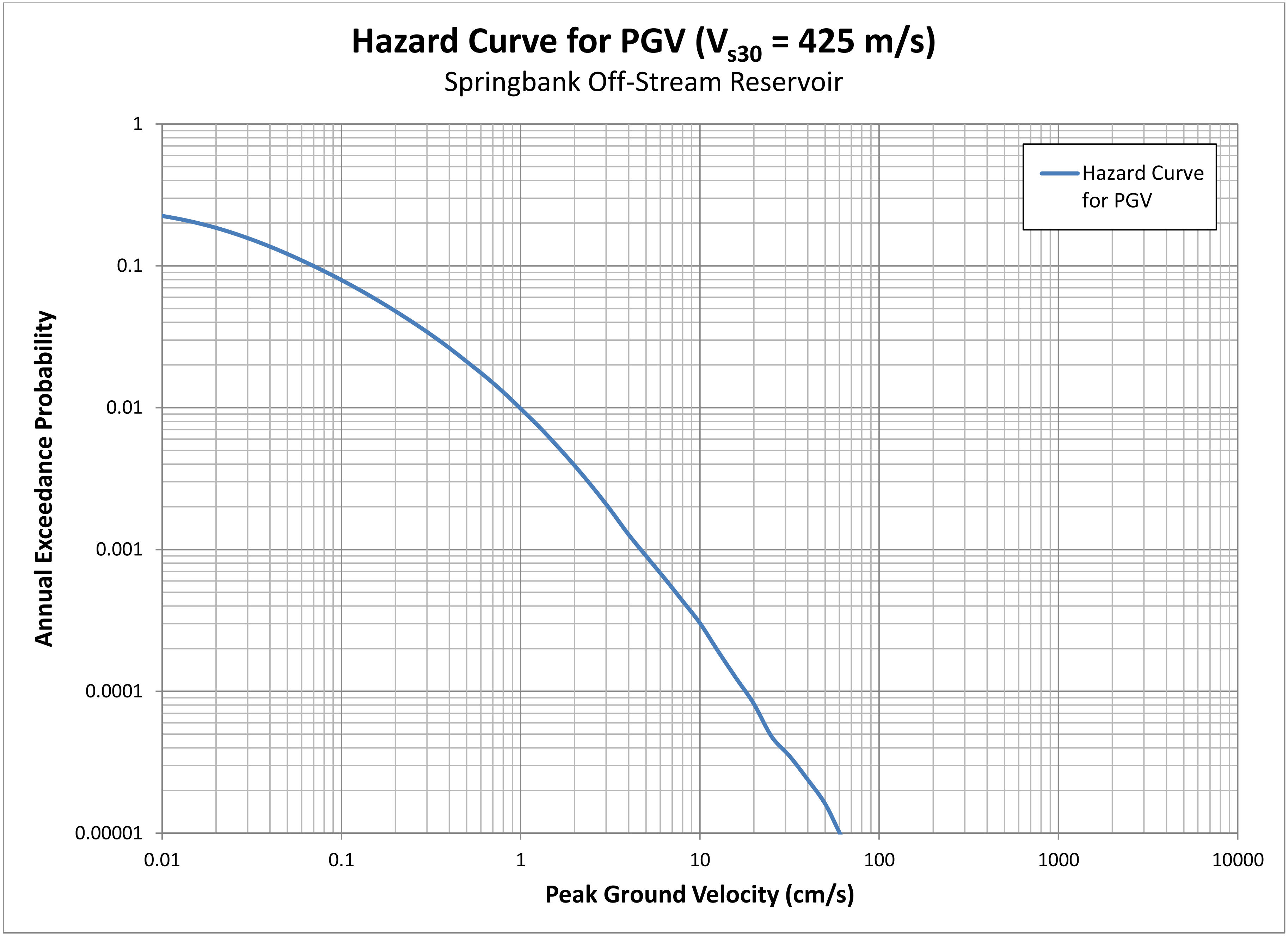


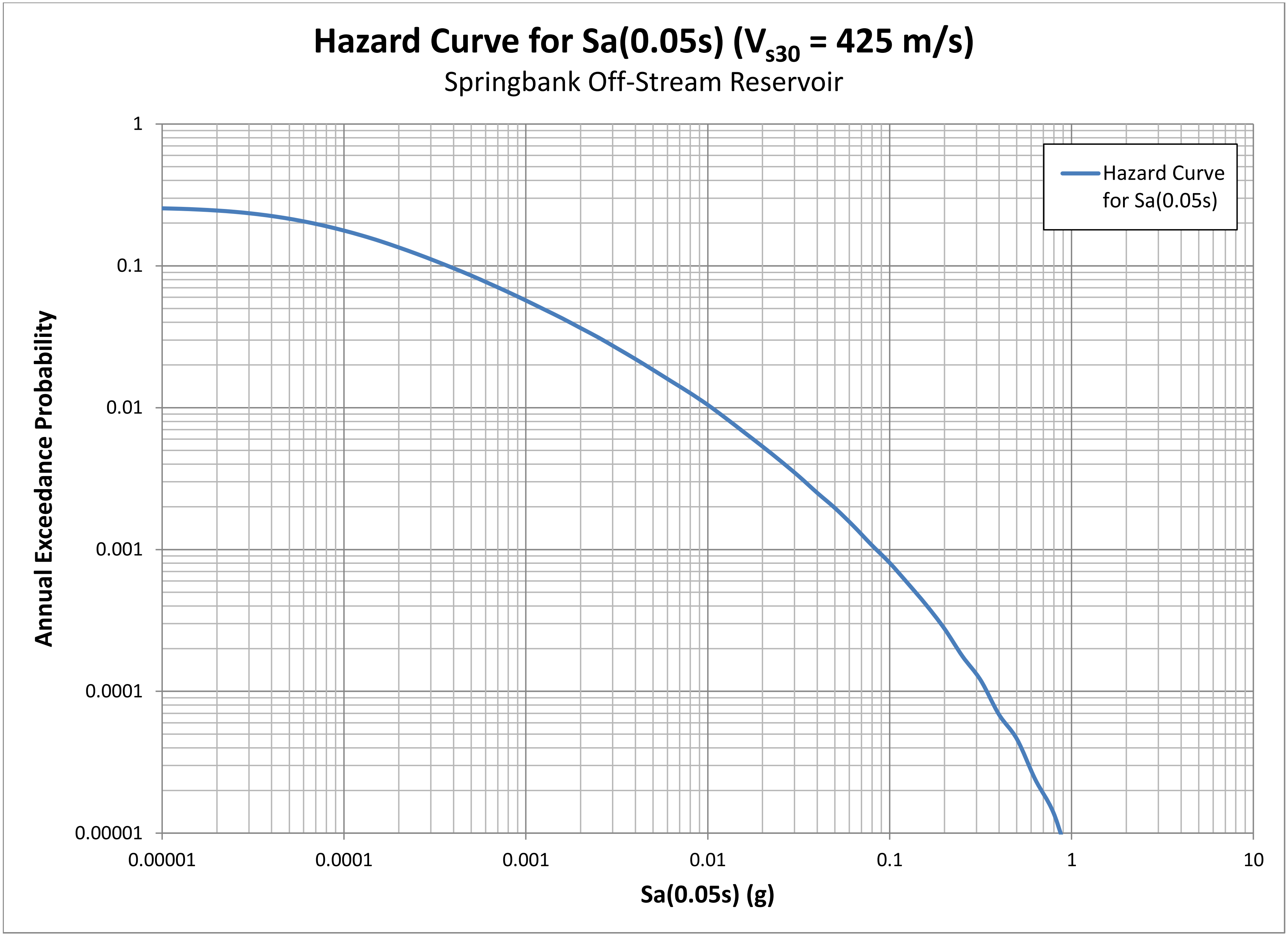
Magnitude Recurrence Relation (CIS)
Lower: Beta=-5.0, Nc=0.002
Best: Beta=-3.5, Nc=0.002
Upper: Beta=-5.0, Nc=0.02
Number of Earthquakes per Year > Mi
0.1
0.01
0.001
0.0001
0.00001
8.5
8.6
8.7
8.8
8.9
9
9.1
9.2
9.3
9.4
9.5
Moment Magnitude

Appendix C HAZARD CURVES

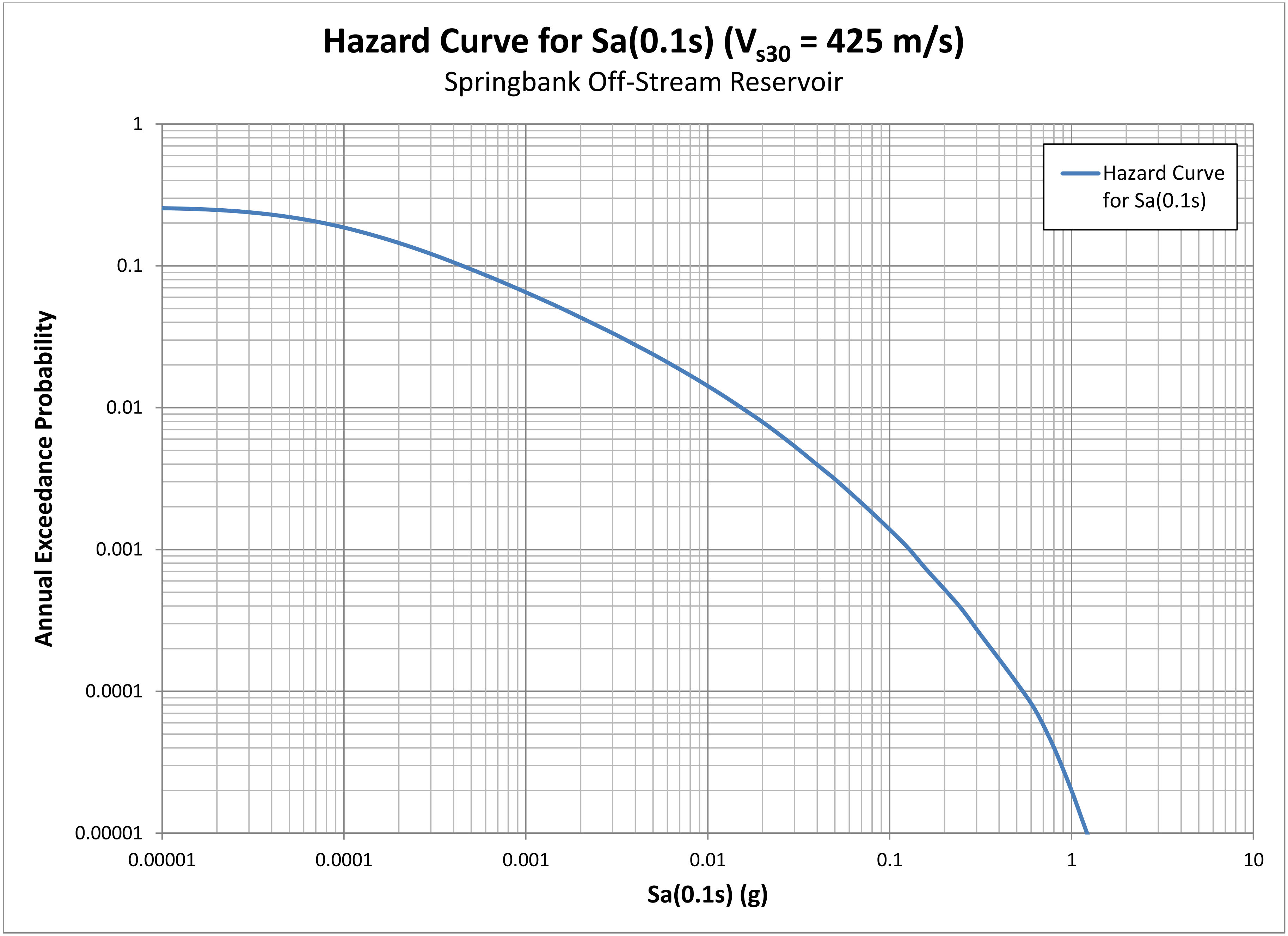


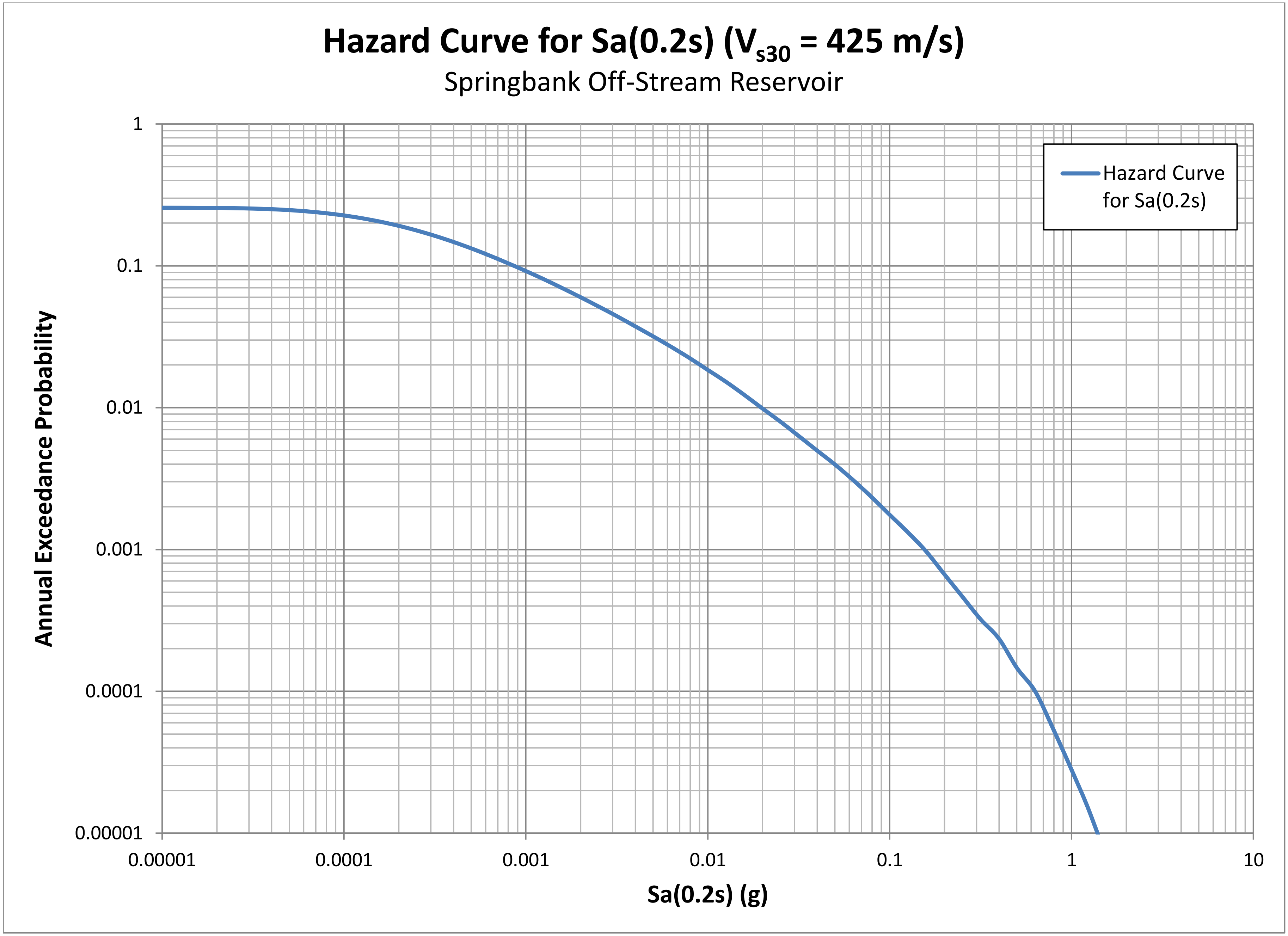
Hazard Curve for PGA (V_{s30} = 425 m/s)
Springbank Off-Stream Reservoir
Annual Exceedance Probability
1
0.1
0.01
0.001
0.0001
0.00001
0.00001
0.0001
0.001
0.01
0.1
1
10
Peak Ground Acceleration (g)
Hazard Curve for PGA


Hazard Curve for PGV (V_{s30} = 425 m/s)
Springbank Off-Stream Reservoir
Hazard Curve for PGV
Annual Exceedance Probability
1
0.1
0.01
0.001
0.0001
0.00001
0.01
0.1
1
10
100
1000
10000
Peak Ground Velocity (cm/s)

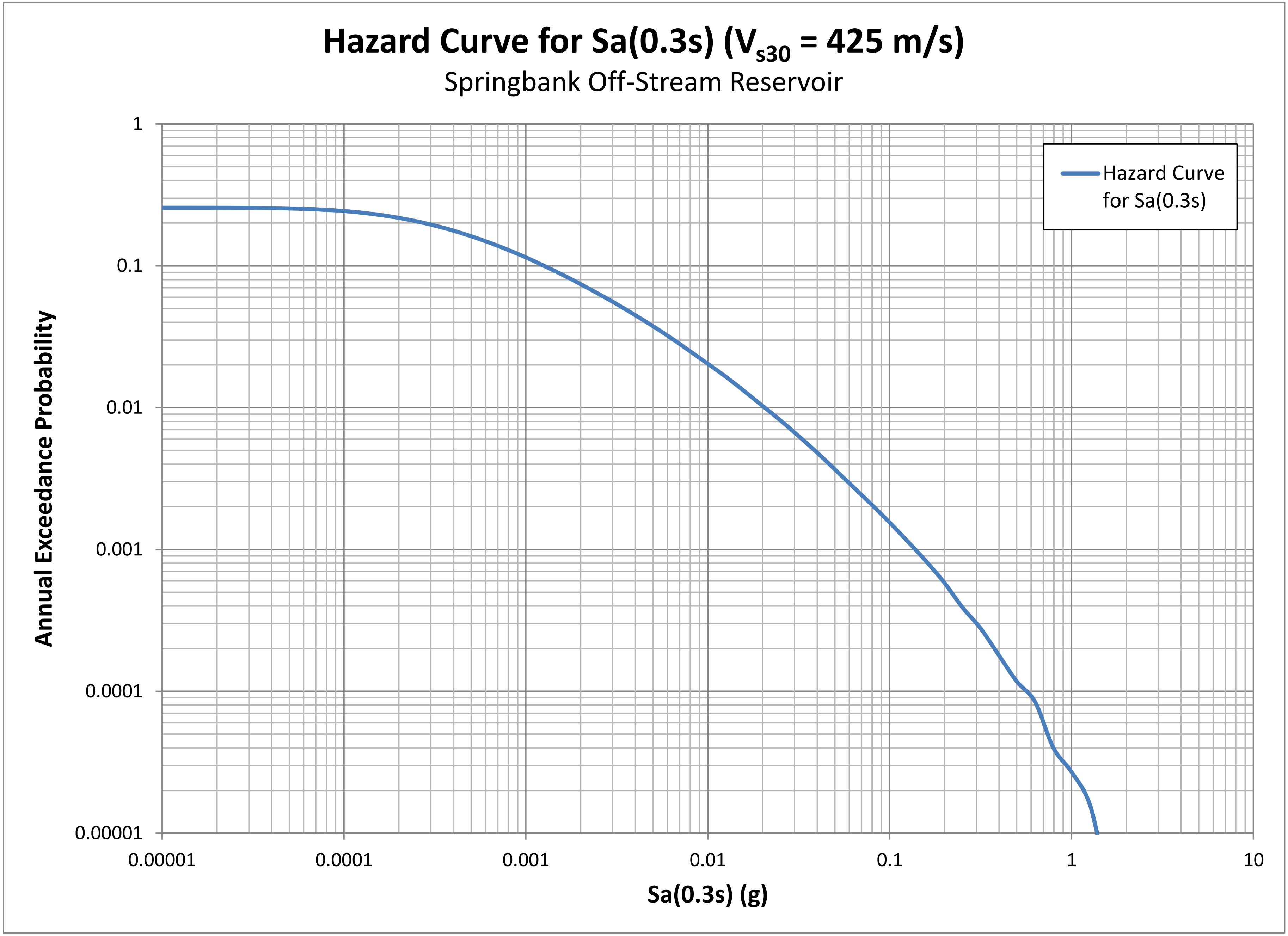


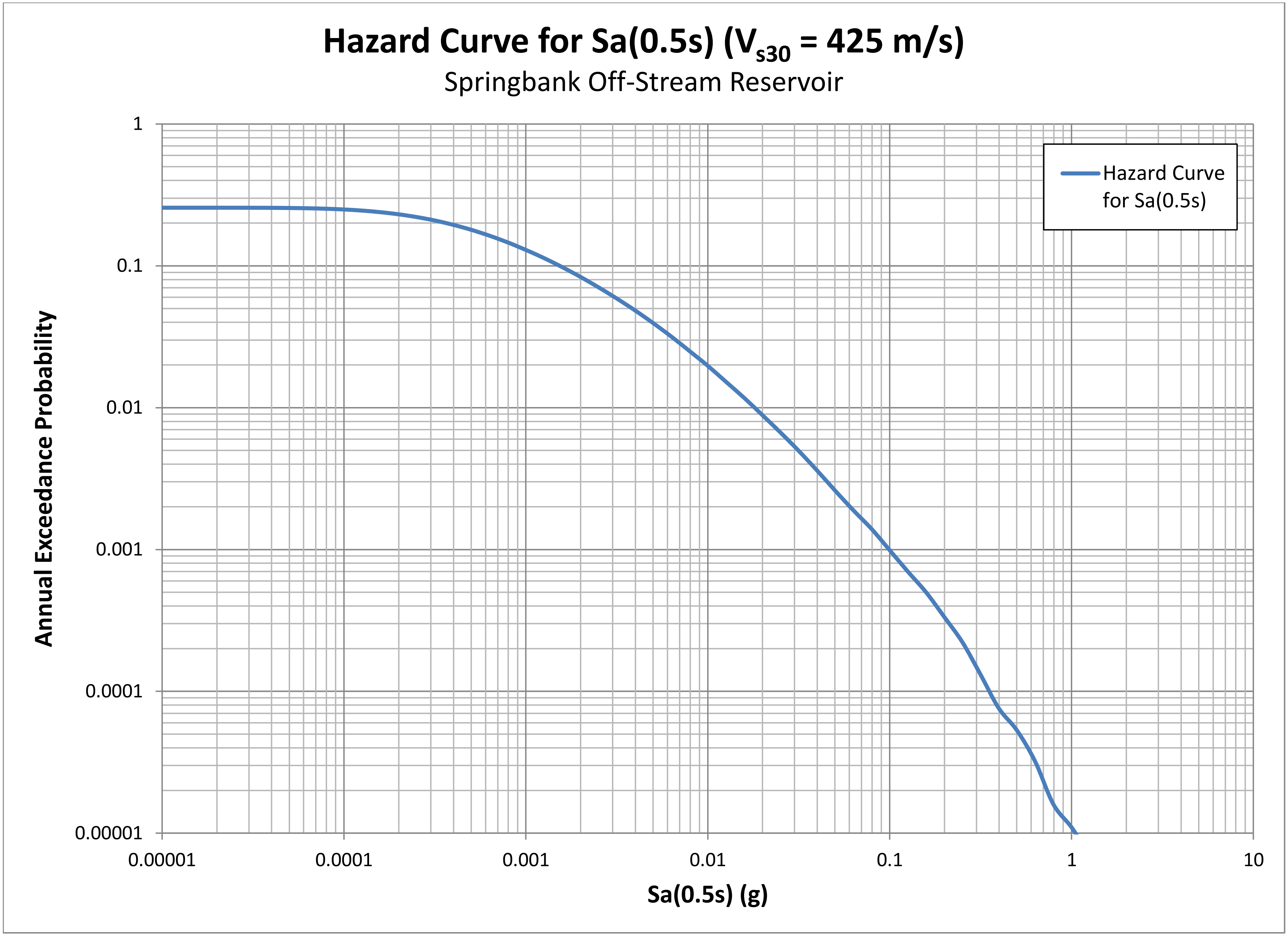
Hazard Curve for Sa(0.05s) (V_{s30} = 425 m/s)
Springbank Off-Stream Reservoir
Hazard Curve for Sa(0.05s)
Annual Exceedance Probability
1
0.1
0.01
0.001
0.0001
0.00001
0.00001
0.0001
0.001
0.01
0.1
1
10
Sa(0.05s) (g)

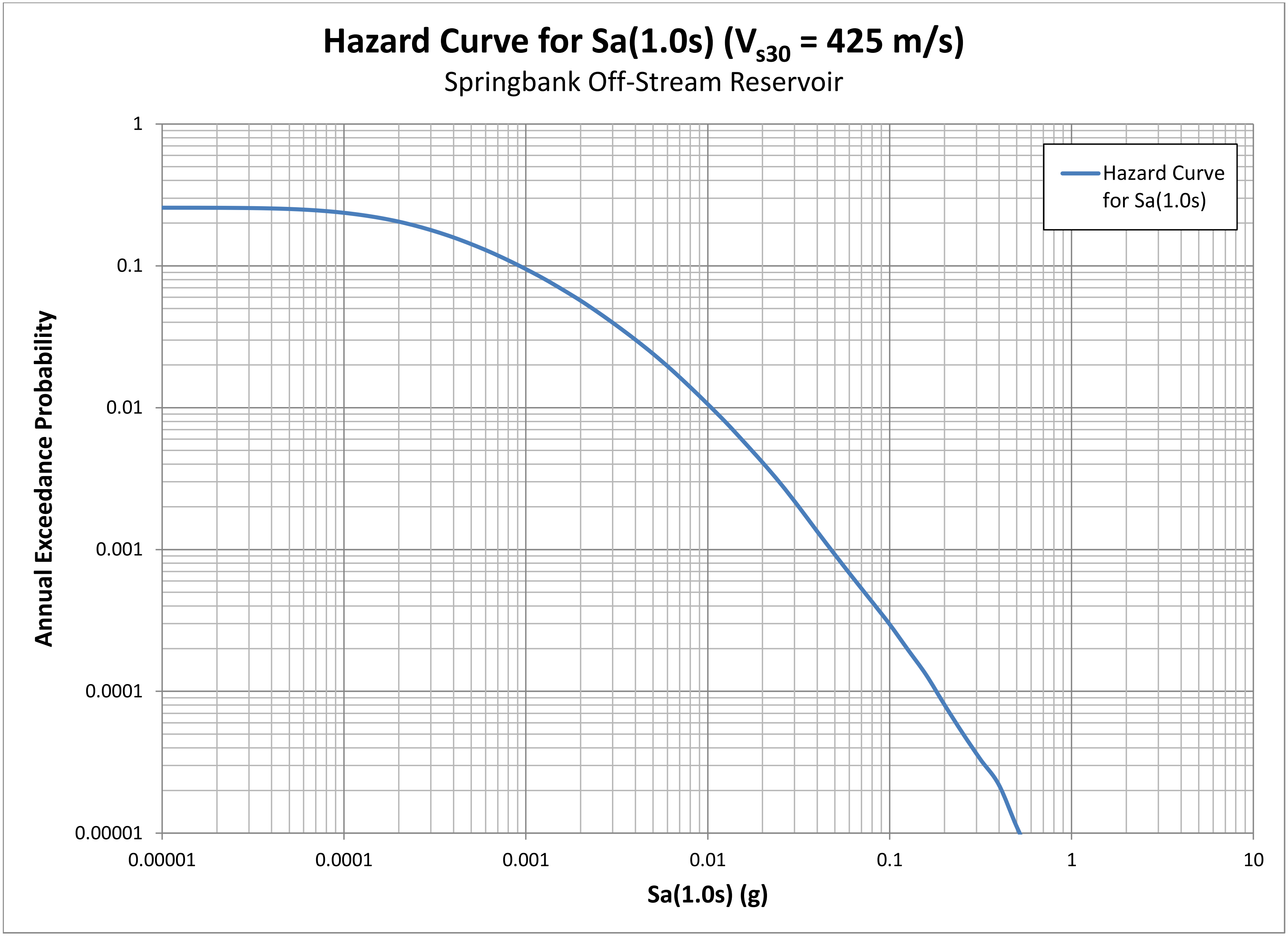

Hazard Curve for Sa(0.1s) (V_{s30} = 425 m/s)
Springbank Off-Stream Reservoir
Annual Exceedance Probability
1
0.1
0.01
0.001
0.0001
0.00001
0.00001
0.0001
0.001
0.01
0.1
1
10
Sa(0.1s) (g)
Hazard Curve for Sa(0.1s)

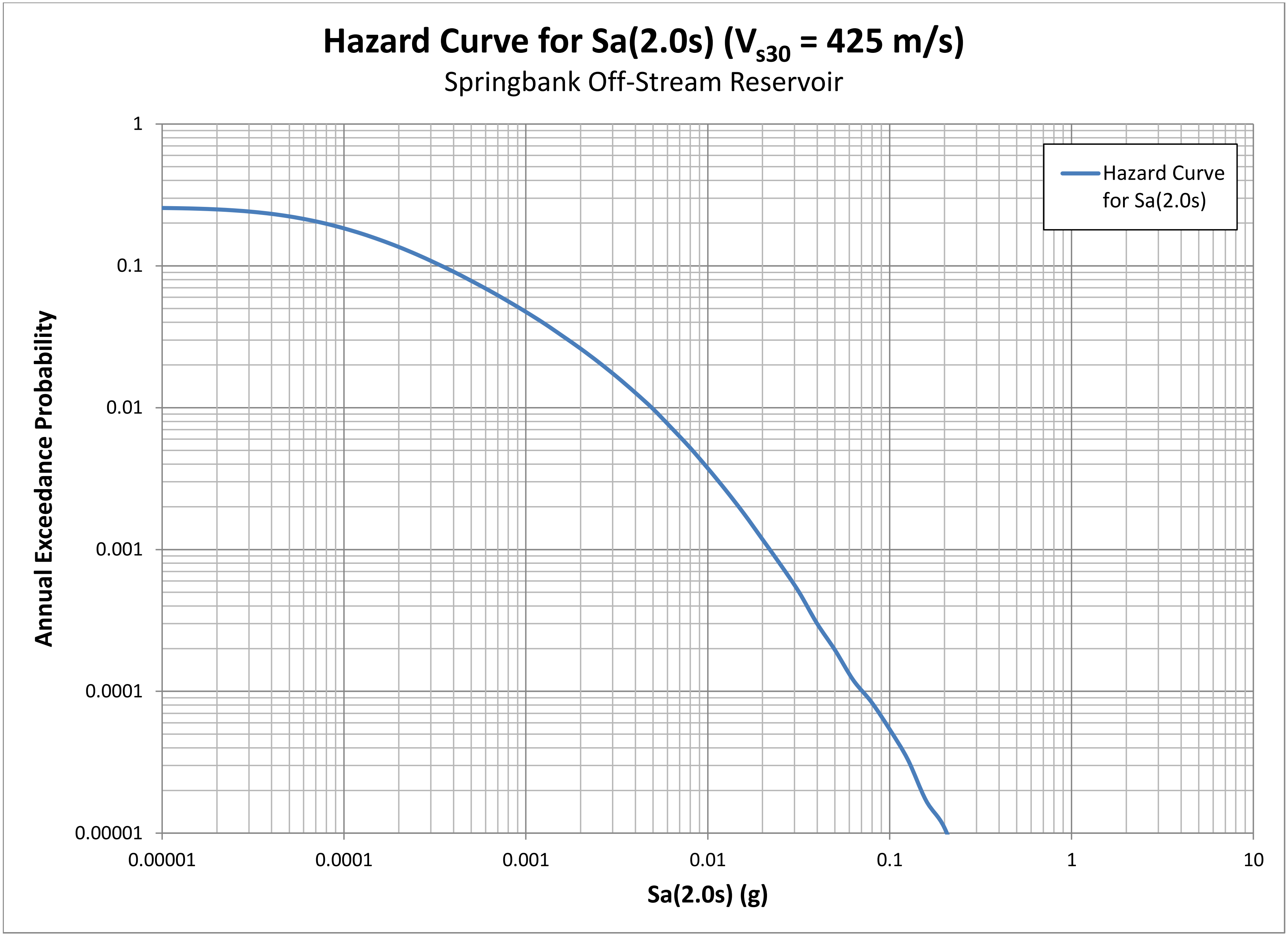


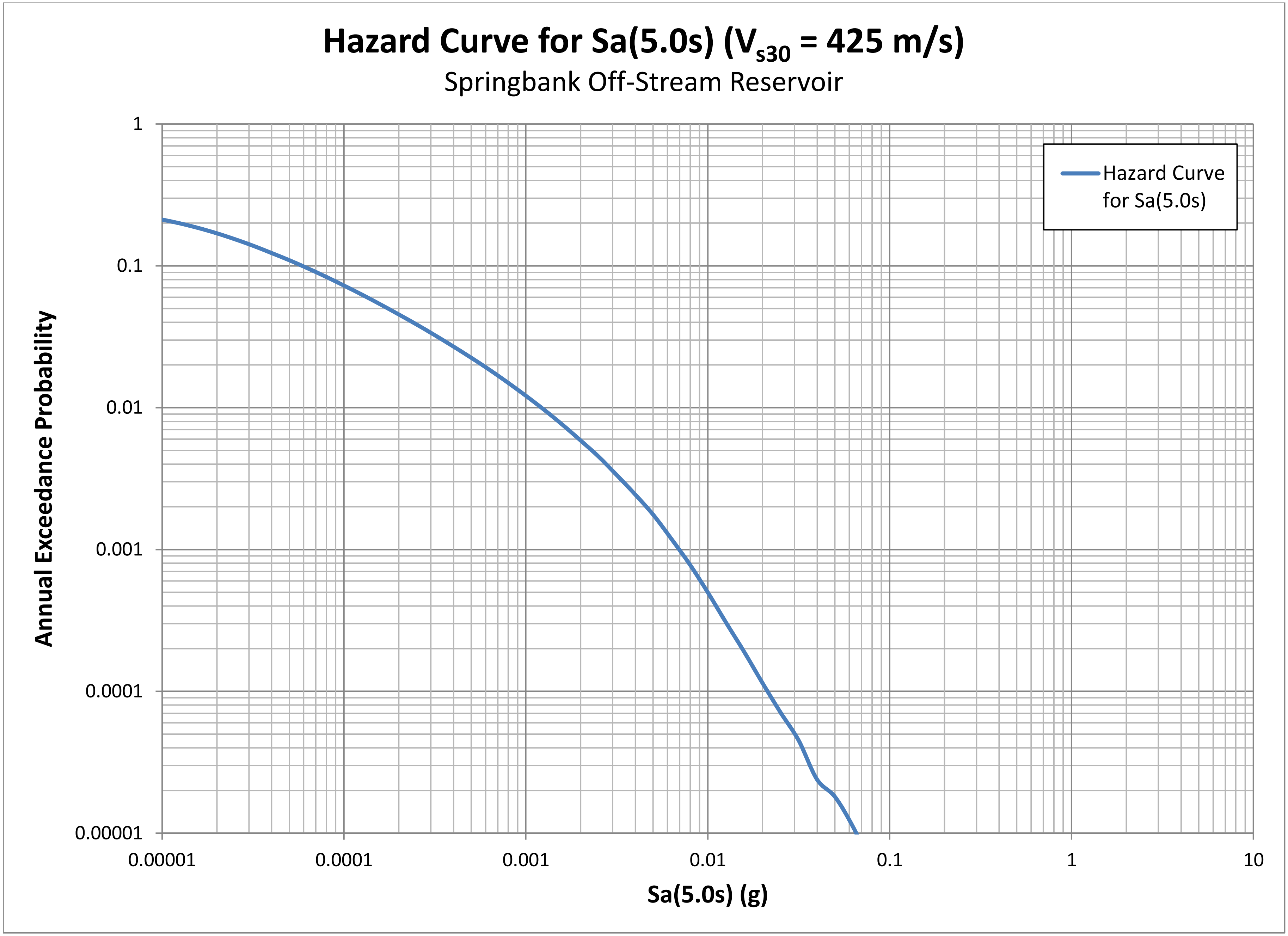
Hazard Curve for Sa(0.2s) (Vs30 = 425 m/s)
Springbank Off-Stream Reservoir
Hazard Curve for Sa(0.2s)
Annual Exceedance Probability
1
0.1
0.01
0.001
0.0001
0.00001
0.00001
0.0001
0.001
0.01
0.1
1
10
Sa(0.2s) (g)


Hazard Curve for Sa(0.3s) (Vs30 = 425 m/s)
Springbank Off-Stream Reservoir
Annual Exceedance Probability
1
0.1
0.01
0.001
0.0001
0.00001
0.00001
0.0001
0.001
0.01
0.1
1
10
Sa(0.3s) (g)
Hazard Curve for Sa(0.3s)

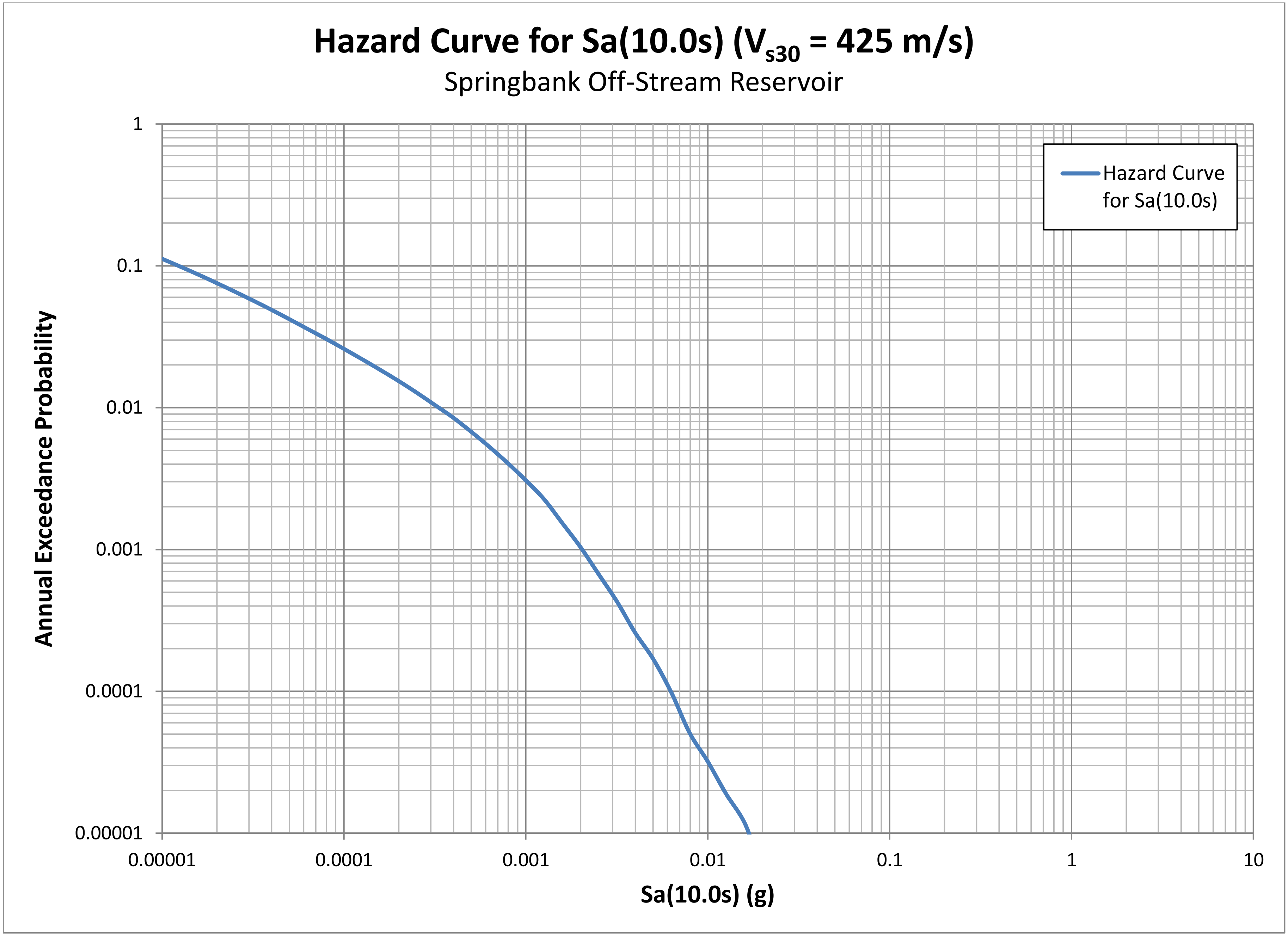

Hazard Curve for Sa(0.5s) (V_{s30} = 425 m/s)
Springbank Off-Stream Reservoir
Annual Exceedance Probability
Sa(0.5s) (g)
Hazard Curve for Sa(0.5s)
1
0.1
0.01
0.001
0.0001
0.00001
0.00001
0.0001
0.001
0.01
0.1
1
10


Hazard Curve for Sa(1.0s) (V_{s30} = 425 m/s)
Springbank Off-Stream Reservoir
1
0.1
0.01
0.001
0.0001
0.00001
Annual Exceedance Probability
0.00001
0.0001
0.001
0.01
0.1
1
10
Sa(1.0s) (g)
Hazard Curve for Sa(1.0s)


Hazard Curve for Sa(2.0s) (V_{s30} = 425 m/s)
Springbank Off-Stream Reservoir
Hazard Curve for Sa(2.0s)
Annual Exceedance Probability
Sa(2.0s) (g)
1
0.1
0.01
0.001
0.0001
0.00001
0.00001
0.0001
0.001
0.01
0.1
1
10

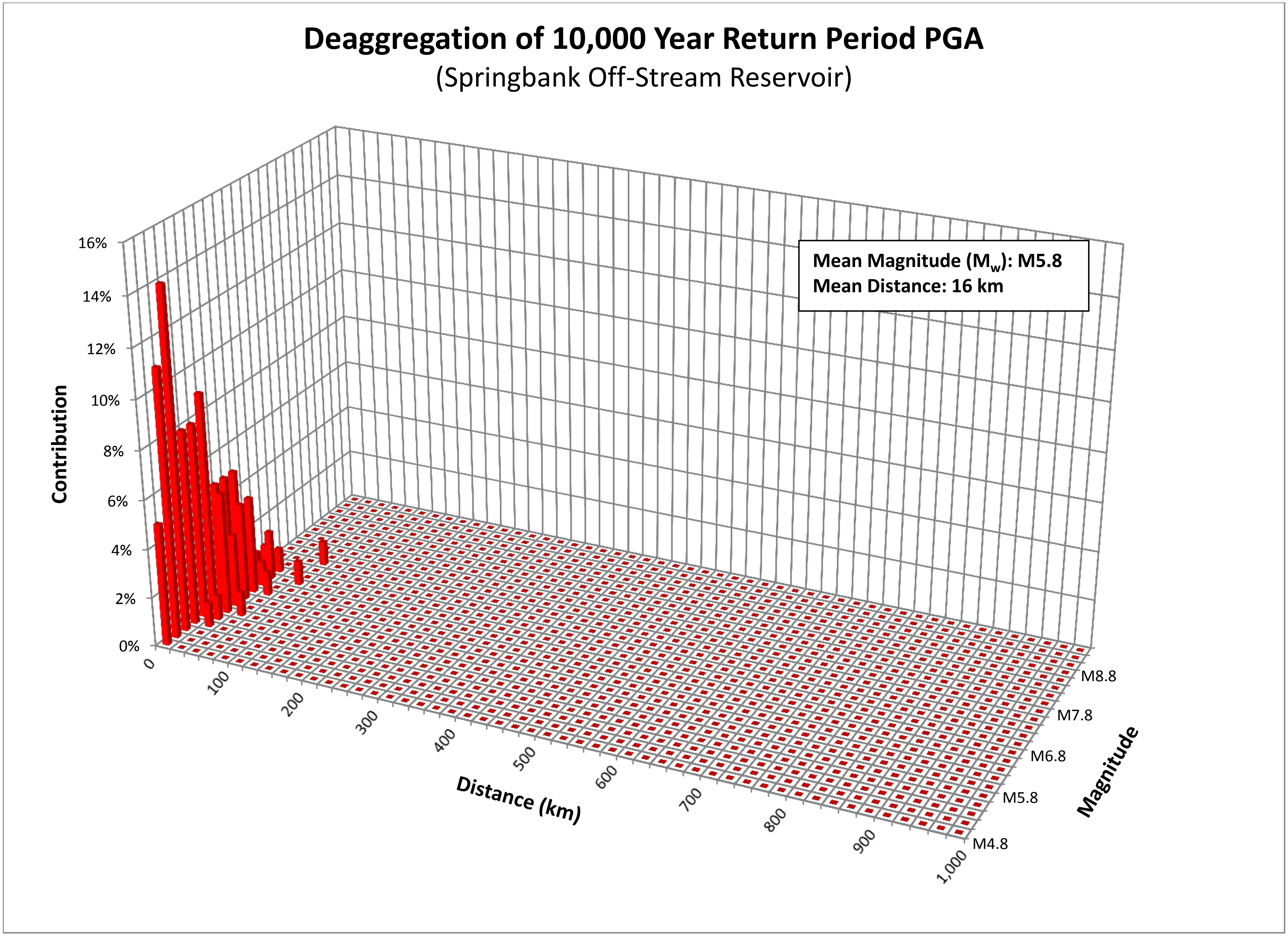


Hazard Curve for Sa(5.0s) (V_{s30} = 425 m/s)
Springbank Off-Stream Reservoir
Annual Exceedance Probability
1
0.1
0.01
0.001
0.0001
0.00001
0.00001
0.0001
0.001
0.01
0.1
1
10
Sa(5.0s) (g)
Hazard Curve for Sa(5.0s)

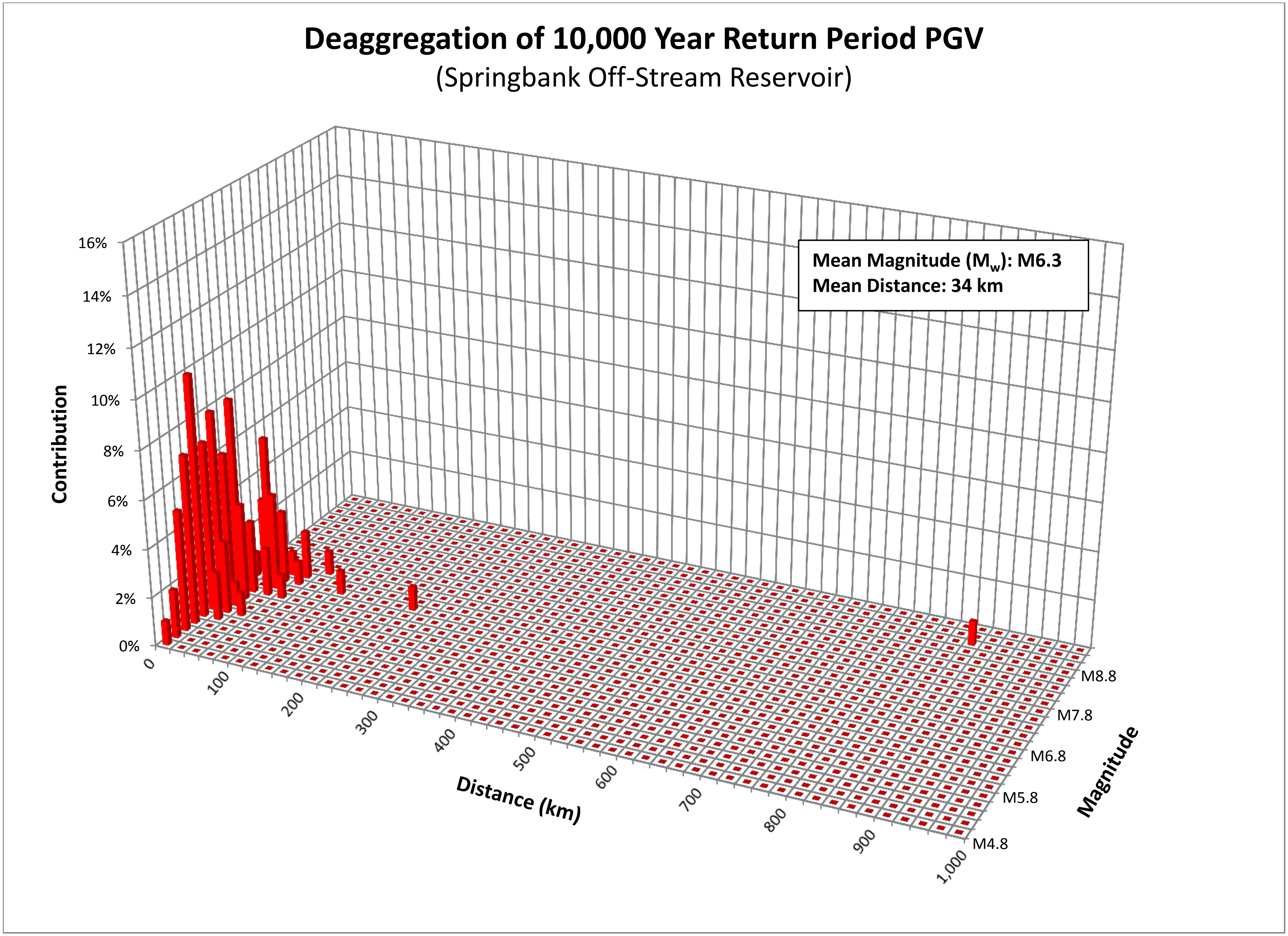


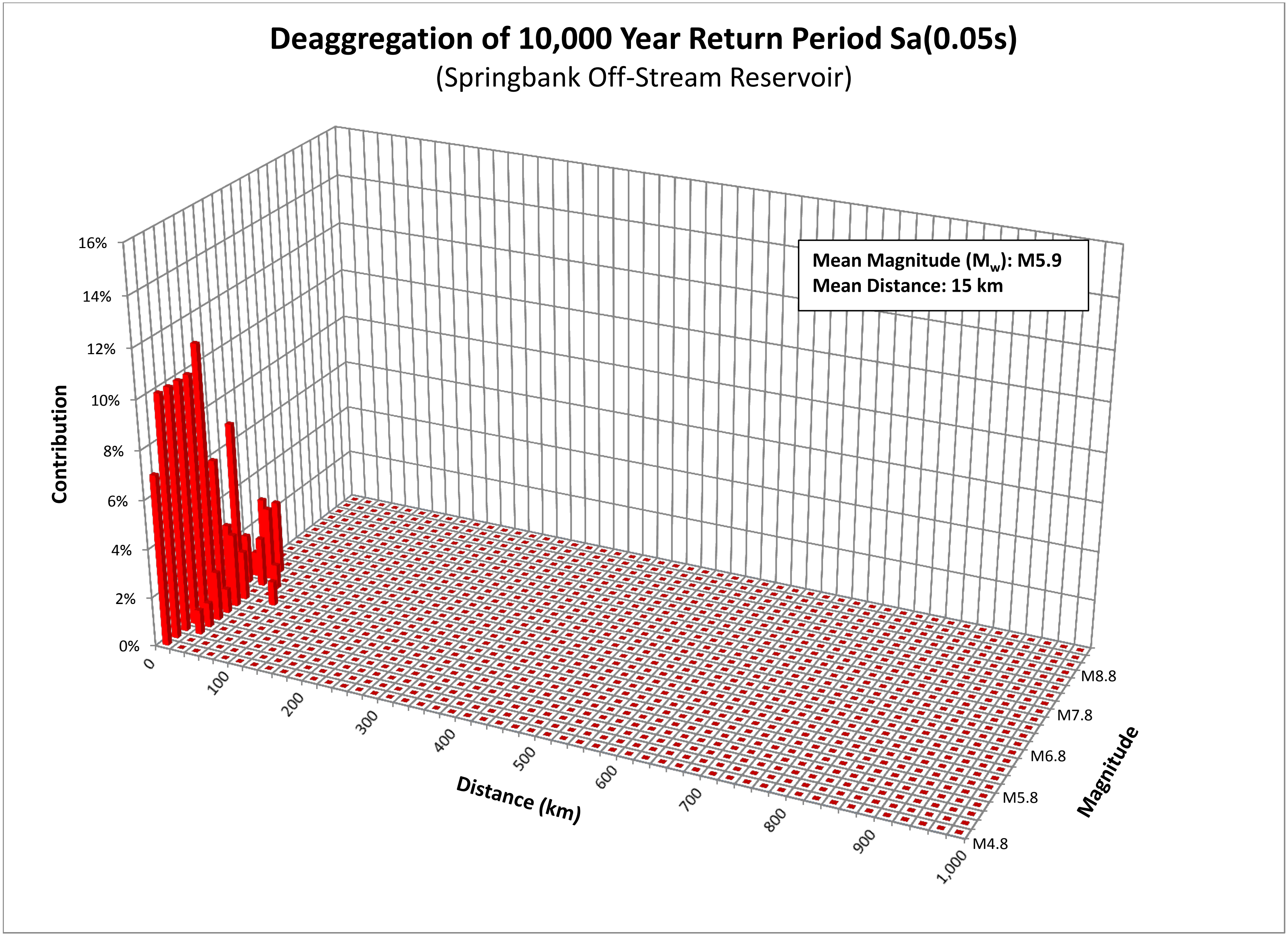
Hazard Curve for Sa(10.0s) (V_{s30} = 425 m/s)
Springbank Off-Stream Reservoir
Annual Exceedance Probability
Sa(10.0s) (g)
Hazard Curve for Sa(10.0s)
1
0.1
0.01
0.001
0.0001
0.00001
0.00001
0.0001
0.001
0.01
0.1
1
10

Appendix D DEAGGREGATION PLOTS

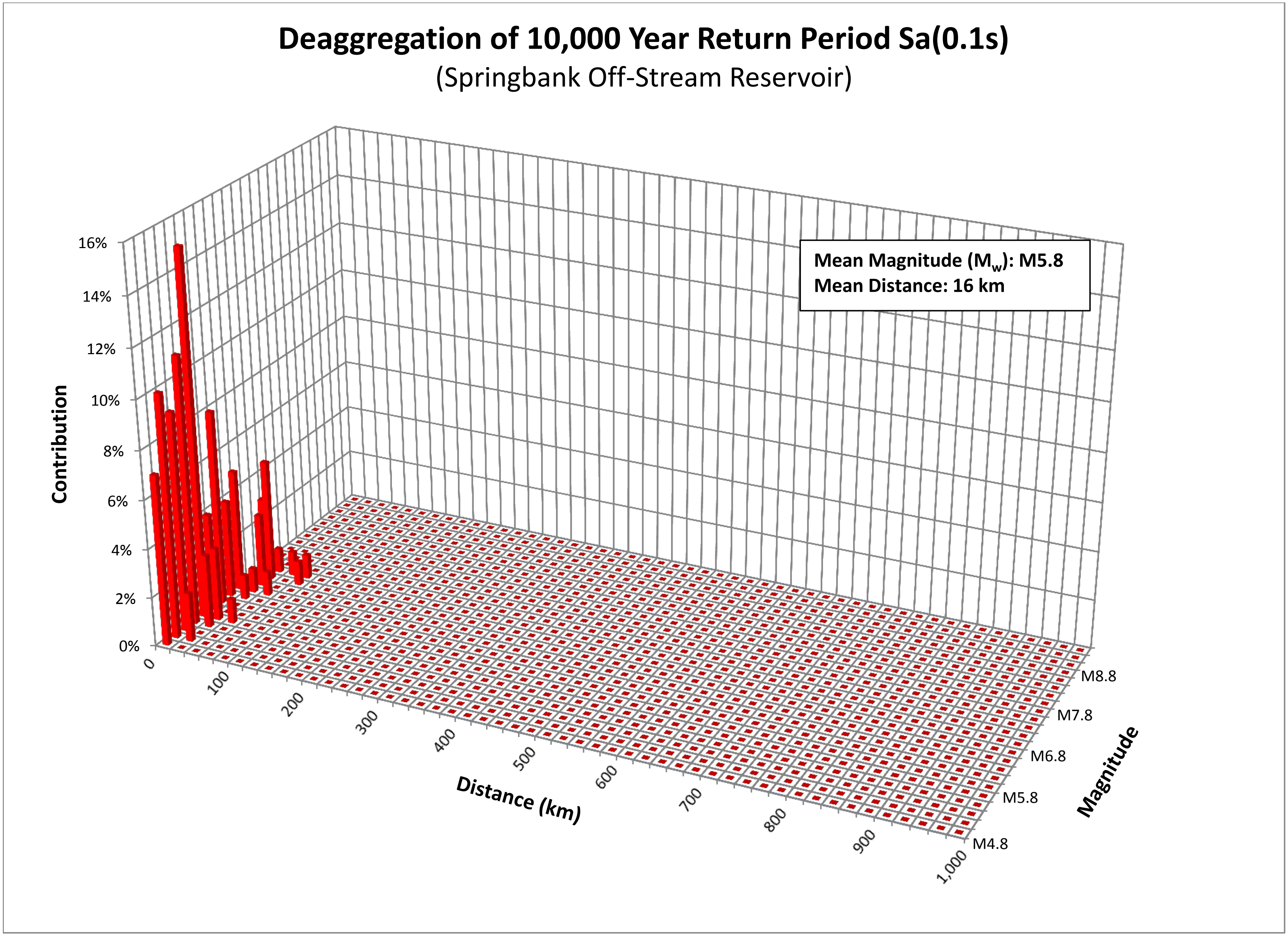


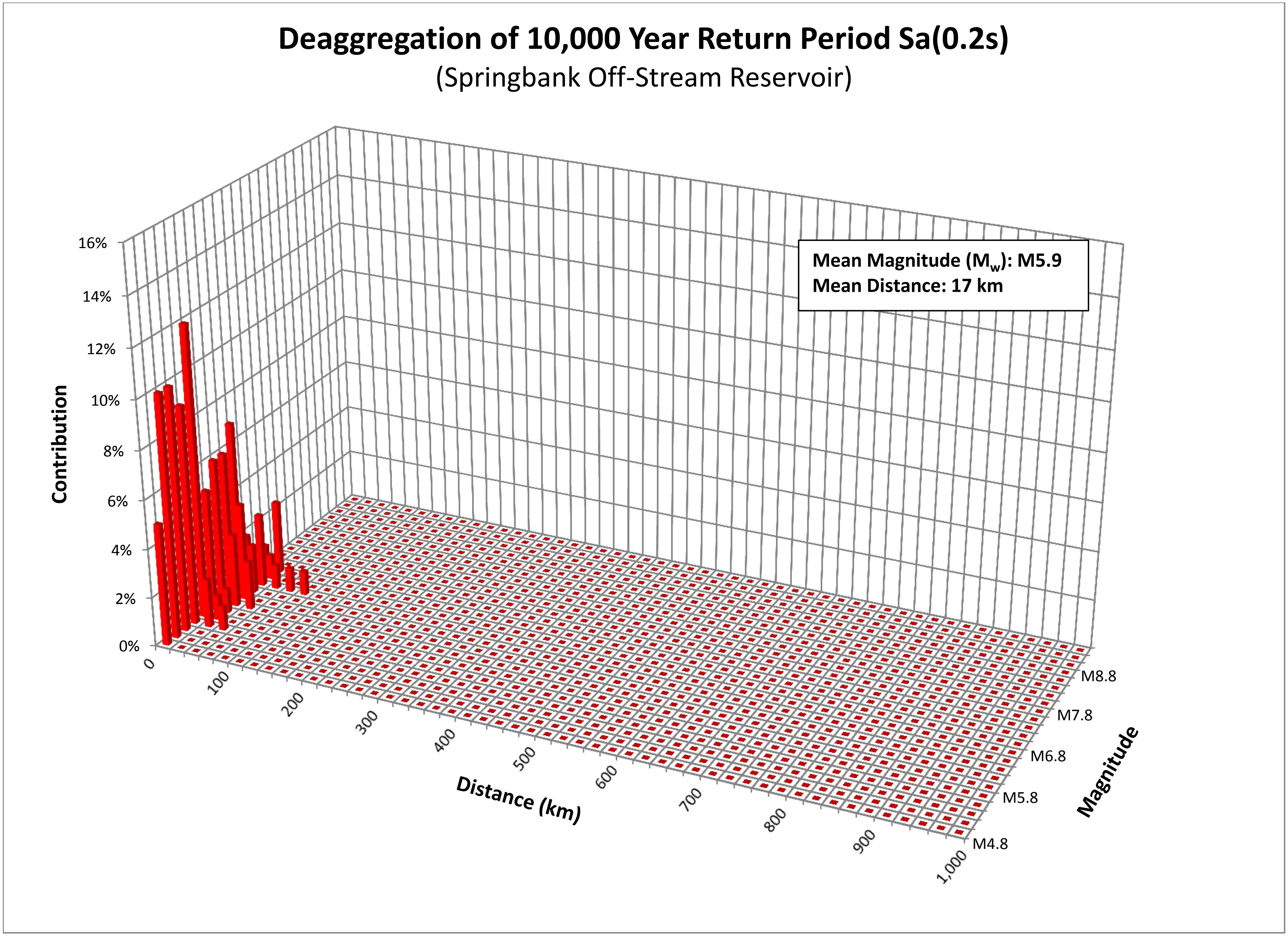
Deaggregation of 10,000 Year Return Period PGA
(Springbank Off-Stream Reservoir)
Mean Magnitude (M_w): M5.8
Mean Distance: 16 km
Contribution
16%
14%
12%
10%
8%
6%
4%
2%
0%
0
100
200
300
400
500
600
700
800
900
1,000
Distance (km)
M4.8
M5.8
M6.8
M7.8
M8.8
Magnitude


Deaggregation of 10,000 Year Return Period PGV
(Springbank Off-Stream Reservoir)
Mean Magnitude (M_w): M6.3
Mean Distance: 34 km
Contribution
16%
14%
12%
10%
8%
6%
4%
2%
0%
0
100
200
300
400
500
600
700
800
900
1,000
Distance (km)
M8.8
M7.8
M6.8
M5.8
M4.8
Magnitude



Deaggregation of 10,000 Year Return Period Sa(0.05s)
(Springbank Off-Stream Reservoir)
Mean Magnitude (Mw): M5.9
Mean Distance: 15 km
Contribution
16%
14%
12%
10%
8%
6%
4%
2%
0%
0
100
200
300
400
500
600
700
800
900
1,000
Distance (km)
M8.8
M7.8
M6.8
M5.8
M4.8
Magnitude

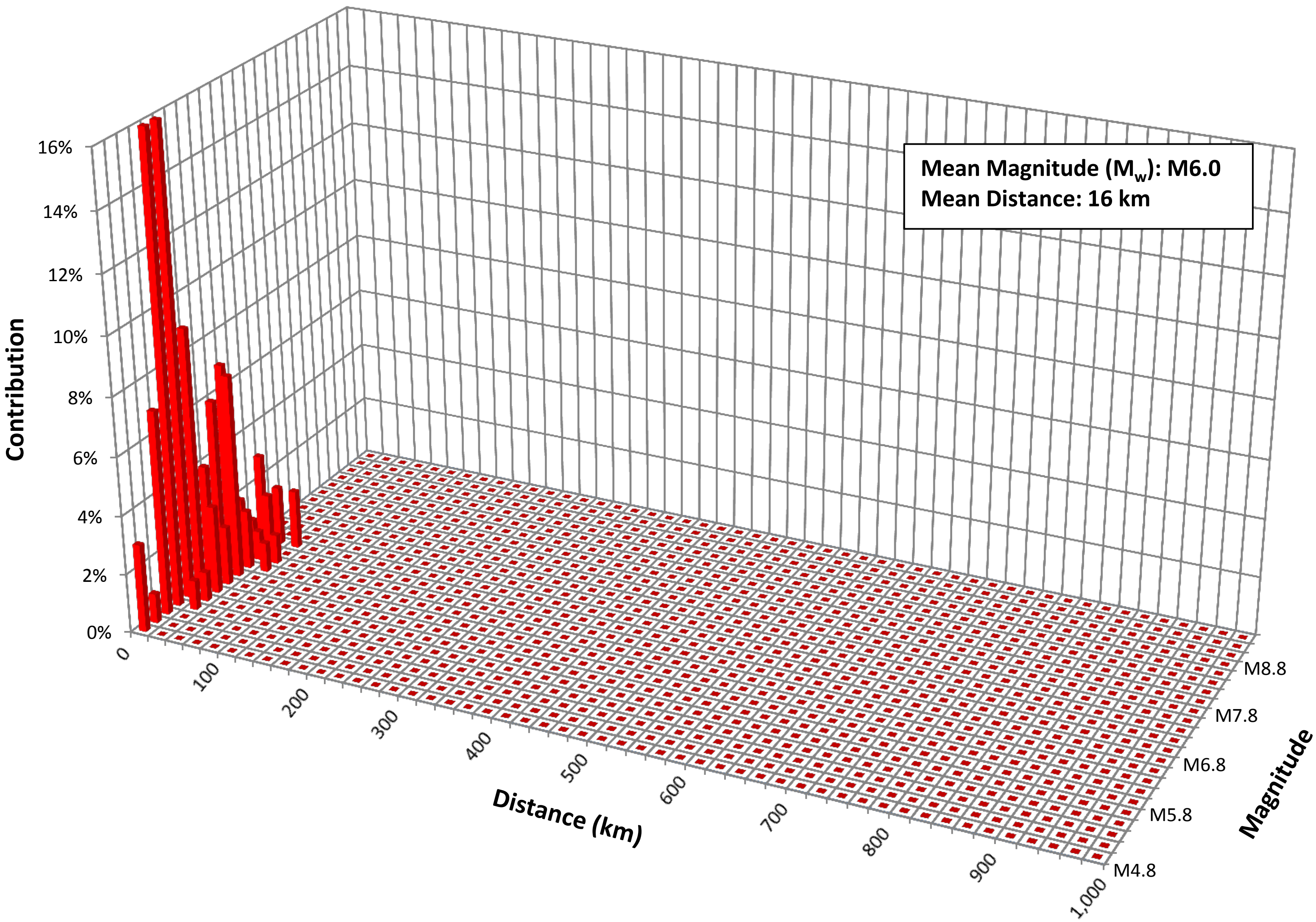

Deaggregation of 10,000 Year Return Period Sa(0.1s)
(Springbank Off-Stream Reservoir)
Mean Magnitude (Mw): M5.8
Mean Distance: 16 km
Contribution
16%
14%
12%
10%
8%
6%
4%
2%
0%
0
100
200
300
400
500
600
700
800
900
1,000
Distance (km)
M8.8
M7.8
M6.8
M5.8
M4.8
Magnitude

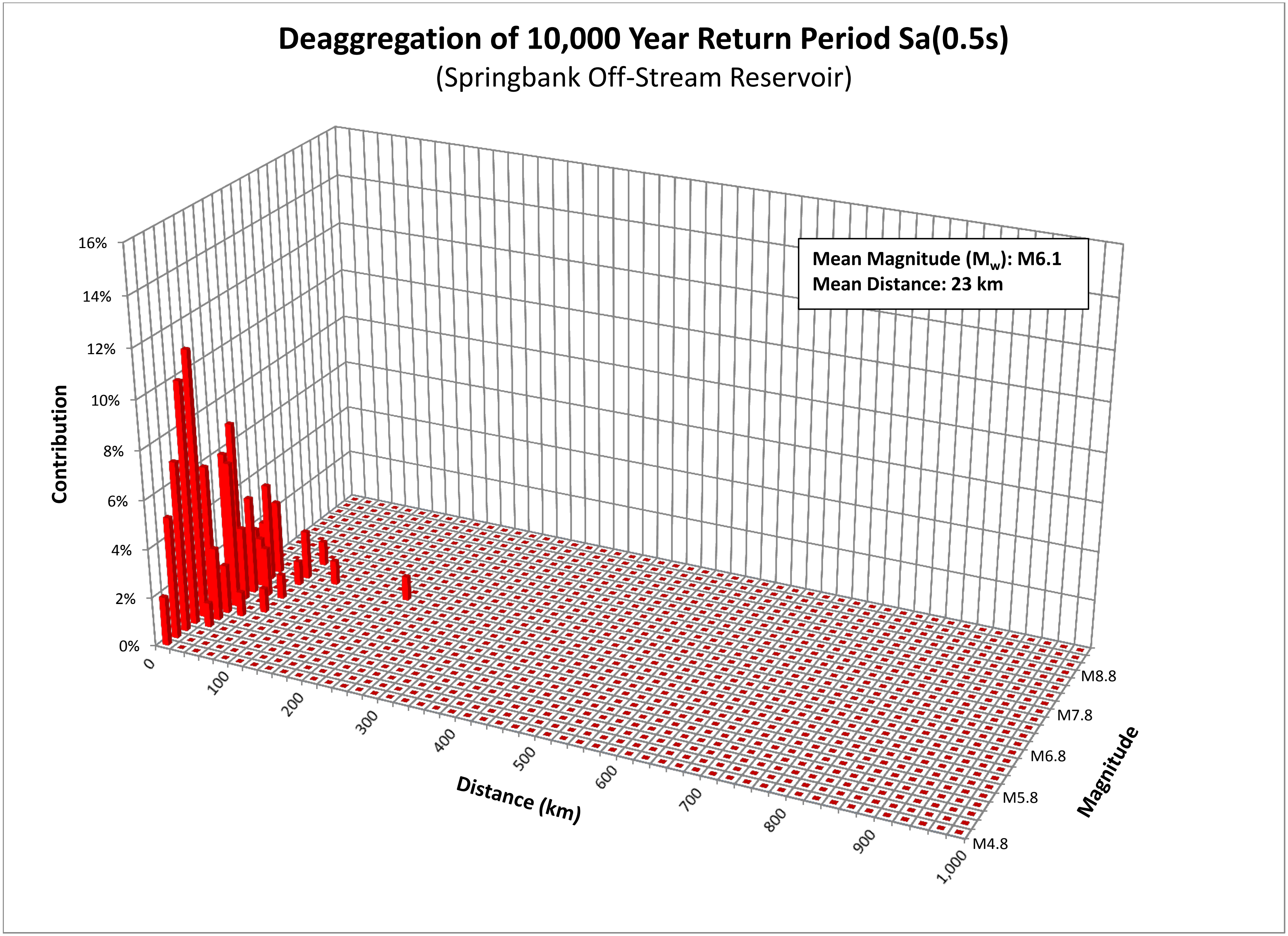


Deaggregation of 10,000 Year Return Period Sa(0.2s)
(Springbank Off-Stream Reservoir)
Mean Magnitude (M_w): M5.9
Mean Distance: 17 km
Contribution
16%
14%
12%
10%
8%
6%
4%
2%
0%
0
100
200
300
400
500
600
700
800
900
1,000
Distance (km)
M4.8
M5.8
M6.8
M7.8
M8.8
Magnitude

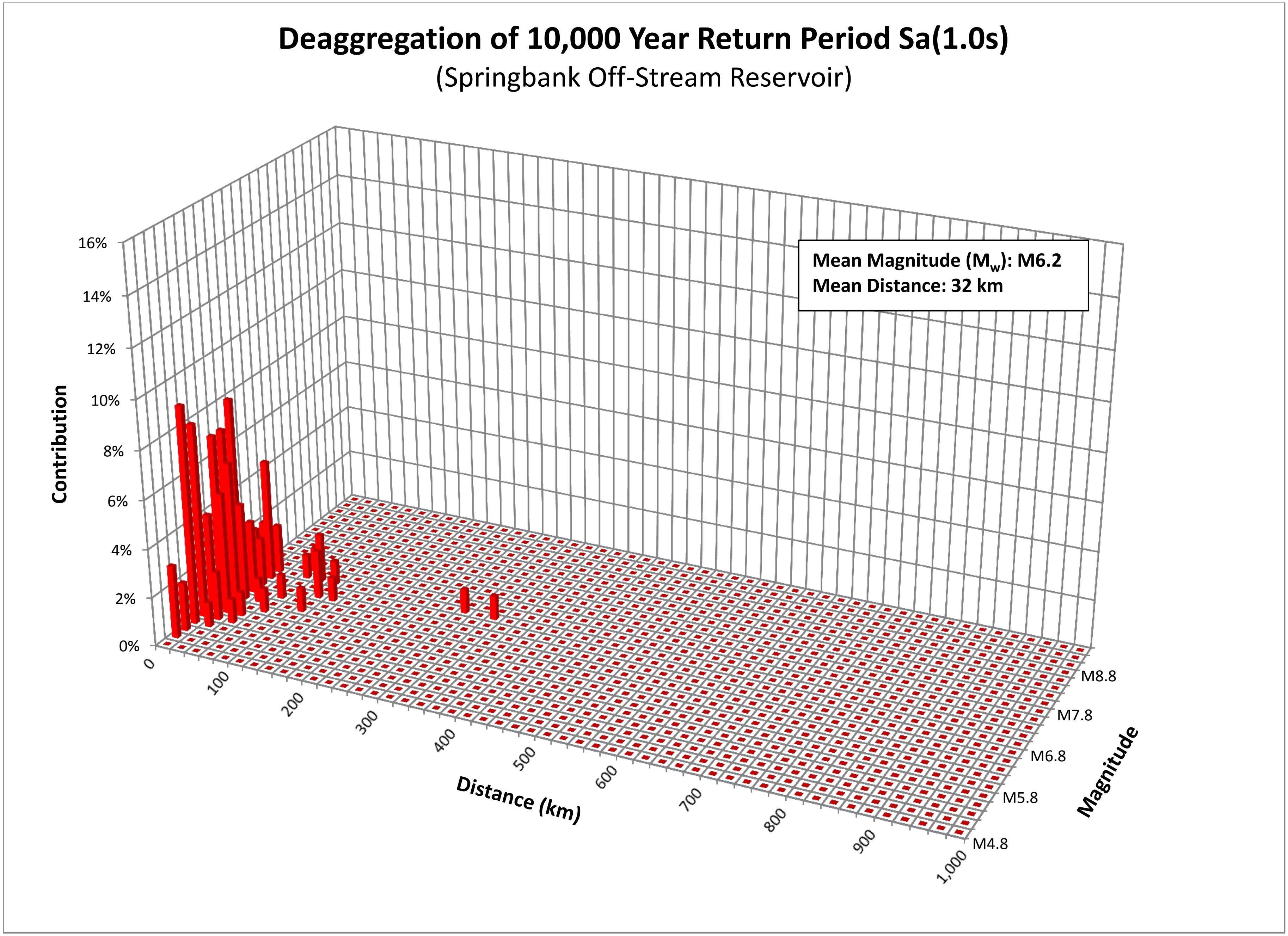
Deaggregation of 10,000 Year Return Period Sa(0.3s)

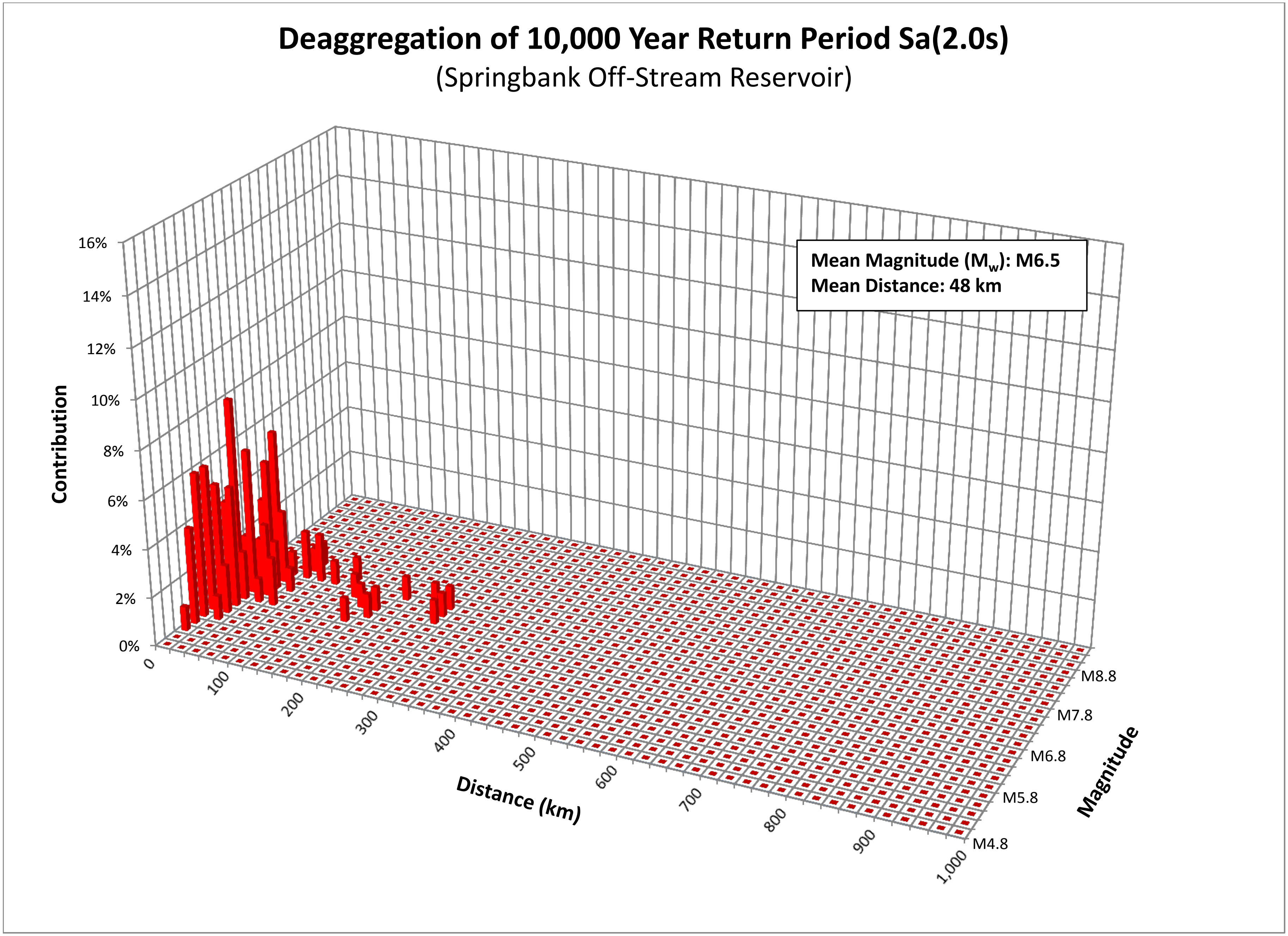
(Springbank Off-Stream Reservoir)



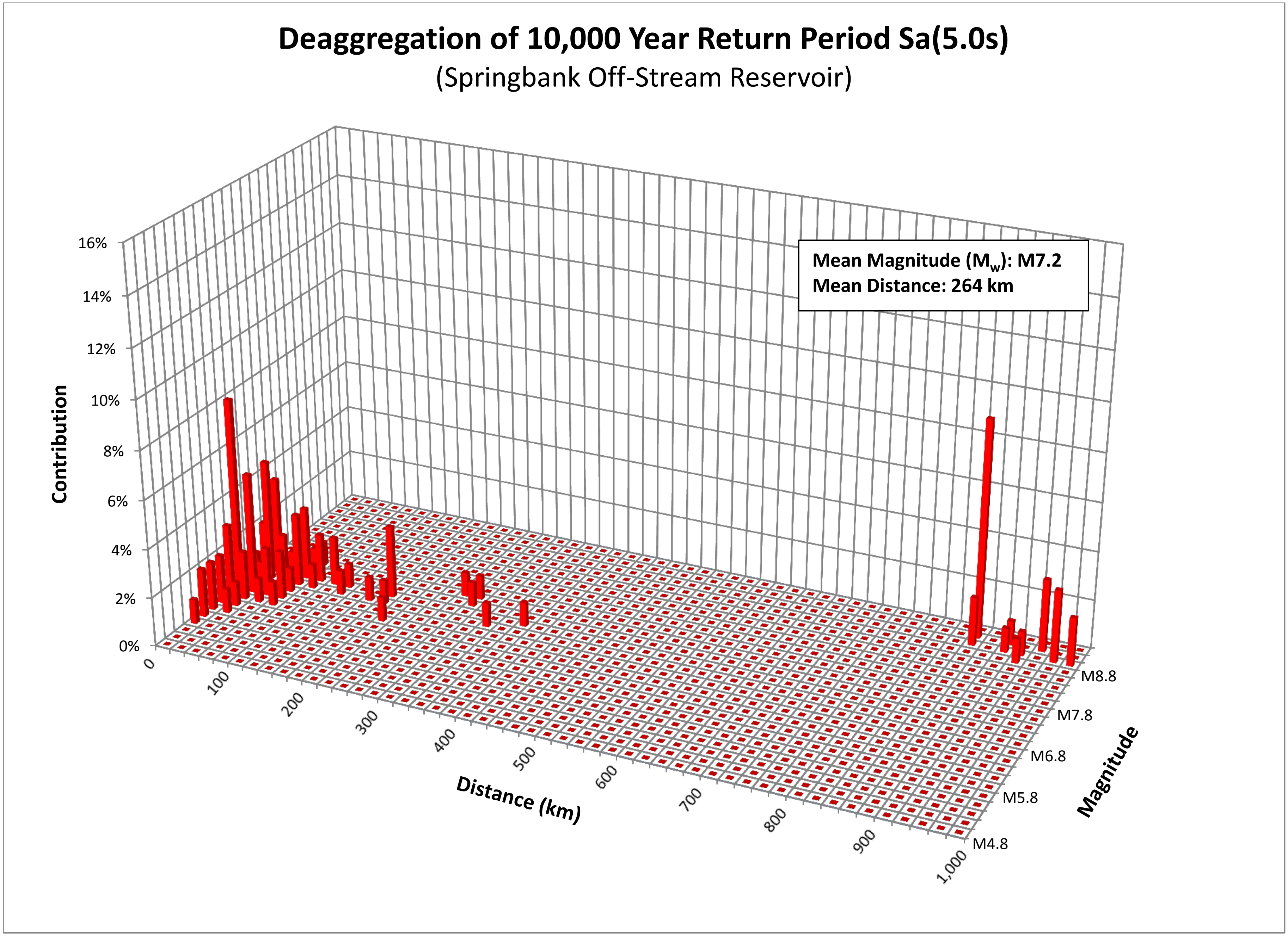


Deaggregation of 10,000 Year Return Period Sa(0.5s)
(Springbank Off-Stream Reservoir)
Mean Magnitude (M_w): M6.1
Mean Distance: 23 km
Contribution
16%
14%
12%
10%
8%
6%
4%
2%
0%
0
100
200
300
400
500
600
700
800
900
1,000
Distance (km)
M4.8
M5.8
M6.8
M7.8
M8.8
Magnitude

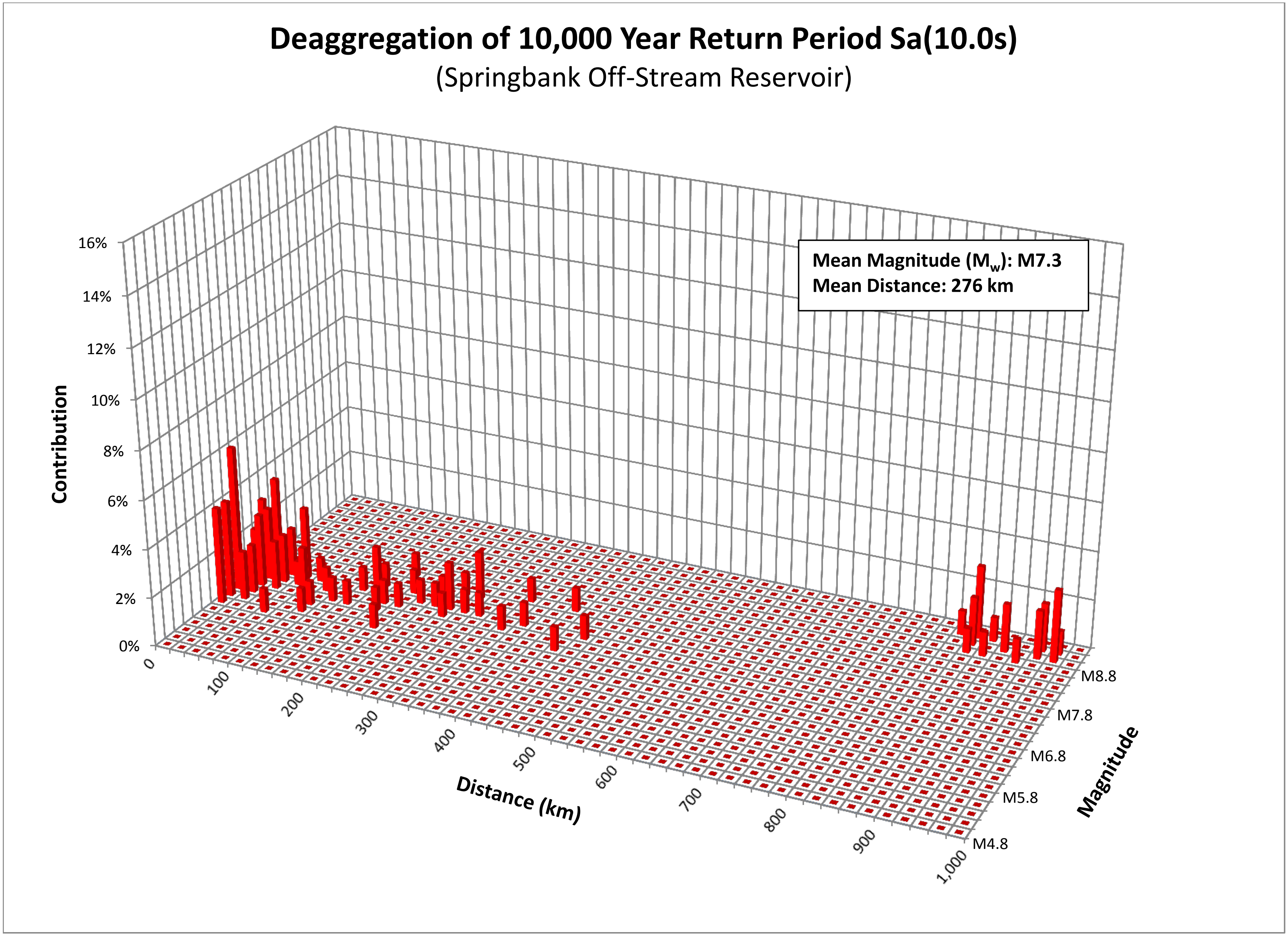

Deaggregation of 10,000 Year Return Period Sa(1.0s)
(Springbank Off-Stream Reservoir)
Mean Magnitude (M_w): M6.2
Mean Distance: 32 km
Contribution
16%
14%
12%
10%
8%
6%
4%
2%
0%
0
100
200
300
400
500
600
700
800
900
1,000
Distance (km)
M4.8
M5.8
M6.8
M7.8
M8.8
Magnitude



Deaggregation of 10,000 Year Return Period Sa(2.0s)
(Springbank Off-Stream Reservoir)
Mean Magnitude (Mw): M6.5
Mean Distance: 48 km
Contribution
0%
2%
4%
6%
8%
10%
12%
14%
16%
Distance (km)
0
100
200
300
400
500
600
700
800
900
1,000
Magnitude
M4.8
M5.8
M6.8
M7.8
M8.8



Deaggregation of 10,000 Year Return Period Sa(5.0s)
(Springbank Off-Stream Reservoir)
Mean Magnitude (Mw): M7.2
Mean Distance: 264 km
Contribution
16%
14%
12%
10%
8%
6%
4%
2%
0%
0
100
200
300
400
500
600
700
800
900
1,000
Distance (km)
M8.8
M7.8
M6.8
M5.8
M4.8
Magnitude



Deaggregation of 10,000 Year Return Period Sa(10.0s)
(Springbank Off-Stream Reservoir)
Mean Magnitude (M_w): M7.3
Mean Distance: 276 km
Contribution
16%
14%
12%
10%
8%
6%
4%
2%
0%
0
100
200
300
400
500
600
700
800
900
1,000
Distance (km)
M8.8
M7.8
M6.8
M5.8
M4.8
Magnitude

Appendix E REVIEW LETTER FROM DR. GAIL ATKINSON

Gail Atkinson, Ph.D., P.Geo
Engineering Seismologist
196 McLeod Rd.
White Lake, ON K0A 3L0

Feb. 28, 2017

Mr. Wayne Quong
Stantec Consulting Ltd.
500-4730 Kingsway
Burnaby, BC V5H 0C6

Review of Seismic Hazard Assessment-Springbank Off-Stream Dam and Reservoir
Stantec Report Feb. 28, 2017 (Project No. 110773396)

Dear Mr. Quong

I have reviewed the Stantec Report providing a Seismic Hazard Assessment for the Springbank Off-Stream Dam and Reservoir (as prepared for Alberta Transportation), dated Feb. 28, 2017 (Project 110773396). I am satisfied that this report is technically sound and represents good state-of-the-art practice in seismic hazard assessment for similar facilities in Canada. It is noted that Section 5.4, Management of Induced Seismicity Risk, contains important recommendations that are integral to the report and its findings.

Thank you for the opportunity to interact with the Stantec team in carrying out this important seismic hazard assessment.

Yours truly

Gail Atkinson, Ph.D., P.Geo., FRSC
Engineering Seismologist

ATTACHMENT 9
FLOODPLAIN BERM

Attachment 9.1 Seepage and Stability Analysis

Attachment 9.1 Seepage and Stability Analysis

Attachment 9.1.1 Seepage Analyses

Section 0+900

Name: Bedrock
Model: Saturated / Unsaturated
Ky'/Kx' Ratio: 0.15
Rotation: 0 °

kv=1.00E-08 m/sec

Name: Topsoil
Model: Saturated / Unsaturated
Ky'/Kx' Ratio: 0.3
Rotation: 0 °

kv=1.00E-10 m/sec

Alberta Transportation SR1 Floodplain Berm

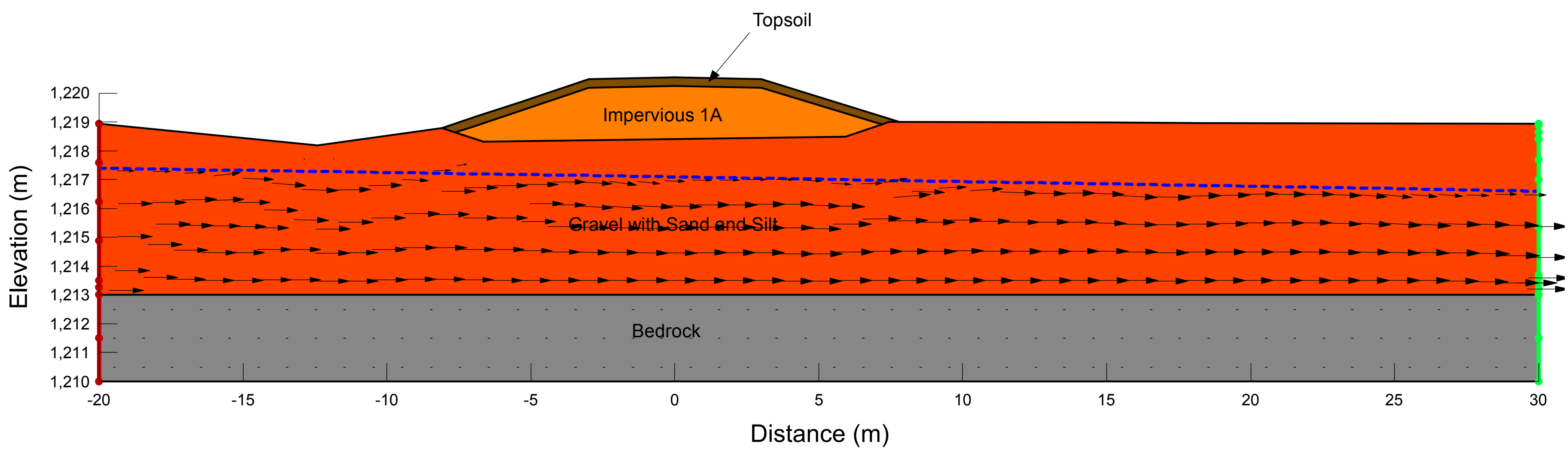
Section 0+900
Seepage Analysis
Normal Headwater = 1217.4 m
Normal Tailwater = 1216.6 m

Name: Gravel with Sand and Silt
Model: Saturated / Unsaturated
Ky'/Kx' Ratio: 1
Rotation: 0 °

kv=1.00E-06 m/sec

Name: Topsoil
Model: Saturated / Unsaturated
Ky'/Kx' Ratio: 0.3
Rotation: 0 °

kv=1.00E-10 m/sec



Stantec

Alberta Transportation SR1 Floodplain Berm

Section 0+900
Seepage Analysis
Flood Operations Headwater = 1219.2 m
Flood Operations Tailwater = 1218.4 m

Name: Bedrock
Model: Saturated / Unsaturated
Ky'/Kx' Ratio: 0.15
Rotation: 0 °

kv=1.00E-08 m/sec

Name: Topsoil
Model: Saturated / Unsaturated
Ky'/Kx' Ratio: 0.3
Rotation: 0 °

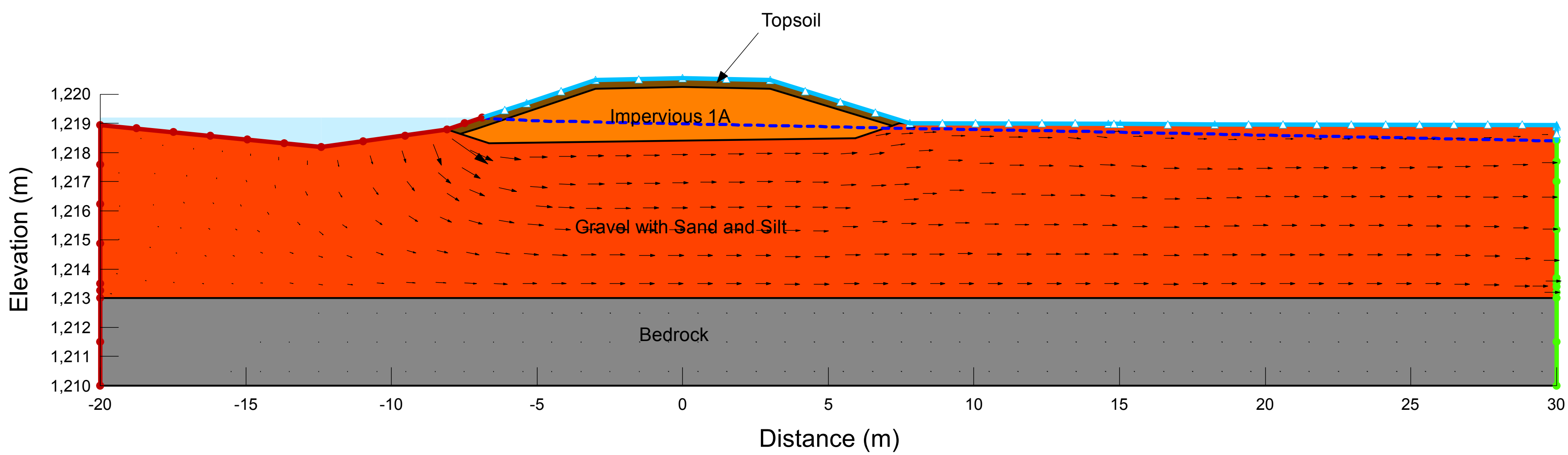
kv=1.00E-10 m/sec

Name: Gravel with Sand and Silt
Model: Saturated / Unsaturated
Ky'/Kx' Ratio: 1
Rotation: 0 °

kv=1.00E-06 m/sec

Name: Topsoil
Model: Saturated / Unsaturated
Ky'/Kx' Ratio: 0.3
Rotation: 0 °

kv=1.00E-10 m/sec



Stantec

Alberta Transportation SR1 Floodplain Berm

Section 0+900
Seepage Analysis
Max IDF Headwater = 1219.7 m
Max IDF Tailwater = 1218.9 m

Name: Bedrock
Model: Saturated / Unsaturated
Ky'/Kx' Ratio: 0.15
Rotation: 0 °

kv=1.00E-08 m/sec

Name: Topsoil
Model: Saturated / Unsaturated
Ky'/Kx' Ratio: 0.3
Rotation: 0 °

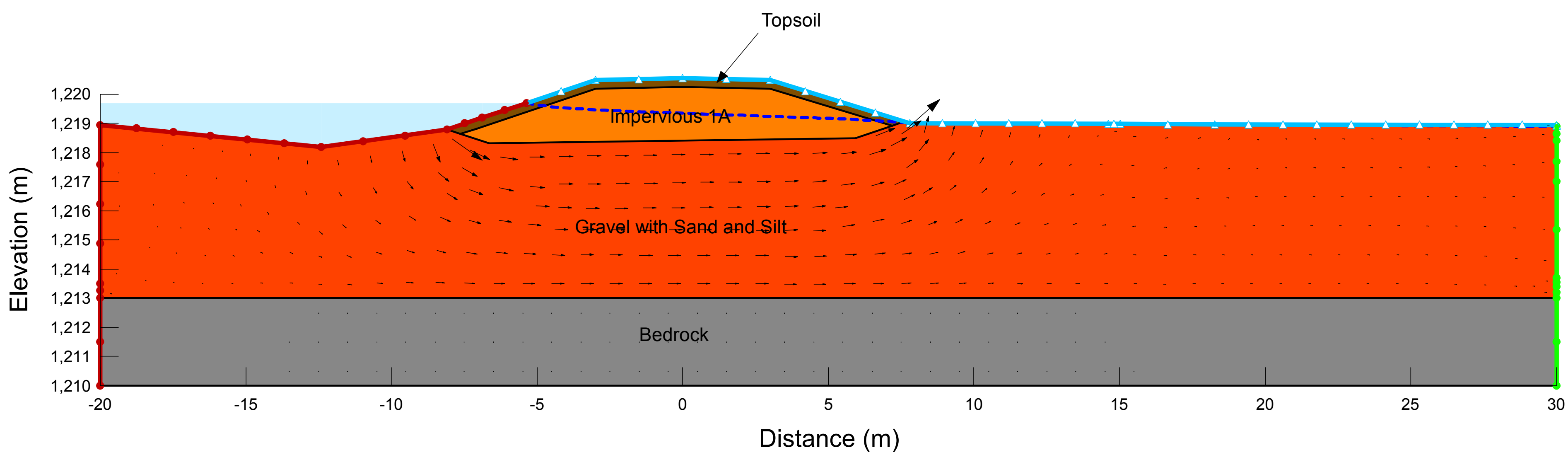
kv=1.00E-10 m/sec

Name: Gravel with Sand and Silt
Model: Saturated / Unsaturated
Ky'/Kx' Ratio: 1
Rotation: 0 °

kv=1.00E-06 m/sec

Name: Topsoil
Model: Saturated / Unsaturated
Ky'/Kx' Ratio: 0.3
Rotation: 0 °

kv=1.00E-10 m/sec



Section 1+600

Stantec

Alberta Transportation SR1 Floodplain Berm

Section 1+600
Seepage Analysis
Normal Headwater = 1213.6 m
Normal Tailwater = 1211.1 m

Name: Riprap
Model: Saturated / Unsaturated
Ky'/Kx' Ratio: 1
Rotation: 0 °

kv=1.00E-06 m/sec

Name: Riprap
Model: Saturated / Unsaturated
Ky'/Kx' Ratio: 1
Rotation: 0 °

kv=3.00E-04 m/sec

Name: Impervious 1A
Model: Saturated / Unsaturated
Ky'/Kx' Ratio: 0.3
Rotation: 0 °

kv=1.00E-10 m/sec

Name: Bedrock
Model: Saturated / Unsaturated
Ky'/Kx' Ratio: 0.15
Rotation: 0 °

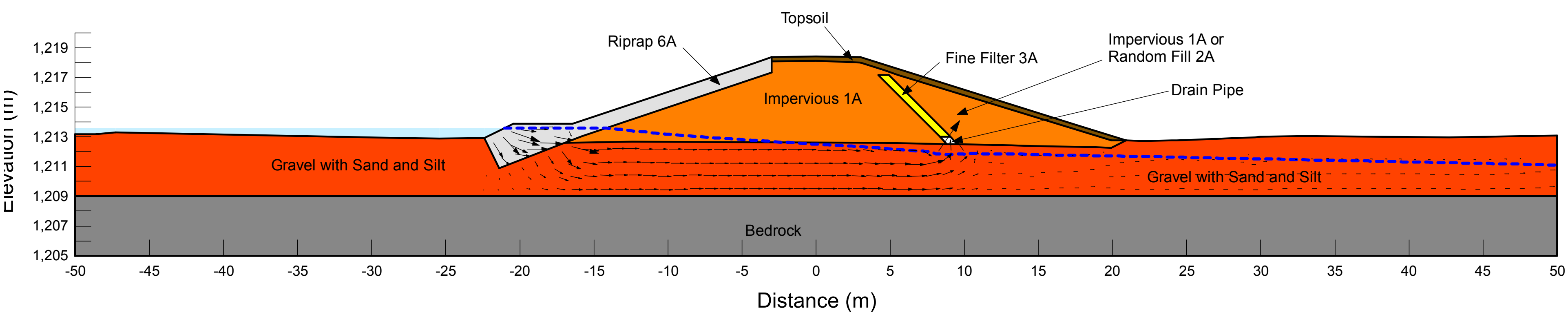
kv=1.00E-08 m/sec

Name: Fine Filter 3A
Model: Saturated / Unsaturated
Ky'/Kx' Ratio: 1
Rotation: 0 °

kv=1.00E-010 m/sec

Name: Fine Filter 3A
Model: Saturated / Unsaturated
Ky'/Kx' Ratio: 1
Rotation: 0 °

kv=1.00E-05 m/sec



Alberta Transportation SR1 Floodplain Berm

Section 1+600
Seepage Analysis
Flood Operations Headwater = 1216.1 m
Flood Operations Tailwater = 1212.1 m

Name: Riprap
Model: Saturated / Unsaturated
Ky'/Kx' Ratio: 1
Rotation: 0 °

kv=1.00E-06 m/sec

Name: Riprap
Model: Saturated / Unsaturated
Ky'/Kx' Ratio: 1
Rotation: 0 °

kv=3.00E-04 m/sec

Name: Impervious 1A
Model: Saturated / Unsaturated
Ky'/Kx' Ratio: 0.3
Rotation: 0 °

kv=1.00E-10 m/sec

Name: Bedrock
Model: Saturated / Unsaturated
Ky'/Kx' Ratio: 0.15
Rotation: 0 °

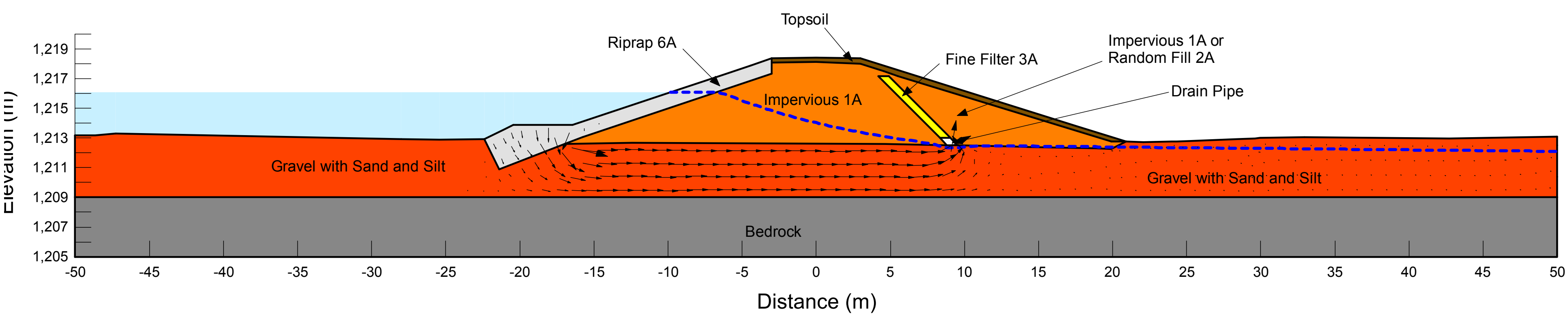
kv=1.00E-08 m/sec

Name: Fine Filter 3A
Model: Saturated / Unsaturated
Ky'/Kx' Ratio: 1
Rotation: 0 °

kv=1.00E-10 m/sec

Name: Fine Filter 3A
Model: Saturated / Unsaturated
Ky'/Kx' Ratio: 1
Rotation: 0 °

kv=1.00E-05 m/sec



Stantec

Alberta Transportation SR1 Floodplain Berm

Section 1+600
Seepage Analysis
Max IDF Headwater = 1217.4 m
Max IDF Tailwater = 1213.8 m

Name: Riprap
Model: Saturated / Unsaturated
Ky'/Kx' Ratio: 1
Rotation: 0 °

kv=1.00E-06 m/sec

Name: Riprap
Model: Saturated / Unsaturated
Ky'/Kx' Ratio: 1
Rotation: 0 °

kv=3.00E-04 m/sec

Name: Impervious 1A
Model: Saturated / Unsaturated
Ky'/Kx' Ratio: 0.3
Rotation: 0 °

kv=1.00E-10 m/sec

Name: Bedrock
Model: Saturated / Unsaturated
Ky'/Kx' Ratio: 0.15
Rotation: 0 °

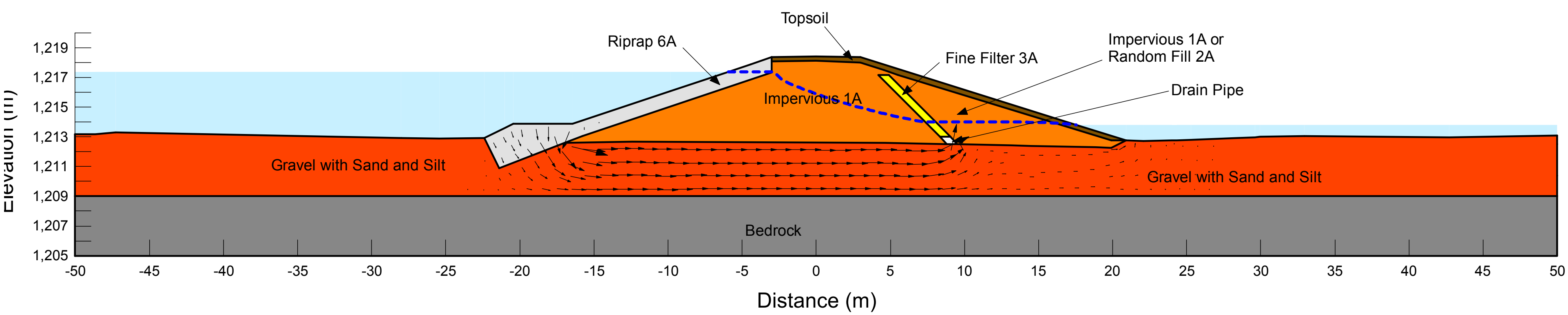
kv=1.00E-08 m/sec

Name: Fine Filter 3A
Model: Saturated / Unsaturated
Ky'/Kx' Ratio: 1
Rotation: 0 °

kv=1.00E-10 m/sec

Name: Fine Filter 3A
Model: Saturated / Unsaturated
Ky'/Kx' Ratio: 1
Rotation: 0 °

kv=1.00E-05 m/sec



Attachment 9.1 Seepage and Stability Analysis
Attachment 9.1.2 Stability Analyses

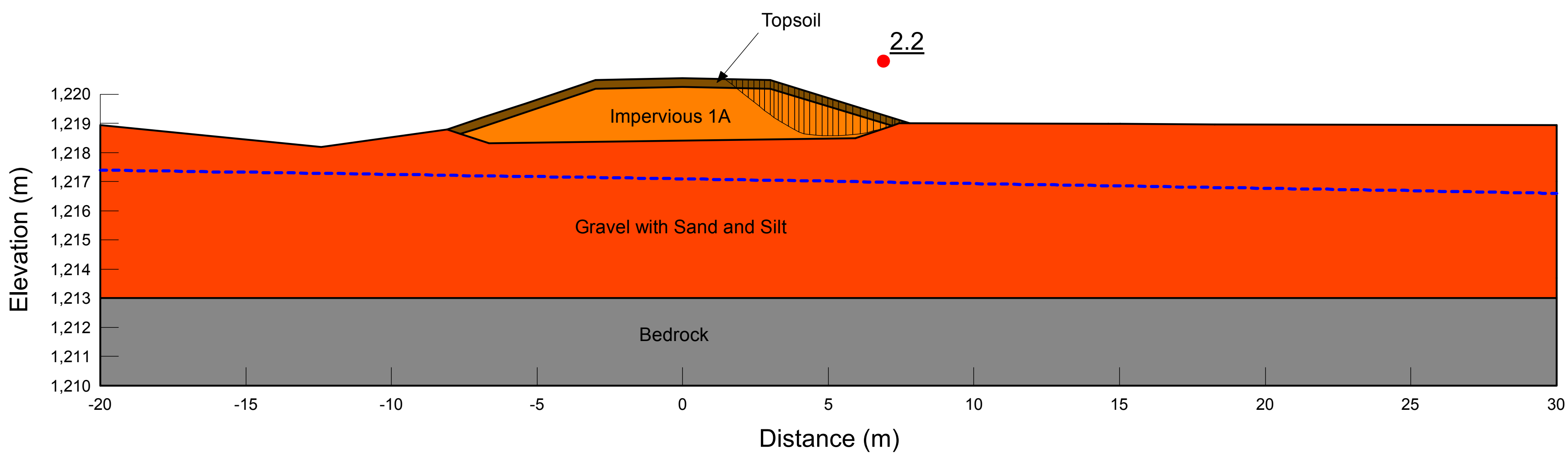
Section 0+900

Alberta Transportation SR1 Floodplain Berm

Section 0+900
Load Case: End of Construction
Undrained, Static Strengths
Incipient Motion in the Downstream Direction

Color	Name	Model	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)
	Bedrock (undrained)	Mohr-Coulomb	21	0	24			
	Gravel with Sand and Silt (undrained)	Mohr-Coulomb	20	0	35			
	Impervious 1A (undrained)	Bilinear	20	0		24	15	141
	Topsoil (undrained)	Bilinear	20	0		24	15	141

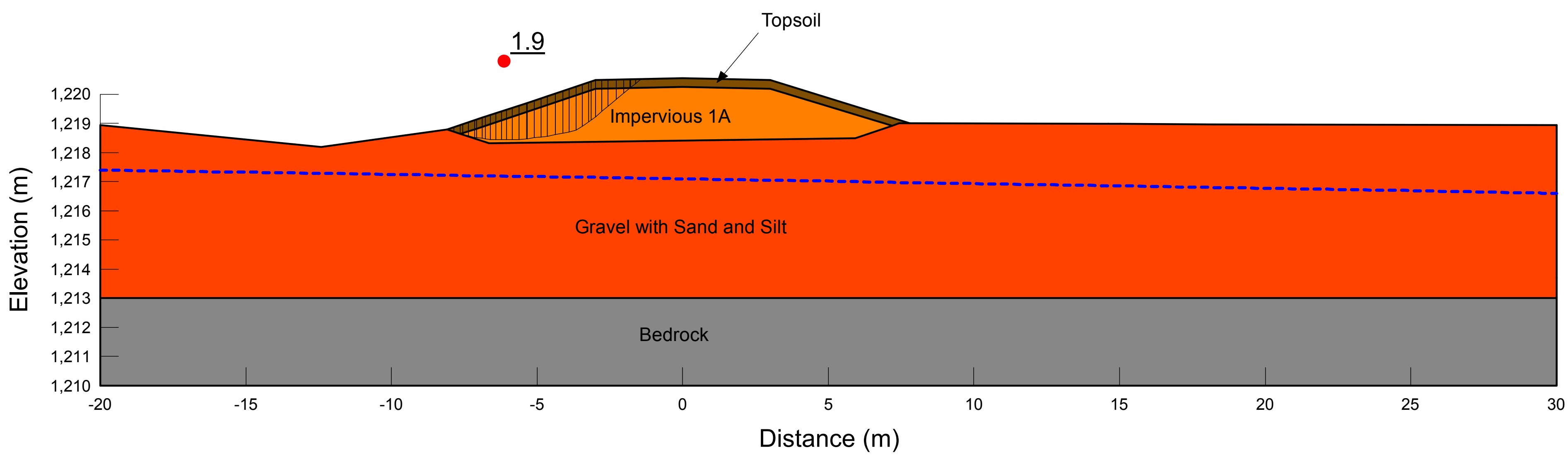
Normal Headwater = 1217.4 m
Normal Tailwater = 1216.6 m



Alberta Transportation SR1 Floodplain Berm
Section 0+900
Load Case: End of Construction
Undrained, Static Strengths
Incipient Motion in the Upstream Direction

Color	Name	Model	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)
	Bedrock (undrained)	Mohr-Coulomb	21	0	24			
	Gravel with Sand and Silt (undrained)	Mohr-Coulomb	20	0	35			
	Impervious 1A (undrained)	Bilinear	20	0		24	15	141
	Topsoil (undrained)	Bilinear	20	0		24	15	141

Normal Headwater = 1217.4 m
Normal Tailwater = 1216.6 m

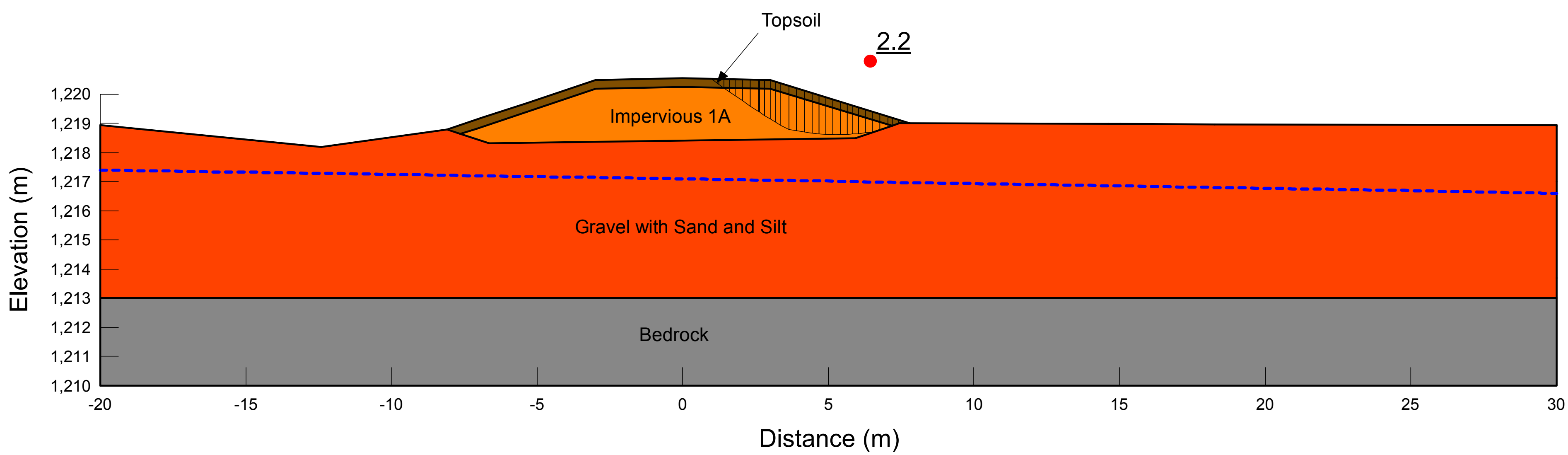


Alberta Transportation SR1 Floodplain Berm

Section 0+900
Load Case: Long Term
Drained, Static Strengths
Incipient Motion in the Downstream Direction

Color	Name	Model	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)
	Bedrock (drained)	Mohr-Coulomb	21	0	24
	Gravel with Sand and Silt (drained)	Mohr-Coulomb	20	0	35
	Impervious 1A (drained)	Mohr-Coulomb	20	0	24
	Topsoil (drained)	Mohr-Coulomb	20	0	24

Normal Headwater = 1217.4 m
Normal Tailwater = 1216.6 m

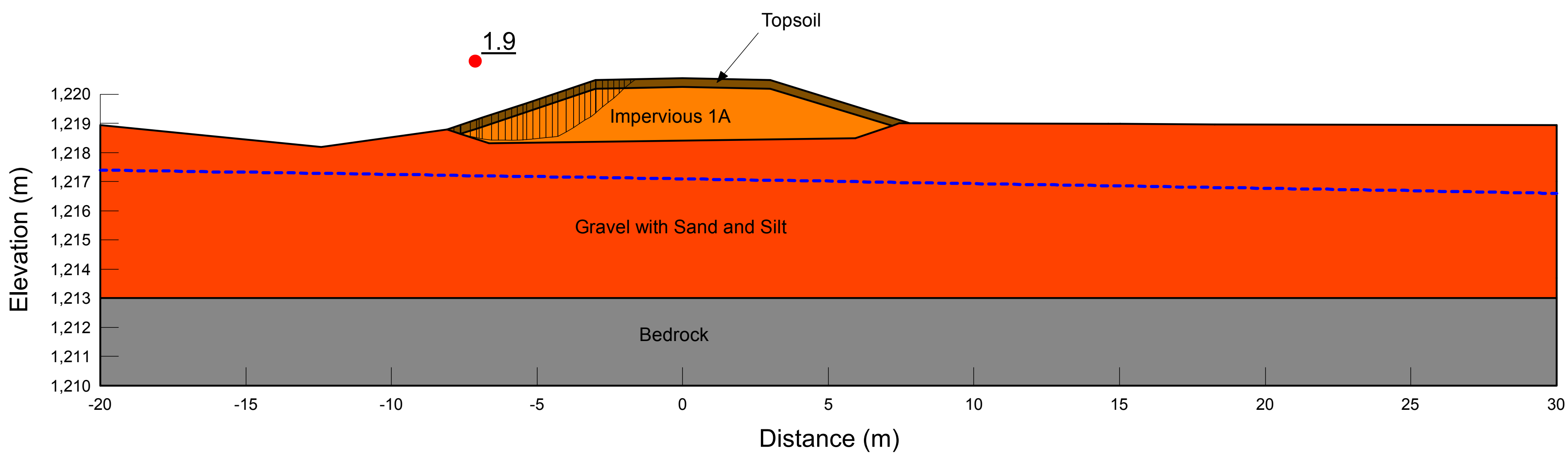


Alberta Transportation SR1 Floodplain Berm

Section 0+900
Load Case: Long Term
Drained, Static Strengths
Incipient Motion in the Upstream Direction

Color	Name	Model	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)
	Bedrock (drained)	Mohr-Coulomb	21	0	24
	Gravel with Sand and Silt (drained)	Mohr-Coulomb	20	0	35
	Impervious 1A (drained)	Mohr-Coulomb	20	0	24
	Topsoil (drained)	Mohr-Coulomb	20	0	24

Normal Headwater = 1217.4 m
Normal Tailwater = 1216.6 m



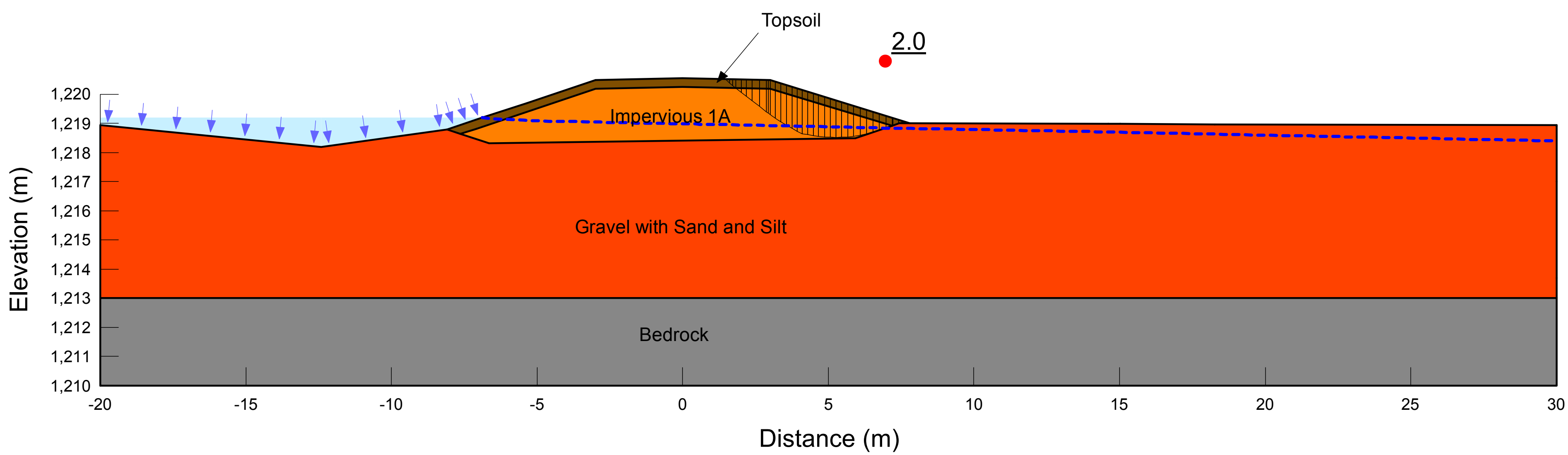
Stantec

Alberta Transportation SR1 Floodplain Berm

Section 0+900
Load Case: Flood Operations - USBR Method
Drained, Static Strengths
Incipient Motion in the Downstream Direction

Color	Name	Model	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)
	Bedrock (drained)	Mohr-Coulomb	21	0	24
	Gravel with Sand and Silt (drained)	Mohr-Coulomb	20	0	35
	Impervious 1A (drained)	Mohr-Coulomb	20	0	24
	Topsoil (drained)	Mohr-Coulomb	20	0	24

Flood Operations Headwater = 1219.2 m
Flood Operations Tailwater = 1218.4 m



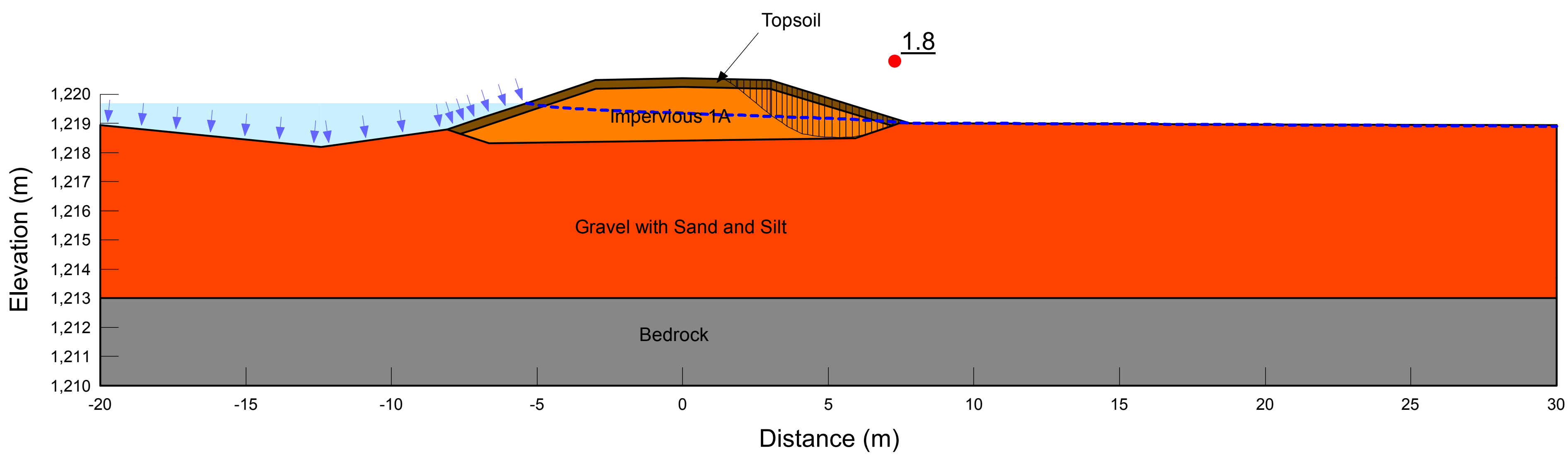
Stantec

Alberta Transportation SR1 Floodplain Berm

Section 0+900
Load Case: Max IDF Flood - USBR Method
Drained, Static Strengths
Incipient Motion in the Downstream Direction

Color	Name	Model	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)
	Bedrock (drained)	Mohr-Coulomb	21	0	24
	Gravel with Sand and Silt (drained)	Mohr-Coulomb	20	0	35
	Impervious 1A (drained)	Mohr-Coulomb	20	0	24
	Topsoil (drained)	Mohr-Coulomb	20	0	24

Max IDF Headwater = 1219.7 m
Max IDF Tailwater = 1218.9 m



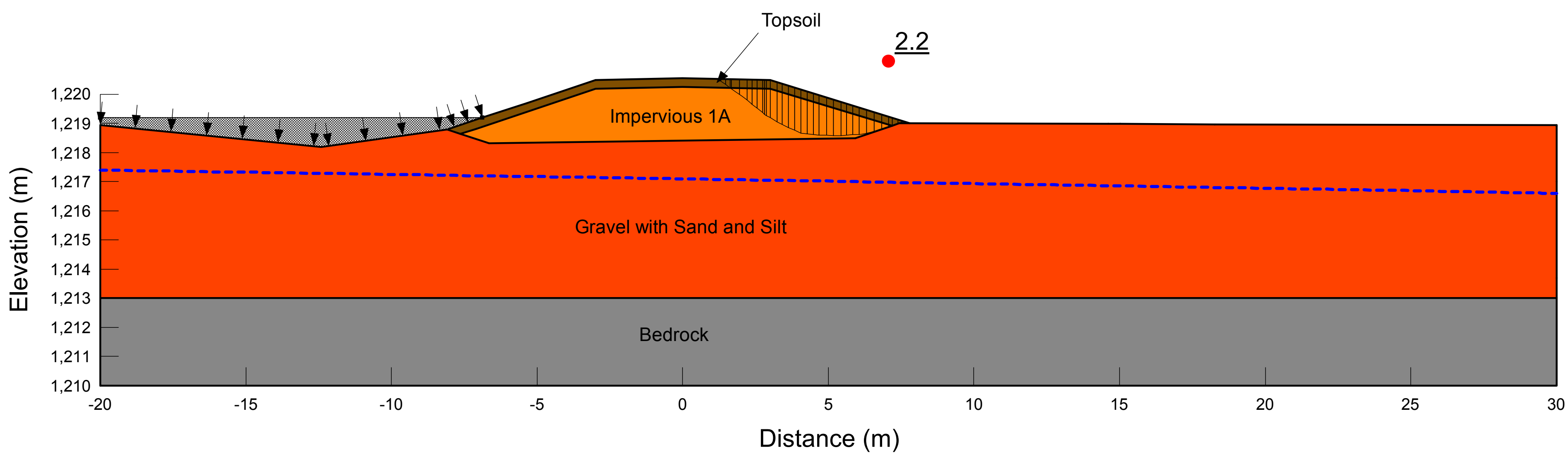
Stantec

Alberta Transportation SR1 Floodplain Berm

Section 0+900
Load Case: Flood Operations - USACE Method
Undrained, Static Strengths
Incipient Motion in the Downstream Direction

Color	Name	Model	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)
	Bedrock (SDD)	Mohr-Coulomb	21	0	24
	Gravel with Sand and Silt (SDD)	Mohr-Coulomb	20	0	35
	Impervious 1A (SDD)	Mohr-Coulomb	20	0	24
	Topsoil (SDD)	Mohr-Coulomb	20	0	24

Normal Headwater = 1217.4 m
Normal Tailwater = 1216.6 m
Flood Operations Headwater/Tailwater applied as surcharge



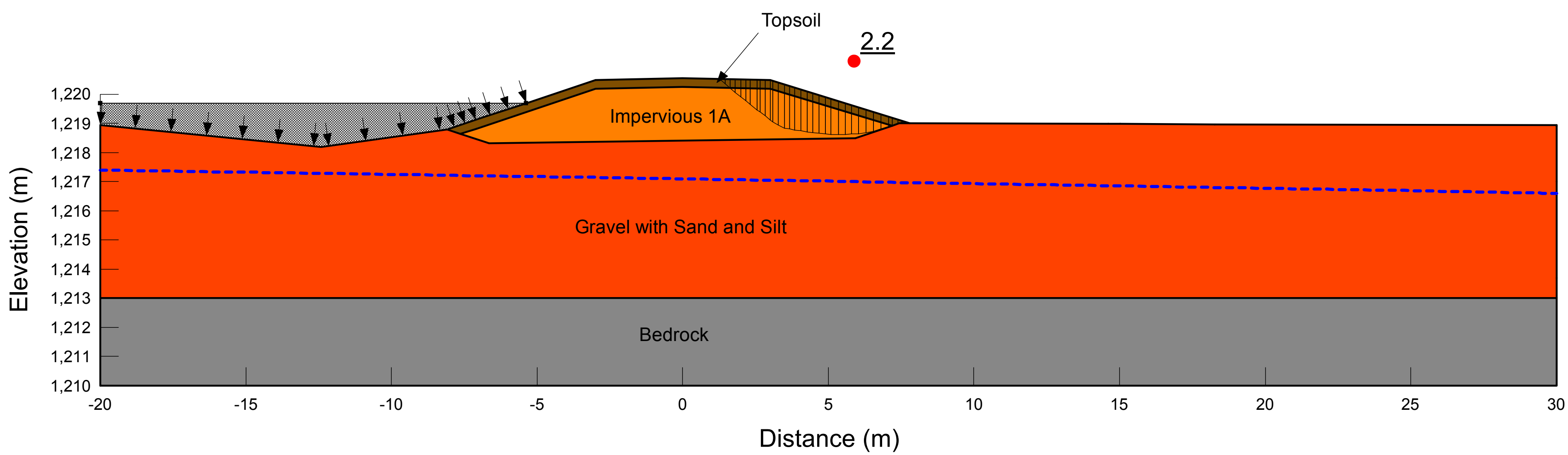
Stantec

Alberta Transportation SR1 Floodplain Berm

Section 0+900
Load Case: Max IDF Flood - USACE Method
Undrained, Static Strengths
Incipient Motion in the Downstream Direction

Color	Name	Model	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)
	Bedrock (SDD)	Mohr-Coulomb	21	0	24
	Gravel with Sand and Silt (SDD)	Mohr-Coulomb	20	0	35
	Impervious 1A (SDD)	Mohr-Coulomb	20	0	24
	Topsoil (SDD)	Mohr-Coulomb	20	0	24

Normal Headwater = 1217.4 m
Normal Tailwater = 1216.6 m
Max IDF Headwater/Tailwater applied as surcharge

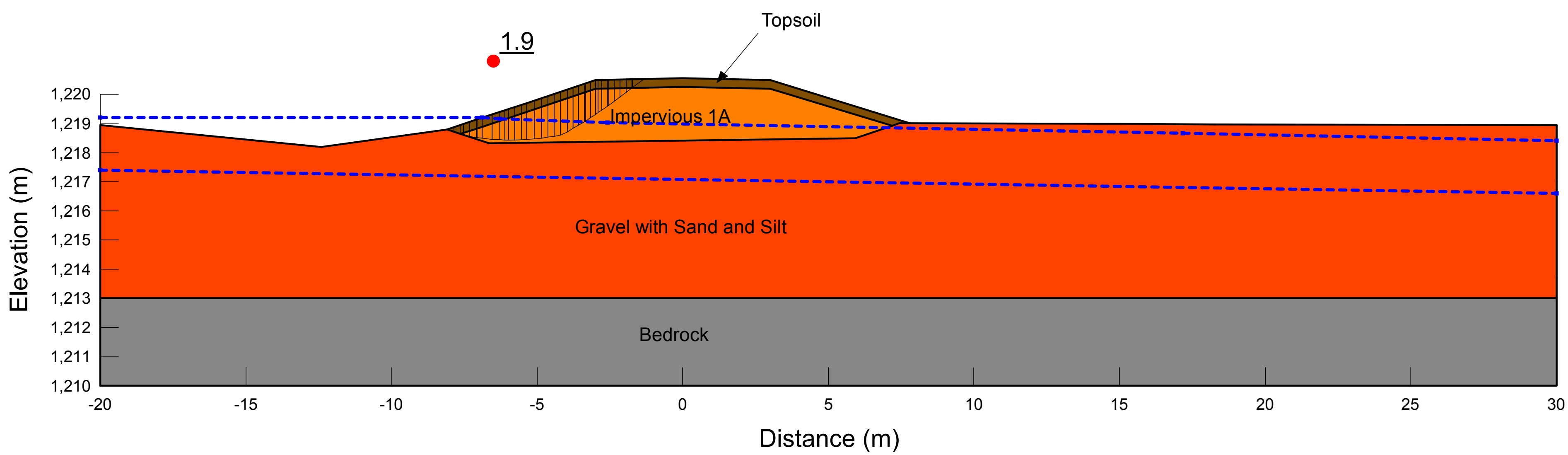


Color	Name	Model	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)	Cohesion R (kPa)	Phi R (°)
	Bedrock (SDD)	Mohr-Coulomb	21	0	24	0	24
	Gravel with Sand and Silt (SDD)	Mohr-Coulomb	20	0	35	0	35
	Impervious 1A (SDD)	Mohr-Coulomb	20	0	24	25	15
	Topsoil (SDD)	Mohr-Coulomb	20	0	24	25	15

Alberta Transportation SR1 Floodplain Berm

Section 0+900
Load Case: Rapid Drawdown - Flood Operations to Normal Condition
Undrained, Static Strengths
Incipient Motion in the Upstream Direction

Flood Operations Headwater = 1219.2 m
Flood Operations Tailwater = 1218.4 m



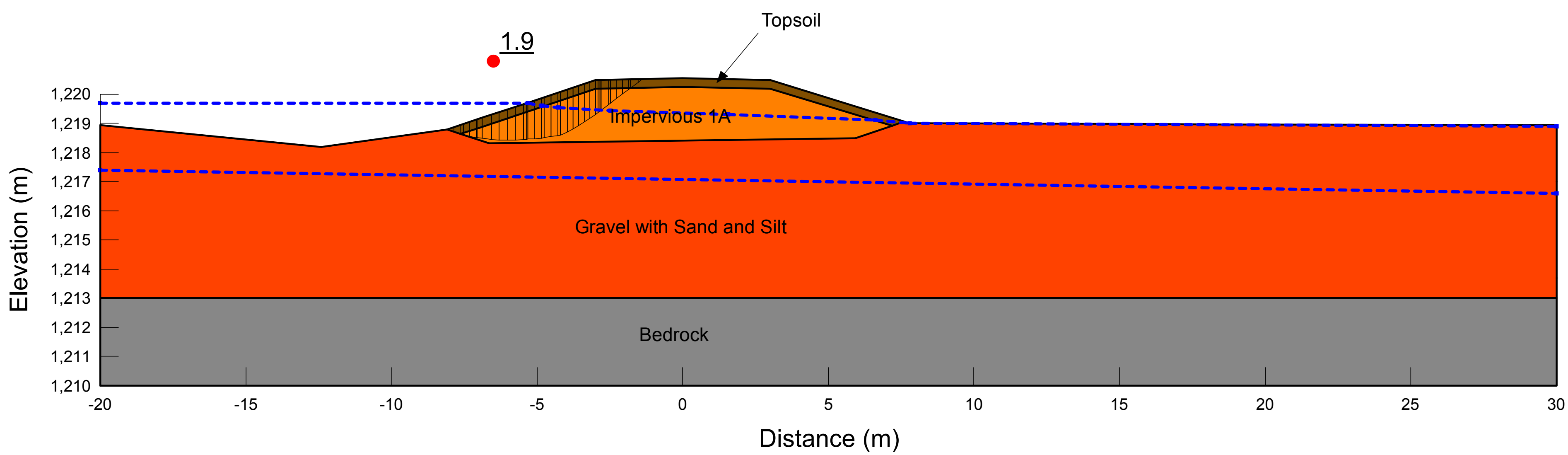
Stantec

Alberta Transportation SR1 Floodplain Berm

Section 0+900
Load Case: Rapid Drawdown - Max IDF Flood to Normal Condition
Undrained, Static Strengths
Incipient Motion in the Upstream Direction

Color	Name	Model	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)	Cohesion R (kPa)	Phi R (°)
	Bedrock (SDD)	Mohr-Coulomb	21	0	24	0	24
	Gravel with Sand and Silt (SDD)	Mohr-Coulomb	20	0	35	0	35
	Impervious 1A (SDD)	Mohr-Coulomb	20	0	24	25	15
	Topsoil (SDD)	Mohr-Coulomb	20	0	24	25	15

Max IDF Headwater = 1219.7 m
Max IDF Tailwater = 1218.9 m



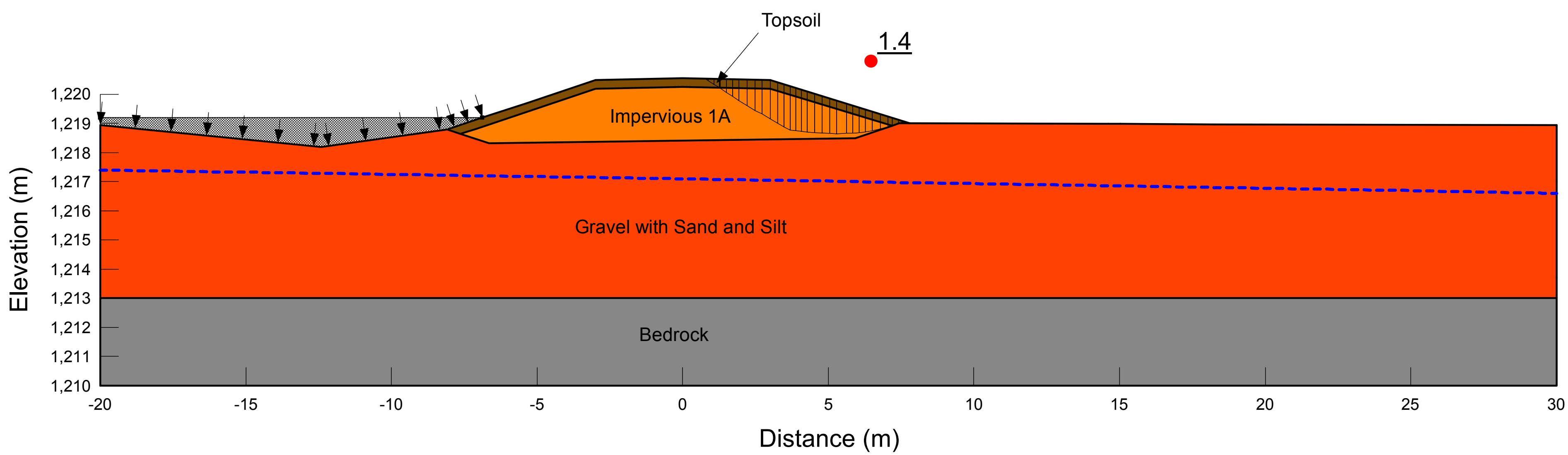
Stantec

Alberta Transportation SR1 Floodplain Berm

Section 0+900
Load Case: Pseudostatic
Undrained, Seismic Strengths
Incipient Motion in the Downstream Direction

Color	Name	Model	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)
	Bedrock (EQ)	Mohr-Coulomb	21	0	24			
	Gravel with Sand and Silt (EQ)	Mohr-Coulomb	20	0	35			
	Impervious 1A (EQ)	Bilinear	20	0		24	15	141
	Topsoil (EQ)	Bilinear	20	0		24	15	141

Normal Headwater = 1217.4 m
Normal Tailwater = 1216.6 m
Flood Operations Headwater/Tailwater applied as surcharge



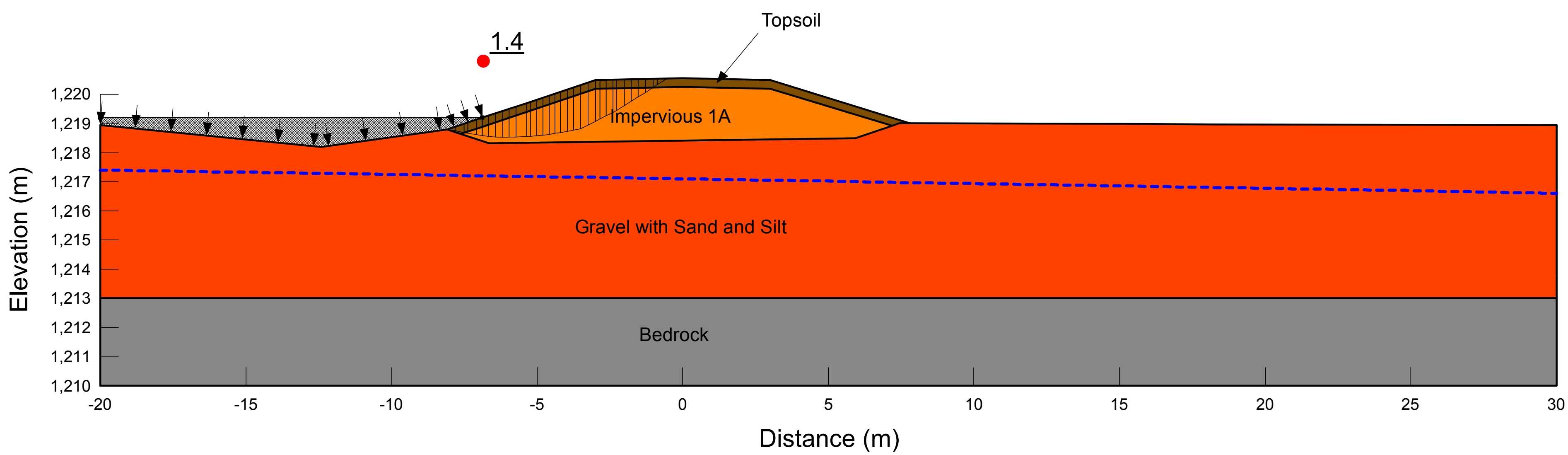
Stantec

Alberta Transportation SR1 Floodplain Berm

Section 0+900
Load Case: Pseudostatic
Undrained, Seismic Strengths
Incipient Motion in the Upstream Direction

Color	Name	Model	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)
	Bedrock (EQ)	Mohr-Coulomb	21	0	24			
	Gravel with Sand and Silt (EQ)	Mohr-Coulomb	20	0	35			
	Impervious 1A (EQ)	Bilinear	20	0		24	15	141
	Topsoil (EQ)	Bilinear	20	0		24	15	141

Normal Headwater = 1217.4 m
Normal Tailwater = 1216.6 m
Flood Operations Headwater/Tailwater applied as surcharge

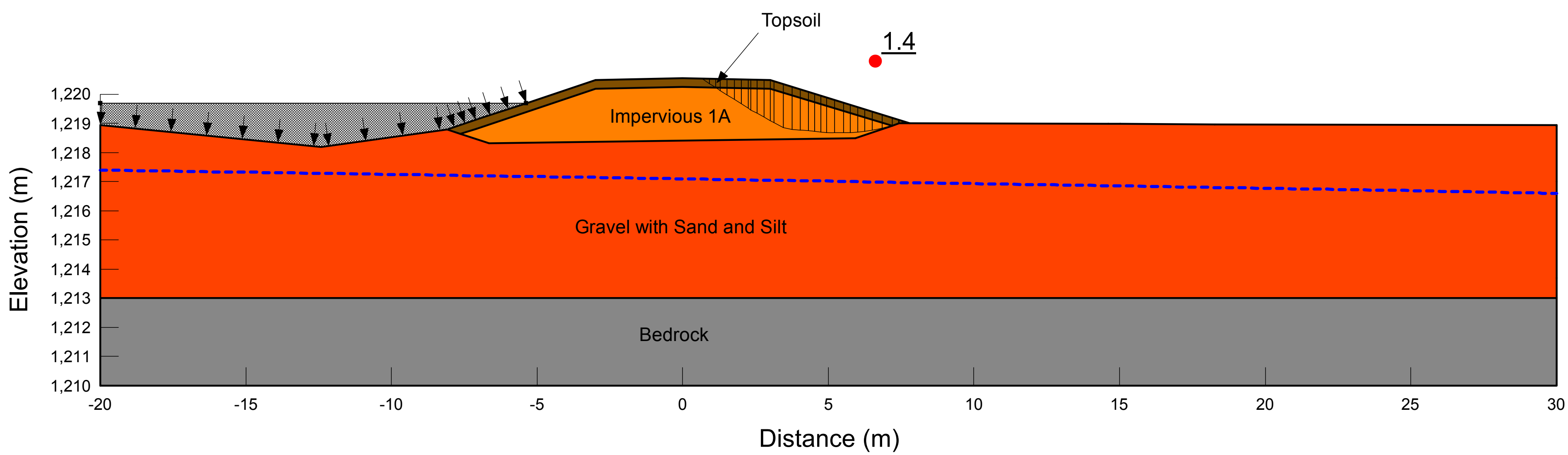


Alberta Transportation SR1 Floodplain Berm

Section 0+900
Load Case: Pseudostatic
Undrained, Seismic Strengths
Incipient Motion in the Downstream Direction

Color	Name	Model	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)
	Bedrock (EQ)	Mohr-Coulomb	21	0	24			
	Gravel with Sand and Silt (EQ)	Mohr-Coulomb	20	0	35			
	Impervious 1A (EQ)	Bilinear	20	0		24	15	141
	Topsoil (EQ)	Bilinear	20	0		24	15	141

Normal Headwater = 1217.4 m
Normal Tailwater = 1216.6 m
Max IDF Headwater/Tailwater applied as surcharge

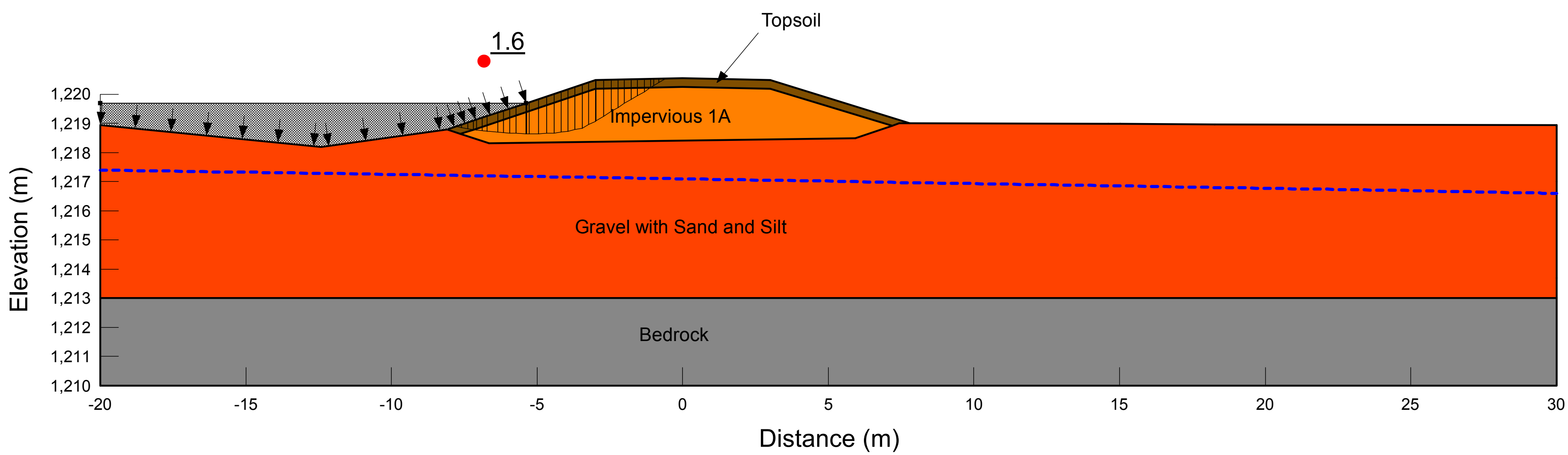


Alberta Transportation SR1 Floodplain Berm

Section 0+900
Load Case: Pseudostatic
Undrained, Seismic Strengths
Incipient Motion in the Upstream Direction

Color	Name	Model	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)
	Bedrock (EQ)	Mohr-Coulomb	21	0	24			
	Gravel with Sand and Silt (EQ)	Mohr-Coulomb	20	0	35			
	Impervious 1A (EQ)	Bilinear	20	0		24	15	141
	Topsoil (EQ)	Bilinear	20	0		24	15	141

Normal Headwater = 1217.4 m
Normal Tailwater = 1216.6 m
Max IDF Headwater/Tailwater applied as surcharge



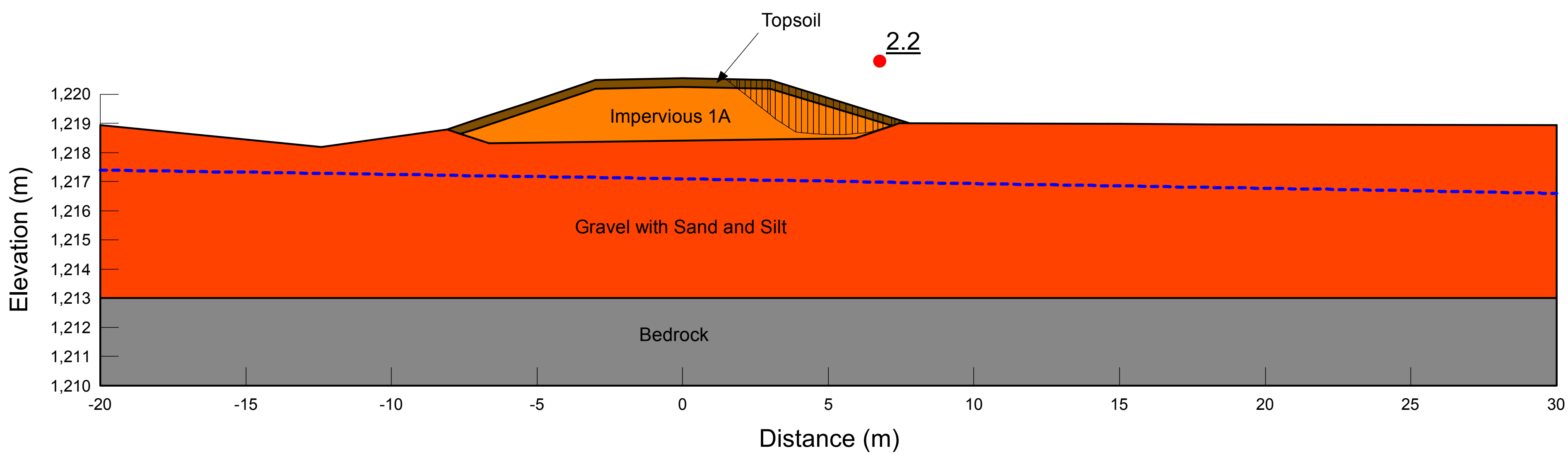
Stantec

Alberta Transportation SR1 Floodplain Berm

Section 0+900
Load Case: Seismic - Post Earthquake
Undrained, Seismic Strengths
Incipient Motion in the Downstream Direction

Color	Name	Model	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)
	Bedrock (EQ)	Mohr-Coulomb	21	0	24			
	Gravel with Sand and Silt (EQ)	Mohr-Coulomb	20	0	35			
	Impervious 1A (EQ)	Bilinear	20	0		24	15	141
	Topsoil (EQ)	Bilinear	20	0		24	15	141

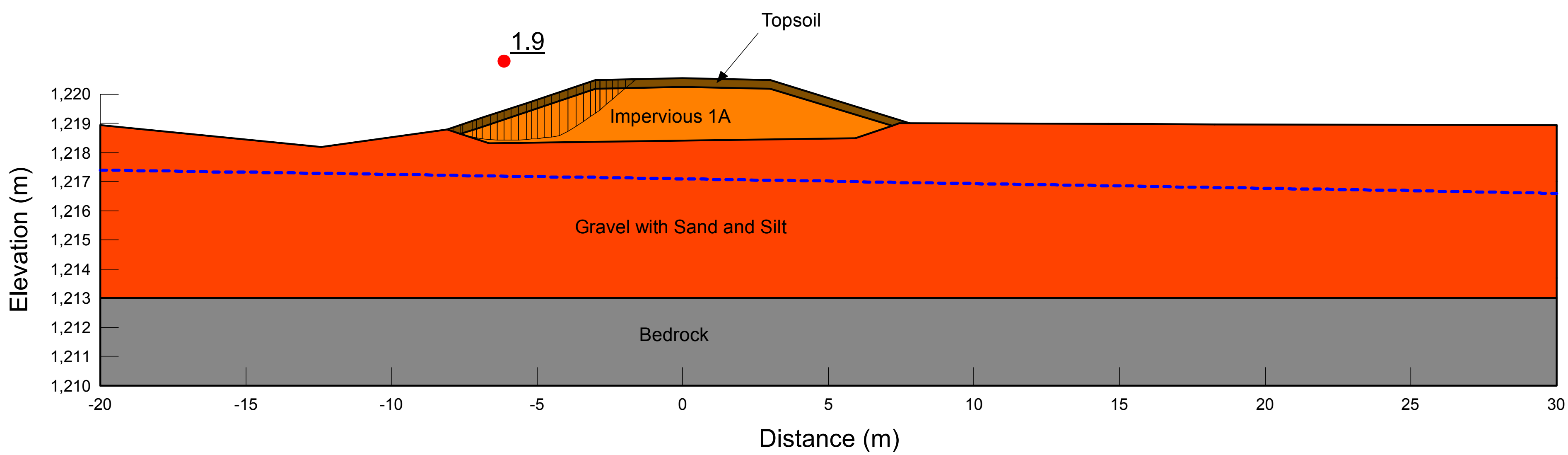
Normal Headwater = 1217.4 m
Normal Tailwater = 1216.6 m



Alberta Transportation SR1 Floodplain Berm
Section 0+900
Load Case: Seismic - Post Earthquake
Undrained, Seismic Strengths
Incipient Motion in the Upstream Direction

Color	Name	Model	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)
	Bedrock (EQ)	Mohr-Coulomb	21	0	24			
	Gravel with Sand and Silt (EQ)	Mohr-Coulomb	20	0	35			
	Impervious 1A (EQ)	Bilinear	20	0		24	15	141
	Topsoil (EQ)	Bilinear	20	0		24	15	141

Normal Headwater = 1217.4 m
Normal Tailwater = 1216.6 m



Section 1+600

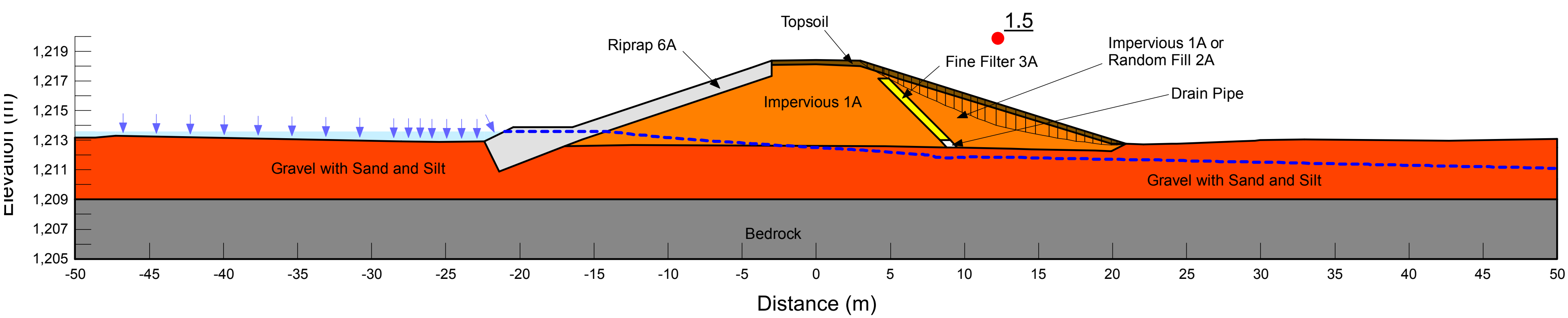
Stantec

Alberta Transportation SR1 Floodplain Berm

Section 1+600
Load Case: End of Construction
Undrained, Static Strengths
Incipient Motion in the Downstream Direction

Color	Name	Model	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)
	Bedrock (undrained)	Mohr-Coulomb	21	0	24			
	Fine Filter 3A (undrained)	Mohr-Coulomb	21	0	33			
	Gravel with Sand and Silt (undrained)	Mohr-Coulomb	20	0	35			
	Impervious 1A (undrained)	Bilinear	20	0		24	15	141
	Riprap (undrained)	Mohr-Coulomb	20	0	35			
	Topsoil (undrained)	Bilinear	20	0		24	15	141

Normal Headwater = 1213.6 m
Normal Tailwater = 1211.1 m



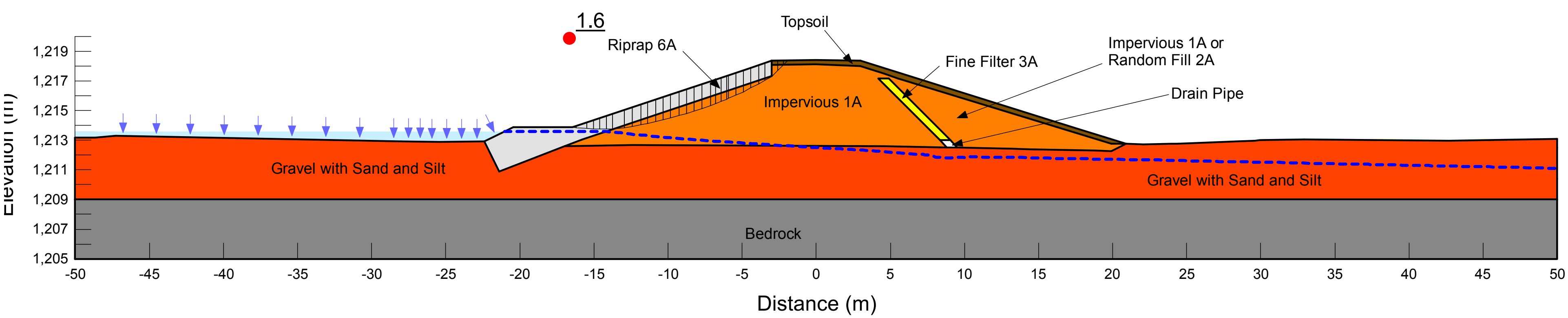
Stantec

Alberta Transportation SR1 Floodplain Berm

Section 1+600
Load Case: End of Construction
Undrained, Static Strengths
Incipient Motion in the Upstream Direction

Normal Headwater = 1213.6 m
Normal Tailwater = 1211.1 m

Color	Name	Model	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)
	Bedrock (undrained)	Mohr-Coulomb	21	0	24			
	Fine Filter 3A (undrained)	Mohr-Coulomb	21	0	33			
	Gravel with Sand and Silt (undrained)	Mohr-Coulomb	20	0	35			
	Impervious 1A (undrained)	Bilinear	20	0		24	15	141
	Riprap (undrained)	Mohr-Coulomb	20	0	35			
	Topsoil (undrained)	Bilinear	20	0		24	15	141

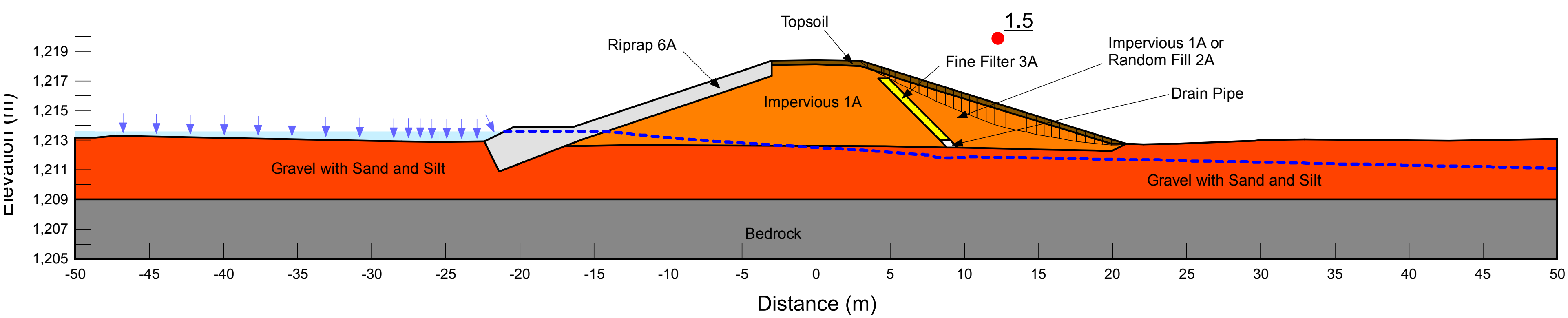


Alberta Transportation SR1 Floodplain Berm

Section 1+600
Load Case: Long Term
Drained, Static Strengths
Incipient Motion in the Downstream Direction

Normal Headwater = 1213.6 m
Normal Tailwater = 1211.1 m

Color	Name	Model	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)
(grey)	Bedrock (drained)	Mohr-Coulomb	21	0	24
(yellow)	Fine Filter 3A (drained)	Mohr-Coulomb	21	0	33
(red-orange)	Gravel with Sand and Silt (drained)	Mohr-Coulomb	20	0	35
(orange)	Impervious 1A (drained)	Mohr-Coulomb	20	0	24
(light grey)	Riprap (drained)	Mohr-Coulomb	20	0	35
(brown)	Topsoil (drained)	Mohr-Coulomb	20	0	24



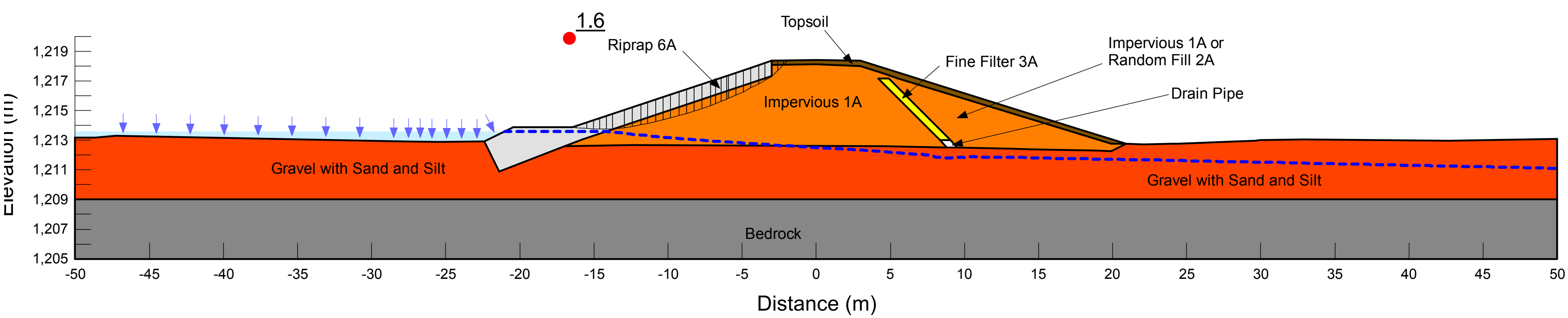
Stantec

Alberta Transportation SR1 Floodplain Berm

Section 1+600
Load Case: Long Term
Drained, Static Strengths
Incipient Motion in the Upstream Direction

Color	Name	Model	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)
	Bedrock (drained)	Mohr-Coulomb	21	0	24
	Fine Filter 3A (drained)	Mohr-Coulomb	21	0	33
	Gravel with Sand and Silt (drained)	Mohr-Coulomb	20	0	35
	Impervious 1A (drained)	Mohr-Coulomb	20	0	24
	Riprap (drained)	Mohr-Coulomb	20	0	35
	Topsoil (drained)	Mohr-Coulomb	20	0	24

Normal Headwater = 1213.6 m
Normal Tailwater = 1211.1 m



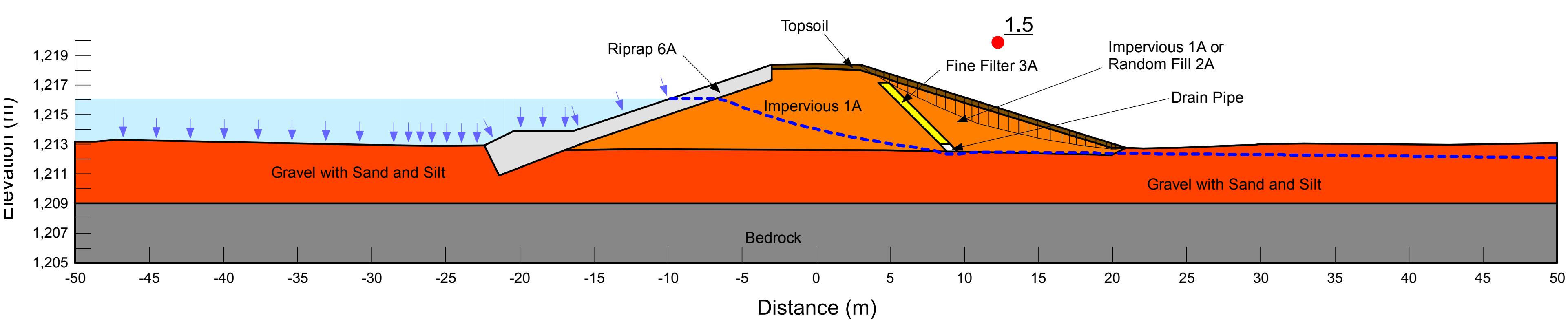
Stantec

Alberta Transportation SR1 Floodplain Berm

Section 1+600
Load Case: Flood Operations - USBR Method
Drained, Static Strengths
Incipient Motion in the Downstream Direction

Color	Name	Model	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)
	Bedrock (drained)	Mohr-Coulomb	21	0	24
	Fine Filter 3A (drained)	Mohr-Coulomb	21	0	33
	Gravel with Sand and Silt (drained)	Mohr-Coulomb	20	0	35
	Impervious 1A (drained)	Mohr-Coulomb	20	0	24
	Riprap (drained)	Mohr-Coulomb	20	0	35
	Topsoil (drained)	Mohr-Coulomb	20	0	24

Operations Headwater = 1216.1 m
Operations Tailwater = 1212.1 m



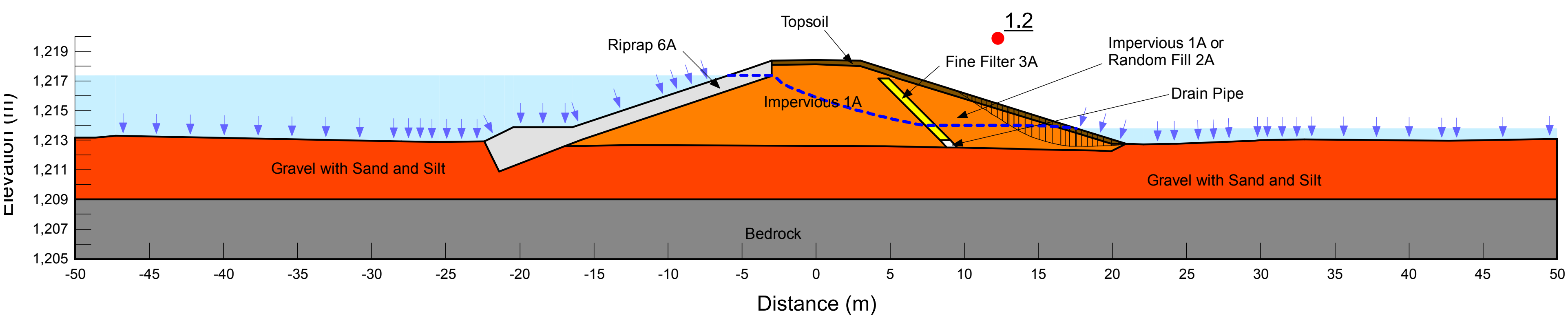
Stantec

Alberta Transportation SR1 Floodplain Berm

Section 1+600
Load Case: Flood Max IDF - USBR Method
Drained, Static Strengths
Incipient Motion in the Downstream Direction

Color	Name	Model	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)
	Bedrock (drained)	Mohr-Coulomb	21	0	24
	Fine Filter 3A (drained)	Mohr-Coulomb	21	0	33
	Gravel with Sand and Silt (drained)	Mohr-Coulomb	20	0	35
	Impervious 1A (drained)	Mohr-Coulomb	20	0	24
	Riprap (drained)	Mohr-Coulomb	20	0	35
	Topsoil (drained)	Mohr-Coulomb	20	0	24

Max IDF Headwater = 1217.4 m
Max IDF Tailwater = 1213.8 m



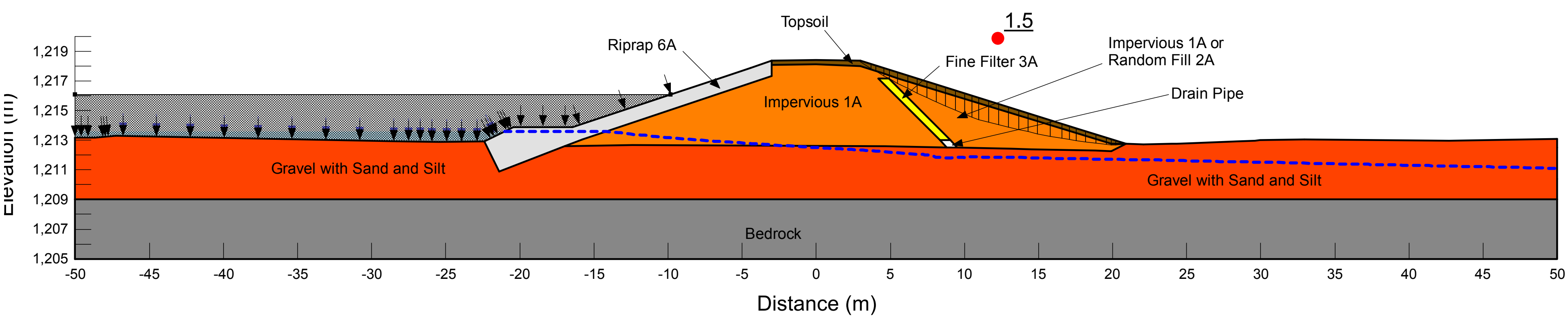
Stantec

Alberta Transportation SR1 Floodplain Berm

Section 1+600
Load Case: Flood Operations - USACE Method
Undrained, Static Strengths
Incipient Motion in the Downstream Direction

Color	Name	Model	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)
	Bedrock (undrained)	Mohr-Coulomb	21	0	24			
	Fine Filter 3A (undrained)	Mohr-Coulomb	21	0	33			
	Gravel with Sand and Silt (undrained)	Mohr-Coulomb	20	0	35			
	Impervious 1A (undrained)	Bilinear	20	0		24	15	141
	Riprap (undrained)	Mohr-Coulomb	20	0	35			
	Topsoil (undrained)	Bilinear	20	0		24	15	141

Normal Headwater = 1213.6 m
Normal Tailwater = 1211.1 m
Flood Operations Headwater/Tailwater applied as surcharge

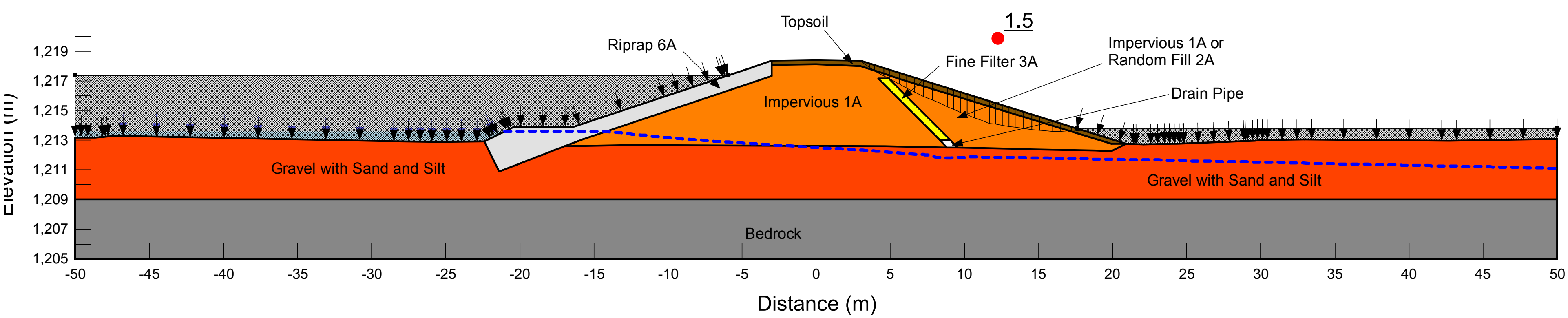


Alberta Transportation SR1 Floodplain Berm

Section 1+600
Load Case: Flood Max IDF - USACE Method
Undrained, Static Strengths
Incipient Motion in the Downstream Direction

Color	Name	Model	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)
	Bedrock (undrained)	Mohr-Coulomb	21	0	24			
	Fine Filter 3A (undrained)	Mohr-Coulomb	21	0	33			
	Gravel with Sand and Silt (undrained)	Mohr-Coulomb	20	0	35			
	Impervious 1A (undrained)	Bilinear	20	0		24	15	141
	Riprap (undrained)	Mohr-Coulomb	20	0	35			
	Topsoil (undrained)	Bilinear	20	0		24	15	141

Normal Headwater = 1213.6 m
Normal Tailwater = 1211.1 m
Max IDF Headwater/Tailwater applied as surcharge



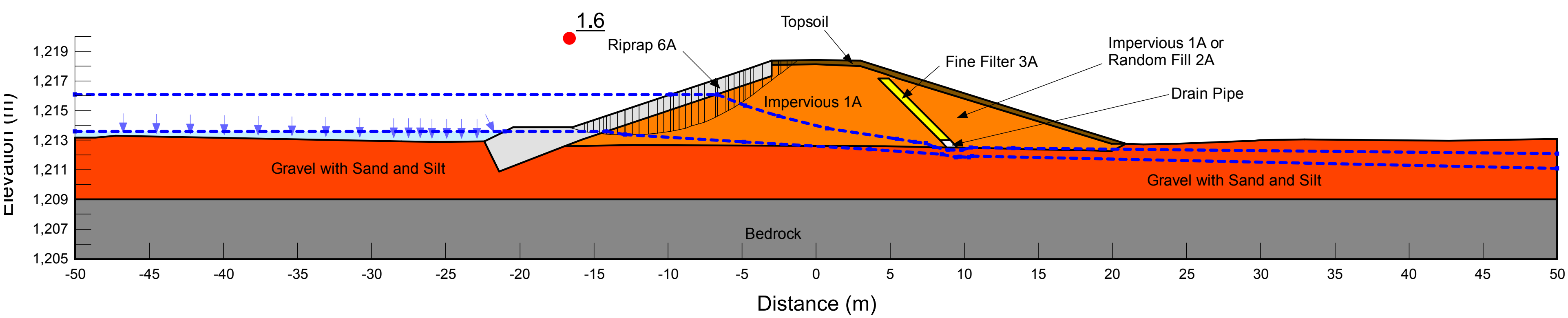
Stantec

Alberta Transportation SR1 Floodplain Berm

Section 1+600
Load Case: Rapid Drawdown - Flood Operations to Normal Condition
Undrained, Static Strengths
Incipient Motion in the Upstream Direction

Flood Operations Headwater = 1216.1 m
Flood Operations Tailwater = 1212.1 m

Color	Name	Model	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)	Cohesion R (kPa)	Phi R (°)
	Bedrock (RDD)	Mohr-Coulomb	21	0	24	0	24
	Fine Filter 3A (RDD)	Mohr-Coulomb	21	0	33	0	33
	Gravel with Sand and Silt (RDD)	Mohr-Coulomb	20	0	35	0	35
	Impervious 1A (RDD)	Mohr-Coulomb	20	0	24	25	15
	Riprap (RDD)	Mohr-Coulomb	20	0	35	0	35
	Topsoil (RDD)	Mohr-Coulomb	20	0	24	25	15



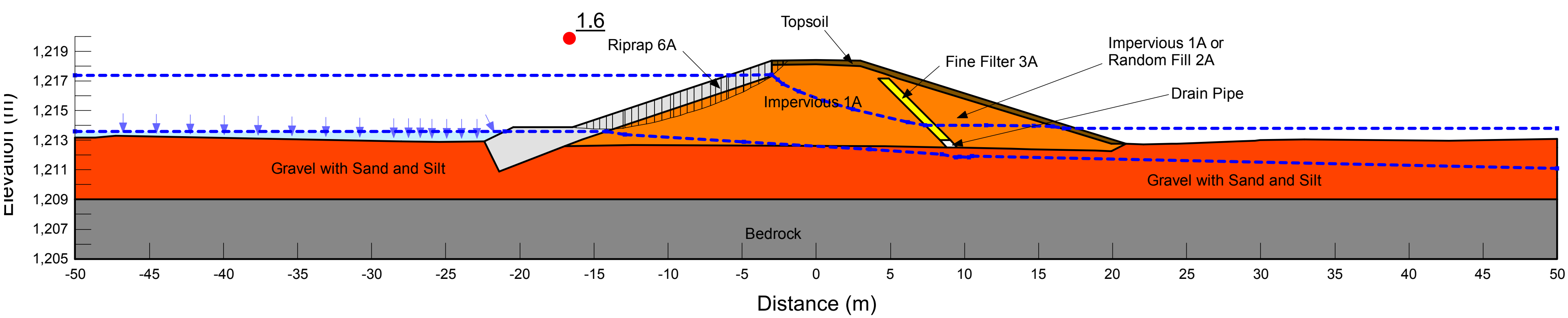
Stantec

Alberta Transportation SR1 Floodplain Berm

Section 1+600
Load Case: Rapid Drawdown - Max IDF Flood to Normal Condition
Undrained, Static Strengths
Incipient Motion in the Upstream Direction

Color	Name	Model	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)	Cohesion R (kPa)	Phi R (°)
	Bedrock (RDD)	Mohr-Coulomb	21	0	24	0	24
	Fine Filter 3A (RDD)	Mohr-Coulomb	21	0	33	0	33
	Gravel with Sand and Silt (RDD)	Mohr-Coulomb	20	0	35	0	35
	Impervious 1A (RDD)	Mohr-Coulomb	20	0	24	25	15
	Riprap (RDD)	Mohr-Coulomb	20	0	35	0	35
	Topsoil (RDD)	Mohr-Coulomb	20	0	24	25	15

Max IDF Headwater = 1217.4 m
Max IDF Tailwater = 1213.8 m



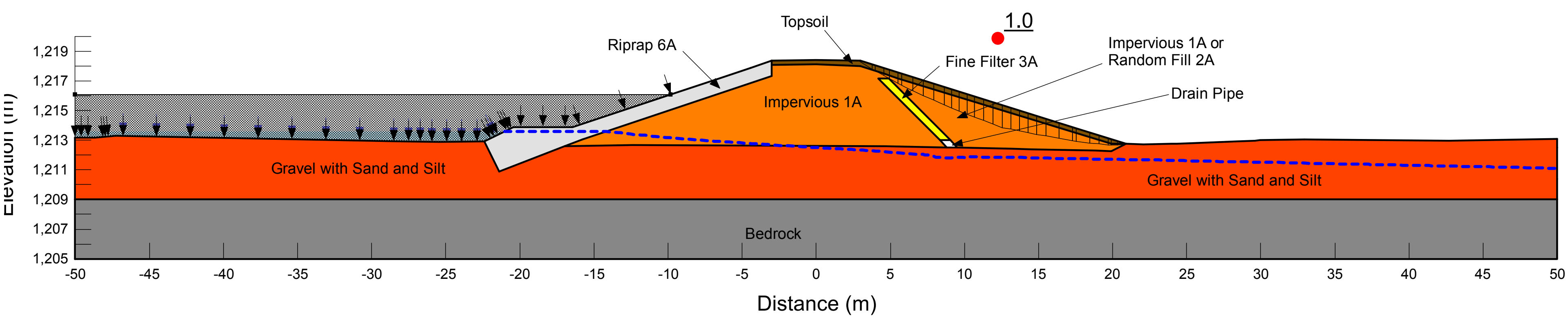
Stantec

Alberta Transportation SR1 Floodplain Berm

Section 1+600
Load Case: Pseudostatic
Undrained, Seismic Strengths
Incipient Motion in the Downstream Direction

Color	Name	Model	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)
	Bedrock (EQ)	Mohr-Coulomb	21	0	24			
	Fine Filter 3A (EQ)	Mohr-Coulomb	21	0	33			
	Gravel with Sand and Silt (EQ)	Mohr-Coulomb	20	0	35			
	Impervious 1A (EQ)	Bilinear	20	0		24	15	141
	Riprap (EQ)	Mohr-Coulomb	20	0	35			
	Topsoil (EQ)	Bilinear	20	0		24	15	141

Normal Headwater = 1213.6 m
Normal Tailwater = 1211.1 m
Flood Operations Headwater/Tailwater applied as surcharge



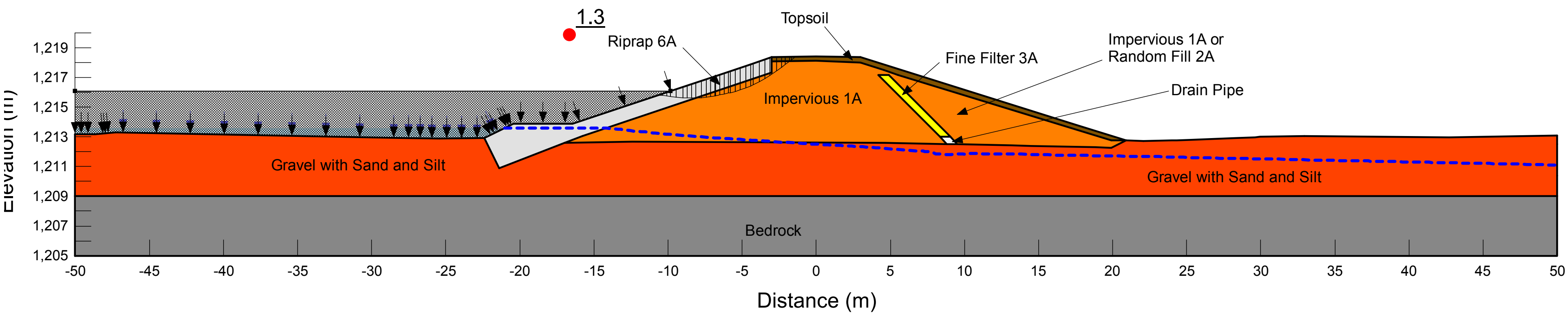
Stantec

Alberta Transportation SR1 Floodplain Berm

Section 1+600
Load Case: Pseudostatic
Undrained, Seismic Strengths
Incipient Motion in the Upstream Direction

Color	Name	Model	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)
	Bedrock (EQ)	Mohr-Coulomb	21	0	24			
	Fine Filter 3A (EQ)	Mohr-Coulomb	21	0	33			
	Gravel with Sand and Silt (EQ)	Mohr-Coulomb	20	0	35			
	Impervious 1A (EQ)	Bilinear	20	0		24	15	141
	Riprap (EQ)	Mohr-Coulomb	20	0	35			
	Topsoil (EQ)	Bilinear	20	0		24	15	141

Normal Headwater = 1213.6 m
Normal Tailwater = 1211.1 m
Flood Operations Headwater/Tailwater applied as surcharge



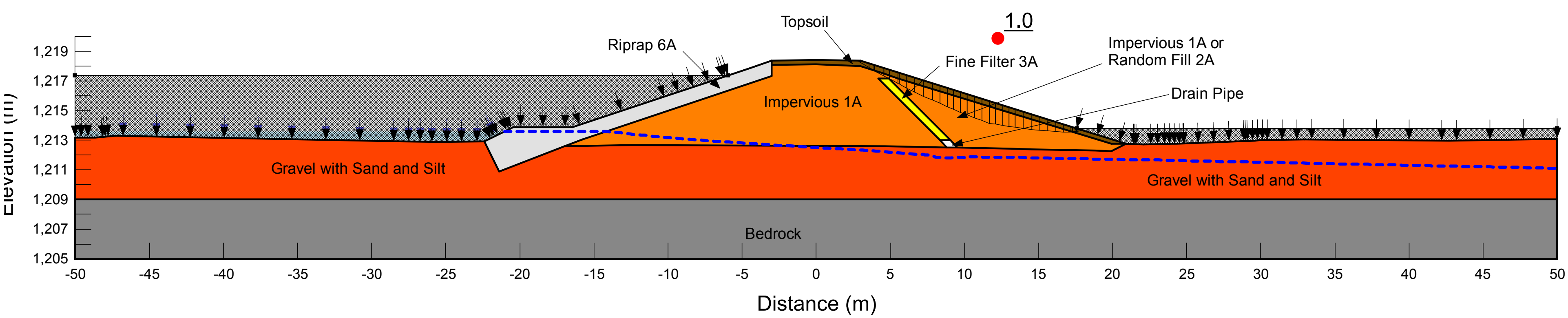
Stantec

Alberta Transportation SR1 Floodplain Berm

Section 1+600
Load Case: Pseudostatic
Undrained, Seismic Strengths
Incipient Motion in the Downstream Direction

Normal Headwater = 1213.6 m
Normal Tailwater = 1211.1 m
Max IDF Headwater/Tailwater applied as surcharge

Color	Name	Model	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)
	Bedrock (EQ)	Mohr-Coulomb	21	0	24			
	Fine Filter 3A (EQ)	Mohr-Coulomb	21	0	33			
	Gravel with Sand and Silt (EQ)	Mohr-Coulomb	20	0	35			
	Impervious 1A (EQ)	Bilinear	20	0		24	15	141
	Riprap (EQ)	Mohr-Coulomb	20	0	35			
	Topsoil (EQ)	Bilinear	20	0		24	15	141



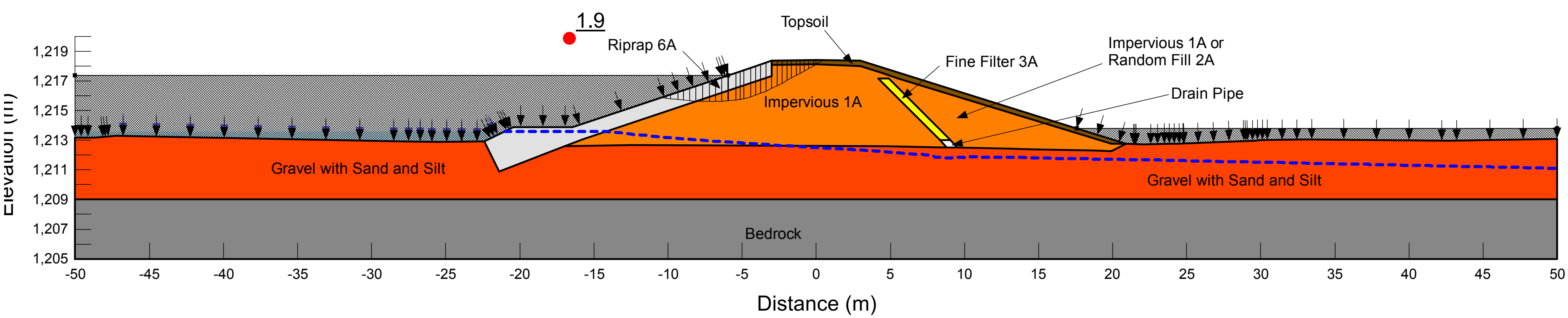
Stantec

Alberta Transportation SR1 Floodplain Berm

Section 1+600
Load Case: Pseudostatic
Undrained, Seismic Strengths
Incipient Motion in the Upstream Direction

Color	Name	Model	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)
	Bedrock (EQ)	Mohr-Coulomb	21	0	24			
	Fine Filter 3A (EQ)	Mohr-Coulomb	21	0	33			
	Gravel with Sand and Silt (EQ)	Mohr-Coulomb	20	0	35			
	Impervious 1A (EQ)	Bilinear	20	0		24	15	141
	Riprap (EQ)	Mohr-Coulomb	20	0	35			
	Topsoil (EQ)	Bilinear	20	0		24	15	141

Normal Headwater = 1213.6 m
Normal Tailwater = 1211.1 m
Max IDF Headwater/Tailwater applied as surcharge



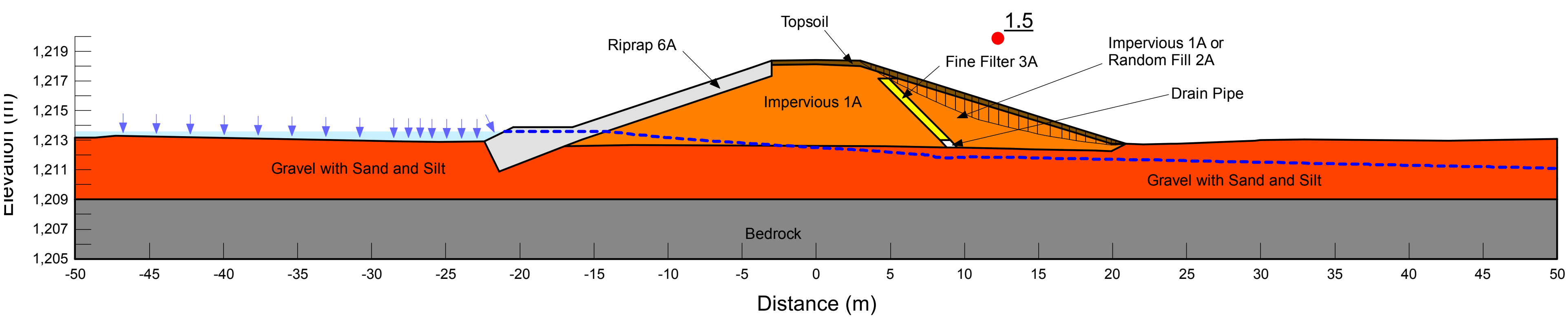
Stantec

Alberta Transportation SR1 Floodplain Berm

Section 1+600
Load Case: Seismic - Post Earthquake
Undrained, Seismic Strengths
Incipient Motion in the Downstream Direction

Normal Headwater = 1213.6 m
Normal Tailwater = 1211.1 m

Color	Name	Model	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)
	Bedrock (EQ)	Mohr-Coulomb	21	0	24			
	Fine Filter 3A (EQ)	Mohr-Coulomb	21	0	33			
	Gravel with Sand and Silt (EQ)	Mohr-Coulomb	20	0	35			
	Impervious 1A (EQ)	Bilinear	20	0		24	15	141
	Impervious 1A (undrained)	Bilinear	20	0		24	15	141
	Riprap (EQ)	Mohr-Coulomb	20	0	35			
	Topsoil (EQ)	Bilinear	20	0		24	15	141



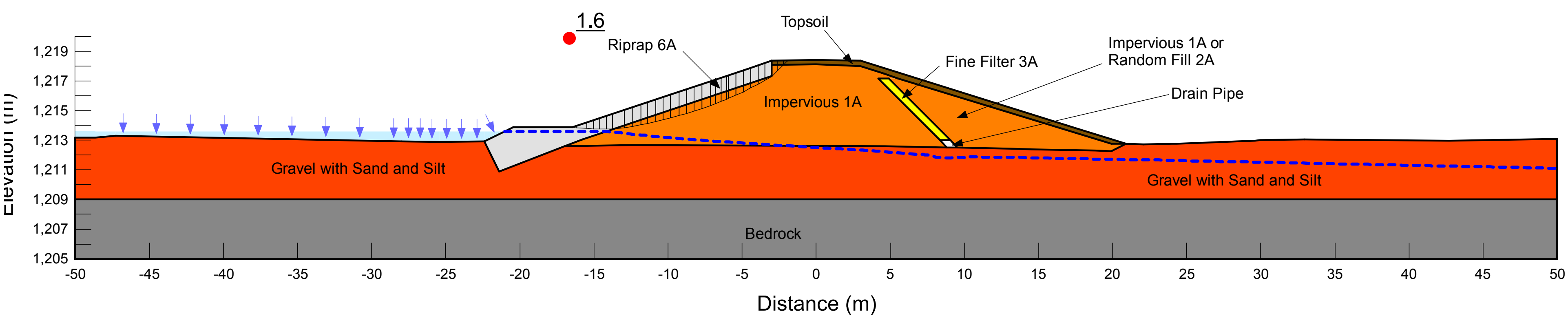
Stantec

Alberta Transportation SR1 Floodplain Berm

Section 1+600
Load Case: Seismic - Post Earthquake
Undrained, Seismic Strengths
Incipient Motion in the Upstream Direction

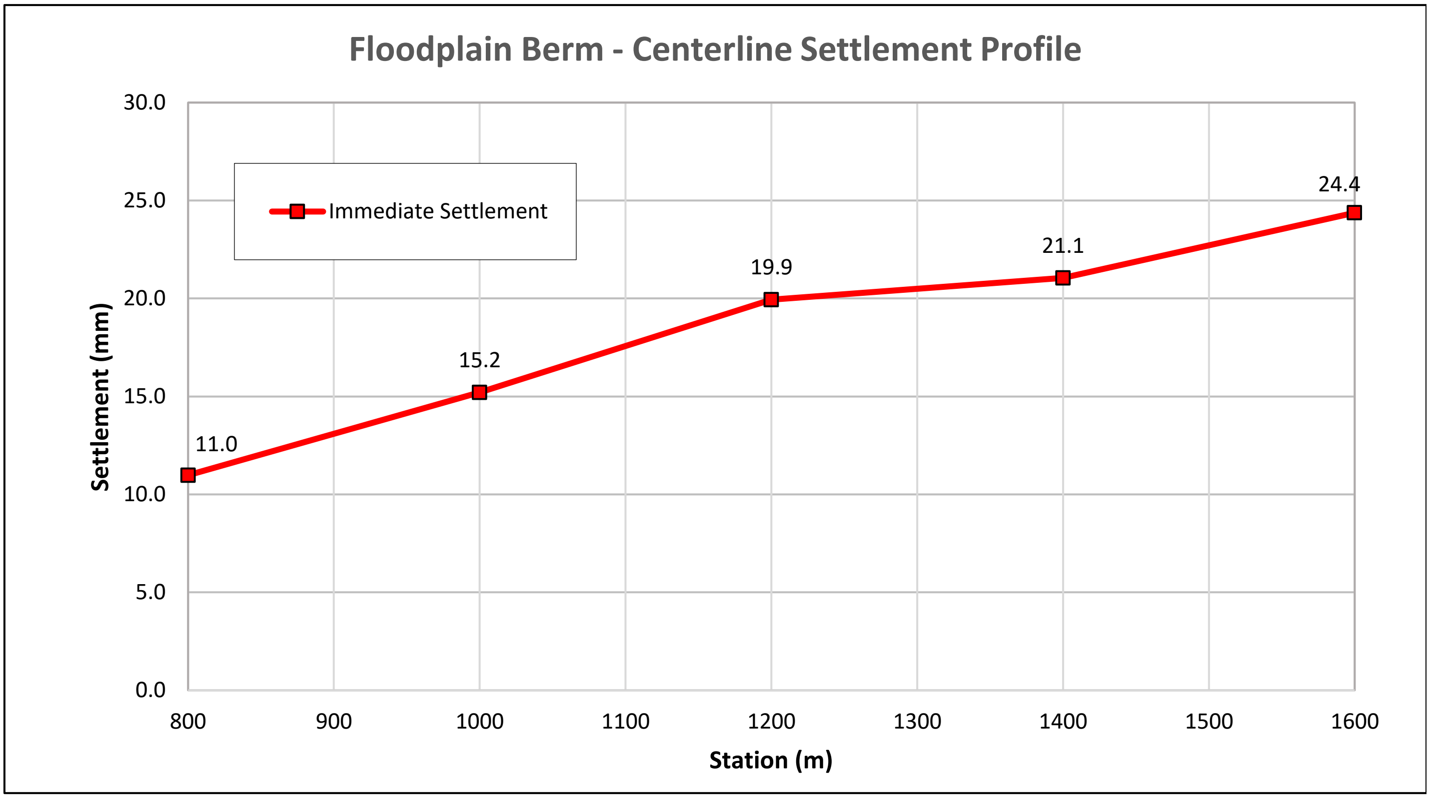
Color	Name	Model	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)
	Bedrock (EQ)	Mohr-Coulomb	21	0	24			
	Fine Filter 3A (EQ)	Mohr-Coulomb	21	0	33			
	Gravel with Sand and Silt (EQ)	Mohr-Coulomb	20	0	35			
	Impervious 1A (EQ)	Bilinear	20	0		24	15	141
	Riprap (EQ)	Mohr-Coulomb	20	0	35			
	Topsoil (EQ)	Bilinear	20	0		24	15	141

Normal Headwater = 1213.6 m
Normal Tailwater = 1211.1 m



Attachment 9.2 Settlement Analysis

Station	Station (m)	Embankment Height (m)	Foundation Settlement (mm)
0+800	800	1.3	11.0
1+000	1000	2.2	15.2
1+200	1200	3.6	19.9
1+400	1400	4.0	21.1
1+600	1600	5.4	24.4



SR1 Floodplain Berm
Settlement Calculations for Berm Centerline Sta. 0+800

4.3 ft (1.3 m) Embankment
13.1 ft (4.0 m) Foundation Material - Sandy Gravel

Nearest Consolidation Test Samples:
No consolidation testing on foundation materials: cohesionless

Based on avg. N=34.5, silty sand and gravel,
C' = 117

Date 2019-11-19
Calc by D. Back
Check by V. Severance

Top of Embankment El.:	1220.8	
Existing Grade El.:	1219.5	
Embankment Thickness (m)	1.3	4.3 ft
Est. Top of Rock El.:	1215.5	
Foundation Thickness (m)	4.0	13.1 ft

Embankment Unit Weight = 20 kN/m^3 (127.3 lb/ft^3) 127.3

$$\Delta H_i = H_c \frac{1}{C'} \log\left(\frac{\sigma'_o + \Delta\sigma_v}{\sigma'_o}\right)$$

Hough Method from FHWA Pub. FHWA NHI-06-088
(Immediate Settlement)

Foundation Material (Sandy Gravel) One Layer 4.0 m (13.1 ft)

Sandy Gravel Unit Weight = 17.4 kN/m^3 (110.7 lb/ft^3) 110.7

Location	Mid Pt. (ft)	H_c (ft)	C'	σ'_o (psf)	H_e(ft.)	$\Delta\sigma_v$(psf)	ΔH
0+000 (Crest)	6.5616	13.1	117	726.37	4.27	542.94	0.027

SUM = 0.027 feet
8 mm

13.1 2.625

Foundation Material (Sandy Gravel) Five Layers - 2.625 Feet Thick

Sandy Gravel Unit Weight = 17.4 kN/m^3 (110.7 lb/ft^3) 110.7

Location	Mid Pt. (ft)	H_c (ft)	C'	σ'_o (psf)	H_e(ft.)	$\Delta\sigma_v$(psf)	ΔH
0+000 (Crest)	1.31	2.625	117	145.27	4.27	542.94	0.015
0+000 (Crest)	3.94	2.625	117	435.82	4.27	542.94	0.008
0+000 (Crest)	6.56	2.625	117	726.37	4.27	542.94	0.005
0+000 (Crest)	9.19	2.625	117	1016.92	4.27	542.94	0.004
0+000 (Crest)	11.81	2.625	117	1307.46	4.27	542.94	0.003
		13.123					

SUM = 0.036 feet
11 mm

SR1 Floodplain Berm
Settlement Calculations for Berm Centerline Sta. 1+000

7.2 ft (2.2 m) Embankment
13.1 ft (4.0 m) Foundation Material - Sandy Gravel

Nearest Consolidation Test Samples:
No consolidation testing on foundation materials: cohesionless

Based on avg. N=34.5, silty sand and gravel,
C' = 117

Date 2019-11-19
Calc by D. Back
Check by V. Severance

Top of Embankment El.:	1220.2	
Existing Grade El.:	1218	
Embankment Thickness (m)	2.2	7.2 ft
Est. Top of Rock El.:	1214	
Foundation Thickness (m)	4.0	13.1 ft

Embankment Unit Weight = 20 kN/m^3 (127.3 lb/ft^3) 127.3

$$\Delta H_i = H_c \frac{1}{C'} \log\left(\frac{\sigma'_o + \Delta\sigma_v}{\sigma'_o}\right)$$

Hough Method from FHWA Pub. FHWA NHI-06-088
(Immediate Settlement)

Foundation Material (Sandy Gravel) One Layer 4.0 m (13.1 ft)

Sandy Gravel Unit Weight = 17.4 kN/m^3 (110.7 lb/ft^3) 110.7

Location	Mid Pt. (ft)	H_c (ft)	C'	σ'_o (psf)	H_e(ft.)	$\Delta\sigma_v$(psf)	ΔH
0+000 (Crest)	6.55	13.1	117	725.09	7.22	918.82	0.040

SUM = 0.040 feet
12 mm

13.1 2.625

Foundation Material (Sandy Gravel) Five Layers - 2.625 Feet Thick

Sandy Gravel Unit Weight = 17.4 kN/m^3 (110.7 lb/ft^3) 110.7

Location	Mid Pt. (ft)	H_c (ft)	C'	σ'_o (psf)	H_e(ft.)	$\Delta\sigma_v$(psf)	ΔH
0+000 (Crest)	1.31	2.625	117	145.27	7.22	918.82	0.019
0+000 (Crest)	3.94	2.625	117	435.82	7.22	918.82	0.011
0+000 (Crest)	6.56	2.625	117	726.37	7.22	918.82	0.008
0+000 (Crest)	9.19	2.625	117	1016.92	7.22	918.82	0.006
0+000 (Crest)	11.81	2.625	117	1307.46	7.22	918.82	0.005
		13.123					

SUM = 0.050 feet
15 mm

SR1 Floodplain Berm
Settlement Calculations for Berm Centerline Sta. 1+200

11.8 ft (3.6 m) Embankment
13.1 ft (4.0 m) Foundation Material - Sandy Gravel

Nearest Consolidation Test Samples:
No consolidation testing on foundation materials: cohesionless

Based on avg. N=34.5, silty sand and gravel,
C' = 117

Date 2019-11-19
Calc by D. Back
Check by V. Severance

Top of Embankment El.:	1219.6	
Existing Grade El.:	1216	
Embankment Thickness (m)	3.6	11.8 ft
Est. Top of Rock El.:	1212	
Foundation Thickness (m)	4.0	13.1 ft

Embankment Unit Weight = 20 kN/m^3 (127.3 lb/ft^3) 127.3

$$\Delta H_i = H_c \frac{1}{C'} \log\left(\frac{\sigma'_o + \Delta\sigma_v}{\sigma'_o}\right)$$

Hough Method from FHWA Pub. FHWA NHI-06-088
(Immediate Settlement)

Foundation Material (Sandy Gravel) One Layer 4.0 m (13.1 ft)

Sandy Gravel Unit Weight = 17.4 kN/m^3 (110.7 lb/ft^3) 110.7

Location	Mid Pt. (ft)	H_c (ft)	C'	σ'_o (psf)	H_e(ft.)	$\Delta\sigma_v$(psf)	ΔH
0+000 (Crest)	6.55	13.1	117	725.09	11.81	1503.53	0.055

SUM = 0.055 feet
17 mm

13.1 2.625

Foundation Material (Sandy Gravel) Five Layers - 2.625 Feet Thick

Sandy Gravel Unit Weight = 17.4 kN/m^3 (110.7 lb/ft^3) 110.7

Location	Mid Pt. (ft)	H_c (ft)	C'	σ'_o (psf)	H_e(ft.)	$\Delta\sigma_v$(psf)	ΔH
0+000 (Crest)	1.31	2.625	117	145.27	11.81	1503.53	0.024
0+000 (Crest)	3.94	2.625	117	435.82	11.81	1503.53	0.015
0+000 (Crest)	6.56	2.625	117	726.37	11.81	1503.53	0.011
0+000 (Crest)	9.19	2.625	117	1016.92	11.81	1503.53	0.009
0+000 (Crest)	11.81	2.625	117	1307.46	11.81	1503.53	0.007
		13.123					

SUM = 0.065 feet
20 mm

SR1 Floodplain Berm
Settlement Calculations for Berm Centerline Sta. 1+400

13.1 ft (4.0 m) Embankment
13.1 ft (4.0 m) Foundation Material - Sandy Gravel

Nearest Consolidation Test Samples:
No consolidation testing on foundation materials: cohesionless

Based on avg. N=34.5, silty sand and gravel,
C' = 117

Date	2019-11-19
Calc by	D. Back
Check by	V. Severance

Top of Embankment El.:	1219	
Existing Grade El.:	1215	
Embankment Thickness (m)	4.0	13.1 ft
Est. Top of Rock El.:	1211	
Foundation Thickness (m)	4.0	13.1 ft

Embankment Unit Weight = 20 kN/m^3 (127.3 lb/ft^3) 127.3

$$\Delta H_i = H_c \frac{1}{C'} \log\left(\frac{\sigma'_o + \Delta\sigma_v}{\sigma'_o}\right)$$

Hough Method from FHWA Pub. FHWA NHI-06-088
(Immediate Settlement)

Foundation Material (Sandy Gravel) One Layer 4.0 m (13.1 ft)

Sandy Gravel Unit Weight = 17.4 kN/m^3 (110.7 lb/ft^3) 110.7

Location	Mid Pt. (ft)	H_c (ft)	C'	σ'_o (psf)	H_e(ft.)	$\Delta\sigma_v$(psf)	ΔH
0+000 (Crest)	6.55	13.1	117	725.09	13.12	1670.58	0.058

SUM = 0.058 feet
18 mm

13.1 2.625

Foundation Material (Sandy Gravel) Five Layers - 2.625 Feet Thick

Sandy Gravel Unit Weight = 17.4 kN/m^3 (110.7 lb/ft^3) 110.7

Location	Mid Pt. (ft)	H_c (ft)	C'	σ'_o (psf)	H_e(ft.)	$\Delta\sigma_v$(psf)	ΔH
0+000 (Crest)	1.31	2.625	117	145.27	13.12	1670.58	0.025
0+000 (Crest)	3.94	2.625	117	435.82	13.12	1670.58	0.015
0+000 (Crest)	6.56	2.625	117	726.37	13.12	1670.58	0.012
0+000 (Crest)	9.19	2.625	117	1016.92	13.12	1670.58	0.009
0+000 (Crest)	11.81	2.625	117	1307.46	13.12	1670.58	0.008
		13.123					

SUM = 0.069 feet
21 mm

SR1 Floodplain Berm
Settlement Calculations for Berm Centerline Sta. 1+600

17.7 ft (5.4 m) Embankment
13.1 ft (4.0 m) Foundation Material - Sandy Gravel

Nearest Consolidation Test Samples:
No consolidation testing on foundation materials: cohesionless

Based on avg. N=34.5, silty sand and gravel,
C' = 117

Date	2019-11-19
Calc by	D. Back
Check by	V. Severance

Top of Embankment El.:	1218.4	
Existing Grade El.:	1213	
Embankment Thickness (m)	5.4	17.7 ft
Est. Top of Rock El.:	1209	
Foundation Thickness (m)	4.0	13.1 ft

Embankment Unit Weight = 20 kN/m^3 (127.3 lb/ft^3) 127.3

$$\Delta H_i = H_c \frac{1}{C'} \log\left(\frac{\sigma'_o + \Delta\sigma_v}{\sigma'_o}\right)$$

Hough Method from FHWA Pub. FHWA NHI-06-088
(Immediate Settlement)

Foundation Material (Sandy Gravel) One Layer 4.0 m (13.1 ft)

Sandy Gravel Unit Weight = 17.4 kN/m^3 (110.7 lb/ft^3) 110.7

Location	Mid Pt. (ft)	H_c (ft)	C'	σ'_o (psf)	H_e(ft.)	$\Delta\sigma_v$(psf)	ΔH
0+000 (Crest)	6.55	13.1	117	725.09	17.72	2255.29	0.069

SUM = 0.069 feet
21 mm

13.1 2.625

Foundation Material (Sandy Gravel) Five Layers - 2.625 Feet Thick

Sandy Gravel Unit Weight = 17.4 kN/m^3 (110.7 lb/ft^3) 110.7

Location	Mid Pt. (ft)	H_c (ft)	C'	σ'_o (psf)	H_e(ft.)	$\Delta\sigma_v$(psf)	ΔH
0+000 (Crest)	1.31	2.625	117	145.27	17.72	2255.29	0.027
0+000 (Crest)	3.94	2.625	117	435.82	17.72	2255.29	0.018
0+000 (Crest)	6.56	2.625	117	726.37	17.72	2255.29	0.014
0+000 (Crest)	9.19	2.625	117	1016.92	17.72	2255.29	0.011
0+000 (Crest)	11.81	2.625	117	1307.46	17.72	2255.29	0.010
		13.123					

SUM = 0.080 feet
24 mm

ATTACMENT 10
DIVERSION STRUCTURE

Attachment 10.1 Stability Analysis Design Memo

Preliminary Design Memo

August 8, 2016

Internal Design Team Use Only

Alberta Transportation SR-1 Project
Diversion Structures
Estimated Bedrock Design Parameters

Calculated By: Vince Severance
Checked By: Dan Back

Based on unconfined compressive strength testing performed on shale and sandstone bedrock samples from in the vicinity of the Diversion Structures.

Table 1 - Estimated Bedrock Strength Parameters - Diversion Structure

Bedrock Type	Percent Bedrock Type Below Bearing Elev.	Unconfined Compressive Strength (psi)	Estimated Basic Friction Angle	Cohesion (psf)
Shale	30	4940	29	4000
Mudstone	40	280	24	2000
Claystone	20	280	24	2000
Sandstone	10	3500	32	6000

Weighted Basic Friction Angle = 26.3 degrees
Weighted Unconf. Comp. Strength = 2000 psi

Recommended Preliminary Friction Angle = 26 degrees (Normal Cases)
Recommended Prelim. UC Strength = 1800 psi (Normal Cases)

References:

Barton, Typical Values of Basic Friction Angle (1973).
FMSM, Lock and Dam 10 DSSS Laboratory Testing on Shale (1999).
ASTM D-5878, Rock Mass Rating System (2008).

Table 2 - Estimated Cross Bed Strength Parameters - Diversion Structures

Bedrock Type	Percent Bedrock Type Below Bearing Elev.	Unconfined Compressive Strength (psi)	Hoek-Brown Coefficients			Estimated Cross Bed Friction Angle	Estimated Cross Bed Cohesion (psf)
			Mi Value	GSI Value	D Value		
Shale	30	4940	6	35	0.5	39.2	3212
Mudstone	40	280	3	30	0.5	12.0	718
Claystone	20	280	4	30	0.5	13.4	805
Sandstone	10	3500	13	55	0.5	50.5	5362

Weighted Cross Bed Friction Angle = 24.3 degrees
Weighted Cross Bed Cohesion = 1,948 psf

Recom. Prelim.Cross Bed Friction Angle = 24 degrees
Recom. Prelim. Cross Bed Cohesion = 1900 psi

References: Generalized Hoek-Brown Failure Criterion (2002).

Table 3 - Estimated Bearing Capacity of Intact Rock (with Cohesion) - Diversion Structures

Bedrock Type	Percent Bedrock Type Below Bearing Elev.	Cohesion (psf)	Estimated Basic Friction Angle	Ultimate Bearing Capacity (psi)	Ultimate Bearing Capacity (psf)	Allowable Bearing Capacity FS=3, (psi)	Allowable Bearing Capacity FS=3, (psf)
Shale	30	4000	29	748	107,712	249	35,856
Mudstone	40	2000	24	363	52,272	121	17,424
Claystone	20	2000	24	363	52,272	121	17,424
Sandstone	10	6000	32	1172	168,768	391	56,304

Weighted Ultimate Bearing Capacity = 80,554 psf

Weighted Allowable Bearing Capacity = 26,842 psf (FS = 3.0)

Recommend Use of "Without Cohesion" Value Below

References: USACE EM 1110-1-2908 (Nov 1994). Equations 6.1 to 6-3 and Figure 6-1

Table 4 - Estimated Bearing Capacity of Intact Rock (without Cohesion) - Diversion Structures

Bedrock Type	Percent Bedrock Type Below Bearing Elev.	Cohesion (psf)	Estimated Basic Friction Angle	Ultimate Bearing Capacity (psi)	Ultimate Bearing Capacity (psf)	Allowable Bearing Capacity FS=3, (psi)	Allowable Bearing Capacity FS=3, (psf)
Shale	30	0	29	381	54,864	127	18,288
Mudstone	40	0	24	219	31,536	73	10,512
Claystone	20	0	24	219	31,536	73	10,512
Sandstone	10	0	32	532	76,608	177	25,488

Weighted Ultimate Bearing Capacity = 43,042 psf
Weighted Allowable Bearing Capacity = 14,342 psf (FS = 3.0)

Recommmended Ultimate Bearing Capacity = 40000 psf 1915 kPa
Recommended Allowable Bearing Capacity = 13000 psf (FS = 3.0) (Normal Cases) 622 kPa

References: USACE EM 1110-1-2908 (Nov 1994). Equations 6.1 to 6-3 and Figure 6-1

Attachment 10.2 Bedrock Design Parameters Memo

Preliminary Design Memo

October 18, 2016

SR1 Diversion Structures

Calculated By: Vince Severance

Internal Design Team Use Only

Checked By: Dan Back

Alberta Transportation SR-1 Project
Diversion Structures
Top of Bedrock, Estimated Bearing Elevations and Bedrock Unit Weight

Rock testing results have been received and the Stantec Geotechnical Engineering Team has evaluated the information. The updated preliminary bedrock bearing elevations and unit weights are presented in Tables 1 and 2 below.

Seven boreholes (DS1 thru DS5, DS9 and, DS10) were advanced within the limits of Elbow River. The bedrock encountered within the Elbow River in the vicinity of the Diversion Structures consists of sedimentary sandstone, mudstone, shale, and claystone. The top of the bedrock surface typically consists of a layer of highly weathered, poor quality bedrock ranging in thickness from 0.88 m to 3.40 m.

Three boreholes (DS6, DS7A, and DS8) were drilled upon the river bluff approximately 23 m above the river bed. Top of bedrock was encountered approximately 14 m above the estimated bearing elevation in these borings.

Table 1 - SR1 Diversion Structure - Top of Bedrock and Estimated Bearing Elevations

Boring	Top of Bedrock Elevation (m)	Top of Estimated/Inferred Bearing Bedrock Elevation (m)	Bedrock Description at Estimated Bearing Elevation
DS1	1209.65	1208.77	Good Quality Gray Mudstone
DS2	1208.71	1207.71	Excellent Quality Gray Shale
DS3	1209.34	1207.24	Good Quality Gray Shale
DS4	1209.59	1207.19	Fair Quality Gray Shale
DS5	1210.00	1206.60	Excellent Quality Gray Mudstone
DS6	1219.20	1206.00	Fair Quality Mudstone
DS7A	1220.10	1208.05	Excellent Quality Sandstone
DS8	1221.01	1206.77	Fair Quality Gray Claystone
DS9	1208.21	1205.61	Fair Quality Gray Shale
DS10	1209.04	1207.04	Fair Quality Mudstone to Shale

Table 2 - SR1 Diversion Structure - Bedrock Unit Weight

Boring	Core Run	Sample	Unit Weight			Bedrock Description
		Elevation (m)	(kg/m^3)	(lb/ft^3)	(KN/m^3)	
FB6	RC10	1206.75	2562	159.9	25.12	Poor Quality Gray Sandstone
DC6	RC19	1207.93	2379	148.5	23.33	Fair Quality Gray Sandstone
DC6	RC20	1206.63	2428	151.6	23.81	Fair Quality Gray Sandstone
DC7A	RC6	1211.34	3059	191.0	30.00	Very Poor Quality Gray Siltstone
		Averages	2607	162.7	25.57	

Recommended Bedrock Unit Weight = 25 KN/m^3

Attachment 10.3 Frost Depth Calculations

Frost Depth Calculation Using Modified Berggren Equation

References: *Canadian Foundation Engineering Manual, 4th Edition*
Canadian Climatic Normals 1981-2010 Springbank A Station Data

13.4.2 Simplified Solutions for Maximum Frost Penetration Neglecting Frost Heave

Frost penetration is proportional to the square root of time for a step change in ground surface temperature. The most useful form of the relationship is the modified Berggren equation as described by Aldrich (1956), Sanger (1963) and Johnston (1981), and shown as Equation 13.3:

$$X = \lambda \sqrt{\frac{2 k_f I_s}{L_s}} \quad (13.3)$$

where

- X = depth of frost penetration
- I_s = surface freezing index which can be estimated from the air freezine index times a ground surface interface factor "n"
- k_f = Thermal conductivity of the frozen soil
- L_s = Volumetric latent heat of the soil
- λ = A dimensionless coefficient (Figure 13.8)

Average Dry Density and Water Content of Lean Clay Till Soils Encountered Between DC1 and DC12:

Dry Density	γ_d =	1491	**kg/m^3**	=	1.491	metric ton/m^3 (93.1 pcf)
Gravimetric Water Content	**w =**	13.70	**Percent**	=	0.137	(fraction)

Volumetric Latent Heat of Soil

$$L_S = \gamma_d w L$$

Eqn. 13.6

Latent Heat of Fusion of Water L = 334 kJ/kg

L_S = (1491 kg/m^3) x (0.137) x (334 kJ/kg)

Latent Heat of Fusion of Water L_S = 68,225 kJ/m^3 (1831 BTU/ft^3)

Thermal Conductivity of Frozen Fine Grained Soil k_f = 1.10 (W/m K) *(Figure 13.7)* (1 W = 1 J/sec)

(1.10 J/sec per m K) x (1 KJ/1000 J) x (3,600 sec / hr) x (24 hr/day)

k_f = 95.04 (KJ/day per m K)

n-Factor	n =	1.0	*(From Table 13.2)*		
Mean Freezing Index	I_m =	1700	°C - Days	(Station Data)	
Mean Annual Air Temp	*MAAT* =	3.1	°C	(Station Data)	(37.58 °F)
Freezing Days	t =	64	days	(Station Data)	
Volumetric Heat Capacity of Frozen Soil	$C = \gamma_d (C_S + C_i w)$			*Eqn. 13.7*	
Specific Heat of Dry Soil	C_S =	0.71	KJ/kg °C	*Eqn. 13.7*	
Specific Heat of Ice	C_i =	2.1	KJ/kg °C	*Eqn. 13.7*	

C = (1491 kg/m^3) x [0.71KJ/kg °C + (2.1KJ/kg °C) x (0.137)]

Volumetric Heat Capacity of Frozen Soil	C =	1487.6	KJ/kg °C		
Design Freezing Index	$I_d = 100 + 1.29 I_m$			*Eqn. 13.4*	
Mean Freezing Index	I_m =	n/a	°C - Days	(Station Data)	
Design Freezing Index	I_d =	1700	°C - Days	(50 yr return chart)	

$I_s = n\ I_d$ = 1.0 (1,700)

Surface Freezing Index I_s = 1700.0 Deg. Days

β = 0.12 $\beta = \frac{MAAT * t}{I_S}$ $\frac{(3.1\ °C) \times (64\ days)}{(1{,}700\ deg.\ C\ days)}$

μ = 0.58 $\mu = \frac{C * I_S}{Ls * t}$ $\frac{(1{,}487.6\ KJ/kg\ °C) \times (1{,}700\ Deg.\ Days)}{(68{,}225\ kJ/m^3) \times (64\ days)}$

λ = 0.90 *(From Fig. 13.8)*

Frost Depth: $x = \lambda \sqrt{\frac{2k_f I_S}{L_S}}$ *Eqn. 13.3*

(0.90) x [(2 x 1.10 W/m K * 3.6 x 24 x 1450.5°C day) / 68225 kJ/

x = 1.96 meters

CANADIAN
FOUNDATION ENGINEERING MANUAL
4th EDITION

CANADIAN GEOTECHNICAL SOCIETY 2006

CANADA

13 Frost Action

13 Frost Action

13.1 Introduction

The Canadian climate results in freezing of the near-surface ground for several months each winter almost everywhere in Canada. The depth of seasonal frost penetration ranges from minimal to several meters, depending upon local climate, soil conditions and snow cover. Ground freezing frequently results in volumetric expansion of the soil which causes heaving of structures located above or adjacent to the freezing soil. Thaw during the following spring will release the excess water, usually causing loss of strength or complete collapse of the soil structure. This natural seasonal process can be very damaging to infrastructure, such as roads and buried pipelines, and may also cause serious problems for buildings (Crawford, 1968; Penner and Crawford, 1983).

This chapter provides a description of the phenomenon of frost heave, its causes and a brief summary of current predictive capabilities. Guidance is provided for simplified prediction of frost penetration and selection of mitigative design measures. The comments are not intended to deal with structures on a permafrost foundation. A thorough understanding of the nature and distribution of frozen soil is required to predict soil behaviour in permafrost regions. The reader is referred to a comprehensive treatment of this more complex topic such as found in Brown (1970), Andersland and Anderson (1978), Johnston (1981) and Andersland and Ladanyi (2004).

13.2 Ice Segregation in Freezing Soil

Water in soil pores begins to freeze as the temperature is lowered through 0°C. Figure 13.1 illustrates the progressive reduction of unfrozen water content as the relative proportions of water and ice change at sub-zero temperatures for sand, silt and clay. Continued formation of ice in the soil pores at progressively decreasing temperatures confines the remaining water to progressively smaller pore spaces. A pressure differential between the ice and water phases draws water from the unfrozen soil into the freezing soil. Fine-grained soils, which freeze over a broader range of temperature, are particularly susceptible to moisture migration along a pressure gradient, resulting in growth of ice lenses. The resulting heave rate and magnitude depend upon soil type, overburden pressure, groundwater conditions, freezing rate, and other factors. The extent of ice lensing that can occur in a clay soil is illustrated in Figure 13.2.

Where restraint in the form of a building is present, heaving pressures develop that may or may not be able to overcome the restraint. Heaving pressures may be very high, depending upon the restraint offered by the surrounding structure and soil; values equivalent to 1800 kPa were measured on a 300 mm diameter plate (Penner and Gold, 1971).

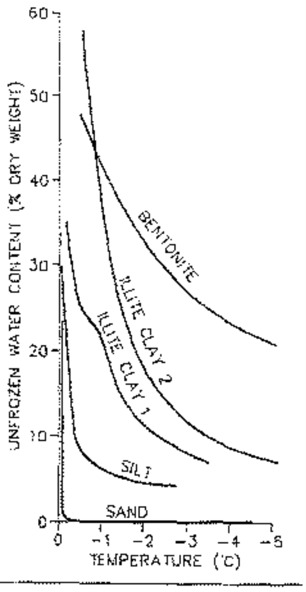


FIGURE 13.1 *Unfrozen water content for a range of frozen soils (after Williams and Smith, 1989)*

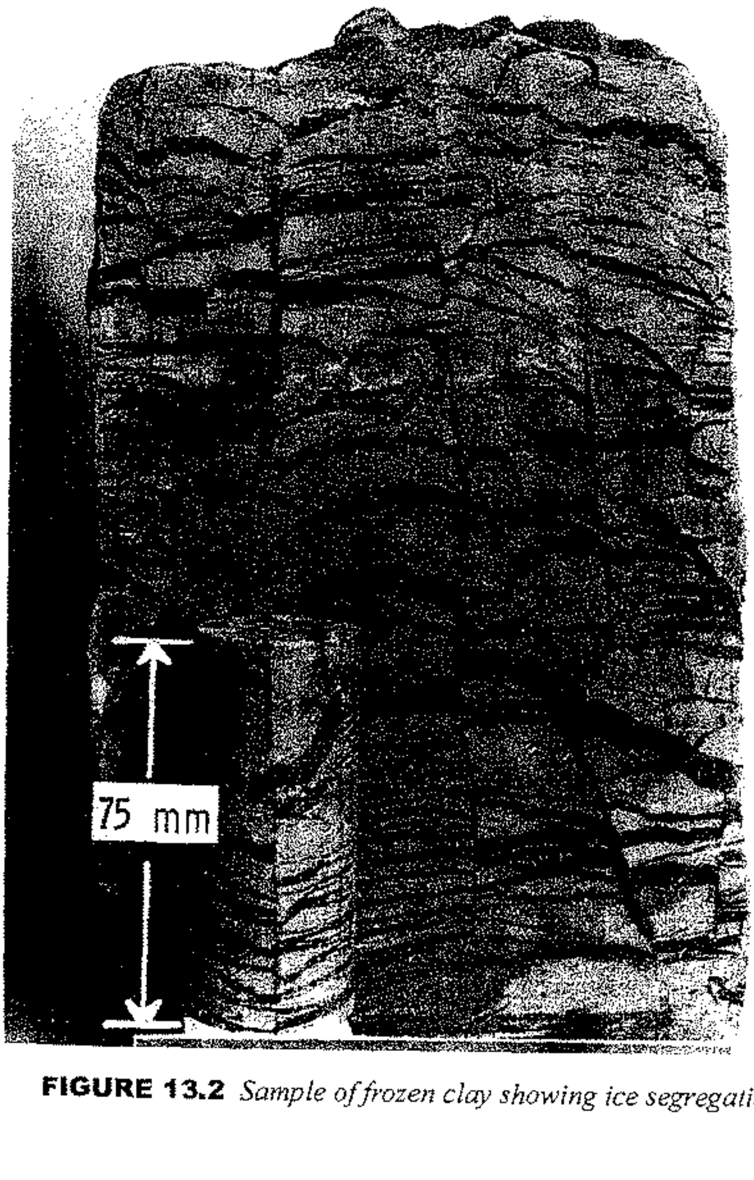


FIGURE 13.2 *Sample of frozen clay showing ice segregation*

The rate of heaving in a frost susceptible soil is limited by the rate of heat extraction from the freezing fringe where water is migrating to feed growing ice lenses. This complex heat and moisture flow phenomenon is normally uncoupled to simplify engineering predictions. Penetration of the freezing isotherm with time and temperature is predicted first by ground thermal analyses without consideration to the impact of moisture redistribution and ice lensing. The predicted extent of frost penetration and knowledge of the thermal gradients that exist within the frozen soil are then used as inputs for prediction of heave magnitudes due to ice segregation.

Engineering methods for predicting ground thermal conditions and frost heave have evolved significantly in the past decade such that practical solution techniques are now available. The remainder of this chapter summarizes current practice in this evolving field together with some practical considerations for mitigating frost heave damage.

13.3 Prediction of Frost Heave Rate

13.3.1 Ice Segregation Models

Several hydrodynamic models have been developed to express the coupled heat and moisture flow that cause frost heave. These models have been reviewed by Nixon (1987, 1991) to evaluate their applicability for practical engineering predictions.

Ice lenses grow within the frozen fringe where the temperature is less than 0°C (Miller, 1978). The temperature of the growing ice lens is related to the overburden pressure (Konrad & Morgenstern, 1982). Ice also forms in the larger pores between the active ice lens and the 0°C isotherm, requiring water to flow through the fringe of partially frozen soil to feed the growing lens. The rate of lens growth is dependent upon the finite hydraulic conductivity of the partially frozen fringe and the rate of heat extraction at the ice lens. All hydrodynamic models therefore relate the velocity of water through the freezing fringe to the temperature gradient, and to the permeability of the partially frozen soil. The heave rate can be computed from the rate of change of the velocity of water in the frozen soil.

A practical method for predicting frost heave magnitude for geotechnical engineering applications was developed by Konrad and Morgenstern (1980). Their semi-empirical formulation does not rely on measurement of the permeability of frozen soils or other physical parameters that characterize the movement of water through the freezing fringe. They relate the water velocity directly to the thermal gradient in the frozen soil. The constant of proportionality is termed the segregation potential (SP). The SP parameter is dependent upon overburden pressure but is considered to be independent of the rate of cooling in the freezing fringe at low cooling rates. The SP parameter must be determined from a series of step temperature freezing tests carried out at various overburden pressures. The tests must reasonably simulate the freezing rates or thermal gradients expected in the field.

The heave rate *(dh/dt)* under field conditions can be predicted from:

$$dh/dt = SP\ G_f + 0.09\ n\ dX/dt \qquad (13.1)$$

where

- SP is the segregation potential determined from freezing tests
- G_f is the thermal gradient in the frozen soil at the freezing fringe, determined from geothermal simulations
- dX/dt is the rate of advance of the frost front determined from geothermal simulations,
- n is the soil porosity reduced to account for the percentage of in-situ porewater that remains frozen within the anticipated range of ground temperatures.

A summary of published data relating the SP parameter to overburden pressure for various soils was presented by Nixon (1987), and is shown in Figure 13.3.

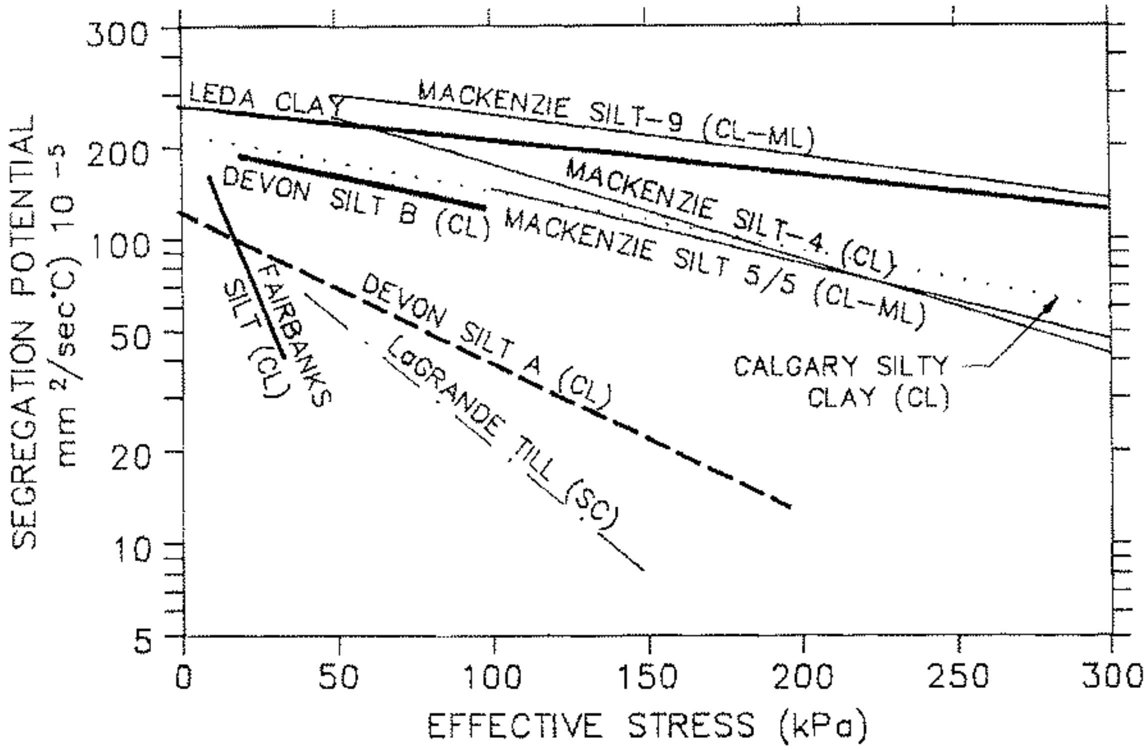


FIGURE 13.3 *Published segregation potential (SP) parameter data (after Nixon, 1987)*

13.3.2 Frost Susceptibility

Frost susceptibility of soils refers to the propensity of the soil to grow ice lenses and heave during freezing. At present, there are no precise criteria for classifying soils according to their frost susceptibility. A common guideline, developed by Casagrande (1932) based on observation and experience, relates frost susceptibility of soils to the percentage of fine fraction less than 0.02 mm.

The Casagrande guide has been extended by the U.S. Corps of Engineers to a widely used classification system, shown in Table 13.1. Soils are listed in four categories, F1 to F4, in approximate increasing order of frost susceptibility and loss of strength during thaw.

Where frost susceptibility and heave are critical parameters in foundation design, laboratory frost heave testing should be carried out. There are no current standards for heave tests; thus, it is important to develop a test program that meets the requirements of the project. This may range from simple confirmation of frost susceptibility and heave rate to determination of specific parameters such as segregation potential (SP) that can be used in a frost heave prediction model.

Frost heave tests are carried out in an insulated freezing cell where precise control can be maintained over temperatures. A sub-zero temperature is applied to the upper or lower sample cap. The other end of the sample may be uncontrolled, insulated or maintained at some positive temperature. The end temperatures might be controlled either as a step temperature change or a time-dependant "ramped" temperature change. The ramped temperature change is chosen if a near-constant freezing rate is desired. The volume of free water drawn into the sample at the unfrozen end cap is measured with time and related to the volumetric increase or sample heave rate. An interpretation of frost heave test data in terms of segregation potential is described by Konrad and Morgenstern (1981).

TABLE 13.1 *U.S. Corps of Engineers Frost Design Soil Classification*

Frost Group	Soil Type	Percentage finer than 0.02 mm, by weight	Typical soil types Under Unified Soil Classification System
F1	Gravelly soils	3 to 10	GW, GP, GW-GM, GP-GM
F2	a) Gravelly soils	10 to 20	GM, GW-GM, GP-GM
	b) Sands	3 to 15	SW, SP, SM, SW-SM, SP-SM
F3	a) Gravelly soils	>20	GM, GC
	b) Sands, except very fine silty sands	>15	SM, SC
	c) Clays, PI >12	--	CL, CH
F4	a) All silts	--	ML, MH
	b) Very fine silty sands	>15	SM
	c) Clays, PI <12	--	CL, CL-ML
	d) Varved clays and other fined-grained, banded sediments	--	CL and ML; CL, ML, and SM; Cl, CH, and ML; CL, CH, ML, and SM

13.3.3 SP from Soil Index Properties

A comprehensive study conducted by Konrad (1999) established that the segregation potential parameter (SP) of saturated fine-grained soils can be adequately related to a few basic soil index properties. For a soil freezing under zero applied overburden pressure, a reference value of the segregation potential, SP_0, is best empirically related to the mean grain size of the fines fraction (<0.075 mm), $d_{50}(FF)$, the specific surface area of the fines fraction, S_s, and the ratio of water content to the liquid limit, w/w_L as illustrated by Figure 13.4. For a ratio w/w_L close to 0.7, the empirical relationship for clayey silts is:

$$SP_0 . S_s = [116 - 75 \log d_{50}(FF)] . 10^3 \text{ mm}^4/(°\text{C.s.g}) \qquad (13.2)$$

where $d_{50}(FF)$ is expressed in μm.

In well-graded soils or gap-graded soils, SP is directly proportional to the relative fines content, i.e. the ratio of actual fines and the amount of fines needed to fill all the pore space between the coarser-grained particles. Details on a complete frost-susceptibility assessment methodology is given in Konrad (1999).

Frost susceptibility assessment was recently extended to non-clay soils such as tills and crushed rock by Konrad (2005).

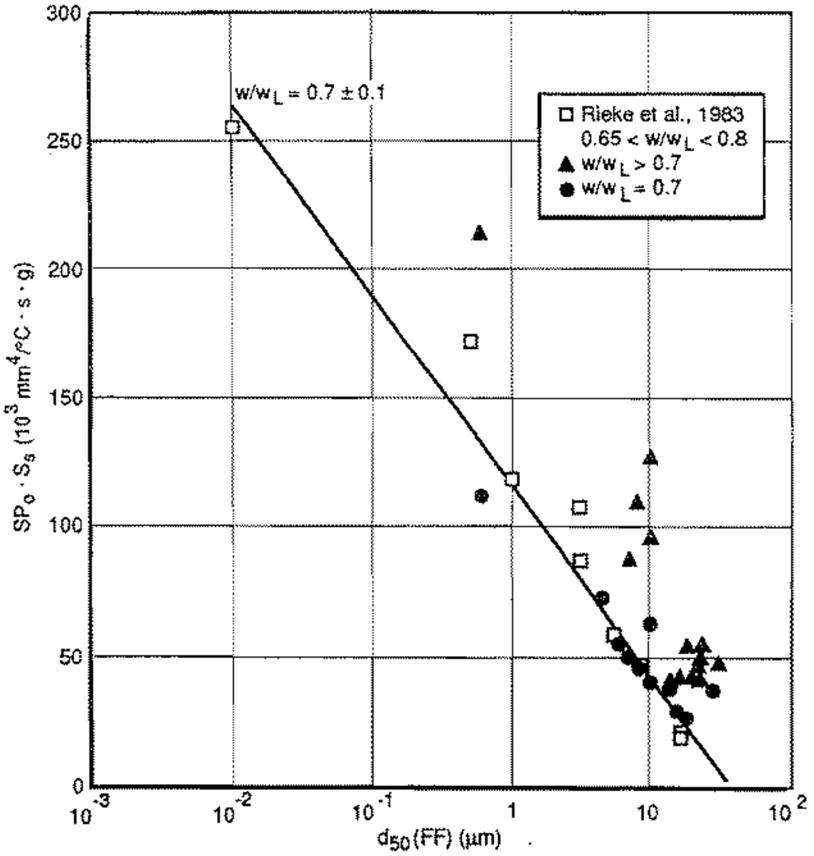


FIGURE 13.4 *Frost susceptibility assessment was recently extended to non-clay soils such as tills and crushed rock by Konrad (2005)*

13.4 Frost Penetration Prediction

13.4.1 Ground Thermal Analyses

The dominant mechanism of heat transfer in soils is thermal conduction. Heat flow in the ground follows Fourier's Law of conduction with a term to account for the release or absorption of latent heat of water during phase change. Heat transfer by mechanisms other than conduction may only be a factor in porous soils where groundwater flow is occurring. Water velocities generally must exceed 10^{-4} cm/s before convective heat flow starts to become significant.

Analytical methods, or closed-form mathematical solutions of the well-known Laplace equation, can provide an approximation of seasonal frost penetration for simple conditions. Prediction of transient ground temperature changes for problems with complex stratigraphy and variable boundary conditions requires solution by numerical methods. Numerical models in common use are either finite difference or finite element solutions. A comprehensive review of numerical methods for ground thermal regime calculations has been provided by Goodrich (1982). Two numerical models in common use in Canada are described by Nixon (1983) and by Hwang (1976).

Numerical methods are required for geotechnical design calculations other than simple prediction of the maximum depth of frost penetration. The usual range of problems involves layered systems, temperature-dependent thermal properties, and time-dependent boundary conditions such as ground surface heat exchange. A realistic simulation of the temperature-dependent liberation or absorption of latent heat during freezing or thawing, associated with the changes in unfrozen water content shown in Figure 13.1, is also an essential feature in any numerical simulation.

Numerical methods are very flexible and can reasonably simulate geotechnical complexities in either one or two dimensions. However, they require familiarity with an appropriate computer program and experience deriving input parameters. The results are normally expressed as temperature isotherms on a two-dimensional plot for various times of interest to the designer. The results can also be expressed as a propagation of the freezing isotherm with time or as a transient thermal gradient which may be input to a subsequent prediction of frost heave in an uncoupled analysis of heat and moisture flow.

13.4.2 Simplified Solutions for Maximum Frost Penetration Neglecting Frost Heave

Frost penetration is proportional to the square root of time for a step change in ground surface temperature. The most useful form of the relationship is the modified Berggren equation as described by Aldrich (1956), Sanger (1963) and Johnston (1981), and shown as Equation 13.3:

$$X = \lambda\sqrt{\frac{2k_f I_s}{L_s}} \tag{13.3}$$

where

- X = depth of frost penetration
- I_s = surface freezing index which can be estimated from the air freezine index times a ground surface interface factor "n"
- k_f = Thermal conductivity of the frozen soil
- L_s = Volumetric latent heat of the soil
- λ = A dimensionless coefficient (Figure 13.8)

The surface freezing index expresses the average negative surface temperature and the time over which it applies. The empirical n-factor can be used to determine surface freezing index from the air-freezing index. Published n-factors for various types of surfaces are shown in Table 13.2. The air-freezing index is a summation of the daily mean degree-days for the freezing period. A long-term mean (30 year) air freezing index can be estimated from monthly mean air temperature data published by Environment Canada. Typical variation in air freezing index within Canada is shown in Figure 13.5.

TABLE 13.2 *Values of n-Factors for Different Surfaces (from Johnston, 1981)*

Surface type	Freezing-n
Spruce trees, brush, moss over peat - soil surface	0.29 (under snow)
As above with trees cleared – soil surface	0.25 (under snow)
Turf	0.5 (under snow)
Snow	1.0
Gravel (most probable range)	0.6 – 1.0 (0.9 – 0.95)
Asphalt pavement	0.29 – 1.0 or greater
(most probable range)	(0.9 – 0.95)
Concrete pavement	0.25 – 0.95
(most probable range)	(0.7 – 0.9)

Winter air temperatures vary substantially from year to year everywhere in Canada. Therefore, it is seldom appropriate to use the long-term mean air-freezing index for design purposes.

Common practice is to choose some return period or recurrence interval and to estimate the most severe winter likely to occur within that period. The US Corps of Engineers method, as described by Linell et al. (1963), is to use either the most severe winter of the previous ten years or the average of the three most severe winters in the previous 30 years.

A simple relationship between design freezing index, taken as the coldest winter over the last 10-year period, and mean freezing index was developed by Horn (1987) by curve fitting data for 20 cities across Canada. The relationship is given as:

$$I_d = 100 + 1.29\, I_m \qquad (13.4)$$

where

I_d = Design Freezing Index (°C-days)
I_m = Mean Freezing Index (°C-days)

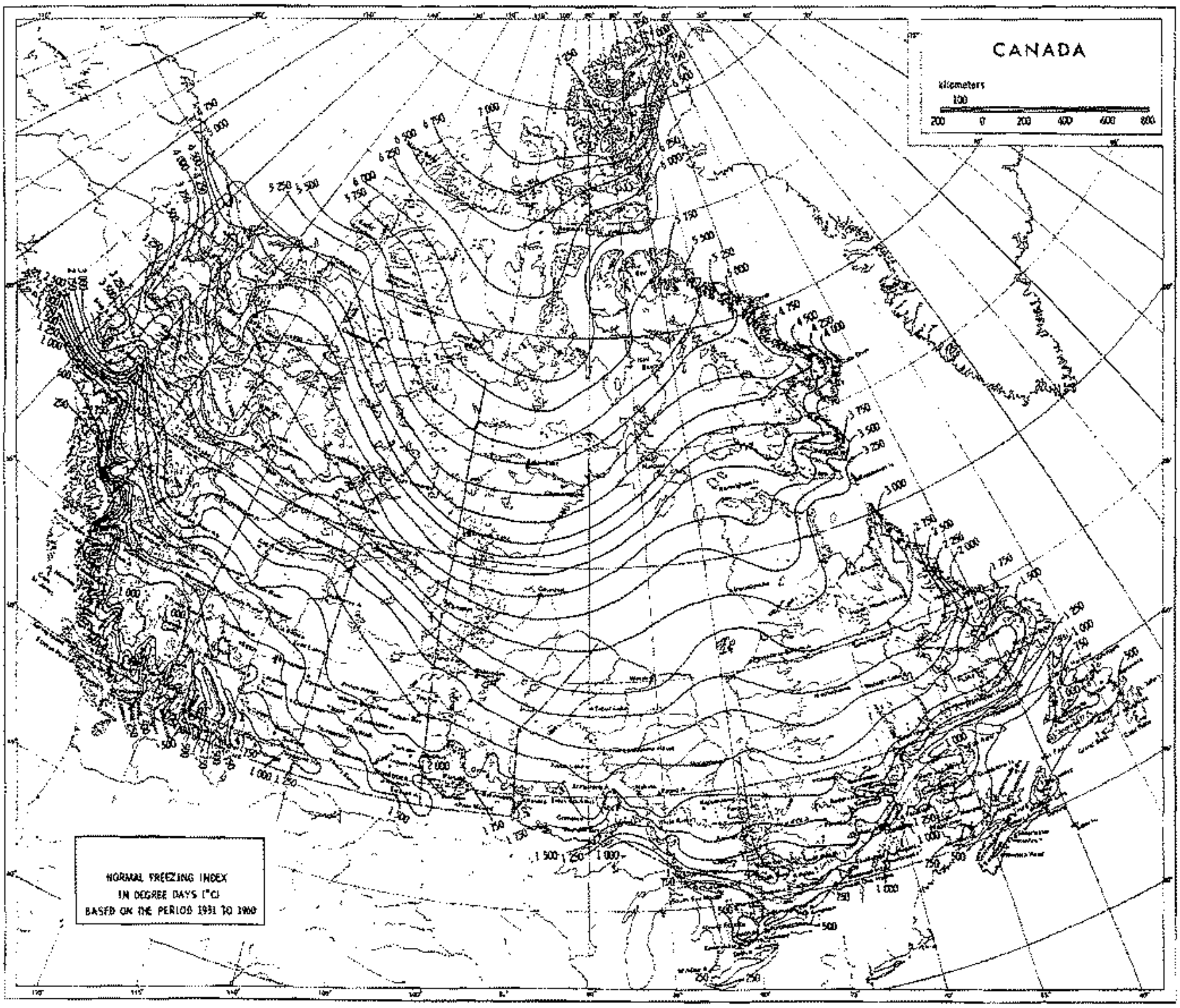


FIGURE 13.6 *Thermal conductivity of frozen coarse-grained soil (after Kersten, 1949)*

This relationship is recommended for the design air freezing index in the absence of an in-depth evaluation of historical climate data. The surface freezing index for the modified Berggren equation then becomes:

$$I_s = n\, I_d \tag{13.5}$$

The thermal conductivity of soil can be estimated from relationships to soil index properties. The relationships developed by Kersten (1949) for frozen coarse and fine-grained soils are shown in Figures 13.6 and 13.7, respectively. Frost penetration depths based on Kersten's relationships for coarse-grained soils may under predict frost depth significantly for unsaturated soils.

The thermal conductivity of coarse-grained soils is also dependent on soil mineralogy. The thermal conductivity of quartz is about four times that of other common soil minerals. The Kersten correlation is only appropriate for sands that have neither a very low nor a very high fraction of quartz particles. A more thorough treatment of soil thermal properties and their variability with index properties and soil constituents has been provided by Farouki (1986). A generalized thermal conductivity model for soils and construction materials is also provided by Côté and Konrad (2005).

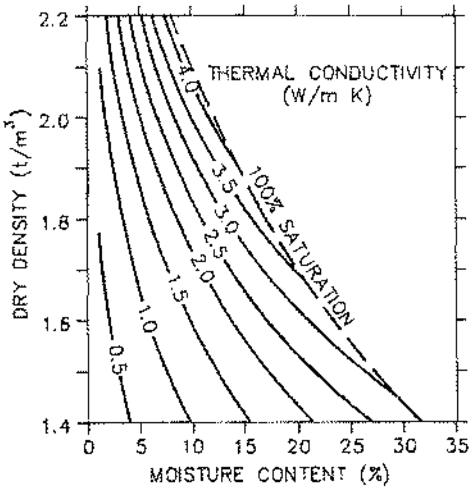


FIGURE 13.6 *Thermal conductivity of frozen coarse-grained soil (after Kersten, 1949)*

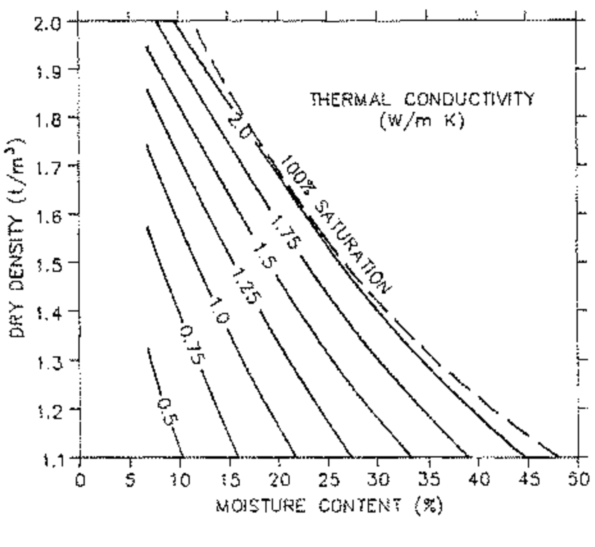


FIGURE 13.7 *Thermal conductivity of frozen fine grained soil (after Kersten, 1949)*

The volumetric latent heat term of the soil (L_s) can be estimated from the relationship:

$$L_s = \gamma_d \, w \, L \tag{13.6}$$

where

γ_d Is the dry unit weight of the soil
w Is the gravimetric water content of the soil expressed as a fraction
L Is the latent heat of fusion of water to ice which can be taken as 334 kJ/kg.

The above relationship for latent heat of the soil, when used in the modified Berggren equation, assumes that all of the water in the soil freezes at 0°C. This will result in under prediction of the freezing depth in fine-grained soils which freeze over a range of temperature, as described in Section 13.2. Alternatively, the volumetric latent heat term can be corrected to account for unfrozen water using the relationships of Figure 13.1 if an average frozen soil temperature can be estimated.

Lambda (λ) is a dimensionless coefficient that is a function of the temperature gradient, the volumetric latent heat of the soil and the volumetric heat capacity of the soil. The coefficient can be determined from a relationship developed by Sanger (1963) shown in Figure 13.8. The dimensionless parameters thermal ratio (β) and fusion parameter (μ) can be determined from:

$$\beta = \frac{MAAT \quad t}{I_S} \quad \text{and} \quad \mu = \frac{CI_S}{Lt}$$

where

$MAAT$ Is the mean annual air temperature (°C) for the site determined from Canadian Climate Normals
t Is the duration of the freezing period (days)
I_s Is the ground surface freezing index (°C-days)
C Is the volumetric heat capacity of the frozen soil

$$C = \gamma_d (C_s + C_i w) \tag{13.7}$$

where

C_s Is the specific heat of dry soil which can be taken as 0.71 kJ/kg °C
C_i Is the specific heat of ice which can be taken as 2.1 kJ/kg °C
w Is the gravimetric water content of the soil

For many practical field freezing situations, λ is close to unity. Omitting it from the freezing equation results in a slight over prediction of frost depth.

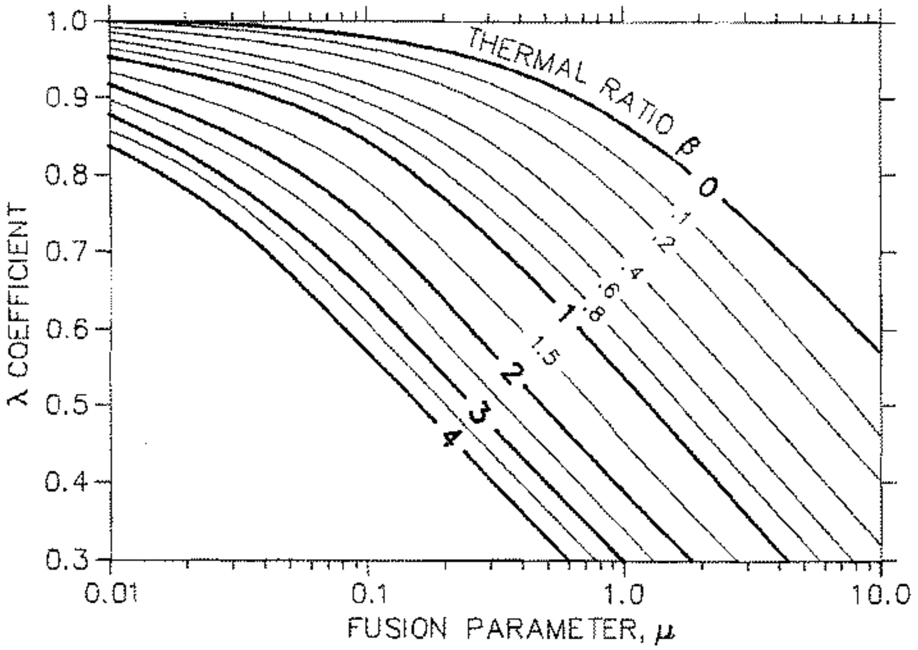


FIGURE 13.8 *Lambda (λ) coefficient for modified Berggren equation (after Sanger, 1963)*

13.4.3 Frost Susceptible Soils

While frost depth in non-frost susceptible soils is readily estimated with the modified Berggren equation, the calculation of frost depth in frost susceptible soils must account for the release of latent heat associated with the formation of ice lenses.

An extension to Stefan's approach yields enough accuracy for practical considerations. Using the segregation potential to quantify the rate of ice formation with Stefan's assumptions gives the modified Stefan equation (Konrad, 2000):

$$X = \sqrt{\frac{2(k_f - SP.L)I_s}{L_s}} \tag{13.8}$$

where

- SP Is the value of the segregation potential in m²/s.°C
- L Is the volumetric latent heat of water, i.e. 334 MJ/m³
- L_s Is the latent heat of soil (Equation 13.6)
- k_f Is the thermal conductivity of the frozen soil from Kersten's relationship given in Figures 13.6 and 13.7
- I_s Is the ground surface freezing index (°C - days)

13.5 Frost Action and Foundations

The conventional approach for protection of building foundations against frost action is to locate shallow foundations at a depth greater than the design depth of frost penetration. The modified Berggren equation, described in Section 13.4.2, may be used to determine the design depth of frost penetration. This procedure can be used to establish the minimum depth of soil cover over an exterior footing. The depth of perimeter foundation walls for heated structures may be reduced somewhat to account for heat loss from the building. Alternatively, foundation depth for protection against frost action may be specified in local building codes or is frequently determined by local

Precipitation (mm)

▼ Normals Data

The minimum number of years used to calculate these Normals is indicated by a code for each element. A "+" beside an extreme date indicates that this date is the first occurrence of the extreme value. Values and dates in bold indicate all-time extremes for the location.

Data used in the calculation of these Normals may be subject to further quality assurance checks. This may result in minor changes to some values presented here.

SPRINGBANK A
ALBERTA

Latitude:	51°06'11.000" N
Longitude:	114°22'28.000" W
Elevation:	1,200.90 m
Climate ID:	303F0PP
WMO ID:	71860
TC ID:	YBW

▼ Temperature

Temperature

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	Code
Daily Average (°C)	-8.2	-6.7	-2.7	3.4	8.1	12.1	14.8	13.7	9.5	3.9	-3.8	-7.0	3.1	C
Standard Deviation	4.2	3.5	3.7	1.5	1.5	1.0	1.6	1.4	1.5	1.6	3.7	4.0	1.0	C
Daily Maximum (°C)	-1.8	-0.0	3.9	10.5	15.3	18.8	22.2	21.2	17.0	11.0	2.3	-0.6	10.0	C
Daily Minimum (°C)	-14.5	-13.4	-9.2	-3.8	0.9	5.4	7.4	6.2	1.9	-3.3	-9.9	-13.3	-3.8	C
Extreme Maximum (°C)	16.5	22.1	23.8	26.5	33.0	31.0	**33.8**	32.1	30.6	27.1	20.4	17.9		
Date (yyyy/dd)	2003/07	1992/27	2004/30	1987/28	1986/30	1986/01	**2002/13**	2003/01	1998/07	1991/11	1999/07	1988/01		

Days with Temperature

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	Code
Extreme Minimum (°C)	**-42.8**	-41.6	-36.3	-21.7	-14.1	-6.1	-0.1	-5.9	-9.8	-29.1	-36.5	-41.6		
Date (yyyy/dd)	**1997/ 25**	1989/ 03	1989/ 01	2002/ 02	2002/ 08	2000/ 19	2002/ 02	1992/ 25	2000/ 23	1991/ 28	1996/ 21	1996/ 29		

▶ Precipitation

▼ Days with Maximum Temperature

Days with Maximum Temperature

t, duration of freezing period.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	Code
<= 0 °C	14.5	12.3	8.5	2.2	0.33	0	0	0	0.05	1.9	9.8	14.4	64	C
> 0 °C	16.5	15.9	22.6	27.8	30.7	30	31	31	30	29.1	20.2	16.6	301.3	C
> 10 °C	1.6	2.9	7.2	16.8	25.7	29.1	30.9	30	25.6	17.9	4.5	1.9	193.9	C
> 20 °C	0	0.09	0.09	1.6	7	12	21.2	19	10.5	3	0.04	0	74.3	C
> 30 °C	0	0	0	0	0	0.09	1.2	0.70	0.05	0	0	0	2.1	C
> 35 °C	0	0	0	0	0	0	0	0	0	0	0	0	0	C

▶ Days with Minimum Temperature

▶ Days with Rainfall

▶ Days With Snowfall

▶ Days with Precipitation

▶ Days with Snow Depth

▶ Wind

▼ Degree Days

Degree Days

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	Code
Above 24 °C	0	0	0	0	0	0	0	0	0	0	0	0	0	C
Above 18 °C	0	0	0	0	0	0.9	7.8	2.6	0	0	0	0	11.3	C
Above 15 °C	0	0	0	0	1.7	9.1	34.9	22.8	3.1	0.4	0	0	72.1	C

Degree Days

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	Code
Above 10 °C	0	0.1	0.2	2.9	25.7	75	151.1	121.5	41.9	7	0	0	425.4	C
Above 5 °C	0.8	2.8	6.6	31.4	112.6	212.8	303.9	268.7	142.4	46.9	5.3	1	1,135	C
Above 0 °C	13	18.3	47.6	119.6	251	362.8	458.8	423.1	284	145	33	14.5	2170.8	C
Below 0 °C	274.4	213.1	125.5	23.5	2.4	0	0	0	0.4	24.3	147.6	235.8	1046.9	C
Below 5 °C	417.1	338.6	239.4	85.3	19	0	0.1	0.6	8.8	81.2	269.9	377.3	1837.2	C
Below 10 °C	571.3	477.1	388.1	206.9	87.1	12.2	2.3	8.4	58.3	196.3	414.6	531.3	2953.8	C
Below 15 °C	726.3	618.2	542.9	354	218.1	96.3	41.1	64.7	169.5	344.7	564.6	686.3	4426.5	C
Below 18 °C	819.3	702.8	635.9	444	309.4	178.1	106.9	137.4	256.4	437.3	654.6	779.3	5461.4	C

I average ground surface freezing index

▶ Humidex

▶ Wind Chill

▶ Humidity

▶ Frost-Free

Legend

- A = WMO "3 and 5 rule" (i.e. no more than 3 consecutive and no more than 5 total missing for **either** temperature **or** precipitation)
- B = At least 25 years
- C = At least 20 years
- D = At least 15 years

▼ Station / Element Metadata

Statistics listed below are provided as a guide to determine the validity of Normals and Extremes calculations. For example, a station with 30 years of record between 1981 and 2010 with no missing years would be a more reliable normal than a station with 15 years of record and 2 missing years. Less than 100% possible observations indicates that out of the total number of observations used, some records were missing.

SPRINGBANK A

Province	AB
Latitude (dd mm):	51 06 N
Country	CAN

Blank Page

65. Calculation models for settlement analyses are given in the CFEM.[1] It is important to keep in mind that differential settlement of isolated footings will always occur because of the natural variability of soils.

66. In situations where calculation models are not available or are considered to be unnecessary, limit states may be avoided by the use of prescriptive measures. Prescriptive measures may be used, for example, to ensure durability against frost action and chemical or biological attack. These measures involve conventional and generally conservative details in the design, and attention to specification and control of materials, workmanship, protection and maintenance procedures.

Frost Penetration

67. The best assessment of frost penetration in a particular locality is local experience. In the absence of local experience, however, daily air temperature measurements can be used to estimate the combined effects of both depth and duration of freezing. The cumulative total of the difference between daily mean air temperatures and the freezing point is known as the "Freezing Index," which is expressed in Celsius degree-days. Freezing index values for a large number of weather stations in Canada are available from Environment Canada at www.climate.services@ec.gc.ca. Figure K-4 shows the average freezing index for regions of Canada for the period 1978-2007 and Figure K-5 shows the 50-year-return-period freezing index for regions of Canada for the period 1958-2007. The contour lines in Figure K-5 were estimated by fitting the 2-parameter Weibull distribution to the annual average freezing index values for each location (see the example in Reference [26]). Information on how the "Freezing Index" can be used to estimate depth of frost penetration is given in CFEM[1] and References [27] to [30].

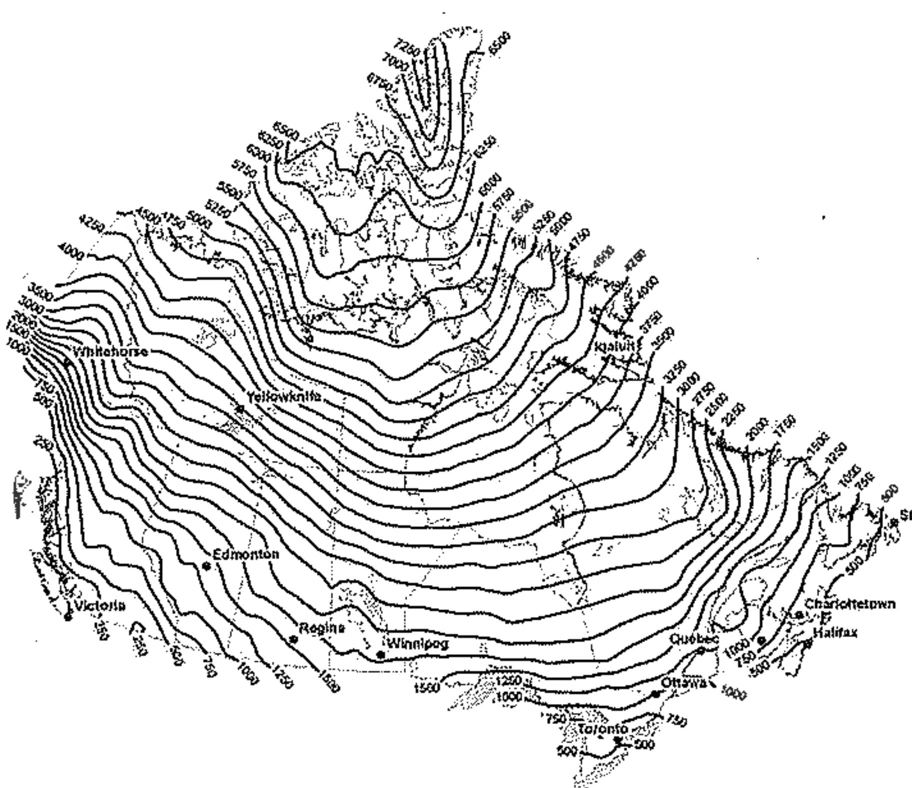


Figure K-4
Annual average freezing index (C degree-days) based on the period 1978-2007

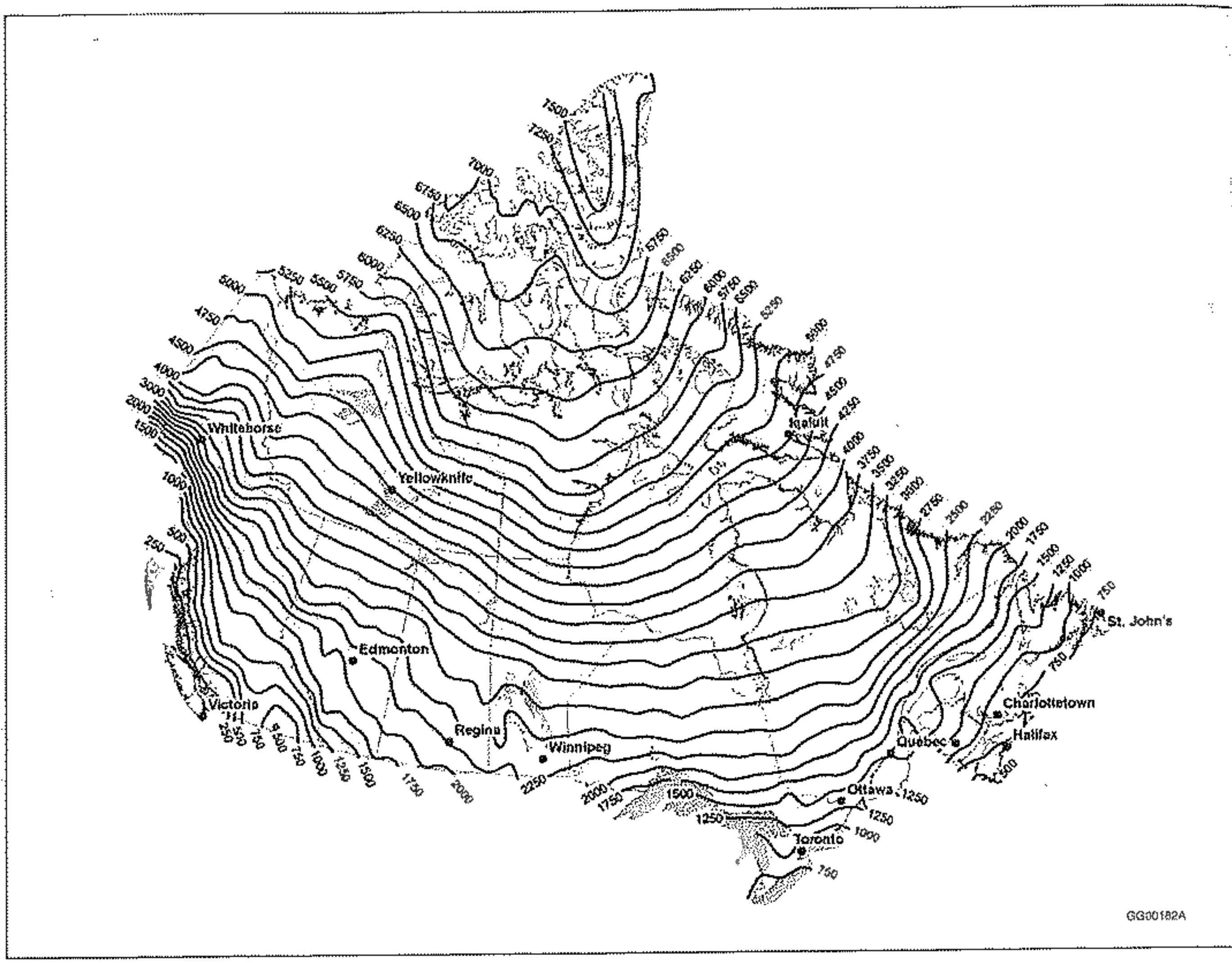


Figure K-5
50-year-return-period freezing index (C degree-days) based on the period 1958-2007

Insulated Shallow Foundations

68. Lightweight plastic insulation has been used to reduce the loss of ground heat and thereby reduce the depth of frost penetration. Insulation should be used for this purpose only after careful examination of the pertinent conditions and with a thorough understanding of its effect on the temperature at the soil-foundation interface.[30] Insulation is of particular benefit in the design of unheated buildings such as warehouses, garages and refrigerated buildings. It is also used to restrict the depth of frost penetration beneath artificial ice surfaces.

69. Insulation with relatively high compressive strengths can be obtained, so that slabs of these materials can be placed directly below the bearing surfaces of foundations. Substantial economic advantages may accrue where such designs are used, because foundations can be located closer to the ground surface, thereby reducing the costs of providing granular fill to replace frost-susceptible soil.[30] Design guidance is also given in the CFEM.[1]

Deep Foundations

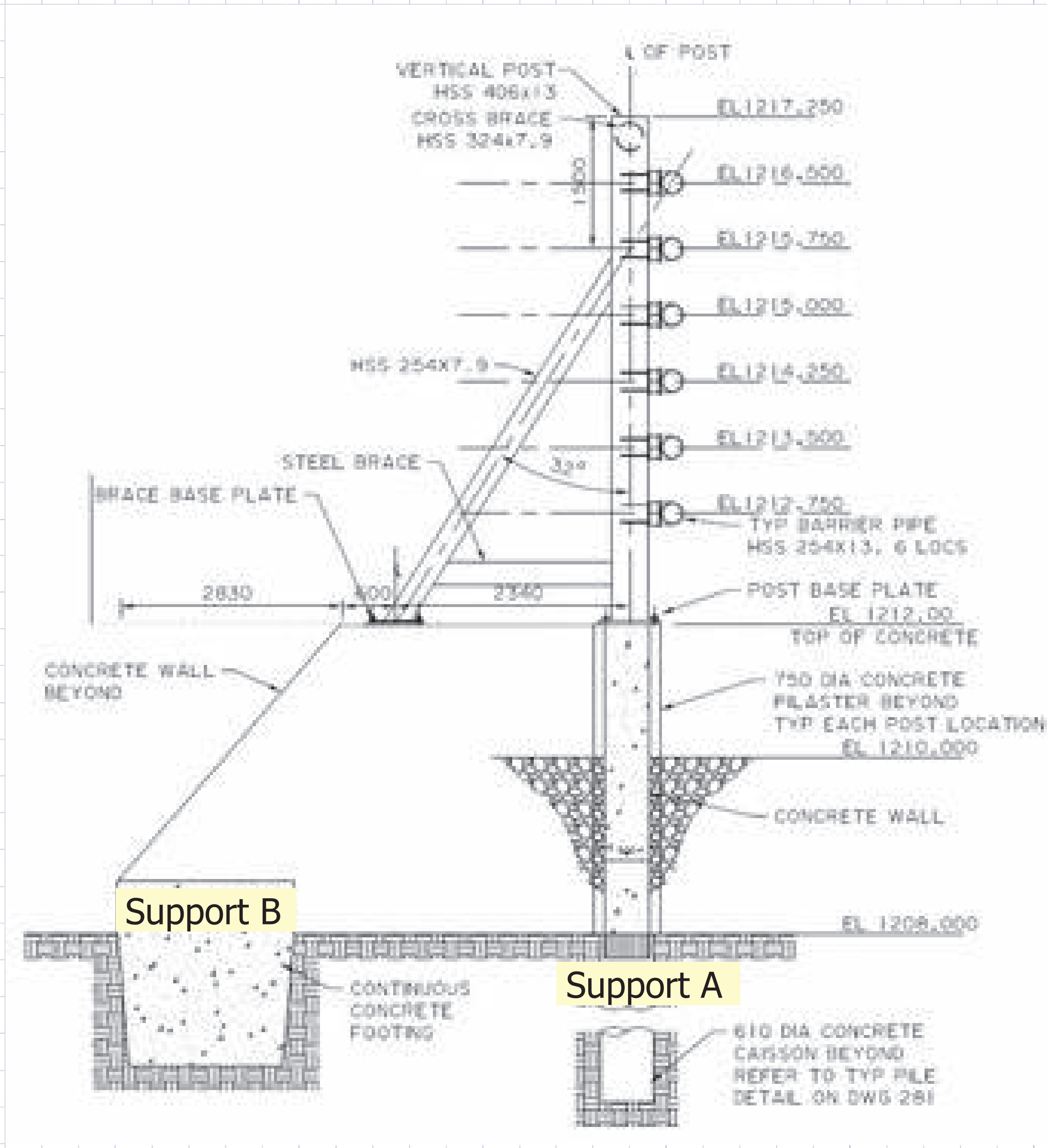
General

70. A deep foundation is a foundation unit that provides support for a building by transferring loads either by end-bearing to a soil or rock at considerable depth below the building, or by adhesion or

Attachment 10.4 Debris Barrier Foundation Design Calculations

ATTACHMENT 10.4.1: SUPPORT A FOUNDATION CALCULATIONS

Diagram of Debris Barrier Support at Section D:



References:
1. Canadian Bridge Design Code (CHBDC, 2014)
2. FHWA-HIF-18-024, Federal Highway Administration, Sections 8 and 10. (FHWA, 2018)
3. Stantec Geotechnical Interpretive Report (Stantec, 2017)
4. Principles of Foundation Engineering, Braja Das, (Das, 2011)

Elevation difference from Base Plate to Bedrock at Section D: $\Delta elev := 4\ m$

Gravity Constant: $g = 9.81\ \frac{m}{s^2}$

Assumed Unit Weight of Concrete: $W_c := 2400\ \frac{kg}{m^3} \cdot g = 23.54\ \frac{kN}{m^3}$

Support B Factored Loads At Bedrock (Provided by Structural Team):

Factored Loads* at Bedrock of Support A and Support B:

Stantec
DEBRIS BARRIER OPTION 3
Oct 23, 2019

SUPPORT A:

	P_1 (kN)	H_1 (kN)	M_1 (kNm)	LOAD CASE
CASE ①	66	1361	0	UN1
CASE ②	111	843	0	UN2

SUPPORT B:

	P_2 (kN)	H_2 (kN)		LOAD CASE
CASE ①	260	1110 ↓	16	UN2
CASE ②	130	532 ↓	30	UN1

These loads are from the superstructure only and do not include concrete weight(s)

Forces for Case 1 (Load Case UN1):

Vertical Load from Superstructure on Support A: $H_{1\_UN1} := 1361\ kN$

Horizontal Load from Superstructure on Support A: $P_{1\_UN1} := 66\ kN$

Moment from Superstructure on Support A: $M_{1\_UN1} := 0\ kN \cdot m$

Forces for Case 2 (Load Case UN2):

Vertical Load from Superstructure on Support A: $H_{1\_UN2} := 843\ kN$

Horizontal Load from Superstructure on Support A: $P_{1\_UN2} := 111\ kN$

Moment from Superstructure on Support A: $M_{1\_UN2} := 0\ kN \cdot m$

Axial (Vertical) Force At Bedrock for Support A:

Bearing Capacity Analyses:

Pile Parameters

Length of Pile below Bedrock: $L_{Pile} := \begin{bmatrix} 2 \\ 4 \\ 6 \\ 8 \\ 10 \end{bmatrix} m$

Pile Diameter $B := 24\ in = 609.6\ mm$

Area of Pile: $A_p := \frac{B^2 \cdot \pi}{4} = 0.292\ m^2$

Perimeter of pile: $p := B \cdot \pi = 1.92\ m$

Assumed depth of innefective bedrock: $D_{ineffective} := 1\ B = 0.61\ m$

References:
1. Canadian Bridge Design Code (CHBDC, 2014)
2. FHWA-HIF-18-024, Federal Highway Administration, Sections 8 and 10. (FHWA, 2018)
3. Stantec Geotechnical Interpretive Report (Stantec, 2017)
4. Principles of Foundation Engineering, Braja Das, (Das, 2011)

Material/Subsurface Parameters

Assumed pile head elevation: $Pile_{elv.} := 1208.00\ m$

Table 6.2 (Concluded)

Application	Limit state	Test Method/Model	Degree of understanding Low	Typical	High
Deep foundations	Compression, ϕ_{gu}	Static analysis	0.35	0.40	0.45
		Static test	0.50	0.60	0.70
		Dynamic analysis	0.35	0.40	0.45
		Dynamic test	0.45	0.50	0.55
	Tension, ϕ_{gu}	Static analysis	0.20	0.30	0.40
		Static test	0.40	0.50	0.60

Assumed compression resistance factor for bedrock from Table 6.2 (CHBDC, 2014): $\phi_{gu} := 0.4$

Table 2. SR1 Diversion Structure – Cross Bed Shear Strength Parameters

Boring	Percent Bedrock Type Below Bearing	Typical Unconfined Compressive Strength MPa (psi)	Hoek-Brown Coefficients Mi Value	GSI Value	D Value	Estimated Cross Bed Friction Angle	Estimated Cross Bed Cohesion kPa (psf)
Shale	30	20.7	6	35	0.5	35.1	124
Mudstone	40	5.5	4	30	0.5	19.8	59
Claystone	20	17.2	4	30	0.5	28.2	93
Sandstone	10	24.1	13	55	0.5	50.5	257

Geologic Strength Index for Top ~15 Meters of Mudstone: $GSI := 30$

Approximate RQD of Mudstone: $RQD := 20\%$

Atmospheric Pressure: $p_a := 0.101325\ MPa$

Assumed Unconfined Compressive Strength of Mudstone: $q_{u\_mudstone} := 5.5\ MPa$

Estimated Cross Bed Friction Angle (Weighted Average):

$$\phi'_p := 35.1\ deg \cdot 30\% + 19.8\ deg \cdot 40\% + 28.2\ deg \cdot 20\% + 50.5\ deg \cdot 10\% = 29.14\ deg$$

References:
1. Canadian Bridge Design Code (CHBDC, 2014)
2. FHWA-HIF-18-024, Federal Highway Administration, Sections 8 and 10. (FHWA, 2018)
3. Stantec Geotechnical Interpretive Report (Stantec, 2017)
4. Principles of Foundation Engineering, Braja Das, (Das, 2011)

TABLE 10-3 SIDE RESISTANCE REDUCTION FACTOR FOR CAVING ROCK

RQD (%)	Joint Modification Factor, α_E	
	Closed joints	Open or gouge-filled joints
100	1.00	0.85
70	0.85	0.55
50	0.60	0.55
30	0.50	0.50
20	0.45	0.45

Regression coefficient assuming caving rock and open or gouge-filled joints (FHWA, 2018): $\alpha_E := 0.45$

Side Friction Capacity

Unit Side Friction Based on Typical Unconfined Compressive Strength: $f_{SN\_calculated} := p_a \cdot \alpha_E \cdot \sqrt{\frac{q_{u\_mudstone}}{p_a}} = 335.93\ kPa$

Limit Side Friction to Reasonable Values for Top 10 Meters $f_{SN\_design} := 200\ kPa$

Length of Effective Bedrock: $\Delta z := L_{Pile} - D_{ineffective} = \begin{bmatrix} 1.39 \\ 3.39 \\ 5.39 \\ 7.39 \\ 9.39 \end{bmatrix} m$

Nominal Side Resistance for Bedrock: $R_{SN} := \pi \cdot B \cdot \Delta z \cdot f_{SN\_design} = \begin{bmatrix} 532.56 \\ 1298.6 \\ 2064.65 \\ 2830.69 \\ 3596.74 \end{bmatrix} kN$

Factored Side Resistance for Bedrock: $R_{SF} := R_{SN} \cdot \phi_{gu} = \begin{bmatrix} 213.02 \\ 519.44 \\ 825.86 \\ 1132.28 \\ 1438.7 \end{bmatrix} kN$

References:
1. Canadian Bridge Design Code (CHBDC, 2014)
2. FHWA-HIF-18-024, Federal Highway Administration, Sections 8 and 10. (FHWA, 2018)
3. Stantec Geotechnical Interpretive Report (Stantec, 2017)
4. Principles of Foundation Engineering, Braja Das, (Das, 2011)

End Bearing Capacity (Goodman, 1980)

Reduce design bearing capacity for end bearing due to *Scale Effect* (Das 2011, Eq. 11.65): $q_{u\_design} := \frac{q_{u\_mudstone}}{5} = 1100\ kPa$

Bearing capacity factor, N_ϕ: $N_\phi := \tan\left(45\ deg + \frac{\phi'_p}{2}\right)^2 = 2.9$

Base Resistance Capacity (Goodman, 1980): $q_{p\_Goodman} := q_{u\_design} \cdot (N_\phi + 1) = 4288.04\ kPa$

Nominal Base Resistance (Goodman, 1980): $Q_{p\_N\_Goodman} := q_{p\_Goodman} \cdot A_p = 1251.52\ kN$

Factored Base Resistance (Goodman, 1980): $Q_{p\_F\_Goodman} := Q_{p\_N\_Goodman} \cdot \phi_{gu} = 500.61\ kN$

Case 1 (Controlling) Bearing Capacity Check:

Estimated Downward Force on Support A (Not Including Foundation Weight): $H_{1\_UN1} = 1361\ kN$

Resistance vs load check for Case 1 and various shaft lengths **assuming no scour**:

$$L_{Pile} = \begin{bmatrix} 2 \\ 4 \\ 6 \\ 8 \\ 10 \end{bmatrix} m \qquad RvsL_{Goodman} := \frac{R_{SF} + Q_{p\_F\_Goodman}}{H_{1\_UN1}} = \begin{bmatrix} 0.52 \\ 0.75 \\ 0.97 \\ 1.2 \\ 1.42 \end{bmatrix}$$

Check for Uplift Capacity Against Adfreeze:

Table 36. Parameters Used for Frost Depth Calculations

Frost Depth Parameter	Value
Mean Annual Air Temperature (MAAT)	3.1 ºC
Average Annual Duration of Freezing Period	64 days
Average Ground Surface Freezing Index	1,046.9 ºC days
50 Year Return Design Freezing Index[1]	1,700 ºC days
Foundation Soil Dry Density	1,491 kg/m³
Thermal Conductivity of Fine Grained Soils (k)	95.0 KJ/day per m K
Calculated Frost Depth	1.96 m

Calculated frost depth (Stantec, 2017): $D_{frost} := 2.0\ m$

13.5.1 Adfreezing

Soil in contact with shallow foundations can freeze to the foundation, developing a substantial adfreeze bond. Backfill soil that is frost susceptible can heave and transmit uplift forces to the foundation. Spread footings normally have sufficient uplift resistance from their expanded base to resist heave, but the structural design of the wall-footing connection must be sufficient to transmit any load applied through adfreeze. Average adfreeze bond stresses, determined from field experiments, typically range from 65 kPa for fine-grained soils frozen to wood or concrete to 100 kPa for fine-grained soils frozen to steel (Penner, 1974). Design adfreeze bonds for saturated gravel frozen to steel piles can be estimated at 150 kPa (Penner and Goodrich, 1983). The most severe uplift conditions can occur where frost penetrates through frost stable gravel fill into highly frost susceptible soils surrounding a foundation. These conditions result in a heaving situation with maximum adfreeze bond stress and have been known to jack H-piles driven to depths in the order of 13 m (Hayley, 1988).

It is good practice to backfill against foundations with non-frost susceptible soil. Provision should be made for drainage around the foundation perimeter, below the maximum depth of frost penetration. The granular backfill should be capped with less permeable soil and a surface grade provided to shed runoff before it enters the backfill.

Assume adfreeze bond stress to be at lower bound of average (CFEM, 2006): $f_{n\_adfreeze} := 65\ kPa$

Design Assumption: Ratcheting of the foundation due to adfreeze will only apply to the drilled shaft (Support A).

Tributary Length of Web Walls Parallel to Stream: $L_{WebWallParallel} := 2.5\ m$

ASSUMED Length of Web Walls Perpendicular to Stream that is tributary to Support A: $L_{WebWallPerpendicular} := 2.0\ m$

Approximate area of pile and web wall tributary to Support A that is subject to adfreeze:

$$A_{frost} := \left(L_{WebWallParallel} \cdot 2 + L_{WebWallPerpendicular} \cdot 2\right) \cdot D_{frost} = 18 \ m^2$$

Calculated uplift force from adfreeze: $F_{y\_A\_adfreeze} := f_{n\_adfreeze} \cdot A_{frost} = 1170 \ kN$

Service Dead Load on Support A: $DL_A := 239.74 \ kN$

Service Dead Load on Support B: $DL_B := 101.49 \ kN$

Table 6.2 (Concluded)

Application	Limit state	Test Method/Model	Degree of understanding Low	Typical	High
Deep foundations	Compression, ϕ_{gu}	Static analysis	0.35	0.40	0.45
		Static test	0.50	0.60	0.70
		Dynamic analysis	0.35	0.40	0.45
		Dynamic test	0.45	0.50	0.55
	Tension, ϕ_{gu}	Static analysis	0.20	0.30	0.40
		Static test	0.40	0.50	0.60
	Lateral, ϕ_{gu}	Static analysis	0.45	0.50	0.55
		Static test	0.45	0.50	0.55
	Settlement or lateral deflection, ϕ_{gs}	Static analysis	0.7	0.8	0.9
		Static test	0.8	0.9	1.0

Assumed uplift resistance factor for Adfreeze from Table 6.2 (CHBDC, 2014): $\phi_{gu} := 0.4$

Resistance vs load check for adfreeze and various shaft lengths:

$$L_{Pile} = \begin{bmatrix} 2 \\ 4 \\ 6 \\ 8 \\ 10 \end{bmatrix} m \qquad RvsL := \frac{R_{SN} \cdot \phi_{gu} + DL_A}{F_{y\_A\_adfreeze}} = \begin{bmatrix} 0.39 \\ 0.65 \\ 0.91 \\ 1.17 \\ 1.43 \end{bmatrix}$$

Based on the Above Calculations, the Bearing Capacity for Foundation Lengths at or Greater than **8 Meters** and a Diameter of $B = 0.61 \ m$ are Sufficient.

References:
1. Canadian Bridge Design Code (CHBDC, 2014)
2. FHWA-HIF-18-024, Federal Highway Administration, Sections 8 and 10. (FHWA, 2018)
3. Stantec Geotechnical Interpretive Report (Stantec, 2017)
4. Principles of Foundation Engineering, Braja Das, (Das, 2011)

ATTACHMENT 10.4.2: SUPPORT A LPILE PRINTOUT

===

LPile for Windows, Version 2019-11.001

Analysis of Individual Piles and Drilled Shafts
Subjected to Lateral Loading Using the p-y Method

===

This copy of LPile is being used by:

Stantec Consulting Ltd.
Stantec Consulting Ltd.

Serial Number of Security Device: 253581973

This copy of LPile is licensed for exclusive use by:

STANTEC, Global License, Global

Use of this program by any entity other than STANTEC, Global License, Global
is a violation of the software license agreement.

Files Used for Analysis

Path to file locations:
\110773396\component_work\dams_diversion\geotechnical\analysis\Debris Barrier Foundations\Support A\

Name of input data file:
SR1 - Debris Barrier - Support A - Service - 20191028 Revision.lp11

Name of output report file:
SR1 - Debris Barrier - Support A - Service - 20191028 Revision.lp11

Name of plot output file:
SR1 - Debris Barrier - Support A - Service - 20191028 Revision.lp11

Name of runtime message file:
SR1 - Debris Barrier - Support A - Service - 20191028 Revision.lp11

Date and Time of Analysis

Date: October 28, 2019 Time: 0:47:38

Problem Title

Project Name: Springbank Off-Stream Storage Project - SR1

Job Number: 110773396

Client: Alberta Transportation

Engineer: Jordan Keeney

Description: Debris Barrier Support A Lateral Analysis

Program Options and Settings

Computational Options:
 - Use unfactored loads in computations (conventional analysis)

Engineering Units Used for Data Input and Computations:
 - International System Units (kilonewtons, meters, millimeters)

Analysis Control Options:
 - Maximum number of iterations allowed = 1000
 - Deflection tolerance for convergence = 2.5400E-07 m
 - Maximum allowable deflection = 2.5400 m
 - Number of pile increments = 100

Loading Type and Number of Cycles of Loading:
- Static loading specified

- Use of p-y modification factors for p-y curves not selected
- Analysis uses layering correction (Method of Georgiadis)
- No distributed lateral loads are entered
- Loading by lateral soil movements acting on pile not selected
- Input of shear resistance at the pile tip not selected
- Input of moment resistance at the pile tip not selected
- Computation of pile-head foundation stiffness matrix not selected
- Push-over analysis of pile not selected
- Buckling analysis of pile not selected

Output Options:
- Output files use decimal points to denote decimal symbols.
- Values of pile-head deflection, bending moment, shear force, and soil reaction are printed for full length of pile.
- Printing Increment (nodal spacing of output points) = 1
- No p-y curves to be computed and reported for user-specified depths
- Print using wide report formats

Pile Structural Properties and Geometry

Number of pile sections defined = 1
Total length of pile = 4.000 m
Depth of ground surface below top of pile = 0.6090 m

Pile diameters used for p-y curve computations are defined using 2 points.

p-y curves are computed using pile diameter values interpolated with depth over the length of the pile. A summary of values of pile diameter vs. depth follows.

Point	Depth Below Pile Head meters	Pile Diameter millimeters
1	0.000	762.00
2	4.000	762.00

Input Structural Properties for Pile Sections:

Pile Section No. 1:

```
   Section 1 is a round drilled shaft, bored pile, or CIDH pile
   Length of section                                    =     4.000000 m
   Shaft Diameter                                       =     0.762000 m
   Shear capacity of section                            =       0.0000 kN
```

Ground Slope and Pile Batter Angles

```
Ground Slope Angle                                      =        0.000 degrees
                                                        =        0.000 radians

Pile Batter Angle                                       =        0.000 degrees
                                                        =        0.000 radians
```

Soil and Rock Layering Information

The soil profile is modelled using 1 layers

Layer 1 is weak rock, p-y criteria by Reese, 1997

```
   Distance from top of pile to top of layer            =     0.609000 m
   Distance from top of pile to bottom of layer         =    15.000000 m
   Effective unit weight at top of layer                =    13.200000 kN/m3
   Effective unit weight at bottom of layer             =    13.200000 kN/m3
   Uniaxial compressive strength at top of layer        =        1500. kPa
   Uniaxial compressive strength at bottom of layer     =        1500. kPa
   Initial modulus of rock at top of layer              =      758424. kPa
   Initial modulus of rock at bottom of layer           =      758424. kPa
   RQD of rock at top of layer                          =    20.000000 %
   RQD of rock at bottom of layer                       =    20.000000 %
   k rm of rock at top of layer                         =    0.0005000
   k rm of rock at bottom of layer                      =    0.0005000
```

(Depth of the lowest soil layer extends 11.000 m below the pile tip)

Summary of Input Soil Properties

Layer Num.	Layer Name (p-y Curve Type)	Layer Depth m	Effective Unit Wt. kN/m3	Uniaxial qu kPa	RQD %	E50 or krm	Rock Mass Modulus kPa
1	Weak	0.6090	13.2000	1500.	20.0000	5.00E-04	758424.
	Rock	15.0000	13.2000	1500.	20.0000	5.00E-04	758424.

Static Loading Type

Static loading criteria were used when computing p-y curves for all analyses.

Pile-head Loading and Pile-head Fixity Conditions

Number of loads specified = 2

Load No.	Load Type	Condition 1	Condition 2	Axial Thrust Force, kN	Compute Top y vs. Pile Length
1	1	V = 45.000000 kN	M = 0.0000 m-kN	945.000000000	No
2	1	V = 73.000000 kN	M = 0.0000 m-kN	603.000000000	No

V = shear force applied normal to pile axis
M = bending moment applied to pile head
y = lateral deflection normal to pile axis
S = pile slope relative to original pile batter angle
R = rotational stiffness applied to pile head

Values of top y vs. pile lengths can be computed only for load types with specified shear loading (Load Types 1, 2, and 3).
Thrust force is assumed to be acting axially for all pile batter angles.

Computations of Nominal Moment Capacity and Nonlinear Bending Stiffness

---

Axial thrust force values were determined from pile-head loading conditions

Number of Pile Sections Analyzed = 1

Pile Section No. 1:

Dimensions and Properties of Drilled Shaft (Bored Pile):

Length of Section	=	4.000000 m
Shaft Diameter	=	0.762000 m
Concrete Cover Thickness (to edge of long. rebar)	=	0.076200 m
Number of Reinforcing Bars	=	12 bars
Yield Stress of Reinforcing Bars	=	413685. kPa
Modulus of Elasticity of Reinforcing Bars	=	199947979. kPa
Gross Area of Shaft	=	0.456037 sq. m
Total Area of Reinforcing Steel	=	0.008400 sq. m
Area Ratio of Steel Reinforcement	=	1.84 percent
Edge-to-Edge Bar Spacing	=	0.120137 m
Maximum Concrete Aggregate Size	=	0.015000 m
Ratio of Bar Spacing to Aggregate Size	=	8.01
Offset of Center of Rebar Cage from Center of Pile	=	0.0000 m

Axial Structural Capacities:

Nom. Axial Structural Capacity = 0.85 Fc Ac + Fy As	=	13968.537 kN
Tensile Load for Cracking of Concrete	=	-1477.413 kN
Nominal Axial Tensile Capacity	=	-3474.958 kN

Reinforcing Bar Dimensions and Positions Used in Computations:

Bar Number	Bar Diam. meters	Bar Area sq. m.	X meters	Y meters
1	0.029900	0.0007000	0.289850	0.00000

2	0.029900	0.0007000	0.251017	0.144925
3	0.029900	0.0007000	0.144925	0.251017
4	0.029900	0.0007000	0.00000	0.289850
5	0.029900	0.0007000	-0.144925	0.251017
6	0.029900	0.0007000	-0.251017	0.144925
7	0.029900	0.0007000	-0.289850	0.00000
8	0.029900	0.0007000	-0.251017	-0.144925
9	0.029900	0.0007000	-0.144925	-0.251017
10	0.029900	0.0007000	0.00000	-0.289850
11	0.029900	0.0007000	0.144925	-0.251017
12	0.029900	0.0007000	0.251017	-0.144925

NOTE: The positions of the above rebars were computed by LPile

Minimum spacing between any two bars not equal to zero = 120.14 millimeters between bars 7 and 8.

Ratio of bar spacing to maximum aggregate size = 8.01

Concrete Properties:

Compressive Strength of Concrete	=	27579. kPa
Modulus of Elasticity of Concrete	=	24855577. kPa
Modulus of Rupture of Concrete	=	-3270. kPa
Compression Strain at Peak Stress	=	0.001886
Tensile Strain at Fracture of Concrete	=	-0.0001154
Maximum Coarse Aggregate Size	=	0.015000 m

Number of Axial Thrust Force Values Determined from Pile-head Loadings = 2

Number	Axial Thrust Force kN
1	603.000
2	945.000

Definitions of Run Messages and Notes:

C = concrete in section has cracked in tension.
Y = stress in reinforcing steel has reached yield stress.
T = ACI 318 criteria for tension-controlled section met, tensile strain in reinforcement exceeds 0.005 while simultaneously compressive strain in

concrete more than 0.003. See ACI 318, Section 10.3.4.
Z = depth of tensile zone in concrete section is less than 10 percent of section depth.

Bending Stiffness (EI) = Computed Bending Moment / Curvature.
Position of neutral axis is measured from edge of compression side of pile.
Compressive stresses and strains are positive in sign.
Tensile stresses and strains are negative in sign.

Axial Thrust Force = 603.000 kN

Bending Curvature rad/m	Bending Moment kN-m	Bending Stiffness kN-m2	Depth to N Axis m	Max Comp Strain m/m	Max Tens Strain m/m	Max Conc Stress kPa	Max Steel Stress kPa	Run Msg
0.00004921	26.2790878	533991.	1.2191626	0.00006000	0.00002250	1721.	11209.	
0.00009843	52.5554031	533963.	0.8007202	0.00007881	0.00000381	2246.	14184.	
0.0001476	78.8188402	533866.	0.6615107	0.00009766	-0.00001484	2766.	17166.	
0.0001969	104.9980551	533390.	0.5920313	0.0001165	-0.00003346	3282.	20153.	
0.0002461	131.0455462	532569.	0.5503932	0.0001354	-0.00005207	3793.	23143.	
0.0002953	156.9460450	531524.	0.5226578	0.0001543	-0.00007067	4298.	26134.	
0.0003445	182.6940966	530335.	0.5028600	0.0001732	-0.00008927	4798.	29126.	
0.0003937	208.2873817	529050.	0.4880203	0.0001921	-0.0001079	5293.	32118.	
0.0004429	208.2873817	470267.	0.4208115	0.0001864	-0.0001511	5136.	30181.	C
0.0004921	208.2873817	423240.	0.4054581	0.0001995	-0.0001755	5477.	32024.	C
0.0005413	208.2873817	384764.	0.3924601	0.0002125	-0.0002000	5809.	33819.	C
0.0005906	208.2873817	352700.	0.3812692	0.0002252	-0.0002248	6133.	35573.	C
0.0006398	208.2873817	325569.	0.3715782	0.0002377	-0.0002498	6451.	-39708.	C
0.0006890	208.2873817	302314.	0.3630819	0.0002502	-0.0002748	6763.	-43933.	C

```
0.0007382   208.2873817      282160.     0.3555532     0.0002625    -0.0003000
     7070.       -48182. C
0.0007874   208.2873817      264525.     0.3488310     0.0002747    -0.0003253
     7372.       -52452. C
0.0008366   215.3610256      257420.     0.3427956     0.0002868    -0.0003507
     7670.       -56740. C
0.0008858   222.9500719      251686.     0.3373562     0.0002988    -0.0003762
     7963.       -61041. C
0.0009350   230.4786509      246491.     0.3324192     0.0003108    -0.0004017
     8253.       -65355. C
0.0009843   237.9449492      241752.     0.3278990     0.0003227    -0.0004273
     8539.       -69685. C
0.0010335   245.3869152      237441.     0.3237964     0.0003346    -0.0004529
     8822.       -74017. C
0.0010827   252.7626889      233461.     0.3199815     0.0003464    -0.0004786
     9102.       -78367. C
0.0011319   260.1285637      229818.     0.3165075     0.0003583    -0.0005042
     9379.       -82716. C
0.0011811   267.4398685      226432.     0.3132549     0.0003700    -0.0005300
     9652.       -87080. C
0.0012303   274.7373944      223307.     0.3102641     0.0003817    -0.0005558
     9923.       -91444. C
0.0012795   282.0083895      220400.     0.3074816     0.0003934    -0.0005816
    10192.       -95814. C
0.0013287   289.2455279      217684.     0.3048714     0.0004051    -0.0006074
    10457.      -100192. C
0.0013780   296.4731539      215155.     0.3024550     0.0004168    -0.0006332
    10721.      -104569. C
0.0014272   303.6792094      212785.     0.3001909     0.0004284    -0.0006591
    10982.      -108950. C
0.0014764   310.8540280      210552.     0.2980465     0.0004400    -0.0006850
    11240.      -113340. C
0.0015256   318.0194908      208457.     0.2960472     0.0004516    -0.0007109
    11496.      -117728. C
0.0015748   325.1755592      206486.     0.2941795     0.0004633    -0.0007367
    11751.      -122113. C
0.0016240   332.3074757      204621.     0.2924043     0.0004749    -0.0007626
    12002.      -126506. C
0.0016732   339.4178350      202852.     0.2907179     0.0004864    -0.0007886
    12252.      -130903. C
0.0017224   346.5189412      201179.     0.2891340     0.0004980    -0.0008145
    12499.      -135299. C
0.0017717   353.6107562      199594.     0.2876440     0.0005096    -0.0008404
    12744.      -139693. C
0.0018209   360.6932413      198089.     0.2862403     0.0005212    -0.0008663
    12988.      -144084. C
0.0018701   367.7532274      196651.     0.2848914     0.0005328    -0.0008922
    13229.      -148482. C
```

0.0019193	374.7965004	195279.	0.2836034	0.0005443	-0.0009182	13468.	-152884.	C
0.0020177	388.8553822	192721.	0.2812319	0.0005674	-0.0009701	13940.	-161681.	C
0.0021161	402.8771203	190383.	0.2791014	0.0005906	-0.0010219	14404.	-170470.	C
0.0022146	416.8464842	188229.	0.2771507	0.0006138	-0.0010737	14861.	-179262.	C
0.0023130	430.7642246	186237.	0.2753578	0.0006369	-0.0011256	15309.	-188058.	C
0.0024114	444.6447260	184391.	0.2737299	0.0006601	-0.0011774	15749.	-196846.	C
0.0025098	458.4876652	182676.	0.2722475	0.0006833	-0.0012292	16183.	-205624.	C
0.0026083	472.2927130	181075.	0.2708945	0.0007066	-0.0012809	16609.	-214394.	C
0.0027067	486.0465834	179572.	0.2696294	0.0007298	-0.0013327	17027.	-223169.	C
0.0028051	499.7569355	178159.	0.2684585	0.0007531	-0.0013844	17436.	-231941.	C
0.0029035	513.4291198	176828.	0.2673832	0.0007764	-0.0014361	17839.	-240703.	C
0.0030020	527.0627880	175572.	0.2663944	0.0007997	-0.0014878	18234.	-249456.	C
0.0031004	540.6575853	174384.	0.2654840	0.0008231	-0.0015394	18622.	-258199.	C
0.0031988	554.2131502	173256.	0.2646449	0.0008466	-0.0015909	19002.	-266933.	C
0.0032972	567.7291152	172183.	0.2638709	0.0008700	-0.0016425	19375.	-275656.	C
0.0033957	581.2051064	171161.	0.2631564	0.0008936	-0.0016939	19740.	-284370.	C
0.0034941	594.6354883	170183.	0.2624833	0.0009171	-0.0017454	20098.	-293083.	C
0.0035925	608.0221675	169247.	0.2618531	0.0009407	-0.0017968	20447.	-301791.	C
0.0036909	621.3682784	168349.	0.2612708	0.0009643	-0.0018482	20788.	-310489.	C
0.0037894	634.6734157	167488.	0.2607328	0.0009880	-0.0018995	21122.	-319177.	C
0.0038878	647.9371660	166659.	0.2602359	0.0010117	-0.0019508	21448.	-327853.	C
0.0039862	661.1591080	165861.	0.2597772	0.0010355	-0.0020020	21767.	-336519.	C
0.0040846	674.3388121	165091.	0.2593541	0.0010594	-0.0020531	22078.	-345174.	C
0.0041831	687.4758398	164347.	0.2589642	0.0010833	-0.0021042	22381.	-353817.	C

```
0.0042815   700.5697444       163627.     0.2586055     0.0011072    -0.0021553
   22676.      -362450. C
0.0043799   713.6200696       162930.     0.2582759     0.0011312    -0.0022063
   22963.      -371070. C
0.0044783   726.6263500       162253.     0.2579737     0.0011553    -0.0022572
   23242.      -379680. C
0.0045768   739.5881106       161596.     0.2576974     0.0011794    -0.0023081
   23513.      -388277. C
0.0046752   752.5048664       160957.     0.2574453     0.0012036    -0.0023589
   23776.      -396863. C
0.0047736   765.3761220       160334.     0.2572163     0.0012279    -0.0024096
   24031.      -405436. C
0.0048720   778.1822805       159724.     0.2570069     0.0012521    -0.0024604
   24277.      -413685. CY
0.0049705   790.3121364       159001.     0.2567531     0.0012762    -0.0025113
   24512.      -413685. CY
0.0050689   801.5268743       158126.     0.2564304     0.0012998    -0.0025627
   24735.      -413685. CY
0.0051673   811.9784612       157137.     0.2560559     0.0013231    -0.0026144
   24946.      -413685. CY
0.0052657   822.0962990       156121.     0.2556750     0.0013463    -0.0026662
   25148.      -413685. CY
0.0053642   831.8693195       155079.     0.2552857     0.0013694    -0.0027181
   25341.      -413685. CY
0.0054626   840.5873609       153880.     0.2547949     0.0013918    -0.0027707
   25521.      -413685. CY
0.0055610   847.8959092       152471.     0.2541780     0.0014135    -0.0028240
   25688.      -413685. CY
0.0056594   853.9420635       150888.     0.2534539     0.0014344    -0.0028781
   25842.      -413685. CY
0.0057579   859.2763859       149235.     0.2526856     0.0014549    -0.0029326
   25986.      -413685. CY
0.0058563   864.5866194       147634.     0.2519500     0.0014755    -0.0029870
   26125.      -413685. CY
0.0062500   885.6049011       141697.     0.2493073     0.0015582    -0.0032043
   26619.      -413685. CY
0.0066437   906.2358710       136405.     0.2470590     0.0016414    -0.0034211
   27013.      -413685. CY
0.0070374   926.4373714       131645.     0.2451051     0.0017249    -0.0036376
   27305.      -413685. CY
0.0074311   942.4217698       126821.     0.2429891     0.0018057    -0.0038568
   27487.      -413685. CY
0.0078248   951.2350309       121567.     0.2403363     0.0018806    -0.0040819
   27569.      -413685. CY
0.0082185   958.7943040       116663.     0.2378013     0.0019544    -0.0043081
   27574.      -413685. CY
0.0086122   966.0961858       112178.     0.2355603     0.0020287    -0.0045338
   27575.      -413685. CY
```

```
0.0090059   973.1606726       108058.     0.2335884     0.0021037    -0.0047588
   27575.       -413685. CY
0.0093996   979.9679938       104256.     0.2318203     0.0021790    -0.0049835
   27572.       -413685. CY
0.0097933   986.5096274       100733.     0.2302011     0.0022544    -0.0052081
   27565.       -413685. CY
0.0101870   992.8680818        97464.     0.2287656     0.0023304    -0.0054321
   27551.       -413685. CY
0.0105807   999.0580668        94423.     0.2274908     0.0024070    -0.0056555
   27579.       -413685. CY
0.0109744         1005.        91584.     0.2263608     0.0024842    -0.0058783
   27572.       -413685. CY
0.0113681         1011.        88929.     0.2253541     0.0025619    -0.0061006
   27550.       -413685. CY
0.0117618         1017.        86440.     0.2244351     0.0026398    -0.0063227
   27578.       -413685. CY
0.0121555         1022.        84099.     0.2235869     0.0027178    -0.0065447
   27561.       -413685. CY
0.0125492         1027.        81849.     0.2227115     0.0027949    -0.0067676
   27579.       -413685. CY
0.0129429         1031.        79661.     0.2217711     0.0028704    -0.0069921
   27558.       -413685. CY
0.0133366         1034.        77533.     0.2207459     0.0029440    -0.0072185
   27578.       -413685. CY
0.0137303         1036.        75451.     0.2196244     0.0030155    -0.0074470
   27537.       -413685. CYT
0.0141240         1037.        73437.     0.2184575     0.0030855    -0.0076770
   27568.       -413685. CYT
0.0145177         1038.        71524.     0.2173478     0.0031554    -0.0079071
   27579.       -413685. CYT
0.0149114         1039.        69703.     0.2162422     0.0032245    -0.0081380
   27527.       -413685. CYT
0.0153051         1040.        67974.     0.2151897     0.0032935    -0.0083690
   27559.       -413685. CYT
0.0156988         1041.        66325.     0.2142400     0.0033633    -0.0085992
   27576.        413685. CYT
0.0160925         1042.        64754.     0.2133512     0.0034334    -0.0088291
   27548.        413685. CYT
0.0164862         1043.        63257.     0.2125188     0.0035036    -0.0090589
   27531.        413685. CYT
0.0168799         1044.        61822.     0.2117750     0.0035747    -0.0092878
   27561.        413685. CYT
0.0172736         1044.        60450.     0.2110899     0.0036463    -0.0095162
   27577.        413685. CYT
0.0176673         1045.        59138.     0.2104483     0.0037181    -0.0097444
   27548.        413685. CYT
0.0180610         1045.        57882.     0.2098482     0.0037901    -0.0099724
   27514.        413685. CYT
```

0.0184547	1045.	56647.	0.2099757	0.0038750	-0.0101875	27559.	413685.	CYT

Axial Thrust Force =   945.000 kN

Bending Curvature rad/m	Bending Moment kN-m	Bending Stiffness kN-m2	Depth to N Axis m	Max Comp Strain m/m	Max Tens Strain m/m	Max Conc Stress kPa	Max Steel Stress kPa	Run Msg
0.00004921	25.9863048	528042.	1.7017409	0.00008375	0.00004625	2389.	15958.	
0.00009843	51.9691142	528006.	1.0420167	0.0001026	0.00002756	2907.	18932.	
0.0001476	77.9487786	527973.	0.8223964	0.0001214	0.00000892	3421.	21915.	
0.0001969	103.9222040	527925.	0.7128006	0.0001403	-0.00000968	3930.	24907.	
0.0002461	129.8501442	527711.	0.6471828	0.0001592	-0.00002825	4435.	27905.	
0.0002953	155.6767224	527225.	0.6035108	0.0001782	-0.00004680	4935.	30907.	
0.0003445	181.3748149	526505.	0.5723574	0.0001972	-0.00006533	5430.	33913.	
0.0003937	206.9312854	525605.	0.5490172	0.0002161	-0.00008385	5920.	36920.	
0.0004429	232.3394775	524571.	0.5308800	0.0002351	-0.0001024	6404.	39929.	
0.0004921	232.3394775	472114.	0.4810856	0.0002368	-0.0001382	6441.	39466.	C
0.0005413	232.3394775	429194.	0.4638266	0.0002511	-0.0001614	6801.	41544.	C
0.0005906	232.3394775	393428.	0.4489389	0.0002651	-0.0001849	7151.	43563.	C
0.0006398	232.3394775	363164.	0.4359474	0.0002789	-0.0002086	7492.	45531.	C
0.0006890	232.7290389	337790.	0.4244951	0.0002925	-0.0002325	7824.	47456.	C
0.0007382	241.5472922	327216.	0.4143142	0.0003058	-0.0002567	8149.	49343.	C
0.0007874	250.1201235	317653.	0.4051836	0.0003190	-0.0002810	8467.	51195.	C
0.0008366	258.5031925	308987.	0.3969591	0.0003321	-0.0003054	8779.	53019.	C

0.0008858	266.7255212	301103.	0.3895083	0.0003450	-0.0003300	9086.	54818.	C
0.0009350	274.8166345	293909.	0.3827308	0.0003579	-0.0003546	9388.	56596.	C
0.0009843	282.8009704	287326.	0.3765448	0.0003706	-0.0003794	9685.	-60111.	C
0.0010335	290.6748851	281263.	0.3708556	0.0003833	-0.0004042	9977.	-64293.	C
0.0010827	298.4583113	275667.	0.3656099	0.0003958	-0.0004292	10265.	-68490.	C
0.0011319	306.1807753	270504.	0.3607783	0.0004084	-0.0004541	10550.	-72696.	C
0.0011811	313.8178119	265699.	0.3562804	0.0004208	-0.0004792	10830.	-76919.	C
0.0012303	321.3958036	261231.	0.3520992	0.0004332	-0.0005043	11107.	-81153.	C
0.0012795	328.9216389	257065.	0.3482054	0.0004455	-0.0005295	11381.	-85395.	C
0.0013287	336.3895054	253164.	0.3445567	0.0004578	-0.0005547	11651.	-89649.	C
0.0013780	343.8142358	249511.	0.3411426	0.0004701	-0.0005799	11918.	-93910.	C
0.0014272	351.2026997	246084.	0.3379436	0.0004823	-0.0006052	12182.	-98177.	C
0.0014764	358.5359881	242848.	0.3349170	0.0004945	-0.0006305	12442.	-102456.	C
0.0015256	365.8580684	239814.	0.3320931	0.0005066	-0.0006559	12701.	-106732.	C
0.0015748	373.1228929	236933.	0.3294002	0.0005187	-0.0006813	12956.	-111023.	C
0.0016240	380.3629795	234211.	0.3268622	0.0005308	-0.0007067	13208.	-115317.	C
0.0016732	387.5920594	231643.	0.3244803	0.0005429	-0.0007321	13458.	-119608.	C
0.0017224	394.7729724	229194.	0.3221979	0.0005550	-0.0007575	13705.	-123912.	C
0.0017717	401.9289777	226867.	0.3200326	0.0005670	-0.0007830	13950.	-128219.	C
0.0018209	409.0741727	224659.	0.3179907	0.0005790	-0.0008085	14192.	-132524.	C
0.0018701	416.2046588	222560.	0.3160577	0.0005911	-0.0008339	14432.	-136829.	C
0.0019193	423.2851190	220542.	0.3141836	0.0006030	-0.0008595	14669.	-141149.	C
0.0020177	437.4141214	216787.	0.3107266	0.0006270	-0.0009105	15136.	-149782.	C
0.0021161	451.4768646	213349.	0.3075844	0.0006509	-0.0009616	15594.	-158418.	C

```
0.0022146   465.4500359      210177.     0.3046875     0.0006748    -0.0010127
   16043.      -167069. C
0.0023130   479.3808349      207256.     0.3020570     0.0006987    -0.0010638
   16484.      -175711. C
0.0024114   493.2374005      204543.     0.2996214     0.0007225    -0.0011150
   16915.      -184362. C
0.0025098   507.0276316      202016.     0.2973666     0.0007463    -0.0011662
   17337.      -193019. C
0.0026083   520.7755375      199663.     0.2953002     0.0007702    -0.0012173
   17752.      -201666. C
0.0027067   534.4807337      197466.     0.2934016     0.0007941    -0.0012684
   18158.      -210303. C
0.0028051   548.1021436      195394.     0.2916009     0.0008180    -0.0013195
   18555.      -218961. C
0.0029035   561.6804446      193447.     0.2899381     0.0008418    -0.0013707
   18944.      -227609. C
0.0030020   575.2159616      191613.     0.2884008     0.0008658    -0.0014217
   19325.      -236247. C
0.0031004   588.7082972      189882.     0.2869771     0.0008897    -0.0014728
   19698.      -244875. C
0.0031988   602.1549464      188243.     0.2856537     0.0009138    -0.0015237
   20063.      -253496. C
0.0032972   615.5315536      186681.     0.2843883     0.0009377    -0.0015748
   20419.      -262130. C
0.0033957   628.8647370      185196.     0.2832115     0.0009617    -0.0016258
   20766.      -270754. C
0.0034941   642.1540741      183783.     0.2821159     0.0009857    -0.0016768
   21106.      -279367. C
0.0035925   655.3991347      182434.     0.2810951     0.0010098    -0.0017277
   21438.      -287970. C
0.0036909   668.5994808      181146.     0.2801431     0.0010340    -0.0017785
   21761.      -296562. C
0.0037894   681.7546664      179912.     0.2792549     0.0010582    -0.0018293
   22077.      -305143. C
0.0038878   694.8642374      178730.     0.2784256     0.0010825    -0.0018800
   22385.      -313714. C
0.0039862   707.9177935      177591.     0.2776350     0.0011067    -0.0019308
   22683.      -322286. C
0.0040846   720.9195569      176495.     0.2768870     0.0011310    -0.0019815
   22973.      -330854. C
0.0041831   733.8751317      175439.     0.2761878     0.0011553    -0.0020322
   23255.      -339412. C
0.0042815   746.7840285      174421.     0.2755344     0.0011797    -0.0020828
   23529.      -347957. C
0.0043799   759.6457479      173438.     0.2749237     0.0012041    -0.0021334
   23794.      -356491. C
0.0044783   772.4597799      172488.     0.2743532     0.0012286    -0.0021839
   24051.      -365013. C
```

0.0045768	785.2256044	171568.	0.2738204	0.0012532	-0.0022343	24299.	-373523.	C
0.0046752	797.9426902	170676.	0.2733230	0.0012778	-0.0022847	24539.	-382020.	C
0.0047736	810.6104948	169810.	0.2728591	0.0013025	-0.0023350	24771.	-390506.	C
0.0048720	823.2284644	168970.	0.2724268	0.0013273	-0.0023852	24993.	-398978.	C
0.0049705	835.7960331	168152.	0.2720243	0.0013521	-0.0024354	25208.	-407439.	C
0.0050689	848.1799603	167330.	0.2716370	0.0013769	-0.0024856	25413.	-413685.	CY
0.0051673	859.8738374	166406.	0.2712139	0.0014014	-0.0025361	25606.	-413685.	CY
0.0052657	870.7112151	165354.	0.2707385	0.0014256	-0.0025869	25788.	-413685.	CY
0.0053642	880.8588730	164211.	0.2702180	0.0014495	-0.0026380	25959.	-413685.	CY
0.0054626	890.7081047	163056.	0.2696933	0.0014732	-0.0026893	26120.	-413685.	CY
0.0055610	900.2262416	161881.	0.2691674	0.0014968	-0.0027407	26272.	-413685.	CY
0.0056594	908.8049878	160582.	0.2685758	0.0015200	-0.0027925	26413.	-413685.	CY
0.0057579	916.0977531	159103.	0.2678828	0.0015424	-0.0028451	26542.	-413685.	CY
0.0058563	922.1626635	157465.	0.2670955	0.0015642	-0.0028983	26660.	-413685.	CY
0.0062500	942.8232885	150852.	0.2639324	0.0016496	-0.0031129	27053.	-413685.	CY
0.0066437	962.9800556	144946.	0.2611863	0.0017352	-0.0033273	27338.	-413685.	CY
0.0070374	982.6638741	139634.	0.2588209	0.0018214	-0.0035411	27514.	-413685.	CY
0.0074311	1002.	134792.	0.2567882	0.0019082	-0.0037543	27579.	-413685.	CY
0.0078248	1015.	129758.	0.2544681	0.0019912	-0.0039713	27564.	-413685.	CY
0.0082185	1023.	124499.	0.2517383	0.0020689	-0.0041936	27569.	-413685.	CY
0.0086122	1030.	119621.	0.2492699	0.0021468	-0.0044157	27570.	-413685.	CY
0.0090059	1037.	115138.	0.2470627	0.0022250	-0.0046375	27567.	-413685.	CY
0.0093996	1043.	110996.	0.2450300	0.0023032	-0.0048593	27561.	-413685.	CY
0.0097933	1050.	107168.	0.2432236	0.0023820	-0.0050805	27556.	-413685.	CY

```
  0.0101870         1056.       103617.     0.2416150     0.0024613    -0.0053012
     27579.      -413685. CY
  0.0105807         1061.       100314.     0.2401813     0.0025413    -0.0055212
     27572.      -413685. CY
  0.0109744         1067.        97229.     0.2388306     0.0026210    -0.0057415
     27551.      -413685. CY
  0.0113681         1073.        94346.     0.2376087     0.0027012    -0.0059613
     27579.      -413685. CY
  0.0117618         1078.        91644.     0.2365132     0.0027818    -0.0061807
     27563.      -413685. CY
  0.0121555         1083.        89110.     0.2355222     0.0028629    -0.0063996
     27570.      -413685. CY
  0.0125492         1088.        86725.     0.2346327     0.0029445    -0.0066180
     27566.      -413685. CY
  0.0129429         1093.        84480.     0.2338250     0.0030264    -0.0068361
     27566.      -413685. CYT
  0.0133366         1098.        82318.     0.2330000     0.0031074    -0.0070551
     27560.      -413685. CYT
  0.0137303         1102.        80227.     0.2321385     0.0031873    -0.0072752
     27579.       413685. CYT
  0.0141240         1104.        78188.     0.2312033     0.0032655    -0.0074970
     27537.       413685. CYT
  0.0145177         1106.        76187.     0.2301312     0.0033410    -0.0077215
     27567.       413685. CYT
  0.0149114         1107.        74254.     0.2291227     0.0034165    -0.0079460
     27579.       413685. CYT
  0.0153051         1108.        72389.     0.2280984     0.0034911    -0.0081714
     27521.       413685. CYT
  0.0156988         1109.        70617.     0.2271395     0.0035658    -0.0083967
     27556.       413685. CYT
  0.0160925         1109.        68921.     0.2262959     0.0036417    -0.0086208
     27575.       413685. CYT
  0.0164862         1110.        67304.     0.2255068     0.0037178    -0.0088447
     27558.       413685. CYT
  0.0168799         1110.        65761.     0.2247691     0.0037941    -0.0090684
     27522.       413685. CYT
  0.0172736         1110.        64262.     0.2247562     0.0038824    -0.0092801
     27564.       413685. CYT


--------------------------------------------------------------------------------
   Summary of Results for Nominal (Unfactored) Moment Capacity for Section 1
--------------------------------------------------------------------------------

Moment values interpolated at maximum compressive strain = 0.003
or maximum developed moment if pile fails at smaller strains.

 Load           Axial Thrust        Nominal Mom. Cap.      Max. Comp.
```

No.	kN	kN-m	Strain
1	603.000	1035.549	0.00300000
2	945.000	1091.781	0.00300000

Note that the values of moment capacity in the table above are not factored by a strength reduction factor (phi-factor).

In ACI 318, the value of the strength reduction factor depends on whether the transverse reinforcing steel bars are tied hoops (0.65) or spirals (0.70).

The above values should be multiplied by the appropriate strength reduction factor to compute ultimate moment capacity according to ACI 318, Section 9.3.2.2 or the value required by the design standard being followed.

The following table presents factored moment capacities and corresponding bending stiffnesses computed for common resistance factor values used for reinforced concrete sections.

Axial Load No.	Resist. Factor for Moment	Nominal Moment Cap kN-m	Ult. (Fac) Ax. Thrust kN	Ult. (Fac) Moment Cap kN-m	Bend. Stiff. at Ult Mom kN-m^2
1	0.65	1036.	391.950000	673.106875	165163.
2	0.65	1092.	614.250000	709.657598	177445.
1	0.75	1036.	422.100000	776.661779	159796.
2	0.75	1092.	661.500000	818.835690	169262.
1	0.90	1036.	452.250000	931.994134	129968.
2	0.90	1092.	708.750000	982.602828	139651.

Computed Values of Pile Loading and Deflection
for Lateral Loading for Load Case Number 1

Pile-head conditions are Shear and Moment (Loading Type 1)

Shear force at pile head = 45.000 kN
Applied moment at pile head = 0.000 kN-m
Axial thrust load on pile head = 945.000 kN

Depth Deflect. Bending Shear Slope Total Bending Soil
Res. Soil Spr. Distrib.

X	y	Moment	Force	S	Stress	Stiffness	p	Es*h	Lat. Load
meters	meters	kN-m	kN	radians	kPa*	kN-m^2	kN/m	kN/m	kN/m
0.00	4.05E-05	2.46E-11	45.0000	-5.27E-05	0.00	528042.	0.00	0.00	0.00
0.04000	3.84E-05	1.8020	45.0000	-5.26E-05	0.00	528042.	0.00	0.00	0.00
0.08000	3.63E-05	3.6040	45.0000	-5.24E-05	0.00	528042.	0.00	0.00	0.00
0.1200	3.42E-05	5.4060	45.0000	-5.21E-05	0.00	528042.	0.00	0.00	0.00
0.1600	3.22E-05	7.2079	45.0000	-5.16E-05	0.00	528042.	0.00	0.00	0.00
0.2000	3.01E-05	9.0099	45.0000	-5.10E-05	0.00	528042.	0.00	0.00	0.00
0.2400	2.81E-05	10.8118	45.0000	-5.03E-05	0.00	528042.	0.00	0.00	0.00
0.2800	2.61E-05	12.6137	45.0000	-4.94E-05	0.00	528042.	0.00	0.00	0.00
0.3200	2.41E-05	14.4155	45.0000	-4.83E-05	0.00	528042.	0.00	0.00	0.00
0.3600	2.22E-05	16.2173	45.0000	-4.72E-05	0.00	528042.	0.00	0.00	0.00
0.4000	2.04E-05	18.0191	45.0000	-4.59E-05	0.00	528042.	0.00	0.00	0.00
0.4400	1.85E-05	19.8208	45.0000	-4.44E-05	0.00	528042.	0.00	0.00	0.00
0.4800	1.68E-05	21.6224	45.0000	-4.29E-05	0.00	528042.	0.00	0.00	0.00
0.5200	1.51E-05	23.4240	45.0000	-4.12E-05	0.00	528042.	0.00	0.00	0.00
0.5600	1.35E-05	25.2255	45.0000	-3.93E-05	0.00	528042.	0.00	0.00	0.00
0.6000	1.20E-05	27.0270	45.0000	-3.74E-05	0.00	528039.	0.00	0.00	0.00
0.6400	1.05E-05	28.8284	40.7129	-3.52E-05	0.00	528035.	-214.3574	815436.	0.00
0.6800	9.15E-06	30.2867	31.9958	-3.30E-05	0.00	528032.	-221.4935	968361.	0.00
0.7200	7.88E-06	31.3905	23.0201	-3.07E-05	0.00	528029.	-227.2955	1154484.	0.00
0.7600	6.70E-06	32.1306	13.8404	-2.83E-05	0.00	528028.	-231.6855	1383952.	0.00
0.8000	5.61E-06	32.4999	4.5152	-2.58E-05	0.00	528028.	-234.5740	1671102.	0.00

0.8400	4.63E-06	32.4938	-4.8933	-2.33E-05	0.00	528028.	-235.8541	2036826.	0.00
0.8800	3.75E-06	32.1102	-14.3182	-2.09E-05	0.00	528028.	-235.3921	2512711.	0.00
0.9200	2.96E-06	31.3499	-23.6863	-1.85E-05	0.00	528030.	-233.0113	3148861.	0.00
0.9600	2.27E-06	30.2167	-32.9158	-1.62E-05	0.00	528032.	-228.4616	4029907.	0.00
1.0000	1.67E-06	28.7179	-41.7434	-1.39E-05	0.00	528035.	-212.9198	5109240.	0.00
1.0400	1.15E-06	26.8783	-49.0703	-1.18E-05	0.00	528040.	-153.4255	5321572.	0.00
1.0800	7.21E-07	24.7931	-54.1337	-9.87E-06	0.00	528042.	-99.7449	5533905.	0.00
1.1200	3.64E-07	22.5483	-57.1740	-8.07E-06	0.00	528042.	-52.2673	5746237.	0.00
1.1600	7.50E-08	20.2198	-58.4428	-6.45E-06	0.00	528042.	-11.1757	5958569.	0.00
1.2000	-1.53E-07	17.8734	-58.1957	-5.01E-06	0.00	528042.	23.5302	6170901.	0.00
1.2400	-3.26E-07	15.5645	-56.6849	-3.75E-06	0.00	528042.	52.0093	6383233.	0.00
1.2800	-4.52E-07	13.3389	-54.1537	-2.65E-06	0.00	528042.	74.5529	6595565.	0.00
1.3200	-5.38E-07	11.2324	-50.8315	-1.72E-06	0.00	528042.	91.5575	6807897.	0.00
1.3600	-5.90E-07	9.2725	-46.9303	-9.43E-07	0.00	528042.	103.4998	7020229.	0.00
1.4000	-6.13E-07	7.4781	-42.6421	-3.09E-07	0.00	528042.	110.9117	7232561.	0.00
1.4400	-6.14E-07	5.8611	-38.1367	1.97E-07	0.00	528042.	114.3575	7444893.	0.00
1.4800	-5.98E-07	4.4271	-33.5613	5.86E-07	0.00	528042.	114.4144	7657225.	0.00
1.5200	-5.68E-07	3.1762	-29.0399	8.74E-07	0.00	528042.	111.6544	7869557.	0.00
1.5600	-5.28E-07	2.1039	-24.6742	1.07E-06	0.00	528042.	106.6298	8081889.	0.00
1.6000	-4.82E-07	1.2022	-20.5444	1.20E-06	0.00	528042.	99.8610	8294221.	0.00
1.6400	-4.32E-07	0.4602	-16.7106	1.26E-06	0.00	528042.	91.8275	8506553.	0.00
1.6800	-3.81E-07	-0.1348	-13.2149	1.27E-06	0.00	528042.	82.9614	8718886.	0.00
1.7200	-3.30E-07	-0.5971	-10.0828	1.25E-06	0.00	528042.	73.6430	8931218.	0.00
1.7600	-2.81E-07	-0.9415	-7.3259	1.19E-06	0.00	528042.	64.1990	9143550.	0.00

```
    1.8000  -2.35E-07    -1.1832    -4.9439   1.11E-06       0.00    528042.
54.9024   9355882.       0.00
    1.8400  -1.92E-07    -1.3371    -2.9264   1.01E-06       0.00    528042.
45.9736   9568214.       0.00
    1.8800  -1.54E-07    -1.4174    -1.2552   9.08E-07       0.00    528042.
37.5840   9780546.       0.00
    1.9200  -1.20E-07    -1.4376    0.09362   8.00E-07       0.00    528042.
29.8587   9992878.       0.00
    1.9600  -8.97E-08    -1.4100     1.1484   6.92E-07       0.00    528042.
22.8818   1.02E+07       0.00
    2.0000  -6.41E-08    -1.3458     1.9401   5.88E-07       0.00    528042.
16.7008   1.04E+07       0.00
    2.0400  -4.26E-08    -1.2548     2.5007   4.90E-07       0.00    528042.
11.3321   1.06E+07       0.00
    2.0800  -2.50E-08    -1.1457     2.8627   3.99E-07       0.00    528042.
6.7659   1.08E+07       0.00
    2.1200  -1.08E-08    -1.0258     3.0574   3.16E-07       0.00    528042.
2.9714   1.11E+07       0.00
    2.1600   3.49E-10    -0.9012     3.1149   2.43E-07       0.00    528042.
-0.09834   1.13E+07       0.00
    2.2000   8.72E-09    -0.7767     3.0629   1.80E-07       0.00    528042.
-2.5024   1.15E+07       0.00
    2.2400   1.47E-08    -0.6561     2.9267   1.26E-07       0.00    528042.
-4.3074   1.17E+07       0.00
    2.2800   1.88E-08    -0.5425     2.7289   8.02E-08       0.00    528042.
-5.5847   1.19E+07       0.00
    2.3200   2.12E-08    -0.4378     2.4890   4.30E-08       0.00    528042.
-6.4068   1.21E+07       0.00
    2.3600   2.22E-08    -0.3434     2.2240   1.35E-08       0.00    528042.
-6.8453   1.23E+07       0.00
    2.4000   2.22E-08    -0.2599     1.9477  -9.40E-09       0.00    528042.
-6.9688   1.25E+07       0.00
    2.4400   2.15E-08    -0.1876     1.6715  -2.63E-08       0.00    528042.
-6.8414   1.28E+07       0.00
    2.4800   2.01E-08    -0.1262     1.4042  -3.82E-08       0.00    528042.
-6.5215   1.30E+07       0.00
    2.5200   1.84E-08   -0.07525     1.1526  -4.59E-08       0.00    528042.
-6.0615   1.32E+07       0.00
    2.5600   1.65E-08   -0.03399     0.9212  -5.00E-08       0.00    528042.
-5.5069   1.34E+07       0.00
    2.6000   1.44E-08   -0.00155     0.7131  -5.13E-08       0.00    528042.
-4.8966   1.36E+07       0.00
    2.6400   1.23E-08    0.02306     0.5299  -5.05E-08       0.00    528042.
-4.2629   1.38E+07       0.00
    2.6800   1.04E-08    0.04085     0.3721  -4.81E-08       0.00    528042.
-3.6318   1.40E+07       0.00
    2.7200   8.49E-09    0.05283     0.2389  -4.46E-08       0.00    528042.
-3.0238   1.42E+07       0.00
```

```
    2.7600   6.79E-09    0.05997     0.1294  -4.03E-08       0.00    528042.
-2.4537   1.45E+07       0.00
    2.8000   5.27E-09    0.06318    0.04167  -3.56E-08       0.00    528042.
-1.9323   1.47E+07       0.00
    2.8400   3.94E-09    0.06331   -0.02629  -3.08E-08       0.00    528042.
-1.4659   1.49E+07       0.00
    2.8800   2.80E-09    0.06108   -0.07676  -2.61E-08       0.00    528042.
-1.0577   1.51E+07       0.00
    2.9200   1.85E-09    0.05717    -0.1120  -2.16E-08       0.00    528042.
-0.7021   1.52E+07       0.00
    2.9600   1.07E-09    0.05213    -0.1341  -1.75E-08       0.00    528042.
-0.4066   1.52E+07       0.00
    3.0000   4.51E-10    0.04644    -0.1457  -1.38E-08       0.00    528042.
-0.1710   1.52E+07       0.00
    3.0400  -2.96E-11    0.04047    -0.1489  -1.05E-08       0.00    528042.
0.01121   1.52E+07       0.00
    3.0800  -3.87E-10    0.03453    -0.1457  -7.64E-09       0.00    528042.
0.1469   1.52E+07       0.00
    3.1200  -6.41E-10    0.02882    -0.1379  -5.24E-09       0.00    528042.
0.2430   1.52E+07       0.00
    3.1600  -8.07E-10    0.02349    -0.1269  -3.26E-09       0.00    528042.
0.3059   1.52E+07       0.00
    3.2000  -9.02E-10    0.01866    -0.1140  -1.66E-09       0.00    528042.
0.3419   1.52E+07       0.00
    3.2400  -9.40E-10    0.01438    -0.1000  -4.11E-10       0.00    528042.
0.3564   1.52E+07       0.00
    3.2800  -9.34E-10    0.01066   -0.08581   5.37E-10       0.00    528042.
0.3543   1.52E+07       0.00
    3.3200  -8.97E-10    0.00751   -0.07192   1.23E-09       0.00    528042.
0.3401   1.52E+07       0.00
    3.3600  -8.36E-10    0.00491   -0.05877   1.70E-09       0.00    528042.
0.3172   1.52E+07       0.00
    3.4000  -7.61E-10    0.00281   -0.04666   1.99E-09       0.00    528042.
0.2886   1.52E+07       0.00
    3.4400  -6.77E-10    0.00117   -0.03575   2.14E-09       0.00    528042.
0.2569   1.52E+07       0.00
    3.4800  -5.90E-10  -5.04E-05   -0.02613   2.18E-09       0.00    528042.
0.2238   1.52E+07       0.00
    3.5200  -5.03E-10  -9.17E-04   -0.01784   2.14E-09       0.00    528042.
0.1907   1.52E+07       0.00
    3.5600  -4.19E-10   -0.00148   -0.01086   2.05E-09       0.00    528042.
0.1587   1.52E+07       0.00
    3.6000  -3.39E-10   -0.00179   -0.00511   1.93E-09       0.00    528042.
0.1284   1.52E+07       0.00
    3.6400  -2.64E-10   -0.00189  -5.42E-04   1.79E-09       0.00    528042.
0.1002   1.52E+07       0.00
    3.6800  -1.95E-10   -0.00183    0.00294   1.65E-09       0.00    528042.
0.07407   1.52E+07       0.00
```

```
    3.7200  -1.32E-10   -0.00165    0.00543   1.52E-09       0.00    528042.
0.05009   1.52E+07       0.00
    3.7600  -7.38E-11   -0.00139    0.00699   1.40E-09       0.00    528042.
0.02800   1.52E+07       0.00
    3.8000  -1.98E-11   -0.00109    0.00770   1.31E-09       0.00    528042.
0.00752   1.52E+07       0.00
    3.8400   3.09E-11  -7.79E-04    0.00761   1.24E-09       0.00    528042.
-0.01170   1.52E+07       0.00
    3.8800   7.92E-11  -4.84E-04    0.00678   1.19E-09       0.00    528042.
-0.03003   1.52E+07       0.00
    3.9200   1.26E-10  -2.37E-04    0.00522   1.16E-09       0.00    528042.
-0.04781   1.52E+07       0.00
    3.9600   1.72E-10  -6.61E-05    0.00296   1.15E-09       0.00    528042.
-0.06531   1.52E+07       0.00
    4.0000   2.18E-10       0.00       0.00   1.15E-09       0.00    528042.
-0.08274   7584236.       0.00
```

* This analysis computed pile response using nonlinear moment-curvature relationships. Values of total stress due to combined axial and bending stresses are computed only for elastic sections only and do not equal the actual stresses in concrete and steel. Stresses in concrete and steel may be interpolated from the output for nonlinear bending properties relative to the magnitude of bending moment developed in the pile.

Output Summary for Load Case No. 1:

```
Pile-head deflection             =     0.00004054 meters
Computed slope at pile head      =    -0.00005271 radians
Maximum bending moment           =    32.49990045 kN-m
Maximum shear force              =   -58.44281877 kN
Depth of maximum bending moment  =     0.80000000 meters below pile head
Depth of maximum shear force     =     1.16000000 meters below pile head
Number of iterations             =              7
Number of zero deflection points =              4
```

Computed Values of Pile Loading and Deflection
for Lateral Loading for Load Case Number 2

Pile-head conditions are Shear and Moment (Loading Type 1)

```
Shear force at pile head                               =       73.000 kN
Applied moment at pile head                            =        0.000 kN-m
Axial thrust load on pile head                         =      603.000 kN
```

Depth X meters	Deflect. y meters	Bending Moment kN-m	Shear Force kN	Slope S radians	Total Stress kPa*	Bending Stiffness kN-m^2	Soil Res. p kN/m	Soil Spr. Es*h kN/m	Distrib. Lat. Load kN/m
0.00	7.95E-05	-2.71E-11	73.0000	-9.62E-05	0.00	533991.	0.00	0.00	0.00
0.04000	7.57E-05	2.9223	73.0000	-9.61E-05	0.00	533991.	0.00	0.00	0.00
0.08000	7.19E-05	5.8446	73.0000	-9.58E-05	0.00	533991.	0.00	0.00	0.00
0.1200	6.80E-05	8.7669	73.0000	-9.52E-05	0.00	533991.	0.00	0.00	0.00
0.1600	6.42E-05	11.6892	73.0000	-9.45E-05	0.00	533991.	0.00	0.00	0.00
0.2000	6.05E-05	14.6115	73.0000	-9.35E-05	0.00	533991.	0.00	0.00	0.00
0.2400	5.68E-05	17.5337	73.0000	-9.23E-05	0.00	533991.	0.00	0.00	0.00
0.2800	5.31E-05	20.4559	73.0000	-9.08E-05	0.00	533991.	0.00	0.00	0.00
0.3200	4.95E-05	23.3781	73.0000	-8.92E-05	0.00	533991.	0.00	0.00	0.00
0.3600	4.60E-05	26.3003	73.0000	-8.73E-05	0.00	533991.	0.00	0.00	0.00
0.4000	4.25E-05	29.2223	73.0000	-8.53E-05	0.00	533985.	0.00	0.00	0.00
0.4400	3.91E-05	32.1444	73.0000	-8.30E-05	0.00	533981.	0.00	0.00	0.00
0.4800	3.59E-05	35.0663	73.0000	-8.04E-05	0.00	533977.	0.00	0.00	0.00
0.5200	3.27E-05	37.9882	73.0000	-7.77E-05	0.00	533974.	0.00	0.00	0.00
0.5600	2.96E-05	40.9101	73.0000	-7.48E-05	0.00	533971.	0.00	0.00	0.00
0.6000	2.67E-05	43.8319	73.0000	-7.16E-05	0.00	533969.	0.00	0.00	0.00
0.6400	2.39E-05	46.7535	67.7431	-6.82E-05	0.00	533966.	-262.8454	439530.	0.00
0.6800	2.13E-05	49.2546	57.0259	-6.46E-05	0.00	533965.	-273.0135	513591.	0.00
0.7200	1.88E-05	51.3187	45.9290	-6.08E-05	0.00	533964.	-281.8300	601134.	0.00
0.7600	1.64E-05	52.9318	34.5079	-5.69E-05	0.00	533961.			

```
-289.2289    705560.       0.00
    0.8000   1.42E-05    54.0821    22.8205  -5.29E-05       0.00    533955.
-295.1382    831398.       0.00
    0.8400   1.22E-05    54.7600    10.9282  -4.88E-05       0.00    533951.
-299.4772    984785.       0.00
    0.8800   1.03E-05    54.9587    -1.1044  -4.47E-05       0.00    533950.
-302.1538   1174232.       0.00
    0.9200   8.59E-06    54.6738   -13.2087  -4.06E-05       0.00    533952.
-303.0588   1411851.       0.00
    0.9600   7.04E-06    53.9040   -25.3110  -3.66E-05       0.00    533956.
-302.0582   1715435.       0.00
    1.0000   5.66E-06    52.6507   -37.3317  -3.26E-05       0.00    533963.
-298.9796   2112188.       0.00
    1.0400   4.44E-06    50.9190   -49.1831  -2.87E-05       0.00    533964.
-293.5885   2645872.       0.00
    1.0800   3.37E-06    48.7175   -60.7658  -2.49E-05       0.00    533965.
-285.5451   3391810.       0.00
    1.1200   2.44E-06    46.0590   -71.9630  -2.14E-05       0.00    533967.
-274.3145   4492406.       0.00
    1.1600   1.66E-06    42.9615   -82.3814  -1.81E-05       0.00    533969.
-246.6091   5958569.       0.00
    1.2000   9.97E-07    39.4693   -90.3906  -1.50E-05       0.00    533972.
-153.8471   6170901.       0.00
    1.2400   4.57E-07    35.7309   -94.9269  -1.22E-05       0.00    533976.
-72.9698   6383233.       0.00
    1.2800   2.43E-08    31.8757   -96.4666  -9.63E-06       0.00    533981.
-4.0134   6595565.       0.00
    1.3200  -3.13E-07    28.0141   -95.4812  -7.39E-06       0.00    533988.
53.2835   6807897.       0.00
    1.3600  -5.67E-07    24.2376   -92.4269  -5.43E-06       0.00    533991.
99.4306   7020229.       0.00
    1.4000  -7.47E-07    20.6202   -87.7355  -3.75E-06       0.00    533991.
135.1375   7232561.       0.00
    1.4400  -8.66E-07    17.2189   -81.8075  -2.33E-06       0.00    533991.
161.2649   7444893.       0.00
    1.4800  -9.34E-07    14.0757   -75.0066  -1.16E-06       0.00    533991.
178.7797   7657225.       0.00
    1.5200  -9.59E-07    11.2185   -67.6567  -2.12E-07       0.00    533991.
188.7134   7869557.       0.00
    1.5600  -9.51E-07     8.6632   -60.0400   5.32E-07       0.00    533991.
192.1240   8081889.       0.00
    1.6000  -9.17E-07     6.4153   -52.3962   1.10E-06       0.00    533991.
190.0638   8294221.       0.00
    1.6400  -8.63E-07     4.4714   -44.9239   1.50E-06       0.00    533991.
183.5519   8506553.       0.00
    1.6800  -7.96E-07     2.8213   -37.7818   1.78E-06       0.00    533991.
173.5516   8718886.       0.00
    1.7200  -7.21E-07     1.4488   -31.0917   1.94E-06       0.00    533991.
```

```
160.9537   8931218.       0.00
    1.7600  -6.41E-07     0.3338   -24.9414   2.00E-06       0.00    533991.
146.5635   9143550.       0.00
    1.8000  -5.60E-07    -0.5466   -19.3883   2.00E-06       0.00    533991.
131.0932   9355882.       0.00
    1.8400  -4.81E-07    -1.2173   -14.4632   1.93E-06       0.00    533991.
115.1581   9568214.       0.00
    1.8800  -4.06E-07    -1.7038   -10.1746   1.82E-06       0.00    533991.
99.2755   9780546.       0.00
    1.9200  -3.36E-07    -2.0314    -6.5117   1.68E-06       0.00    533991.
83.8677   9992878.       0.00
    1.9600  -2.71E-07    -2.2248    -3.4490   1.52E-06       0.00    533991.
69.2664   1.02E+07       0.00
    2.0000  -2.14E-07    -2.3074    -0.9493   1.35E-06       0.00    533991.
55.7194   1.04E+07       0.00
    2.0400  -1.63E-07    -2.3008     1.0331   1.18E-06       0.00    533991.
43.3988   1.06E+07       0.00
    2.0800  -1.20E-07    -2.2248     2.5492   1.01E-06       0.00    533991.
32.4092   1.08E+07       0.00
    2.1200  -8.25E-08    -2.0969     3.6534   8.48E-07       0.00    533991.
22.7975   1.11E+07       0.00
    2.1600  -5.17E-08    -1.9326     4.4005   6.97E-07       0.00    533991.
14.5619   1.13E+07       0.00
    2.2000  -2.67E-08    -1.7449     4.8450   5.60E-07       0.00    533991.
7.6611   1.15E+07       0.00
    2.2400  -6.92E-09    -1.5450     5.0387   4.36E-07       0.00    533991.
2.0231   1.17E+07       0.00
    2.2800   8.22E-09    -1.3418     5.0302   3.28E-07       0.00    533991.
-2.4473   1.19E+07       0.00
    2.3200   1.93E-08    -1.1426     4.8640   2.35E-07       0.00    533991.
-5.8606   1.21E+07       0.00
    2.3600   2.70E-08    -0.9527     4.5801   1.57E-07       0.00    533991.
-8.3368   1.23E+07       0.00
    2.4000   3.19E-08    -0.7762     4.2134   9.21E-08       0.00    533991.
-9.9998   1.25E+07       0.00
    2.4400   3.44E-08    -0.6156     3.7939   4.00E-08       0.00    533991.
-10.9727   1.28E+07       0.00
    2.4800   3.51E-08    -0.4727     3.3470  -8.06E-10       0.00    533991.
-11.3745   1.30E+07       0.00
    2.5200   3.44E-08    -0.3479     2.8932  -3.15E-08       0.00    533991.
-11.3168   1.32E+07       0.00
    2.5600   3.26E-08    -0.2412     2.4488  -5.36E-08       0.00    533991.
-10.9024   1.34E+07       0.00
    2.6000   3.01E-08    -0.1520     2.0263  -6.83E-08       0.00    533991.
-10.2233   1.36E+07       0.00
    2.6400   2.71E-08   -0.07911     1.6346  -7.70E-08       0.00    533991.
-9.3602   1.38E+07       0.00
    2.6800   2.39E-08   -0.02121     1.2797  -8.07E-08       0.00    533991.
```

```
-8.3827   1.40E+07      0.00
    2.7200   2.06E-08    0.02327     0.9651  -8.07E-08       0.00    533991.
-7.3485   1.42E+07      0.00
    2.7600   1.75E-08    0.05600     0.6920  -7.77E-08       0.00    533991.
-6.3049   1.45E+07      0.00
    2.8000   1.44E-08    0.07864     0.4602  -7.27E-08       0.00    533991.
-5.2889   1.47E+07      0.00
    2.8400   1.16E-08    0.09281     0.2678  -6.62E-08       0.00    533991.
-4.3285   1.49E+07      0.00
    2.8800   9.13E-09     0.1001     0.1124  -5.90E-08       0.00    533991.
-3.4433   1.51E+07      0.00
    2.9200   6.92E-09     0.1018   -0.00896  -5.14E-08       0.00    533991.
-2.6233   1.52E+07      0.00
    2.9600   5.01E-09    0.09935   -0.09944  -4.39E-08       0.00    533991.
-1.9007   1.52E+07      0.00
    3.0000   3.40E-09    0.09385    -0.1633  -3.67E-08       0.00    533991.
-1.2910   1.52E+07      0.00
    3.0400   2.08E-09    0.08629    -0.2049  -2.99E-08       0.00    533991.
-0.7880   1.52E+07      0.00
    3.0800   1.01E-09    0.07747    -0.2283  -2.38E-08       0.00    533991.
-0.3830   1.52E+07      0.00
    3.1200   1.74E-10    0.06803    -0.2373  -1.83E-08       0.00    533991.
-0.06606   1.52E+07      0.00
    3.1600  -4.58E-10    0.05849    -0.2351  -1.36E-08       0.00    533991.
0.1736   1.52E+07      0.00
    3.2000  -9.15E-10    0.04922    -0.2247  -9.58E-09       0.00    533991.
0.3468   1.52E+07      0.00
    3.2400  -1.22E-09    0.04051    -0.2085  -6.21E-09       0.00    533991.
0.4641   1.52E+07      0.00
    3.2800  -1.41E-09    0.03254    -0.1885  -3.48E-09       0.00    533991.
0.5353   1.52E+07      0.00
    3.3200  -1.50E-09    0.02543    -0.1664  -1.31E-09       0.00    533991.
0.5696   1.52E+07      0.00
    3.3600  -1.52E-09    0.01923    -0.1435   3.66E-10       0.00    533991.
0.5750   1.52E+07      0.00
    3.4000  -1.47E-09    0.01395    -0.1208   1.61E-09       0.00    533991.
0.5585   1.52E+07      0.00
    3.4400  -1.39E-09    0.00957   -0.09913   2.49E-09       0.00    533991.
0.5262   1.52E+07      0.00
    3.4800  -1.27E-09    0.00602   -0.07895   3.07E-09       0.00    533991.
0.4830   1.52E+07      0.00
    3.5200  -1.14E-09    0.00325   -0.06063   3.42E-09       0.00    533991.
0.4329   1.52E+07      0.00
    3.5600  -1.00E-09    0.00117   -0.04439   3.59E-09       0.00    533991.
0.3792   1.52E+07      0.00
    3.6000  -8.55E-10  -3.00E-04   -0.03032   3.62E-09       0.00    533991.
0.3241   1.52E+07      0.00
    3.6400  -7.10E-10   -0.00125   -0.01845   3.56E-09       0.00    533991.
```

```
0.2694   1.52E+07       0.00
    3.6800  -5.70E-10   -0.00178   -0.00874   3.45E-09       0.00    533991.
0.2161   1.52E+07       0.00
    3.7200  -4.35E-10   -0.00195   -0.00112   3.31E-09       0.00    533991.
0.1648   1.52E+07       0.00
    3.7600  -3.05E-10   -0.00187    0.00449   3.17E-09       0.00    533991.
0.1157   1.52E+07       0.00
    3.8000  -1.81E-10   -0.00159    0.00818   3.04E-09       0.00    533991.
0.06876   1.52E+07       0.00
    3.8400  -6.23E-11   -0.00121    0.01002   2.93E-09       0.00    533991.
0.02362   1.52E+07       0.00
    3.8800   5.31E-11  -7.92E-04    0.01009   2.86E-09       0.00    533991.
-0.02014   1.52E+07       0.00
    3.9200   1.66E-10  -4.05E-04    0.00843   2.81E-09       0.00    533991.
-0.06301   1.52E+07       0.00
    3.9600   2.78E-10  -1.18E-04    0.00506   2.79E-09       0.00    533991.
-0.1054   1.52E+07       0.00
    4.0000   3.89E-10       0.00       0.00   2.79E-09       0.00    533991.
-0.1477   7584236.       0.00
```

* This analysis computed pile response using nonlinear moment-curvature relationships. Values of total stress due to combined axial and bending stresses are computed only for elastic sections only and do not equal the actual stresses in concrete and steel. Stresses in concrete and steel may be interpolated from the output for nonlinear bending properties relative to the magnitude of bending moment developed in the pile.

Output Summary for Load Case No. 2:

```
Pile-head deflection              =     0.00007954 meters
Computed slope at pile head       =    -0.00009621 radians
Maximum bending moment            =    54.95871581 kN-m
Maximum shear force               =   -96.46657553 kN
Depth of maximum bending moment   =     0.88000000 meters below pile head
Depth of maximum shear force      =     1.28000000 meters below pile head
Number of iterations              =              9
Number of zero deflection points =              4
```

Summary of Pile-head Responses for Conventional Analyses

Definitions of Pile-head Loading Conditions:

Load Type 1: Load 1 = Shear, V, kN, and Load 2 = Moment, M, kN-m
Load Type 2: Load 1 = Shear, V, kN, and Load 2 = Slope, S, radians

Load Type 3: Load 1 = Shear, V, kN, and Load 2 = Rot. Stiffness, R, kN-m/rad.
Load Type 4: Load 1 = Top Deflection, y, m, and Load 2 = Moment, M, kN-m
Load Type 5: Load 1 = Top Deflection, y, m, and Load 2 = Slope, S, radians

Load Case No.	Load Type 1	Pile-head Load 1	Load Type 2	Pile-head Load 2	Axial Loading kN	Pile-head Deflection meters	Pile-head Rotation radians	Max Shear in Pile kN	Max Moment in Pile kN-m
1	V, kN	45.0000	M, kN-m	0.00	945.0000	4.05E-05	-5.27E-05	-58.4428	32.4999
2	V, kN	73.0000	M, kN-m	0.00	603.0000	7.95E-05	-9.62E-05	-96.4666	54.9587

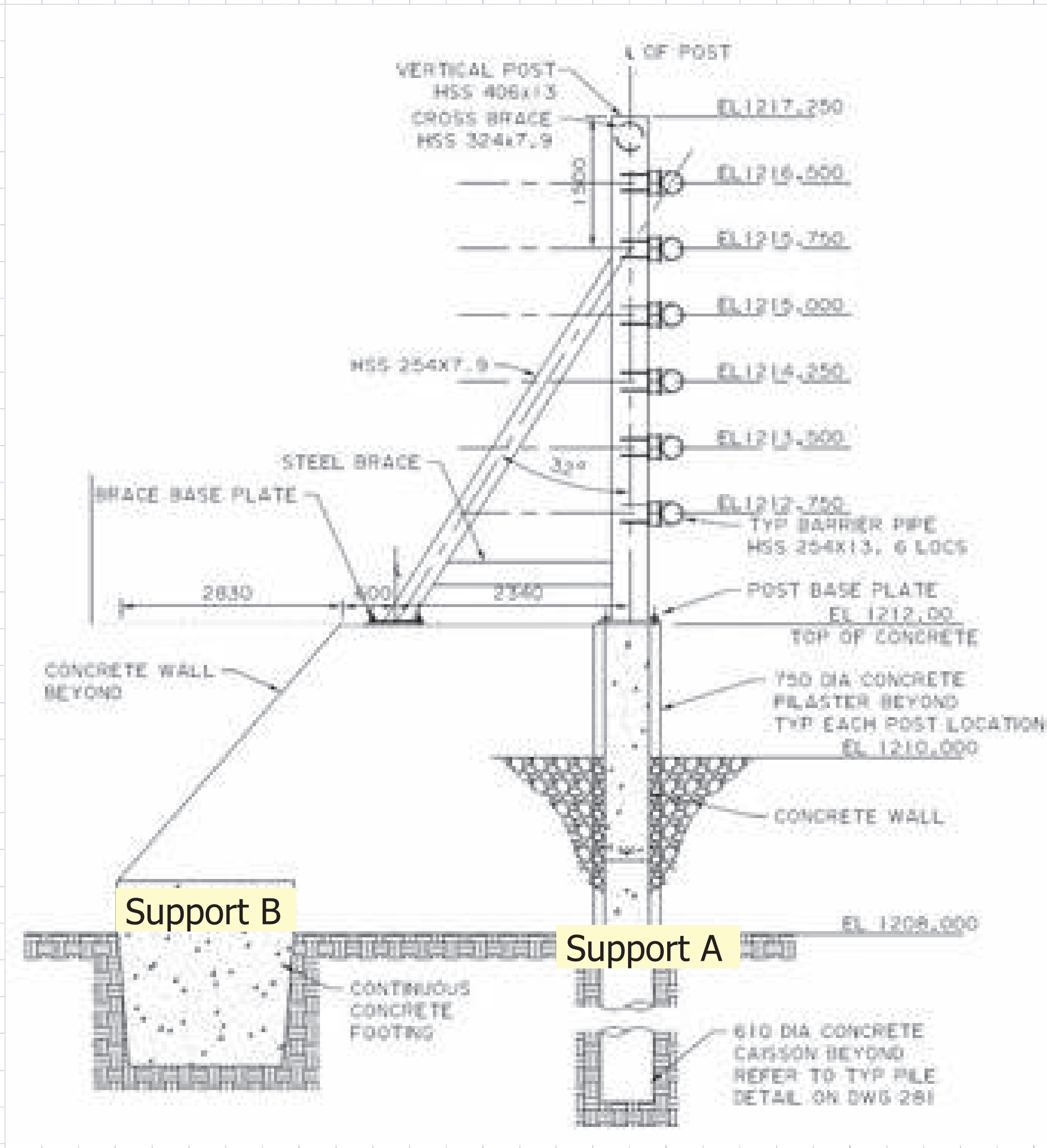
Maximum pile-head deflection = 0.0000795392 meters
Maximum pile-head rotation = -0.0000962073 radians = -0.005512 deg.

The analysis ended normally.

ATTACHMENT 3: SUPPORT B FOUNDATION CALCULATIONS

Stantec

Diagram of Debris Barrier Support at Section D:



Elevation difference from Base Plate to Bedrock at Section D: $\Delta elev := 4\ m$

Gravity Constant: $g = 9.81\ \frac{m}{s^2}$

References:
1. Statec Geotechnical Interpretive Report (Stantec, 2017)

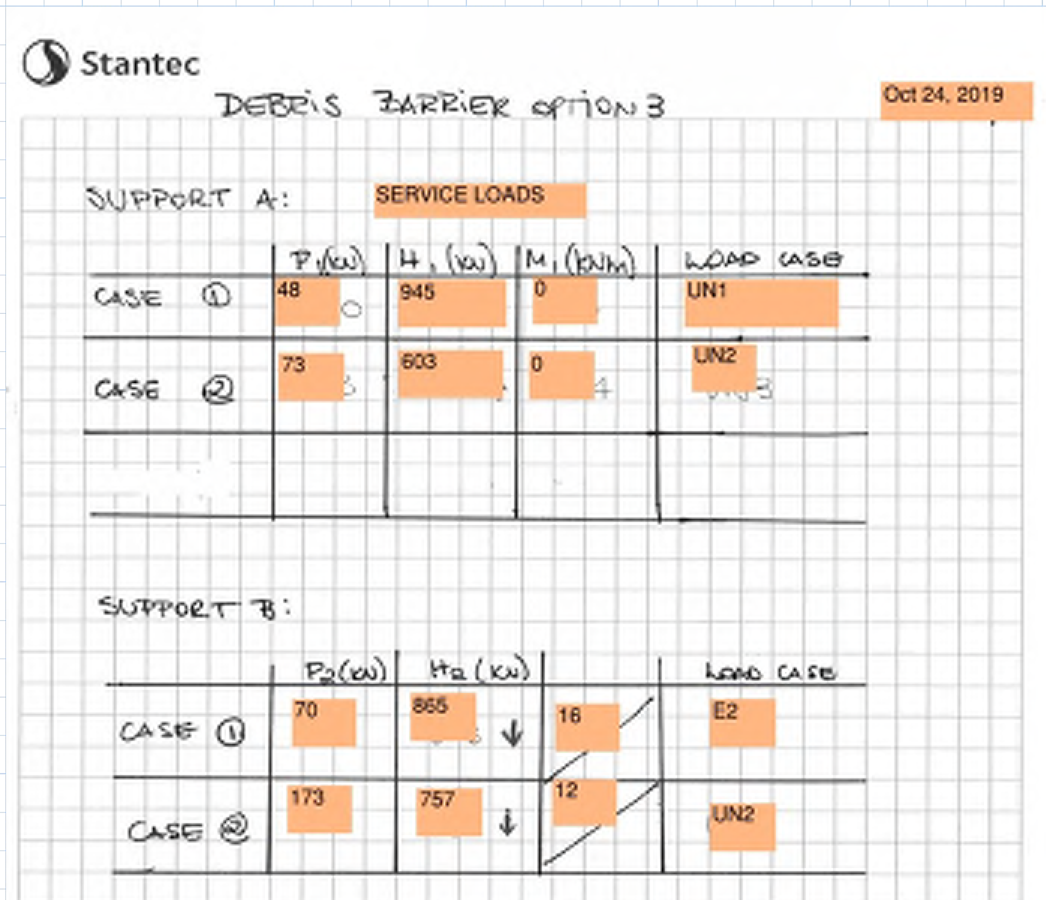
Stantec

Assumed Unit Weight of Concrete: $W_c := 2400 \frac{kg}{m^3} \cdot g = 23.54 \frac{kN}{m^3}$

Unit Weight of Water: $W_w := 9.807 \frac{kN}{m^3}$

Support B Unfactored Service Loads At Bedrock (Provided by Structural Team):

Loads* at Bedrock of Support A and Support B, Determined from SAP:


Stantec
DEBRIS BARRIER OPTION 3
Oct 24, 2019

SUPPORT A: SERVICE LOADS

	P_1 (kN)	H_1 (kN)	M_1 (kNm)	LOAD CASE
CASE ①	48	945	0	UN1
CASE ②	73	603	0	UN2

SUPPORT B:

	P_2 (kN)	H_2 (kN)		LOAD CASE
CASE ①	70	865	16	E2
CASE ②	173	757	12	UN2

These loads include concrete weight(s) above the bedrock elevation

Forces for Case 2 (Load Case UN2):

Vertical Load from Superstructure on Support B At Bedrock: $H_{2\_UN1} := 865\ kN$

Horizontal Load from Superstructure on Support B At Bedrock: $P_{2\_UN1} := 70\ kN$

Moment from Superstructure on Support B At Bedrock: $M_{2\_UN1} := 16\ kN \cdot m$

References:
1. Statec Geotechnical Interpretive Report (Stantec, 2017)

Footing and Bedrock Parameters:

Width of Strip Footing: $B_{strip} := 1\ m$

Length between Supports: $L_{strip} := 2.5\ m$

Depth of Strip Footing: $D_f := 1\ m$

Table 1. Allowable Bearing Capacity of Intact Rock (without Cohesion) - Diversion Structures

Bedrock Type	Percent Bedrock Type Below Bearing	Typical Unconfined Compressive Strength MPa	Cohesion Mpa	Estimated Basic Friction Angle (phi)	Ultimate Bearing Capacity [1] kPa	Allowable Bearing Capacity FOS = 3.0 kPa
Shale	30	20.7	0	29	2,627	876
Mudstone	40	5.5	0	24	1,510	503
Claystone	20	17.2	0	24	1,510	503
Sandstone	10	24.1	0	32	3,668	1,220

[1] Derived from USACE EM 1110-1-2908, Rock Foundations, Equation 6-1, 1994.

Assume weighted average of bedrock parameters for design:

Ultimate Bearing Capacity (Weighted Average):

$$q_{ult\_avg} := 2627\ kPa \cdot 30\% + 1510\ kPa \cdot 40\% + 1510\ kPa \cdot 20\% + 3668\ kPa \cdot 10\% = 2060.9\ \frac{kN}{m^2}$$

Allowable Bearing Capacity (Weighted Average):

$$q_{all\_avg} := \frac{q_{ult\_avg}}{3} = 686.97\ \frac{kN}{m^2}$$

Table 2. SR1 Diversion Structure – Cross Bed Shear Strength Parameters

Boring	Percent Bedrock Type Below Bearing	Typical Unconfined Compressive Strength MPa (psi)	Hoek-Brown Coefficients: Mi Value	GSI Value	D Value	Estimated Cross Bed Friction Angle	Estimated Cross Bed Cohesion kPa (psf)
Shale	30	20.7	6	35	0.5	35.1	124
Mudstone	40	5.5	4	30	0.5	19.8	59
Claystone	20	17.2	4	30	0.5	28.2	93
Sandstone	10	24.1	13	55	0.5	50.5	257

Estimated Cross Bed Friction Angle (Weighted Average):

$$\phi'_p := 35.1\ deg \cdot 30\% + 19.8\ deg \cdot 40\% + 28.2\ deg \cdot 20\% + 50.5\ deg \cdot 10\% = 29.14\ deg$$

References:
1. Statec Geotechnical Interpretive Report (Stantec, 2017)

Bearing Capacity Check:

Resultant Vertical Force: $Q := H_{2\_UN1} = 865\ kN$

Weight of Foundation: $W_{foundation} := (W_c - W_w) \cdot D_f \cdot B_{strip} \cdot L_{strip} = 34.32\ kN$

Total Vertical Force: $Q_{total} := Q + W_{foundation} = 899.32\ kN$

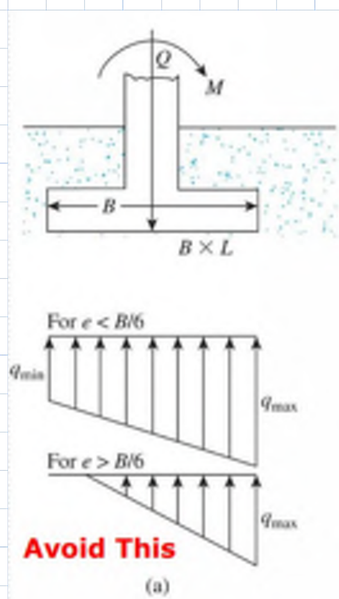
Resultant Horizontal Force: $H_B := P_{2\_UN1} = 70\ kN$

Tributary Area of Strip Footing: $A_{strip} := B_{strip} \cdot L_{strip} = 2.5\ m^2$

Eccentricity about the Base of the Footing: $e_B := \frac{M_{2\_UN1}}{Q_{total}} = 0.02\ m$

Check e<B/6: $e_B = 0.02\ m$ $\frac{B_{strip}}{6} = 0.17\ m$

Is e<B/6? Yes, for the assessed footing widths ($B_{strip} = 1\ m$)



References:
1. Statec Geotechnical Interpretive Report (Stantec, 2017)

Max Pressure Beneath Footing: $q_{max} := \frac{Q_{total}}{B_{strip} \cdot L_{strip}} \left(1 + \frac{6\ e_B}{B_{strip}}\right) = 398.13\ \frac{kN}{m^2}$

Min Pressure Beneath Footing: $q_{min} := \frac{Q_{total}}{B_{strip} \cdot L_{strip}} \left(1 - \frac{6\ e_B}{B_{strip}}\right) = 321.33\ \frac{kN}{m^2}$

Effective Footing Width: $B' := B_{strip} - 2\ e_B = 0.96\ m$

Effective Footing Length: $L' := L_{strip} = 2.5\ m$

Design Vertical Pressure: $q_u := \frac{Q_{total}}{B' \cdot L'} = 373\ \frac{kN}{m^2}$

Factor of Safety of Average Stress with Respect to Allowable: $FOS := \frac{q_{ult\_avg}}{q_u} = 5.53$

Factor of Safety of Max Pressure with Respect to Allowable: $FOS := \frac{q_{ult\_avg}}{q_{max}} = 5.18$

Based on the Above Calculations, the Factors of Safety Against Bearing Capacity Failure for the Assessed Foundation ($B_{strip} = 1\ m$, $L_{strip} = 2.5\ m$, $D_f = 1\ m$) are Sufficient.

References:
1. Statec Geotechnical Interpretive Report (Stantec, 2017)

Lateral Resistance Check:

Recommended Coefficient of Sliding Resistance: $\mu := 0.45$

Assumed Submerged Unit Weight of Mudstone from sample EP-1: $\gamma' := 22 \frac{kN}{m^3} - W_w = 12.19 \frac{kN}{m^3}$

Height of Soil Resistance: $H_o := D_f = 1\ m$

Earth Pressure Coefficients:

Active Earth Pressure Coefficient: $K_a := \tan\left(45\ deg - \frac{\phi'_p}{2}\right)^2 = 0.345$

At Rest Earth Pressure Coefficient: $K_o := 1 - \sin\left(\phi'_p\right) = 0.513$

Passive Earth Pressure Coefficient: $K_p := \tan\left(45\ deg + \frac{\phi'_p}{2}\right)^2 = 2.898$

Passive Lateral Force per Length of Strip Footing : $P_p := \frac{1}{2} K_p \cdot \gamma' \cdot H_o^2 \cdot L_{strip} = 44.17\ kN$

FOS Against Sliding Assuming no Scour and Ignoring Foundation Weight:

$$FOS_{sliding\_1} := \frac{\mu \cdot \left(H_{2\_UN1}\right) + P_p}{P_{2\_UN1}} = 6.19$$

FOS Against Sliding Assuming no Scour, but Including Foundation Weight:

$$FOS_{sliding\_2} := \frac{\mu \cdot \left(H_{2\_UN1} + W_{foundation}\right) + P_p}{P_{2\_UN1}} = 6.41$$

Based on the Above Calculations, the Factors of Safety Against Sliding for the Assessed Foundation ($B_{strip} = 1\ m$, $L_{strip} = 2.5\ m$, $D_f = 1\ m$) are Sufficient.

References:
1. Statec Geotechnical Interpretive Report (Stantec, 2017)

ATTACHMENT 11
DIVERSION CHANNEL

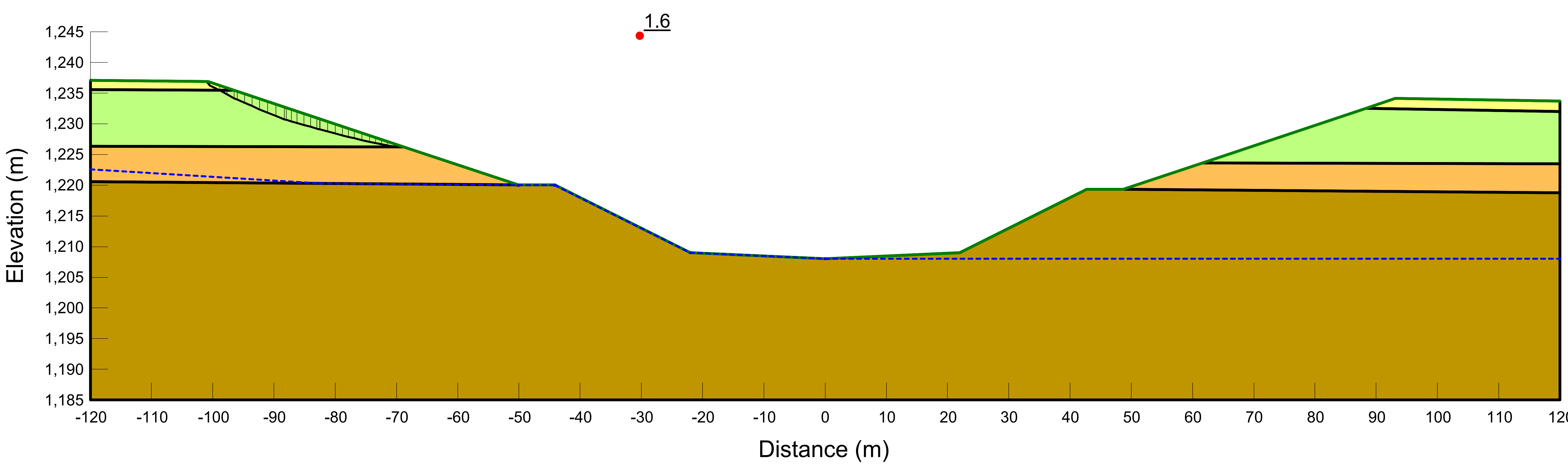
Attachment 11.1
Diversion Channel
Slope Stability Results

Stantec	Alberta Transportation	Slope Stability Analysis	Note:
	Springbank Offstream Storage Project (SR1)	Diversion Channel Station 10+150 m Ref. 1	The results of the analysis shown here are based on available subsurface information, laboratory results, and approximate soil properties. The drawing depicts approximate subsurface conditions based on specific borings at the time of drilling. No warranties can be made regarding the continuity of subsurface conditions.
	Preliminary Geotechnical Assessment Report		

Failure Mechanism:
Optimized rotational failure through GL/GT units

Groundwater Conditions:
Existing Groundwater
15 m Below Surface
No Groundwater Control

Color	Name	Unit Weight (kN/m³)	Strength Function	Cohesion' (kPa)	Phi' (°)
	Basal Granular Till	22		0	35
	Brazeau Formation	21	Brazeau Formation		
	Glacial Till	18		0	27
	Glacio-Lacustrine	18		0	23

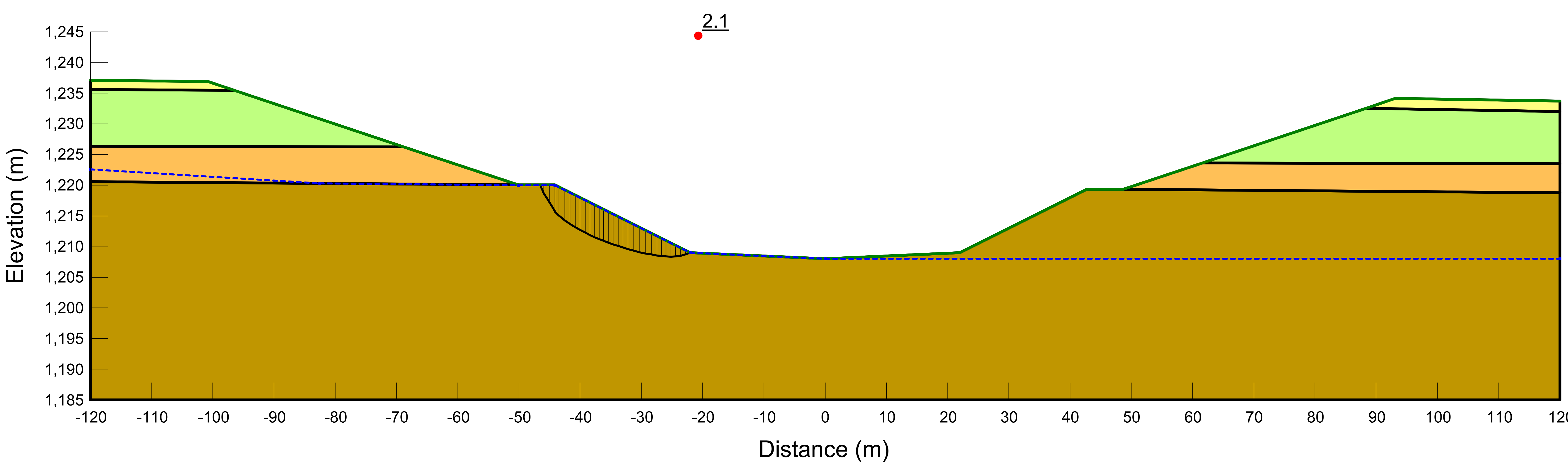


Stantec	**Alberta Transportation**	**Slope Stability Analysis**	Note:
	Springbank Offstream Storage Project (SR1)	Diversion Channel Station 10+150 m Ref. 2	The results of the analysis shown here are based on available subsurface information, laboratory results, and approximate soil properties. The drawing depicts approximate subsurface conditions based on specific borings at the time of drilling. No warranties can be made regarding the continuity of subsurface conditions.
	Preliminary Geotechnical Assessment Report		

Failure Mechanism:
Optimized rotational failure through the bedrock

Groundwater Conditions:
Existing Groundwater
15 m Below Surface
No Groundwater Control

Color	Name	Unit Weight (kN/m³)	Strength Function	Cohesion' (kPa)	Phi' (°)
	Basal Granular Till	22		0	35
	Brazeau Formation	21	Brazeau Formation		
	Glacial Till	18		0	27
	Glacio-Lacustrine	18		0	23

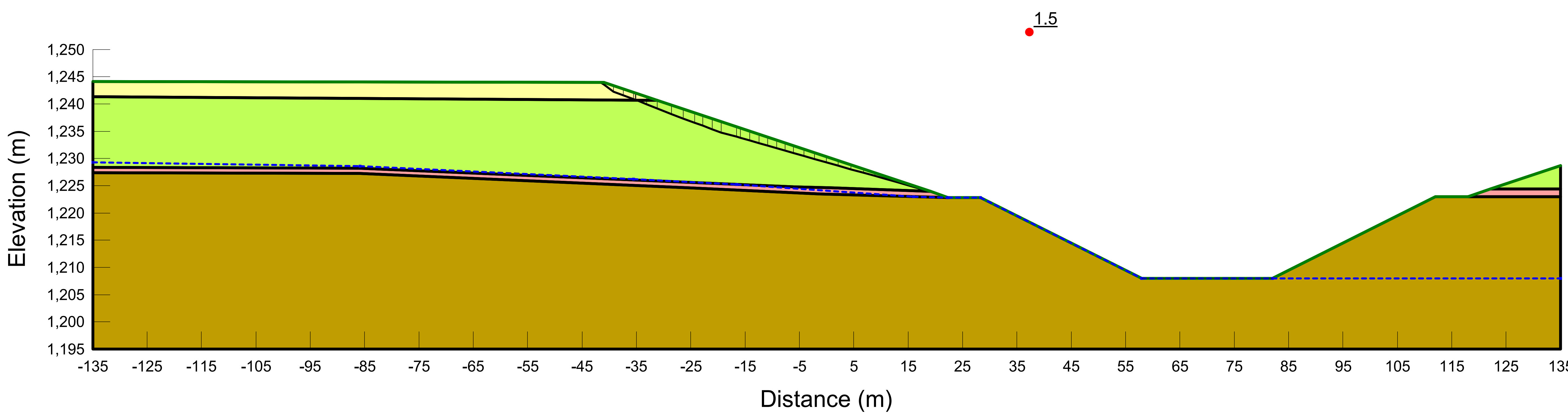


Stantec	Alberta Transportation	Slope Stability Analysis	Note:
	Springbank Offstream Storage Project (SR1)	Diversion Channel Station 10+400 m Ref. 1	The results of the analysis shown here are based on available subsurface information, laboratory results, and approximate soil properties. The drawing depicts approximate subsurface conditions based on specific borings at the time of drilling. No warranties can be made regarding the continuity of subsurface conditions.
	Preliminary Geotechnical Assessment Report		

Failure Mechanism:
Optimized rotational failure through glacigenic units

Groundwater Conditions:
Existing Groundwater
15 m Below Surface
No GW Control

Color	Name	Unit Weight (kN/m³)	Strength Function	Cohesion' (kPa)	Phi' (°)
	Basal Granular Till	22		0	35
	Brazeau Formation	21	Brazeau Formation		
	Glacial Till	18		0	27
	Glacio-Lacustrine	18		0	23



Stantec

Alberta Transportation

Springbank Offstream Storage Project (SR1)

Preliminary Geotechnical Assessment Report

Slope Stability Analysis

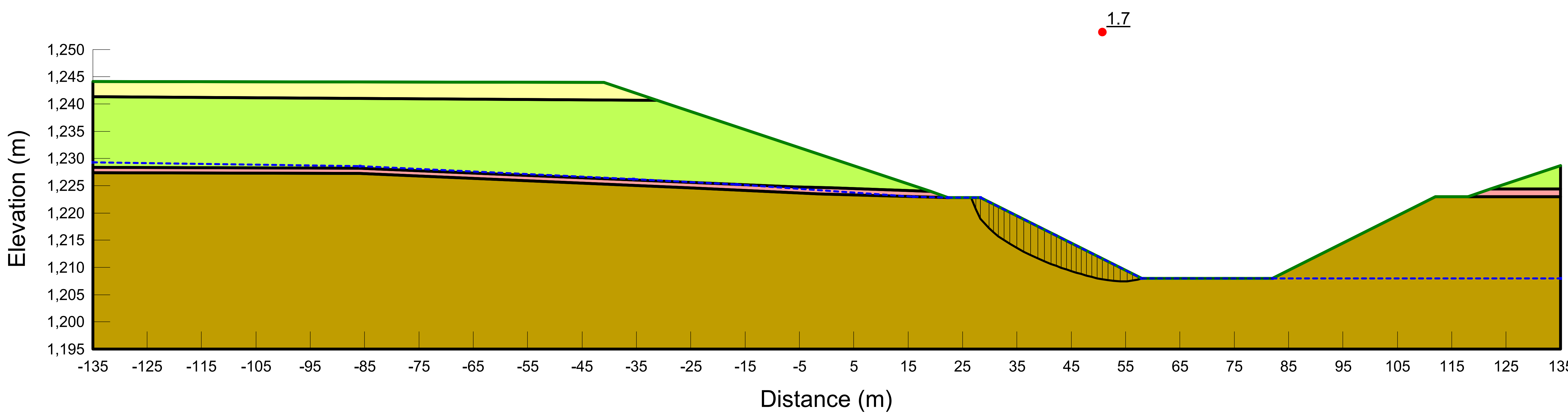
Diversion Channel
Station 10+400 m
Ref. 2

Note:
The results of the analysis shown here are based on available subsurface information, laboratory results, and approximate soil properties. The drawing depicts approximate subsurface conditions based on specific borings at the time of drilling.
No warranties can be made regarding the continuity of subsurface conditions.

Failure Mechanism:
Optimized rotational failure through the bedrock

Groundwater Conditions:
Existing Groundwater
15 m Below Surface
No GW Control

Color	Name	Unit Weight (kN/m³)	Strength Function	Cohesion' (kPa)	Phi' (°)
	Basal Granular Till	22		0	35
	Brazeau Formation	21	Brazeau Formation		
	Glacial Till	18		0	27
	Glacio-Lacustrine	18		0	23



Stantec

Alberta Transportation

Springbank Offstream Storage Project (SR1)

Preliminary Geotechnical Assessment Report

Slope Stability Analysis

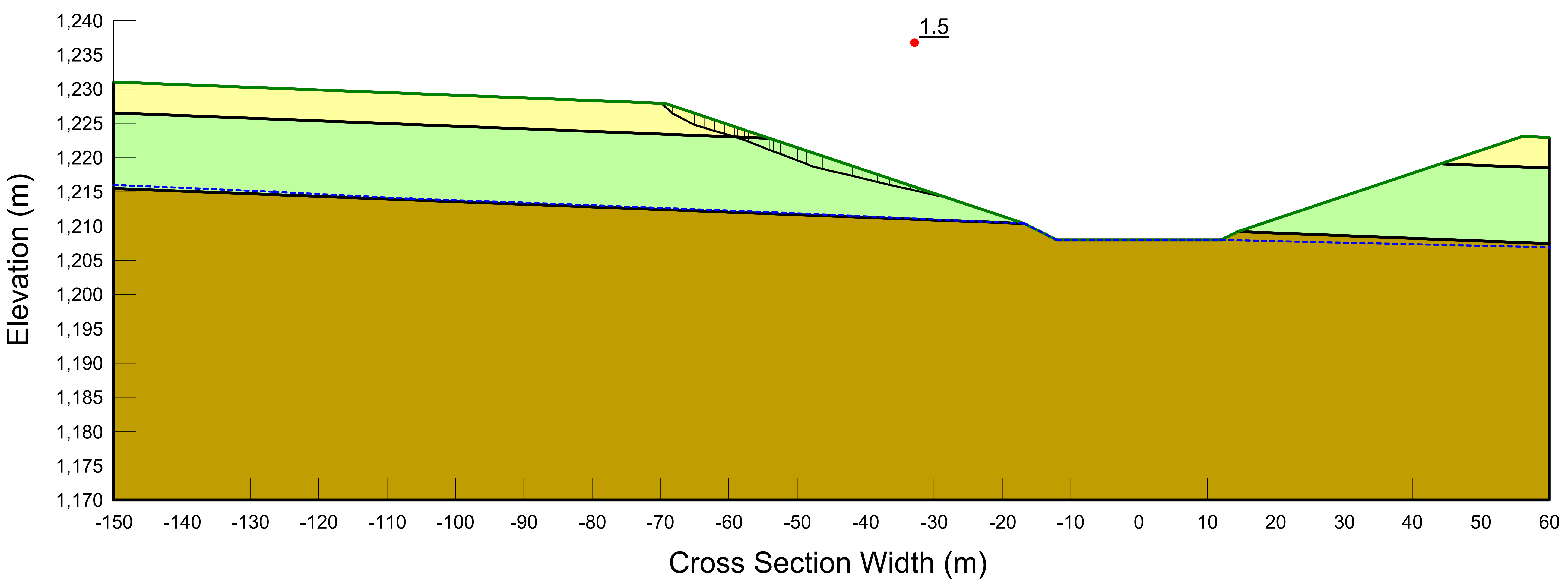
Diversion Channel
Station 11+000 m
Ref. 1

Note:
The results of the analysis shown here are based on available subsurface information, laboratory results, and approximate soil properties. The drawing depicts approximate subsurface conditions based on specific borings at the time of drilling.
No warranties can be made regarding the continuity of subsurface conditions.

Failure Mechanism:
Optimized rotational failure through GL/GT units

Groundwater Conditions:
Exisiting Groundwater
15 m Below Surface
No GW Control

Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)	Strength Function
	Brazeau Formation	21			Brazeau Formation
	Glacial Till	18	0	27	
	Glacio-Lacustrine	18	0	23	

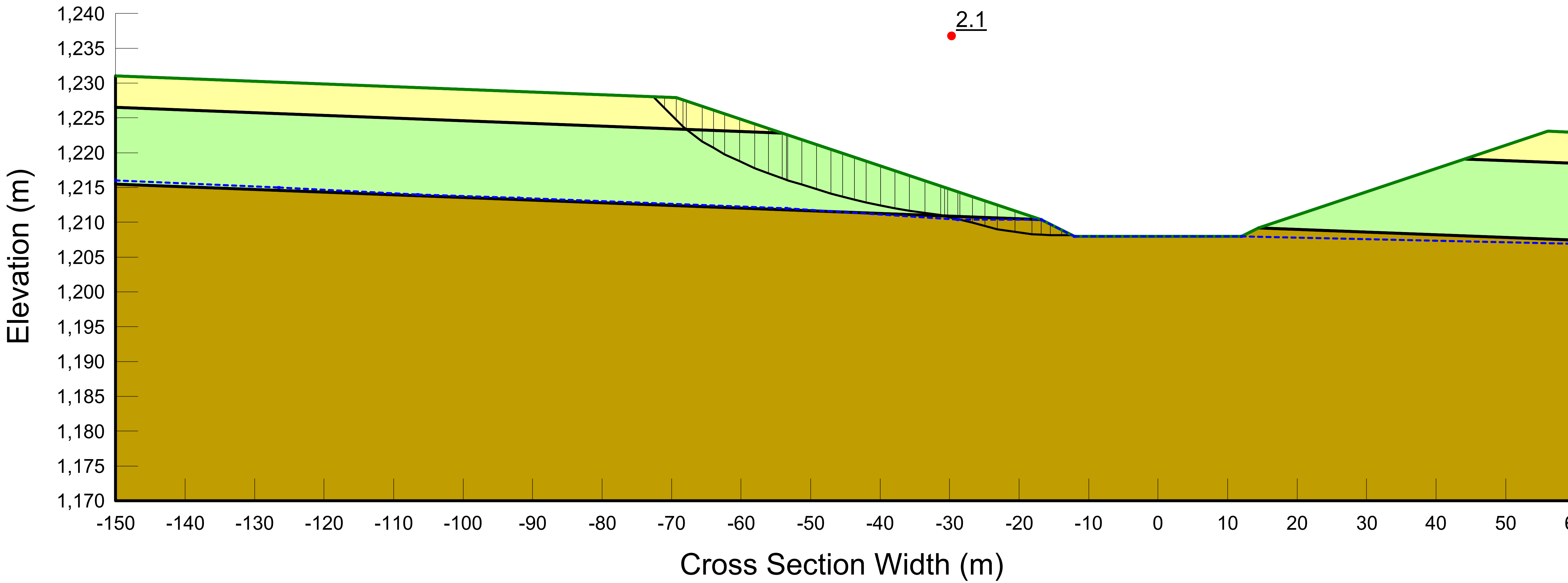


Stantec	Alberta Transportation	Slope Stability Analysis	Note:
	Springbank Offstream Storage Project (SR1)	Diversion Channel Station 11+000 m Ref. 2	The results of the analysis shown here are based on available subsurface information, laboratory results, and approximate soil properties. The drawing depicts approximate subsurface conditions based on specific borings at the time of drilling. No warranties can be made regarding the continuity of subsurface conditions.
	Preliminary Geotechnical Assessment Report		

Failure Mechanism:
Optimized rotational failure through all units

Groundwater Conditions:
Exisitng Groundwater
15 m Below Surface
No GW Control

Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)	Strength Function
	Brazeau Formation	21			Brazeau Formation
	Glacial Till	18	0	27	
	Glacio-Lacustrine	18	0	23	

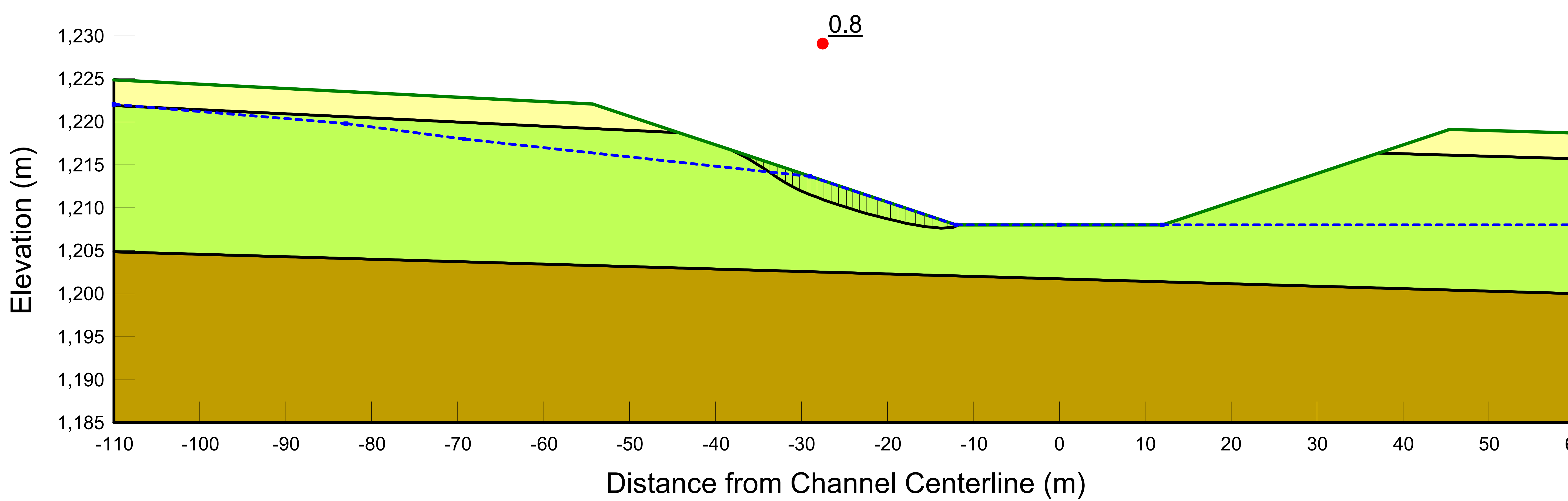


Alberta Transportation	Slope Stability Analysis	Note:
Springbank Offstream Storage Project (SR1)	Diversion Channel Station 11+400 m Ref. 1	The results of the analysis shown here are based on available subsurface information, laboratory results, and approximate soil properties. The drawing depicts approximate subsurface conditions based on specific borings at the time of drilling. No warranties can be made regarding the continuity of subsurface conditions.
Preliminary Geotechnical Assessment Report		

Failure Mechanism:
Optimized rotational failure through GT unit

Groundwater Conditions:
Existing Groundwater
3 m Below Surface
No GW Control

Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)	Strength Function
	Brazeau Formation	21			Brazeau Formation
	Glacial Till	18	0	27	
	Glacio-Lacustrine	18	0	23	

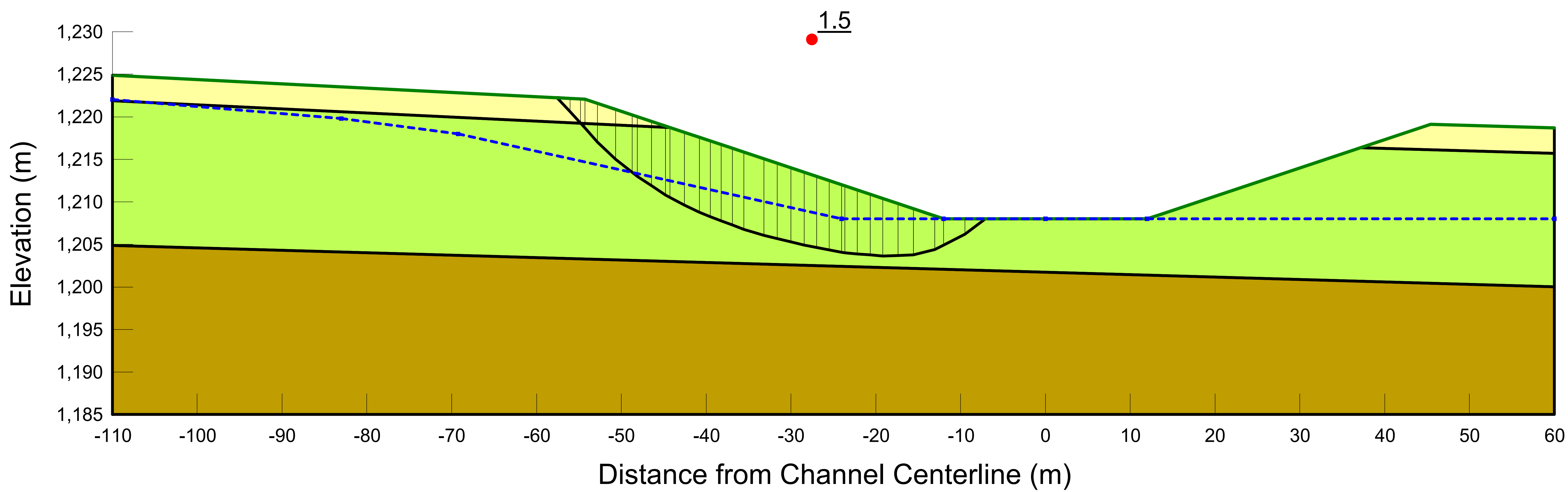


Stantec	**Alberta Transportation**	**Slope Stability Analysis**	Note: The results of the analysis shown here are based on available subsurface information, laboratory results, and approximate soil properties. The drawing depicts approximate subsurface conditions based on specific borings at the time of drilling. No warranties can be made regarding the continuity of subsurface conditions.
	Springbank Offstream Storage Project (SR1)	Diversion Channel Station 11+400 m Ref. 2	
	Preliminary Geotechnical Assessment Report		

Failure Mechanism:
Optimized rotational failure through GL/GT units

Groundwater Conditions:
Existing Groundwater with GW Control
12 m Horizontal from Channel Toe and 3 m Vertical Below Surface

Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)	Strength Function
	Brazeau Formation	21			Brazeau Formation
	Glacial Till	18	0	27	
	Glacio-Lacustrine	18	0	23	

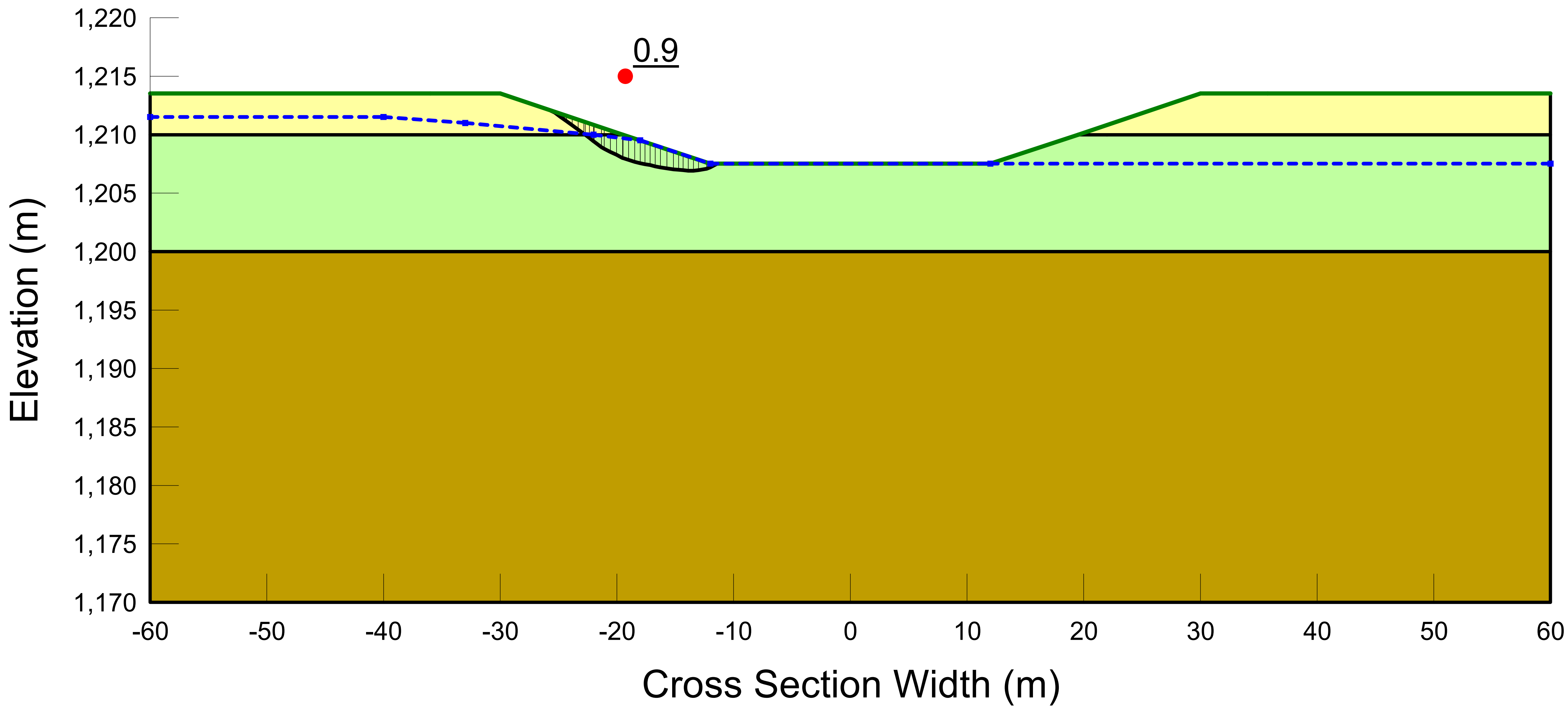


Stantec	**Alberta Transportation**	**Slope Stability Analysis**	Note: The results of the analysis shown here are based on available subsurface information, laboratory results, and approximate soil properties. The drawing depicts approximate subsurface conditions based on specific borings at the time of drilling. No warranties can be made regarding the continuity of subsurface conditions.
	Springbank Offstream Storage Project (SR1)	Channel Diversion Station 11+900 m Ref. 1	
	Preliminary Geotechnical Assessment Report		

Failure Mechanism:
Optimized rotational failure through the GL/GT units

Groundwater Conditions:
Existing Groundwater
3 m Below Surface
No GW Control

Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)	Strength Function
	Brazeau Formation	21			Brazeau Formation
	Glacial Till	18	0	27	
	Glacio-Lacustrine	18	0	23	

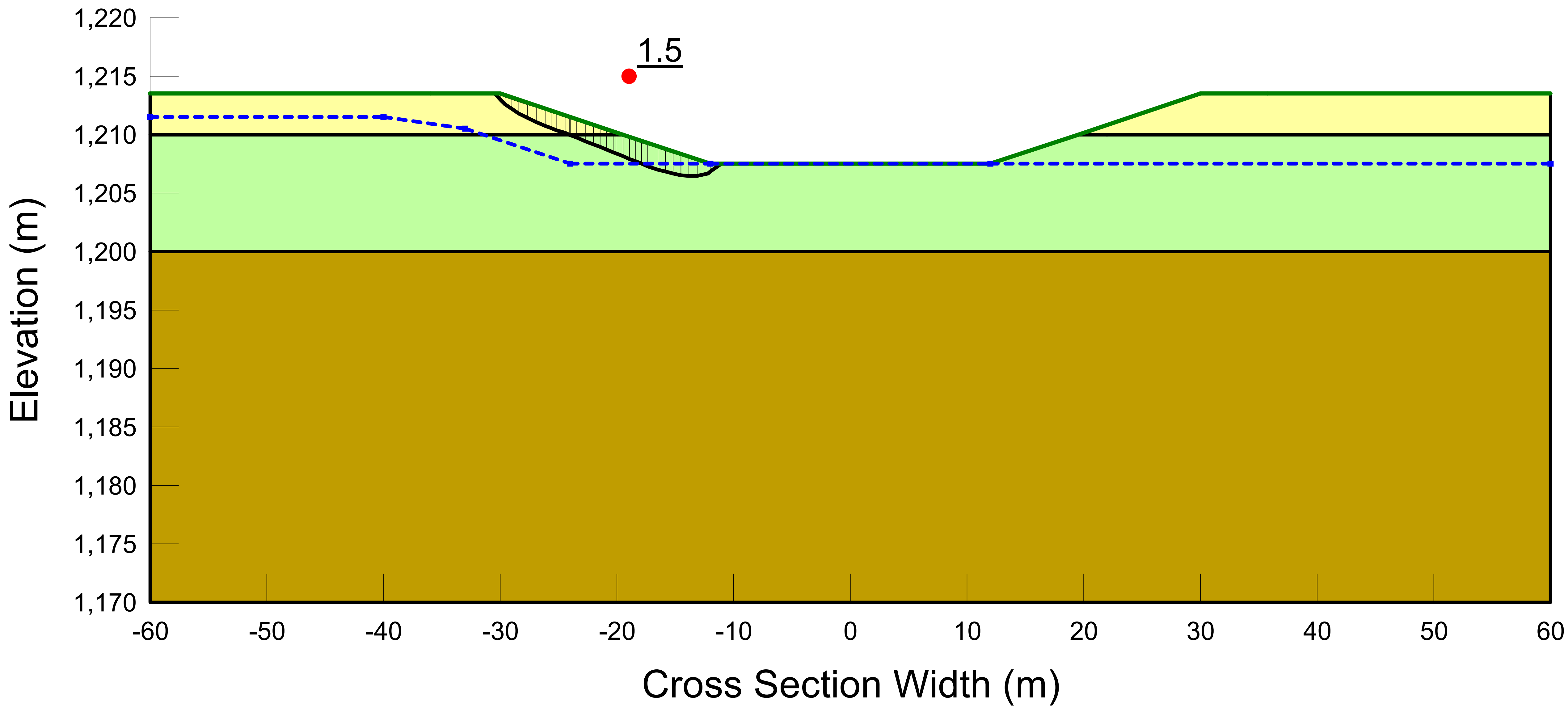


Stantec	Alberta Transportation	Slope Stability Analysis	Note:
	Springbank Offstream Storage Project (SR1)	Channel Diversion Station 11+900 m Ref. 2	The results of the analysis shown here are based on available subsurface information, laboratory results, and approximate soil properties. The drawing depicts approximate subsurface conditions based on specific borings at the time of drilling. No warranties can be made regarding the continuity of subsurface conditions.
	Preliminary Geotechnical Assessment Report		

Failure Mechanism:
Optimized rotational failure through the GL/GT units

Groundwater Conditions:
Existing Groundwater with GW Control
12 m Horizontal from Channel Toe and
3 m Vertical Below Surface

Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)	Strength Function
	Brazeau Formation	21			Brazeau Formation
	Glacial Till	18	0	27	
	Glacio-Lacustrine	18	0	23	



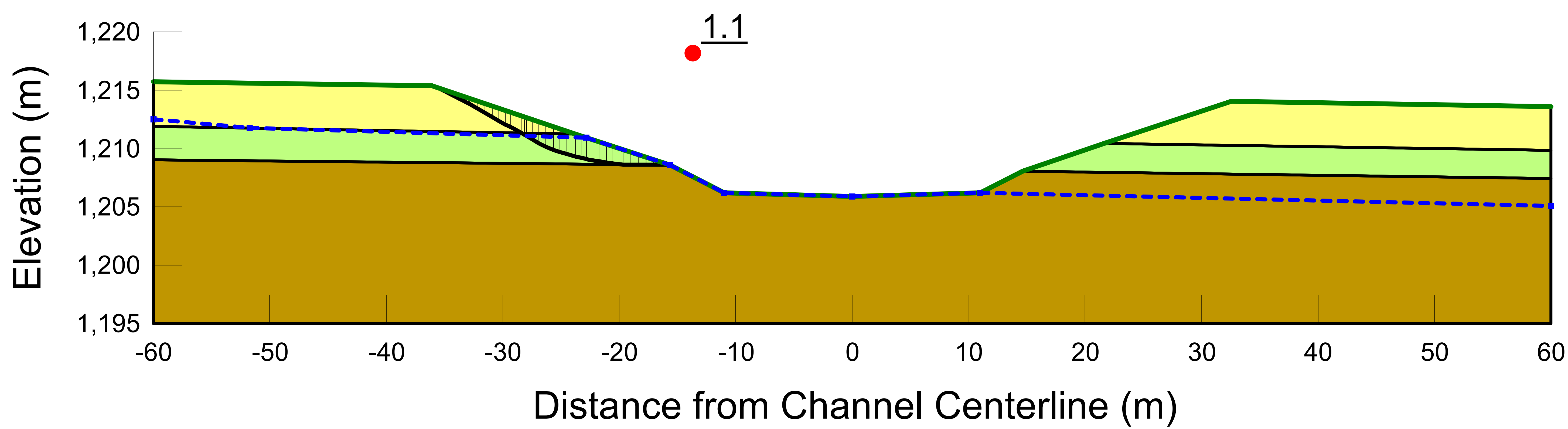
Stantec	Alberta Transportation	Slope Stability Analysis	Note:
	Springbank Offstream Storage Project (SR1)	Channel Diversion Station 12+400 m Ref. 1	The results of the analysis shown here are based on available subsurface information, laboratory results, and approximate soil properties. The drawing depicts approximate subsurface conditions based on specific borings at the time of drilling. No warranties can be made regarding the continuity of subsurface conditions.
	Preliminary Geotechnical Assessment Report		

Failure Mechanism:
Optimized rotational failure through GL/GT units

Groundwater Conditions:
Existing Groundwater
3 m Below Surface
No GW Control

Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)	Strength Function
	Brazeau Formation	21			Brazeau Formation
	Glacial Till	18	0	27	
	Glacio-Lacustrine	18	0	23	

*The strength function defines a unique non-linear relationship of shear resistance that varies based on the normal stress.



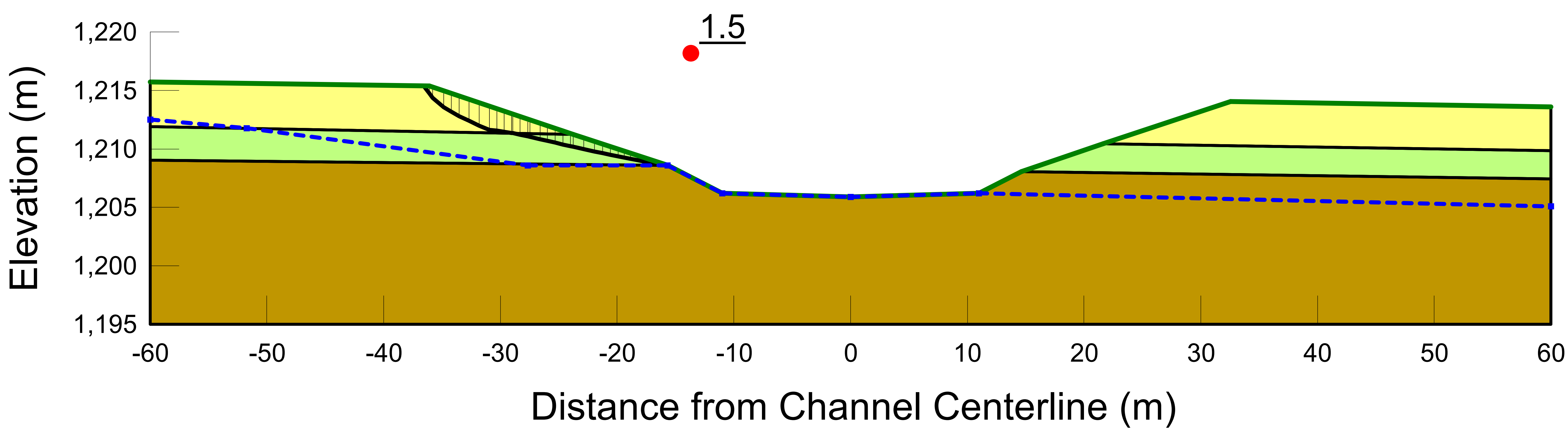
Note:
The results of the analysis shown here are based on available subsurface information, laboratory results, and approximate soil properties. The drawing depicts approximate subsurface conditions based on specific borings at the time of drilling.
No warranties can be made regarding the continuity of subsurface conditions.

Failure Mechanism:
Optimized rotational failure through GL/GT units

Groundwater Conditions:
Existing Groundwater with GW Control
12 m Horizontal from Channel Toe and
3 m Vertical Below Surface

Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)	Strength Function
	Brazeau Formation	21			Brazeau Formation
	Glacial Till	18	0	27	
	Glacio-Lacustrine	18	0	23	

*The strength function defines a unique non-linear relationship of shear resistance that varies based on the normal stress.



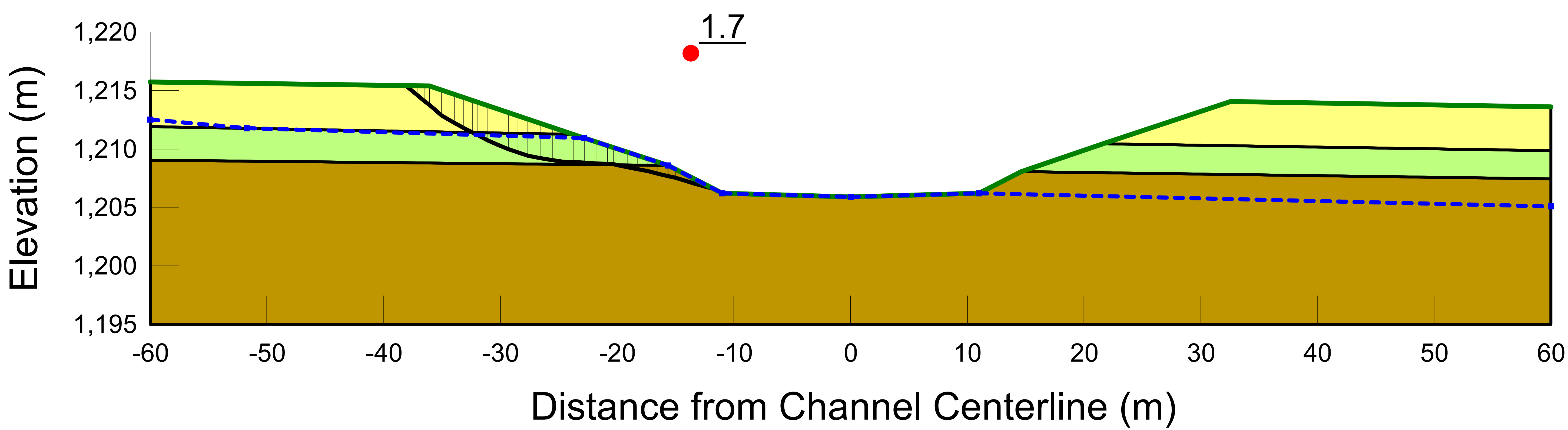
Stantec	**Alberta Transportation**	**Slope Stability Analysis**	Note:
	Springbank Offstream Storage Project (SR1)	Channel Diversion Station 12+400 m Ref. 3	The results of the analysis shown here are based on available subsurface information, laboratory results, and approximate soil properties. The drawing depicts approximate subsurface conditions based on specific borings at the time of drilling. No warranties can be made regarding the continuity of subsurface conditions.
	Preliminary Geotechnical Assessment Report		

Failure Mechanism:
Optimized rotational failure through all units

Groundwater Conditions:
Existing Groundwater
3 m Below Surface
No GW Control

Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)	Strength Function
	Brazeau Formation	21			Brazeau Formation
	Glacial Till	18	0	27	
	Glacio-Lacustrine	18	0	23	

*The strength function defines a unique non-linear relationship of shear resistance that varies based on the normal stress.



Stantec

Alberta Transportation

Springbank Offstream Storage Project (SR1)

Preliminary Geotechnical Assessment Report

Slope Stability Analysis

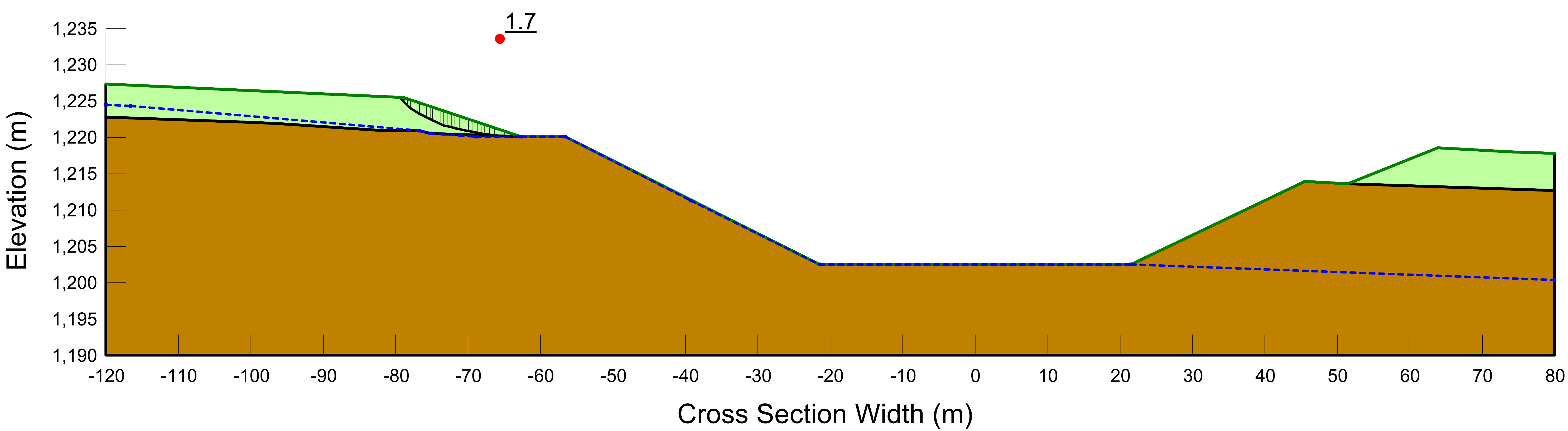
Diversion Channel
Station 14+000 m
Ref. 1

Note:
The results of the analysis shown here are based on available subsurface information, laboratory results, and approximate soil properties. The drawing depicts approximate subsurface conditions based on specific borings at the time of drilling.
No warranties can be made regarding the continuity of subsurface conditions.

Failure Mechanism:
Optimized rotational material through GT unit

Groundwater Conditions:
Existing Groundwater
3 m Below Surface
No GW control

Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)	Strength Function
	Coalspur Formation	21			Coalspur Formation
	Glacial Till	18	0	27	

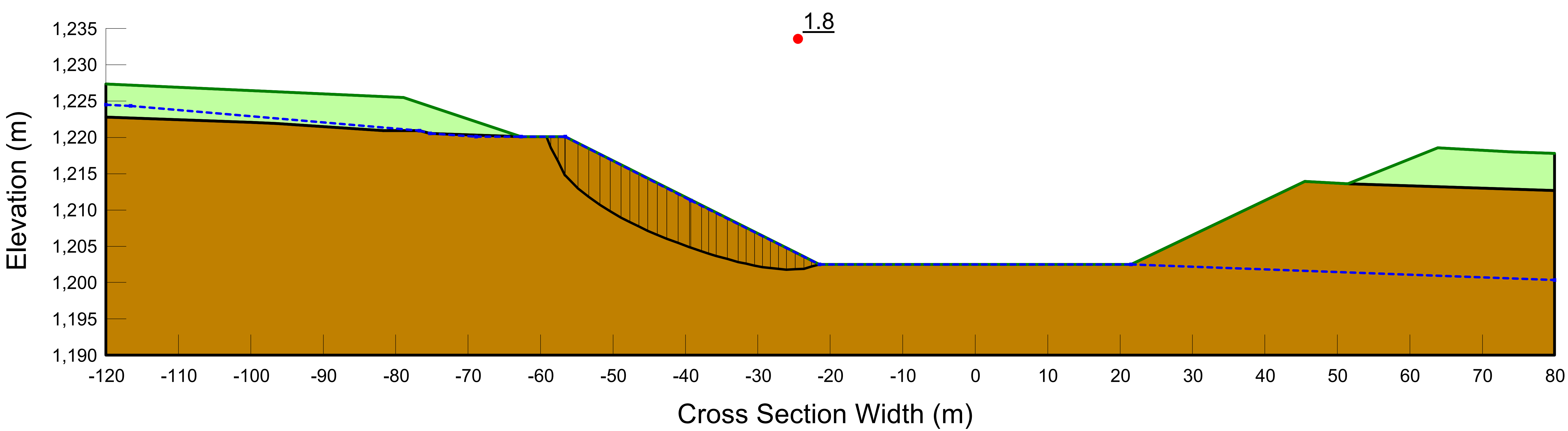


Stantec	**Alberta Transportation**	**Slope Stability Analysis**	Note: The results of the analysis shown here are based on available subsurface information, laboratory results, and approximate soil properties. The drawing depicts approximate subsurface conditions based on specific borings at the time of drilling. No warranties can be made regarding the continuity of subsurface conditions.
	Springbank Offstream Storage Project (SR1)	Diversion Channel Station 14+000 m Ref. 2	
	Preliminary Geotechnical Assessment Report		

Failure Mechanism:
Optimized rotational material through the bedrock

Groundwater Conditions:
Existing Groundwater
3 m Below Surface
No GW Control

Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)	Strength Function
	Coalspur Formation	21			Coalspur Formation
	Glacial Till	18	0	27	



Attachment 11.2 Emergency Spillway Soil Parameters

Internal Geotechnical Design Recommendations

Recommended Geotechnical Parameters
SR-1 Emergency Spillway Structures
Revised 12-September-2018

Geotechnical Information required for the Emergency Spillway structural design (Article references below refer to Chapter 5 – Project Data in the Emergency Spillway Structural Design Report)

5.3 <u>Foundation Parameters</u>

- Soil Classifications
  - Soil Layer 1 - Lean to Fat Clay (CL to CH) Lacustrine
    Layer thickness ranges from 1.8 m to 2.7 m from existing surface.
    (Based on Borings DC23 and DC24)
  - Soil Layer 2 - Lean Clay Glacial Till with Sand and Gravel (CL)
    Layer thickness ranges from 3.9 m to 4.6 m from base of lacustrine.
    (Based on Borings DC23 and DC24)
  - Depths to bedrock range from 6.4 m to 6.6 m
    (Based on Borings DC23 and DC24)
- Allowable bedrock bearing capacity (q_a)
  - 622 kPa (13,000 psf)
    (Derived from Brazeau Formation data)
- Effective soil angle of repose (Effective Friction Angle)(φ)
  - Lean Clay Glacial Till with Sand: Φ = 27 degrees
  - Fat Clay (Lacustrine): Φ = 23 degrees
- Effective Friction Angle of Bedrock (φ)
  - Weathered Sandstone and Mudstone Bedrock: Φ = 24 degrees
    (Derived from Brazeau Formation data)
- Effective cohesion (c)
  - c = 0 kPa (all layers)
- Coefficient of sliding friction (μ)
  - Lean Clay Glacial Till with Sand: μ = 0.51
  - Fat Clay (Lacustrine): μ = 0.42
  - Bedrock: μ = 0.45
- Settlement
  - Settlement of rock bearing structural elements should be negligible.
- Subgrade Modulus
  - Lean to Fat Clay (Lacustrine): 27 MN/m^3 (99.4 lb/in^3)
  - Lean Clay Glacial Till with Sand: 34 MN/m^3 (125.2 lb/in^3)
  - Weathered Bedrock/Crushed Rock: 81.5 MN/m^3 (300.1 lb/in^3)
  - Bedrock: 136 MN/m^3 (500.8 lb/in^3)

Due to potential settlement problems associated with partial soil and partial rock bearing structural elements, all individual structural elements should be supported entirely by either rock or soil bearing foundations. Soil and highly weathered bedrock should be excavated to competent rock and backfilled with durable crushed stone or flowable fill if possible. If two adjacent structural elements must be supported as one rock bearing and the other soil bearing, then a structural joint shall be provided between these elements to provide independent movement and rotation between them.

5.4 Level Bedding, Backfill and Embankment Fill Parameters

Lacustrine soils are not recommended for use as backfill material.

- γ_{sat}
  - Embankment Soils: 2040 kg/m^3 or 20.0 kN/m^3 (127.3 lb/ft^3)
- γ_{moist}
  - Embankment Soils: 2040 kg/m^3 or 20.0 kN/m^3 (127.3 lb/ft^3)
- Φ_{eff}
  - Embankment Shell: Φ = 27 degrees
- K_o
  - Embankment Shell: $K_o = 0.55$
- K_a
  - Embankment Shell: $K_a = 0.38$
- K_p
  - Embankment Shell: $K_p = 2.66$
- Permeability
  - Embankment Shell: k_v = 3.00 E -08 cm/sec
  - Lean Clay Till Foundation Soils: k_v = 3.00 E -08 cm/sec

5.5 Sandy Gravel (Floodplain Berm Fluvial Soils) 3:1 Downward Backfill Parameters

- γ_{sat}
  - Fluvial Soil Backfill: 2040 kg/m^3 or 20.0 kN/m^3 (127.3 lb/ft^3)
- γ_{moist}
  - Fluvial Soil Backfill: 2040 kg/m^3 or 20.0 kN/m^3 (127.3 lb/ft^3)
- Φ_{eff}
  - Fluvial Soil Backfill: Φ = 38 degrees
- K_a
  - Fluvial Soil Backfill: $K_a = 0.21$
- K_p
  - Fluvial Soil Backfill: $K_p = 2.2$

5.6 Seepage Parameters and Uplift Assumptions

- Assume full uplift between the headwater and tailwater condition. Uplift should be modified to account for any cutoff or drains as appropriate. Uplift pressures may be affected by different bearing materials and/or by specific requirements of the design criteria used.

5.7 Frost Considerations

- Frost depth
  - Recommended design frost depth = 2.0 meters
- Non-frost susceptible backfill
  - Gravel and clean sands

Should there be any questions contact:

Vince Severance 859 422-3031
Dan Back 859 422-3034

ATTACHMENT 12
OFF-STREAM STORAGE DAM

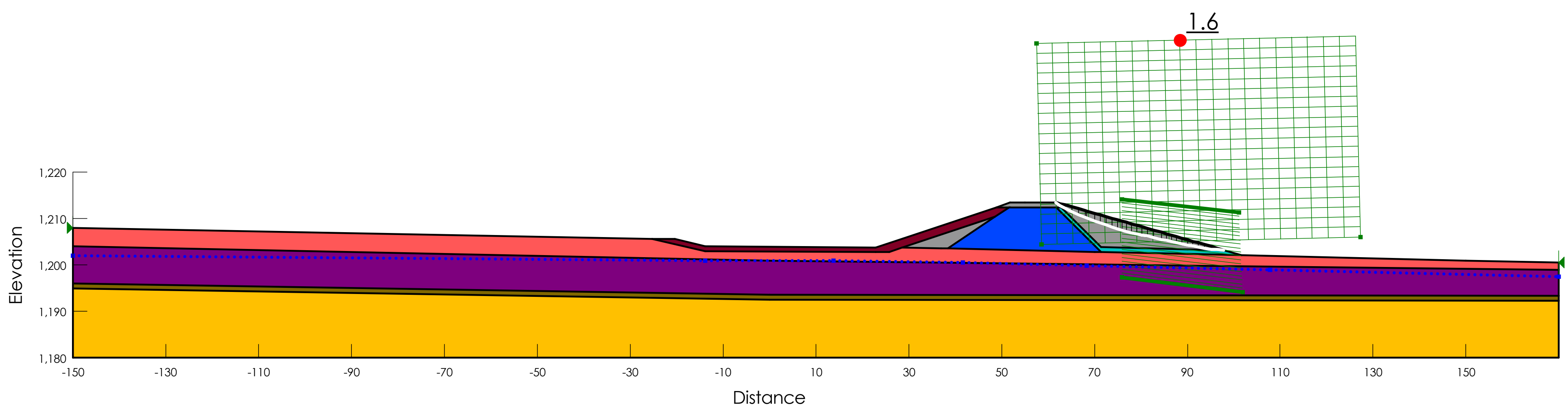
Attachment 12.1
Slope Stability and Seepage Analyses

12.1.1 Slope Stability Analyses
Sta. 20+000

Alberta Transportation SR1 Storage Dam

Section 20+000
Load Case: End of Construction, Year 3
B-bar Analysis
Effective Stress Parameters

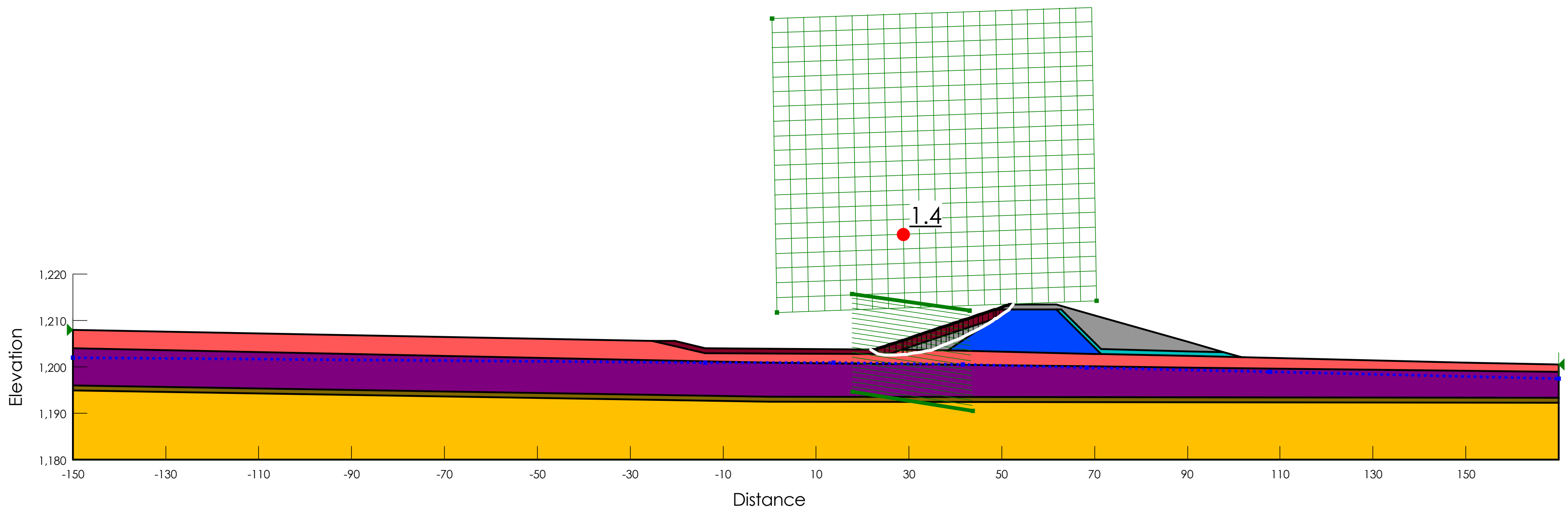
Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)	B-bar	Add Weight
	Drain	21	0	33	0	Yes
	Embankment Core (Drained, Year 3)	20	0	28	0	Yes
	Embankment Shell (Drained, Year 3)	20	0	24	0	Yes
	Glacial Till (Drained)	18	0	27	0.1	No
	Glacio-Lacustrine (Drained)	18	0	23	0.15	No
	Rock Toe	20	0	33	0	Yes
	Sandstone				0	No
	Weathered Bedrock	21	0	35	0	No



Alberta Transportation SR1 Storage Dam

Section 20+000
Load Case: End of Construction, Year 3
B-bar Analysis
Effective Stress Parameters

Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)	B-bar	Add Weight
	Drain	21	0	33	0	Yes
	Embankment Core (Drained, Year 3)	20	0	28	0	Yes
	Embankment Shell (Drained, Year 3)	20	0	24	0	Yes
	Glacial Till (Drained)	18	0	27	0.1	No
	Glacio-Lacustrine (Drained)	18	0	23	0.15	No
	Rock Toe	20	0	33	0	Yes
	Sandstone				0	No
	Weathered Bedrock	21	0	35	0	No

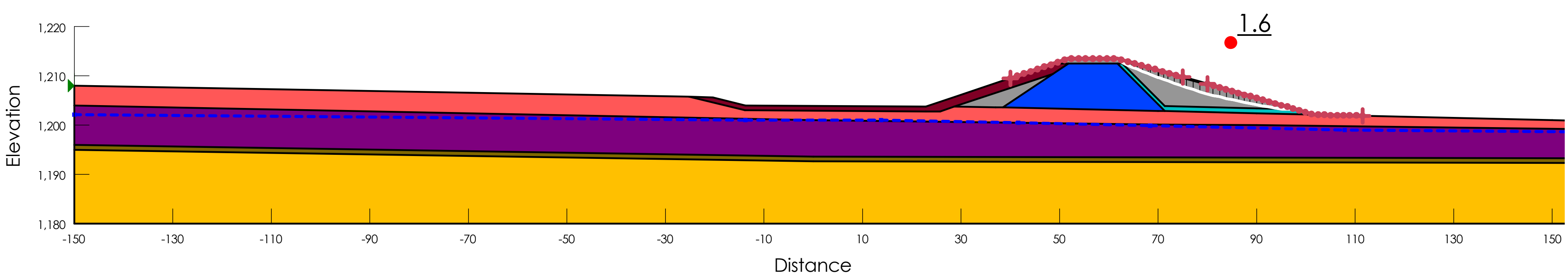


Stantec

Alberta Transportation SR1 Storage Dam

Section 20+000
Load Case: End of Construction
Total Stress Parameters
Incipient Motion in the Downstream Direction

Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)
	Drain	21		0				33
	Embankment Core (Undrained)	20		0	28	19	427	
	Embankment Shell (Undrained)	20		0	24	15	141	
	Glacial Till (Undrained)	18		0	27	19	363.2	
	Glacio-Lacustrine (Undrained)	18	Glacio-Lacustrine (Undrained)					0
	Rock Toe	20		0				33
	Sandstone							
	Weathered Bedrock	21		0				35

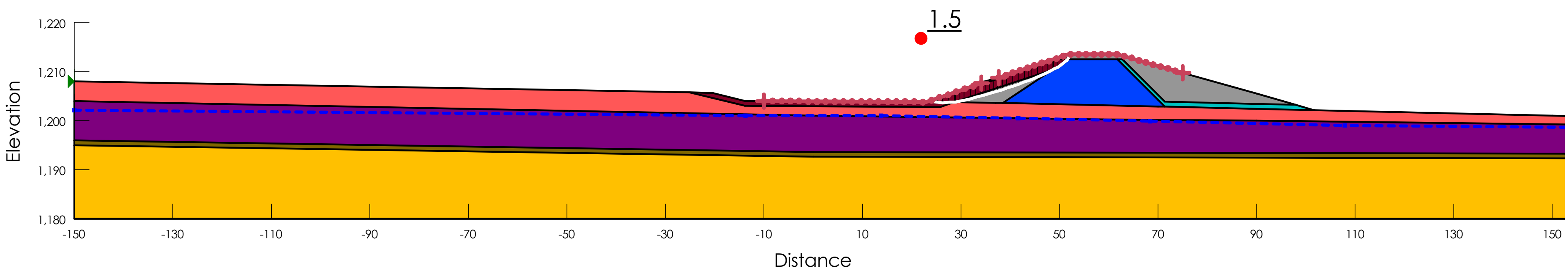


Stantec

Alberta Transportation SR1 Storage Dam

Section 20+000
Load Case: End of Construction
Total Stress Parameters
Incipient Motion in the Upstream Direction

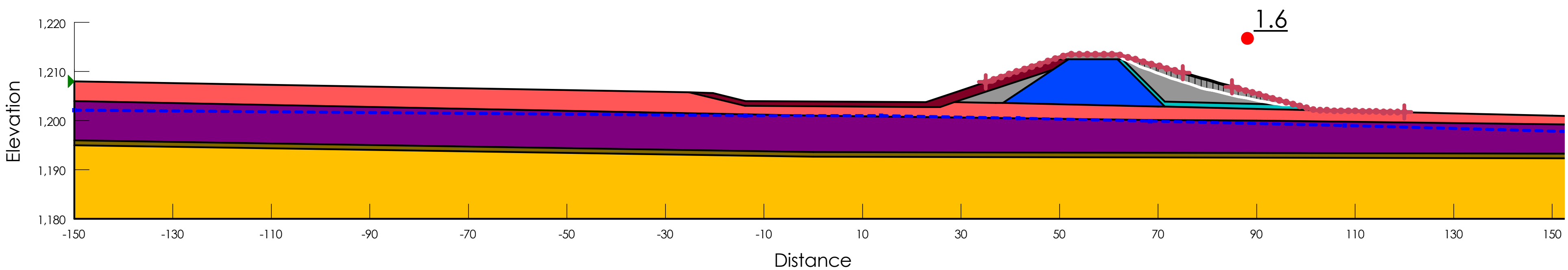
Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)
	Drain	21		0				33
	Embankment Core (Undrained)	20		0	28	19	427	
	Embankment Shell (Undrained)	20		0	24	15	141	
	Glacial Till (Undrained)	18		0	27	19	363.2	
	Glacio-Lacustrine (Undrained)	18	Glacio-Lacustrine (Undrained)					0
	Rock Toe	20		0				33
	Sandstone							
	Weathered Bedrock	21		0				35



Alberta Transportation SR1 Storage Dam

Section 20+000
Load Case: Long Term
Effective Stress Parameters
Incipient Motion in the Downstream Direction

Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)
	Drain	21	0	33
	Embankment Core (Drained)	20	0	28
	Embankment Shell (Drained)	20	0	24
	Glacial Till (Drained)	18	0	27
	Glacio-Lacustrine (Drained)	18	0	23
	Rock Toe	20	0	33
	Sandstone			
	Weathered Bedrock	21	0	35

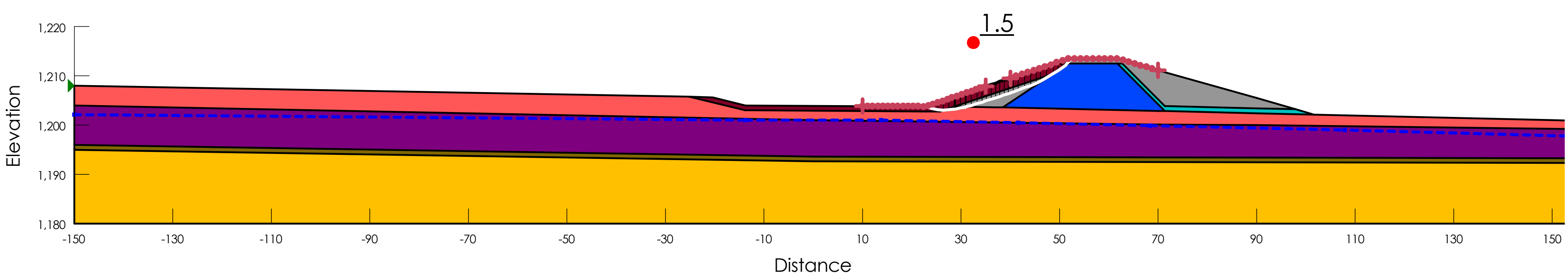


Stantec

Alberta Transportation SR1 Storage Dam

Section 20+000
Load Case: Long Term
Effective Stress Parameters
Incipient Motion in the Upstream Direction

Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)
	Drain	21	0	33
	Embankment Core (Drained)	20	0	28
	Embankment Shell (Drained)	20	0	24
	Glacial Till (Drained)	18	0	27
	Glacio-Lacustrine (Drained)	18	0	23
	Rock Toe	20	0	33
	Sandstone			
	Weathered Bedrock	21	0	35

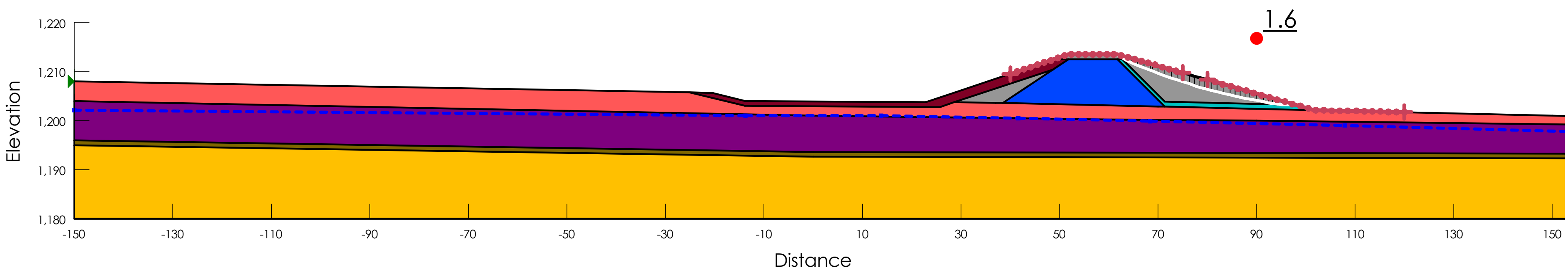


Stantec

Alberta Transportation SR1 Storage Dam

Section 20+000
Load Case: Post Earthquake
Post Earthquake Parameters
Incipient Motion in the Downstream Direction

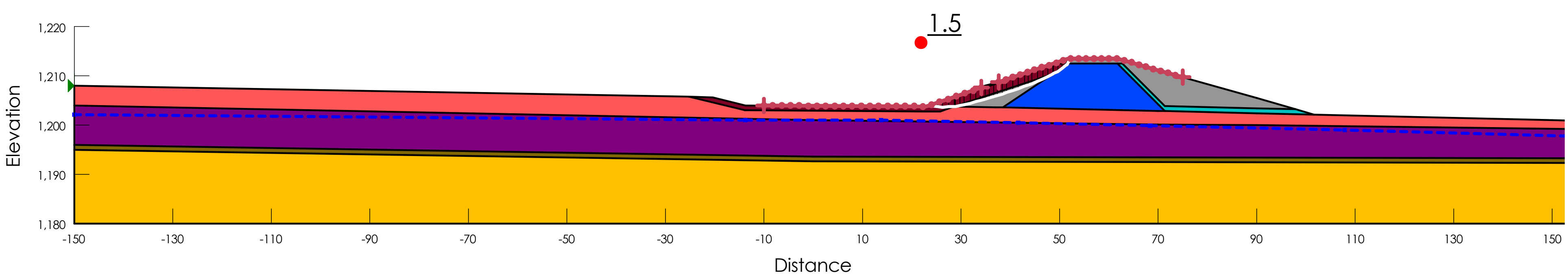
Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)
	Drain	21		0				33
	Embankment Core (EQ/Pseudo)	20		0	28	15	243	
	Embankment Shell (EQ/Pseudo)	20		0	24	12	86	
	Glacial Till (EQ/Pseudo)	18		0	27	15	199	
	Glacio-Lacustrine (EQ/Pseudo)	18	Glacio-Lacustrine (Seismic)					0
	Rock Toe	20		0				33
	Sandstone							
	Weathered Bedrock	21		0				35



Alberta Transportation SR1 Storage Dam

Section 20+000
Load Case: Post Earthquake
Post Earthquake Parameters
Incipient Motion in the Upstream Direction

Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)
	Drain	21		0				33
	Embankment Core (EQ/Pseudo)	20		0	28	15	243	
	Embankment Shell (EQ/Pseudo)	20		0	24	12	86	
	Glacial Till (EQ/Pseudo)	18		0	27	15	199	
	Glacio-Lacustrine (EQ/Pseudo)	18	Glacio-Lacustrine (Seismic)					0
	Rock Toe	20		0				33
	Sandstone							
	Weathered Bedrock	21		0				35

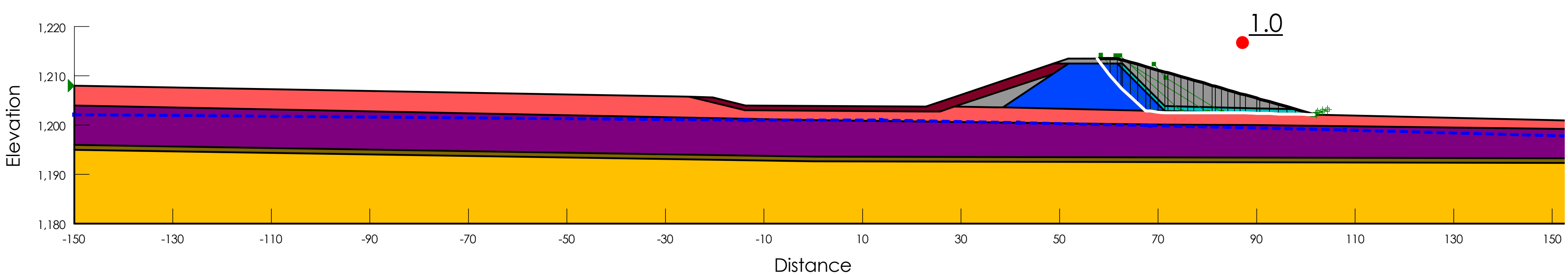


Stantec

Alberta Transportation SR1 Storage Dam

Section 20+000
Load Case: Pseudostatic
Pseudostatic Parameters
Incipient Motion in the Downstream Direction

Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)	Cohesion R (kPa)	Phi R (°)
	Drain	21		0				33	0	0
	Embankment Core (EQ/Pseudo)	20		0	28	15	243			
	Embankment Shell (EQ/Pseudo)	20		0	24	12	86			
	Glacial Till (EQ/Pseudo)	18		0	27	15	199			
	Glacio-Lacustrine (EQ/Pseudo)	18	Glacio-Lacustrine (Seismic)					0	0	0
	Rock Toe	20		0				33	0	0
	Sandstone									
	Weathered Bedrock	21		0				35	0	0

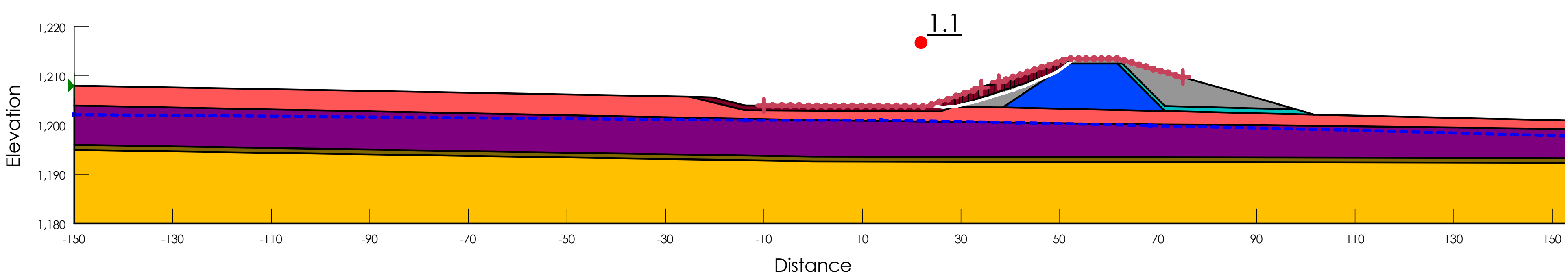


Stantec

Alberta Transportation SR1 Storage Dam

Section 20+000
Load Case: Pseudostatic
Pseudostatic Parameters
Incipient Motion in the Upstream Direction

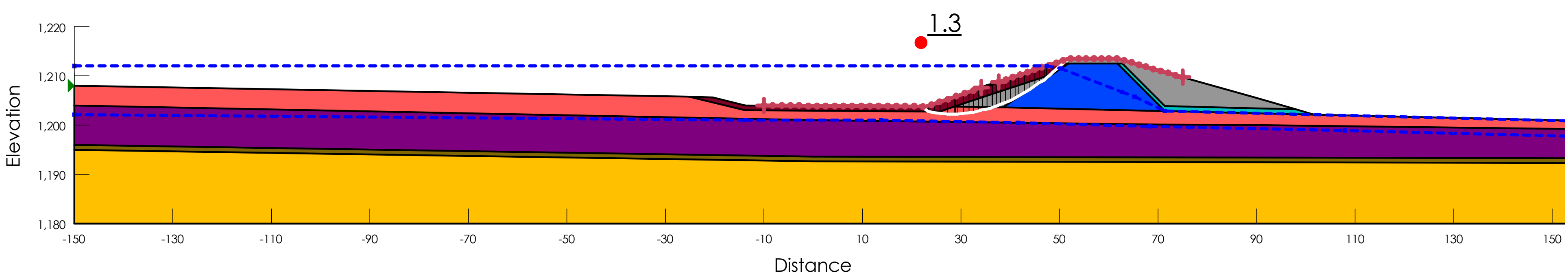
Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)	Cohesion R (kPa)	Phi R (°)
	Drain	21		0				33	0	0
	Embankment Core (EQ/Pseudo)	20		0	28	15	243			
	Embankment Shell (EQ/Pseudo)	20		0	24	12	86			
	Glacial Till (EQ/Pseudo)	18		0	27	15	199			
	Glacio-Lacustrine (EQ/Pseudo)	18	Glacio-Lacustrine (Seismic)					0	0	0
	Rock Toe	20		0				33	0	0
	Sandstone									
	Weathered Bedrock	21		0				35	0	0



Alberta Transportation SR1 Storage Dam

Section 20+000
Load Case: Rapid Drawdown
Effective and Total Stress Parameters
Incipient Motion in the Upstream Direction

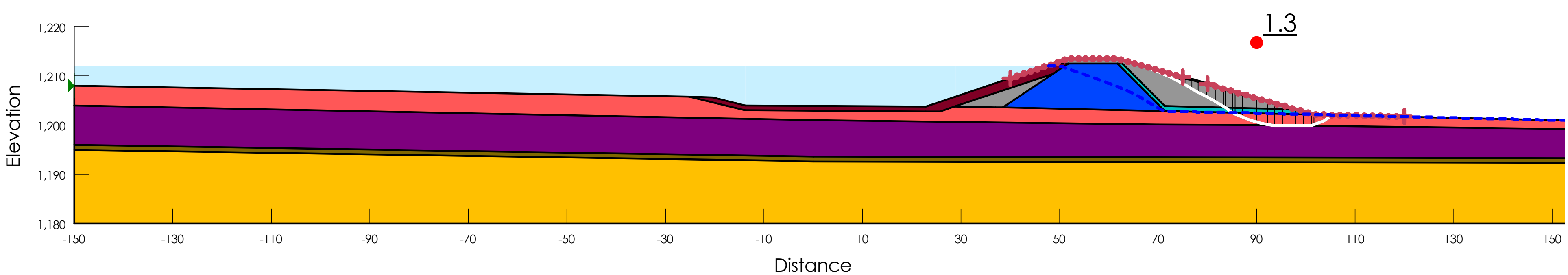
Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)	Cohesion R (kPa)	Phi R (°)
	Drain	21	0	33	0	0
	Embankment Core (RDD)	20	0	28	80	19
	Embankment Shell (RDD)	20	0	24	25	15
	Glacial Till (RDD)	18	0	27	60	19
	Glacio-Lacustrine (RDD)	18	0	23	15	20
	Rock Toe	20	0	33	0	0
	Sandstone					
	Weathered Bedrock	21	0	35	0	0



Alberta Transportation SR1 Storage Dam

Section 20+000
Load Case: USBR Flood
Effective Stress Parameters
Incipient Motion in the Downstream Direction

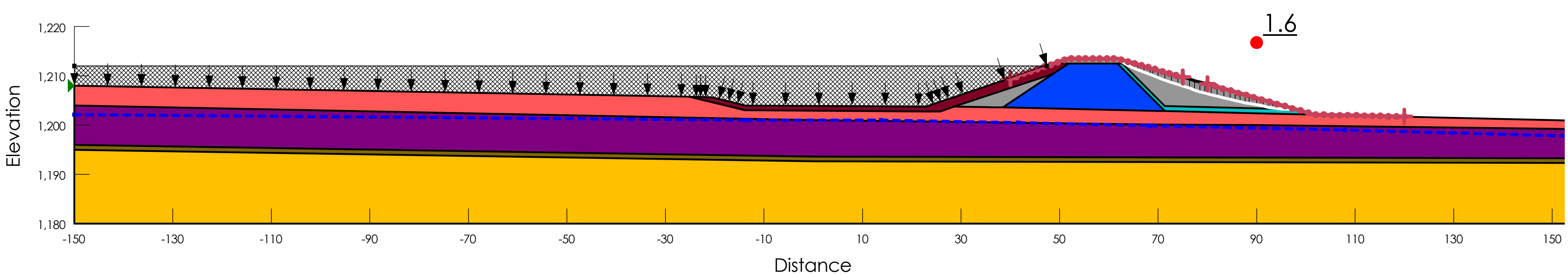
Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)
	Drain	21	0	33
	Embankment Core (Drained)	20	0	28
	Embankment Shell (Drained)	20	0	24
	Glacial Till (Drained)	18	0	27
	Glacio-Lacustrine (Drained)	18	0	23
	Rock Toe	20	0	33
	Sandstone			
	Weathered Bedrock	21	0	35



Alberta Transportation SR1 Storage Dam

Section 20+000
Load Case: USACE Flood
Total Stress Parameters
Incipient Motion in the Downstream Direction

Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)
	Drain	21		0				33
	Embankment Core (Undrained)	20		0	28	19	427	
	Embankment Shell (Undrained)	20		0	24	15	141	
	Glacial Till (Undrained)	18		0	27	19	363.2	
	Glacio-Lacustrine (Undrained)	18	Glacio-Lacustrine (Undrained)					0
	Rock Toe	20		0				33
	Sandstone							
	Weathered Bedrock	21		0				35



Attachment 12.1
Slope Stability and Seepage Analyses

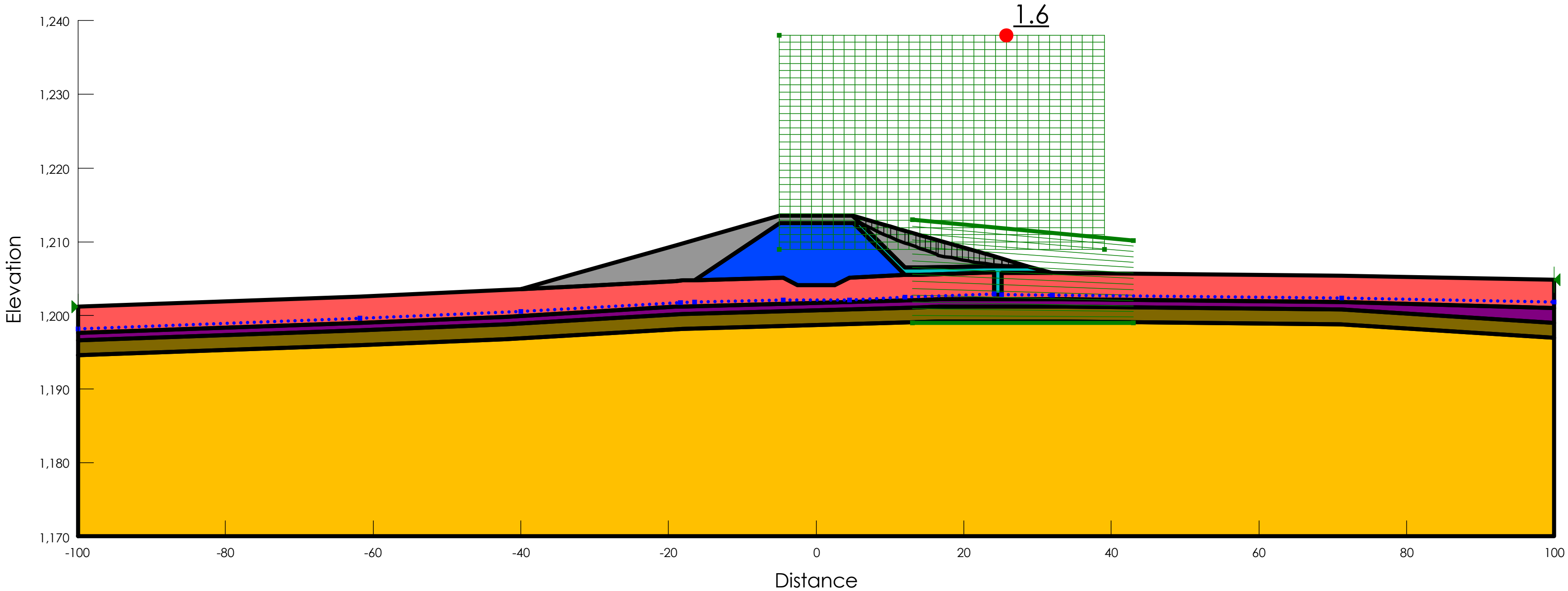
12.1.2 Slope Stability Analyses
Sta. 21+050

Stantec

Alberta Transportation SR1 Storage Dam

Section 21+050
Load Case: End of Construction, Year 3
B-bar Analysis
Effective Stress Parameters

Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)	B-bar	Add Weight
	Drain	21	0	30	0	Yes
	Embankment Core (Drained, Year 3)	20	0	28	0	Yes
	Embankment Shell (Drained, Year 3)	20	0	24	0	Yes
	Glacial Till (Drained)	18	0	27	0.1	No
	Glacio-Lacustrine (Drained)	18	0	23	0.15	No
	Sandstone				0	No
	Weathered Bedrock	21	0	35	0	No

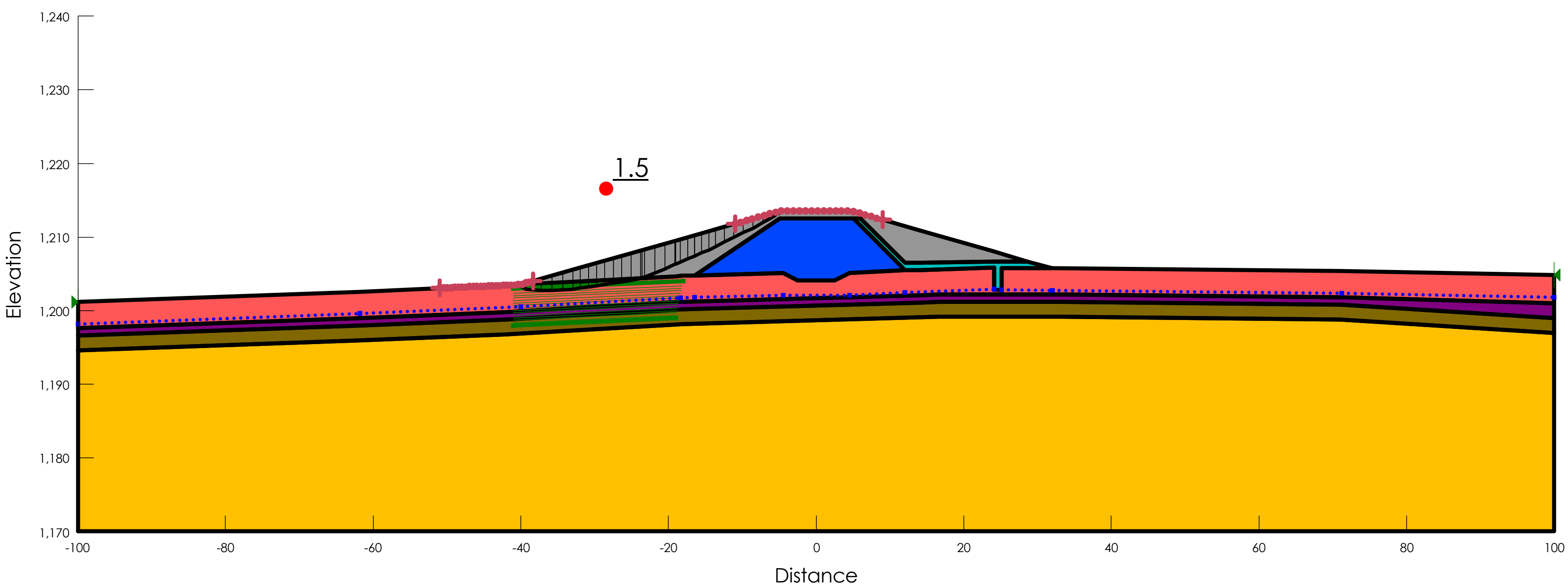


Stantec

Alberta Transportation SR1 Storage Dam

Section 21+050
Load Case: End of Construction, Year 3
B-bar Analysis
Effective Stress Parameters

Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)	B-bar	Add Weight
	Drain	21	0	30	0	Yes
	Embankment Core (Drained, Year 3)	20	0	28	0	Yes
	Embankment Shell (Drained, Year 3)	20	0	24	0	Yes
	Glacial Till (Drained)	18	0	27	0.1	No
	Glacio-Lacustrine (Drained)	18	0	23	0.15	No
	Sandstone				0	No
	Weathered Bedrock	21	0	35	0	No

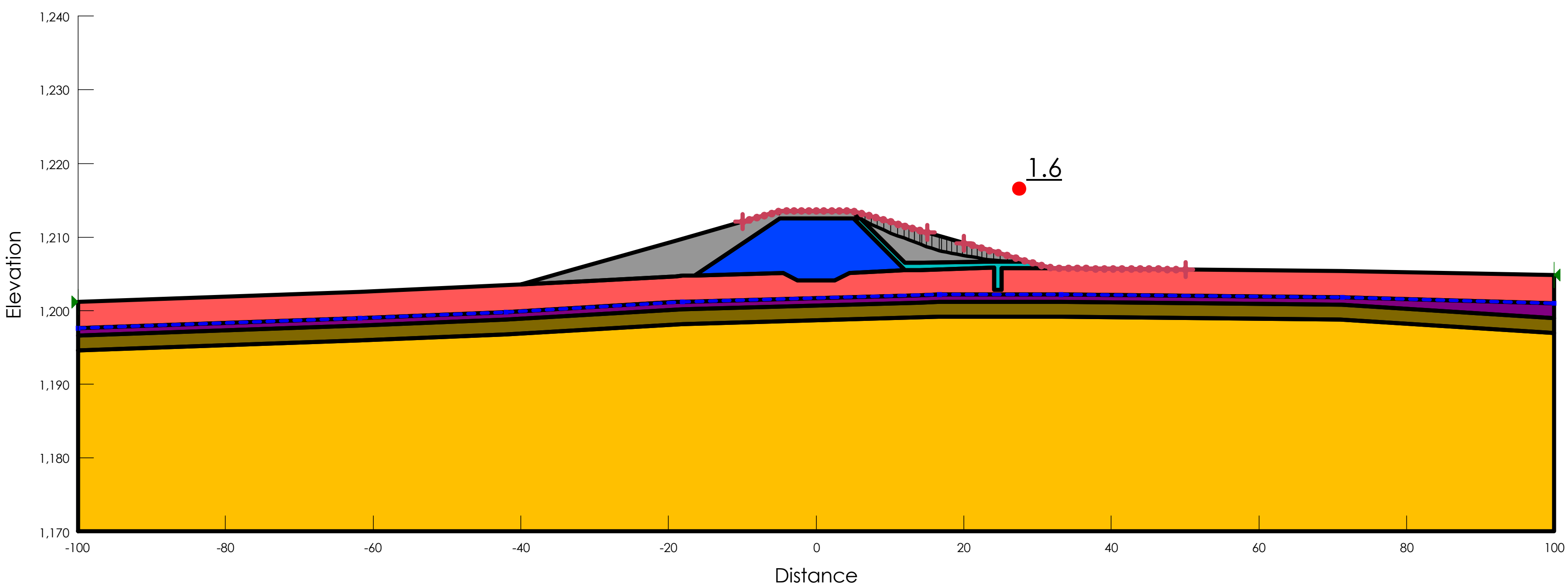


Stantec

Alberta Transportation SR1 Storage Dam

Section 21+050
Load Case: End of Construction
Total Stress Parameters
Incipient Motion in the Downstream Direction

Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)
	Drain	21		0				30
	Embankment Core (Undrained)	20		0	28	19	427	
	Embankment Shell (Undrained)	20		0	24	15	141	
	Glacial Till (Undrained)	18		0	27	19	363.2	
	Glacio-Lacustrine (Undrained)	18	Glacio-Lacustrine (Undrained)					0
	Sandstone							
	Weathered Bedrock	21		0				35

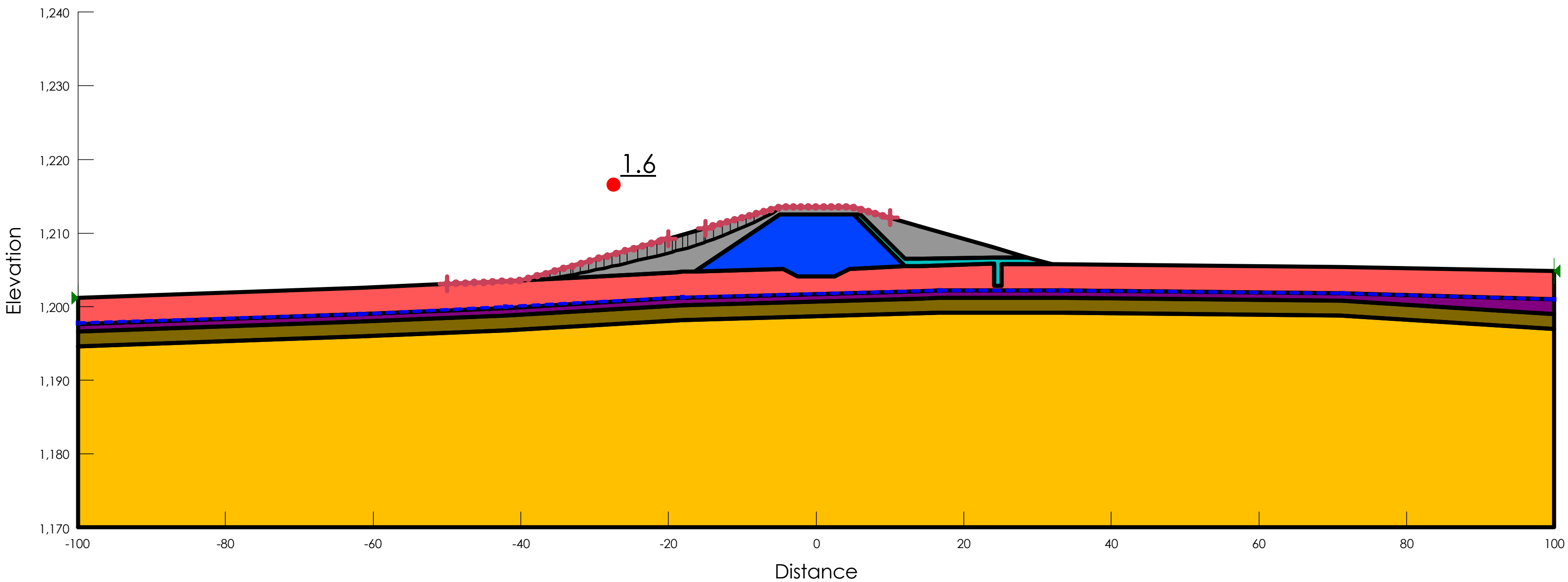


Stantec

Alberta Transportation SR1 Storage Dam

Section 21+050
Load Case: End of Construction
Total Stress Parameters
Incipient Motion in the Upstream Direction

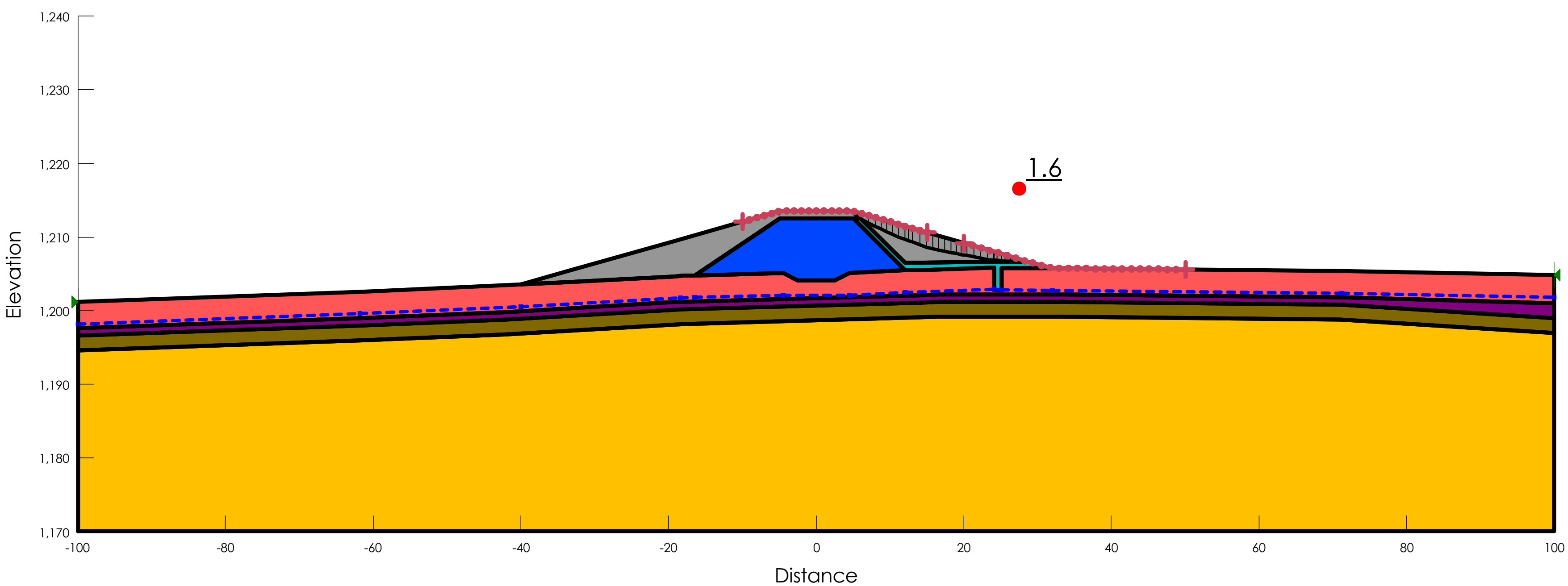
Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)
	Drain	21		0				30
	Embankment Core (Undrained)	20		0	28	19	427	
	Embankment Shell (Undrained)	20		0	24	15	141	
	Glacial Till (Undrained)	18		0	27	19	363.2	
	Glacio-Lacustrine (Undrained)	18	Glacio-Lacustrine (Undrained)					0
	Sandstone							
	Weathered Bedrock	21		0				35



Alberta Transportation SR1 Storage Dam

Section 21+050
Load Case: Long Term
Effective Stress Parameters
Incipient Motion in the Downstream Direction

Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)
	Drain	21	0	30
	Embankment Core (Drained)	20	0	28
	Embankment Shell (Drained)	20	0	24
	Glacial Till (Drained)	18	0	27
	Glacio-Lacustrine (Drained)	18	0	23
	Sandstone			
	Weathered Bedrock	21	0	35

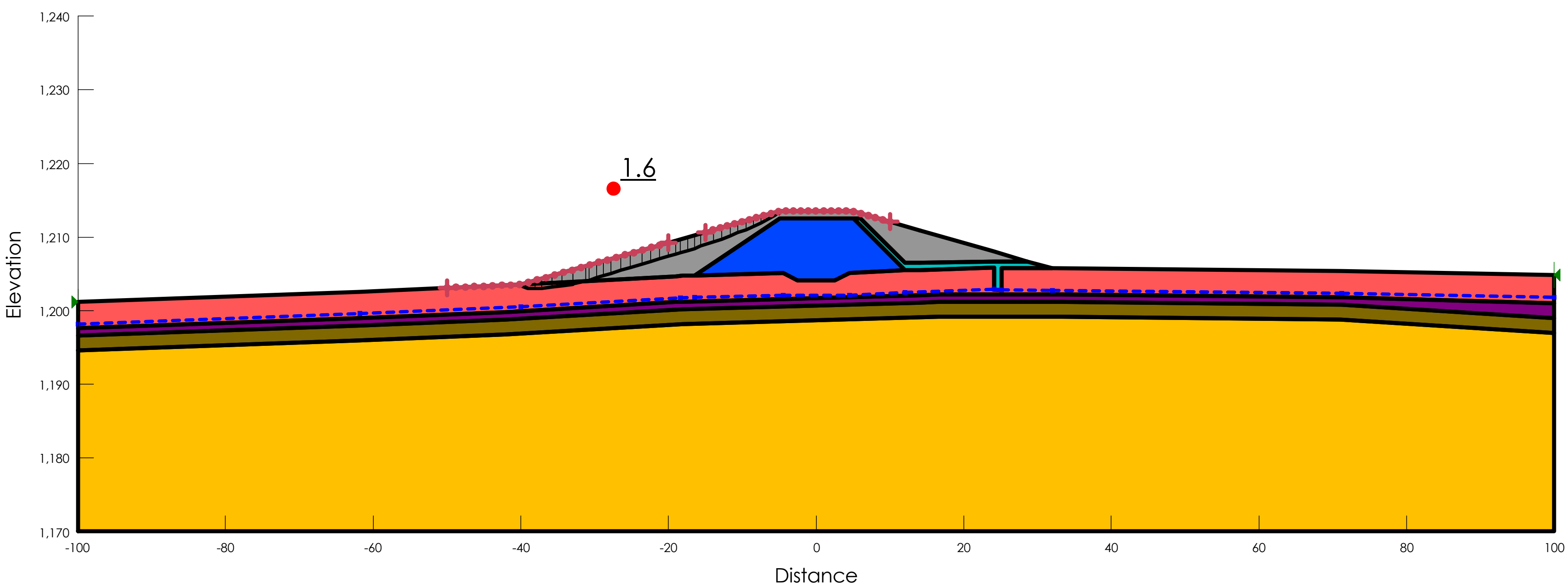


Stantec

Alberta Transportation SR1 Storage Dam

Section 21+050
Load Case: Long Term
Effective Stress Parameters
Incipient Motion in the Upstream Direction

Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)
	Drain	21	0	30
	Embankment Core (Drained)	20	0	28
	Embankment Shell (Drained)	20	0	24
	Glacial Till (Drained)	18	0	27
	Glacio-Lacustrine (Drained)	18	0	23
	Sandstone			
	Weathered Bedrock	21	0	35

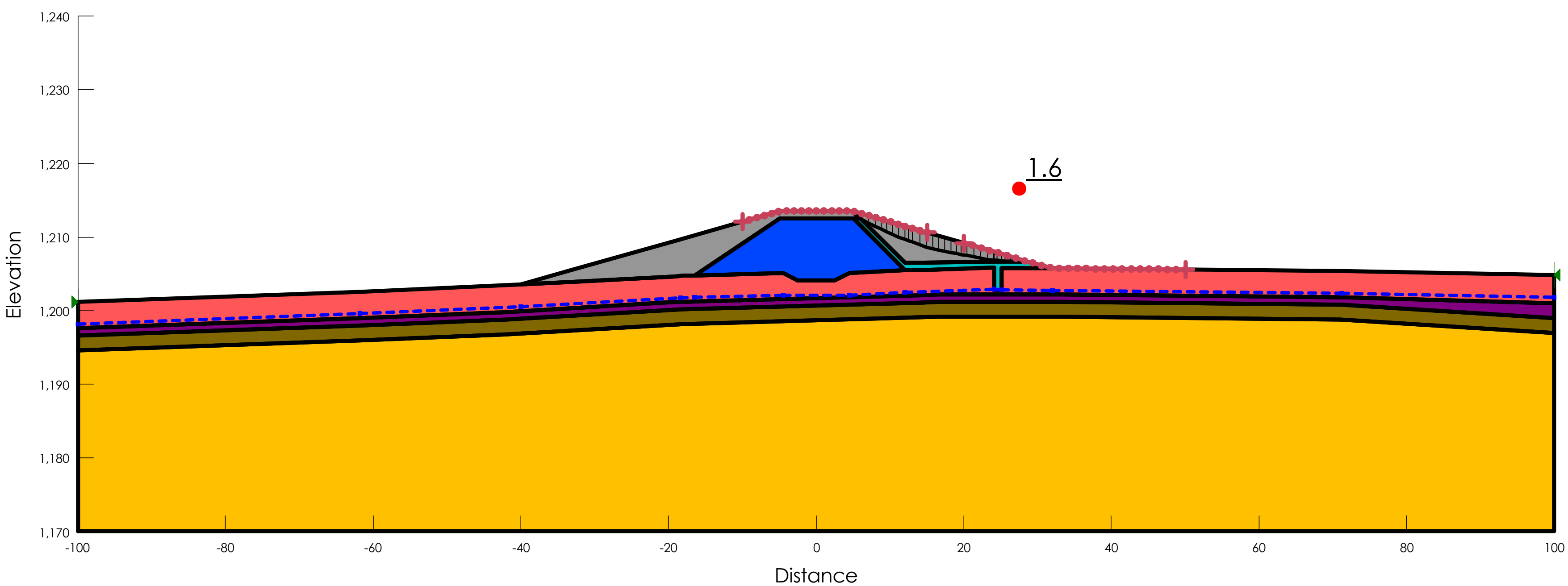


Stantec

Alberta Transportation SR1 Storage Dam

Section 21+050
Load Case: Post Earthquake
Post Earthquake Parameters
Incipient Motion in the Downstream Direction

Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)
	Drain	21		0				30
	Embankment Core (EQ/Pseudo)	20		0	28	15	243	
	Embankment Shell (EQ/Pseudo)	20		0	24	12	86	
	Glacial Till (EQ/Pseudo)	18		0	27	15	199	
	Glacio-Lacustrine (EQ/Pseudo)	18	Glacio-Lacustrine (Seismic)					0
	Sandstone							
	Weathered Bedrock	21		0				35

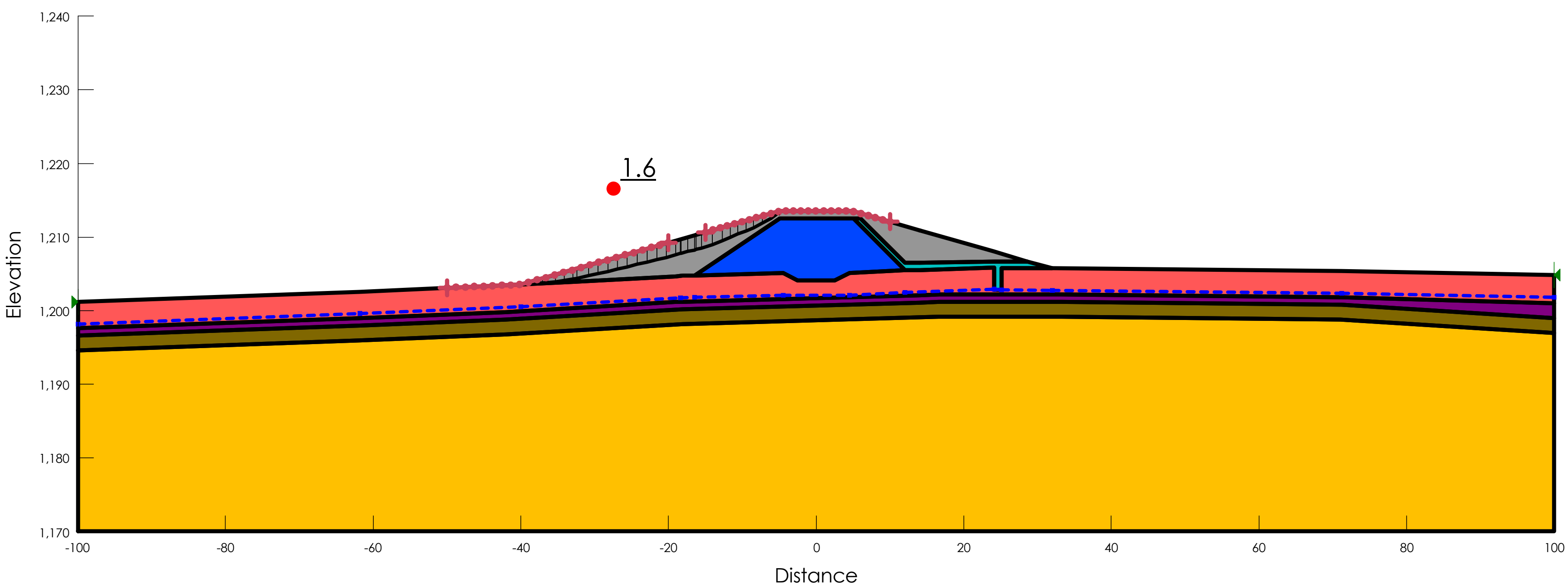


Stantec

Alberta Transportation SR1 Storage Dam

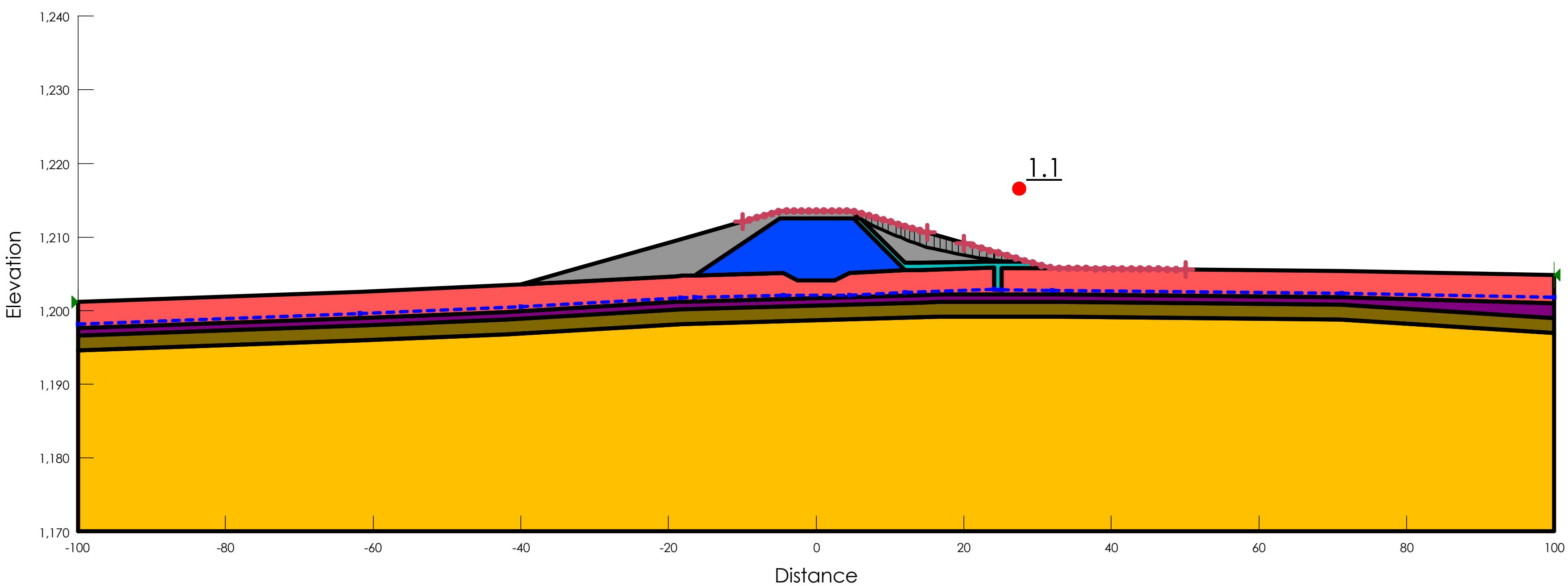
Section 21+050
Load Case: Post Earthquake
Post Earthquake Parameters
Incipient Motion in the Upstream Direction

Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)
	Drain	21		0				30
	Embankment Core (EQ/Pseudo)	20		0	28	15	243	
	Embankment Shell (EQ/Pseudo)	20		0	24	12	86	
	Glacial Till (EQ/Pseudo)	18		0	27	15	199	
	Glacio-Lacustrine (EQ/Pseudo)	18	Glacio-Lacustrine (Seismic)					0
	Sandstone							
	Weathered Bedrock	21		0				35



Alberta Transportation SR1 Storage Dam

Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)	Cohesion R (kPa)	Phi R (°)
	Drain	21		0				30	0	0
	Embankment Core (EQ/Pseudo)	20		0	28	15	243			
	Embankment Shell (EQ/Pseudo)	20		0	24	12	86			
	Glacial Till (EQ/Pseudo)	18		0	27	15	199			
	Glacio-Lacustrine (EQ/Pseudo)	18	Glacio-Lacustrine (Seismic)					0	0	0
	Sandstone									
	Weathered Bedrock	21		0				35	0	0

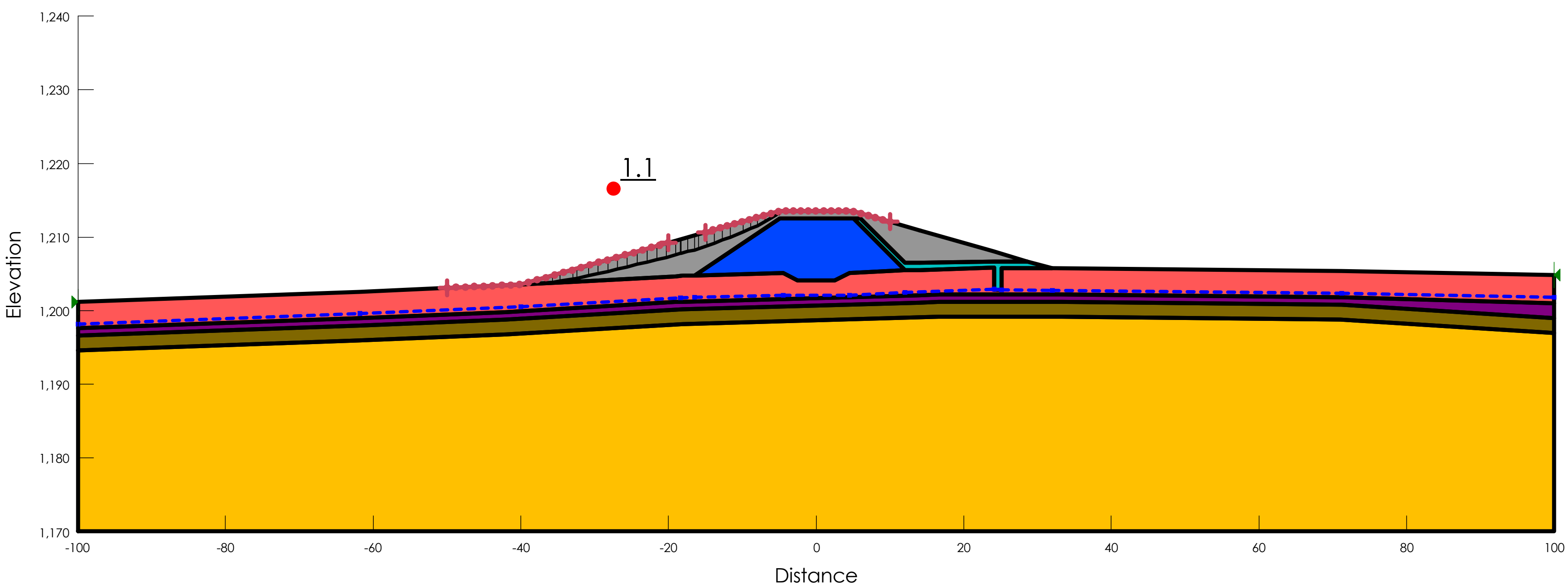


Stantec

Alberta Transportation SR1 Storage Dam

Section 21+050
Load Case: Rapid Drawdown
Effective and Total Stress Parameters
Incipient Motion in the Upstream Direction

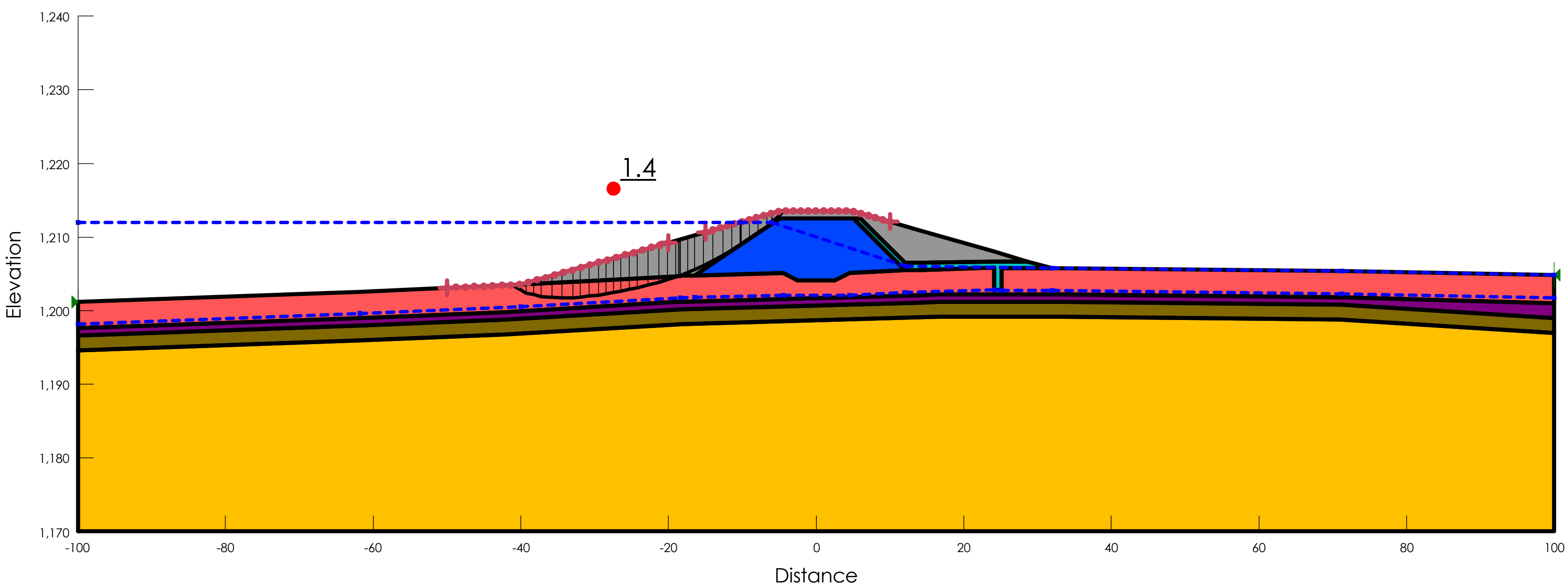
Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)	Cohesion R (kPa)	Phi R (°)
	Drain	21		0				30	0	0
	Embankment Core (EQ/Pseudo)	20		0	28	15	243			
	Embankment Shell (EQ/Pseudo)	20		0	24	12	86			
	Glacial Till (EQ/Pseudo)	18		0	27	15	199			
	Glacio-Lacustrine (EQ/Pseudo)	18	Glacio-Lacustrine (Seismic)					0	0	0
	Sandstone									
	Weathered Bedrock	21		0				35	0	0



Alberta Transportation SR1 Storage Dam

Section 21+050
Load Case: Rapid Drawdown
Effective and Total Stress Parameters
Incipient Motion in the Upstream Direction

Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)	Cohesion R (kPa)	Phi R (°)	Piezometric Line After Drawdown
	Drain	21	0	30	0	0	1
	Embankment Core (RDD)	20	0	28	80	19	1
	Embankment Shell (RDD)	20	0	24	25	15	1
	Glacial Till (RDD)	18	0	27	60	19	1
	Glacio-Lacustrine (RDD)	18	0	23	15	20	1
	Sandstone						1
	Weathered Bedrock	21	0	35	0	0	1

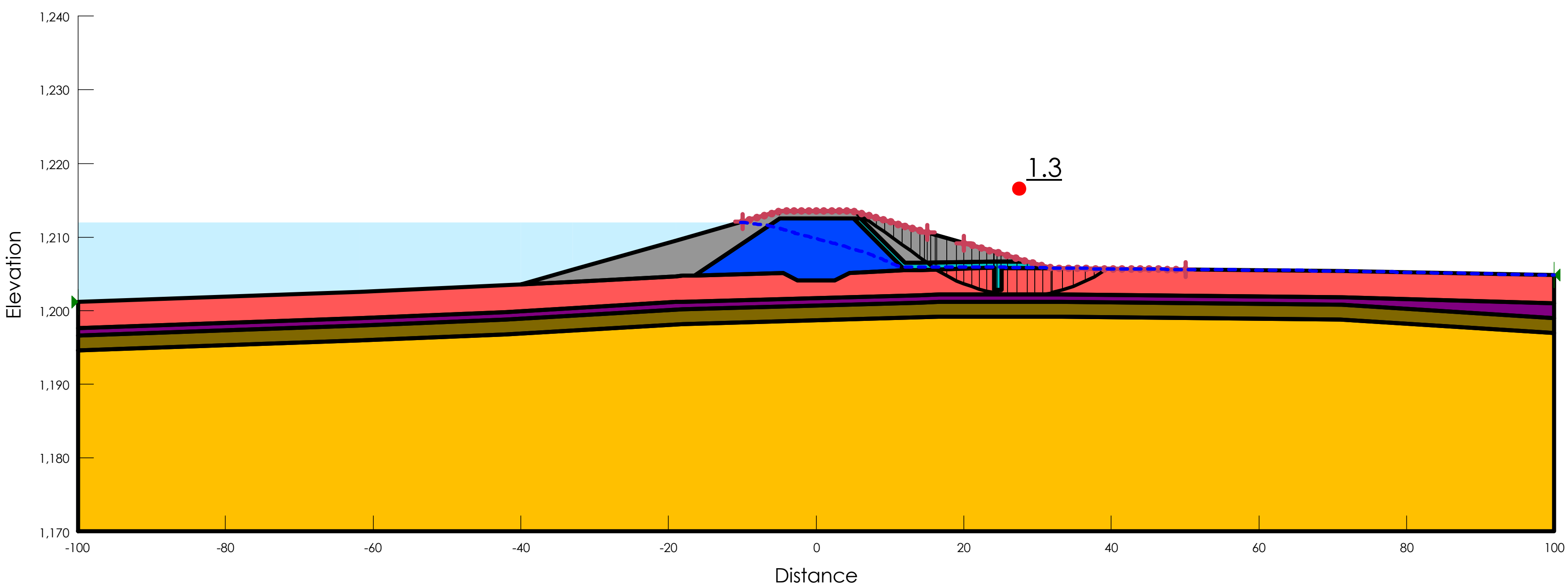


Stantec

Alberta Transportation SR1 Storage Dam

Section 21+050
Load Case: USBR Flood
Effective Stress Parameters
Incipient Motion in the Downstream Direction

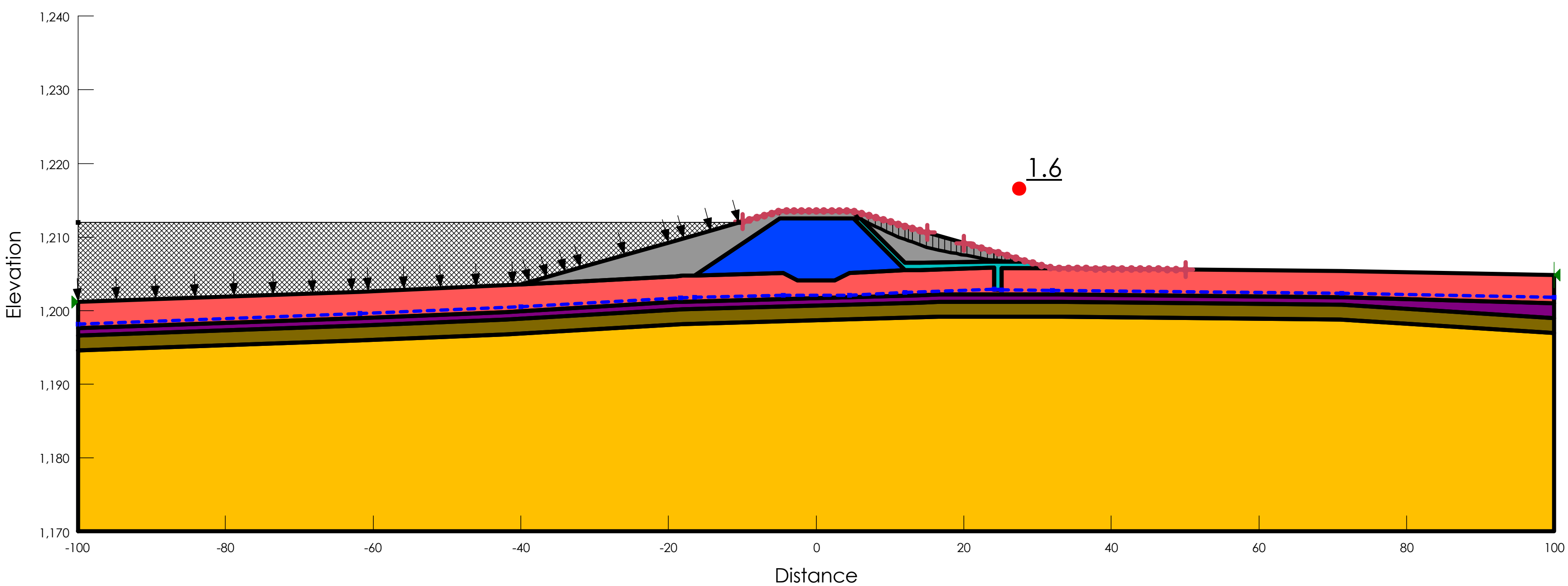
Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)
	Drain	21	0	30
	Embankment Core (Drained)	20	0	28
	Embankment Shell (Drained)	20	0	24
	Glacial Till (Drained)	18	0	27
	Glacio-Lacustrine (Drained)	18	0	23
	Sandstone			
	Weathered Bedrock	21	0	35



Alberta Transportation SR1 Storage Dam

Section 21+050
Load Case: Pseudostatic
Pseudostatic Parameters
Incipient Motion in the Downstream Direction

Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)
	Drain	21		0				30
	Embankment Core (Undrained)	20		0	28	19	427	
	Embankment Shell (Undrained)	20		0	24	15	141	
	Glacial Till (Undrained)	18		0	27	19	363.2	
	Glacio-Lacustrine (Undrained)	18	Glacio-Lacustrine (Undrained)					0
	Sandstone							
	Weathered Bedrock	21		0				35



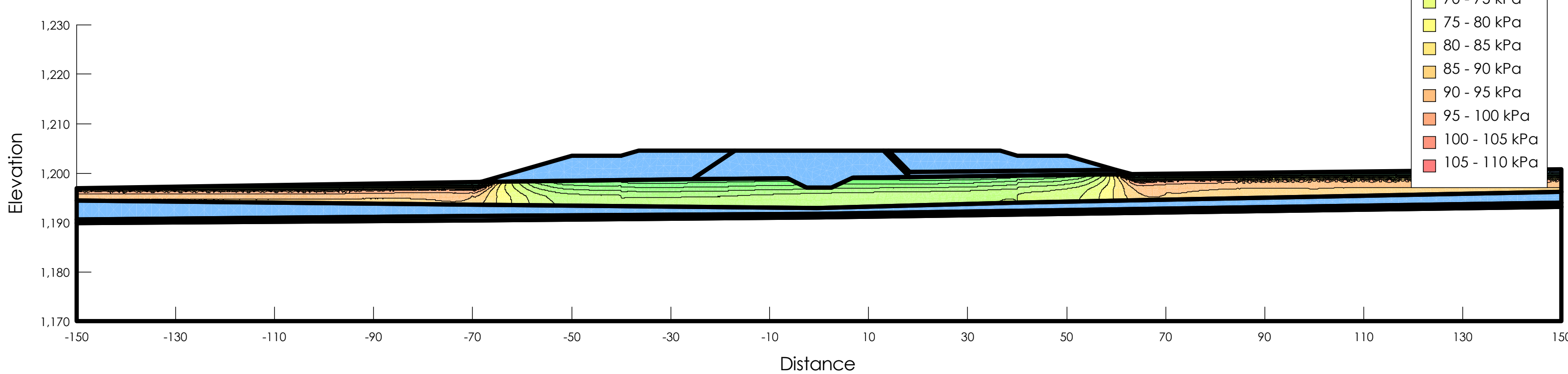
Attachment 12.1
Slope Stability and Seepage Analyses

12.1.2 Slope Stability Analyses
Sta. 21+750

Alberta Transportation SR1 Storage Dam

Section 21+750
Load Case: End of Construction, Year 2

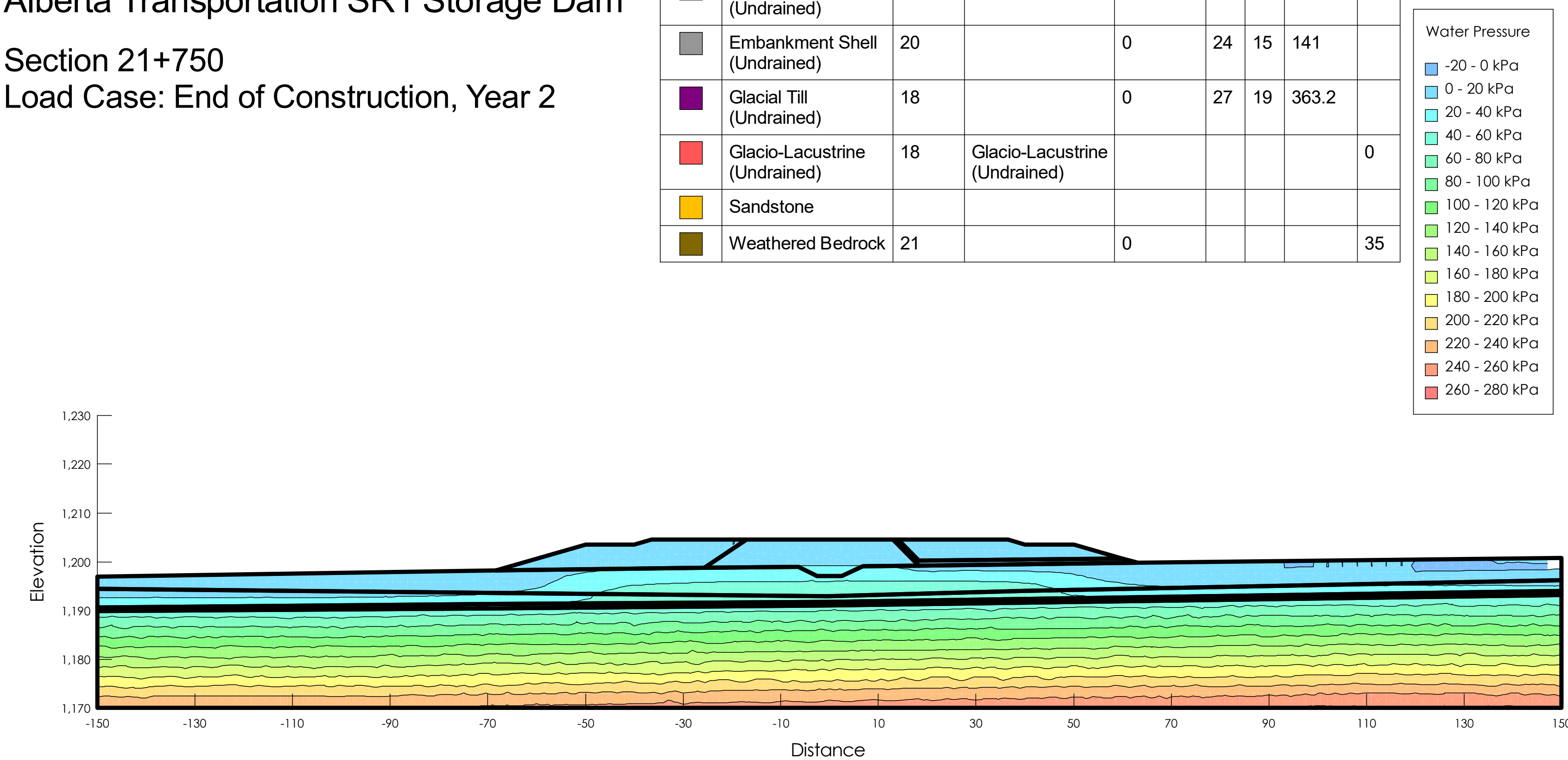
Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)
	Drain	21		0				33
	Embankment Core (Undrained)	20		0	28	19	427	
	Embankment Shell (Undrained)	20		0	24	15	141	
	Glacial Till (Undrained)	18		0	27	19	363.2	
	Glacio-Lacustrine (Undrained)	18	Glacio-Lacustrine (Undrained)					0
	Sandstone							
	Weathered Bedrock	21		0				35



Alberta Transportation SR1 Storage Dam

Section 21+750
Load Case: End of Construction, Year 2

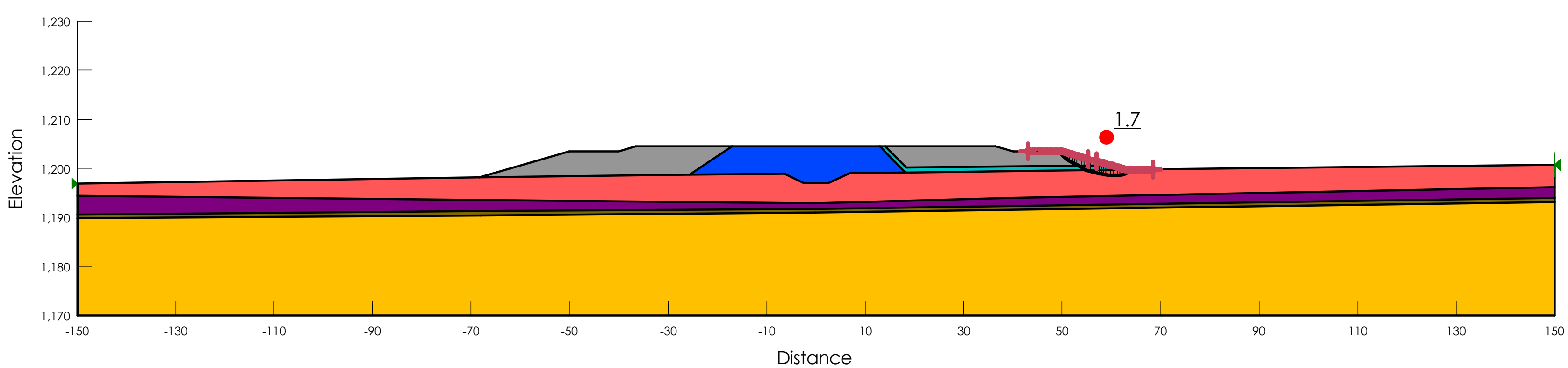
Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)
	Drain	21		0				33
	Embankment Core (Undrained)	20		0	28	19	427	
	Embankment Shell (Undrained)	20		0	24	15	141	
	Glacial Till (Undrained)	18		0	27	19	363.2	
	Glacio-Lacustrine (Undrained)	18	Glacio-Lacustrine (Undrained)					0
	Sandstone							
	Weathered Bedrock	21		0				35



Alberta Transportation SR1 Storage Dam

Section 21+750
Load Case: End of Construction, Year 2
Effective Stress Parameters
Incipient Motion in the Downstream Direction

Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)
	Drain	21	0	33
	Embankment Core (Drained)	20	0	28
	Embankment Shell (Drained)	20	0	24
	Glacial Till (Drained)	18	0	27
	Glacio-Lacustrine (Drained)	18	0	23
	Sandstone			
	Weathered Bedrock	21	0	35

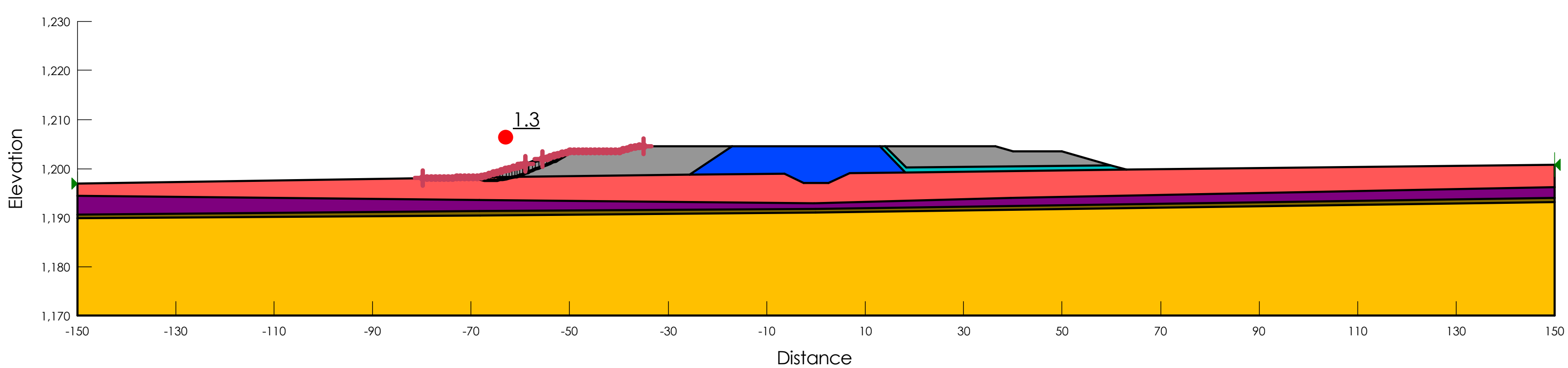


Stantec

Alberta Transportation SR1 Storage Dam

Section 21+750
Load Case: End of Construction, Year 2
Effective Stress Parameters
Incipient Motion in the Upstream Direction

Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)
	Drain	21	0	33
	Embankment Core (Drained)	20	0	28
	Embankment Shell (Drained)	20	0	24
	Glacial Till (Drained)	18	0	27
	Glacio-Lacustrine (Drained)	18	0	23
	Sandstone			
	Weathered Bedrock	21	0	35

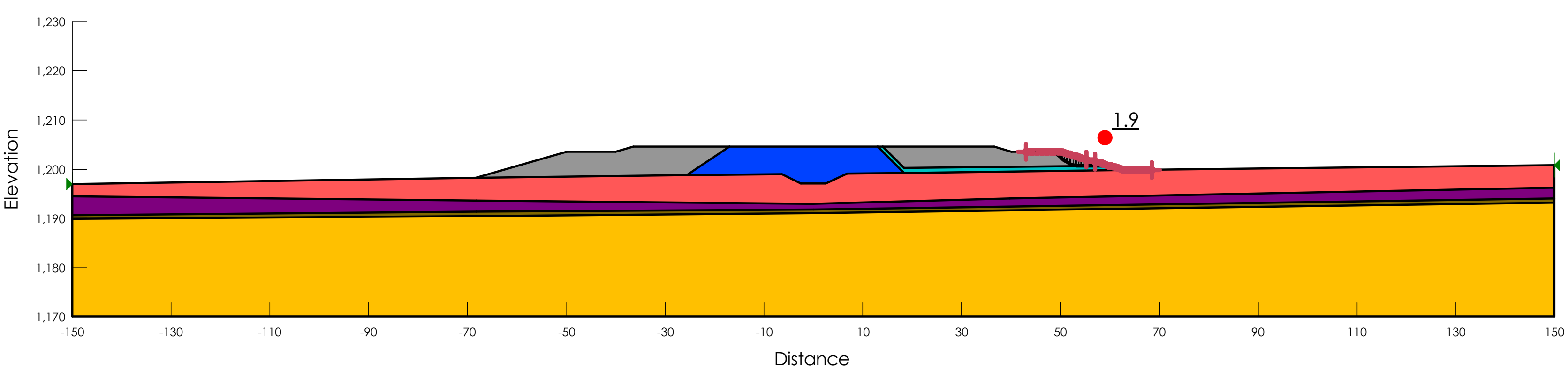


Stantec

Alberta Transportation SR1 Storage Dam

Section 21+750
Load Case: End of Construction, Year 2
Total Stress Parameters
Incipient Motion in the Downstream Direction

Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)
	Drain	21		0				33
	Embankment Core (Undrained)	20		0	28	19	427	
	Embankment Shell (Undrained)	20		0	24	15	141	
	Glacial Till (Undrained)	18		0	27	19	363.2	
	Glacio-Lacustrine (Undrained)	18	Glacio-Lacustrine (Undrained)					0
	Sandstone							
	Weathered Bedrock	21		0				35

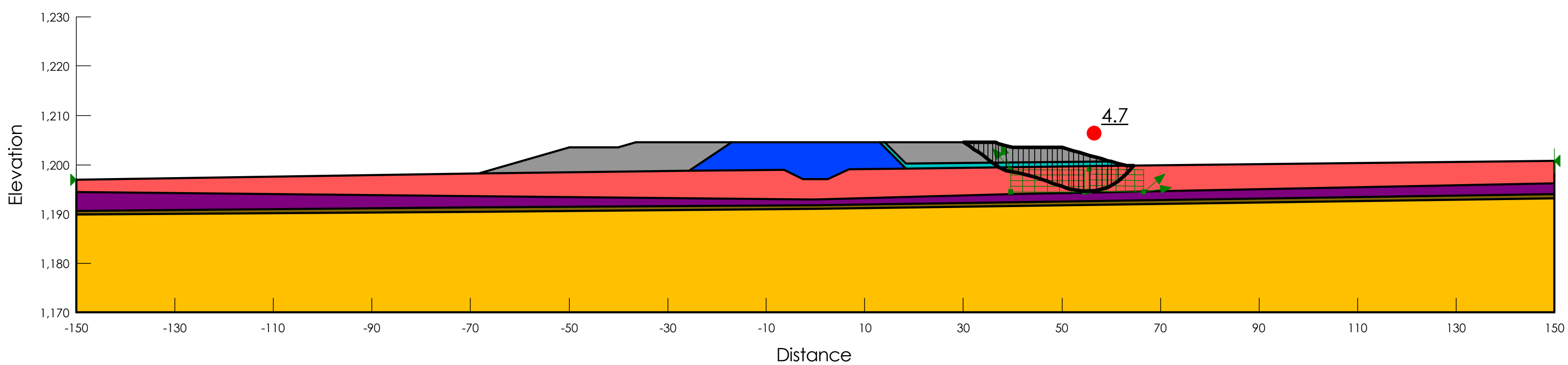


Stantec

Alberta Transportation SR1 Storage Dam

Section 21+750
Load Case: End of Construction, Year 2
Total Stress Parameters
Incipient Motion in the Downstream Direction

Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)
	Drain	21		0				33
	Embankment Core (Undrained)	20		0	28	19	427	
	Embankment Shell (Undrained)	20		0	24	15	141	
	Glacial Till (Undrained)	18		0	27	19	363.2	
	Glacio-Lacustrine (Undrained)	18	Glacio-Lacustrine (Undrained)					0
	Sandstone							
	Weathered Bedrock	21		0				35

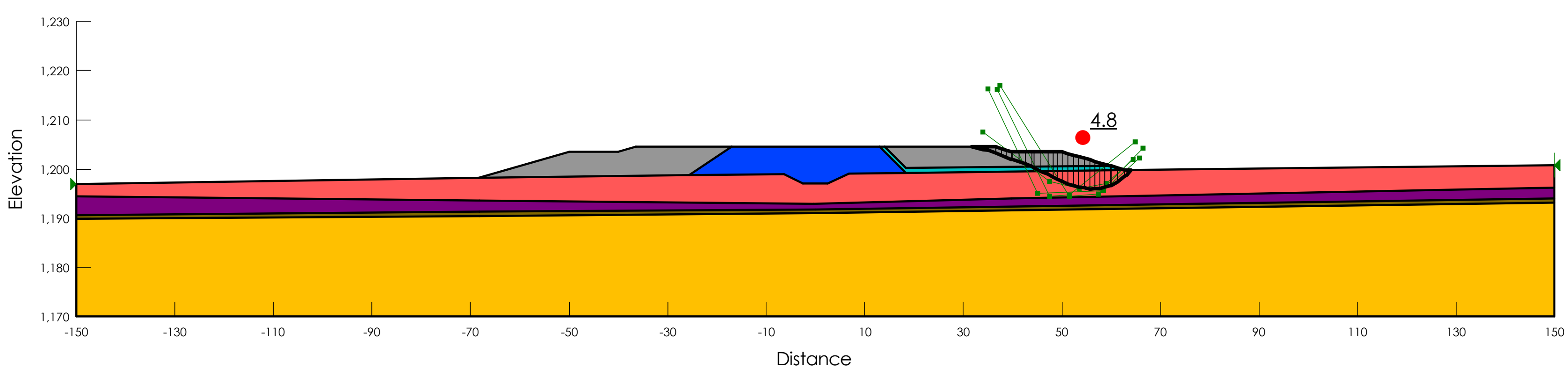


Stantec

Alberta Transportation SR1 Storage Dam

Section 21+750
Load Case: End of Construction, Year 2
Total Stress Parameters
Incipient Motion in the Downstream Direction

Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)
	Drain	21		0				33
	Embankment Core (Undrained)	20		0	28	19	427	
	Embankment Shell (Undrained)	20		0	24	15	141	
	Glacial Till (Undrained)	18		0	27	19	363.2	
	Glacio-Lacustrine (Undrained)	18	Glacio-Lacustrine (Undrained)					0
	Sandstone							
	Weathered Bedrock	21		0				35

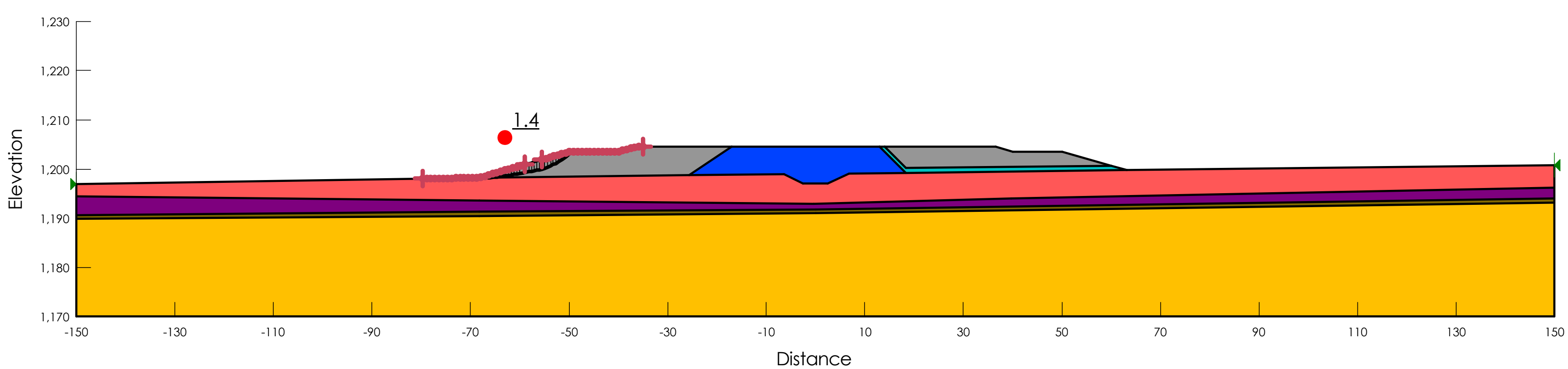


Stantec

Alberta Transportation SR1 Storage Dam

Section 21+750
Load Case: End of Construction, Year 2
Total Stress Parameters
Incipient Motion in the Upstream Direction

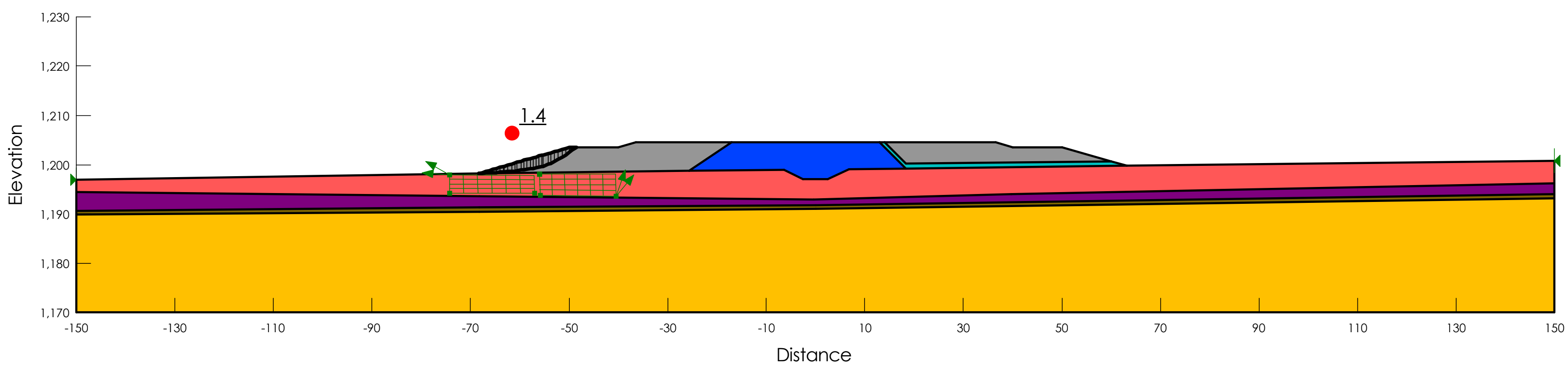
Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)
	Drain	21		0				33
	Embankment Core (Undrained)	20		0	28	19	427	
	Embankment Shell (Undrained)	20		0	24	15	141	
	Glacial Till (Undrained)	18		0	27	19	363.2	
	Glacio-Lacustrine (Undrained)	18	Glacio-Lacustrine (Undrained)					0
	Sandstone							
	Weathered Bedrock	21		0				35



Alberta Transportation SR1 Storage Dam

Section 21+750
Load Case: End of Construction, Year 2
Total Stress Parameters
Incipient Motion in the Upstream Direction

Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)
	Drain	21		0				33
	Embankment Core (Undrained)	20		0	28	19	427	
	Embankment Shell (Undrained)	20		0	24	15	141	
	Glacial Till (Undrained)	18		0	27	19	363.2	
	Glacio-Lacustrine (Undrained)	18	Glacio-Lacustrine (Undrained)					0
	Sandstone							
	Weathered Bedrock	21		0				35

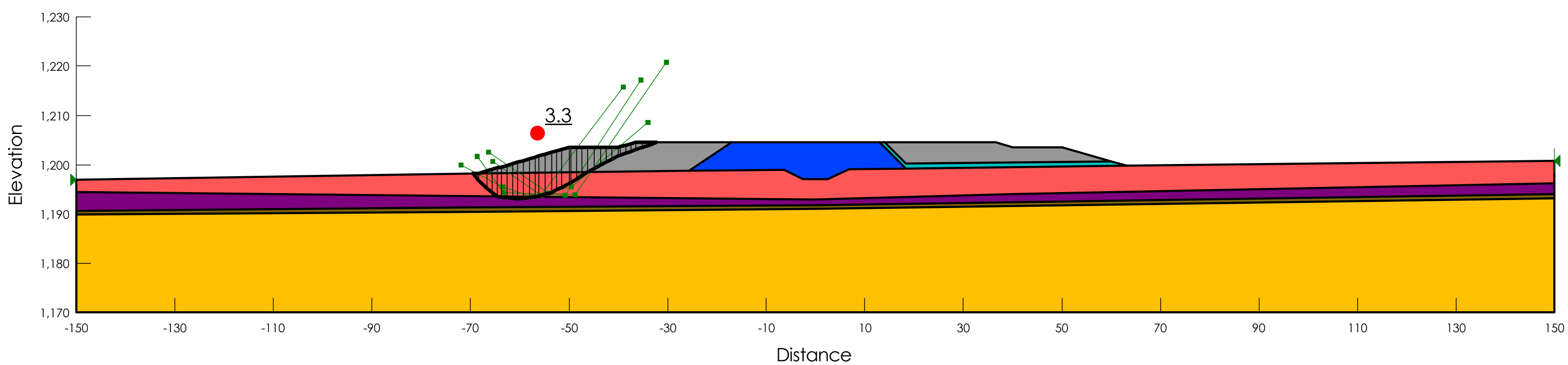


Stantec

Alberta Transportation SR1 Storage Dam

Section 21+750
Load Case: End of Construction, Year 2
Total Stress Parameters
Incipient Motion in the Upstream Direction

Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)
	Drain	21		0				33
	Embankment Core (Undrained)	20		0	28	19	427	
	Embankment Shell (Undrained)	20		0	24	15	141	
	Glacial Till (Undrained)	18		0	27	19	363.2	
	Glacio-Lacustrine (Undrained)	18	Glacio-Lacustrine (Undrained)					0
	Sandstone							
	Weathered Bedrock	21		0				35

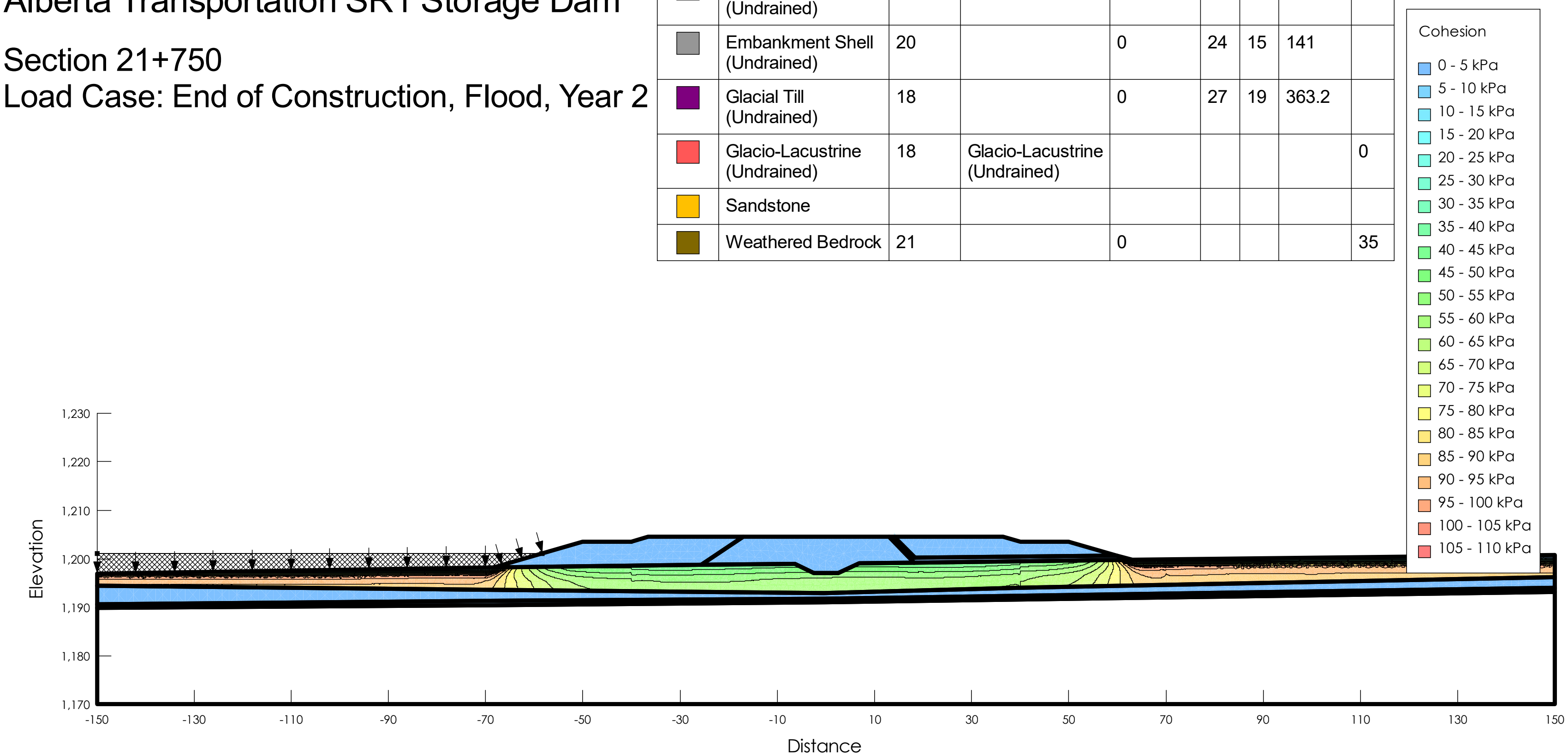


Stantec

Alberta Transportation SR1 Storage Dam

Section 21+750
Load Case: End of Construction, Flood, Year 2

Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)
	Drain	21		0				33
	Embankment Core (Undrained)	20		0	28	19	427	
	Embankment Shell (Undrained)	20		0	24	15	141	
	Glacial Till (Undrained)	18		0	27	19	363.2	
	Glacio-Lacustrine (Undrained)	18	Glacio-Lacustrine (Undrained)					0
	Sandstone							
	Weathered Bedrock	21		0				35

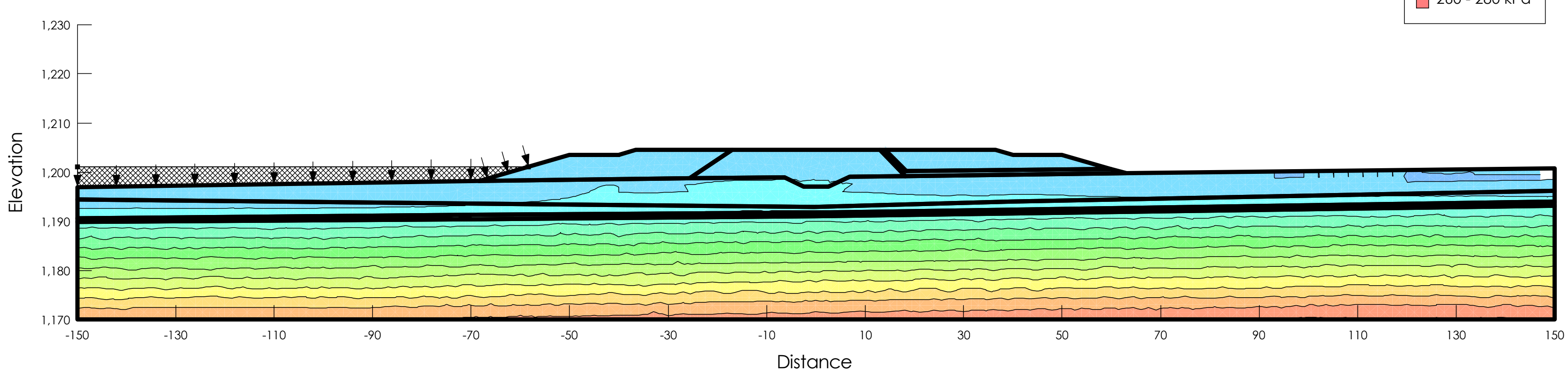


Alberta Transportation SR1 Storage Dam

Section 21+750
Load Case: End of Construction, Flood, Year 2

Color	Name	Unit Weight (kN/m^3)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)
	Drain	21		0				33
	Embankment Core (Undrained)	20		0	28	19	427	
	Embankment Shell (Undrained)	20		0	24	15	141	
	Glacial Till (Undrained)	18		0	27	19	363.2	
	Glacio-Lacustrine (Undrained)	18	Glacio-Lacustrine (Undrained)					0
	Sandstone							
	Weathered Bedrock	21		0				35

Water Pressure
- -20 - 0 kPa
- 0 - 20 kPa
- 20 - 40 kPa
- 40 - 60 kPa
- 60 - 80 kPa
- 80 - 100 kPa
- 100 - 120 kPa
- 120 - 140 kPa
- 140 - 160 kPa
- 160 - 180 kPa
- 180 - 200 kPa
- 200 - 220 kPa
- 220 - 240 kPa
- 240 - 260 kPa
- 260 - 280 kPa

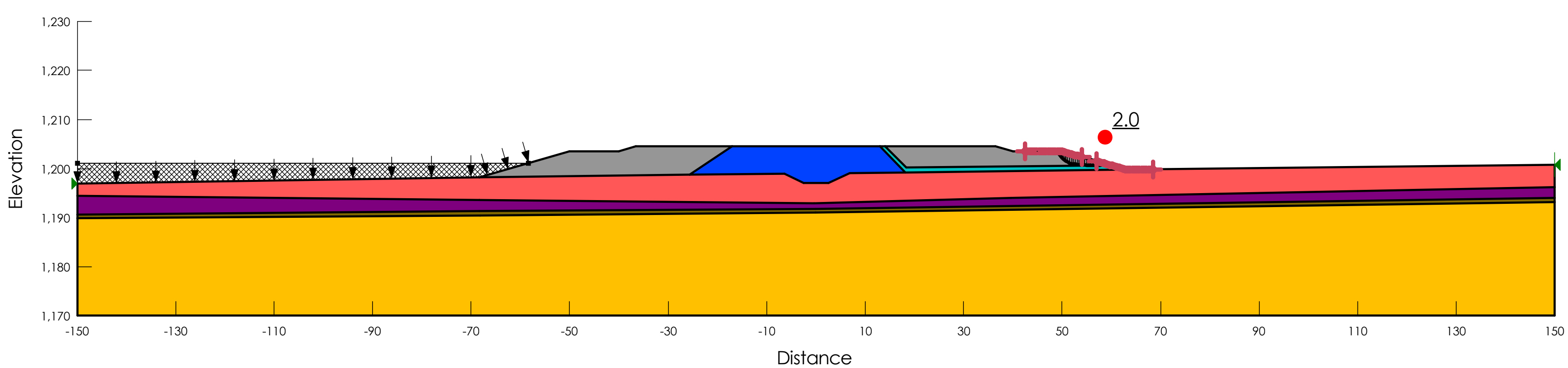


Stantec

Alberta Transportation SR1 Storage Dam

Section 21+750
Load Case: End of Construction, Flood, Year 2
Total Stress Parameters
Incipient Motion in the Downstream Direction

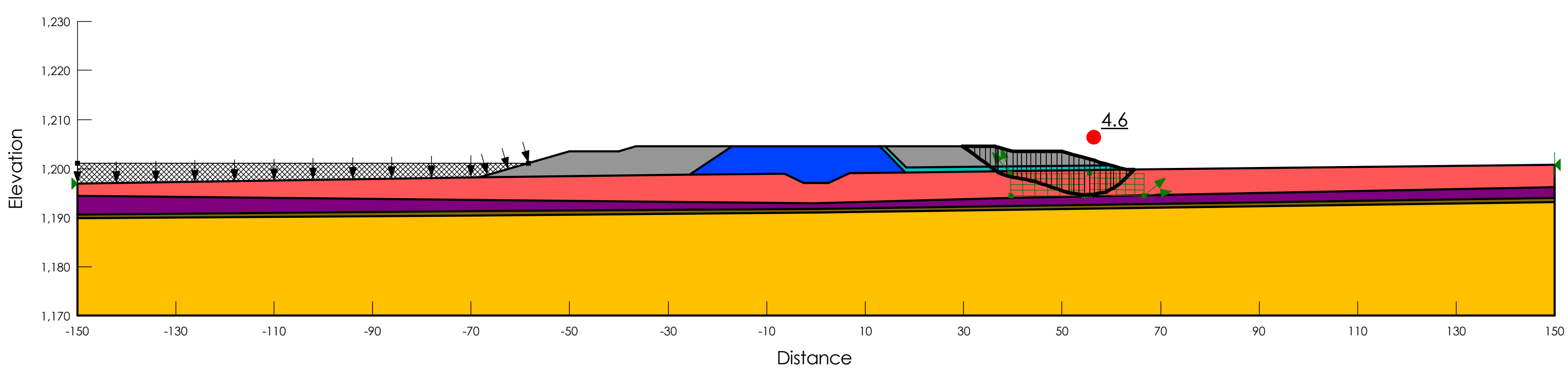
Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)
	Drain	21		0				33
	Embankment Core (Undrained)	20		0	28	19	427	
	Embankment Shell (Undrained)	20		0	24	15	141	
	Glacial Till (Undrained)	18		0	27	19	363.2	
	Glacio-Lacustrine (Undrained)	18	Glacio-Lacustrine (Undrained)					0
	Sandstone							
	Weathered Bedrock	21		0				35



Alberta Transportation SR1 Storage Dam

Section 21+750
Load Case: End of Construction, Flood, Year 2
Total Stress Parameters
Incipient Motion in the Downstream Direction

Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)
	Drain	21		0				33
	Embankment Core (Undrained)	20		0	28	19	427	
	Embankment Shell (Undrained)	20		0	24	15	141	
	Glacial Till (Undrained)	18		0	27	19	363.2	
	Glacio-Lacustrine (Undrained)	18	Glacio-Lacustrine (Undrained)					0
	Sandstone							
	Weathered Bedrock	21		0				35

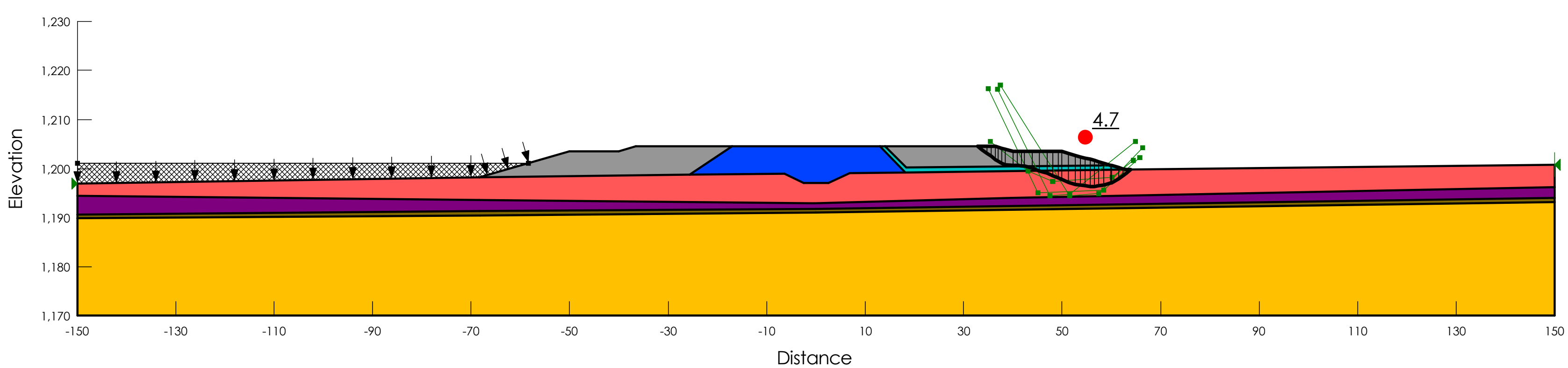


Stantec

Alberta Transportation SR1 Storage Dam

Section 21+750
Load Case: End of Construction, Flood, Year 2
Total Stress Parameters
Incipient Motion in the Downstream Direction

Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)
	Drain	21		0				33
	Embankment Core (Undrained)	20		0	28	19	427	
	Embankment Shell (Undrained)	20		0	24	15	141	
	Glacial Till (Undrained)	18		0	27	19	363.2	
	Glacio-Lacustrine (Undrained)	18	Glacio-Lacustrine (Undrained)					0
	Sandstone							
	Weathered Bedrock	21		0				35

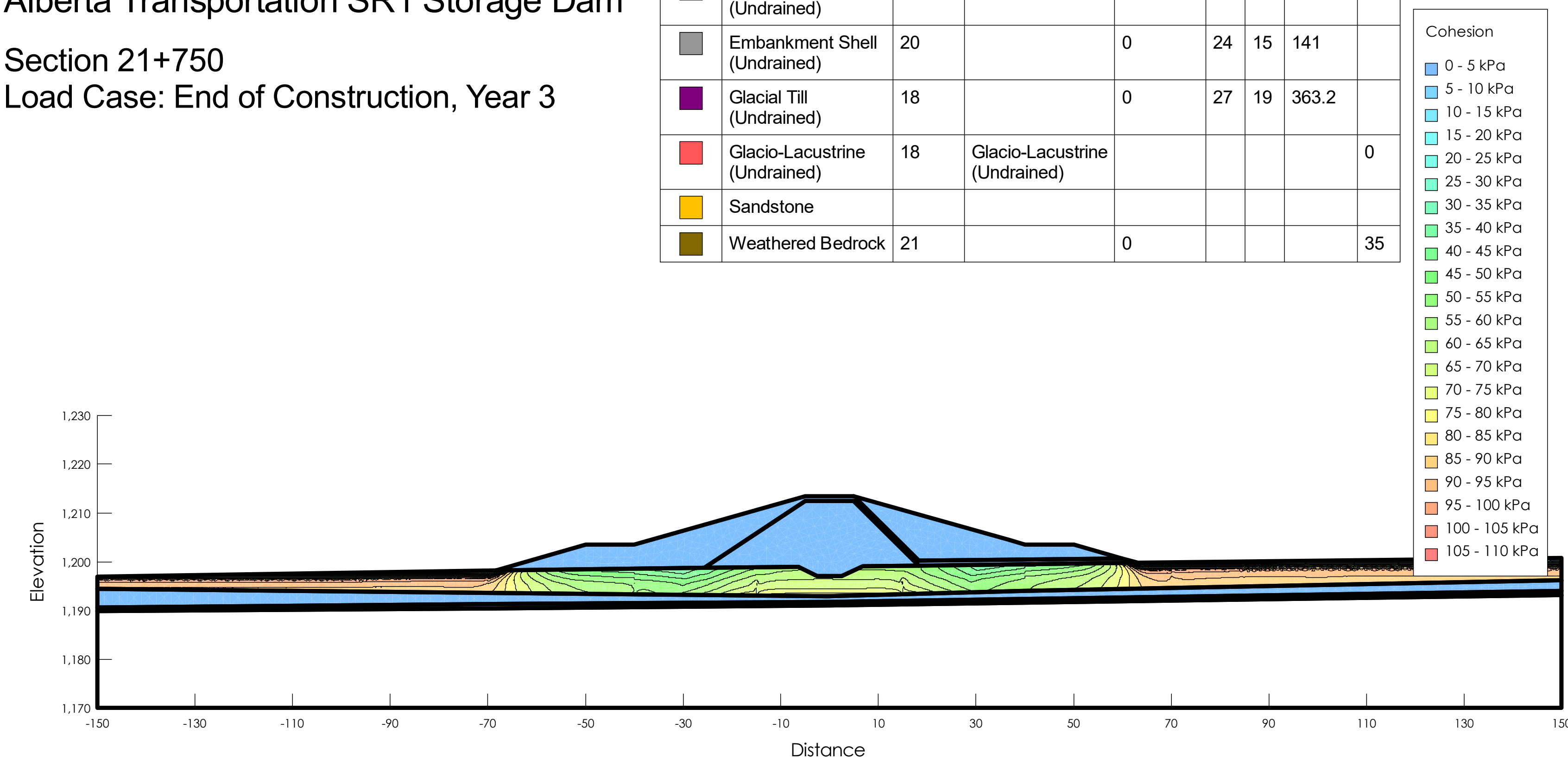


Stantec

Alberta Transportation SR1 Storage Dam

Section 21+750
Load Case: End of Construction, Year 3

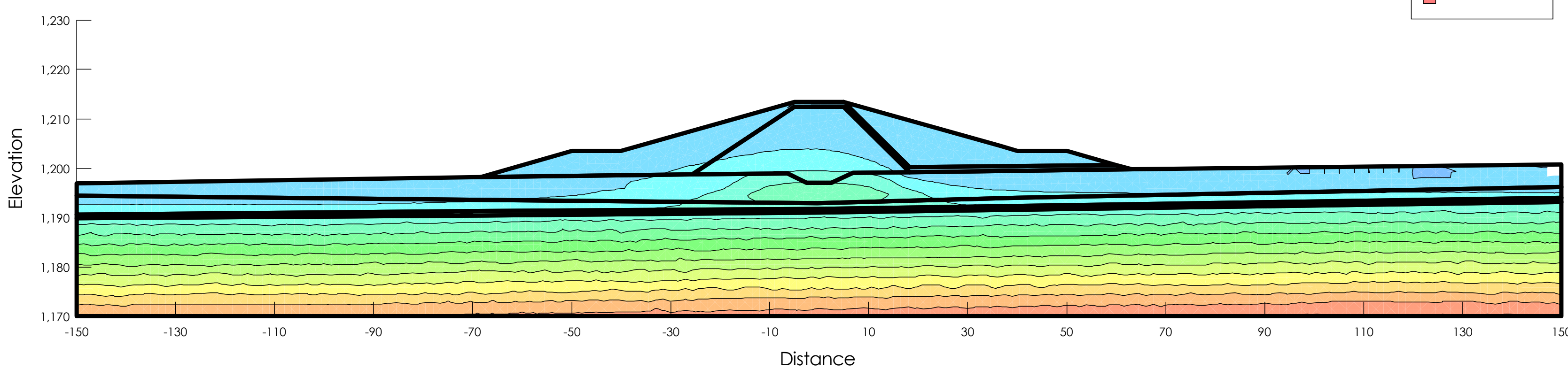
Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)
	Drain	21		0				33
	Embankment Core (Undrained)	20		0	28	19	427	
	Embankment Shell (Undrained)	20		0	24	15	141	
	Glacial Till (Undrained)	18		0	27	19	363.2	
	Glacio-Lacustrine (Undrained)	18	Glacio-Lacustrine (Undrained)					0
	Sandstone							
	Weathered Bedrock	21		0				35



Alberta Transportation SR1 Storage Dam

Section 21+750
Load Case: End of Construction, Year 3

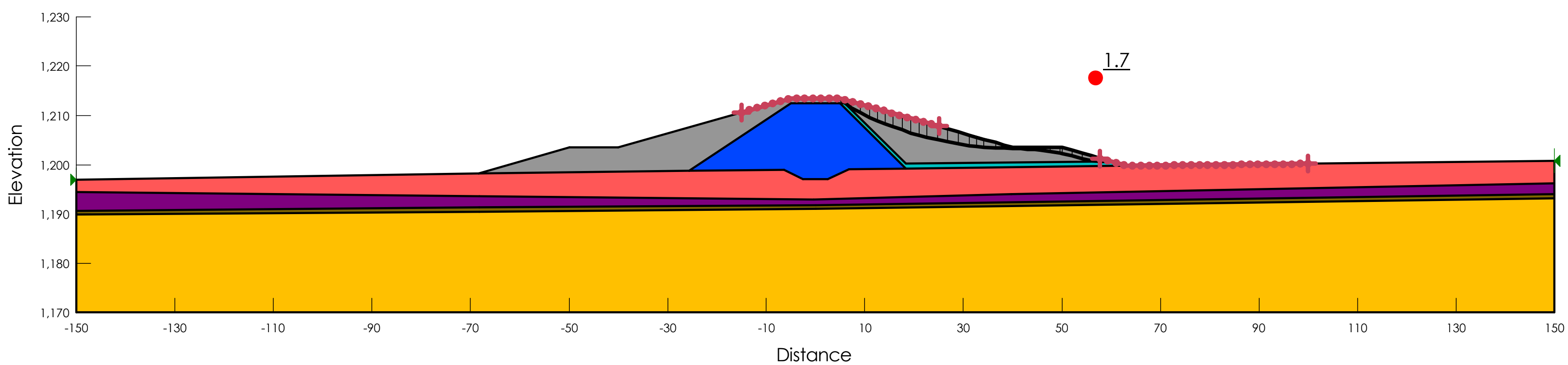
Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)
	Drain	21		0				33
	Embankment Core (Undrained)	20		0	28	19	427	
	Embankment Shell (Undrained)	20		0	24	15	141	
	Glacial Till (Undrained)	18		0	27	19	363.2	
	Glacio-Lacustrine (Undrained)	18	Glacio-Lacustrine (Undrained)					0
	Sandstone							
	Weathered Bedrock	21		0				35



Alberta Transportation SR1 Storage Dam

Section 21+750
Load Case: End of Construction, Year 3
Effective Stress Parameters
Incipient Motion in the Downstream Direction

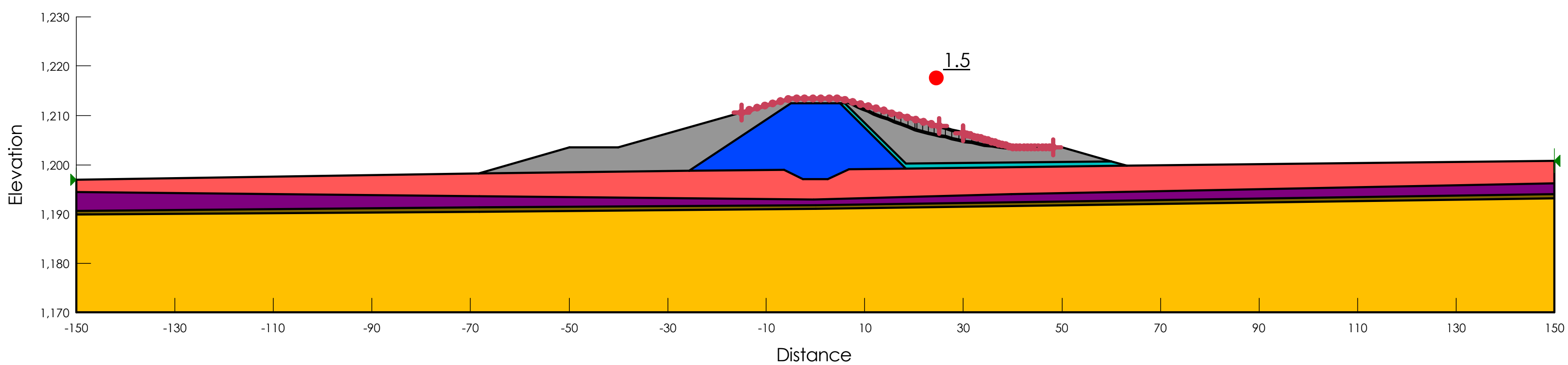
Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)
	Drain	21	0	33
	Embankment Core (Drained)	20	0	28
	Embankment Shell (Drained)	20	0	24
	Glacial Till (Drained)	18	0	27
	Glacio-Lacustrine (Drained)	18	0	23
	Sandstone			
	Weathered Bedrock	21	0	35



Alberta Transportation SR1 Storage Dam

Section 21+750
Load Case: End of Construction, Year 3
Effective Stress Parameters
Incipient Motion in the Downstream Direction

Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)
	Drain	21	0	33
	Embankment Core (Drained)	20	0	28
	Embankment Shell (Drained)	20	0	24
	Glacial Till (Drained)	18	0	27
	Glacio-Lacustrine (Drained)	18	0	23
	Sandstone			
	Weathered Bedrock	21	0	35

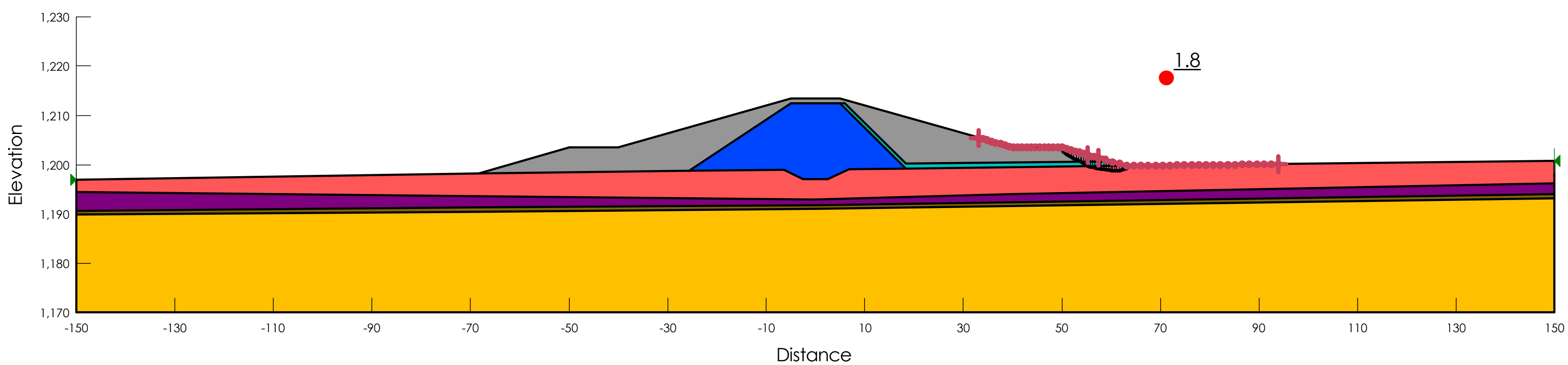


Stantec

Alberta Transportation SR1 Storage Dam

Section 21+750
Load Case: End of Construction, Year 3
Effective Stress Parameters
Incipient Motion in the Downstream Direction

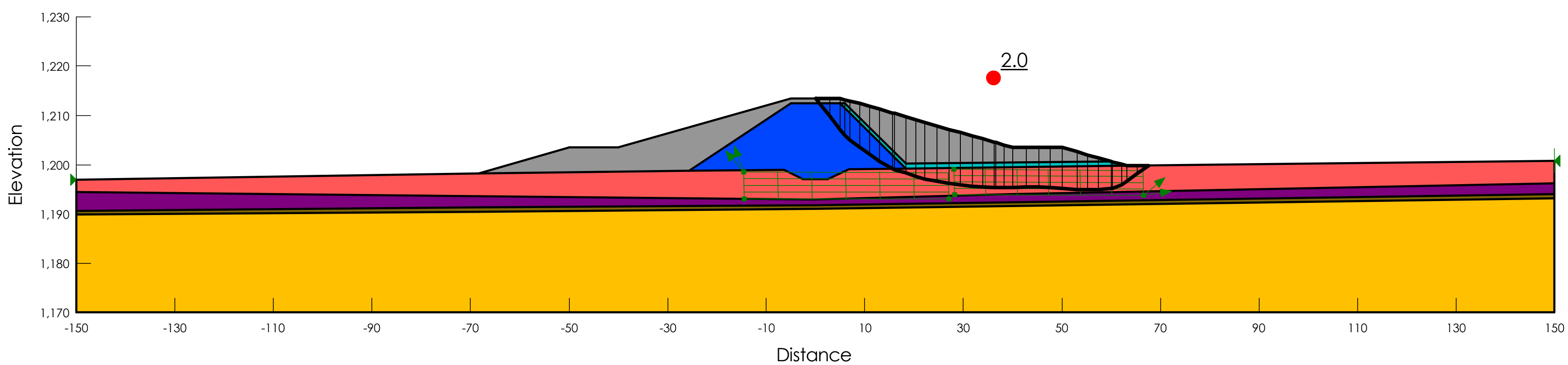
Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)
	Drain	21	0	33
	Embankment Core (Drained)	20	0	28
	Embankment Shell (Drained)	20	0	24
	Glacial Till (Drained)	18	0	27
	Glacio-Lacustrine (Drained)	18	0	23
	Sandstone			
	Weathered Bedrock	21	0	35



Alberta Transportation SR1 Storage Dam

Section 21+750
Load Case: End of Construction, Year 3
Effective Stress Parameters
Incipient Motion in the Downstream Direction

Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)
	Drain	21	0	33
	Embankment Core (Drained)	20	0	28
	Embankment Shell (Drained)	20	0	24
	Glacial Till (Drained)	18	0	27
	Glacio-Lacustrine (Drained)	18	0	23
	Sandstone			
	Weathered Bedrock	21	0	35

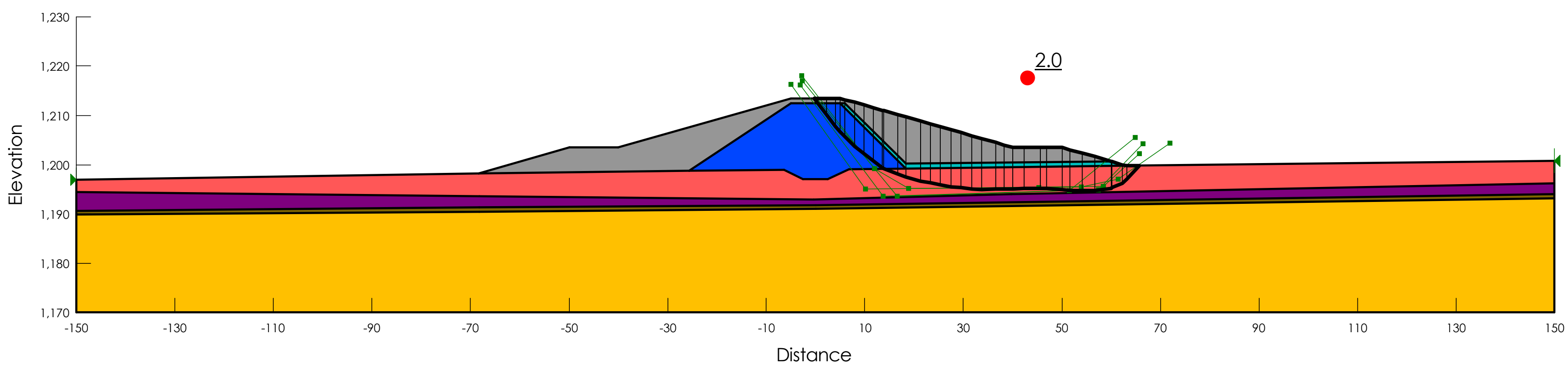


Stantec

Alberta Transportation SR1 Storage Dam

Section 21+750
Load Case: End of Construction, Year 3
Effective Stress Parameters
Incipient Motion in the Downstream Direction

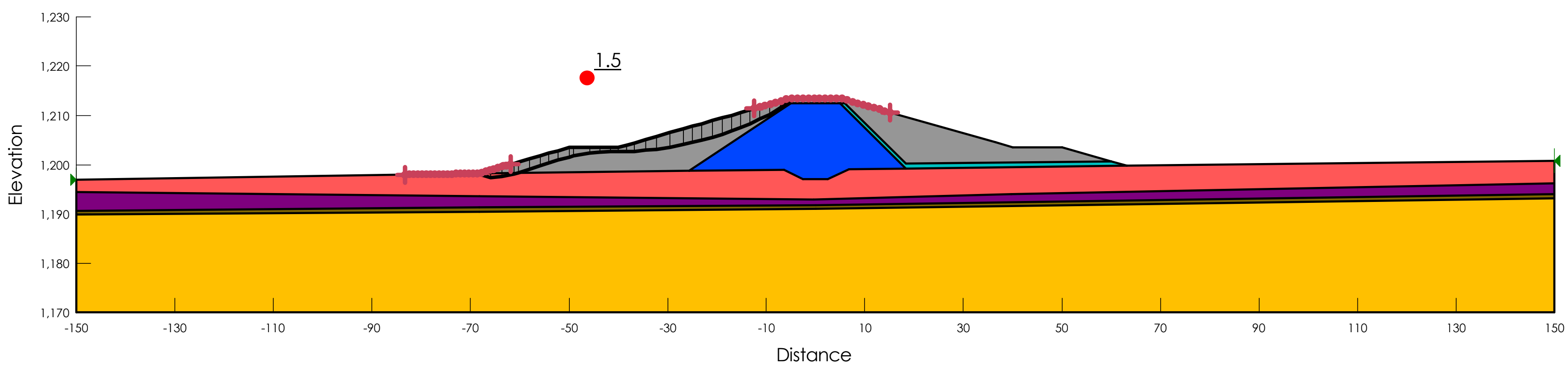
Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)
	Drain	21	0	33
	Embankment Core (Drained)	20	0	28
	Embankment Shell (Drained)	20	0	24
	Glacial Till (Drained)	18	0	27
	Glacio-Lacustrine (Drained)	18	0	23
	Sandstone			
	Weathered Bedrock	21	0	35



Alberta Transportation SR1 Storage Dam

Section 21+750
Load Case: End of Construction, Year 3
Effective Stress Parameters
Incipient Motion in the Upstream Direction

Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)
	Drain	21	0	33
	Embankment Core (Drained)	20	0	28
	Embankment Shell (Drained)	20	0	24
	Glacial Till (Drained)	18	0	27
	Glacio-Lacustrine (Drained)	18	0	23
	Sandstone			
	Weathered Bedrock	21	0	35

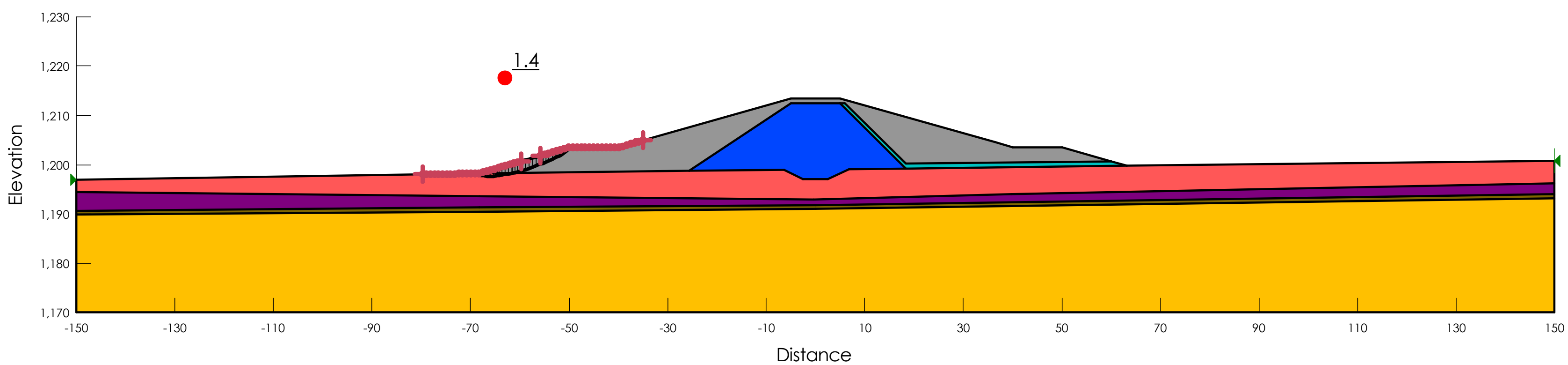


Stantec

Alberta Transportation SR1 Storage Dam

Section 21+750
Load Case: End of Construction, Year 3
Effective Stress Parameters
Incipient Motion in the Upstream Direction

Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)
	Drain	21	0	33
	Embankment Core (Drained)	20	0	28
	Embankment Shell (Drained)	20	0	24
	Glacial Till (Drained)	18	0	27
	Glacio-Lacustrine (Drained)	18	0	23
	Sandstone			
	Weathered Bedrock	21	0	35

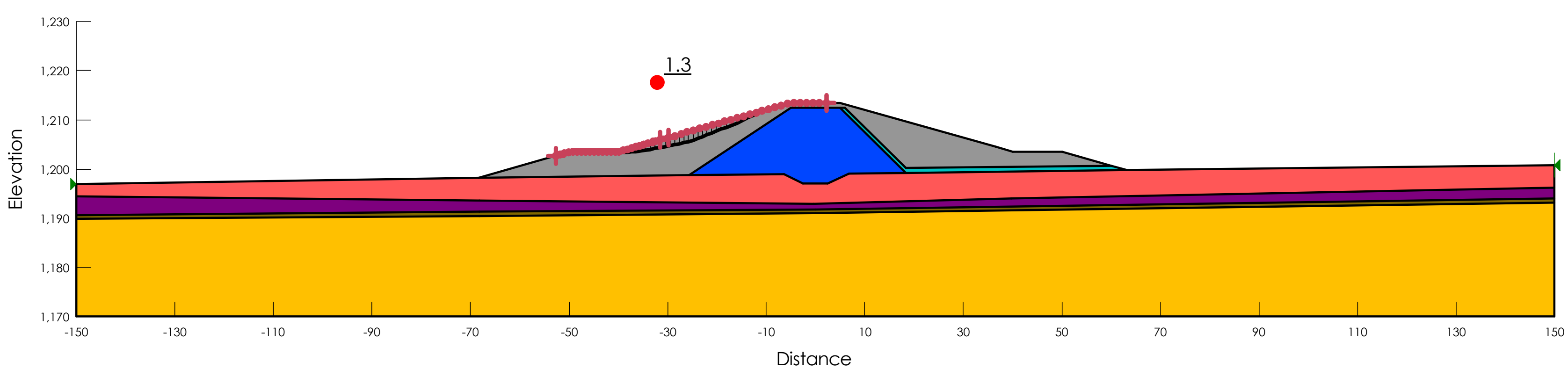


Stantec

Alberta Transportation SR1 Storage Dam

Section 21+750
Load Case: End of Construction, Year 3
Effective Stress Parameters
Incipient Motion in the Upstream Direction

Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)
	Drain	21	0	33
	Embankment Core (Drained)	20	0	28
	Embankment Shell (Drained)	20	0	24
	Glacial Till (Drained)	18	0	27
	Glacio-Lacustrine (Drained)	18	0	23
	Sandstone			
	Weathered Bedrock	21	0	35

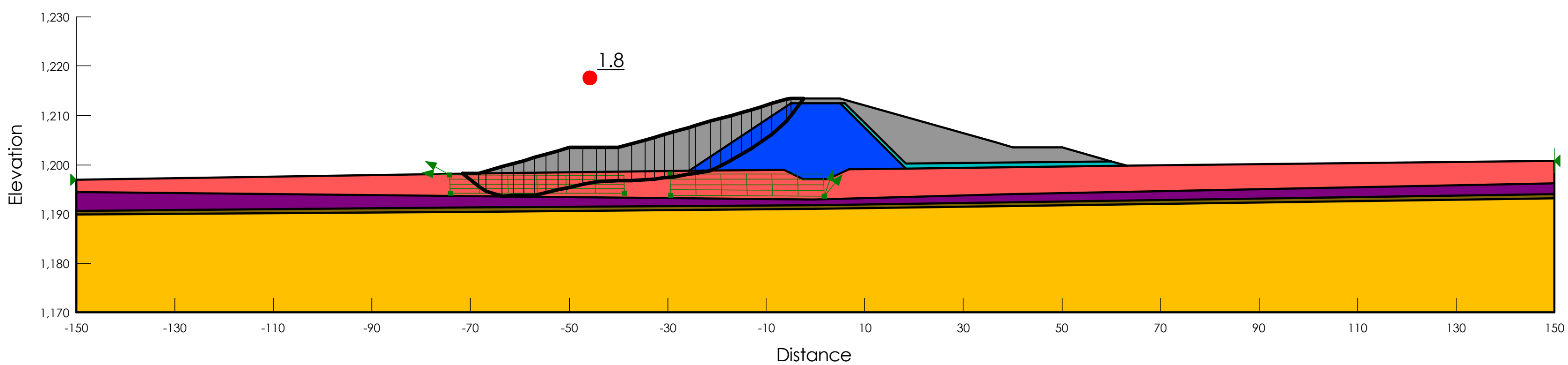


Stantec

Alberta Transportation SR1 Storage Dam

Section 21+750
Load Case: End of Construction, Year 3
Effective Stress Parameters
Incipient Motion in the Upstream Direction

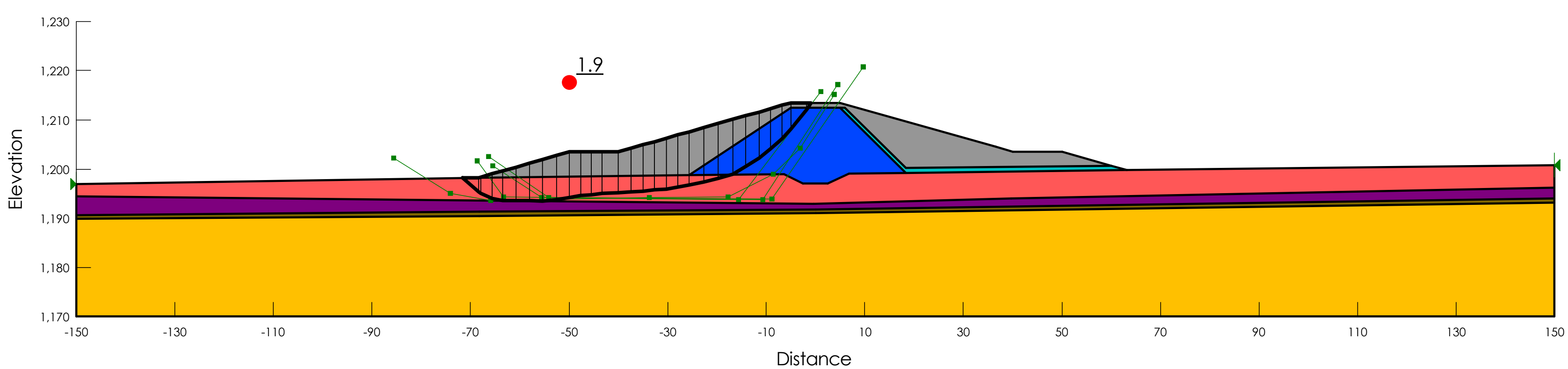
Color	Name	Unit Weight (kN/m^3)	Cohesion' (kPa)	Phi' (°)
	Drain	21	0	33
	Embankment Core (Drained)	20	0	28
	Embankment Shell (Drained)	20	0	24
	Glacial Till (Drained)	18	0	27
	Glacio-Lacustrine (Drained)	18	0	23
	Sandstone			
	Weathered Bedrock	21	0	35



Alberta Transportation SR1 Storage Dam

Section 21+750
Load Case: End of Construction, Year 3
Effective Stress Parameters
Incipient Motion in the Upstream Direction

Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)
	Drain	21	0	33
	Embankment Core (Drained)	20	0	28
	Embankment Shell (Drained)	20	0	24
	Glacial Till (Drained)	18	0	27
	Glacio-Lacustrine (Drained)	18	0	23
	Sandstone			
	Weathered Bedrock	21	0	35

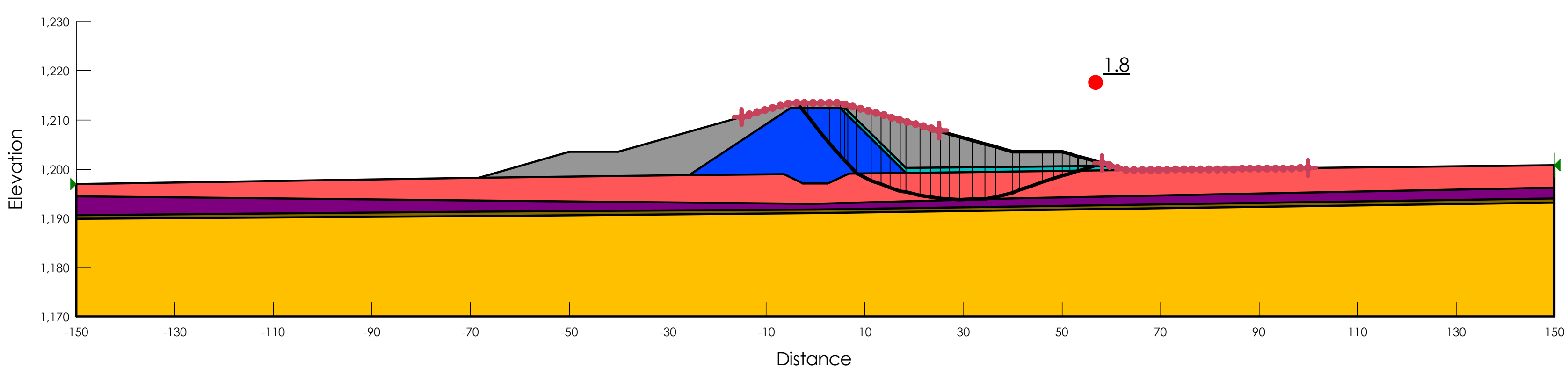


Stantec

Alberta Transportation SR1 Storage Dam

Section 21+750
Load Case: End of Construction, Year 3
Total Stress Parameters
Incipient Motion in the Downstream Direction

Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)
	Drain	21		0				33
	Embankment Core (Undrained)	20		0	28	19	427	
	Embankment Shell (Undrained)	20		0	24	15	141	
	Glacial Till (Undrained)	18		0	27	19	363.2	
	Glacio-Lacustrine (Undrained)	18	Glacio-Lacustrine (Undrained)					0
	Sandstone							
	Weathered Bedrock	21		0				35

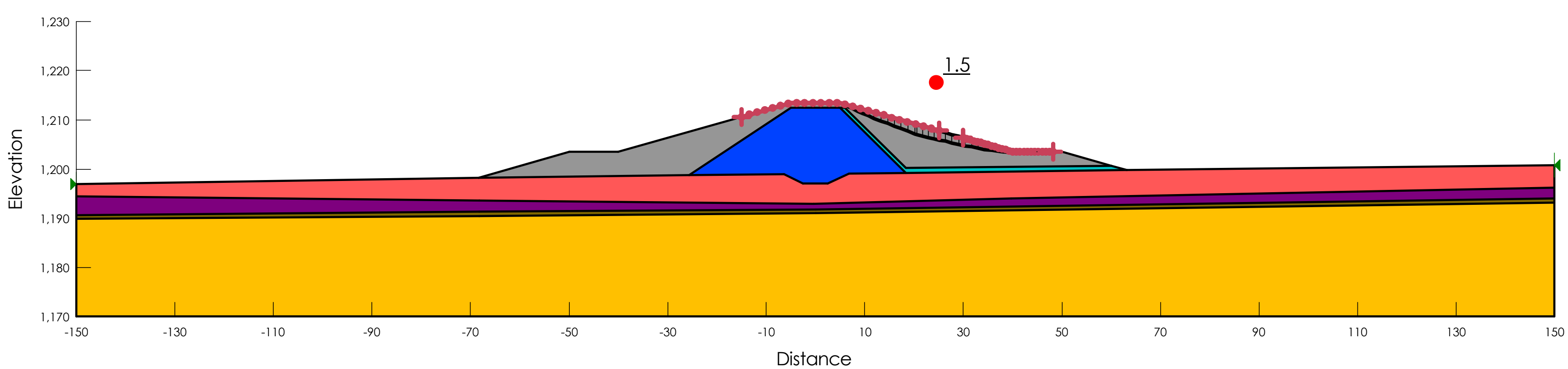


Stantec

Alberta Transportation SR1 Storage Dam

Section 21+750
Load Case: End of Construction, Year 3
Total Stress Parameters
Incipient Motion in the Downstream Direction

Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)
	Drain	21		0				33
	Embankment Core (Undrained)	20		0	28	19	427	
	Embankment Shell (Undrained)	20		0	24	15	141	
	Glacial Till (Undrained)	18		0	27	19	363.2	
	Glacio-Lacustrine (Undrained)	18	Glacio-Lacustrine (Undrained)					0
	Sandstone							
	Weathered Bedrock	21		0				35

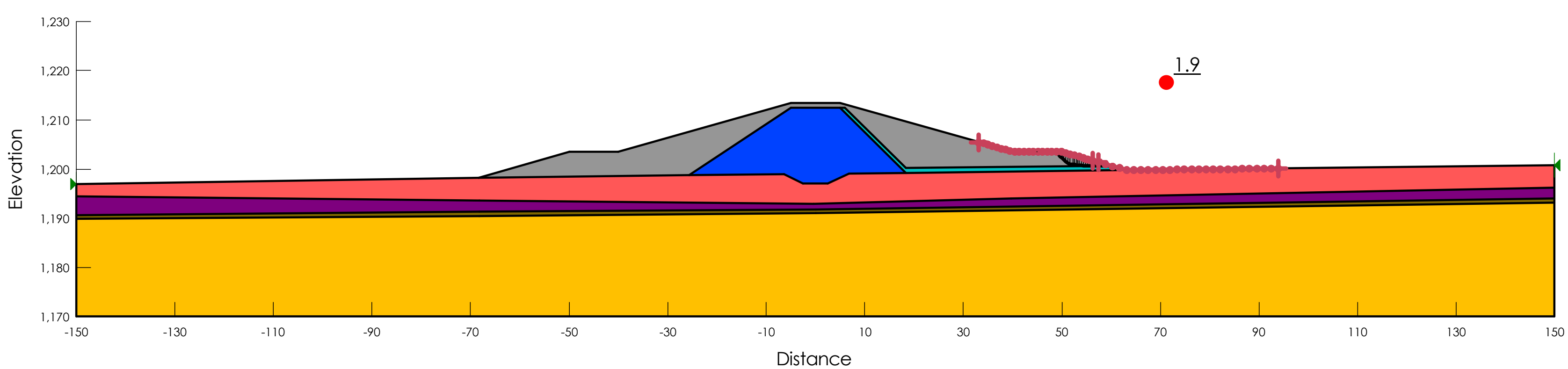


Stantec

Alberta Transportation SR1 Storage Dam

Section 21+750
Load Case: End of Construction, Year 3
Total Stress Parameters
Incipient Motion in the Downstream Direction

Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)
	Drain	21		0				33
	Embankment Core (Undrained)	20		0	28	19	427	
	Embankment Shell (Undrained)	20		0	24	15	141	
	Glacial Till (Undrained)	18		0	27	19	363.2	
	Glacio-Lacustrine (Undrained)	18	Glacio-Lacustrine (Undrained)					0
	Sandstone							
	Weathered Bedrock	21		0				35

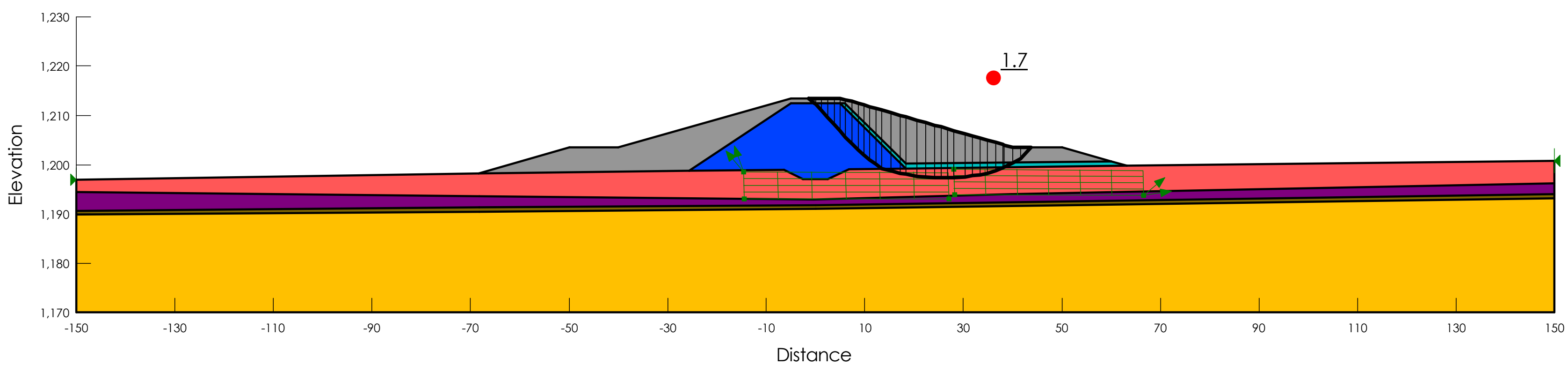


Stantec

Alberta Transportation SR1 Storage Dam

Section 21+750
Load Case: End of Construction, Year 3
Total Stress Parameters
Incipient Motion in the Downstream Direction

Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)
	Drain	21		0				33
	Embankment Core (Undrained)	20		0	28	19	427	
	Embankment Shell (Undrained)	20		0	24	15	141	
	Glacial Till (Undrained)	18		0	27	19	363.2	
	Glacio-Lacustrine (Undrained)	18	Glacio-Lacustrine (Undrained)					0
	Sandstone							
	Weathered Bedrock	21		0				35

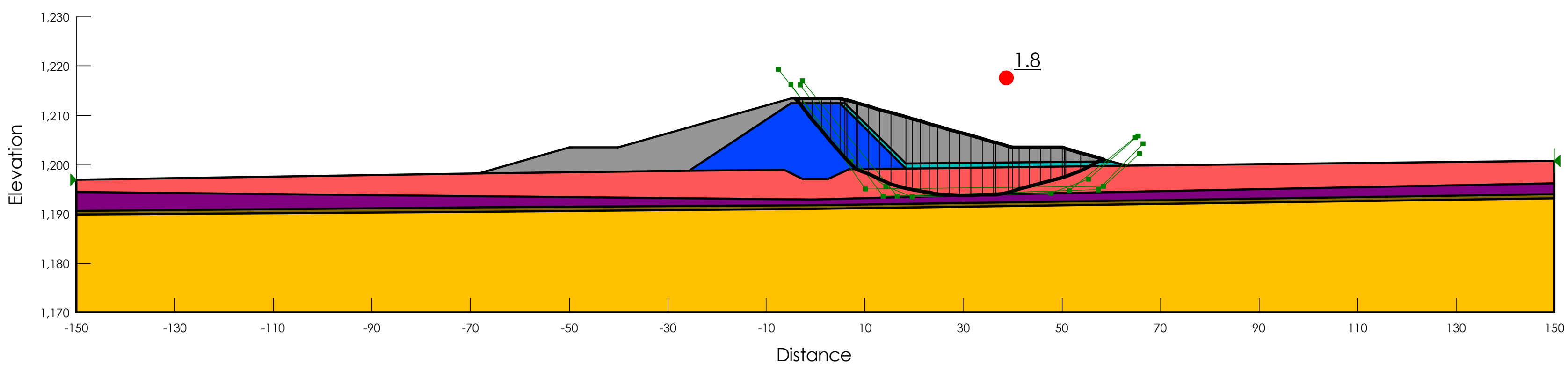


Stantec

Alberta Transportation SR1 Storage Dam

Section 21+750
Load Case: End of Construction, Year 3
Total Stress Parameters
Incipient Motion in the Downstream Direction

Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)
	Drain	21		0				33
	Embankment Core (Undrained)	20		0	28	19	427	
	Embankment Shell (Undrained)	20		0	24	15	141	
	Glacial Till (Undrained)	18		0	27	19	363.2	
	Glacio-Lacustrine (Undrained)	18	Glacio-Lacustrine (Undrained)					0
	Sandstone							
	Weathered Bedrock	21		0				35

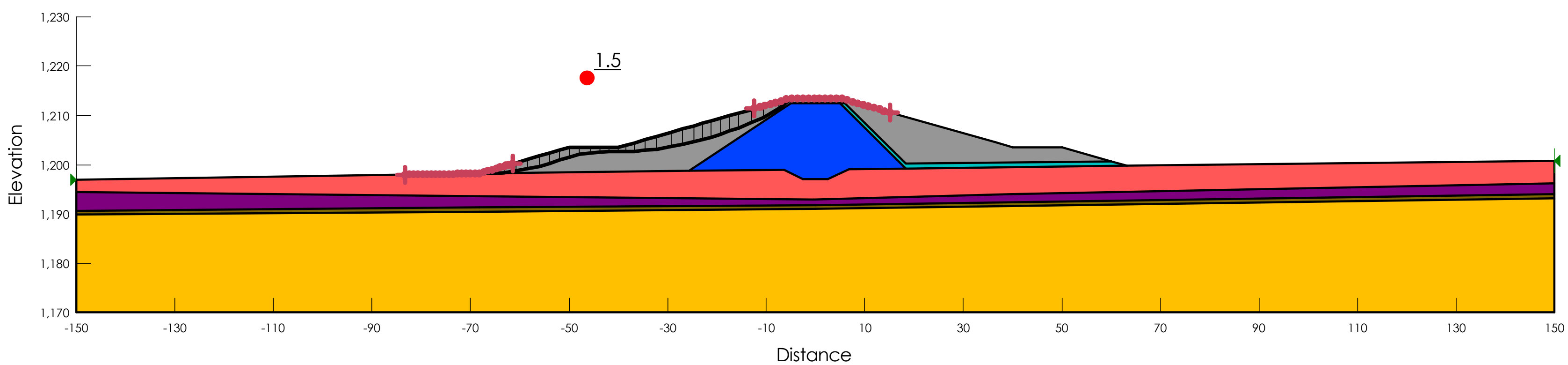


Stantec

Alberta Transportation SR1 Storage Dam

Section 21+750
Load Case: End of Construction, Year 3
Total Stress Parameters
Incipient Motion in the Upstream Direction

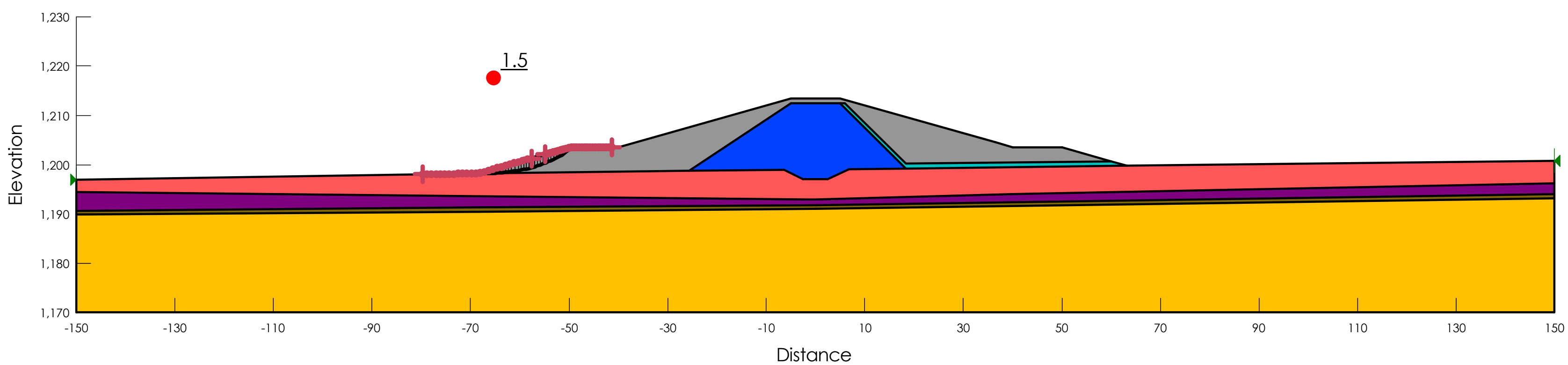
Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)
	Drain	21		0				33
	Embankment Core (Undrained)	20		0	28	19	427	
	Embankment Shell (Undrained)	20		0	24	15	141	
	Glacial Till (Undrained)	18		0	27	19	363.2	
	Glacio-Lacustrine (Undrained)	18	Glacio-Lacustrine (Undrained)					0
	Sandstone							
	Weathered Bedrock	21		0				35



Alberta Transportation SR1 Storage Dam

Section 21+750
Load Case: End of Construction, Year 3
Total Stress Parameters
Incipient Motion in the Upstream Direction

Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)
	Drain	21		0				33
	Embankment Core (Undrained)	20		0	28	19	427	
	Embankment Shell (Undrained)	20		0	24	15	141	
	Glacial Till (Undrained)	18		0	27	19	363.2	
	Glacio-Lacustrine (Undrained)	18	Glacio-Lacustrine (Undrained)					0
	Sandstone							
	Weathered Bedrock	21		0				35

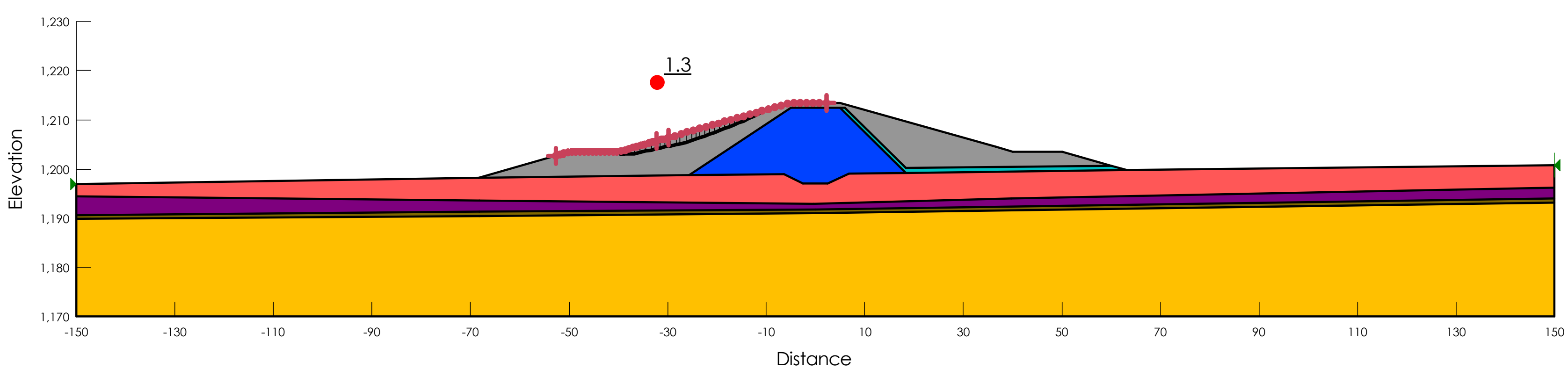


Stantec

Alberta Transportation SR1 Storage Dam

Section 21+750
Load Case: End of Construction, Year 3
Total Stress Parameters
Incipient Motion in the Upstream Direction

Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)
	Drain	21		0				33
	Embankment Core (Undrained)	20		0	28	19	427	
	Embankment Shell (Undrained)	20		0	24	15	141	
	Glacial Till (Undrained)	18		0	27	19	363.2	
	Glacio-Lacustrine (Undrained)	18	Glacio-Lacustrine (Undrained)					0
	Sandstone							
	Weathered Bedrock	21		0				35

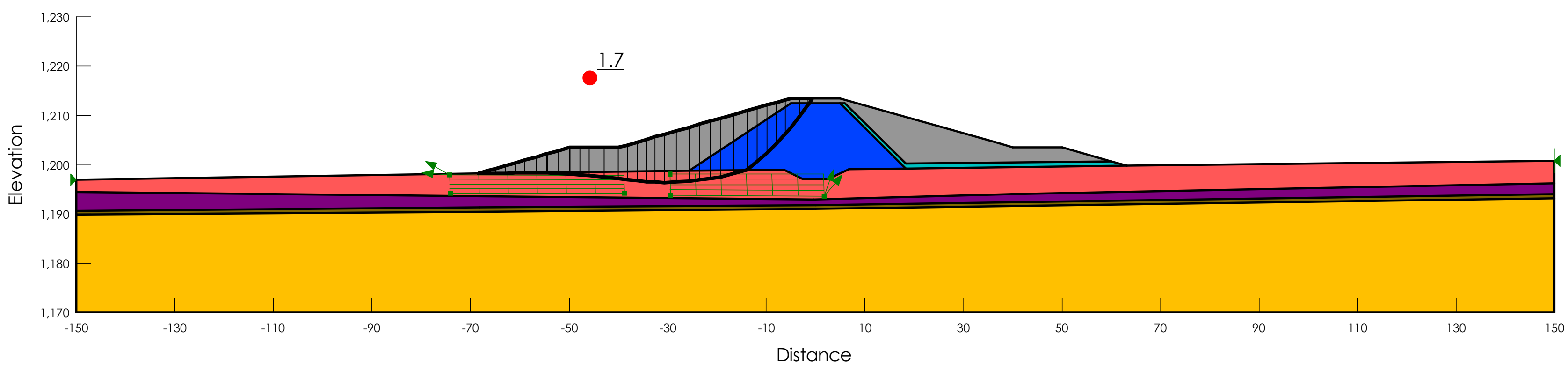


Stantec

Alberta Transportation SR1 Storage Dam

Section 21+750
Load Case: End of Construction, Year 3
Total Stress Parameters
Incipient Motion in the Upstream Direction

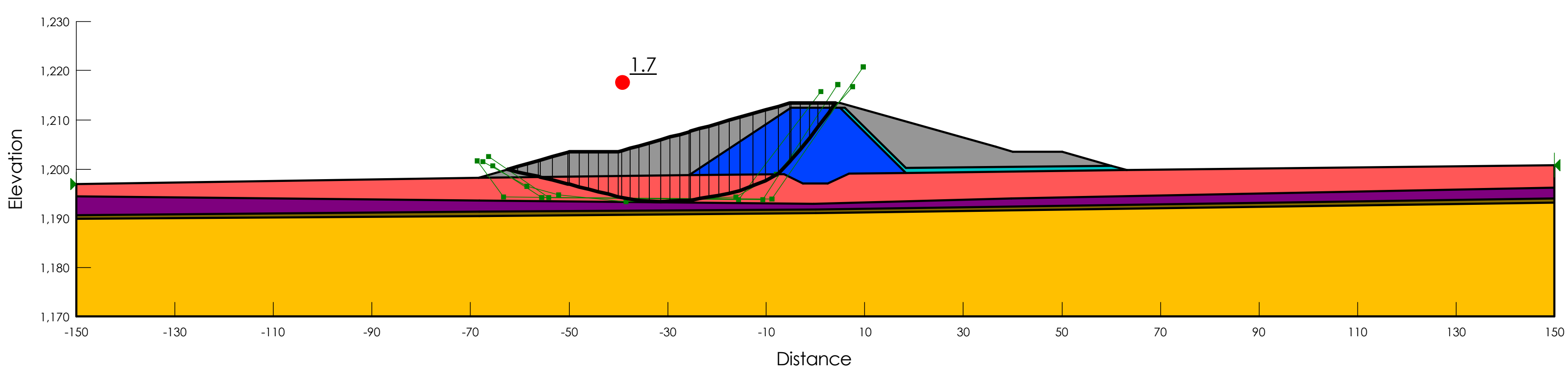
Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)
	Drain	21		0				33
	Embankment Core (Undrained)	20		0	28	19	427	
	Embankment Shell (Undrained)	20		0	24	15	141	
	Glacial Till (Undrained)	18		0	27	19	363.2	
	Glacio-Lacustrine (Undrained)	18	Glacio-Lacustrine (Undrained)					0
	Sandstone							
	Weathered Bedrock	21		0				35



Alberta Transportation SR1 Storage Dam

Section 21+750
Load Case: End of Construction, Year 3
Total Stress Parameters
Incipient Motion in the Upstream Direction

Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)
	Drain	21		0				33
	Embankment Core (Undrained)	20		0	28	19	427	
	Embankment Shell (Undrained)	20		0	24	15	141	
	Glacial Till (Undrained)	18		0	27	19	363.2	
	Glacio-Lacustrine (Undrained)	18	Glacio-Lacustrine (Undrained)					0
	Sandstone							
	Weathered Bedrock	21		0				35

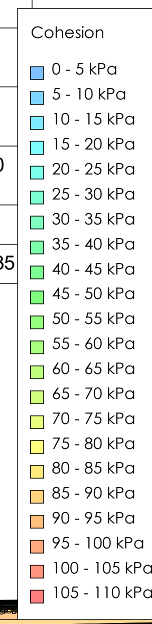


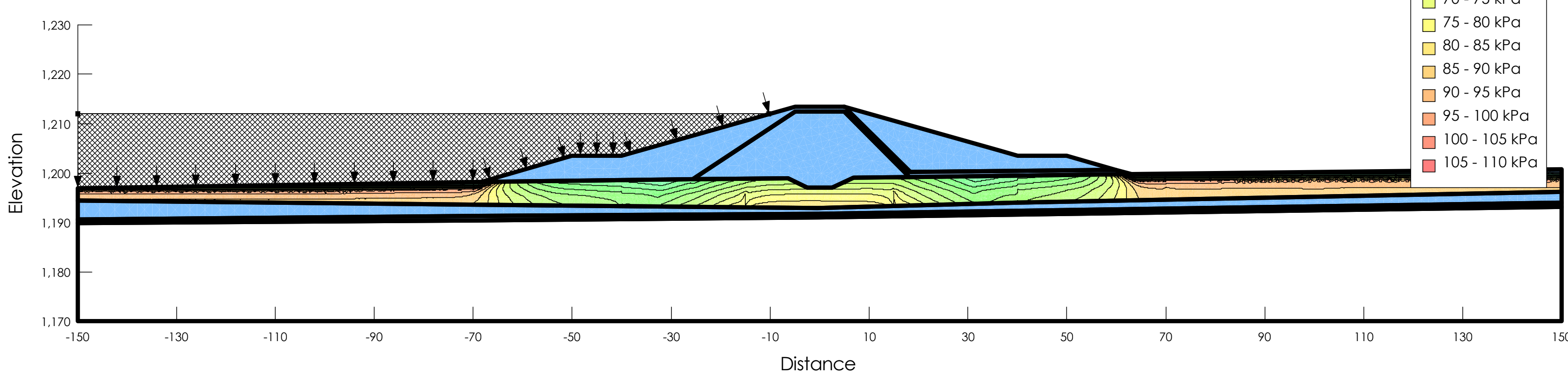
Alberta Transportation SR1 Storage Dam

Section 21+750

Load Case: End of Construction, Flood, Year 3

Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)
	Drain	21		0				33
	Embankment Core (Undrained)	20		0	28	19	427	
	Embankment Shell (Undrained)	20		0	24	15	141	
	Glacial Till (Undrained)	18		0	27	19	363.2	
	Glacio-Lacustrine (Undrained)	18	Glacio-Lacustrine (Undrained)					0
	Sandstone							
	Weathered Bedrock	21		0				35

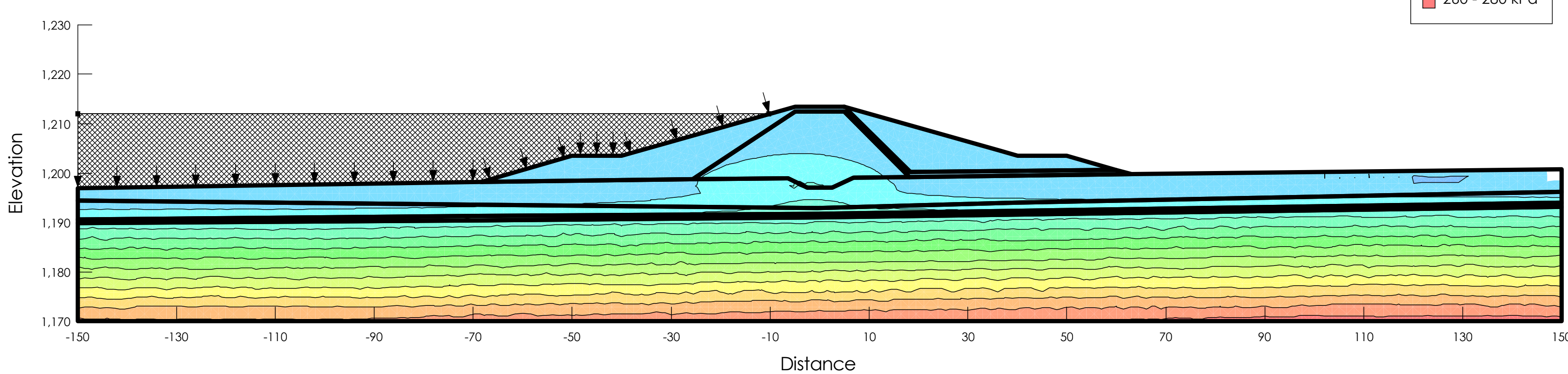




Alberta Transportation SR1 Storage Dam

Section 21+750
Load Case: End of Construction, Flood, Year 3

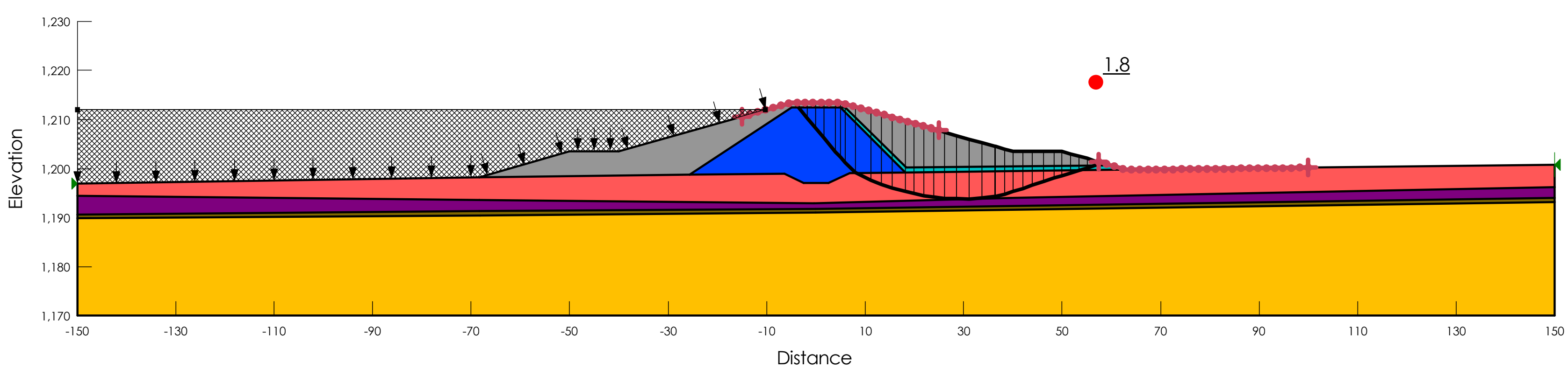
Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)
	Drain	21		0				33
	Embankment Core (Undrained)	20		0	28	19	427	
	Embankment Shell (Undrained)	20		0	24	15	141	
	Glacial Till (Undrained)	18		0	27	19	363.2	
	Glacio-Lacustrine (Undrained)	18	Glacio-Lacustrine (Undrained)					0
	Sandstone							
	Weathered Bedrock	21		0				35



Alberta Transportation SR1 Storage Dam

Section 21+750
Load Case: End of Construction, Flood, Year 3
Total Stress Parameters
Incipient Motion in the Downstream Direction

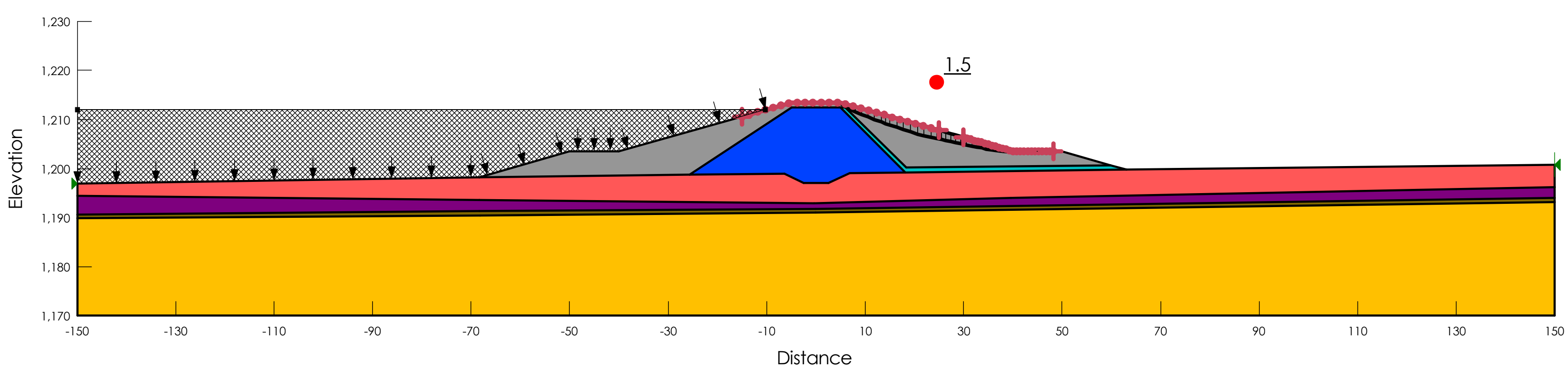
Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)
	Drain	21		0				33
	Embankment Core (Undrained)	20		0	28	19	427	
	Embankment Shell (Undrained)	20		0	24	15	141	
	Glacial Till (Undrained)	18		0	27	19	363.2	
	Glacio-Lacustrine (Undrained)	18	Glacio-Lacustrine (Undrained)					0
	Sandstone							
	Weathered Bedrock	21		0				35



Alberta Transportation SR1 Storage Dam

Section 21+750
Load Case: End of Construction, Flood, Year 3
Total Stress Parameters
Incipient Motion in the Downstream Direction

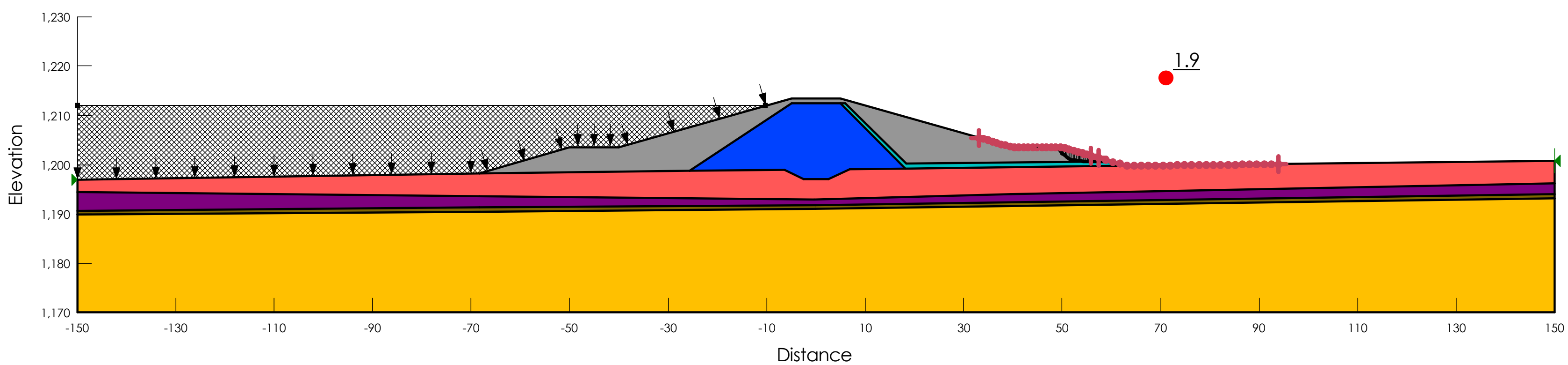
Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)
	Drain	21		0				33
	Embankment Core (Undrained)	20		0	28	19	427	
	Embankment Shell (Undrained)	20		0	24	15	141	
	Glacial Till (Undrained)	18		0	27	19	363.2	
	Glacio-Lacustrine (Undrained)	18	Glacio-Lacustrine (Undrained)					0
	Sandstone							
	Weathered Bedrock	21		0				35



Alberta Transportation SR1 Storage Dam

Section 21+750
Load Case: End of Construction, Flood, Year 3
Total Stress Parameters
Incipient Motion in the Downstream Direction

Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)
	Drain	21		0				33
	Embankment Core (Undrained)	20		0	28	19	427	
	Embankment Shell (Undrained)	20		0	24	15	141	
	Glacial Till (Undrained)	18		0	27	19	363.2	
	Glacio-Lacustrine (Undrained)	18	Glacio-Lacustrine (Undrained)					0
	Sandstone							
	Weathered Bedrock	21		0				35

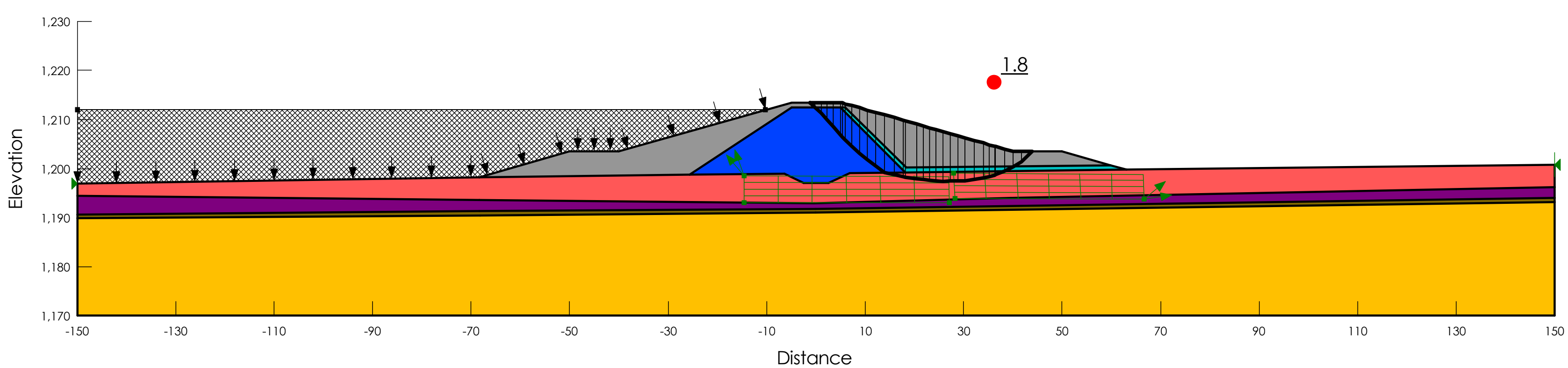


Stantec

Alberta Transportation SR1 Storage Dam

Section 21+750
Load Case: End of Construction, Flood, Year 3
Total Stress Parameters
Incipient Motion in the Downstream Direction

Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)
	Drain	21		0				33
	Embankment Core (Undrained)	20		0	28	19	427	
	Embankment Shell (Undrained)	20		0	24	15	141	
	Glacial Till (Undrained)	18		0	27	19	363.2	
	Glacio-Lacustrine (Undrained)	18	Glacio-Lacustrine (Undrained)					0
	Sandstone							
	Weathered Bedrock	21		0				35

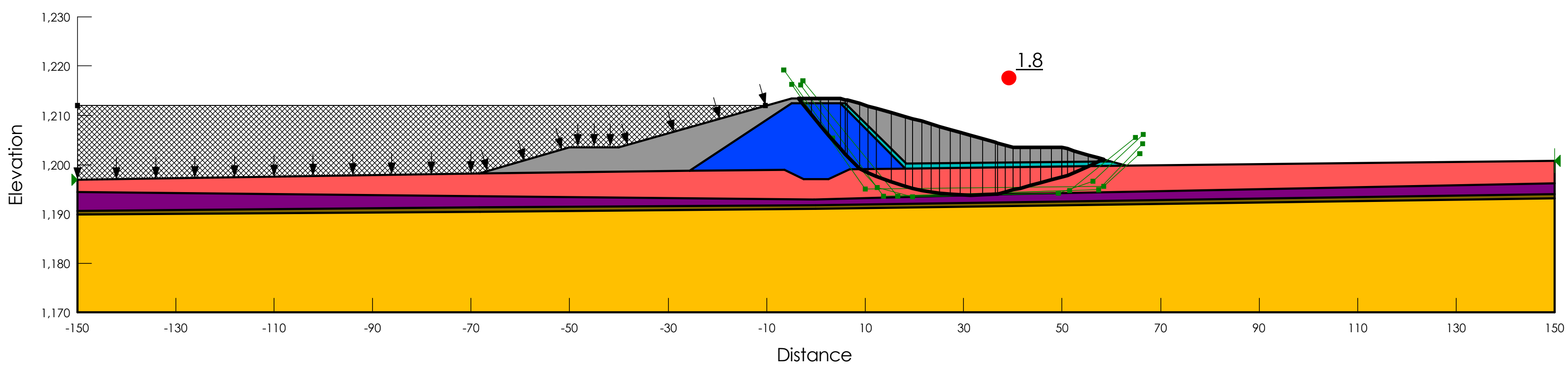


Stantec

Alberta Transportation SR1 Storage Dam

Section 21+750
Load Case: End of Construction, Flood, Year 3
Total Stress Parameters
Incipient Motion in the Downstream Direction

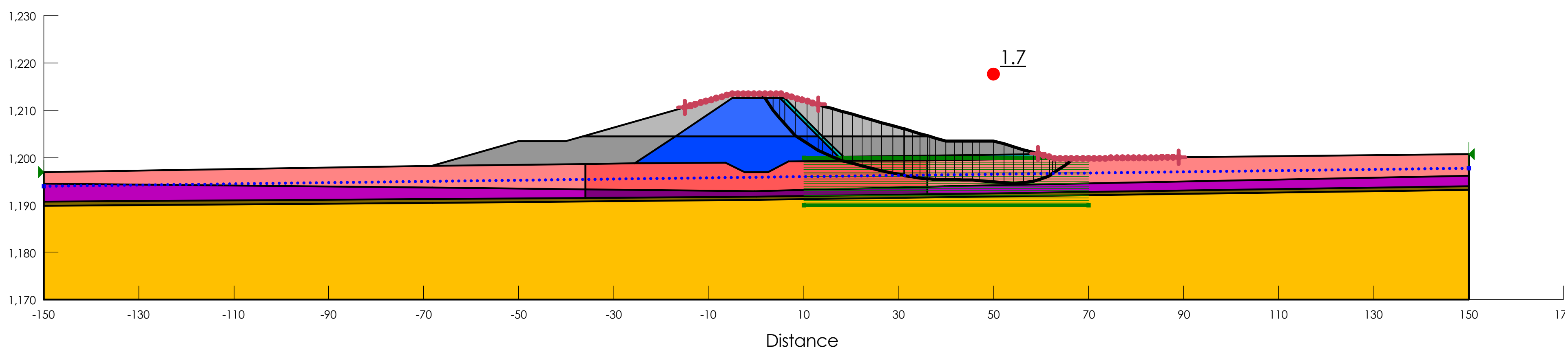
Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)
	Drain	21		0				33
	Embankment Core (Undrained)	20		0	28	19	427	
	Embankment Shell (Undrained)	20		0	24	15	141	
	Glacial Till (Undrained)	18		0	27	19	363.2	
	Glacio-Lacustrine (Undrained)	18	Glacio-Lacustrine (Undrained)					0
	Sandstone							
	Weathered Bedrock	21		0				35



Alberta Transportation SR1 Storage Dam

Section 21+750
Load Case: End of Construction Year 3
B-bar Analysis
Effective Stress Parameters

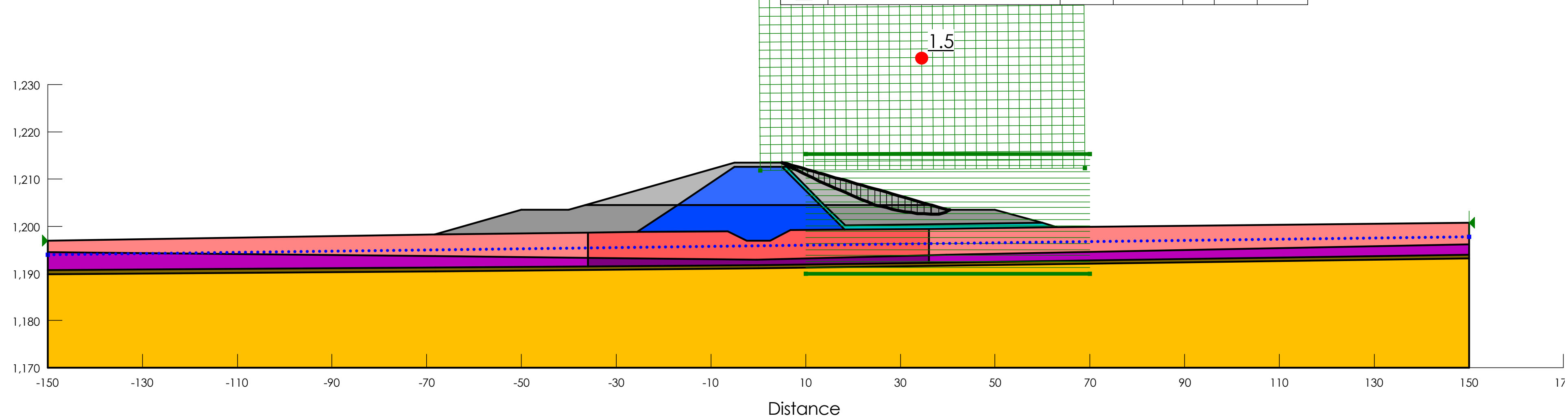
Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)	B-bar	Add Weight
	Drain	21	0	33	0	Yes
	Embankment Core (Drained, Year 2)	20	0	28	0.4	Yes
	Embankment Core (Drained, Year 3)	20	0	28	0	Yes
	Embankment Shell (Drained, Year 2)	20	0	24	0.18	Yes
	Embankment Shell (Drained, Year 3)	20	0	24	0	Yes
	Glacial Till (Drained, Crest/Slope)	18	0	27	0.15	No
	Glacial Till (Drained, Slope/Toe)	18	0	27	0.1	No
	Glacio-Lacustrine (Drained, Crest/Slope)	18	0	23	0.3	No
	Glacio-Lacustrine (Drained, Slope/Toe)	18	0	23	0.25	No
	Sandstone				0	No
	Weathered Bedrock	21	0	35	0	No



Alberta Transportation SR1 Storage Dam

Section 21+750
Load Case: End of Construction Year 3
B-bar Analysis
Effective Stress Parameters

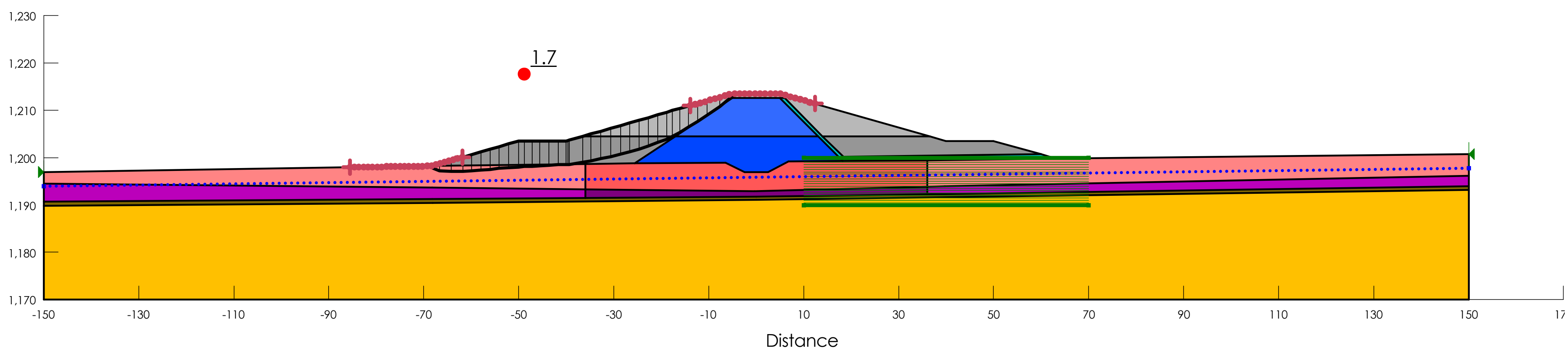
Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)	B-bar	Add Weight
	Drain	21	0	33	0	Yes
	Embankment Core (Drained, Year 2)	20	0	28	0.4	Yes
	Embankment Core (Drained, Year 3)	20	0	28	0	Yes
	Embankment Shell (Drained, Year 2)	20	0	24	0.18	Yes
	Embankment Shell (Drained, Year 3)	20	0	24	0	Yes
	Glacial Till (Drained, Crest/Slope)	18	0	27	0.15	No
	Glacial Till (Drained, Slope/Toe)	18	0	27	0.1	No
	Glacio-Lacustrine (Drained, Crest/Slope)	18	0	23	0.3	No
	Glacio-Lacustrine (Drained, Slope/Toe)	18	0	23	0.25	No
	Sandstone				0	No
	Weathered Bedrock	21	0	35	0	No



Alberta Transportation SR1 Storage Dam

Section 21+750
Load Case: End of Construction Year 3
B-bar Analysis
Effective Stress Parameters

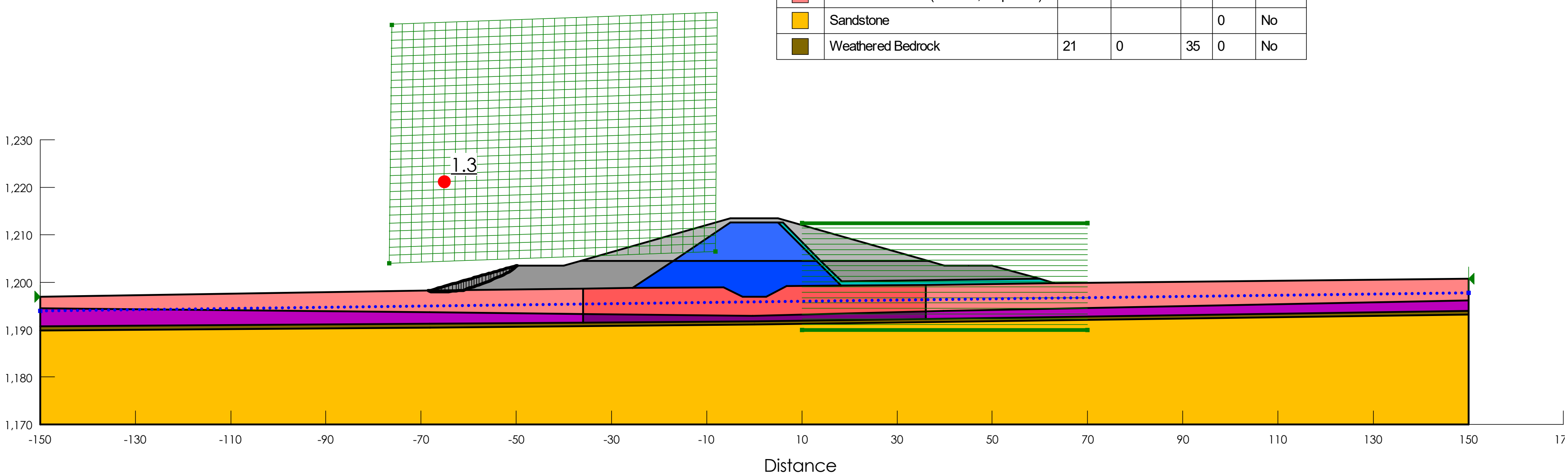
Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)	B-bar	Add Weight
	Drain	21	0	33	0	Yes
	Embankment Core (Drained, Year 2)	20	0	28	0.4	Yes
	Embankment Core (Drained, Year 3)	20	0	28	0	Yes
	Embankment Shell (Drained, Year 2)	20	0	24	0.18	Yes
	Embankment Shell (Drained, Year 3)	20	0	24	0	Yes
	Glacial Till (Drained, Crest/Slope)	18	0	27	0.15	No
	Glacial Till (Drained, Slope/Toe)	18	0	27	0.1	No
	Glacio-Lacustrine (Drained, Crest/Slope)	18	0	23	0.3	No
	Glacio-Lacustrine (Drained, Slope/Toe)	18	0	23	0.25	No
	Sandstone				0	No
	Weathered Bedrock	21	0	35	0	No



Alberta Transportation SR1 Storage Dam

Section 21+750
Load Case: End of Construction Year 3
B-bar Analysis
Effective Stress Parameters

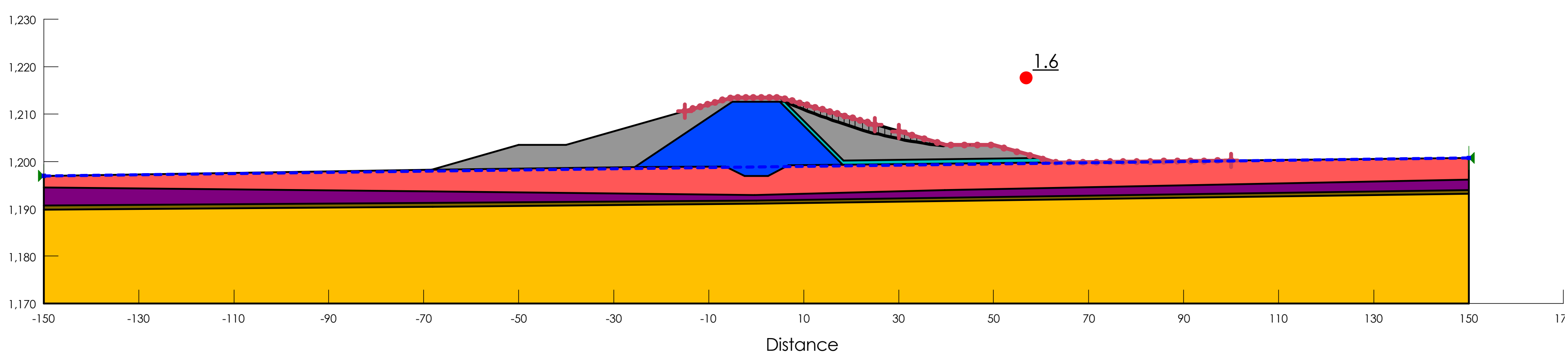
Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)	B-bar	Add Weight
	Drain	21	0	33	0	Yes
	Embankment Core (Drained, Year 2)	20	0	28	0.4	Yes
	Embankment Core (Drained, Year 3)	20	0	28	0	Yes
	Embankment Shell (Drained, Year 2)	20	0	24	0.18	Yes
	Embankment Shell (Drained, Year 3)	20	0	24	0	Yes
	Glacial Till (Drained, Crest/Slope)	18	0	27	0.15	No
	Glacial Till (Drained, Slope/Toe)	18	0	27	0.1	No
	Glacio-Lacustrine (Drained, Crest/Slope)	18	0	23	0.3	No
	Glacio-Lacustrine (Drained, Slope/Toe)	18	0	23	0.25	No
	Sandstone				0	No
	Weathered Bedrock	21	0	35	0	No



Alberta Transportation SR1 Storage Dam

Section 21+750
Load Case: Long Term
Effective Stress Parameters
Incipient Motion in the Downstream Direction

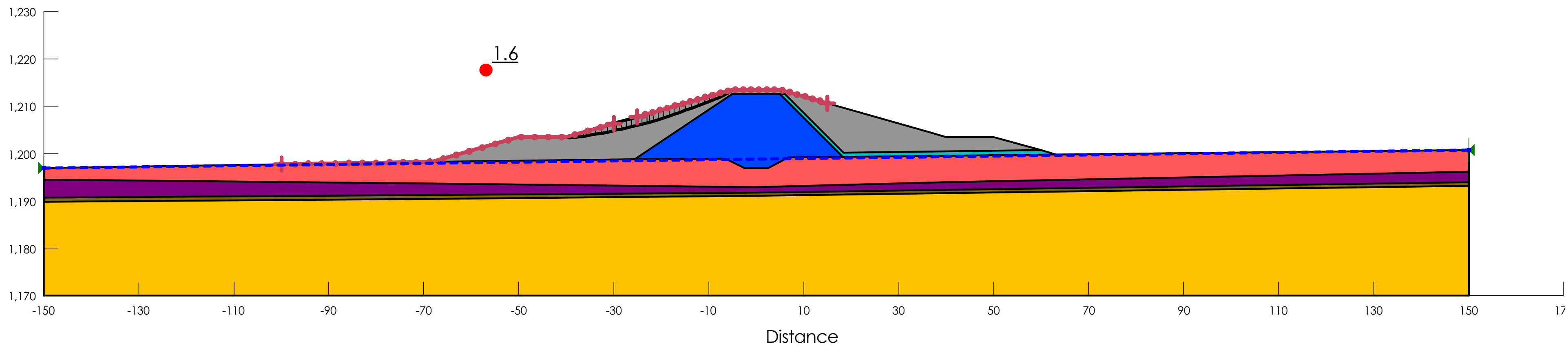
Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)
	Drain	21	0	33
	Embankment Core (Drained)	20	0	28
	Embankment Shell (Drained)	20	0	24
	Glacial Till (Drained)	18	0	27
	Glacio-Lacustrine (Drained)	18	0	23
	Sandstone			
	Weathered Bedrock	21	0	35



Alberta Transportation SR1 Storage Dam

Section 21+750
Load Case: Pseudostatic
Pseudostatic Parameters
Incipient Motion in the Downstream Direction

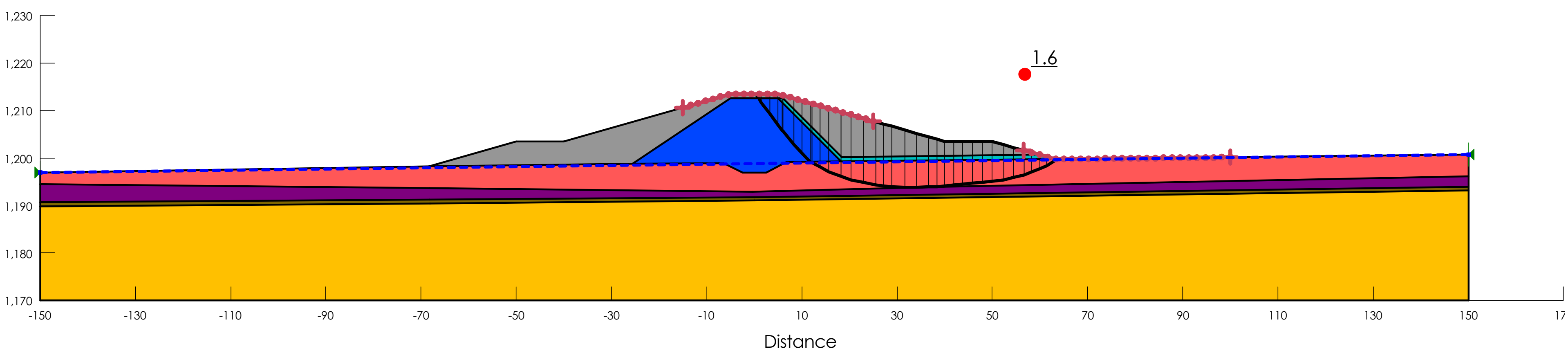
Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)
	Drain	21	0	33
	Embankment Core (Drained)	20	0	28
	Embankment Shell (Drained)	20	0	24
	Glacial Till (Drained)	18	0	27
	Glacio-Lacustrine (Drained)	18	0	23
	Sandstone			
	Weathered Bedrock	21	0	35



Stantec

Alberta Transportation SR1 Storage Dam

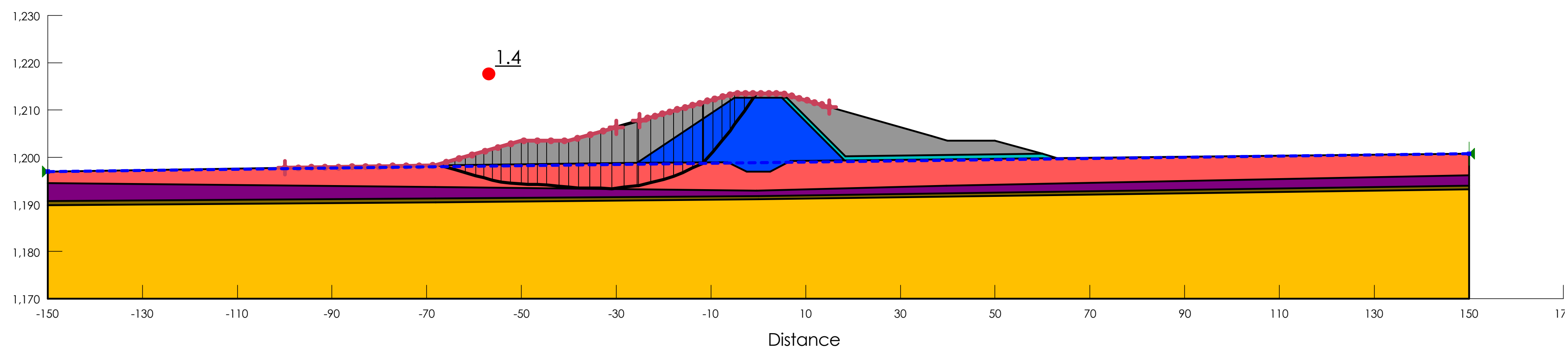
Color	Name	Unit Weight (kN/m^3)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)
	Drain	21		0				33
	Embankment Core (EQ/Pseudo)	20		0	28	15	243	
	Embankment Shell (EQ/Pseudo)	20		0	24	12	86	
	Glacial Till (EQ/Pseudo)	18		0	27	15	199	
	Glacio-Lacustrine (EQ/Pseudo)	18	Glacio-Lacustrine (Seismic)					0
	Sandstone							
	Weathered Bedrock	21		0				35



Alberta Transportation SR1 Storage Dam

Section 21+750
Load Case: Pseudostatic
Pseudostatic Parameters
Incipient Motion in the Downstream Direction

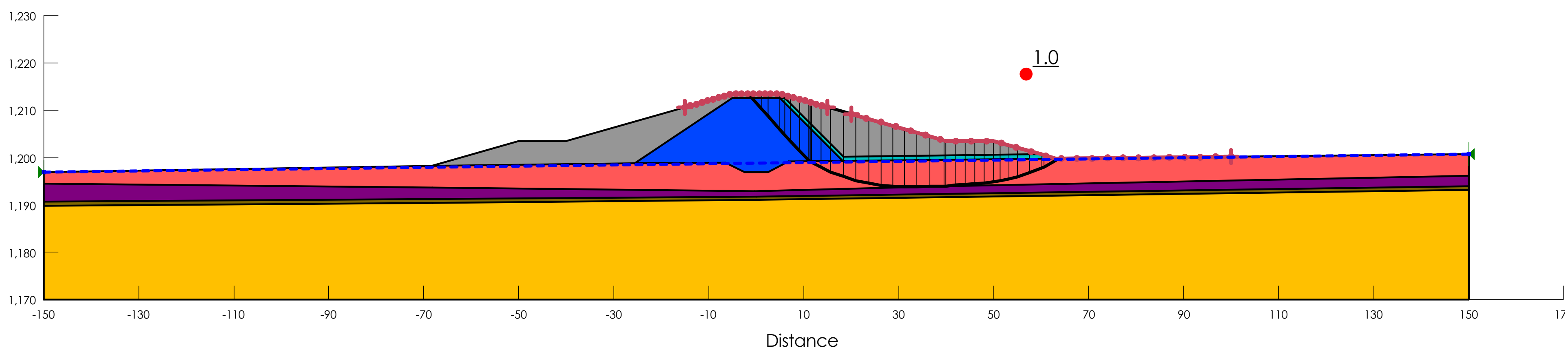
Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)
	Drain	21		0				33
	Embankment Core (EQ/Pseudo)	20		0	28	15	243	
	Embankment Shell (EQ/Pseudo)	20		0	24	12	86	
	Glacial Till (EQ/Pseudo)	18		0	27	15	199	
	Glacio-Lacustrine (EQ/Pseudo)	18	Glacio-Lacustrine (Seismic)					0
	Sandstone							
	Weathered Bedrock	21		0				35



Alberta Transportation SR1 Storage Dam

Section 21+750
Load Case: Pseudostatic
Pseudostatic Parameters
Incipient Motion in the Downstream Direction

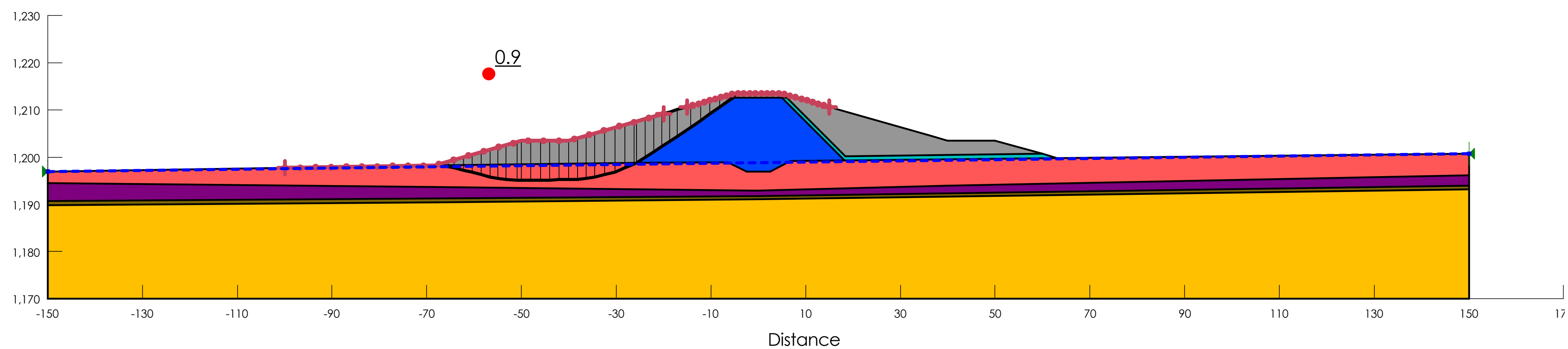
Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)	Cohesion R (kPa)	Phi R (°)
	Drain	21		0				33	0	0
	Embankment Core (EQ/Pseudo)	20		0	28	15	243			
	Embankment Shell (EQ/Pseudo)	20		0	24	12	86			
	Glacial Till (EQ/Pseudo)	18		0	27	15	199			
	Glacio-Lacustrine (EQ/Pseudo)	18	Glacio-Lacustrine (Seismic)					0	0	0
	Sandstone									
	Weathered Bedrock	21		0				35	0	0



Alberta Transportation SR1 Storage Dam

Section 21+750
Load Case: Long Term
Effective and Total Stress Parameters
Incipient Motion in the Downstream Direction

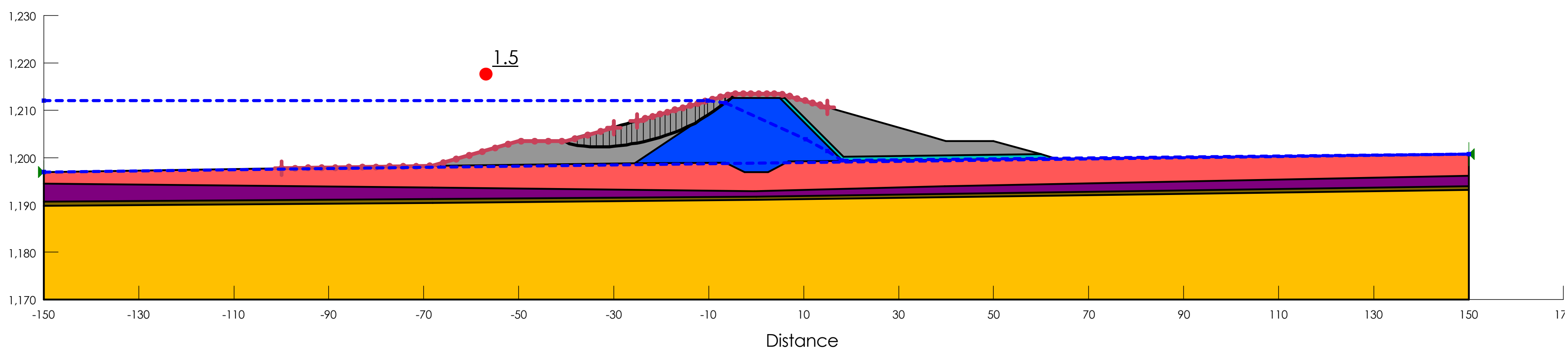
Color	Name	Unit Weight (kN/m^3)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)	Cohesion R (kPa)	Phi R (°)
	Drain	21		0				33	0	0
	Embankment Core (EQ/Pseudo)	20		0	28	15	243			
	Embankment Shell (EQ/Pseudo)	20		0	24	12	86			
	Glacial Till (EQ/Pseudo)	18		0	27	15	199			
	Glacio-Lacustrine (EQ/Pseudo)	18	Glacio-Lacustrine (Seismic)					0	0	0
	Sandstone									
	Weathered Bedrock	21		0				35	0	0



Alberta Transportation SR1 Storage Dam

Section 21+750
Load Case: Long Term
Effective and Total Stress Parameters
Incipient Motion in the Downstream Direction

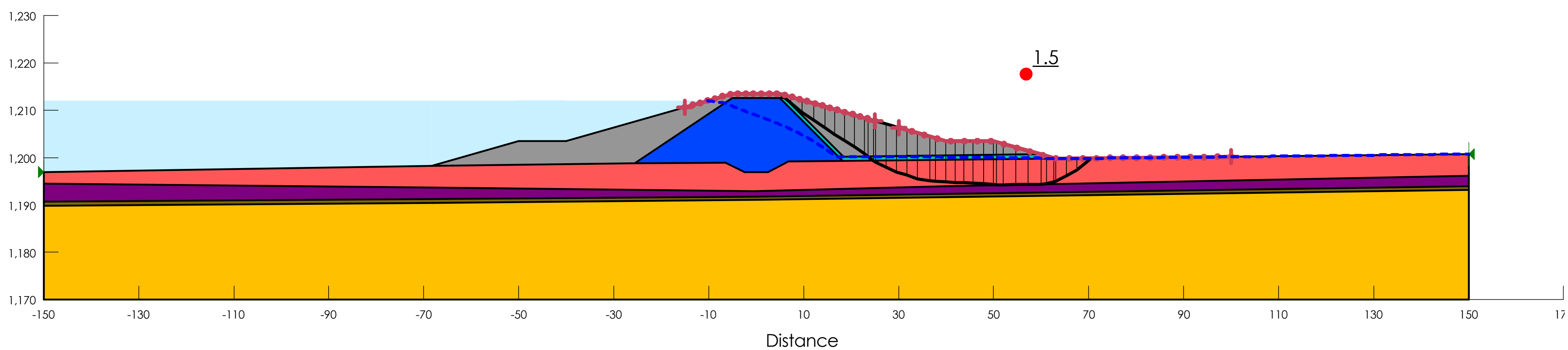
Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)	Cohesion R (kPa)	Phi R (°)	Piezometric Line After Drawdown
	Drain	21	0	33	0	0	1
	Embankment Core (RDD)	20	0	28	80	19	1
	Embankment Shell (RDD)	20	0	24	25	15	1
	Glacial Till (RDD)	18	0	27	60	19	1
	Glacio-Lacustrine (RDD)	18	0	23	15	20	1
	Sandstone						1
	Weathered Bedrock	21	0	35	0	0	1



Alberta Transportation SR1 Storage Dam

Section 21+750
Load Case: USBR Flood
Effective Stress Parameters
Incipient Motion in the Downstream Direction

Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)
	Drain	21	0	33
	Embankment Core (Drained)	20	0	28
	Embankment Shell (Drained)	20	0	24
	Glacial Till (Drained)	18	0	27
	Glacio-Lacustrine (Drained)	18	0	23
	Sandstone			
	Weathered Bedrock	21	0	35



Attachment 12.1
Slope Stability and Seepage Analyses

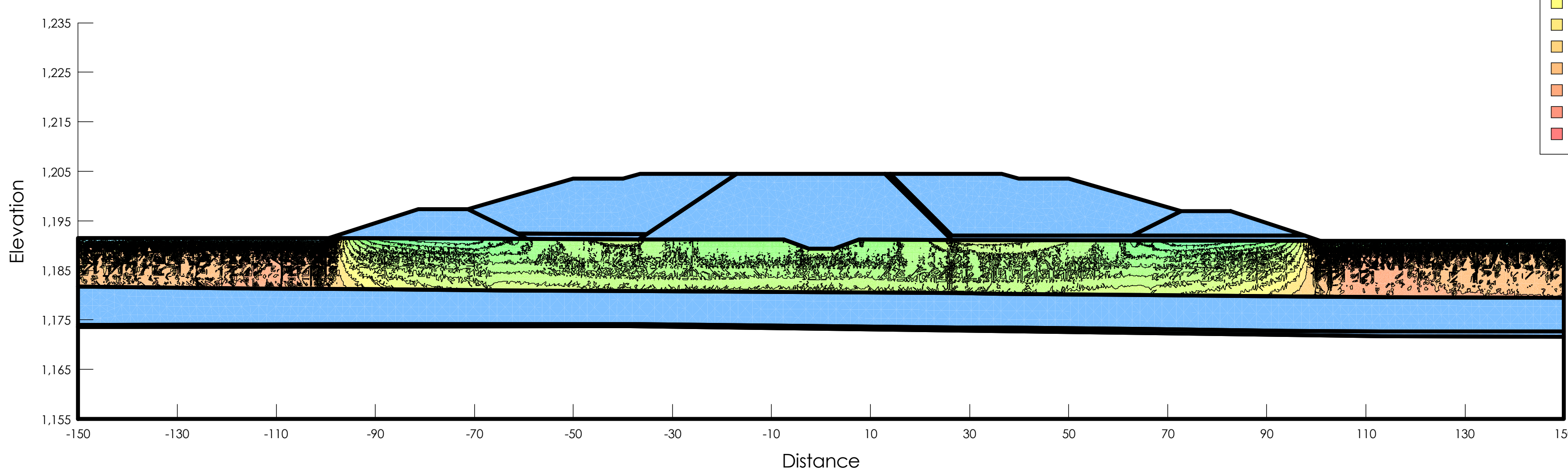
12.1.4 Slope Stability Analyses
Sta. 22+500

Alberta Transportation SR1 Storage Dam

Section 22+500
Load Case: End Construction, Year 2

Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)
	Drain	21		0				33
	Embankment Core (Undrained)	20		0	28	19	427	
	Embankment Shell (Undrained)	20		0	24	15	141	
	Glacial Till (Undrained)	18		0	27	19	363.2	
	Glacio-Lacustrine (Undrained)	18	GL Undrained					0
	Granular Zone	21		0				33
	Rock Toe	20		0				33
	Sandstone							
	Weathered Bedrock	21		0				35

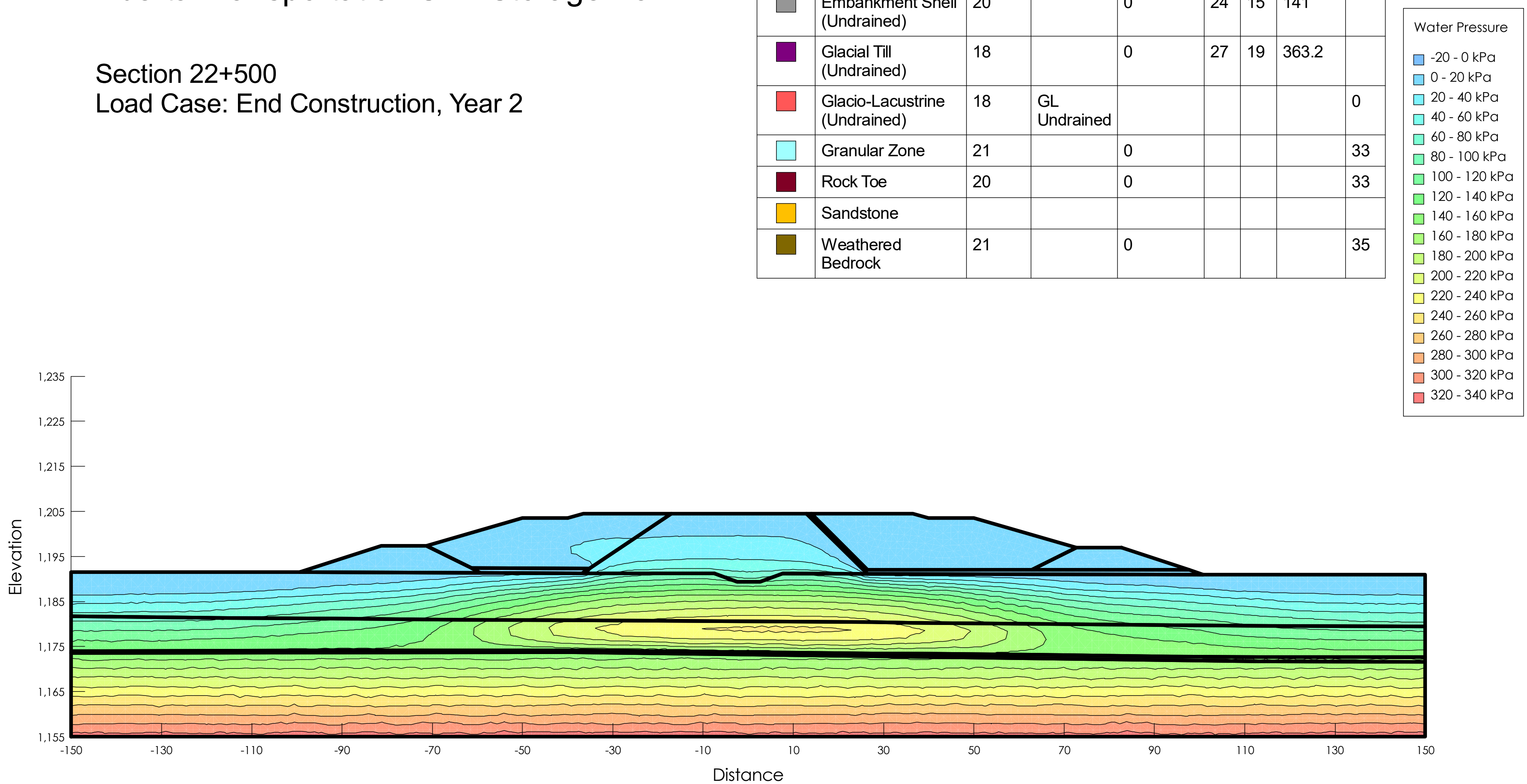
Cohesion
- 0 - 5 kPa
- 5 - 10 kPa
- 10 - 15 kPa
- 15 - 20 kPa
- 20 - 25 kPa
- 25 - 30 kPa
- 30 - 35 kPa
- 35 - 40 kPa
- 40 - 45 kPa
- 45 - 50 kPa
- 50 - 55 kPa
- 55 - 60 kPa
- 60 - 65 kPa
- 65 - 70 kPa
- 70 - 75 kPa
- 75 - 80 kPa
- 80 - 85 kPa
- 85 - 90 kPa
- 90 - 95 kPa
- 95 - 100 kPa
- 100 - 105 kPa
- 105 - 110 kPa



Alberta Transportation SR1 Storage Dam

Section 22+500
Load Case: End Construction, Year 2

Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)
	Drain	21		0				33
	Embankment Core (Undrained)	20		0	28	19	427	
	Embankment Shell (Undrained)	20		0	24	15	141	
	Glacial Till (Undrained)	18		0	27	19	363.2	
	Glacio-Lacustrine (Undrained)	18	GL Undrained					0
	Granular Zone	21		0				33
	Rock Toe	20		0				33
	Sandstone							
	Weathered Bedrock	21		0				35

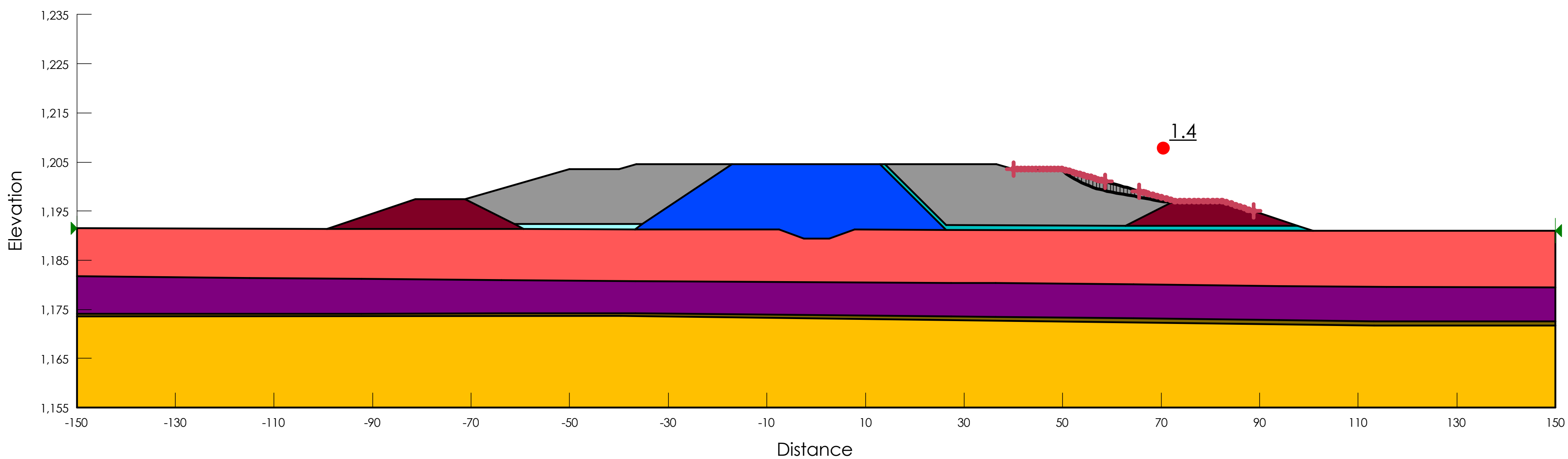


Stantec

Alberta Transportation SR1 Storage Dam

Section 22+500
Load Case: End Construction, Year 2
Effective Stress Parameters
Incipient Motion in the Downstream Direction

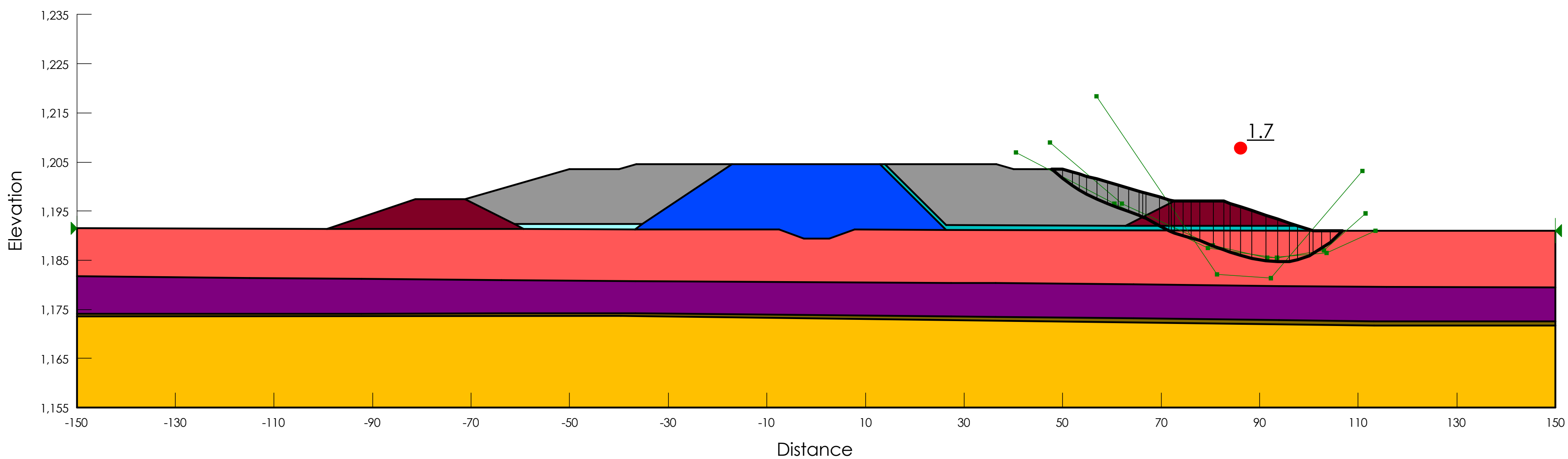
Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)
	Drain	21	0	33
	Embankment Core (Drained)	20	0	28
	Embankment Shell (Drained)	20	0	24
	Glacial Till (Drained)	18	0	27
	Glacio-Lacustrine (Drained)	18	0	23
	Granular Zone	21	0	33
	Rock Toe	20	0	33
	Sandstone			
	Weathered Bedrock	21	0	35



Alberta Transportation SR1 Storage Dam

Section 22+500
Load Case: End Construction, Year 2
Effective Stress Parameters
Incipient Motion in the Downstream Direction

Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)
	Drain	21	0	33
	Embankment Core (Drained)	20	0	28
	Embankment Shell (Drained)	20	0	24
	Glacial Till (Drained)	18	0	27
	Glacio-Lacustrine (Drained)	18	0	23
	Granular Zone	21	0	33
	Rock Toe	20	0	33
	Sandstone			
	Weathered Bedrock	21	0	35



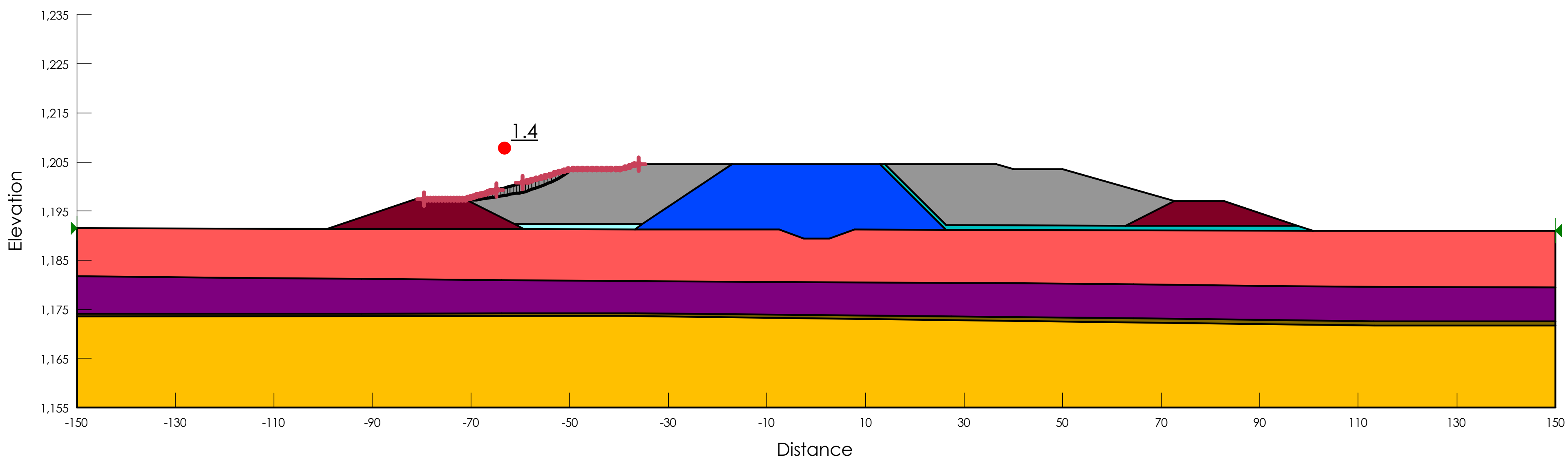
Stantec

Alberta Transportation SR1 Storage Dam

Section 22+500
Load Case: End Construction, Year 2
Effective Stress Parameters

Incipient Motion in the Upstream Direction

Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)
	Drain	21	0	33
	Embankment Core (Drained)	20	0	28
	Embankment Shell (Drained)	20	0	24
	Glacial Till (Drained)	18	0	27
	Glacio-Lacustrine (Drained)	18	0	23
	Granular Zone	21	0	33
	Rock Toe	20	0	33
	Sandstone			
	Weathered Bedrock	21	0	35

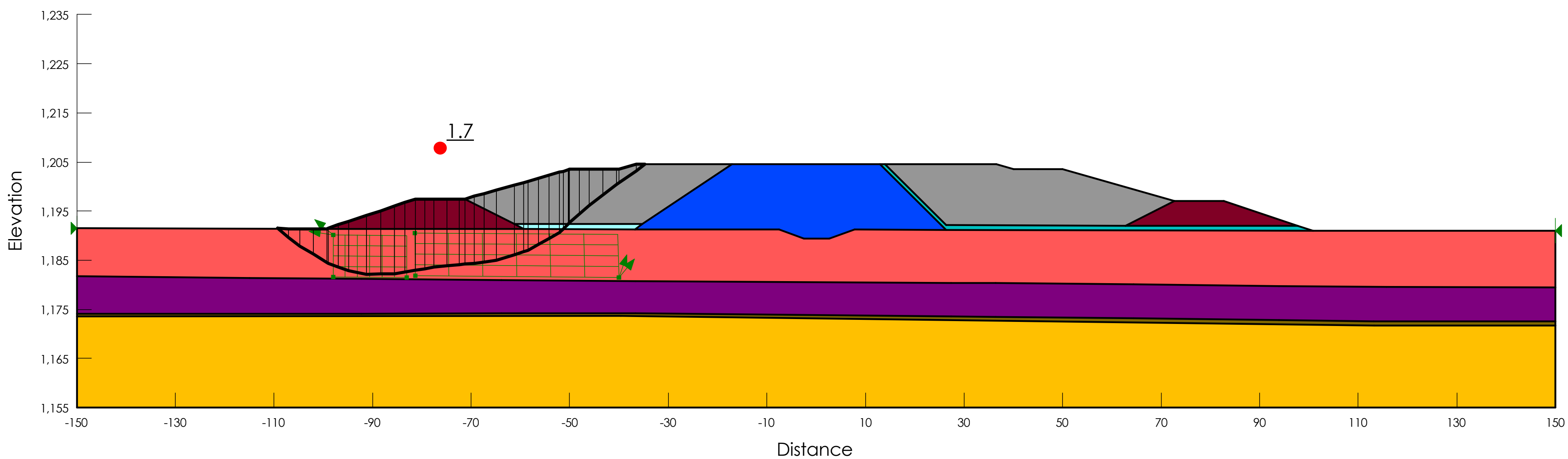


Stantec

Alberta Transportation SR1 Storage Dam

Section 22+500
Load Case: End Construction, Year 2
Effective Stress Parameters
Incipient Motion in the Upstream Direction

Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)
	Drain	21	0	33
	Embankment Core (Drained)	20	0	28
	Embankment Shell (Drained)	20	0	24
	Glacial Till (Drained)	18	0	27
	Glacio-Lacustrine (Drained)	18	0	23
	Granular Zone	21	0	33
	Rock Toe	20	0	33
	Sandstone			
	Weathered Bedrock	21	0	35

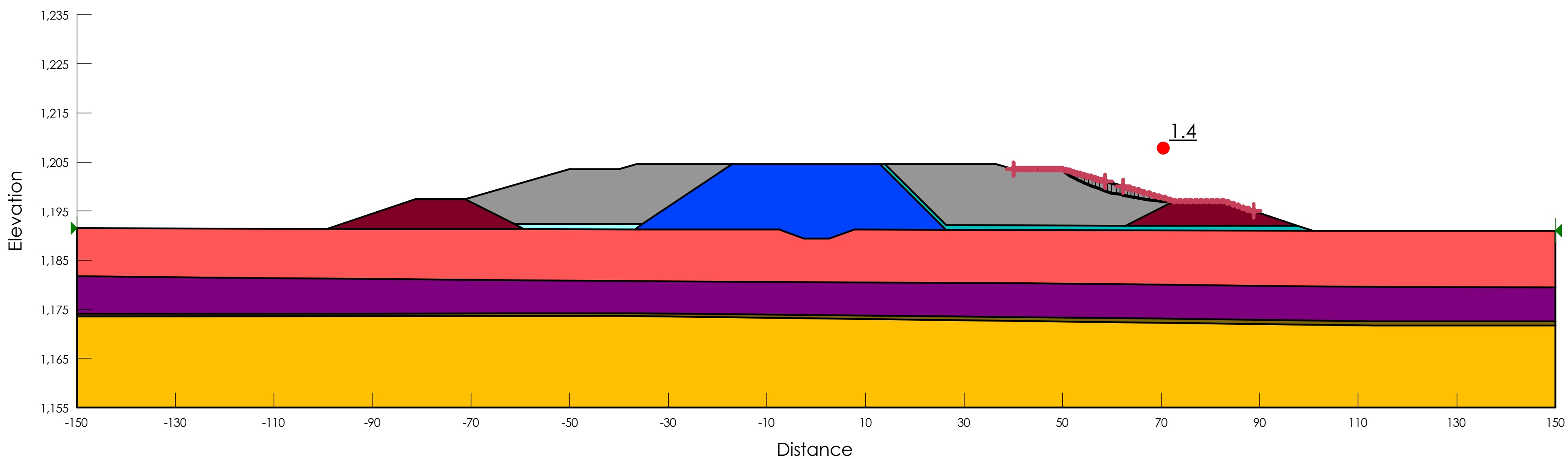


Stantec

Alberta Transportation SR1 Storage Dam

Section 22+500
Load Case: End Construction, Year 2
Total Stress Parameters
Incipient Motion in the Downstream Direction

Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)
	Drain	21		0				33
	Embankment Core (Undrained)	20		0	28	19	427	
	Embankment Shell (Undrained)	20		0	24	15	141	
	Glacial Till (Undrained)	18		0	27	19	363.2	
	Glacio-Lacustrine (Undrained)	18	GL Undrained					0
	Granular Zone	21		0				33
	Rock Toe	20		0				33
	Sandstone							
	Weathered Bedrock	21		0				35

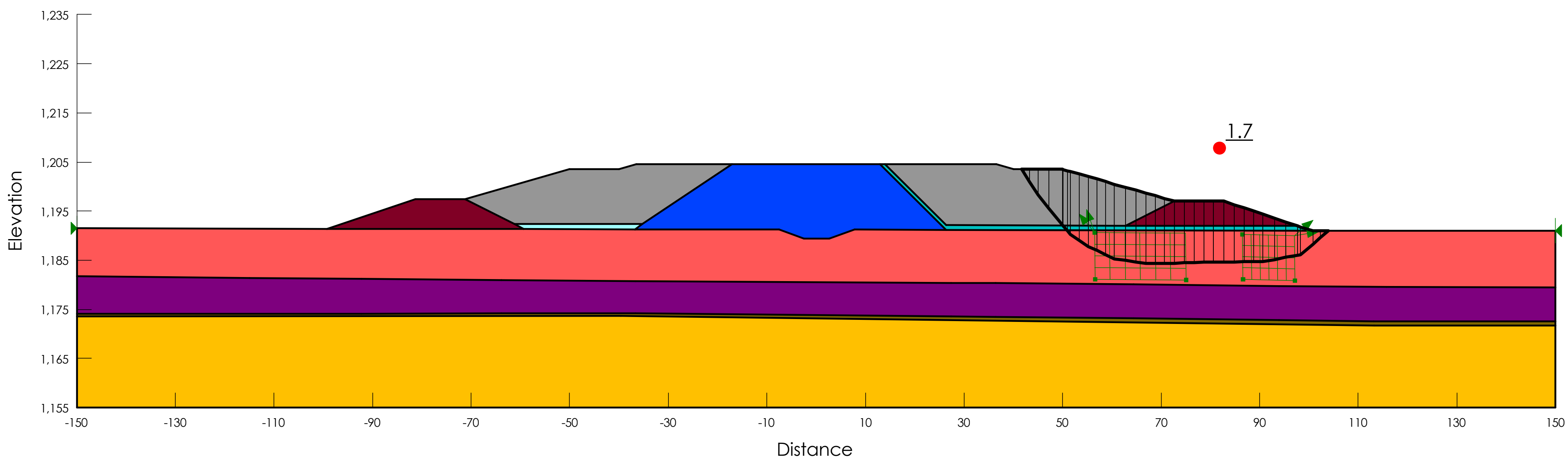


Stantec

Alberta Transportation SR1 Storage Dam

Section 22+500
Load Case: End Construction, Year 2
Total Stress Parameters
Incipient Motion in the Downstream Direction

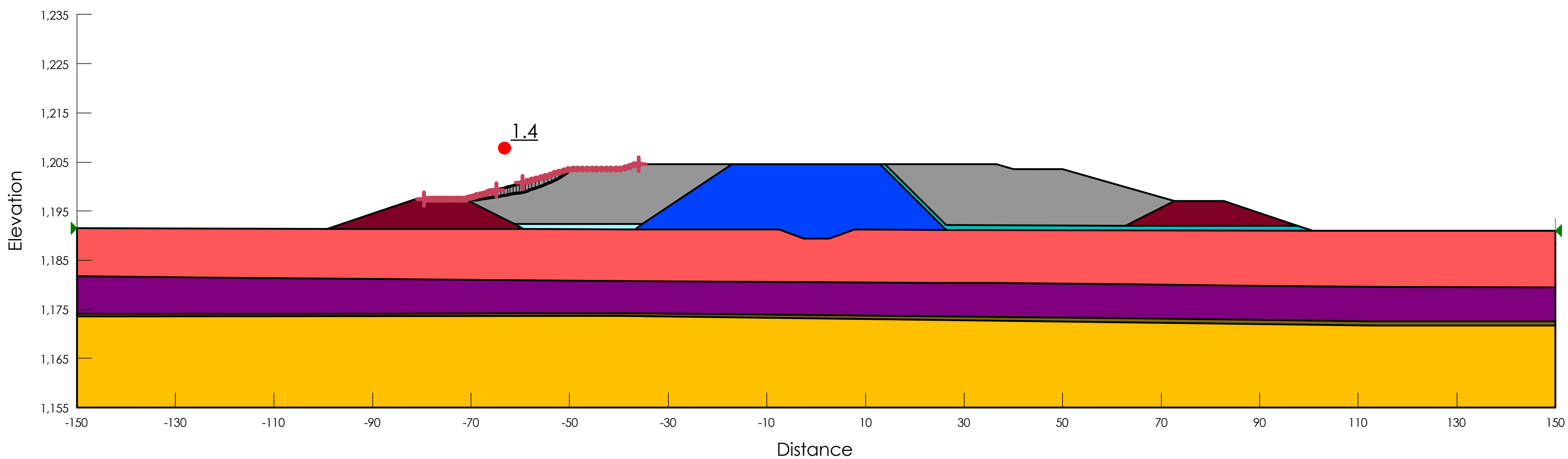
Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)
	Drain	21		0				33
	Embankment Core (Undrained)	20		0	28	19	427	
	Embankment Shell (Undrained)	20		0	24	15	141	
	Glacial Till (Undrained)	18		0	27	19	363.2	
	Glacio-Lacustrine (Undrained)	18	GL Undrained					0
	Granular Zone	21		0				33
	Rock Toe	20		0				33
	Sandstone							
	Weathered Bedrock	21		0				35



Alberta Transportation SR1 Storage Dam

Section 22+500
Load Case: End Construction, Year 2
Total Stress Parameters
Incipient Motion in the Upstream Direction

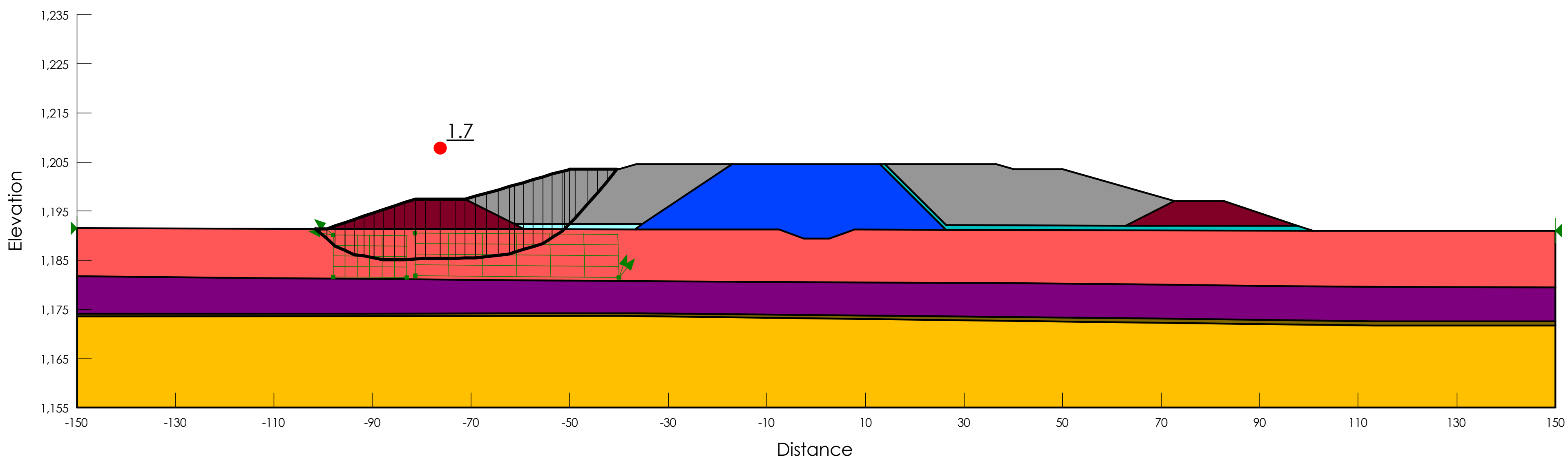
Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)
	Drain	21		0				33
	Embankment Core (Undrained)	20		0	28	19	427	
	Embankment Shell (Undrained)	20		0	24	15	141	
	Glacial Till (Undrained)	18		0	27	19	363.2	
	Glacio-Lacustrine (Undrained)	18	GL Undrained					0
	Granular Zone	21		0				33
	Rock Toe	20		0				33
	Sandstone							
	Weathered Bedrock	21		0				35



Alberta Transportation SR1 Storage Dam

Section 22+500
Load Case: End Construction, Year 2
Total Stress Parameters
Incipient Motion in the Upstream Direction

Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)
	Drain	21		0				33
	Embankment Core (Undrained)	20		0	28	19	427	
	Embankment Shell (Undrained)	20		0	24	15	141	
	Glacial Till (Undrained)	18		0	27	19	363.2	
	Glacio-Lacustrine (Undrained)	18	GL Undrained					0
	Granular Zone	21		0				33
	Rock Toe	20		0				33
	Sandstone							
	Weathered Bedrock	21		0				35

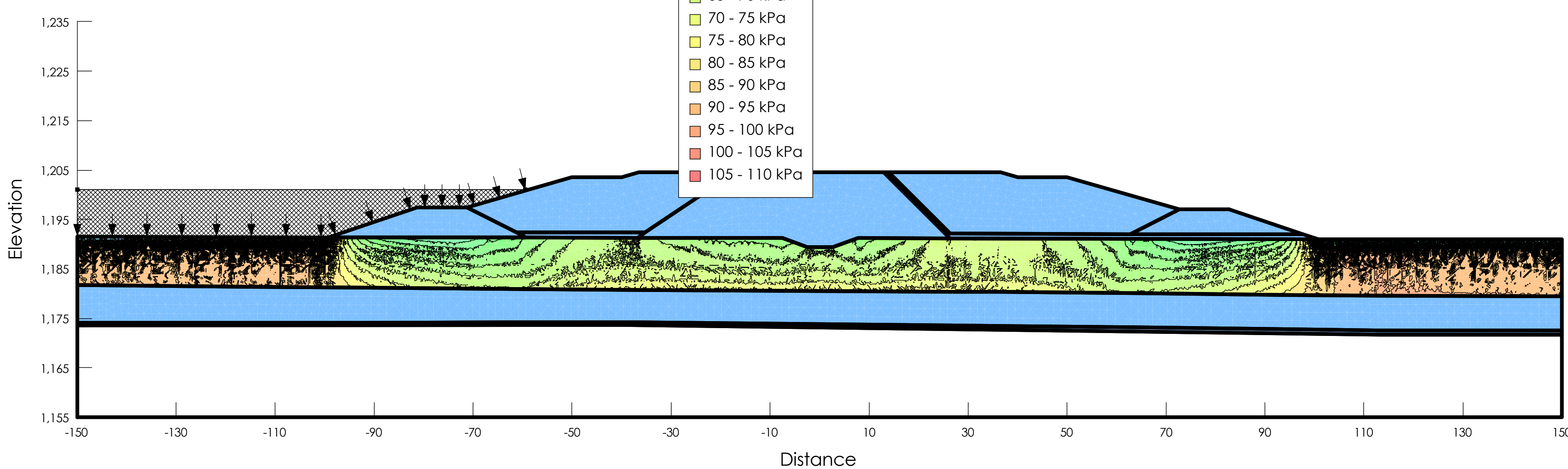


Stantec

Alberta Transportation SR1 Storage Dam

Section 22+500
Load Case: End Construction, Year 2, Flood

Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)
	Drain	21		0				33
	Embankment Core (Undrained)	20		0	28	19	427	
	Embankment Shell (Undrained)	20		0	24	15	141	
	Glacial Till (Undrained)	18		0	27	19	363.2	
	Glacio-Lacustrine (Undrained)	18	GL Undrained					0
	Granular Zone	21		0				33
	Rock Toe	20		0				33
	Sandstone							
	Weathered Bedrock	21		0				35

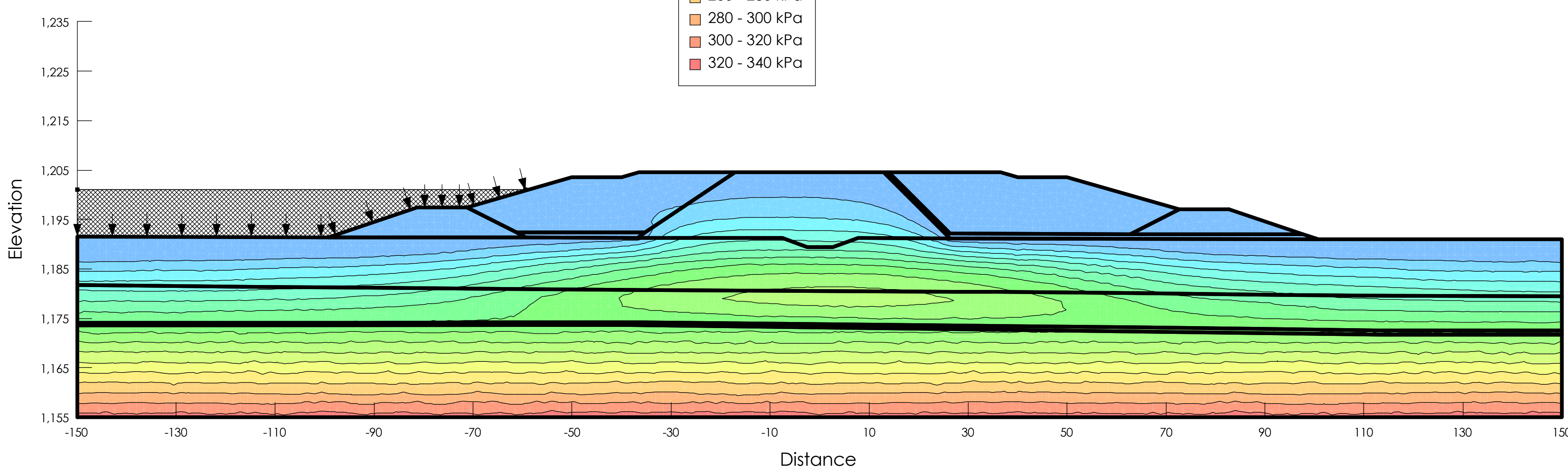


Stantec

Alberta Transportation SR1 Storage Dam

Section 22+500
Load Case: End Construction, Year 2, Flood

Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)
	Drain	21		0				33
	Embankment Core (Undrained)	20		0	28	19	427	
	Embankment Shell (Undrained)	20		0	24	15	141	
	Glacial Till (Undrained)	18		0	27	19	363.2	
	Glacio-Lacustrine (Undrained)	18	GL Undrained					0
	Granular Zone	21		0				33
	Rock Toe	20		0				33
	Sandstone							
	Weathered Bedrock	21		0				35

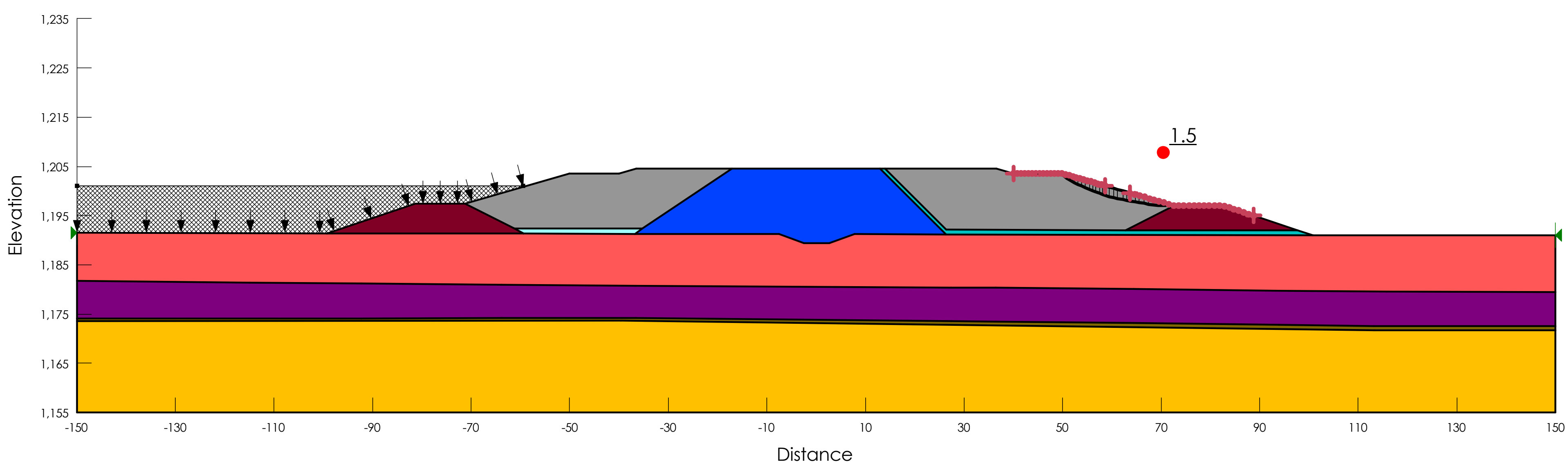


Stantec

Alberta Transportation SR1 Storage Dam

Section 22+500
Load Case: End Construction, Year 2, Flood
Total Stress Parameters
Incipient Motion in the Downstream Direction

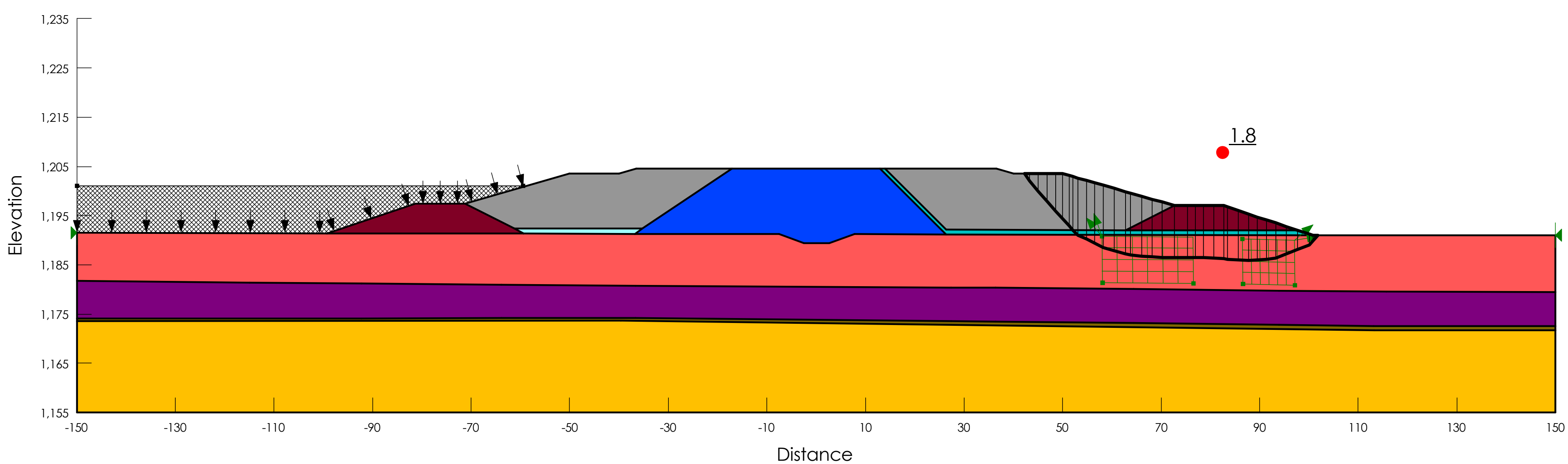
Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)
	Drain	21		0				33
	Embankment Core (Undrained)	20		0	28	19	427	
	Embankment Shell (Undrained)	20		0	24	15	141	
	Glacial Till (Undrained)	18		0	27	19	363.2	
	Glacio-Lacustrine (Undrained)	18	GL Undrained					0
	Granular Zone	21		0				33
	Rock Toe	20		0				33
	Sandstone							
	Weathered Bedrock	21		0				35



Alberta Transportation SR1 Storage Dam

Section 22+500
Load Case: End Construction, Year 2, Flood
Total Stress Parameters
Incipient Motion in the Downstream Direction

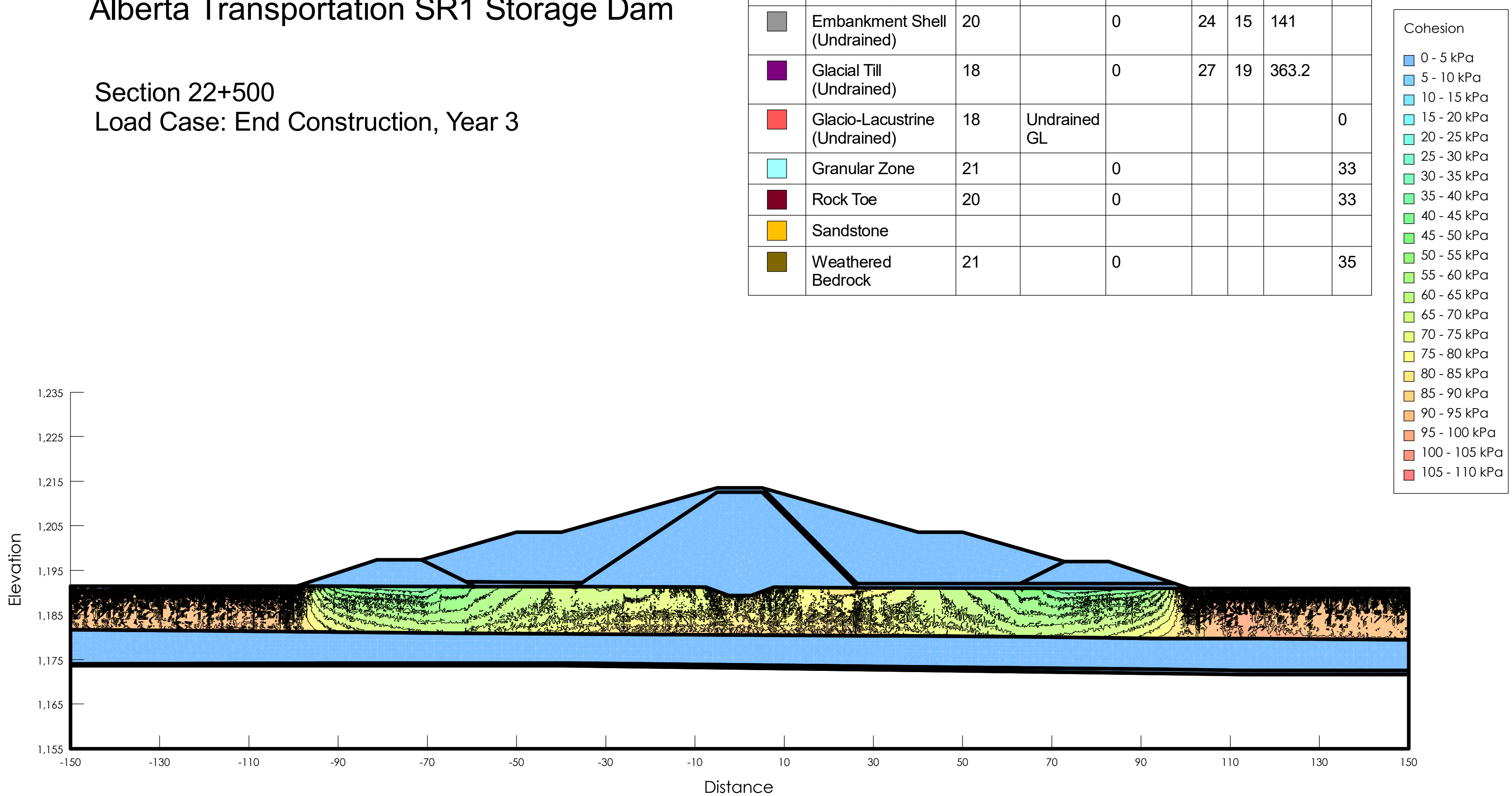
Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)
	Drain	21		0				33
	Embankment Core (Undrained)	20		0	28	19	427	
	Embankment Shell (Undrained)	20		0	24	15	141	
	Glacial Till (Undrained)	18		0	27	19	363.2	
	Glacio-Lacustrine (Undrained)	18	GL Undrained					0
	Granular Zone	21		0				33
	Rock Toe	20		0				33
	Sandstone							
	Weathered Bedrock	21		0				35



Alberta Transportation SR1 Storage Dam

Section 22+500
Load Case: End Construction, Year 3

Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)
	Drain	21		0				33
	Embankment Core (Undrained)	20		0	28	19	427	
	Embankment Shell (Undrained)	20		0	24	15	141	
	Glacial Till (Undrained)	18		0	27	19	363.2	
	Glacio-Lacustrine (Undrained)	18	Undrained GL					0
	Granular Zone	21		0				33
	Rock Toe	20		0				33
	Sandstone							
	Weathered Bedrock	21		0				35

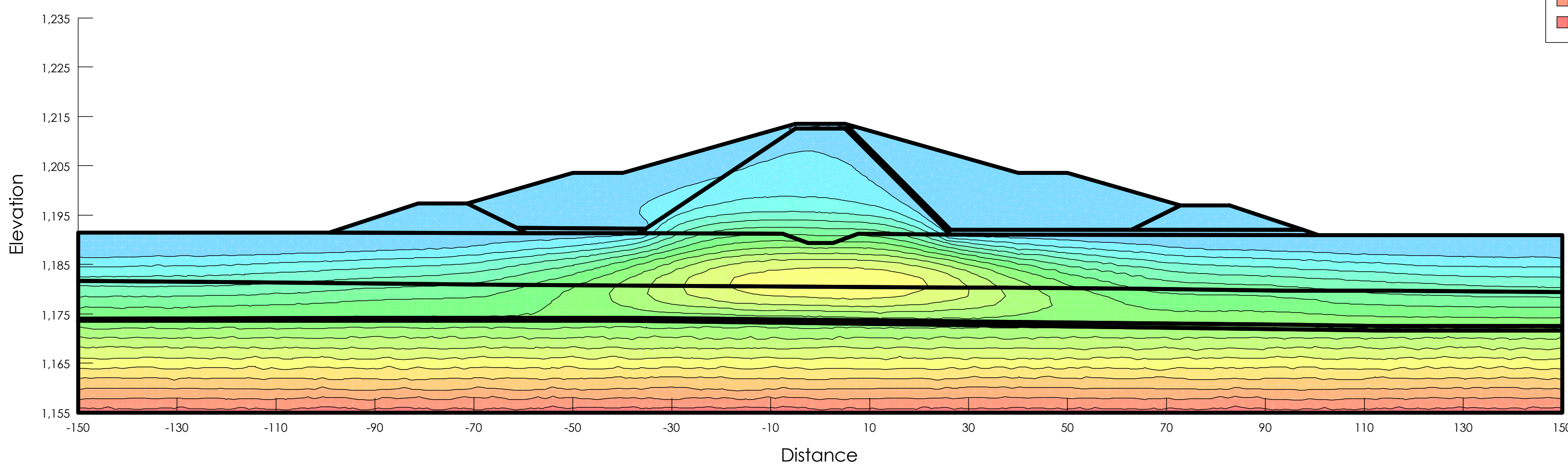


Alberta Transportation SR1 Storage Dam

Section 22+500
Load Case: End Construction, Year 3

Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)
	Drain	21		0				33
	Embankment Core (Undrained)	20		0	28	19	427	
	Embankment Shell (Undrained)	20		0	24	15	141	
	Glacial Till (Undrained)	18		0	27	19	363.2	
	Glacio-Lacustrine (Undrained)	18	Undrained GL					0
	Granular Zone	21		0				33
	Rock Toe	20		0				33
	Sandstone							
	Weathered Bedrock	21		0				35

Water Pressure
- -20 - 0 kPa
- 0 - 20 kPa
- 20 - 40 kPa
- 40 - 60 kPa
- 60 - 80 kPa
- 80 - 100 kPa
- 100 - 120 kPa
- 120 - 140 kPa
- 140 - 160 kPa
- 160 - 180 kPa
- 180 - 200 kPa
- 200 - 220 kPa
- 220 - 240 kPa
- 240 - 260 kPa
- 260 - 280 kPa
- 280 - 300 kPa
- 300 - 320 kPa
- 320 - 340 kPa

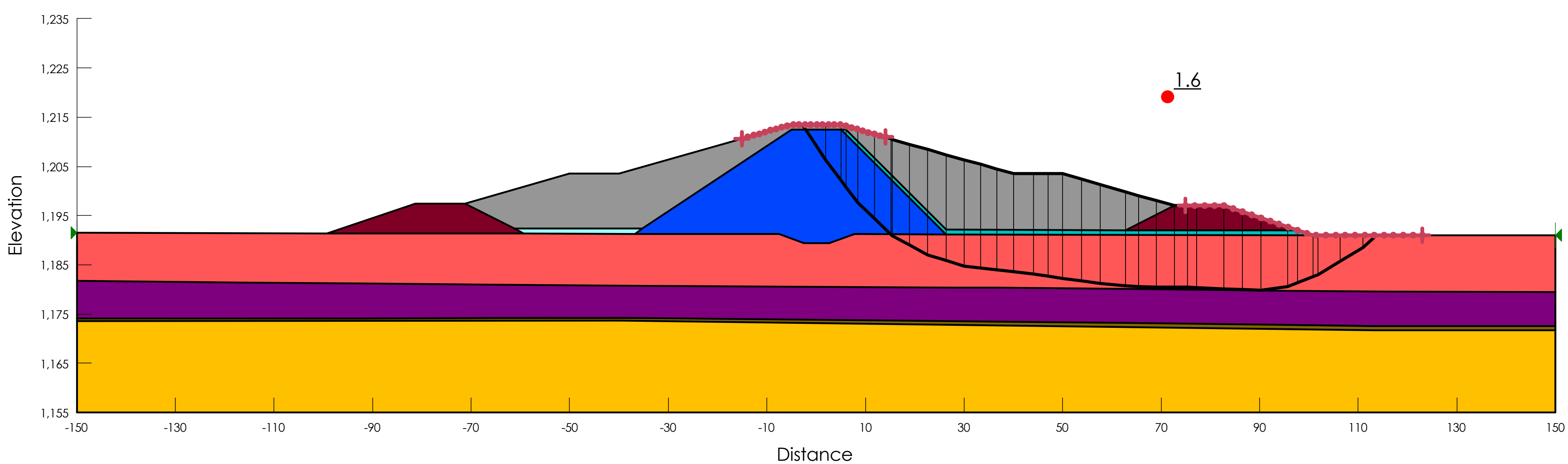


Stantec

Alberta Transportation SR1 Storage Dam

Section 22+500
Load Case: End Construction, Year 3
Effective Stress Parameters
Incipient Motion in the Downstream Direction

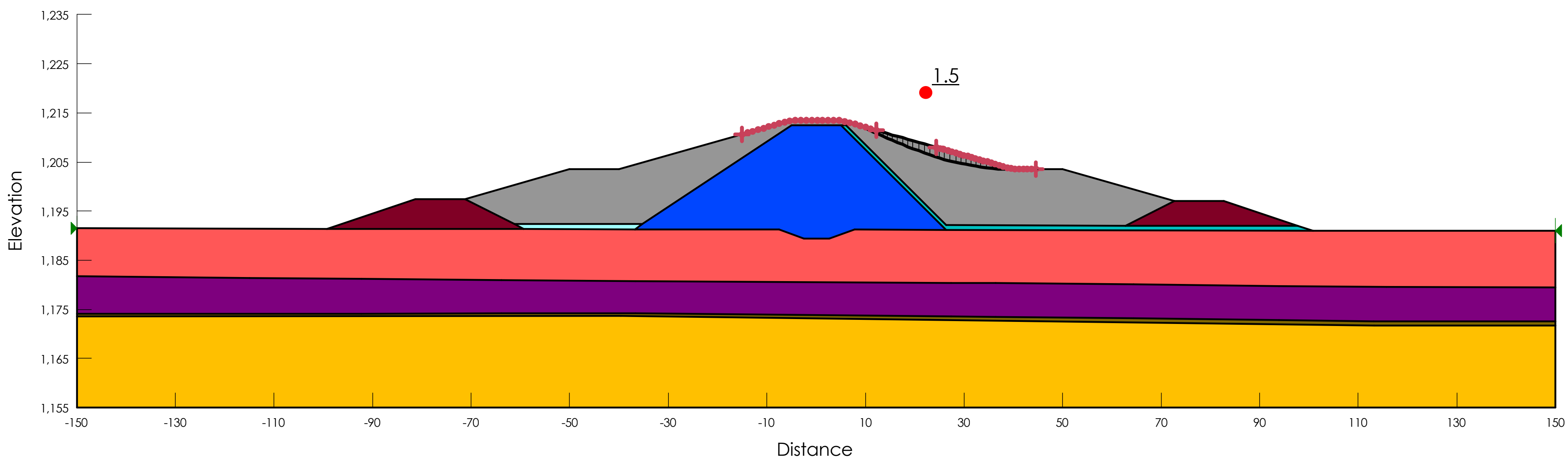
Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)
	Drain	21	0	33
	Embankment Core (Drained)	20	0	28
	Embankment Shell (Drained)	20	0	24
	Glacial Till (Drained)	18	0	27
	Glacio-Lacustrine (Drained)	18	0	23
	Granular Zone	21	0	33
	Rock Toe	20	0	33
	Sandstone			
	Weathered Bedrock	21	0	35



Alberta Transportation SR1 Storage Dam

Section 22+500
Load Case: End Construction, Year 3
Effective Stress Parameters
Incipient Motion in the Downstream Direction

Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)
	Drain	21	0	33
	Embankment Core (Drained)	20	0	28
	Embankment Shell (Drained)	20	0	24
	Glacial Till (Drained)	18	0	27
	Glacio-Lacustrine (Drained)	18	0	23
	Granular Zone	21	0	33
	Rock Toe	20	0	33
	Sandstone			
	Weathered Bedrock	21	0	35



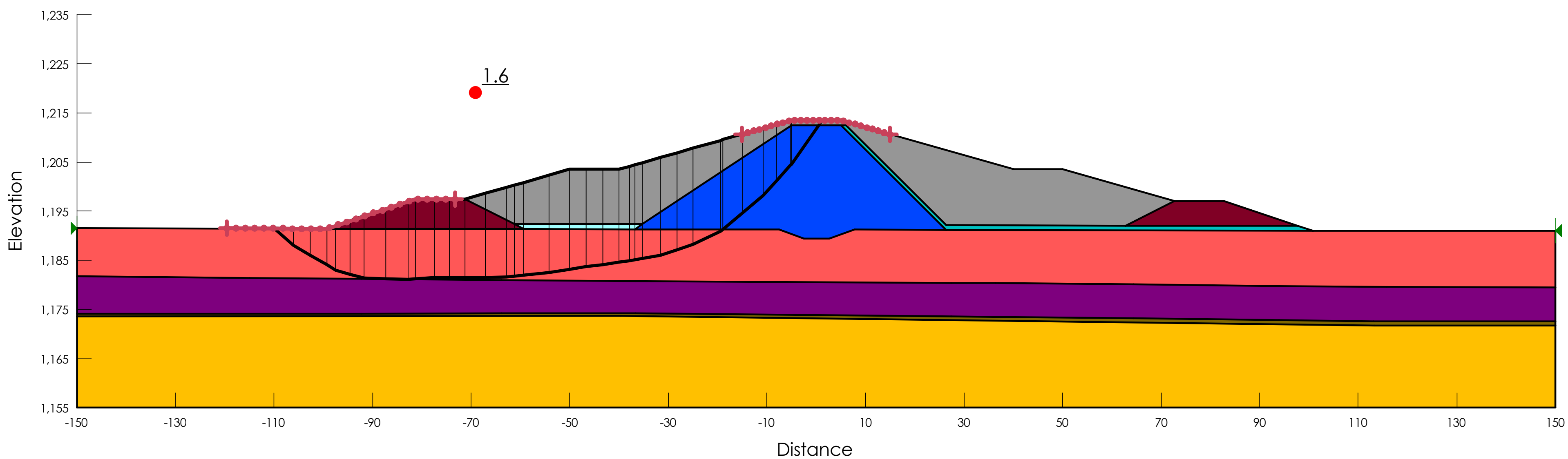
Stantec

Alberta Transportation SR1 Storage Dam

Section 22+500
Load Case: End Construction, Year 3
Effective Stress Parameters

Incipient Motion in the Upstream Direction

Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)
	Drain	21	0	33
	Embankment Core (Drained)	20	0	28
	Embankment Shell (Drained)	20	0	24
	Glacial Till (Drained)	18	0	27
	Glacio-Lacustrine (Drained)	18	0	23
	Granular Zone	21	0	33
	Rock Toe	20	0	33
	Sandstone			
	Weathered Bedrock	21	0	35



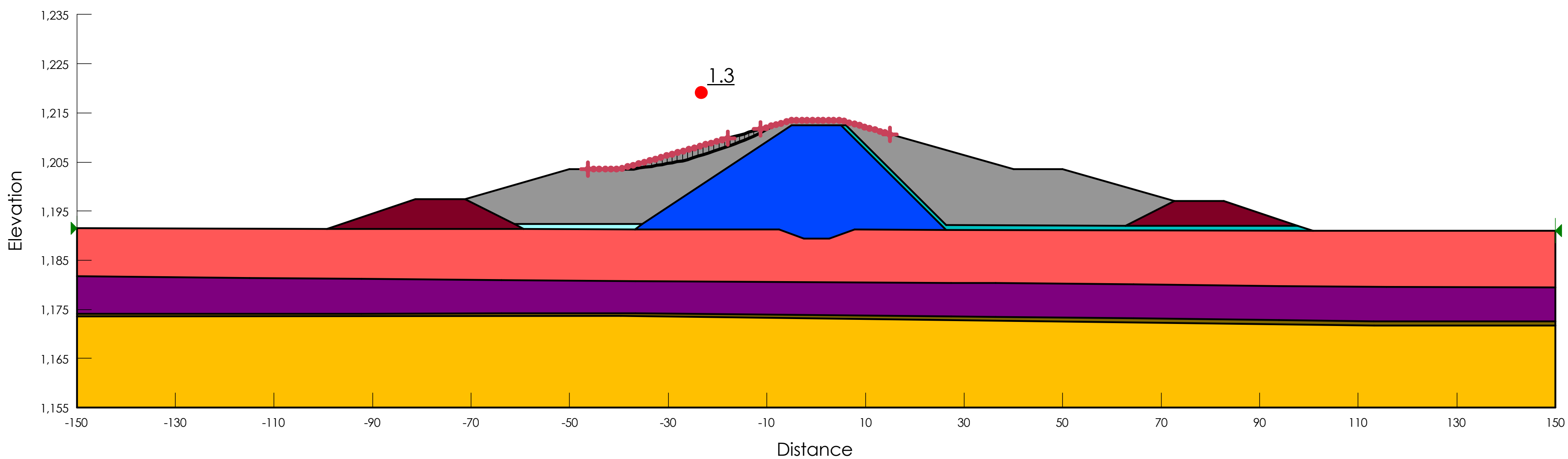
Stantec

Alberta Transportation SR1 Storage Dam

Section 22+500
Load Case: End Construction, Year 3
Effective Stress Parameters

Incipient Motion in the Upstream Direction

Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)
	Drain	21	0	33
	Embankment Core (Drained)	20	0	28
	Embankment Shell (Drained)	20	0	24
	Glacial Till (Drained)	18	0	27
	Glacio-Lacustrine (Drained)	18	0	23
	Granular Zone	21	0	33
	Rock Toe	20	0	33
	Sandstone			
	Weathered Bedrock	21	0	35

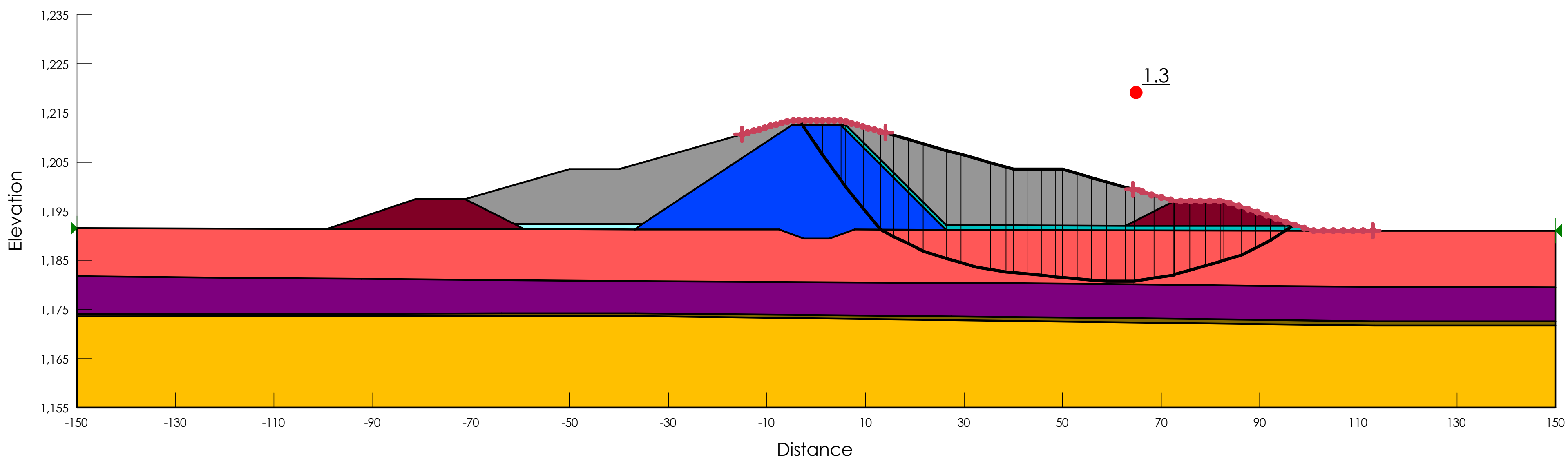


Stantec

Alberta Transportation SR1 Storage Dam

Section 22+500
Load Case: End Construction, Year 3
Total Stress Parameters
Incipient Motion in the Downstream Direction

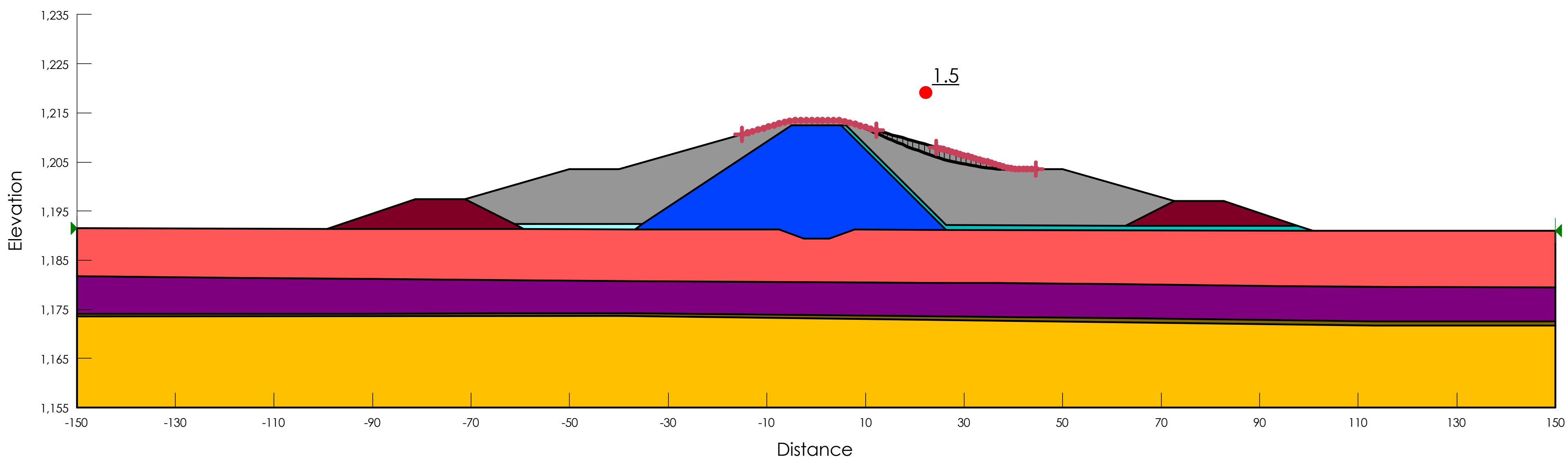
Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)
	Drain	21		0				33
	Embankment Core (Undrained)	20		0	28	19	427	
	Embankment Shell (Undrained)	20		0	24	15	141	
	Glacial Till (Undrained)	18		0	27	19	363.2	
	Glacio-Lacustrine (Undrained)	18	Undrained GL					0
	Granular Zone	21		0				33
	Rock Toe	20		0				33
	Sandstone							
	Weathered Bedrock	21		0				35



Alberta Transportation SR1 Storage Dam

Section 22+500
Load Case: End Construction, Year 3
Total Stress Parameters
Incipient Motion in the Downstream Direction

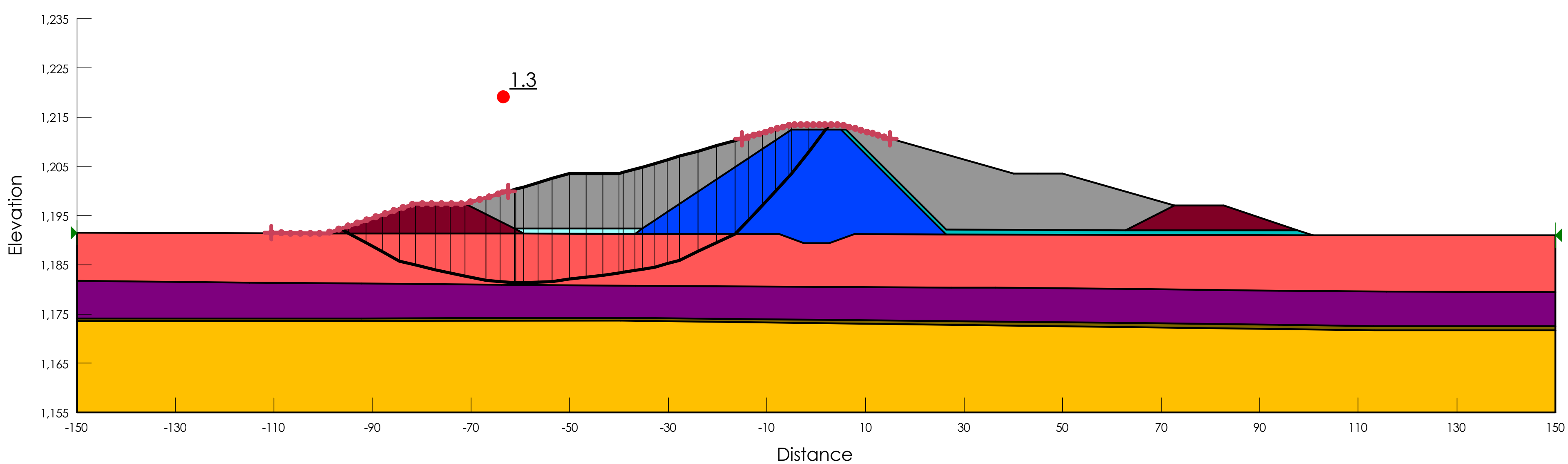
Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)
	Drain	21		0				33
	Embankment Core (Undrained)	20		0	28	19	427	
	Embankment Shell (Undrained)	20		0	24	15	141	
	Glacial Till (Undrained)	18		0	27	19	363.2	
	Glacio-Lacustrine (Undrained)	18	Undrained GL					0
	Granular Zone	21		0				33
	Rock Toe	20		0				33
	Sandstone							
	Weathered Bedrock	21		0				35



Alberta Transportation SR1 Storage Dam

Section 22+500
Load Case: End Construction, Year 3
Total Stress Parameters
Incipient Motion in the Upstream Direction

Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)
	Drain	21		0				33
	Embankment Core (Undrained)	20		0	28	19	427	
	Embankment Shell (Undrained)	20		0	24	15	141	
	Glacial Till (Undrained)	18		0	27	19	363.2	
	Glacio-Lacustrine (Undrained)	18	Undrained GL					0
	Granular Zone	21		0				33
	Rock Toe	20		0				33
	Sandstone							
	Weathered Bedrock	21		0				35

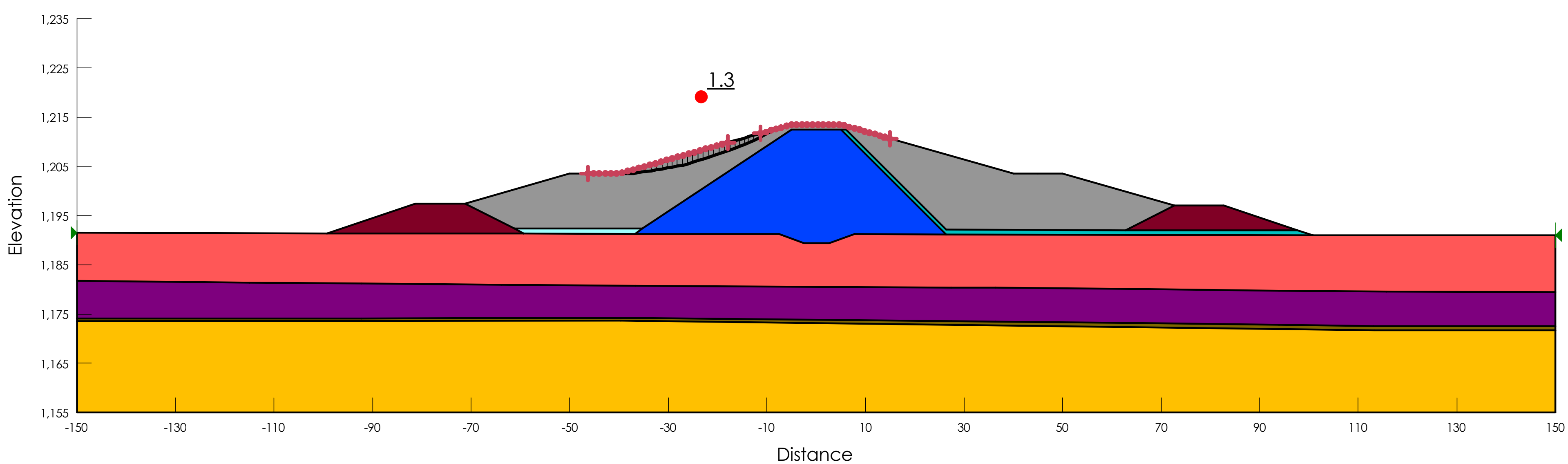


Stantec

Alberta Transportation SR1 Storage Dam

Section 22+500
Load Case: End Construction, Year 3
Total Stress Parameters
Incipient Motion in the Upstream Direction

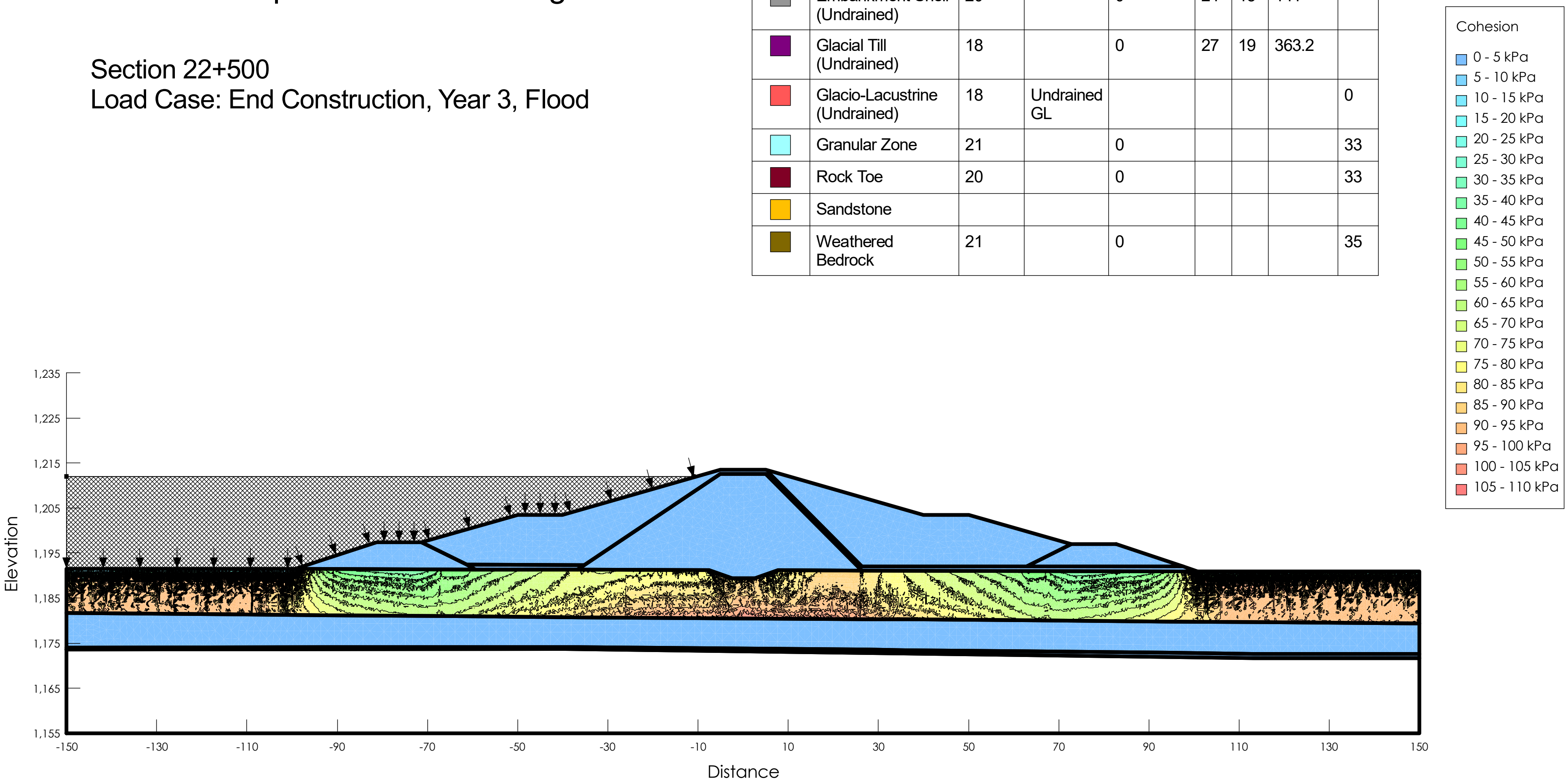
Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)
	Drain	21		0				33
	Embankment Core (Undrained)	20		0	28	19	427	
	Embankment Shell (Undrained)	20		0	24	15	141	
	Glacial Till (Undrained)	18		0	27	19	363.2	
	Glacio-Lacustrine (Undrained)	18	Undrained GL					0
	Granular Zone	21		0				33
	Rock Toe	20		0				33
	Sandstone							
	Weathered Bedrock	21		0				35



Alberta Transportation SR1 Storage Dam

Section 22+500
Load Case: End Construction, Year 3, Flood

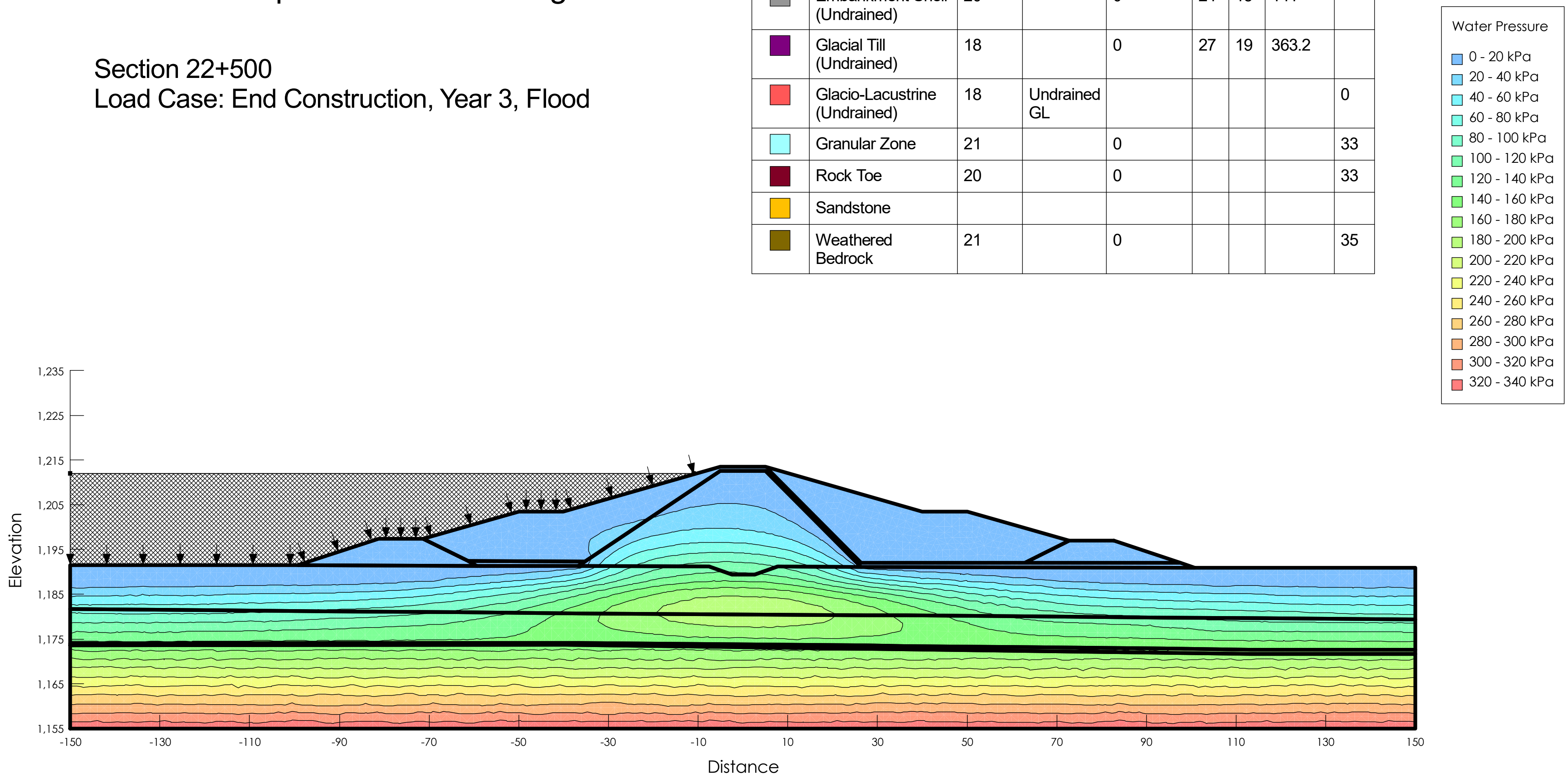
Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)
	Drain	21		0				33
	Embankment Core (Undrained)	20		0	28	19	427	
	Embankment Shell (Undrained)	20		0	24	15	141	
	Glacial Till (Undrained)	18		0	27	19	363.2	
	Glacio-Lacustrine (Undrained)	18	Undrained GL					0
	Granular Zone	21		0				33
	Rock Toe	20		0				33
	Sandstone							
	Weathered Bedrock	21		0				35



Alberta Transportation SR1 Storage Dam

Section 22+500
Load Case: End Construction, Year 3, Flood

Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)
	Drain	21		0				33
	Embankment Core (Undrained)	20		0	28	19	427	
	Embankment Shell (Undrained)	20		0	24	15	141	
	Glacial Till (Undrained)	18		0	27	19	363.2	
	Glacio-Lacustrine (Undrained)	18	Undrained GL					0
	Granular Zone	21		0				33
	Rock Toe	20		0				33
	Sandstone							
	Weathered Bedrock	21		0				35

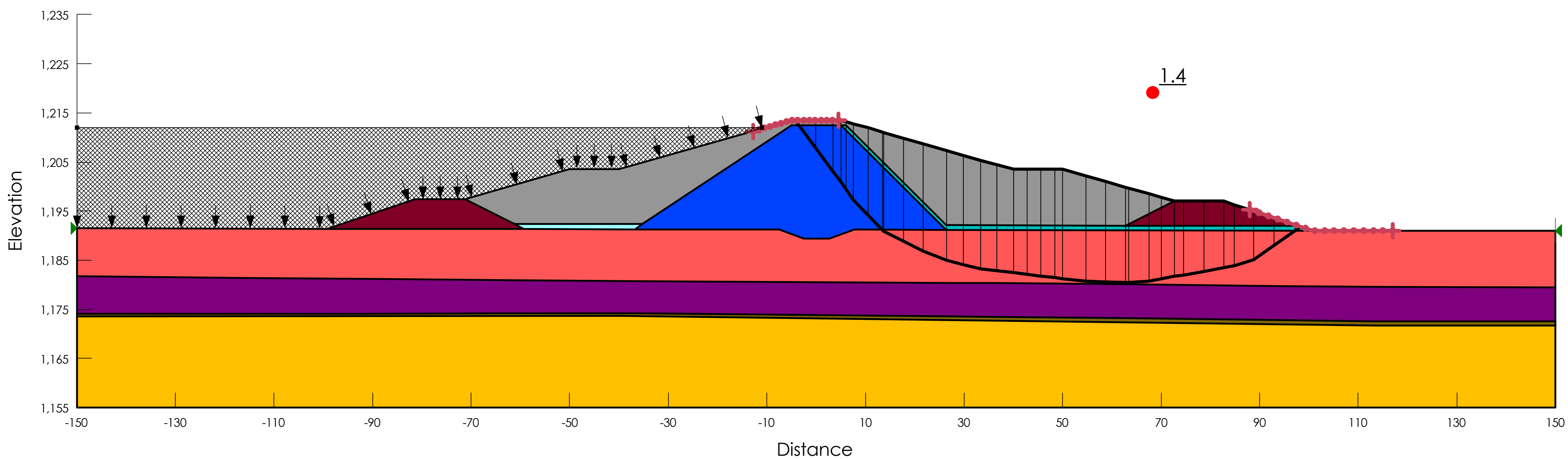


Stantec

Alberta Transportation SR1 Storage Dam

Section 22+500
Load Case: End Construction, Year 3, Flood
Total Stress Parameters
Incipient Motion in the Downstream Direction

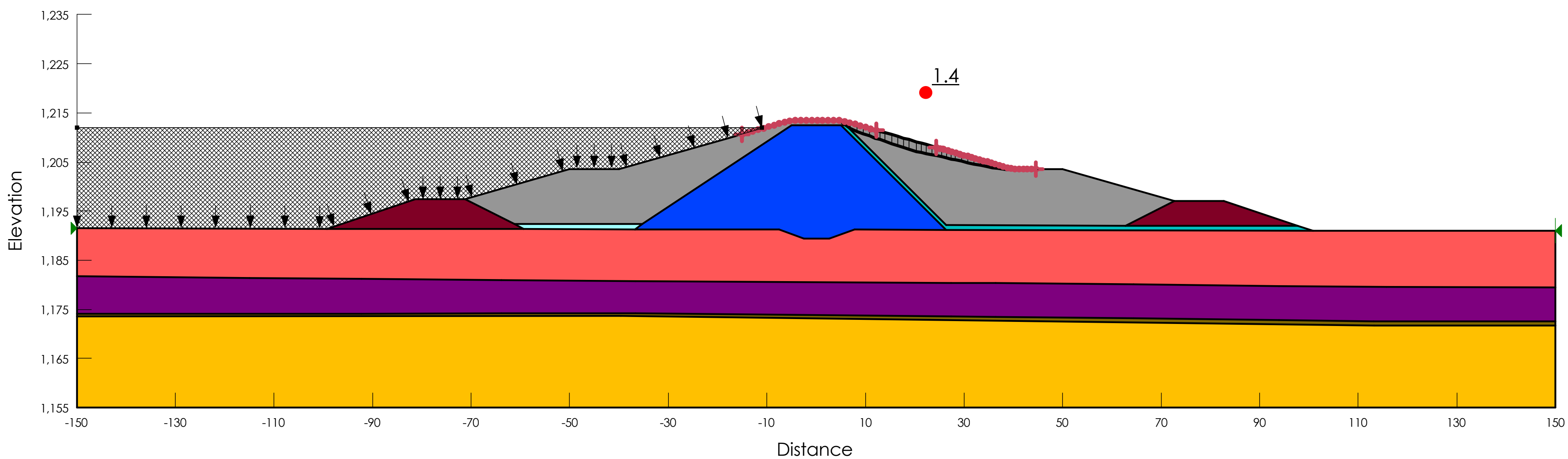
Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)
	Drain	21		0				33
	Embankment Core (Undrained)	20		0	28	19	427	
	Embankment Shell (Undrained)	20		0	24	15	141	
	Glacial Till (Undrained)	18		0	27	19	363.2	
	Glacio-Lacustrine (Undrained)	18	Undrained GL					0
	Granular Zone	21		0				33
	Rock Toe	20		0				33
	Sandstone							
	Weathered Bedrock	21		0				35



Alberta Transportation SR1 Storage Dam

Section 22+500
Load Case: End Construction, Year 3, Flood
Total Stress Parameters
Incipient Motion in the Downstream Direction

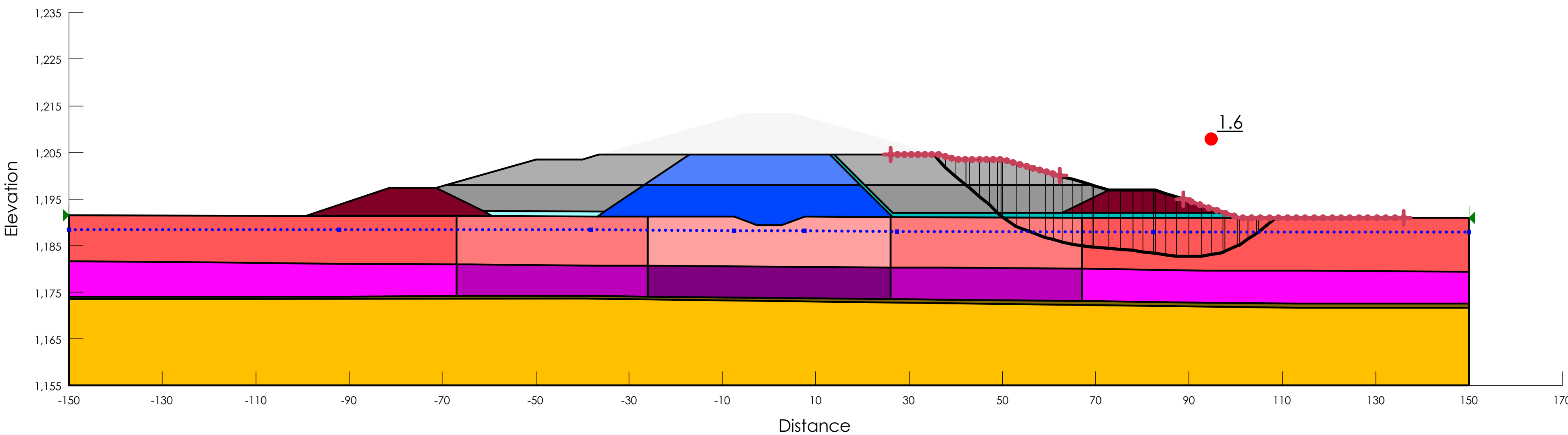
Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)
	Drain	21		0				33
	Embankment Core (Undrained)	20		0	28	19	427	
	Embankment Shell (Undrained)	20		0	24	15	141	
	Glacial Till (Undrained)	18		0	27	19	363.2	
	Glacio-Lacustrine (Undrained)	18	Undrained GL					0
	Granular Zone	21		0				33
	Rock Toe	20		0				33
	Sandstone							
	Weathered Bedrock	21		0				35



Alberta Transportation SR1 Storage Dam

Section 22+500
Load Case: End Construction, Year 2, B-Bar
Effective Stress Parameters
Incipient Motion in the Downstream Direction

Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)	B-bar	Add Weight
	Drain	21	0	33	0	Yes
	Embankment Core (Drained, Year 1)	20	0	28	0.5	Yes
	Embankment Core (Drained, Year 2)	20	0	28	0	Yes
	Embankment Shell (Drained, Year 1)	20	0	24	0.25	Yes
	Embankment Shell (Drained, Year 2)	20	0	24	0	Yes
	Glacial Till (Drained, Crest)	18	0	27	0.65	No
	Glacial Till (Drained, Slope)	18	0	27	0.4	No
	Glacial Till (Drained, Toe)	18	0	27	0.25	No
	Glacio-Lacustrine (Drained, Crest)	18	0	23	0.85	No
	Glacio-Lacustrine (Drained, Slope)	18	0	23	0.6	No
	Glacio-Lacustrine (Drained, Toe)	18	0	23	0.35	No
	Granular Zone	21	0	33	0	Yes
	Rock Toe	20	0	33	0	Yes
	Sandstone				0	No
	Weathered Bedrock	21	0	35	0	No

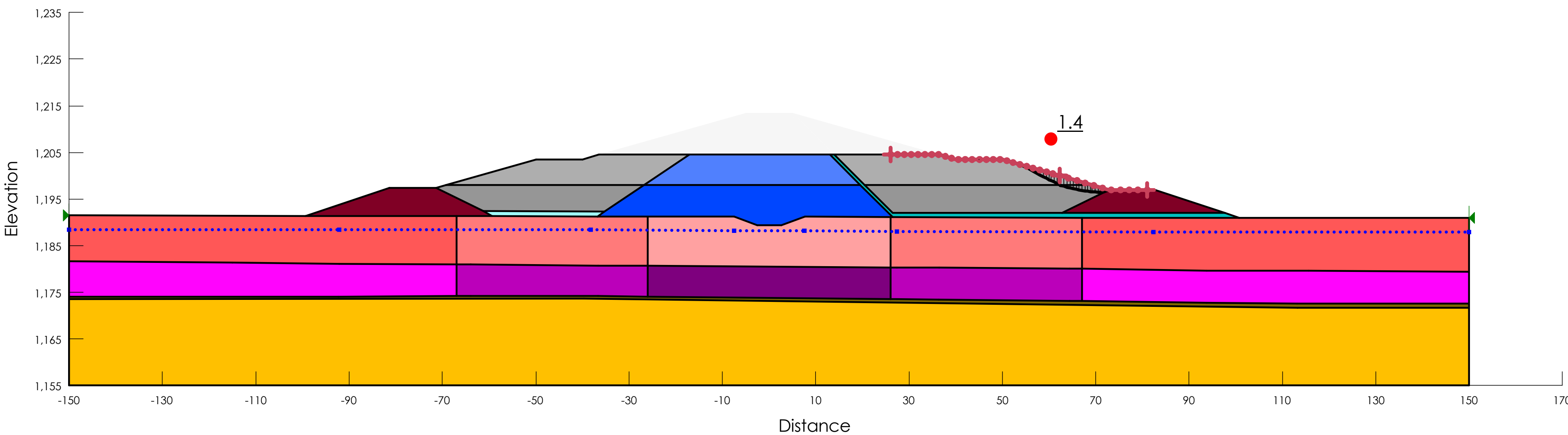


Stantec

Alberta Transportation SR1 Storage Dam

Section 22+500
Load Case: End Construction, Year 2, B-Bar
Effective Stress Parameters
Incipient Motion in the Downstream Direction

Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)	B-bar	Add Weight
	Drain	21	0	33	0	Yes
	Embankment Core (Drained, Year 1)	20	0	28	0.5	Yes
	Embankment Core (Drained, Year 2)	20	0	28	0	Yes
	Embankment Shell (Drained, Year 1)	20	0	24	0.25	Yes
	Embankment Shell (Drained, Year 2)	20	0	24	0	Yes
	Glacial Till (Drained, Crest)	18	0	27	0.65	No
	Glacial Till (Drained, Slope)	18	0	27	0.4	No
	Glacial Till (Drained, Toe)	18	0	27	0.25	No
	Glacio-Lacustrine (Drained, Crest)	18	0	23	0.85	No
	Glacio-Lacustrine (Drained, Slope)	18	0	23	0.6	No
	Glacio-Lacustrine (Drained, Toe)	18	0	23	0.35	No
	Granular Zone	21	0	33	0	Yes
	Rock Toe	20	0	33	0	Yes
	Sandstone				0	No
	Weathered Bedrock	21	0	35	0	No

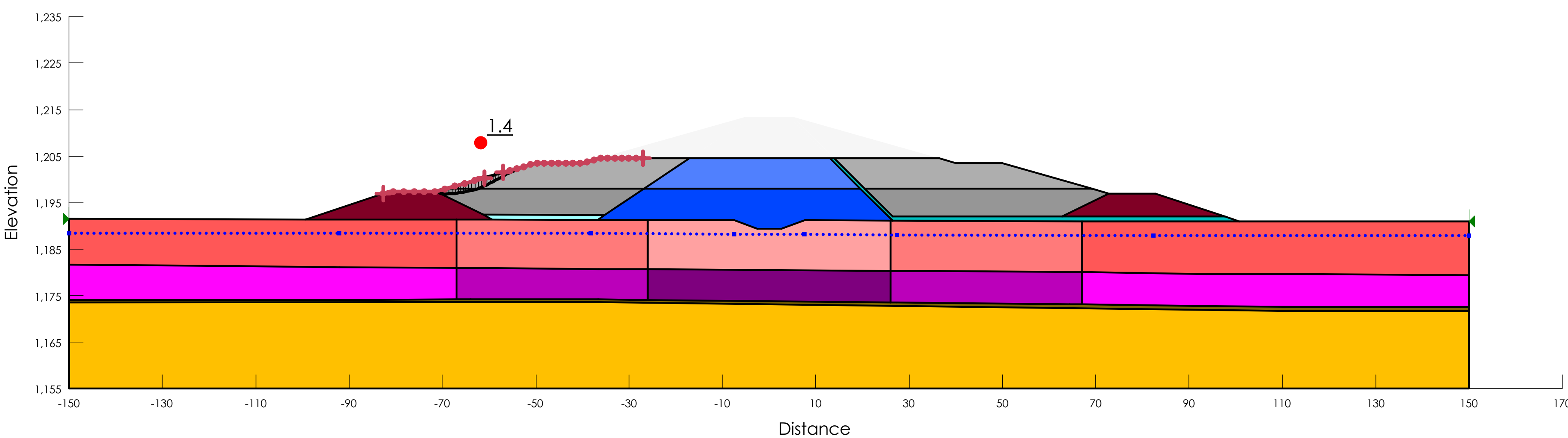


Stantec

Alberta Transportation SR1 Storage Dam

Section 22+500
Load Case: End Construction, Year 2, B-Bar
Effective Stress Parameters
Incipient Motion in the Upstream Direction

Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)	B-bar	Add Weight
	Drain	21	0	33	0	Yes
	Embankment Core (Drained, Year 1)	20	0	28	0.5	Yes
	Embankment Core (Drained, Year 2)	20	0	28	0	Yes
	Embankment Shell (Drained, Year 1)	20	0	24	0.25	Yes
	Embankment Shell (Drained, Year 2)	20	0	24	0	Yes
	Glacial Till (Drained, Crest)	18	0	27	0.65	No
	Glacial Till (Drained, Slope)	18	0	27	0.4	No
	Glacial Till (Drained, Toe)	18	0	27	0.25	No
	Glacio-Lacustrine (Drained, Crest)	18	0	23	0.85	No
	Glacio-Lacustrine (Drained, Slope)	18	0	23	0.6	No
	Glacio-Lacustrine (Drained, Toe)	18	0	23	0.35	No
	Granular Zone	21	0	33	0	Yes
	Rock Toe	20	0	33	0	Yes
	Sandstone				0	No
	Weathered Bedrock	21	0	35	0	No

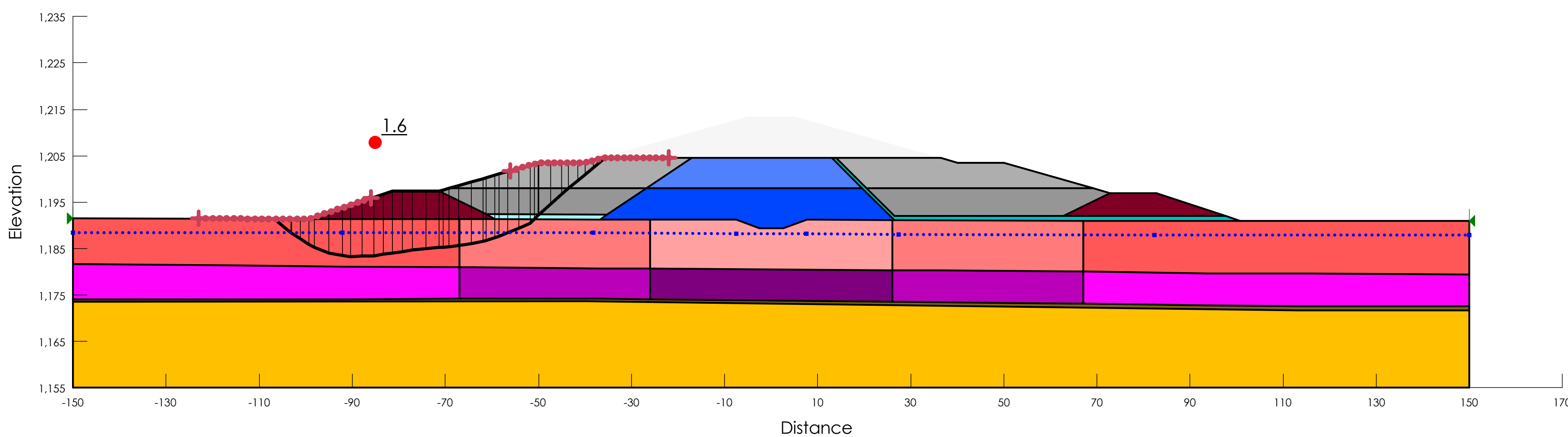


Stantec

Alberta Transportation SR1 Storage Dam

Section 22+500
Load Case: End Construction, Year 2, B-Bar
Effective Stress Parameters
Incipient Motion in the Upstream Direction

Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)	B-bar	Add Weight
	Drain	21	0	33	0	Yes
	Embankment Core (Drained, Year 1)	20	0	28	0.5	Yes
	Embankment Core (Drained, Year 2)	20	0	28	0	Yes
	Embankment Shell (Drained, Year 1)	20	0	24	0.25	Yes
	Embankment Shell (Drained, Year 2)	20	0	24	0	Yes
	Glacial Till (Drained, Crest)	18	0	27	0.65	No
	Glacial Till (Drained, Slope)	18	0	27	0.4	No
	Glacial Till (Drained, Toe)	18	0	27	0.25	No
	Glacio-Lacustrine (Drained, Crest)	18	0	23	0.85	No
	Glacio-Lacustrine (Drained, Slope)	18	0	23	0.6	No
	Glacio-Lacustrine (Drained, Toe)	18	0	23	0.35	No
	Granular Zone	21	0	33	0	Yes
	Rock Toe	20	0	33	0	Yes
	Sandstone				0	No
	Weathered Bedrock	21	0	35	0	No

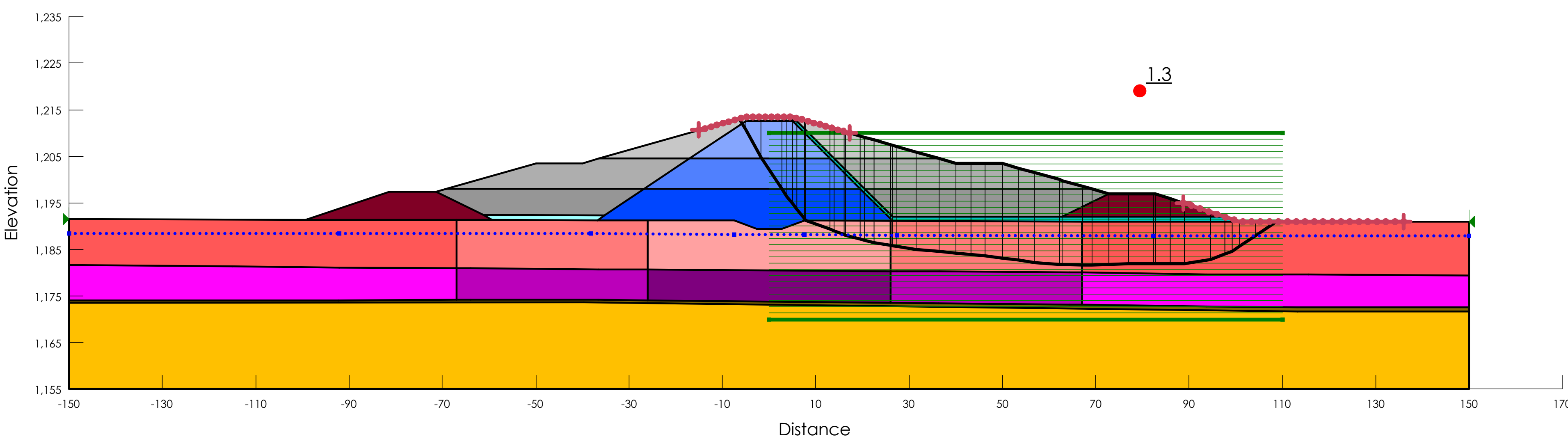


Stantec

Alberta Transportation SR1 Storage Dam

Section 22+500
Load Case: End Construction, Year 3, B-Bar
Effective Stress Parameters
Incipient Motion in the Downstream Direction

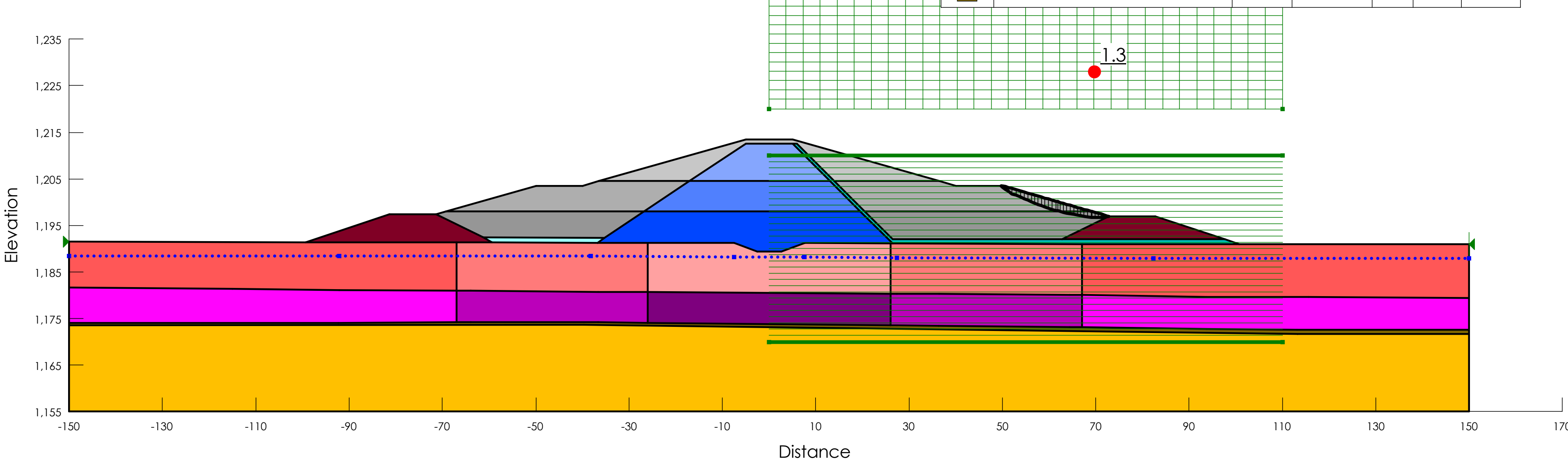
Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)	B-bar	Add Weight
	Drain	21	0	33	0	Yes
	Embankment Core (Drained, Year 1)	20	0	28	0.5	Yes
	Embankment Core (Drained, Year 2)	20	0	28	0.4	Yes
	Embankment Core (Drained, Year 3)	20	0	28	0	Yes
	Embankment Shell (Drained, Year 1)	20	0	24	0.18	Yes
	Embankment Shell (Drained, Year 2)	20	0	24	0.15	Yes
	Embankment Shell (Drained, Year 3)	20	0	24	0	Yes
	Glacial Till (Drained, Crest)	18	0	27	0.45	No
	Glacial Till (Drained, Slope)	18	0	27	0.3	No
	Glacial Till (Drained, Toe)	18	0	27	0.15	No
	Glacio-Lacustrine (Drained, Crest)	18	0	23	0.8	No
	Glacio-Lacustrine (Drained, Slope)	18	0	23	0.45	No
	Glacio-Lacustrine (Drained, Toe)	18	0	23	0.3	No
	Granular Zone	21	0	33	0	Yes
	Rock Toe	20	0	33	0	Yes
	Sandstone				0	No
	Weathered Bedrock	21	0	35	0	No



Alberta Transportation SR1 Storage Dam

Section 22+500
Load Case: End Construction, Year 3, B-Bar
Effective Stress Parameters
Incipient Motion in the Downstream Direction

Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)	B-bar	Add Weight
	Drain	21	0	33	0	Yes
	Embankment Core (Drained, Year 1)	20	0	28	0.5	Yes
	Embankment Core (Drained, Year 2)	20	0	28	0.4	Yes
	Embankment Core (Drained, Year 3)	20	0	28	0	Yes
	Embankment Shell (Drained, Year 1)	20	0	24	0.18	Yes
	Embankment Shell (Drained, Year 2)	20	0	24	0.15	Yes
	Embankment Shell (Drained, Year 3)	20	0	24	0	Yes
	Glacial Till (Drained, Crest)	18	0	27	0.45	No
	Glacial Till (Drained, Slope)	18	0	27	0.3	No
	Glacial Till (Drained, Toe)	18	0	27	0.15	No
	Glacio-Lacustrine (Drained, Crest)	18	0	23	0.8	No
	Glacio-Lacustrine (Drained, Slope)	18	0	23	0.45	No
	Glacio-Lacustrine (Drained, Toe)	18	0	23	0.3	No
	Granular Zone	21	0	33	0	Yes
	Rock Toe	20	0	33	0	Yes
	Sandstone				0	No
	Weathered Bedrock	21	0	35	0	No

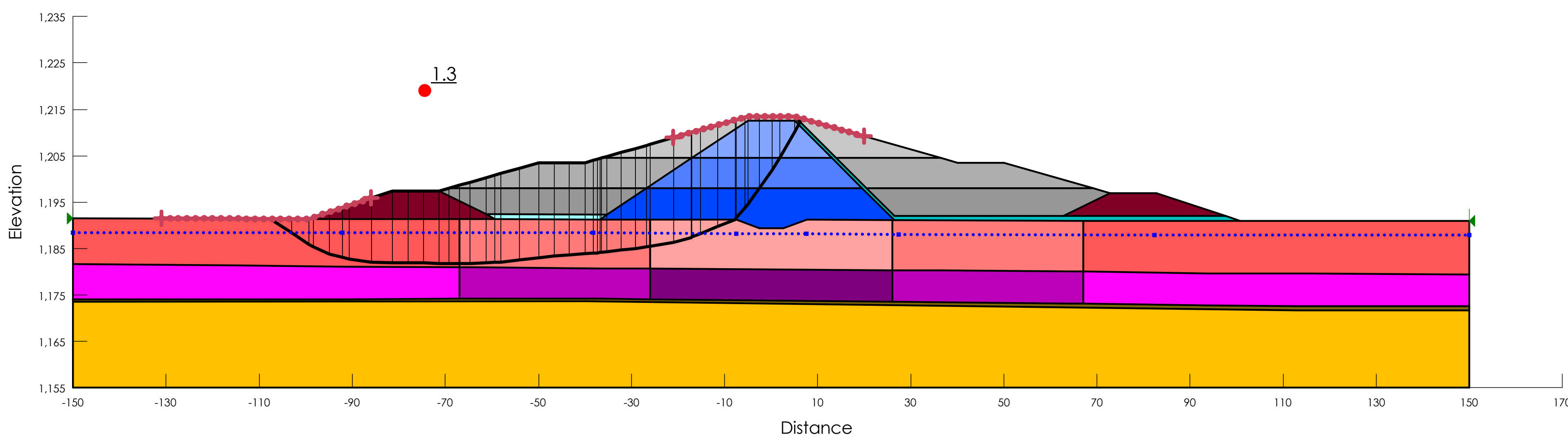


Stantec

Alberta Transportation SR1 Storage Dam

Section 22+500
Load Case: End Construction, Year 3, B-Bar
Effective Stress Parameters
Incipient Motion in the Upstream Direction

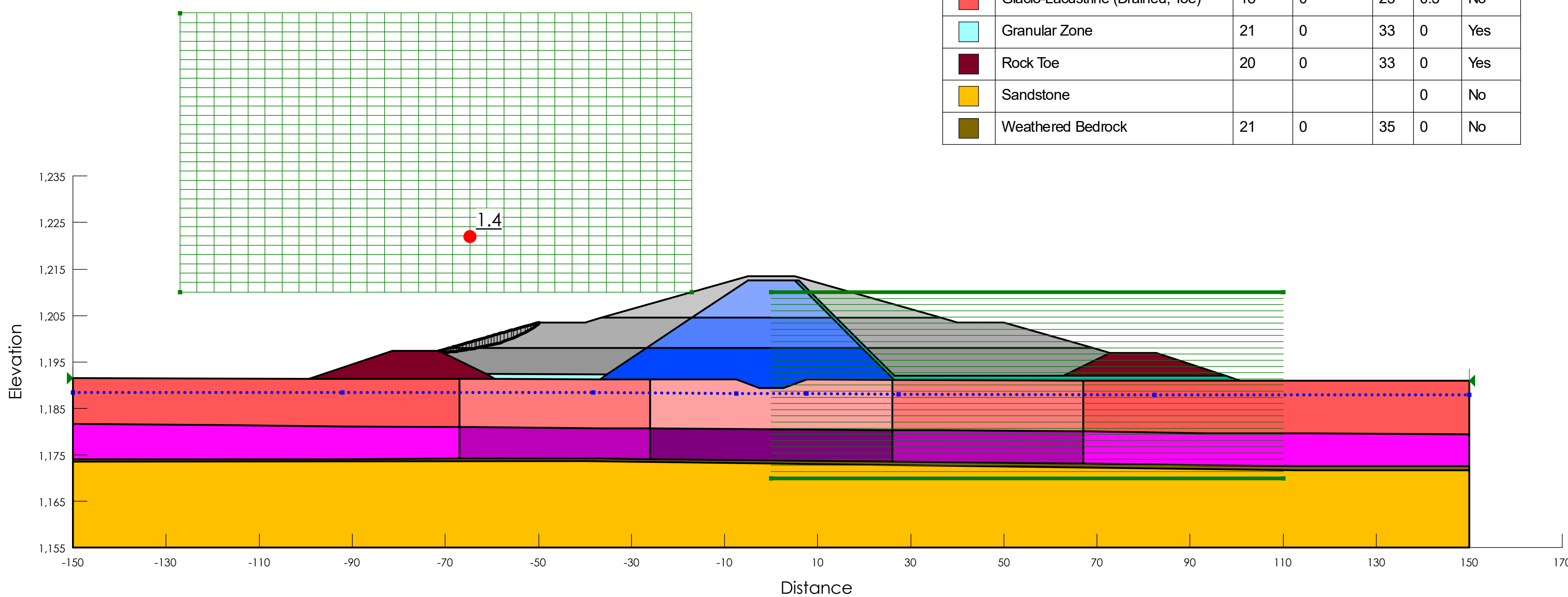
Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)	B-bar	Add Weight
	Drain	21	0	33	0	Yes
	Embankment Core (Drained, Year 1)	20	0	28	0.5	Yes
	Embankment Core (Drained, Year 2)	20	0	28	0.4	Yes
	Embankment Core (Drained, Year 3)	20	0	28	0	Yes
	Embankment Shell (Drained, Year 1)	20	0	24	0.18	Yes
	Embankment Shell (Drained, Year 2)	20	0	24	0.15	Yes
	Embankment Shell (Drained, Year 3)	20	0	24	0	Yes
	Glacial Till (Drained, Crest)	18	0	27	0.45	No
	Glacial Till (Drained, Slope)	18	0	27	0.3	No
	Glacial Till (Drained, Toe)	18	0	27	0.15	No
	Glacio-Lacustrine (Drained, Crest)	18	0	23	0.8	No
	Glacio-Lacustrine (Drained, Slope)	18	0	23	0.45	No
	Glacio-Lacustrine (Drained, Toe)	18	0	23	0.3	No
	Granular Zone	21	0	33	0	Yes
	Rock Toe	20	0	33	0	Yes
	Sandstone				0	No
	Weathered Bedrock	21	0	35	0	No



Alberta Transportation SR1 Storage Dam

Section 22+500
Load Case: End Construction, Year 3, B-Bar
Effective Stress Parameters
Incipient Motion in the Upstream Direction

Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)	B-bar	Add Weight
	Drain	21	0	33	0	Yes
	Embankment Core (Drained, Year 1)	20	0	28	0.5	Yes
	Embankment Core (Drained, Year 2)	20	0	28	0.4	Yes
	Embankment Core (Drained, Year 3)	20	0	28	0	Yes
	Embankment Shell (Drained, Year 1)	20	0	24	0.18	Yes
	Embankment Shell (Drained, Year 2)	20	0	24	0.15	Yes
	Embankment Shell (Drained, Year 3)	20	0	24	0	Yes
	Glacial Till (Drained, Crest)	18	0	27	0.45	No
	Glacial Till (Drained, Slope)	18	0	27	0.3	No
	Glacial Till (Drained, Toe)	18	0	27	0.15	No
	Glacio-Lacustrine (Drained, Crest)	18	0	23	0.8	No
	Glacio-Lacustrine (Drained, Slope)	18	0	23	0.45	No
	Glacio-Lacustrine (Drained, Toe)	18	0	23	0.3	No
	Granular Zone	21	0	33	0	Yes
	Rock Toe	20	0	33	0	Yes
	Sandstone				0	No
	Weathered Bedrock	21	0	35	0	No

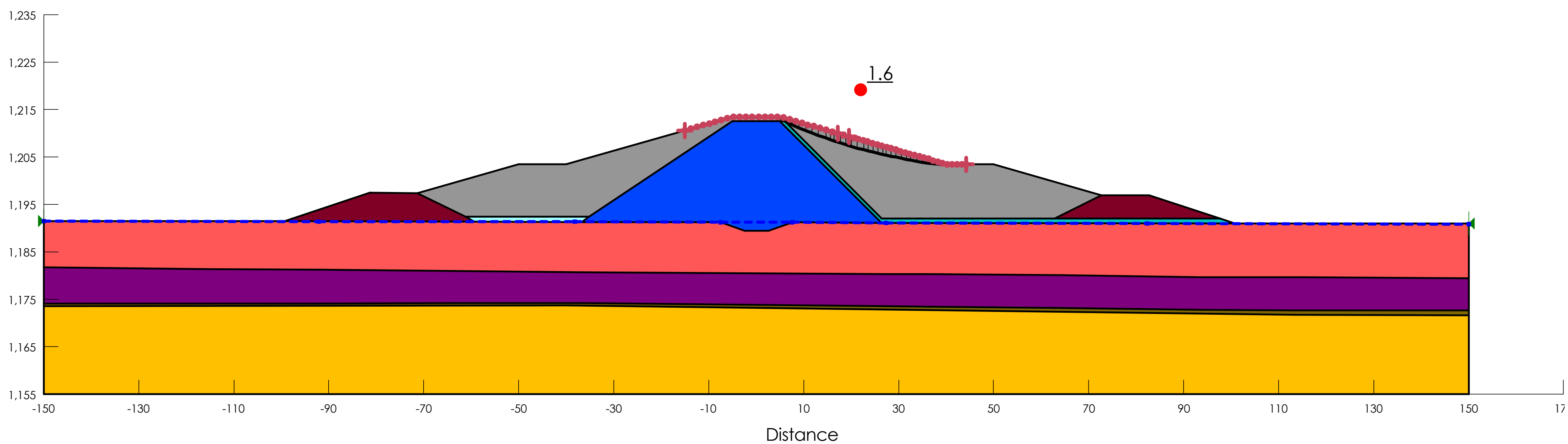


Stantec

Alberta Transportation SR1 Storage Dam

Section 22+500
Load Case: Long Term
Effective Stress Parameters
Incipient Motion in the Downstream Direction

Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)
	Drain	21	0	33
	Embankment Core (Drained)	20	0	28
	Embankment Shell (Drained)	20	0	24
	Glacial Till (Drained)	18	0	27
	Glacio-Lacustrine (Drained)	18	0	23
	Granular Zone	21	0	33
	Rock Toe	20	0	33
	Sandstone			
	Weathered Bedrock	21	0	35

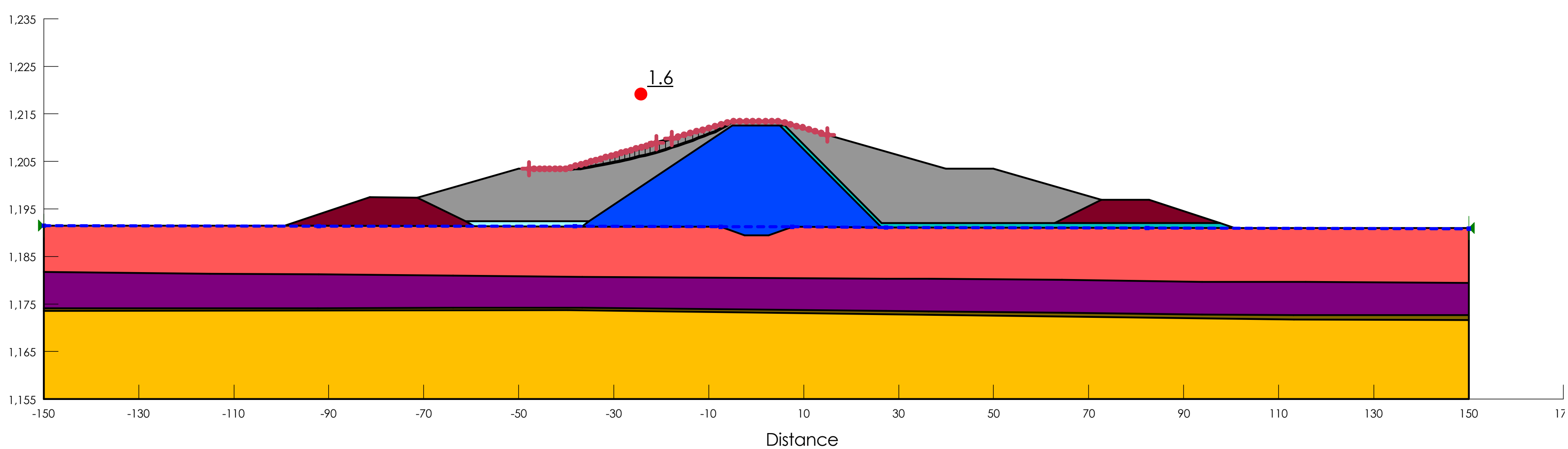


Stantec

Alberta Transportation SR1 Storage Dam

Section 22+500
Load Case: Long Term
Effective Stress Parameters
Incipient Motion in the Upstream Direction

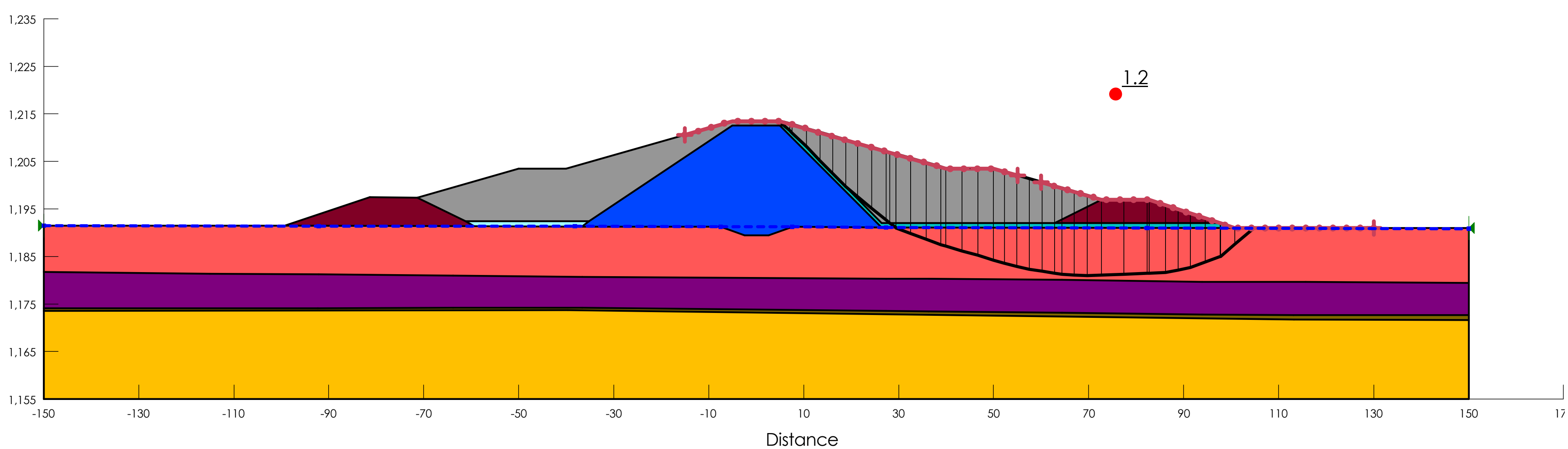
Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)
	Drain	21	0	33
	Embankment Core (Drained)	20	0	28
	Embankment Shell (Drained)	20	0	24
	Glacial Till (Drained)	18	0	27
	Glacio-Lacustrine (Drained)	18	0	23
	Granular Zone	21	0	33
	Rock Toe	20	0	33
	Sandstone			
	Weathered Bedrock	21	0	35



Alberta Transportation SR1 Storage Dam

Section 22+500
Load Case: Post Earthquake
Post Earthquake Parameters
Incipient Motion in the Downstream Direction

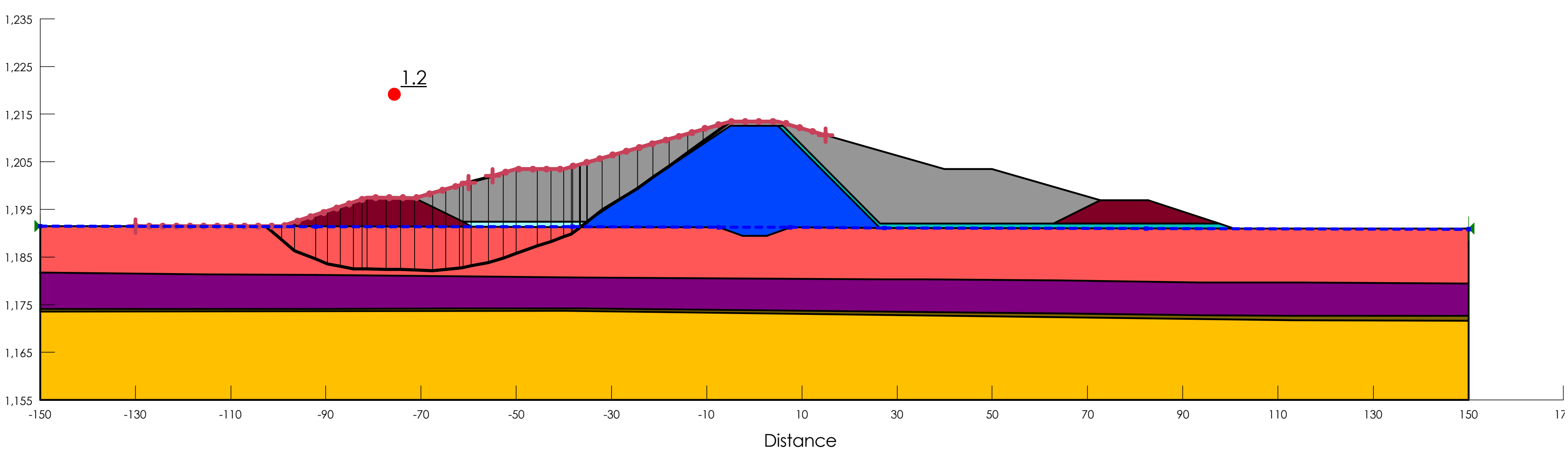
Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)
	Drain	21		0				33
	Embankment Core (EQ/Pseudo)	20		0	28	15	243	
	Embankment Shell (EQ/Pseudo)	20		0	24	12	86	
	Glacial Till (EQ/Pseudo)	18		0	27	15	199	
	Glacio-Lacustrine (EQ/Pseudo)	18	Glacio-Lacustrine (Seismic)					0
	Granular Zone	21		0				33
	Rock Toe	20		0				33
	Sandstone							
	Weathered Bedrock	21		0				35



Alberta Transportation SR1 Storage Dam

Section 22+500
Load Case: Post Earthquake
Post Earthquake Parameters
Incipient Motion in the Upstream Direction

Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)
	Drain	21		0				33
	Embankment Core (EQ/Pseudo)	20		0	28	15	243	
	Embankment Shell (EQ/Pseudo)	20		0	24	12	86	
	Glacial Till (EQ/Pseudo)	18		0	27	15	199	
	Glacio-Lacustrine (EQ/Pseudo)	18	Glacio-Lacustrine (Seismic)					0
	Granular Zone	21		0				33
	Rock Toe	20		0				33
	Sandstone							
	Weathered Bedrock	21		0				35

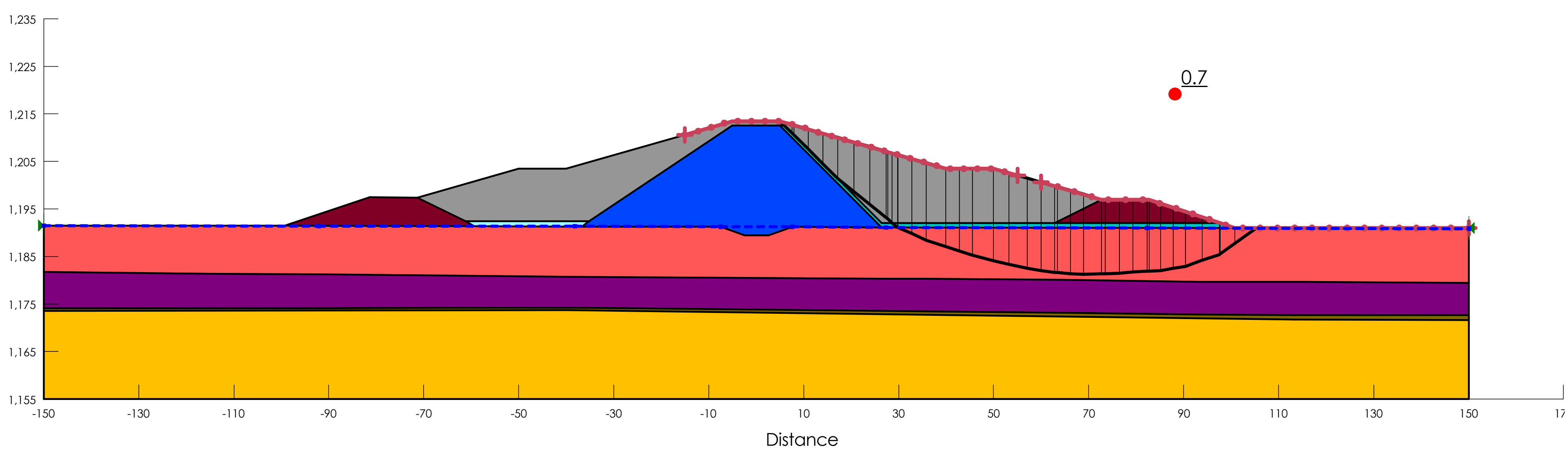


Stantec

Alberta Transportation SR1 Storage Dam

Section 22+500
Load Case: Pseudostatic
Pseudostatic Parameters
Incipient Motion in the Downstream Direction

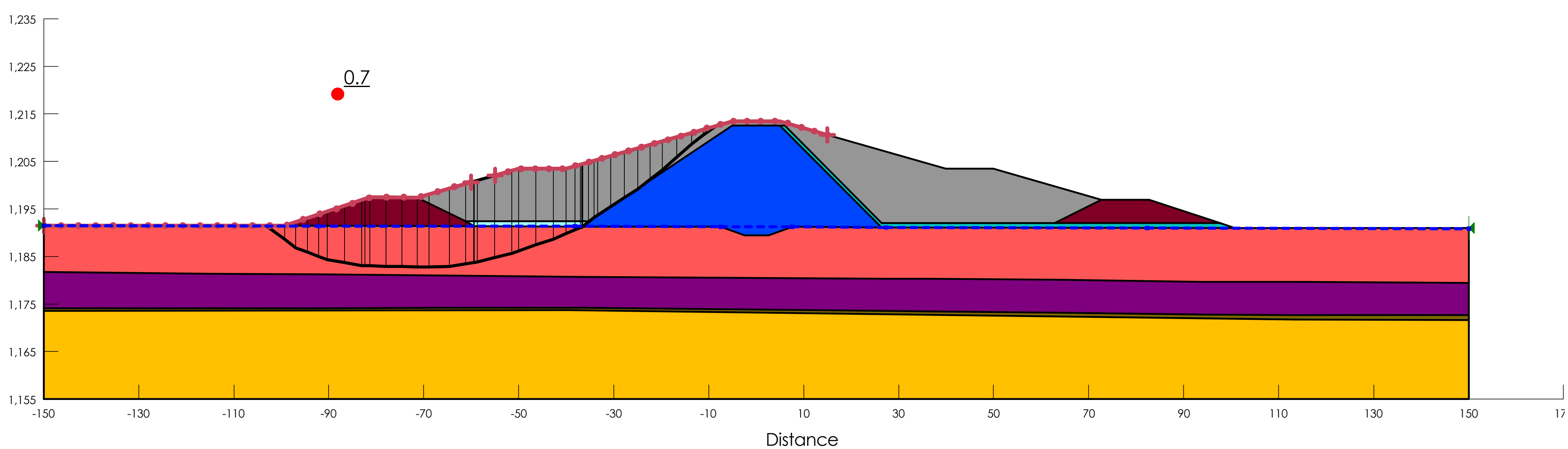
Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)	Cohesion R (kPa)	Phi R (°)
	Drain	21		0				33	0	0
	Embankment Core (EQ/Pseudo)	20		0	28	15	243			
	Embankment Shell (EQ/Pseudo)	20		0	24	12	86			
	Glacial Till (EQ/Pseudo)	18		0	27	15	199			
	Glacio-Lacustrine (EQ/Pseudo)	18	Glacio-Lacustrine (Seismic)					0	0	0
	Granular Zone	21		0				33	0	0
	Rock Toe	20		0				33	0	0
	Sandstone									
	Weathered Bedrock	21		0				35	0	0



Alberta Transportation SR1 Storage Dam

Section 22+500
Load Case: Pseudostatic
Pseudostatic Parameters
Incipient Motion in the Upstream Direction

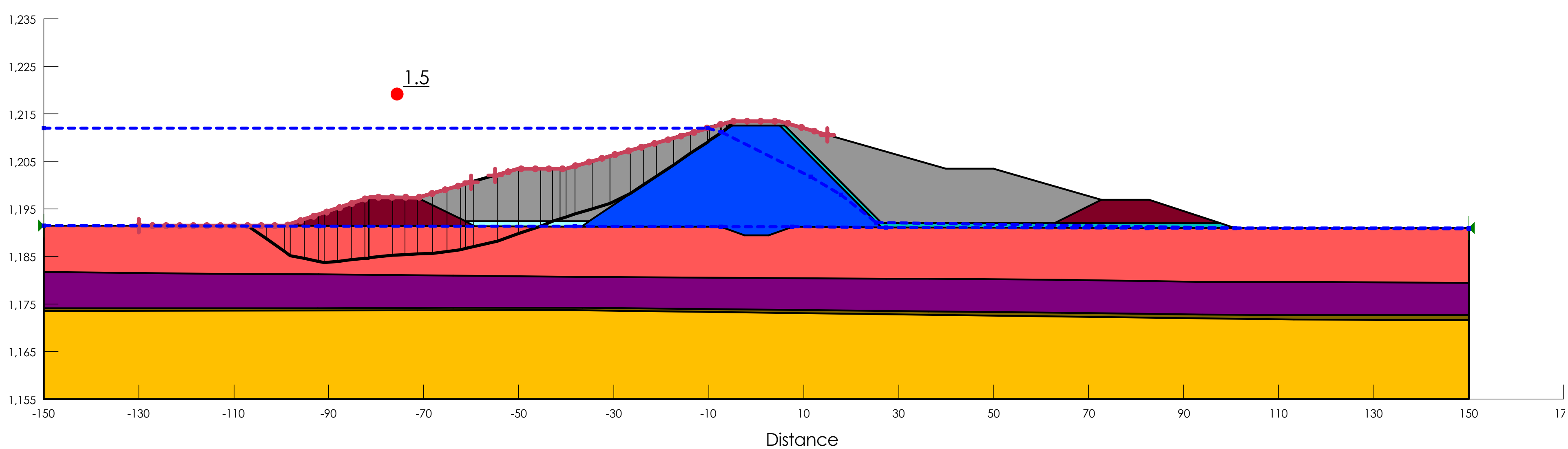
Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)	Cohesion R (kPa)	Phi R (°)
	Drain	21		0				33	0	0
	Embankment Core (EQ/Pseudo)	20		0	28	15	243			
	Embankment Shell (EQ/Pseudo)	20		0	24	12	86			
	Glacial Till (EQ/Pseudo)	18		0	27	15	199			
	Glacio-Lacustrine (EQ/Pseudo)	18	Glacio-Lacustrine (Seismic)					0	0	0
	Granular Zone	21		0				33	0	0
	Rock Toe	20		0				33	0	0
	Sandstone									
	Weathered Bedrock	21		0				35	0	0



Alberta Transportation SR1 Storage Dam

Section 22+500
Load Case: Rapid Drawdown
Effective and Total Parameters
Incipient Motion in the Upstream Direction

Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)	Cohesion R (kPa)	Phi R (°)
	Drain	21	0	33	0	0
	Embankment Core (RDD)	20	0	28	80	19
	Embankment Shell (RDD)	20	0	24	25	15
	Glacial Till (RDD)	18	0	27	60	19
	Glacio-Lacustrine (RDD)	18	0	23	15	20
	Granular Zone	21	0	33	0	0
	Rock Toe	20	0	33	0	0
	Sandstone					
	Weathered Bedrock	21	0	35	0	0

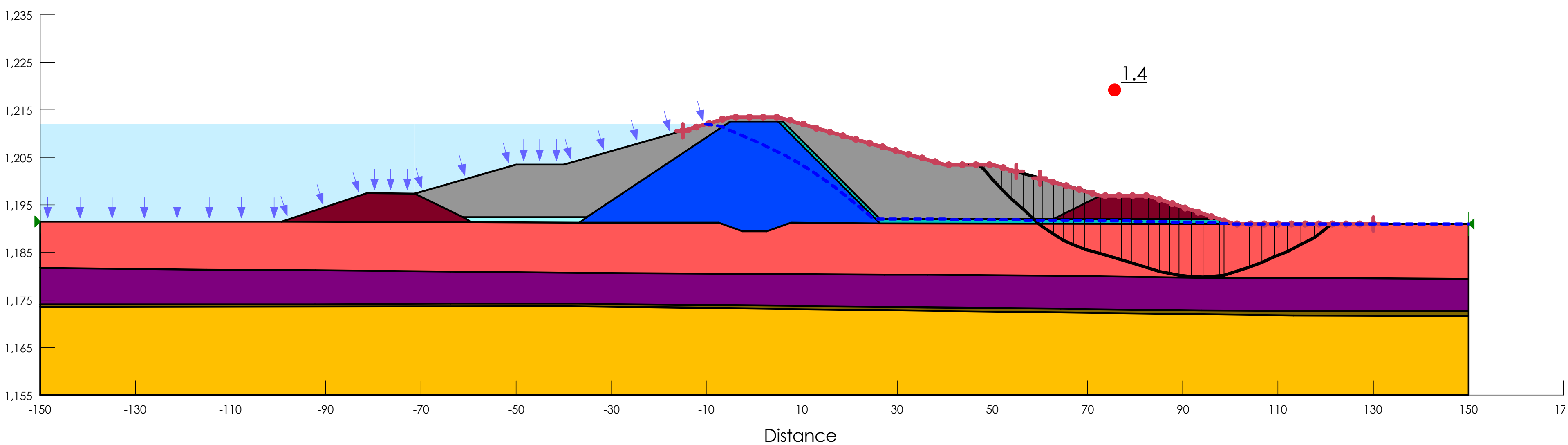


Stantec

Alberta Transportation SR1 Storage Dam

Section 22+500
Load Case: USBR Flood
Effective Parameters
Incipient Motion in the Downstream Direction

Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)
	Drain	21	0	33
	Embankment Core (Drained)	20	0	28
	Embankment Shell (Drained)	20	0	24
	Glacial Till (Drained)	18	0	27
	Glacio-Lacustrine (Drained)	18	0	23
	Granular Zone	21	0	33
	Rock Toe	20	0	33
	Sandstone			
	Weathered Bedrock	21	0	35



Attachment 12.1
Slope Stability and Seepage Analyses

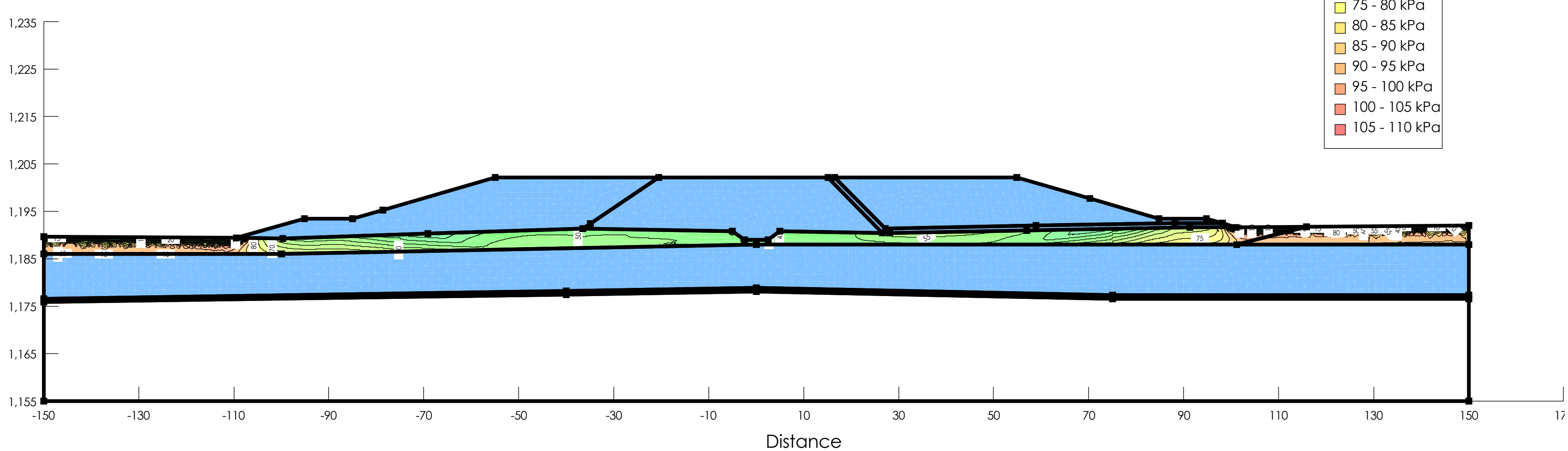
12.1.5 Slope Stability Analyses
Sta. 22+990 - Original Lacustrine Foundation

Stantec

Alberta Transportation SR1 Storage Dam

Section 22+990
Load Case: End of Construction, Year 2
Total Stress Parameters
Incipient Motion in the Upstream Direction

Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)
	Drain	21		0				33
	Embankment Core (Undrained)	20		0	28	19	[illegible]	
	Embankment Shell (Undrained)	20		0	24	15		
	Glacial Till (Undrained)	18		0	27	19		
	Glacio-Lacustrine (Undrained)	18	Undrained GL					
	Sandstone							
	Weathered Bedrock	21		0				



Stantec

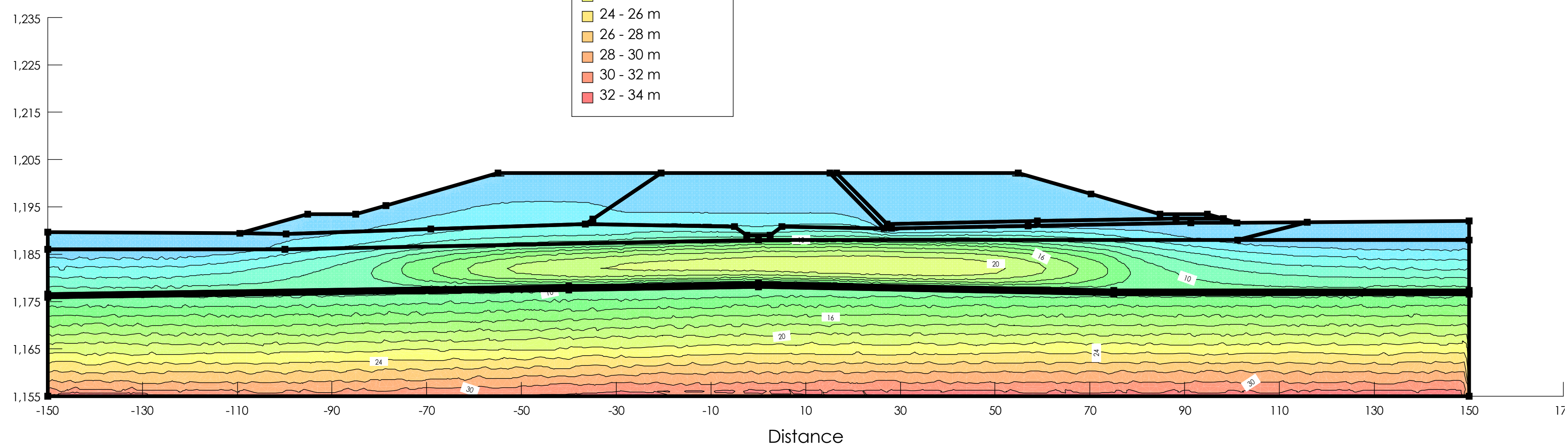
Alberta Transportation SR1 Storage Dam

Section 22+990
Load Case: End of Construction, Year 2
Total Stress Parameters
Incipient Motion in the Upstream Directio

Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)
	Drain	21		0				33
	Embankment Core (Undrained)	20		0	28	19	427	
	Embankment Shell (Undrained)	20		0	24	15	141	
	Glacial Till (Undrained)	18		0	27	19	363.2	
	Glacio-Lacustrine (Undrained)	18	Undrained GL					0
	Sandstone							
	Weathered Bedrock	21		0				35

Water Pressure Head

- -2 - 0 m
- 0 - 2 m
- 2 - 4 m
- 4 - 6 m
- 6 - 8 m
- 8 - 10 m
- 10 - 12 m
- 12 - 14 m
- 14 - 16 m
- 16 - 18 m
- 18 - 20 m
- 20 - 22 m
- 22 - 24 m
- 24 - 26 m
- 26 - 28 m
- 28 - 30 m
- 30 - 32 m
- 32 - 34 m

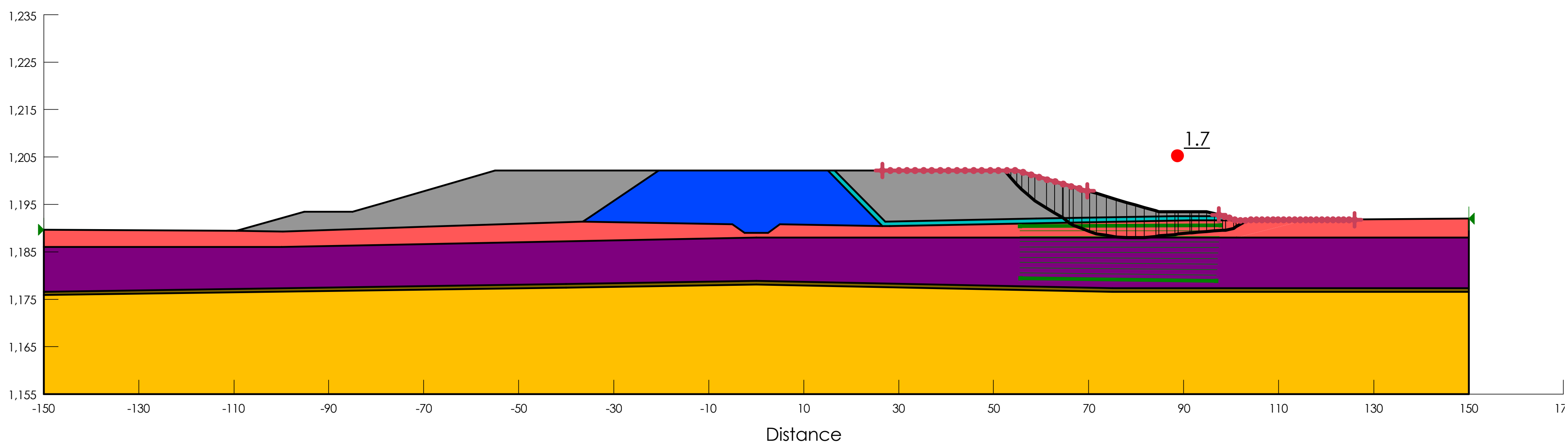


Stantec

Alberta Transportation SR1 Storage Dam

Section 22+990
Load Case: End of Construction, Year 2
Effective Stress Parameters
Incipient Motion in the Downstream Direction

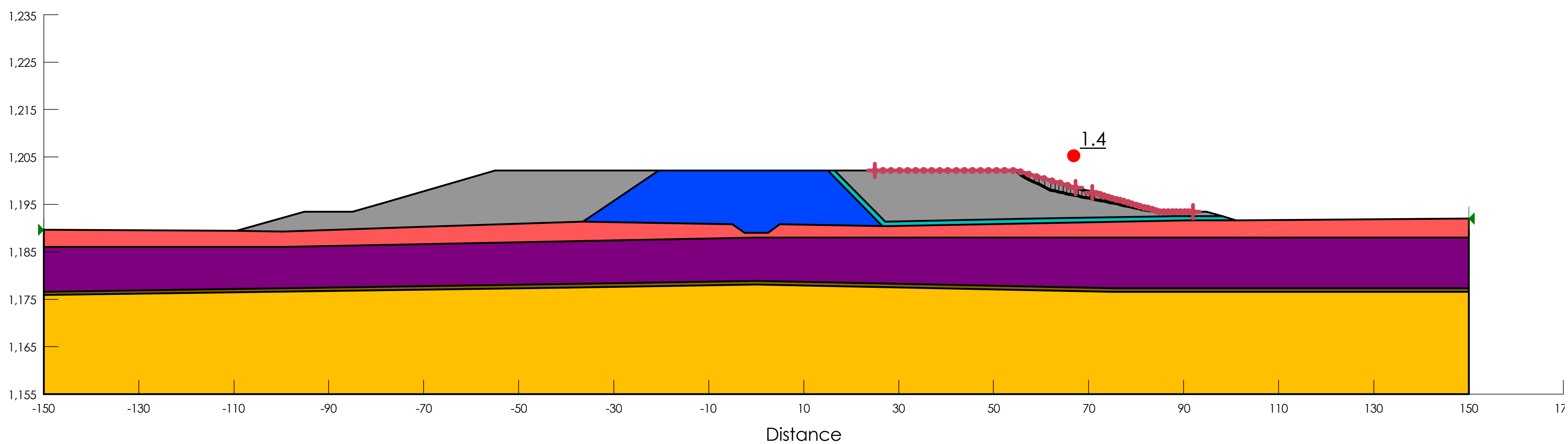
Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)
	Drain	21	0	33
	Embankment Core (Drained)	20	0	28
	Embankment Shell (Drained)	20	0	24
	Glacial Till (Drained)	18	0	27
	Glacio-Lacustrine (Drained)	18	0	23
	Sandstone			
	Weathered Bedrock	21	0	35



Alberta Transportation SR1 Storage Dam

Section 22+990
Load Case: End of Construction, Year 2
Effective Stress Parameters
Incipient Motion in the Downstream Direction

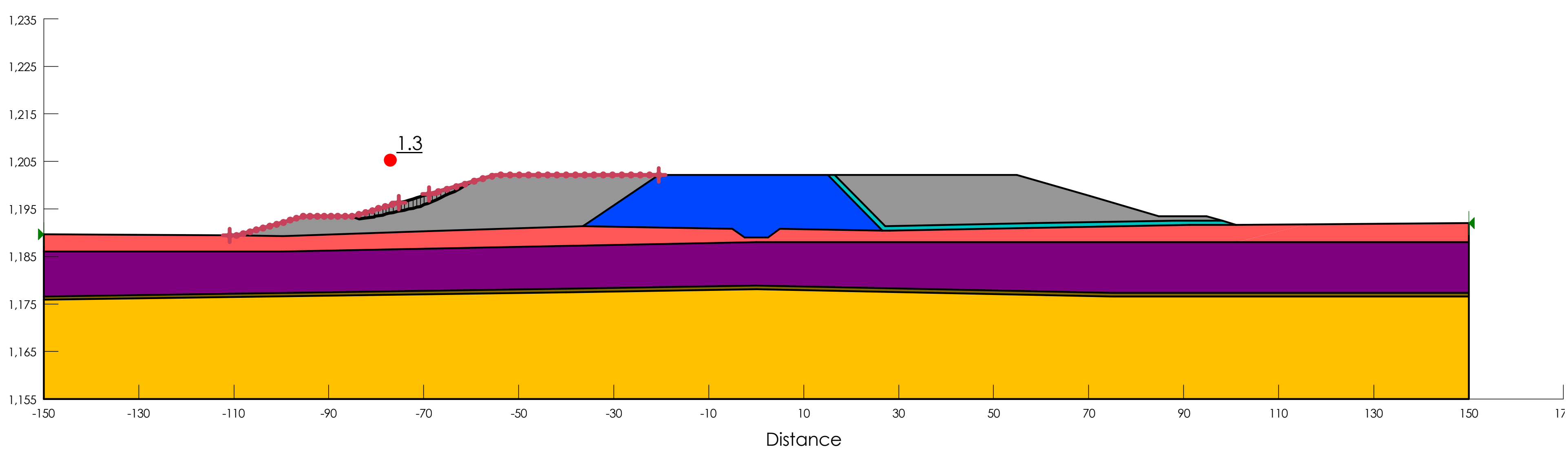
Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)
	Drain	21	0	33
	Embankment Core (Drained)	20	0	28
	Embankment Shell (Drained)	20	0	24
	Glacial Till (Drained)	18	0	27
	Glacio-Lacustrine (Drained)	18	0	23
	Sandstone			
	Weathered Bedrock	21	0	35



Alberta Transportation SR1 Storage Dam

Section 22+990
Load Case: End of Construction, Year 2
Effective Stress Parameters
Incipient Motion in the Upstream Direction

Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)
	Drain	21	0	33
	Embankment Core (Drained)	20	0	28
	Embankment Shell (Drained)	20	0	24
	Glacial Till (Drained)	18	0	27
	Glacio-Lacustrine (Drained)	18	0	23
	Sandstone			
	Weathered Bedrock	21	0	35

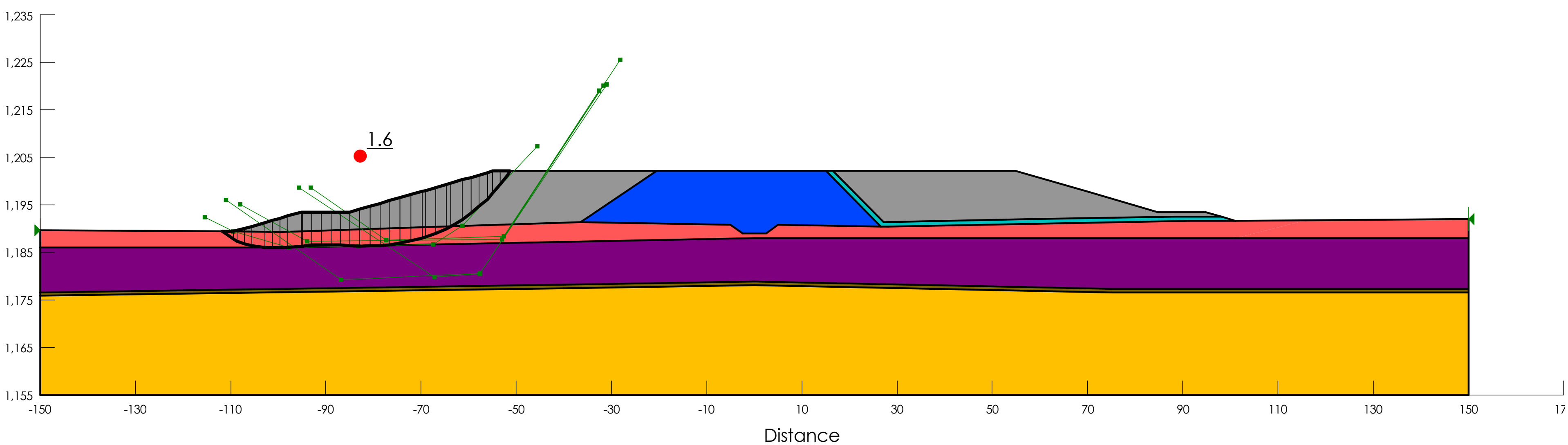


Stantec

Alberta Transportation SR1 Storage Dam

Section 22+990
Load Case: End of Construction, Year 2
Effective Stress Parameters
Incipient Motion in the Upstream Direction

Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)
	Drain	21	0	33
	Embankment Core (Drained)	20	0	28
	Embankment Shell (Drained)	20	0	24
	Glacial Till (Drained)	18	0	27
	Glacio-Lacustrine (Drained)	18	0	23
	Sandstone			
	Weathered Bedrock	21	0	35

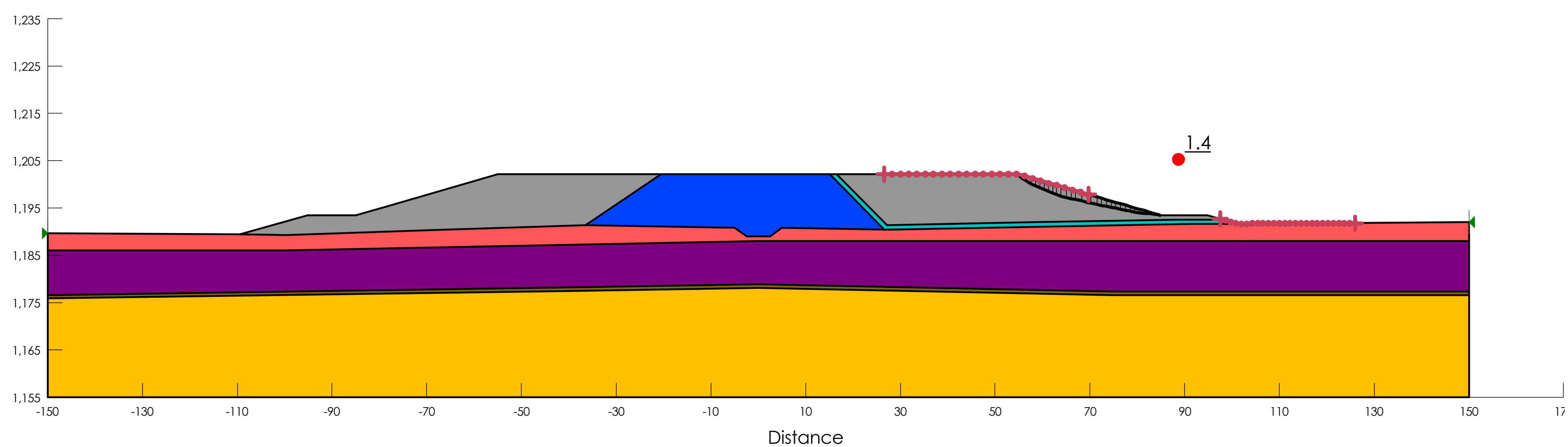


Stantec

Alberta Transportation SR1 Storage Dam

Section 22+990
Load Case: End of Construction, Year 2
Total Stress Parameters
Incipient Motion in the Downstream Direction

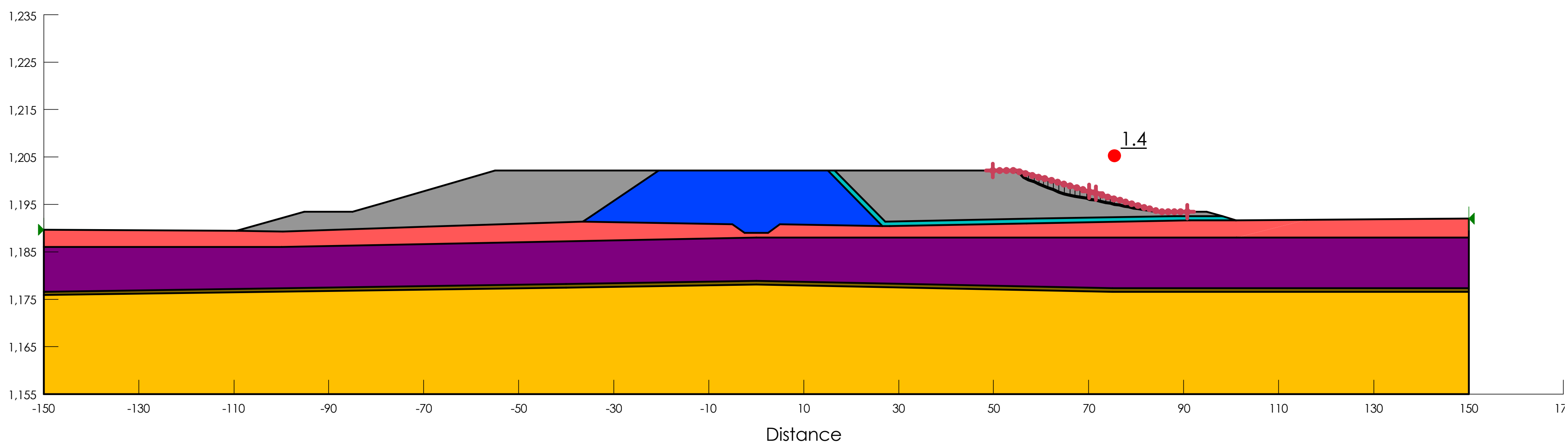
Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)
	Drain	21		0				33
	Embankment Core (Undrained)	20		0	28	19	427	
	Embankment Shell (Undrained)	20		0	24	15	141	
	Glacial Till (Undrained)	18		0	27	19	363.2	
	Glacio-Lacustrine (Undrained)	18	Undrained GL					0
	Sandstone							
	Weathered Bedrock	21		0				35



Alberta Transportation SR1 Storage Dam

Section 22+990
Load Case: End of Construction, Year 2
Total Stress Parameters
Incipient Motion in the Downstream Direction

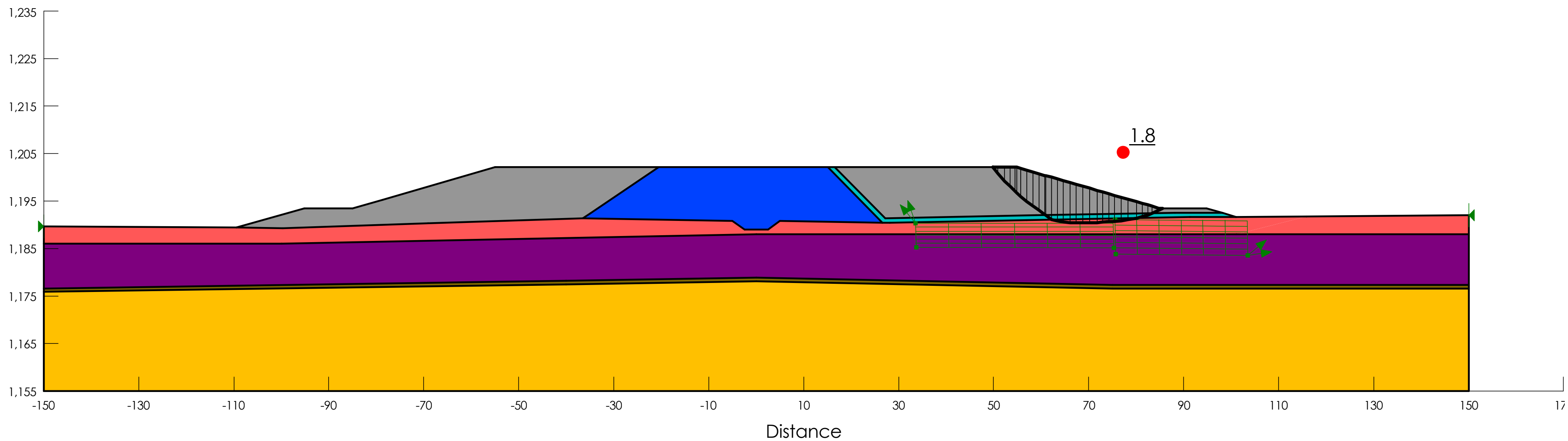
Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)
	Drain	21		0				33
	Embankment Core (Undrained)	20		0	28	19	427	
	Embankment Shell (Undrained)	20		0	24	15	141	
	Glacial Till (Undrained)	18		0	27	19	363.2	
	Glacio-Lacustrine (Undrained)	18	Undrained GL					0
	Sandstone							
	Weathered Bedrock	21		0				35



Alberta Transportation SR1 Storage Dam

Section 22+990
Load Case: End of Construction, Year 2
Total Stress Parameters
Incipient Motion in the Downstream Direction

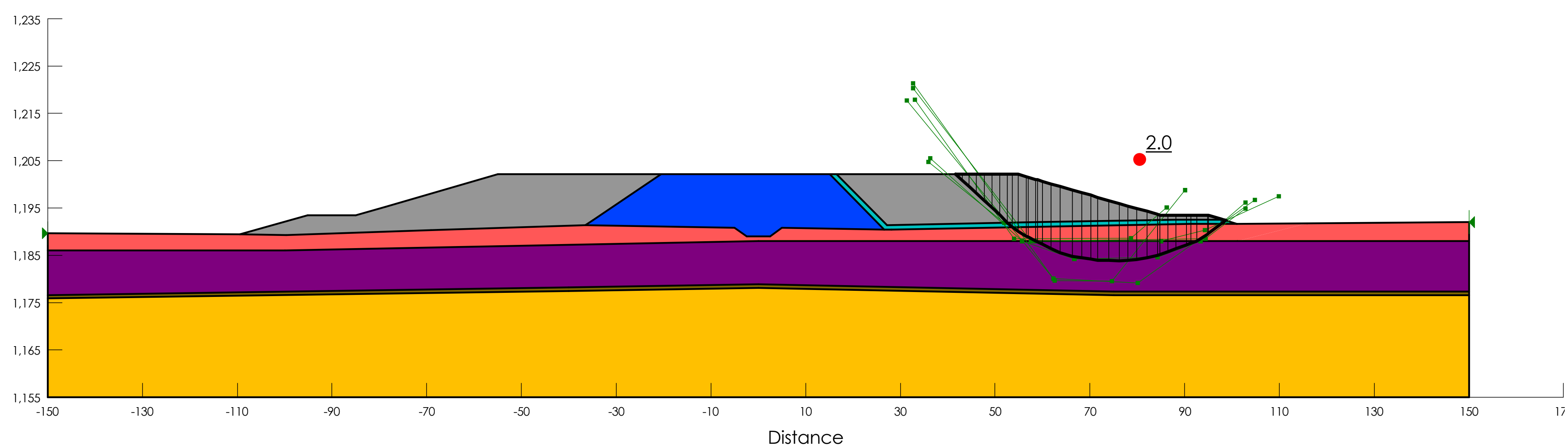
Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)
	Drain	21		0				33
	Embankment Core (Undrained)	20		0	28	19	427	
	Embankment Shell (Undrained)	20		0	24	15	141	
	Glacial Till (Undrained)	18		0	27	19	363.2	
	Glacio-Lacustrine (Undrained)	18	Undrained GL					0
	Sandstone							
	Weathered Bedrock	21		0				35



Alberta Transportation SR1 Storage Dam

Section 22+990
Load Case: End of Construction, Year 2
Total Stress Parameters
Incipient Motion in the Downstream Direction

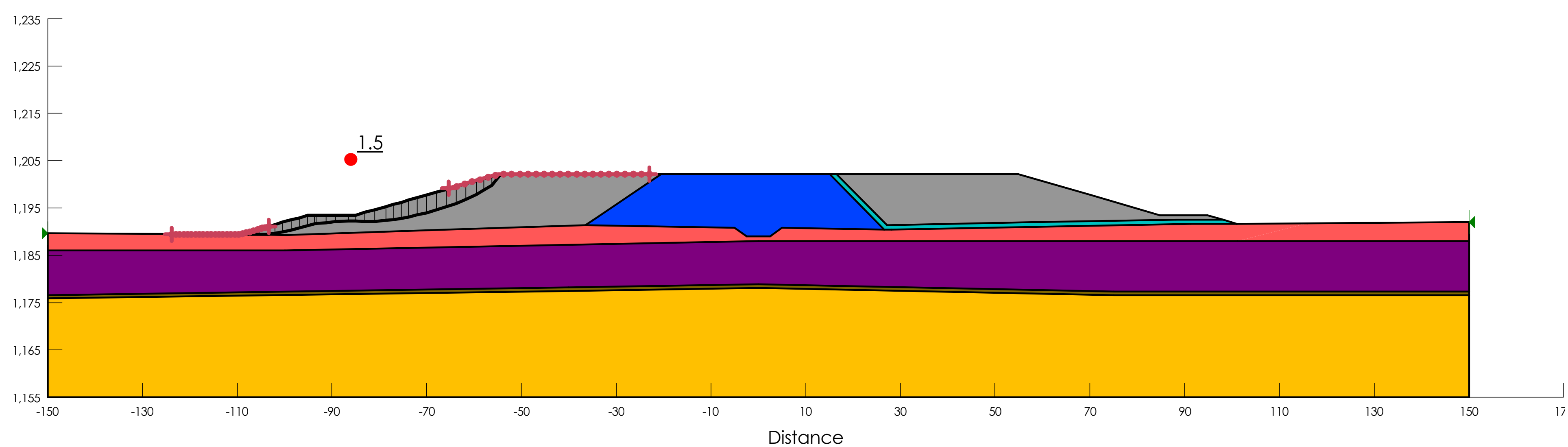
Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)
	Drain	21		0				33
	Embankment Core (Undrained)	20		0	28	19	427	
	Embankment Shell (Undrained)	20		0	24	15	141	
	Glacial Till (Undrained)	18		0	27	19	363.2	
	Glacio-Lacustrine (Undrained)	18	Undrained GL					0
	Sandstone							
	Weathered Bedrock	21		0				35



Alberta Transportation SR1 Storage Dam

Section 22+990
Load Case: End of Construction, Year 2
Total Stress Parameters
Incipient Motion in the Upstream Direction

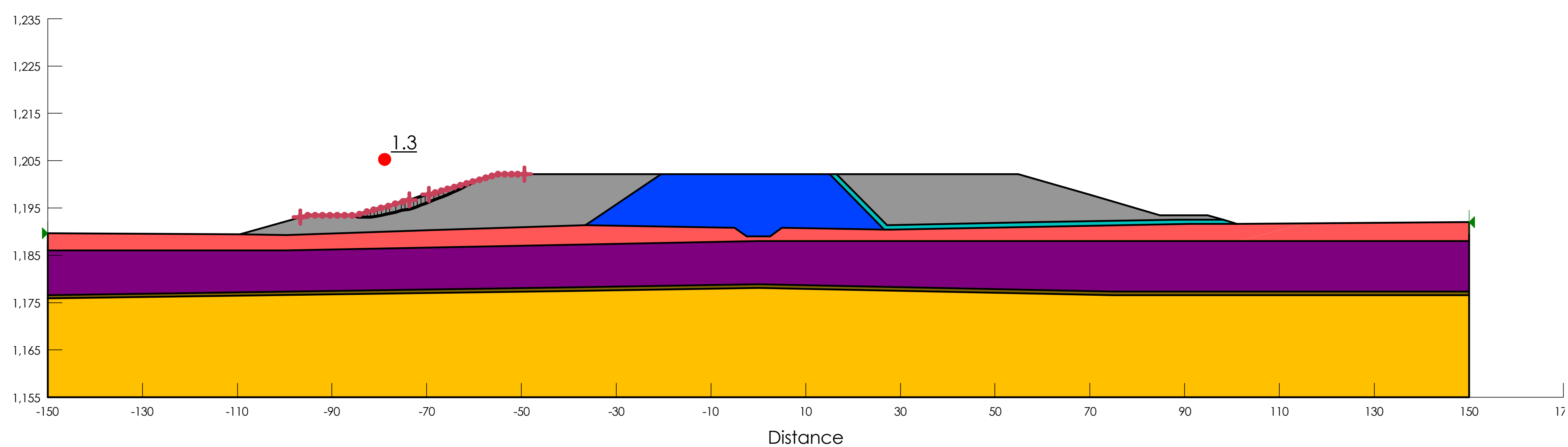
Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)
	Drain	21		0				33
	Embankment Core (Undrained)	20		0	28	19	427	
	Embankment Shell (Undrained)	20		0	24	15	141	
	Glacial Till (Undrained)	18		0	27	19	363.2	
	Glacio-Lacustrine (Undrained)	18	Undrained GL					0
	Sandstone							
	Weathered Bedrock	21		0				35



Alberta Transportation SR1 Storage Dam

Section 22+990
Load Case: End of Construction, Year 2
Total Stress Parameters
Incipient Motion in the Upstream Direction

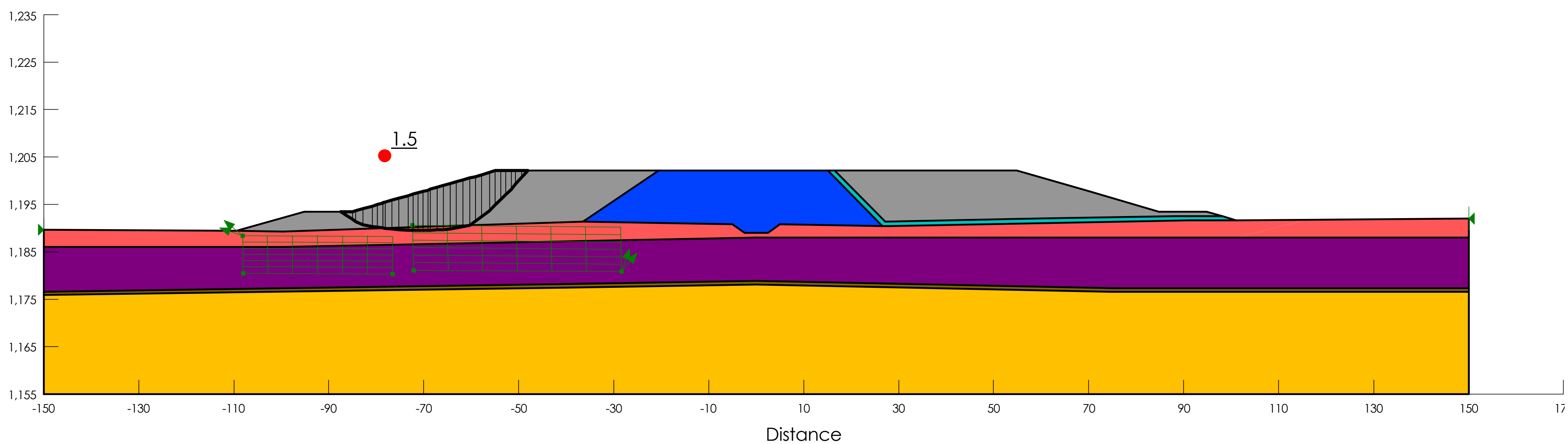
Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)
	Drain	21		0				33
	Embankment Core (Undrained)	20		0	28	19	427	
	Embankment Shell (Undrained)	20		0	24	15	141	
	Glacial Till (Undrained)	18		0	27	19	363.2	
	Glacio-Lacustrine (Undrained)	18	Undrained GL					0
	Sandstone							
	Weathered Bedrock	21		0				35



Alberta Transportation SR1 Storage Dam

Section 22+990
Load Case: End of Construction, Year 2
Total Stress Parameters
Incipient Motion in the Upstream Direction

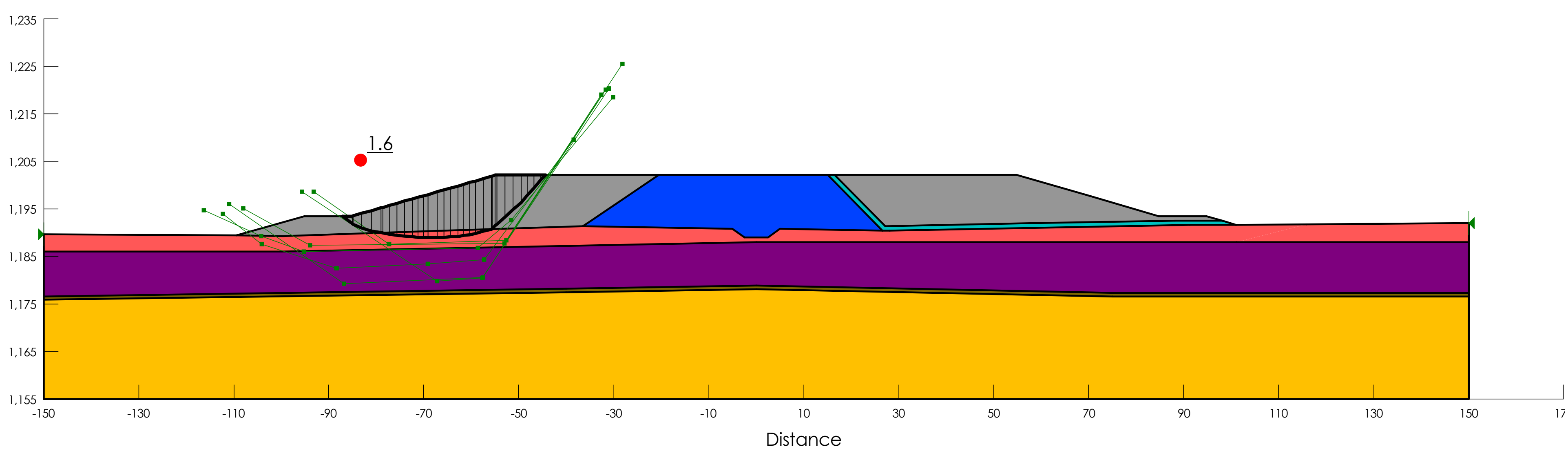
Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)
	Drain	21		0				33
	Embankment Core (Undrained)	20		0	28	19	427	
	Embankment Shell (Undrained)	20		0	24	15	141	
	Glacial Till (Undrained)	18		0	27	19	363.2	
	Glacio-Lacustrine (Undrained)	18	Undrained GL					0
	Sandstone							
	Weathered Bedrock	21		0				35



Alberta Transportation SR1 Storage Dam

Section 22+990
Load Case: End of Construction, Year 2
Total Stress Parameters
Incipient Motion in the Upstream Direction

Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)
	Drain	21		0				33
	Embankment Core (Undrained)	20		0	28	19	427	
	Embankment Shell (Undrained)	20		0	24	15	141	
	Glacial Till (Undrained)	18		0	27	19	363.2	
	Glacio-Lacustrine (Undrained)	18	Undrained GL					0
	Sandstone							
	Weathered Bedrock	21		0				35

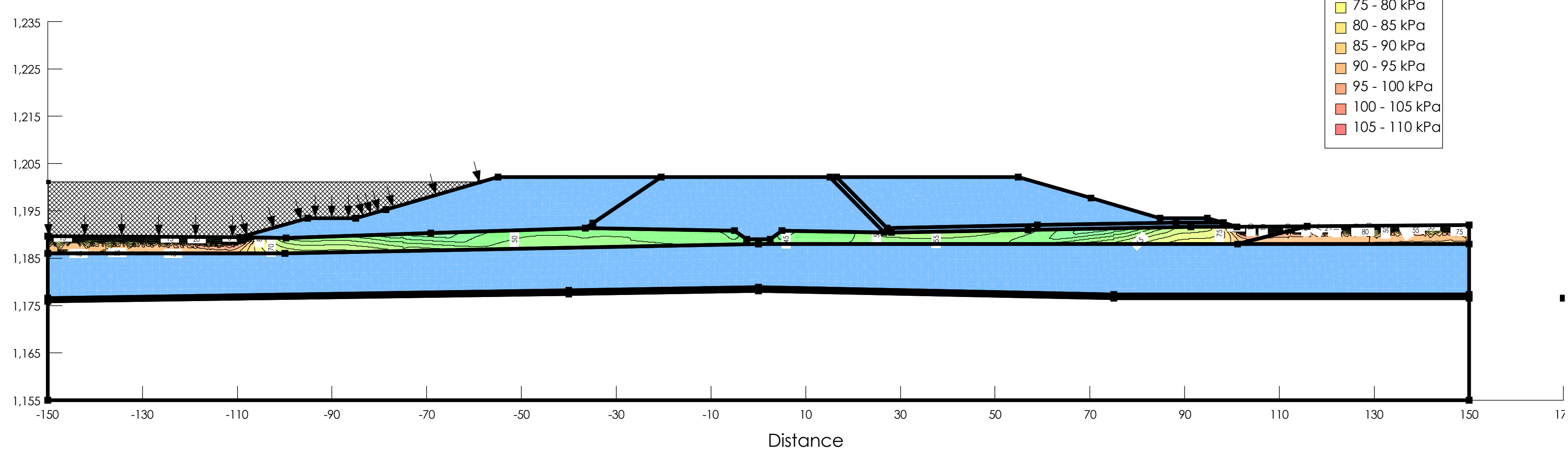


Stantec

Alberta Transportation SR1 Storage Dam

Section 22+990
Load Case: End Construction, Year 2, Flood
Total Stress Parameters
Incipient Motion in the Downstream Direction

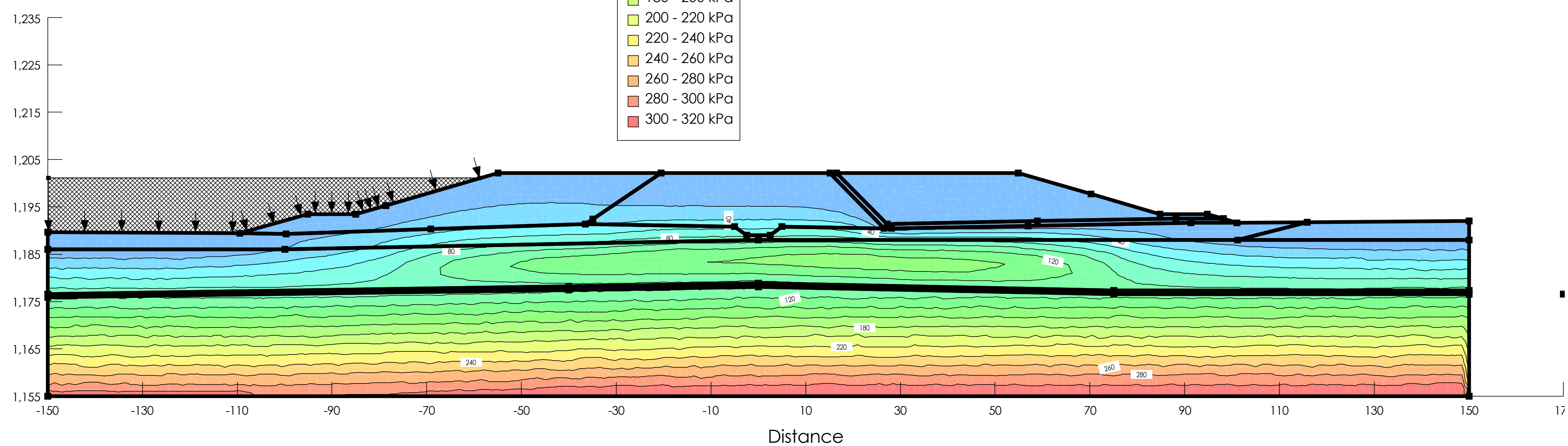
Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)
	Drain	21		0				33
	Embankment Core (Undrained)	20		0	28	19	[illegible]	
	Embankment Shell (Undrained)	20		0	24	15		
	Glacial Till (Undrained)	18		0	27	19		
	Glacio-Lacustrine (Undrained)	18	Undrained GL					
	Sandstone							
	Weathered Bedrock	21		0				



Alberta Transportation SR1 Storage Dam

Section 22+990
Load Case: End Construction, Year 2, Flood
Total Stress Parameters
Incipient Motion in the Downstream Direction

Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)
	Drain	21		0				33
	Embankment Core (Undrained)	20		0	28	19	427	
	Embankment Shell (Undrained)	20		0	24	15	141	
	Glacial Till (Undrained)	18		0	27	19	363.2	
	Glacio-Lacustrine (Undrained)	18	Undrained GL					0
	Sandstone							
	Weathered Bedrock	21		0				35

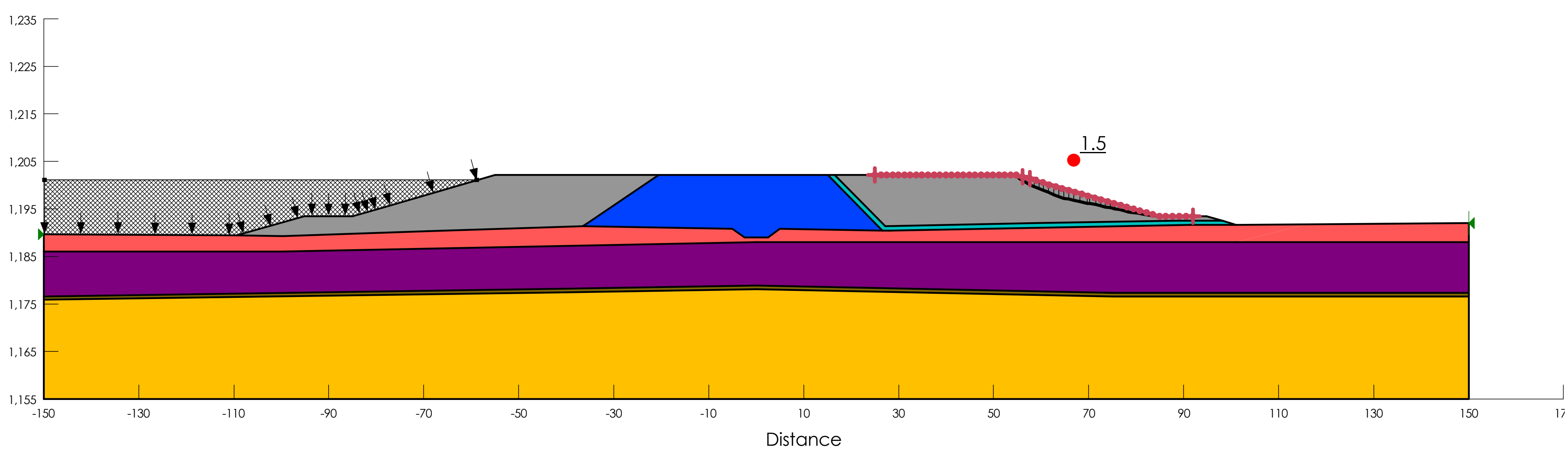


Stantec

Alberta Transportation SR1 Storage Dam

Section 22+990
Load Case: End Construction, Year 2, Flood
Total Stress Parameters
Incipient Motion in the Downstream Direction

Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)
	Drain	21		0				33
	Embankment Core (Undrained)	20		0	28	19	427	
	Embankment Shell (Undrained)	20		0	24	15	141	
	Glacial Till (Undrained)	18		0	27	19	363.2	
	Glacio-Lacustrine (Undrained)	18	Undrained GL					0
	Sandstone							
	Weathered Bedrock	21		0				35

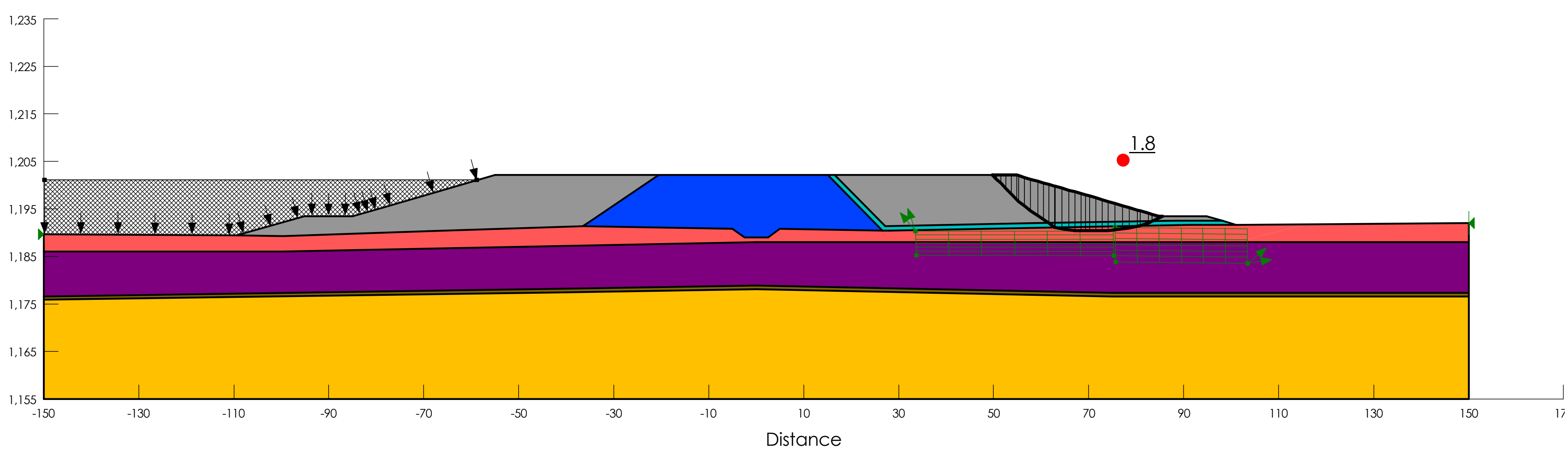


Stantec

Alberta Transportation SR1 Storage Dam

Section 22+990
Load Case: End Construction, Year 2, Flood
Total Stress Parameters
Incipient Motion in the Downstream Direction

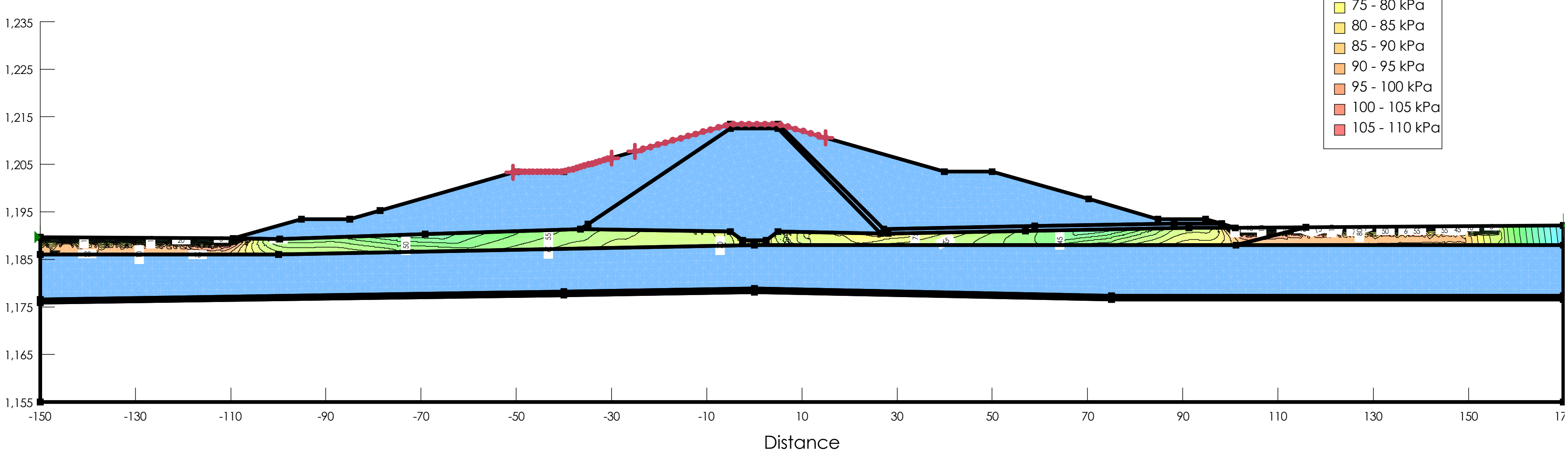
Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)
	Drain	21		0				33
	Embankment Core (Undrained)	20		0	28	19	427	
	Embankment Shell (Undrained)	20		0	24	15	141	
	Glacial Till (Undrained)	18		0	27	19	363.2	
	Glacio-Lacustrine (Undrained)	18	Undrained GL					0
	Sandstone							
	Weathered Bedrock	21		0				35



Alberta Transportation SR1 Storage Dam

Section 22+990
Load Case: End of Construction, Year 3
Total Stress Parameters
Incipient Motion in the Upstream Direction

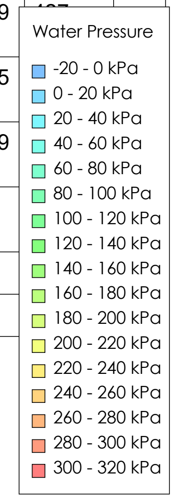
Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)
	Drain	21		0				33
	Embankment Core (Undrained)	20		0	28	19	[illegible]	
	Embankment Shell (Undrained)	20		0	24	15		
	Glacial Till (Undrained)	18		0	27	19		
	Glacio-Lacustrine (Undrained)	18	Undrained GL					
	Sandstone							
	Weathered Bedrock	21		0				

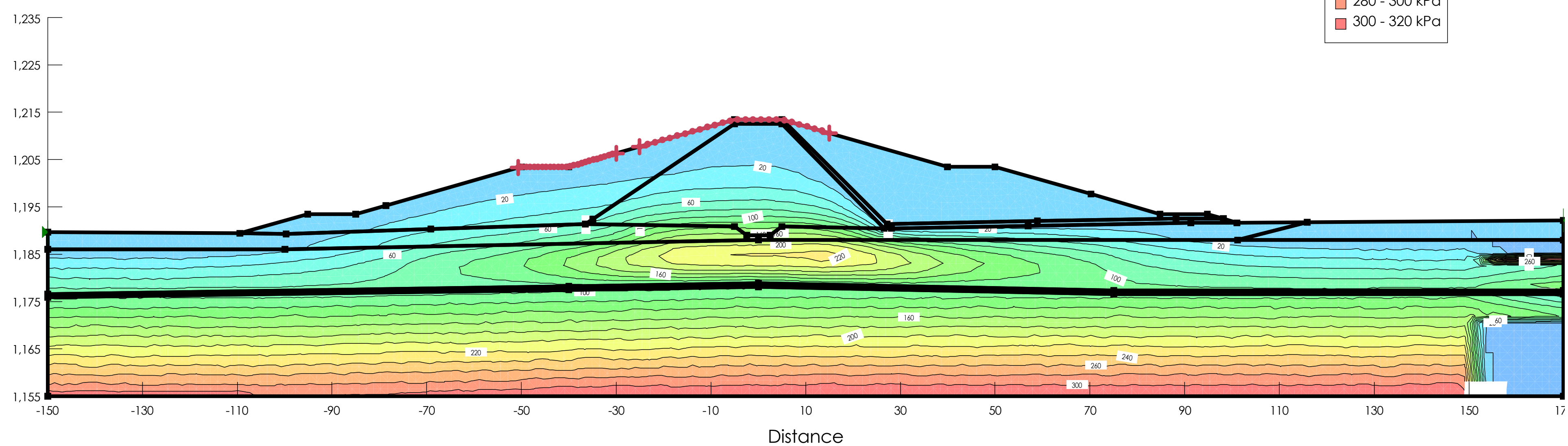


Alberta Transportation SR1 Storage Dam

Section 22+990
Load Case: End of Construction, Year 3
Total Stress Parameters
Incipient Motion in the Upstream Direction

Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)
	Drain	21		0				33
	Embankment Core (Undrained)	20		0	28	19	[illegible]	
	Embankment Shell (Undrained)	20		0	24	15		
	Glacial Till (Undrained)	18		0	27	19		
	Glacio-Lacustrine (Undrained)	18	Undrained GL					
	Sandstone							
	Weathered Bedrock	21		0				

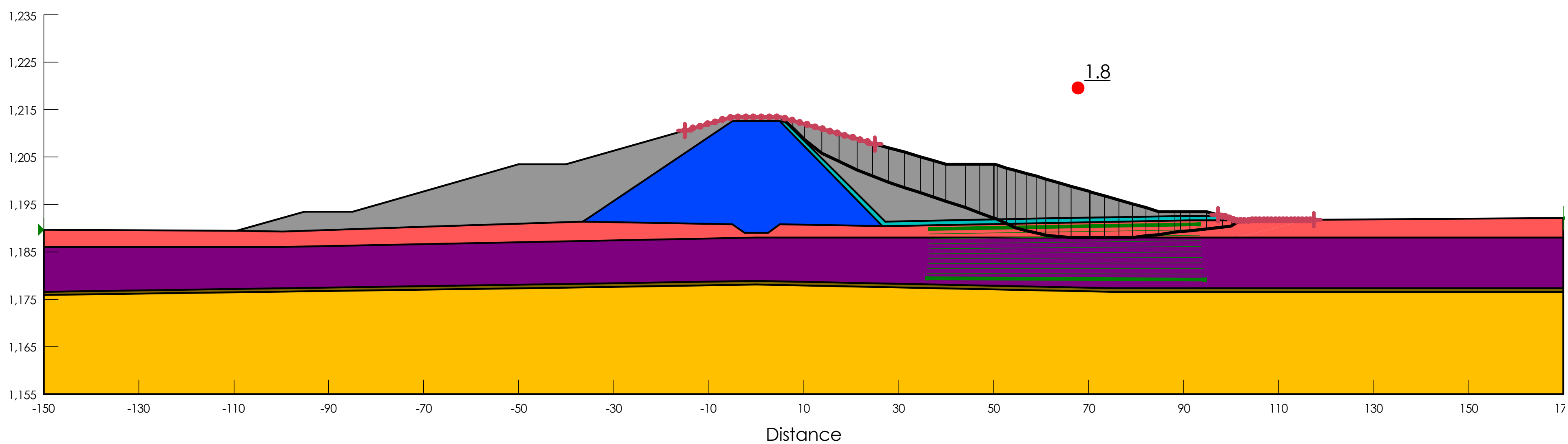




Alberta Transportation SR1 Storage Dam

Section 22+990
Load Case: End of Construction, Year 3
Effective Stress Parameters
Incipient Motion in the Downstream Direction

Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)
	Drain	21	0	33
	Embankment Core (Drained)	20	0	28
	Embankment Shell (Drained)	20	0	24
	Glacial Till (Drained)	18	0	27
	Glacio-Lacustrine (Drained)	18	0	23
	Sandstone			
	Weathered Bedrock	21	0	35

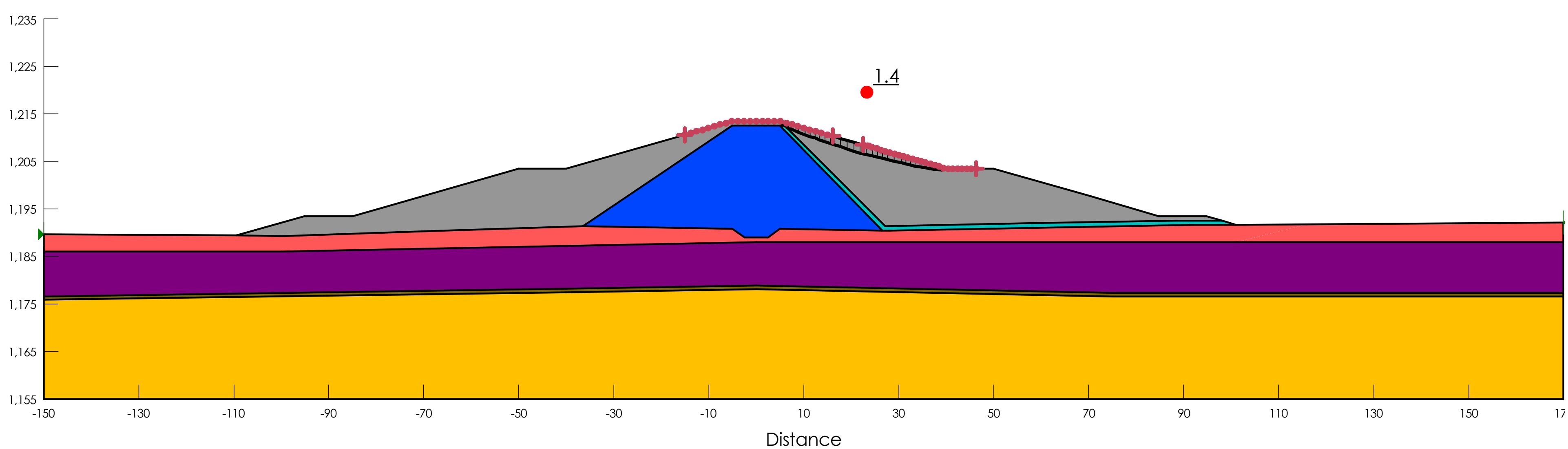


Stantec

Alberta Transportation SR1 Storage Dam

Section 22+990
Load Case: End of Construction, Year 3
Effective Stress Parameters
Incipient Motion in the Downstream Direction

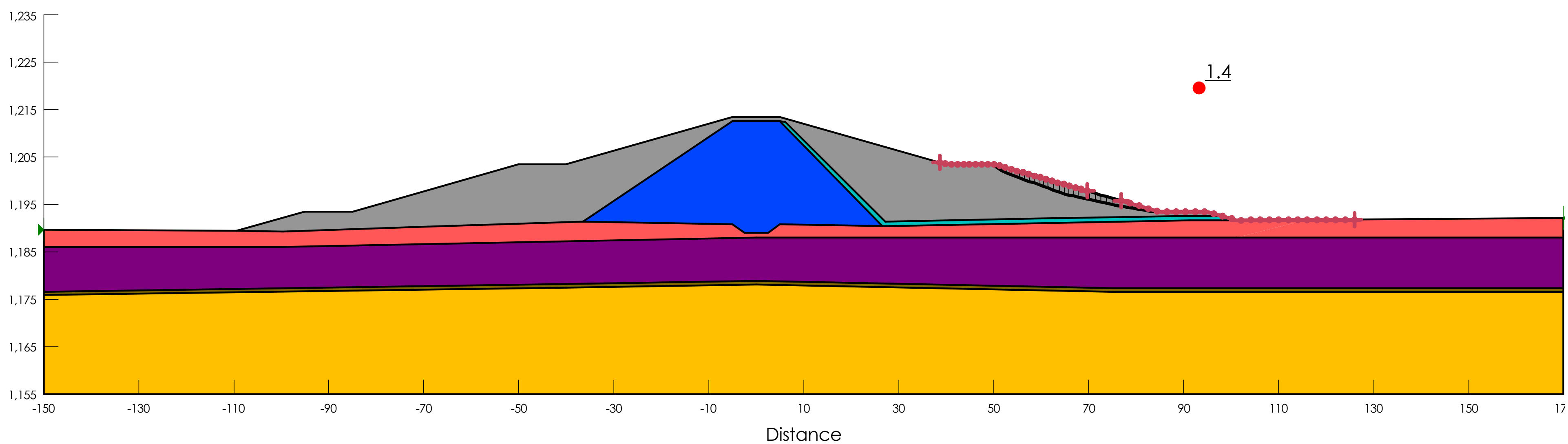
Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)
	Drain	21	0	33
	Embankment Core (Drained)	20	0	28
	Embankment Shell (Drained)	20	0	24
	Glacial Till (Drained)	18	0	27
	Glacio-Lacustrine (Drained)	18	0	23
	Sandstone			
	Weathered Bedrock	21	0	35



Alberta Transportation SR1 Storage Dam

Section 22+990
Load Case: End of Construction, Year 3
Effective Stress Parameters
Incipient Motion in the Downstream Direction

Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)
	Drain	21	0	33
	Embankment Core (Drained)	20	0	28
	Embankment Shell (Drained)	20	0	24
	Glacial Till (Drained)	18	0	27
	Glacio-Lacustrine (Drained)	18	0	23
	Sandstone			
	Weathered Bedrock	21	0	35

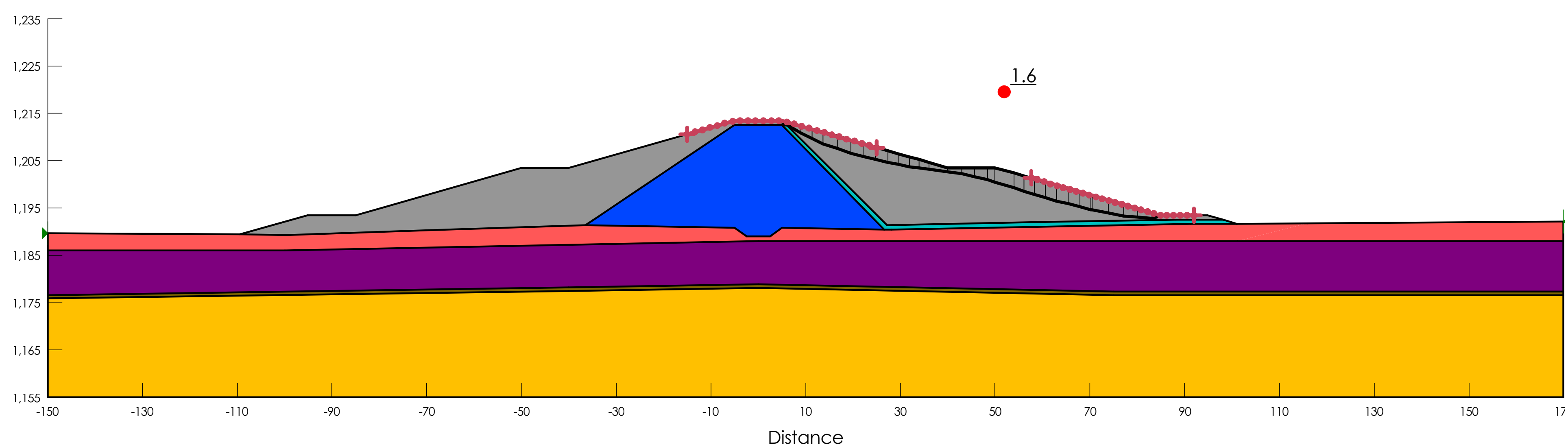


Stantec

Alberta Transportation SR1 Storage Dam

Section 22+990
Load Case: End of Construction, Year 3
Effective Stress Parameters
Incipient Motion in the Downstream Direction

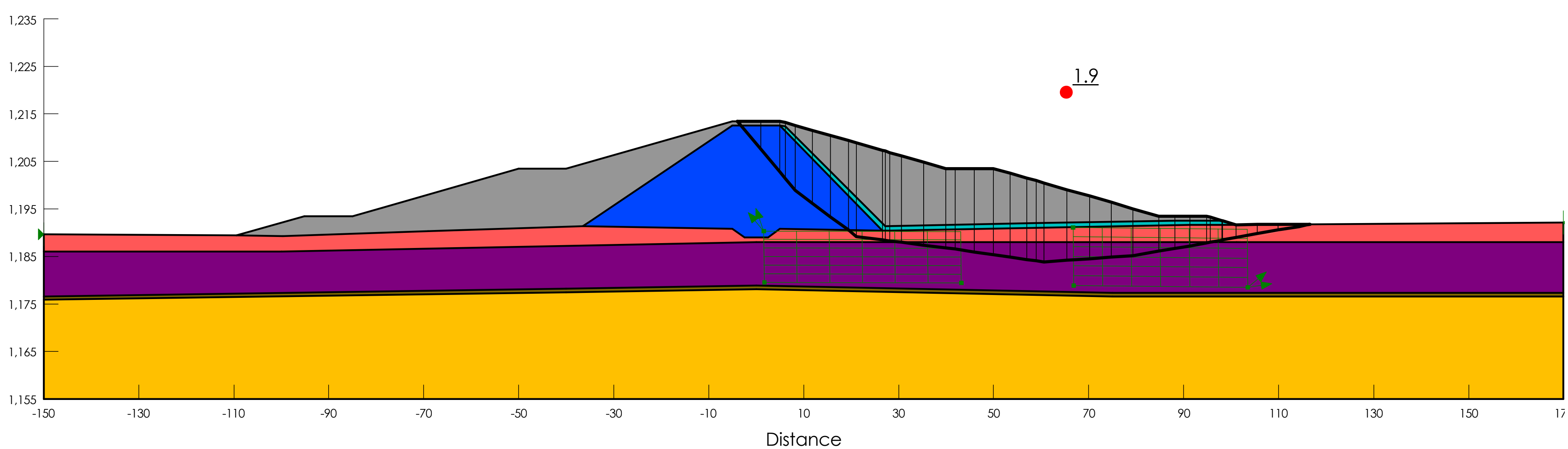
Color	Name	Unit Weight (kN/m^3)	Cohesion' (kPa)	Phi' (°)
	Drain	21	0	33
	Embankment Core (Drained)	20	0	28
	Embankment Shell (Drained)	20	0	24
	Glacial Till (Drained)	18	0	27
	Glacio-Lacustrine (Drained)	18	0	23
	Sandstone			
	Weathered Bedrock	21	0	35



Alberta Transportation SR1 Storage Dam

Section 22+990
Load Case: End of Construction, Year 3
Effective Stress Parameters
Incipient Motion in the Downstream Direction

Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)
	Drain	21	0	33
	Embankment Core (Drained)	20	0	28
	Embankment Shell (Drained)	20	0	24
	Glacial Till (Drained)	18	0	27
	Glacio-Lacustrine (Drained)	18	0	23
	Sandstone			
	Weathered Bedrock	21	0	35

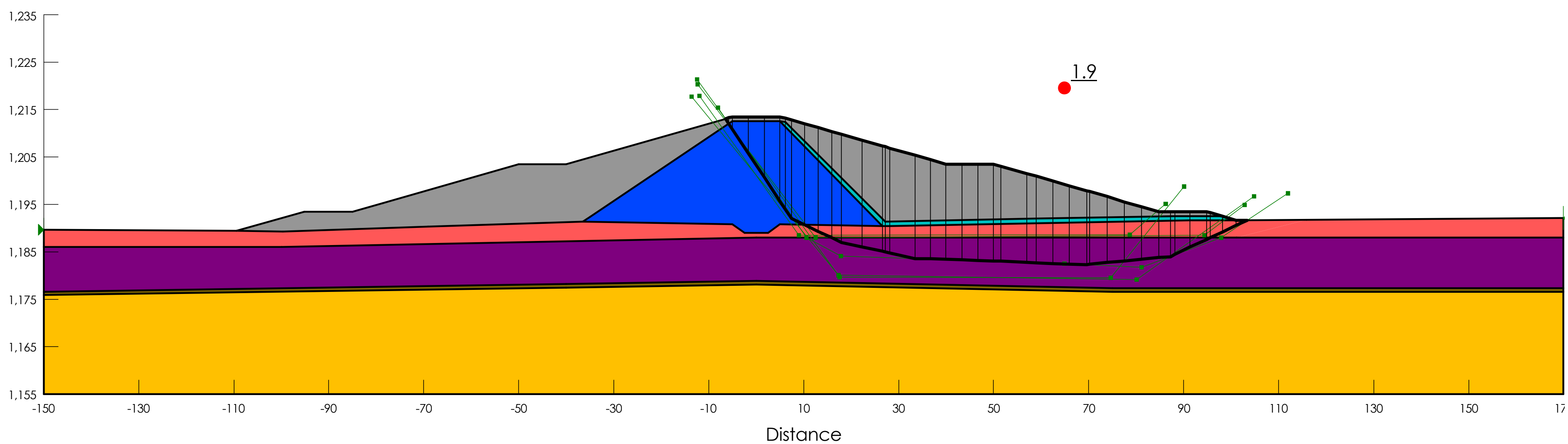


Stantec

Alberta Transportation SR1 Storage Dam

Section 22+990
Load Case: End of Construction, Year 3
Effective Stress Parameters
Incipient Motion in the Downstream Direction

Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)
	Drain	21	0	33
	Embankment Core (Drained)	20	0	28
	Embankment Shell (Drained)	20	0	24
	Glacial Till (Drained)	18	0	27
	Glacio-Lacustrine (Drained)	18	0	23
	Sandstone			
	Weathered Bedrock	21	0	35

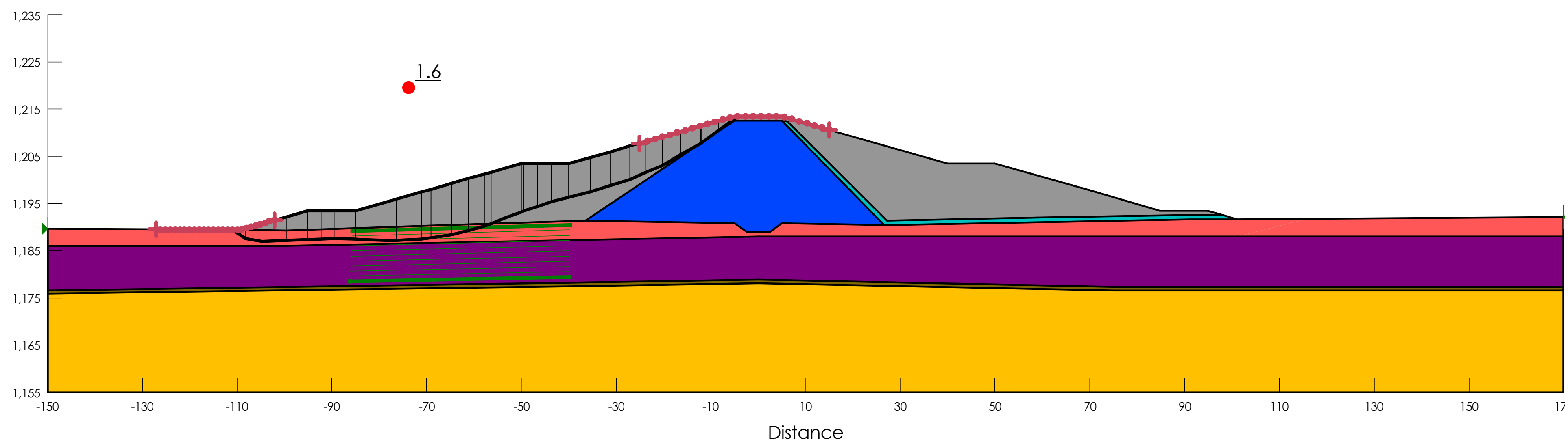


Stantec

Alberta Transportation SR1 Storage Dam

Section 22+990
Load Case: End of Construction, Year 3
Effective Stress Parameters
Incipient Motion in the Upstream Direction

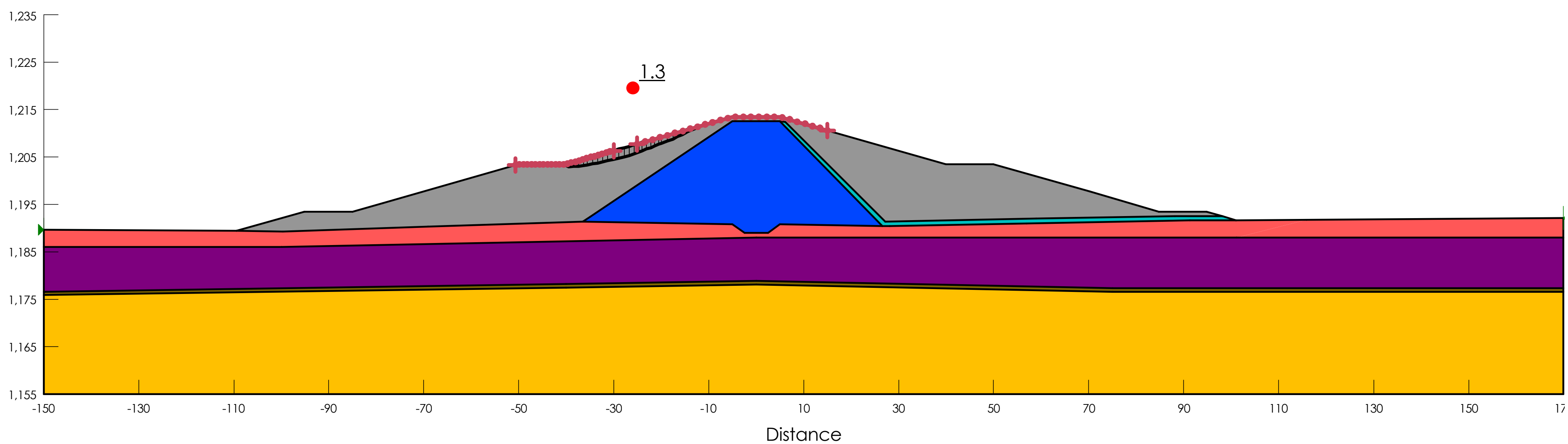
Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)
	Drain	21	0	33
	Embankment Core (Drained)	20	0	28
	Embankment Shell (Drained)	20	0	24
	Glacial Till (Drained)	18	0	27
	Glacio-Lacustrine (Drained)	18	0	23
	Sandstone			
	Weathered Bedrock	21	0	35



Alberta Transportation SR1 Storage Dam

Section 22+990
Load Case: End of Construction, Year 3
Effective Stress Parameters
Incipient Motion in the Upstream Direction

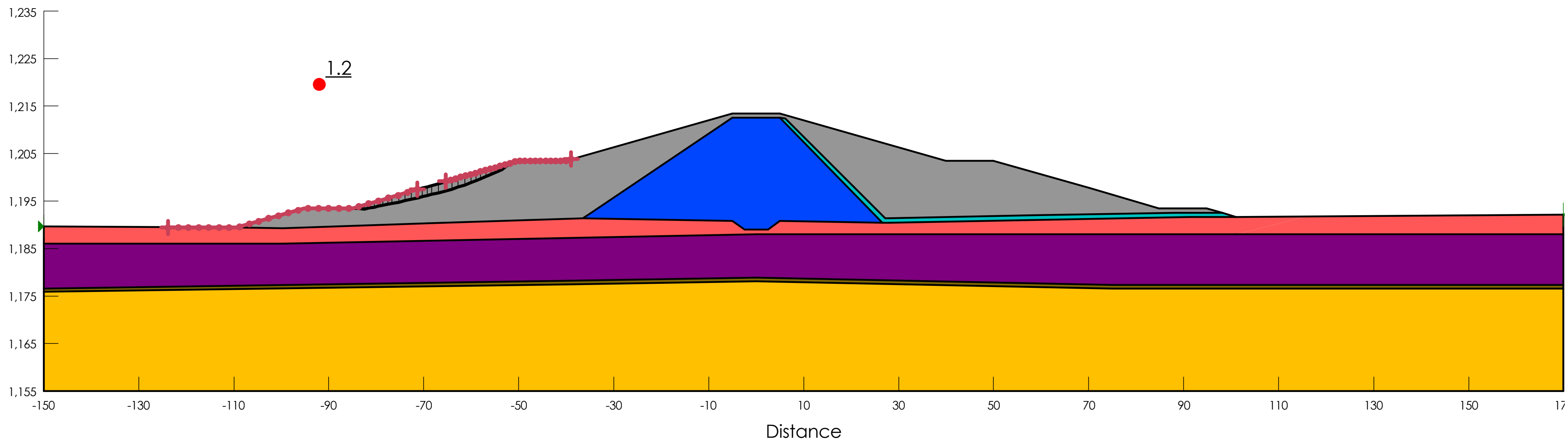
Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)
	Drain	21	0	33
	Embankment Core (Drained)	20	0	28
	Embankment Shell (Drained)	20	0	24
	Glacial Till (Drained)	18	0	27
	Glacio-Lacustrine (Drained)	18	0	23
	Sandstone			
	Weathered Bedrock	21	0	35



Alberta Transportation SR1 Storage Dam

Section 22+990
Load Case: End of Construction, Year 3
Effective Stress Parameters
Incipient Motion in the Upstream Direction

Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)
	Drain	21	0	33
	Embankment Core (Drained)	20	0	28
	Embankment Shell (Drained)	20	0	24
	Glacial Till (Drained)	18	0	27
	Glacio-Lacustrine (Drained)	18	0	23
	Sandstone			
	Weathered Bedrock	21	0	35

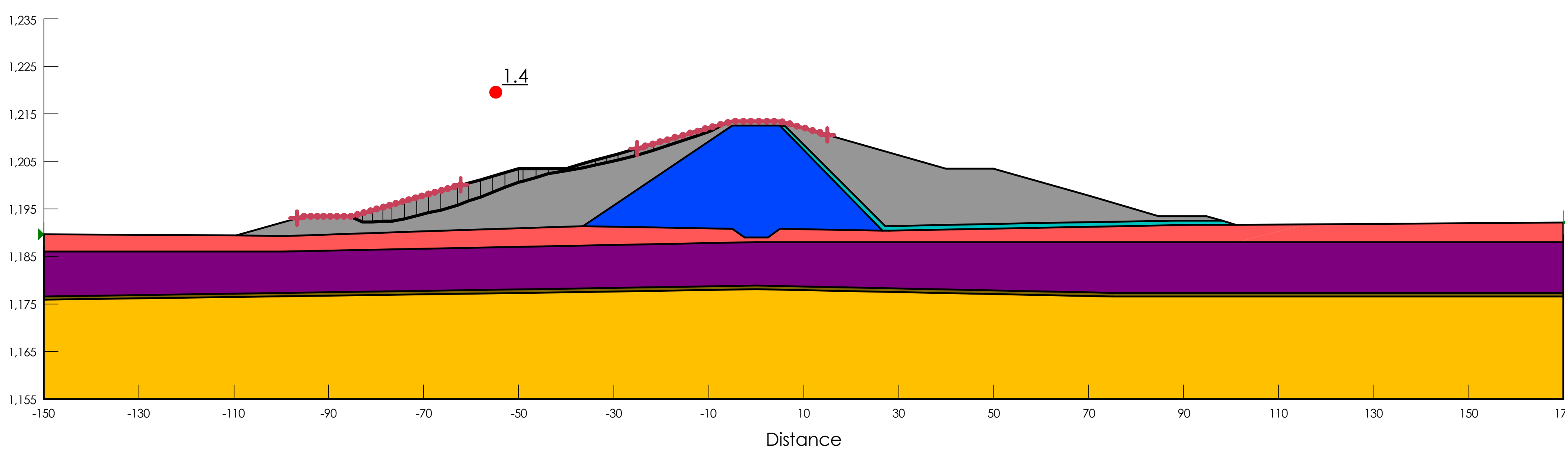


Stantec

Alberta Transportation SR1 Storage Dam

Section 22+990
Load Case: End of Construction, Year 3
Effective Stress Parameters
Incipient Motion in the Upstream Direction

Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)
	Drain	21	0	33
	Embankment Core (Drained)	20	0	28
	Embankment Shell (Drained)	20	0	24
	Glacial Till (Drained)	18	0	27
	Glacio-Lacustrine (Drained)	18	0	23
	Sandstone			
	Weathered Bedrock	21	0	35

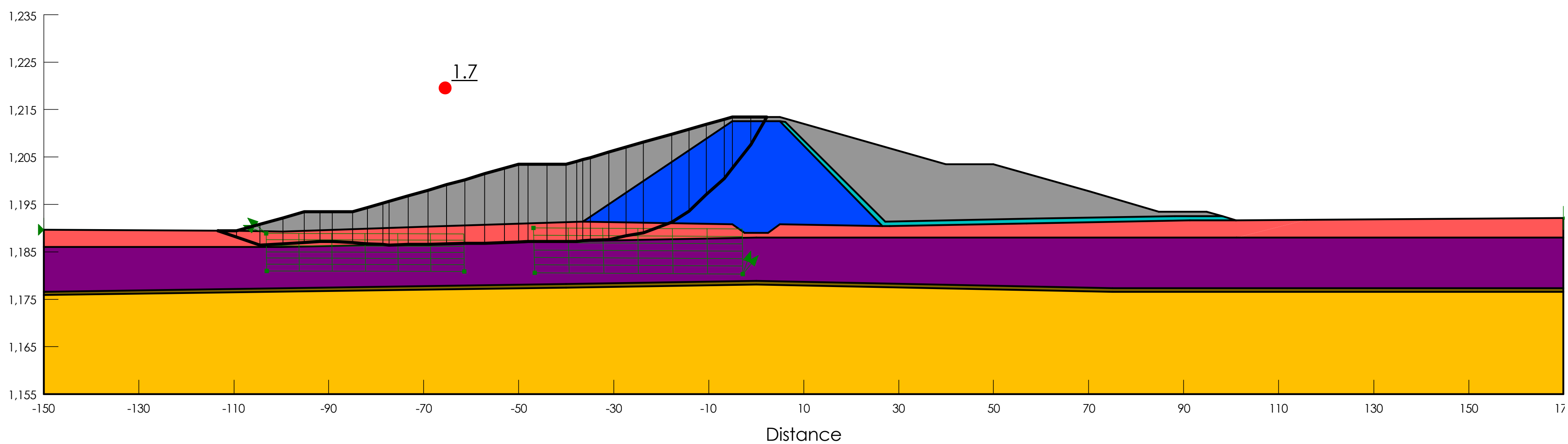


Stantec

Alberta Transportation SR1 Storage Dam

Section 22+990
Load Case: End of Construction, Year 3
Effective Stress Parameters
Incipient Motion in the Upstream Direction

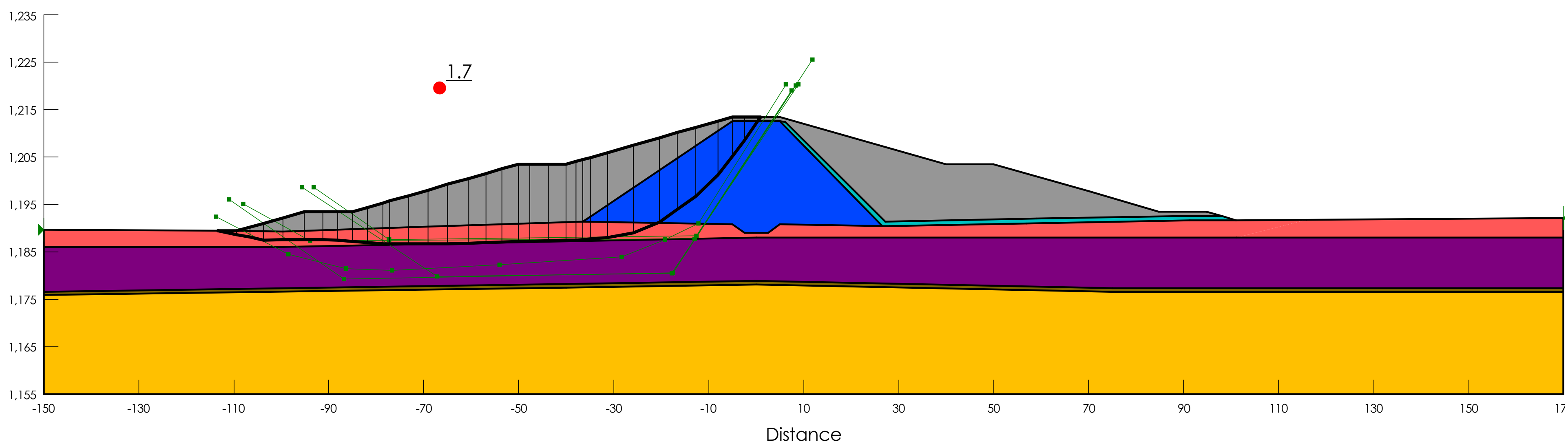
Color	Name	Unit Weight (kN/m^3)	Cohesion' (kPa)	Phi' (°)
	Drain	21	0	33
	Embankment Core (Drained)	20	0	28
	Embankment Shell (Drained)	20	0	24
	Glacial Till (Drained)	18	0	27
	Glacio-Lacustrine (Drained)	18	0	23
	Sandstone			
	Weathered Bedrock	21	0	35



Alberta Transportation SR1 Storage Dam

Section 22+990
Load Case: End of Construction, Year 3
Effective Stress Parameters
Incipient Motion in the Upstream Direction

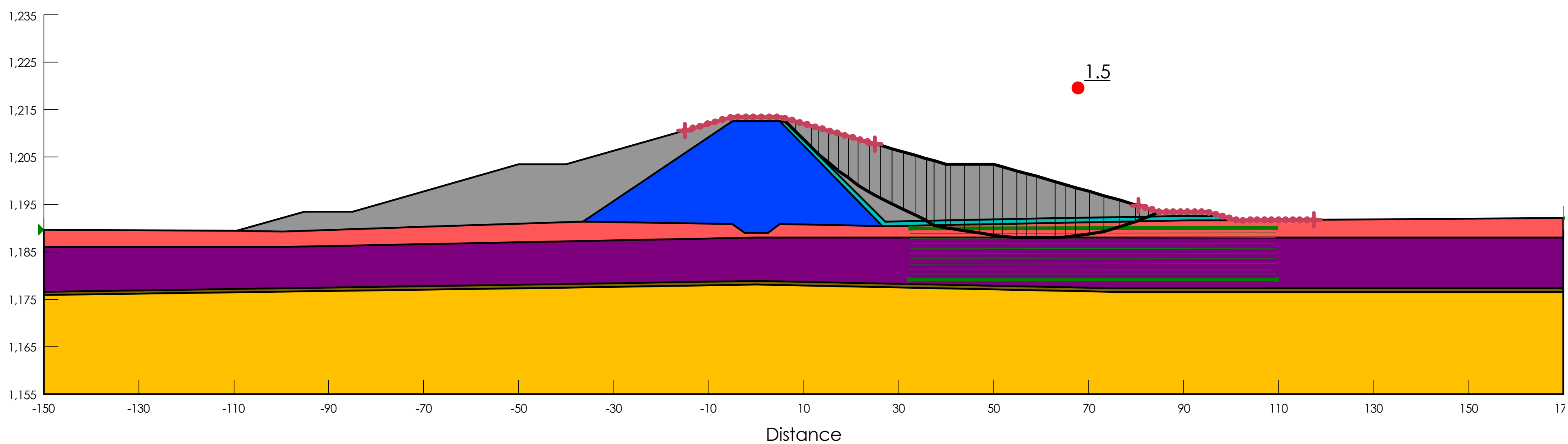
Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)
	Drain	21	0	33
	Embankment Core (Drained)	20	0	28
	Embankment Shell (Drained)	20	0	24
	Glacial Till (Drained)	18	0	27
	Glacio-Lacustrine (Drained)	18	0	23
	Sandstone			
	Weathered Bedrock	21	0	35



Alberta Transportation SR1 Storage Dam

Section 22+990
Load Case: End of Construction, Year 3
Total Stress Parameters
Incipient Motion in the Downstream Direction

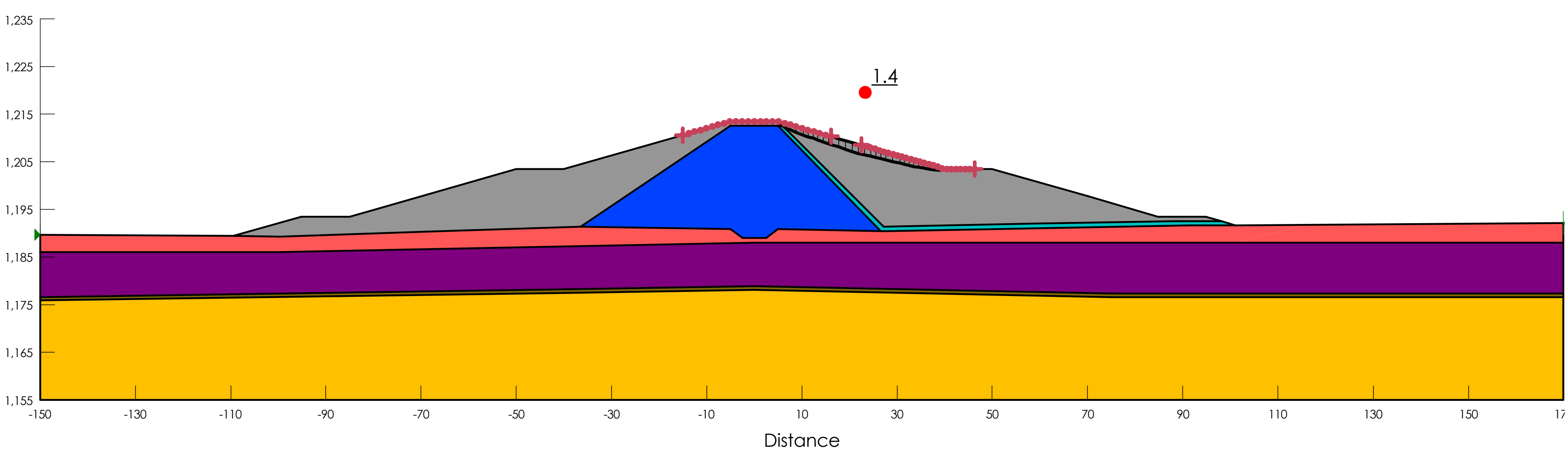
Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)
	Drain	21		0				33
	Embankment Core (Undrained)	20		0	28	19	427	
	Embankment Shell (Undrained)	20		0	24	15	141	
	Glacial Till (Undrained)	18		0	27	19	363.2	
	Glacio-Lacustrine (Undrained)	18	Undrained GL					0
	Sandstone							
	Weathered Bedrock	21		0				35



Alberta Transportation SR1 Storage Dam

Section 22+990
Load Case: End of Construction, Year 3
Total Stress Parameters
Incipient Motion in the Downstream Direction

Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)
	Drain	21		0				33
	Embankment Core (Undrained)	20		0	28	19	427	
	Embankment Shell (Undrained)	20		0	24	15	141	
	Glacial Till (Undrained)	18		0	27	19	363.2	
	Glacio-Lacustrine (Undrained)	18	Undrained GL					0
	Sandstone							
	Weathered Bedrock	21		0				35

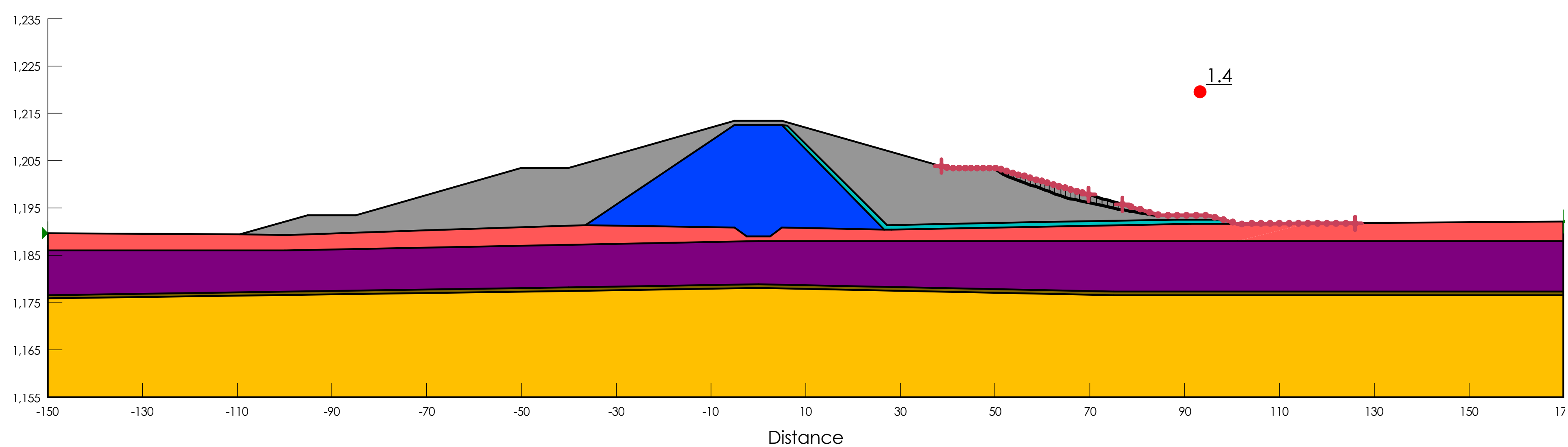


Stantec

Alberta Transportation SR1 Storage Dam

Section 22+990
Load Case: End of Construction, Year 3
Total Stress Parameters
Incipient Motion in the Downstream Direction

Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)
	Drain	21		0				33
	Embankment Core (Undrained)	20		0	28	19	427	
	Embankment Shell (Undrained)	20		0	24	15	141	
	Glacial Till (Undrained)	18		0	27	19	363.2	
	Glacio-Lacustrine (Undrained)	18	Undrained GL					0
	Sandstone							
	Weathered Bedrock	21		0				35

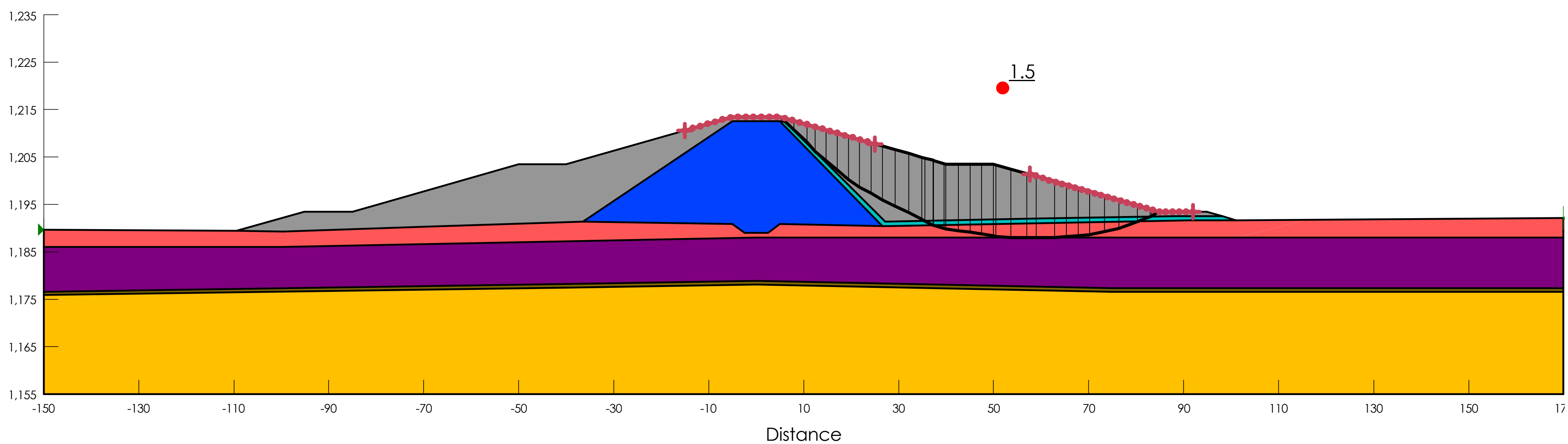


Stantec

Alberta Transportation SR1 Storage Dam

Section 22+990
Load Case: End of Construction, Year 3
Total Stress Parameters
Incipient Motion in the Downstream Direction

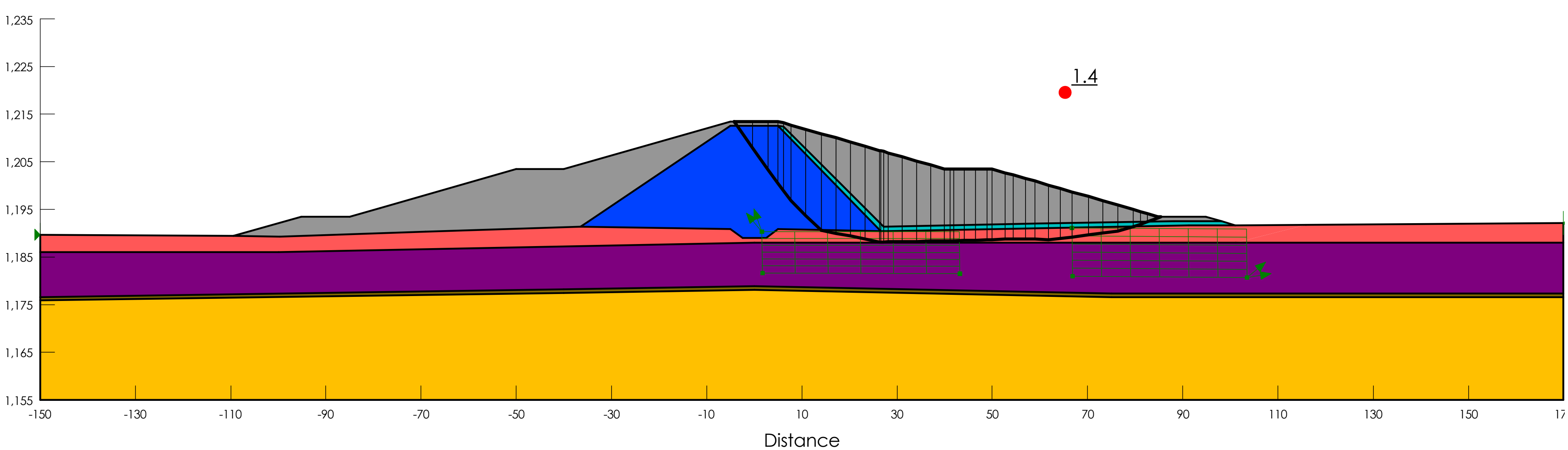
Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)
	Drain	21		0				33
	Embankment Core (Undrained)	20		0	28	19	427	
	Embankment Shell (Undrained)	20		0	24	15	141	
	Glacial Till (Undrained)	18		0	27	19	363.2	
	Glacio-Lacustrine (Undrained)	18	Undrained GL					0
	Sandstone							
	Weathered Bedrock	21		0				35



Alberta Transportation SR1 Storage Dam

Section 22+990
Load Case: End of Construction, Year 3
Total Stress Parameters
Incipient Motion in the Downstream Direction

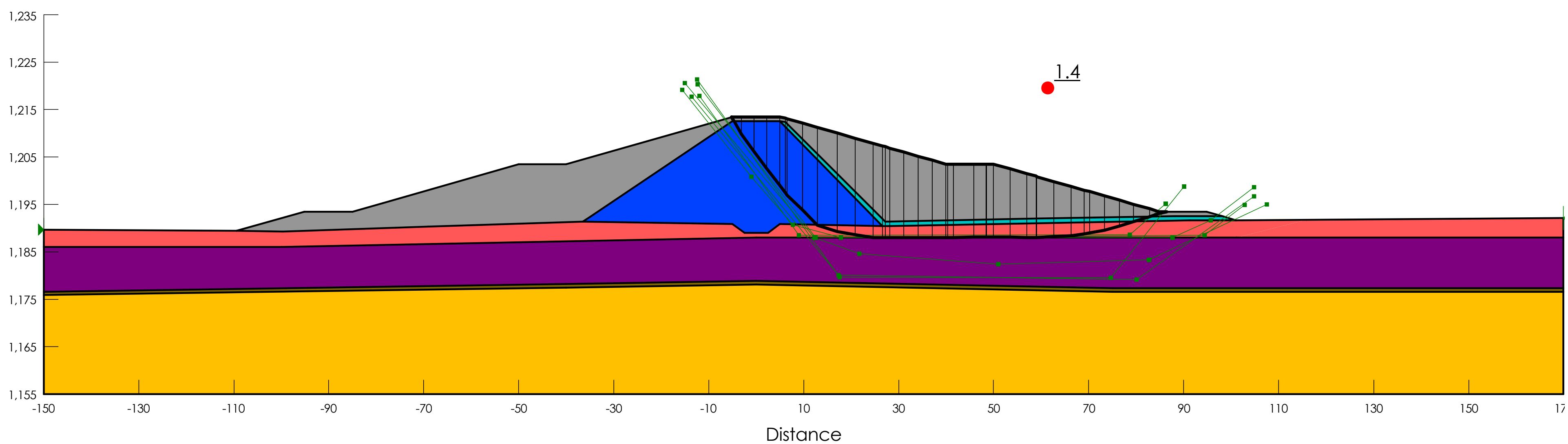
Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)
	Drain	21		0				33
	Embankment Core (Undrained)	20		0	28	19	427	
	Embankment Shell (Undrained)	20		0	24	15	141	
	Glacial Till (Undrained)	18		0	27	19	363.2	
	Glacio-Lacustrine (Undrained)	18	Undrained GL					0
	Sandstone							
	Weathered Bedrock	21		0				35



Alberta Transportation SR1 Storage Dam

Section 22+990
Load Case: End of Construction, Year 3
Total Stress Parameters
Incipient Motion in the Downstream Direction

Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)
	Drain	21		0				33
	Embankment Core (Undrained)	20		0	28	19	427	
	Embankment Shell (Undrained)	20		0	24	15	141	
	Glacial Till (Undrained)	18		0	27	19	363.2	
	Glacio-Lacustrine (Undrained)	18	Undrained GL					0
	Sandstone							
	Weathered Bedrock	21		0				35

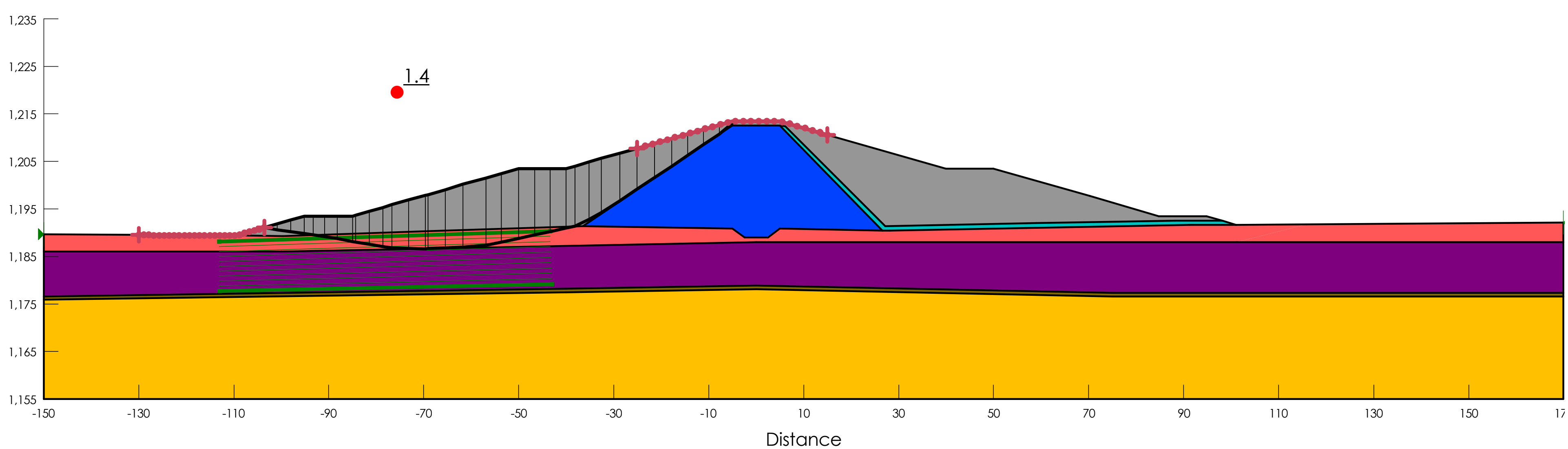


Stantec

Alberta Transportation SR1 Storage Dam

Section 22+990
Load Case: End of Construction, Year 3
Total Stress Parameters
Incipient Motion in the Upstream Direction

Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)
	Drain	21		0				33
	Embankment Core (Undrained)	20		0	28	19	427	
	Embankment Shell (Undrained)	20		0	24	15	141	
	Glacial Till (Undrained)	18		0	27	19	363.2	
	Glacio-Lacustrine (Undrained)	18	Undrained GL					0
	Sandstone							
	Weathered Bedrock	21		0				35

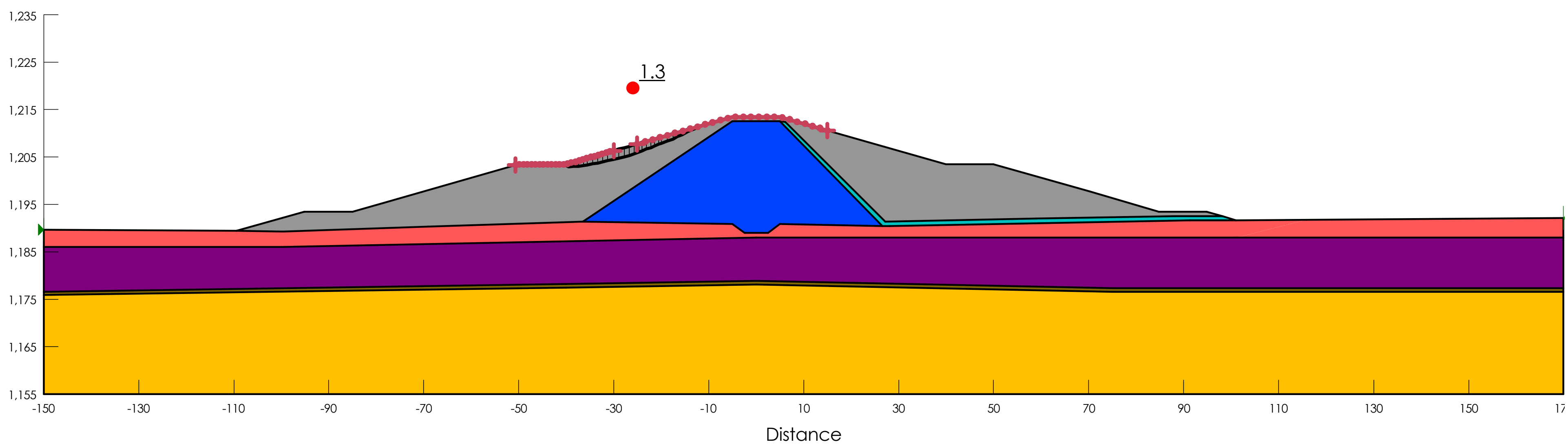


Stantec

Alberta Transportation SR1 Storage Dam

Section 22+990
Load Case: End of Construction, Year 3
Total Stress Parameters
Incipient Motion in the Upstream Direction

Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)
	Drain	21		0				33
	Embankment Core (Undrained)	20		0	28	19	427	
	Embankment Shell (Undrained)	20		0	24	15	141	
	Glacial Till (Undrained)	18		0	27	19	363.2	
	Glacio-Lacustrine (Undrained)	18	Undrained GL					0
	Sandstone							
	Weathered Bedrock	21		0				35

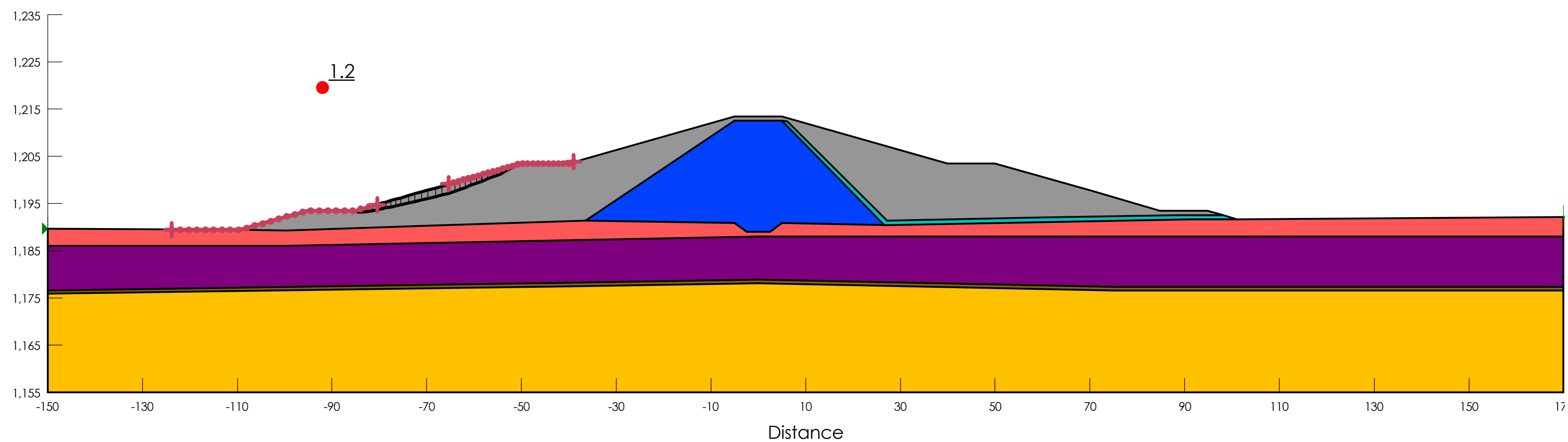


Stantec

Alberta Transportation SR1 Storage Dam

Section 22+990
Load Case: End of Construction, Year 3
Total Stress Parameters
Incipient Motion in the Upstream Direction

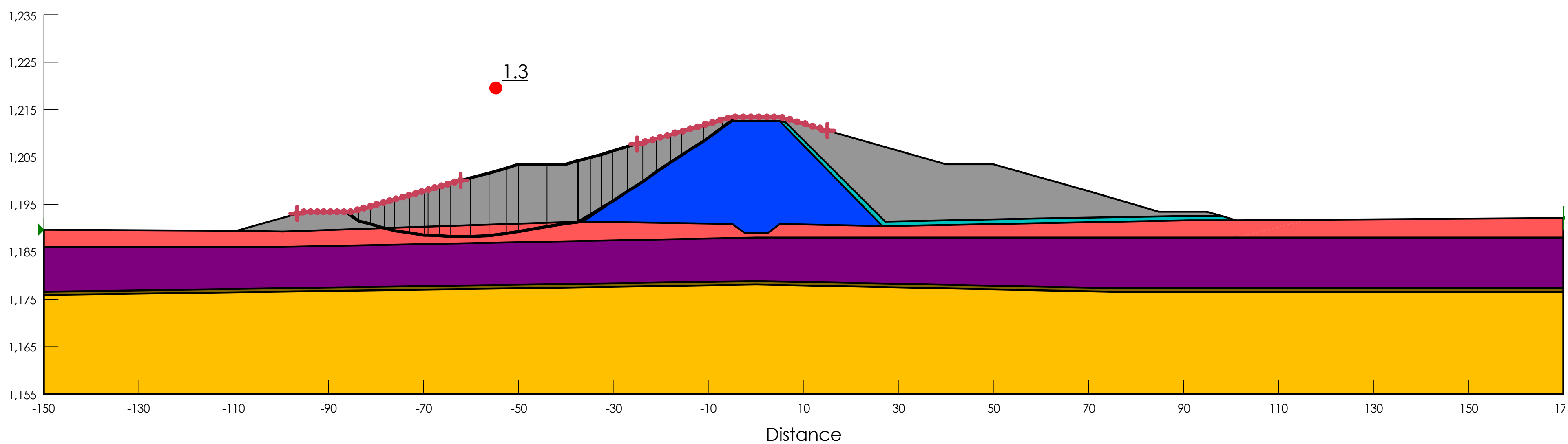
Color	Name	Unit Weight (kN/m^3)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)
	Drain	21		0				33
	Embankment Core (Undrained)	20		0	28	19	427	
	Embankment Shell (Undrained)	20		0	24	15	141	
	Glacial Till (Undrained)	18		0	27	19	363.2	
	Glacio-Lacustrine (Undrained)	18	Undrained GL					0
	Sandstone							
	Weathered Bedrock	21		0				35



Alberta Transportation SR1 Storage Dam

Section 22+990
Load Case: End of Construction, Year 3
Total Stress Parameters
Incipient Motion in the Upstream Direction

Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)
	Drain	21		0				33
	Embankment Core (Undrained)	20		0	28	19	427	
	Embankment Shell (Undrained)	20		0	24	15	141	
	Glacial Till (Undrained)	18		0	27	19	363.2	
	Glacio-Lacustrine (Undrained)	18	Undrained GL					0
	Sandstone							
	Weathered Bedrock	21		0				35

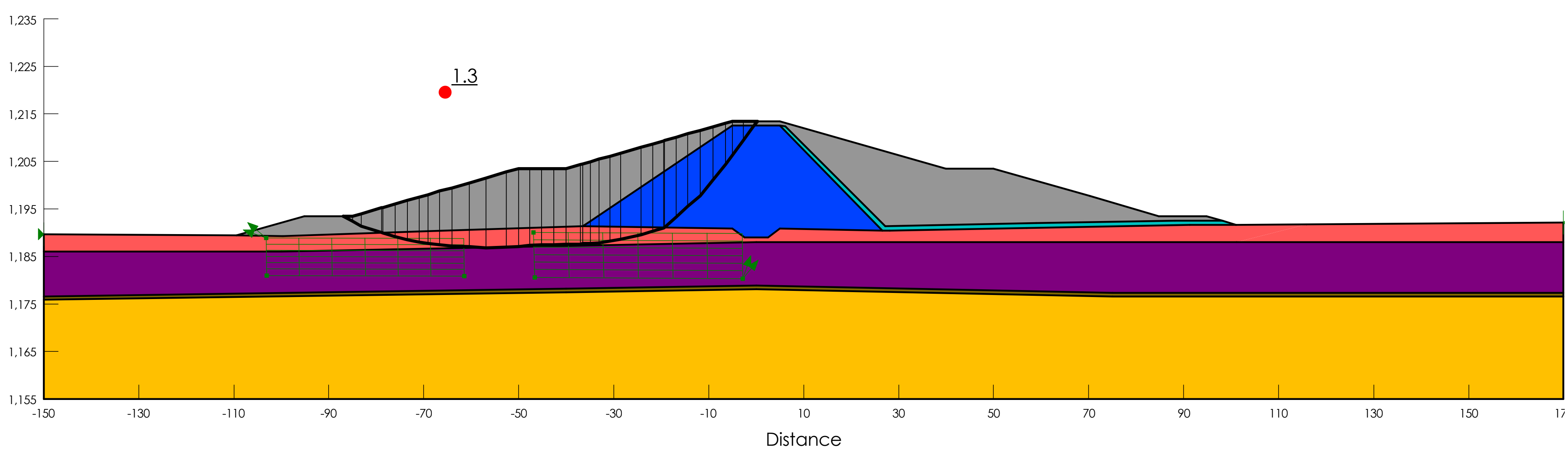


Stantec

Alberta Transportation SR1 Storage Dam

Section 22+990
Load Case: End of Construction, Year 3
Total Stress Parameters
Incipient Motion in the Upstream Direction

Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)
	Drain	21		0				33
	Embankment Core (Undrained)	20		0	28	19	427	
	Embankment Shell (Undrained)	20		0	24	15	141	
	Glacial Till (Undrained)	18		0	27	19	363.2	
	Glacio-Lacustrine (Undrained)	18	Undrained GL					0
	Sandstone							
	Weathered Bedrock	21		0				35

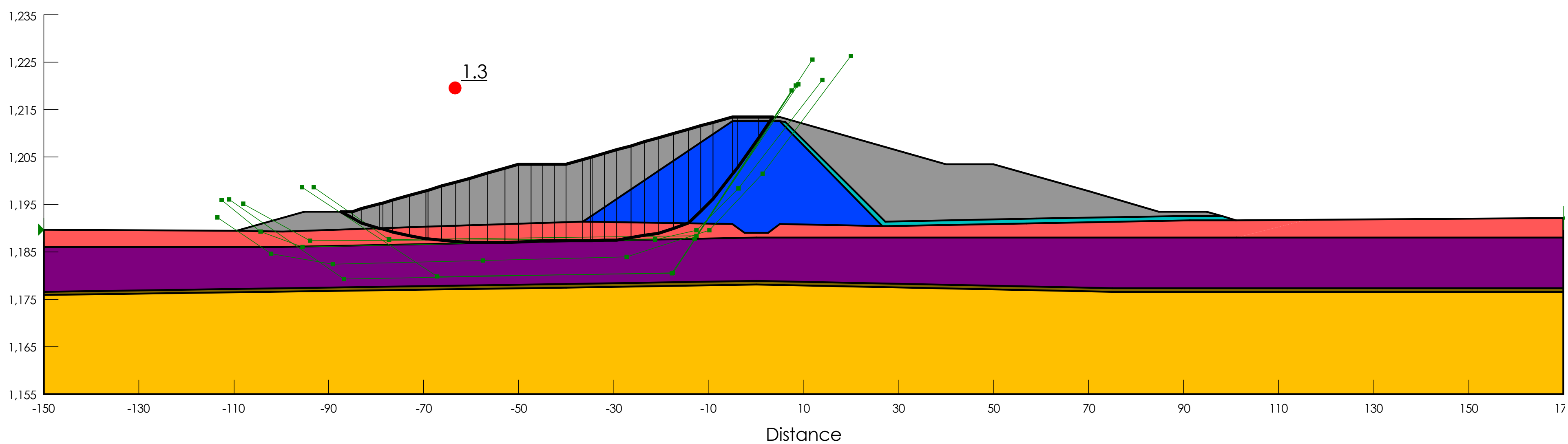


Stantec

Alberta Transportation SR1 Storage Dam

Section 22+990
Load Case: End of Construction, Year 3
Total Stress Parameters
Incipient Motion in the Upstream Direction

Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)
	Drain	21		0				33
	Embankment Core (Undrained)	20		0	28	19	427	
	Embankment Shell (Undrained)	20		0	24	15	141	
	Glacial Till (Undrained)	18		0	27	19	363.2	
	Glacio-Lacustrine (Undrained)	18	Undrained GL					0
	Sandstone							
	Weathered Bedrock	21		0				35

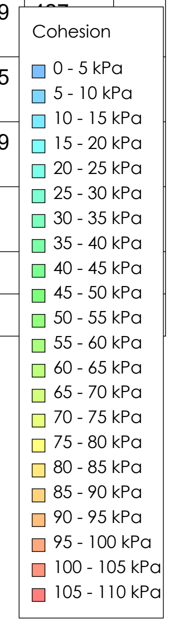


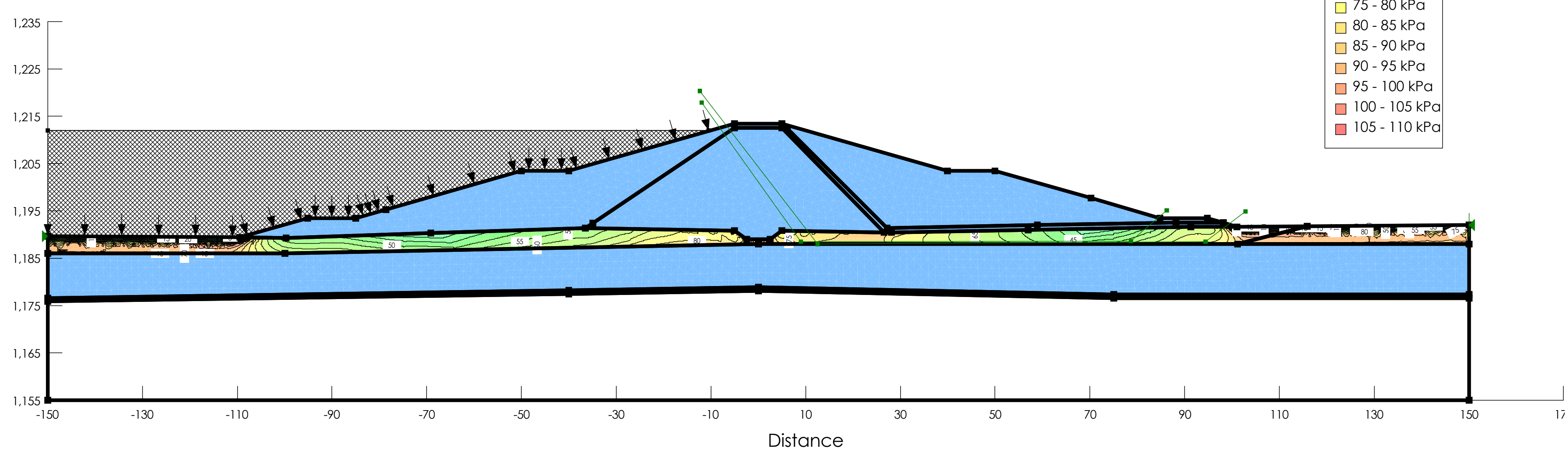
Stantec

Alberta Transportation SR1 Storage Dam

Section 22+990
Load Case: End of Construction, Year 3, Flood
Total Stress Parameters
Incipient Motion in the Downstream Direction

Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)
	Drain	21		0				33
	Embankment Core (Undrained)	20		0	28	19	[illegible]	
	Embankment Shell (Undrained)	20		0	24	15		
	Glacial Till (Undrained)	18		0	27	19		
	Glacio-Lacustrine (Undrained)	18	Undrained GL					
	Sandstone							
	Weathered Bedrock	21		0				



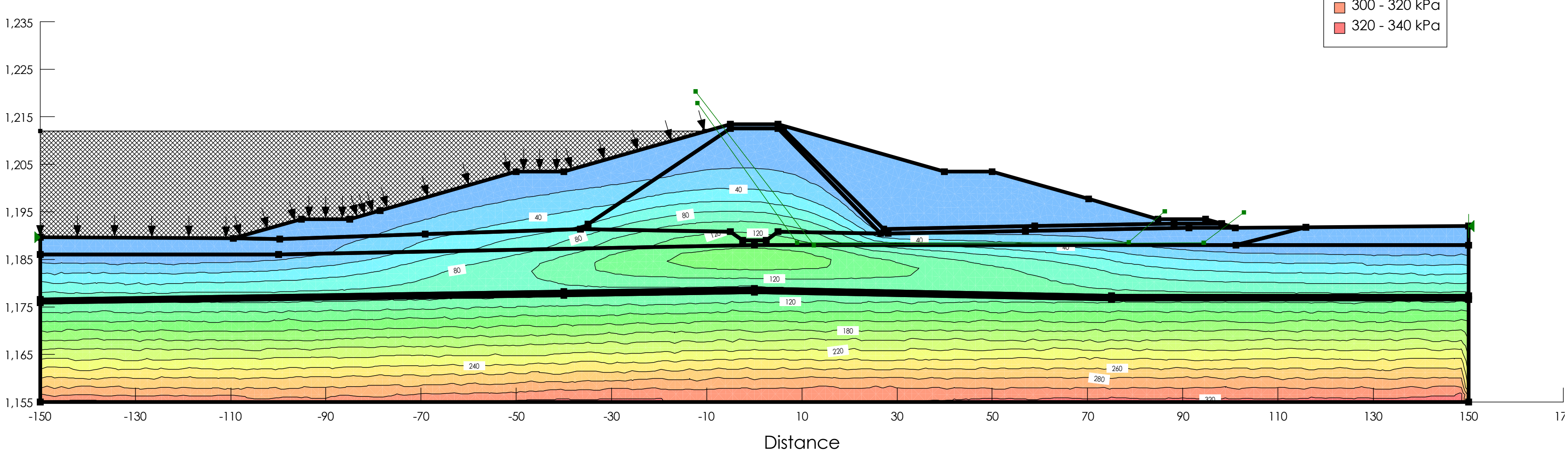


Stantec

Alberta Transportation SR1 Storage Dam

Section 22+990
Load Case: End of Construction, Year 3, Flood
Total Stress Parameters
Incipient Motion in the Downstream Direction

Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)
	Drain	21		0				33
	Embankment Core (Undrained)	20		0	28	19	[illegible]	
	Embankment Shell (Undrained)	20		0	24	15		
	Glacial Till (Undrained)	18		0	27	19		
	Glacio-Lacustrine (Undrained)	18	Undrained GL					
	Sandstone							
	Weathered Bedrock	21		0				

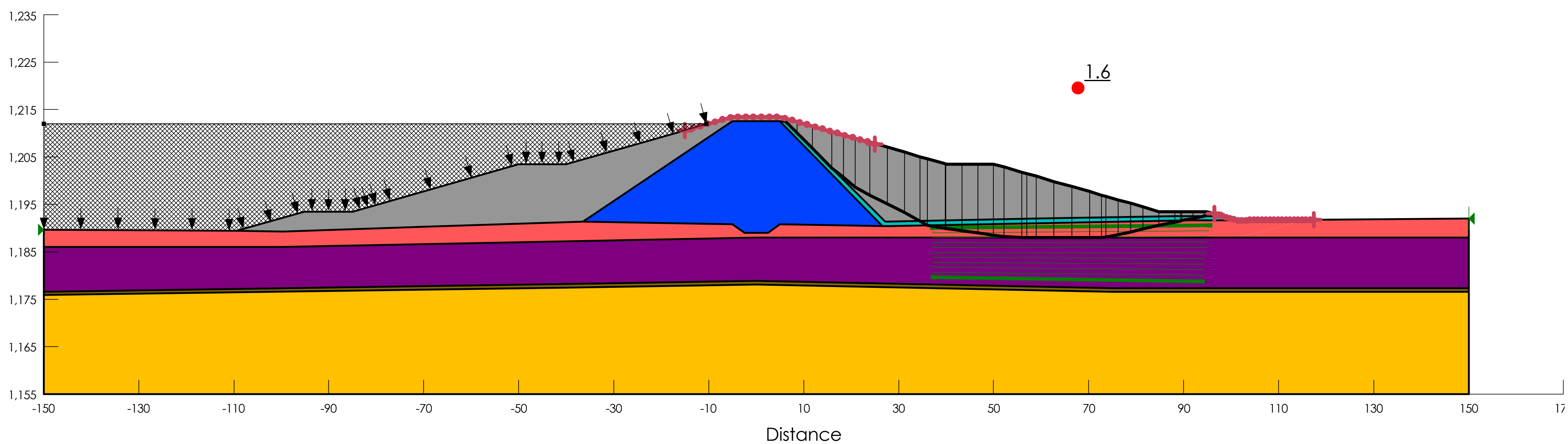


Stantec

Alberta Transportation SR1 Storage Dam

Section 22+990
Load Case: End of Construction, Year 3, Flood
Total Stress Parameters
Incipient Motion in the Downstream Direction

Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)
	Drain	21		0				33
	Embankment Core (Undrained)	20		0	28	19	427	
	Embankment Shell (Undrained)	20		0	24	15	141	
	Glacial Till (Undrained)	18		0	27	19	363.2	
	Glacio-Lacustrine (Undrained)	18	Undrained GL					0
	Sandstone							
	Weathered Bedrock	21		0				35

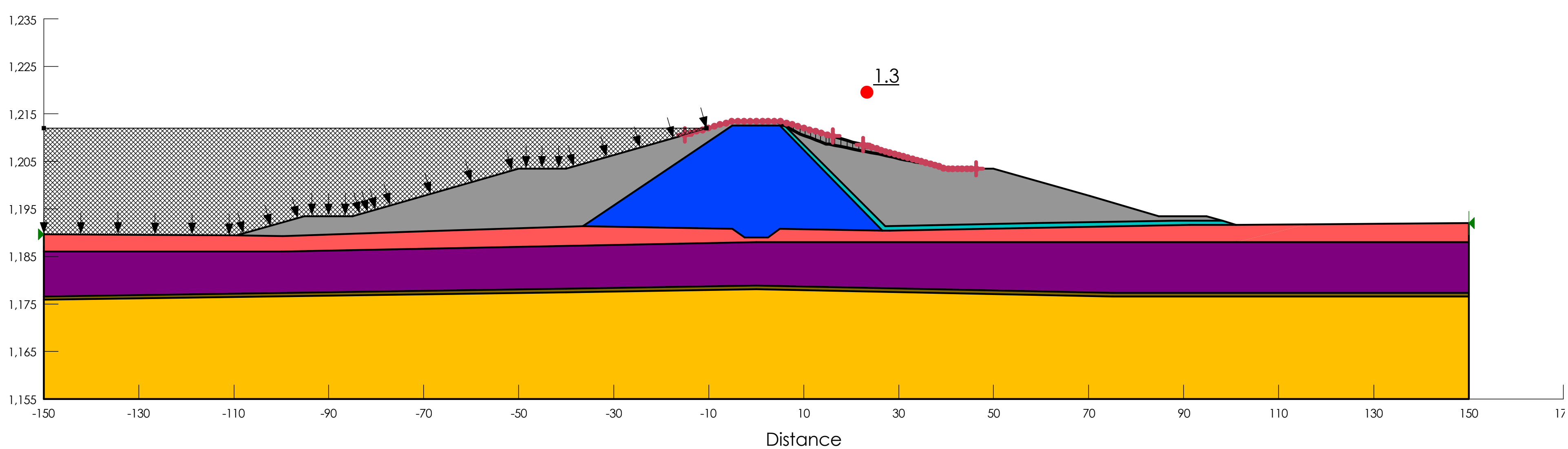


Stantec

Alberta Transportation SR1 Storage Dam

Section 22+990
Load Case: End of Construction, Year 3, Flood
Total Stress Parameters
Incipient Motion in the Downstream Direction

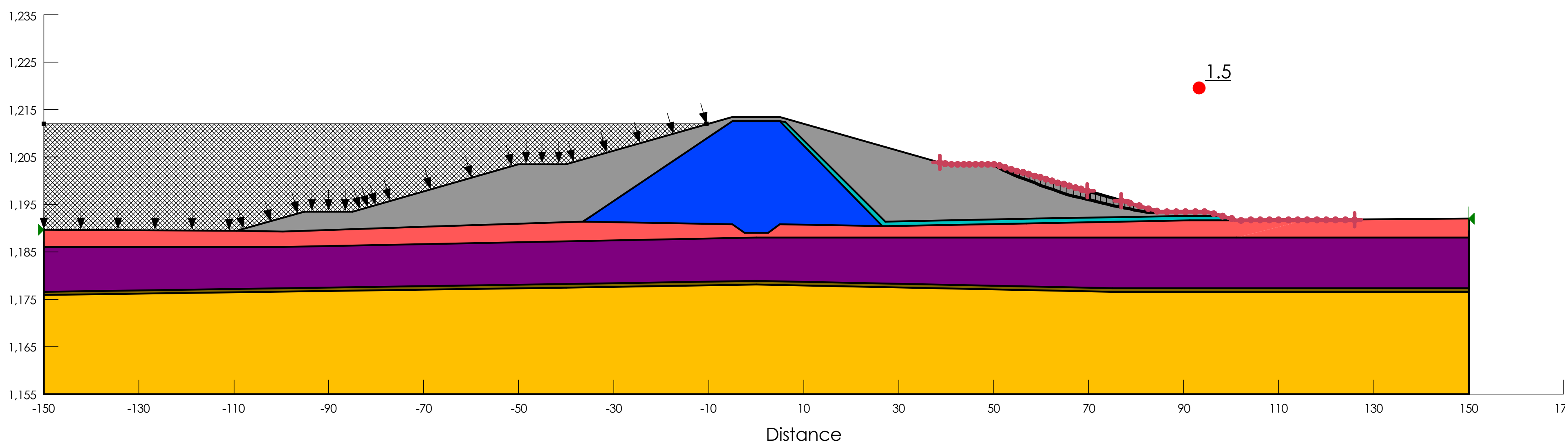
Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)
	Drain	21		0				33
	Embankment Core (Undrained)	20		0	28	19	427	
	Embankment Shell (Undrained)	20		0	24	15	141	
	Glacial Till (Undrained)	18		0	27	19	363.2	
	Glacio-Lacustrine (Undrained)	18	Undrained GL					0
	Sandstone							
	Weathered Bedrock	21		0				35



Alberta Transportation SR1 Storage Dam

Section 22+990
Load Case: End of Construction, Year 3, Flood
Total Stress Parameters
Incipient Motion in the Downstream Direction

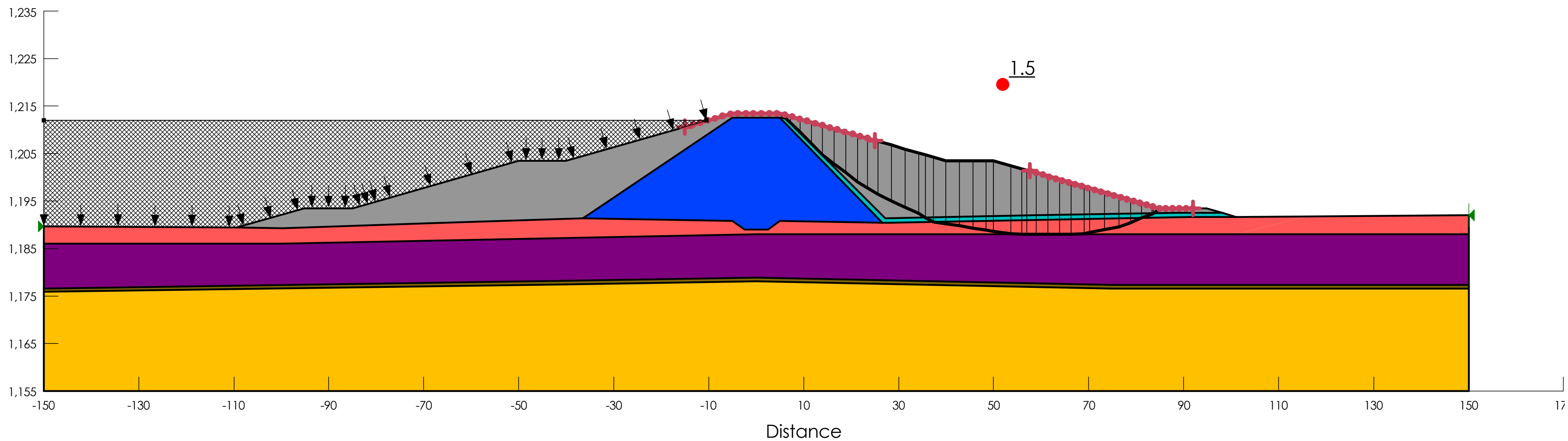
Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)
	Drain	21		0				33
	Embankment Core (Undrained)	20		0	28	19	427	
	Embankment Shell (Undrained)	20		0	24	15	141	
	Glacial Till (Undrained)	18		0	27	19	363.2	
	Glacio-Lacustrine (Undrained)	18	Undrained GL					0
	Sandstone							
	Weathered Bedrock	21		0				35



Alberta Transportation SR1 Storage Dam

Section 22+990
Load Case: End of Construction, Year 3, Flood
Total Stress Parameters
Incipient Motion in the Downstream Direction

Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)
	Drain	21		0				33
	Embankment Core (Undrained)	20		0	28	19	427	
	Embankment Shell (Undrained)	20		0	24	15	141	
	Glacial Till (Undrained)	18		0	27	19	363.2	
	Glacio-Lacustrine (Undrained)	18	Undrained GL					0
	Sandstone							
	Weathered Bedrock	21		0				35

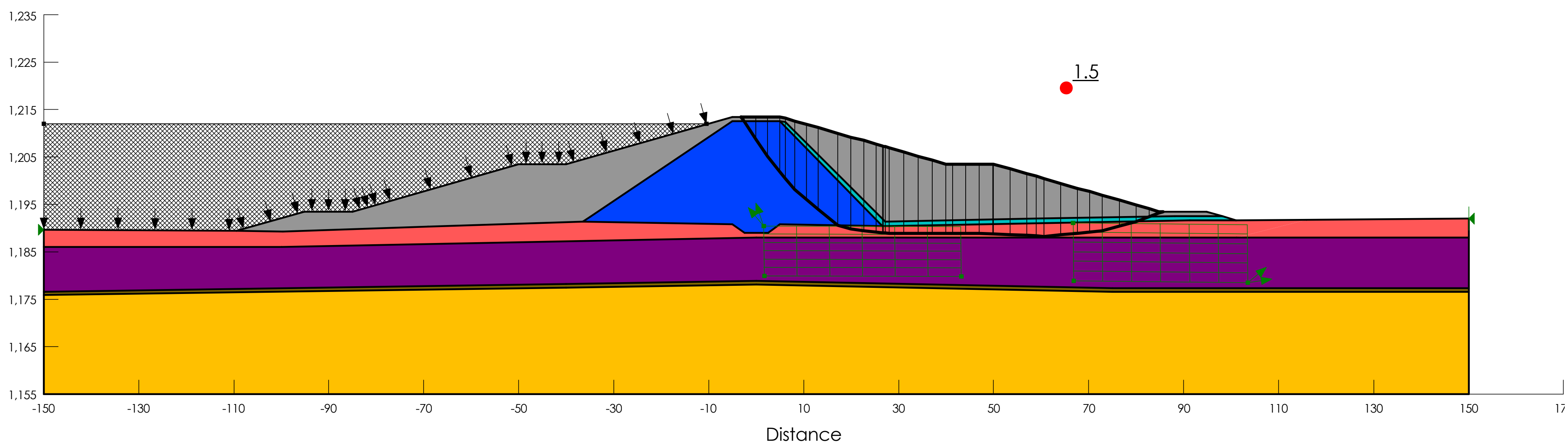


Stantec

Alberta Transportation SR1 Storage Dam

Section 22+990
Load Case: End of Construction, Year 3, Flood
Total Stress Parameters
Incipient Motion in the Downstream Direction

Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)
	Drain	21		0				33
	Embankment Core (Undrained)	20		0	28	19	427	
	Embankment Shell (Undrained)	20		0	24	15	141	
	Glacial Till (Undrained)	18		0	27	19	363.2	
	Glacio-Lacustrine (Undrained)	18	Undrained GL					0
	Sandstone							
	Weathered Bedrock	21		0				35

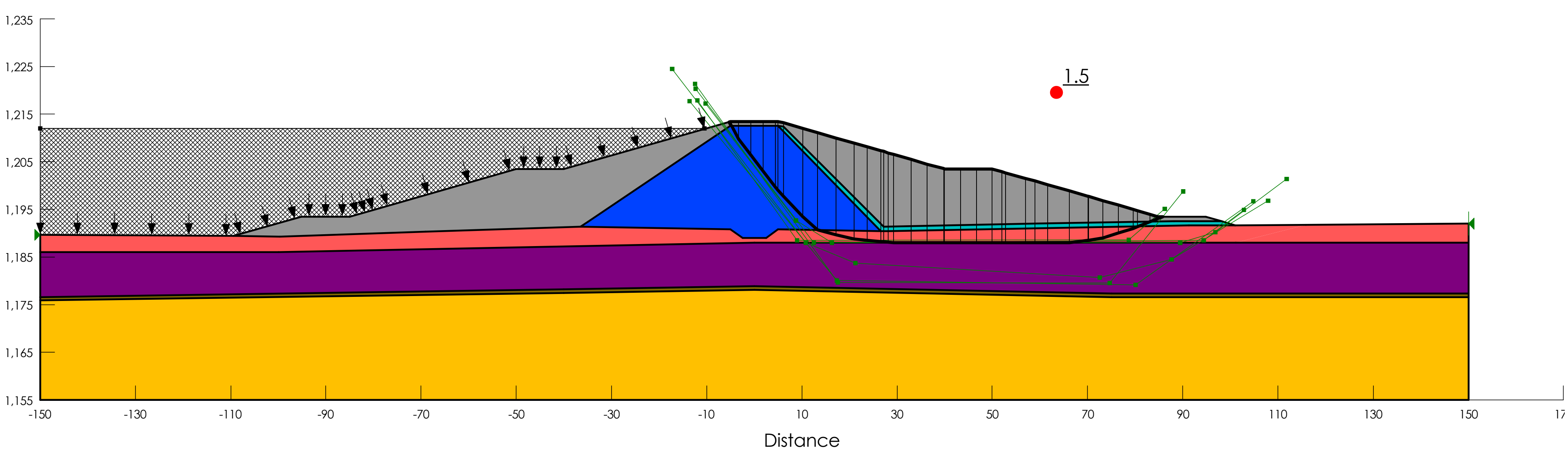


Stantec

Alberta Transportation SR1 Storage Dam

Section 22+990
Load Case: End of Construction, Year 3, Flood
Total Stress Parameters
Incipient Motion in the Downstream Direction

Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)
	Drain	21		0				33
	Embankment Core (Undrained)	20		0	28	19	427	
	Embankment Shell (Undrained)	20		0	24	15	141	
	Glacial Till (Undrained)	18		0	27	19	363.2	
	Glacio-Lacustrine (Undrained)	18	Undrained GL					0
	Sandstone							
	Weathered Bedrock	21		0				35



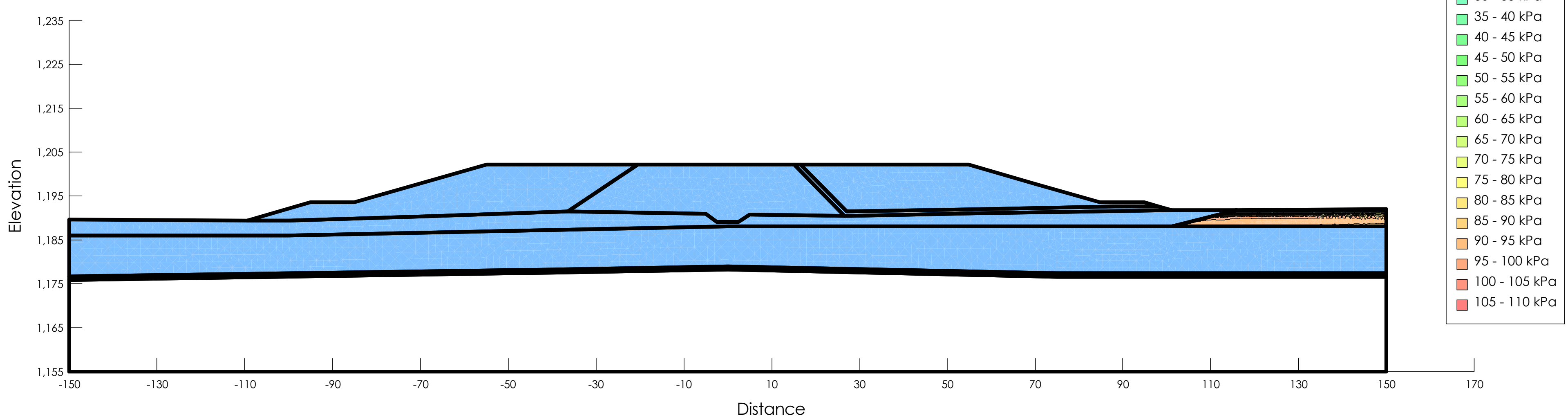
Attachment 12.1
Slope Stability and Seepage Analyses

12.1.6 Slope Stability Analyses
Sta. 22+990 - Replaced Lacustrine Foundation

Alberta Transportation SR1 Storage Dam

Section 22+990
Load Case: End of Construction, Year 2

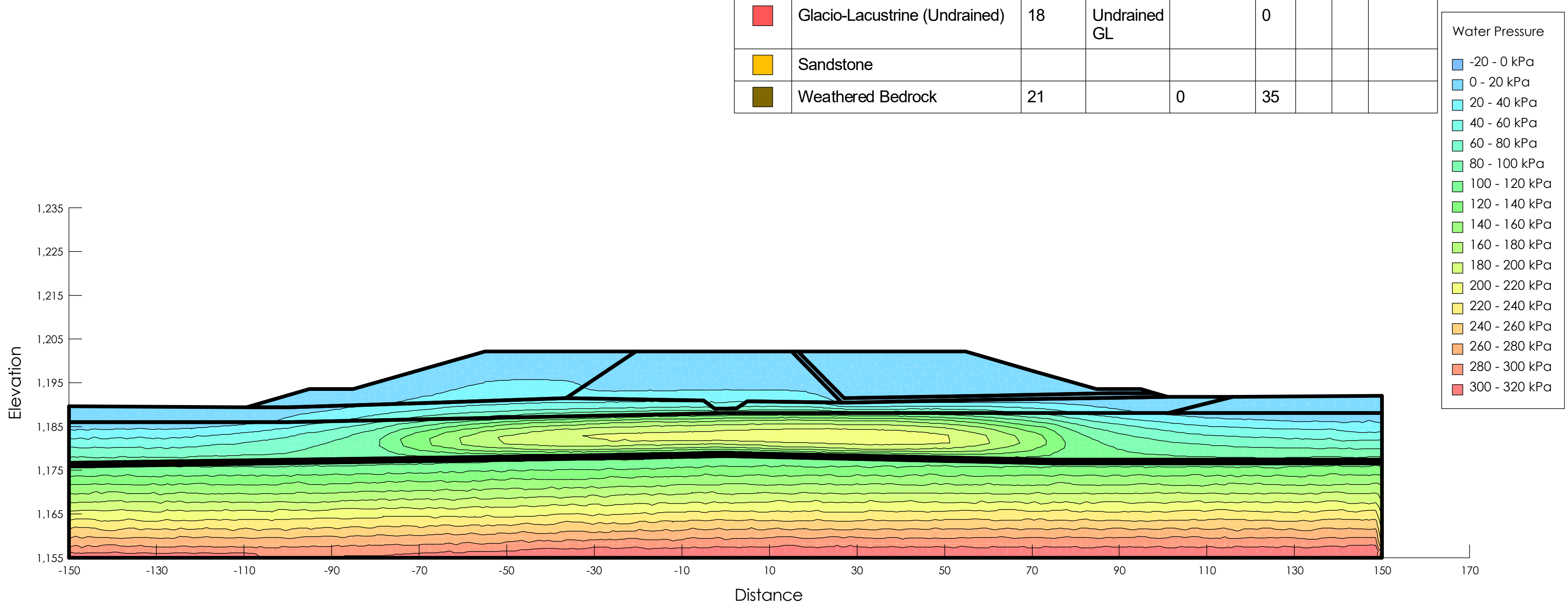
Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi' (°)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)
	Compacted Till (Undrained)	20		0		28	19	427
	Drain	21		0	33			
	Embankment Core (Undrained)	20		0		28	19	427
	Embankment Shell (Undrained)	20		0		24	15	141
	Glacial Till (Undrained)	18		0		27	19	363.2
	Glacio-Lacustrine (Undrained)	18	Undrained GL		0			
	Sandstone							
	Weathered Bedrock	21		0	35			



Alberta Transportation SR1 Storage Dam

Section 22+990
Load Case: End of Construction, Year 2

Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi' (°)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)
	Compacted Till (Undrained)	20		0		28	19	427
	Drain	21		0	33			
	Embankment Core (Undrained)	20		0		28	19	427
	Embankment Shell (Undrained)	20		0		24	15	141
	Glacial Till (Undrained)	18		0		27	19	363.2
	Glacio-Lacustrine (Undrained)	18	Undrained GL		0			
	Sandstone							
	Weathered Bedrock	21		0	35			

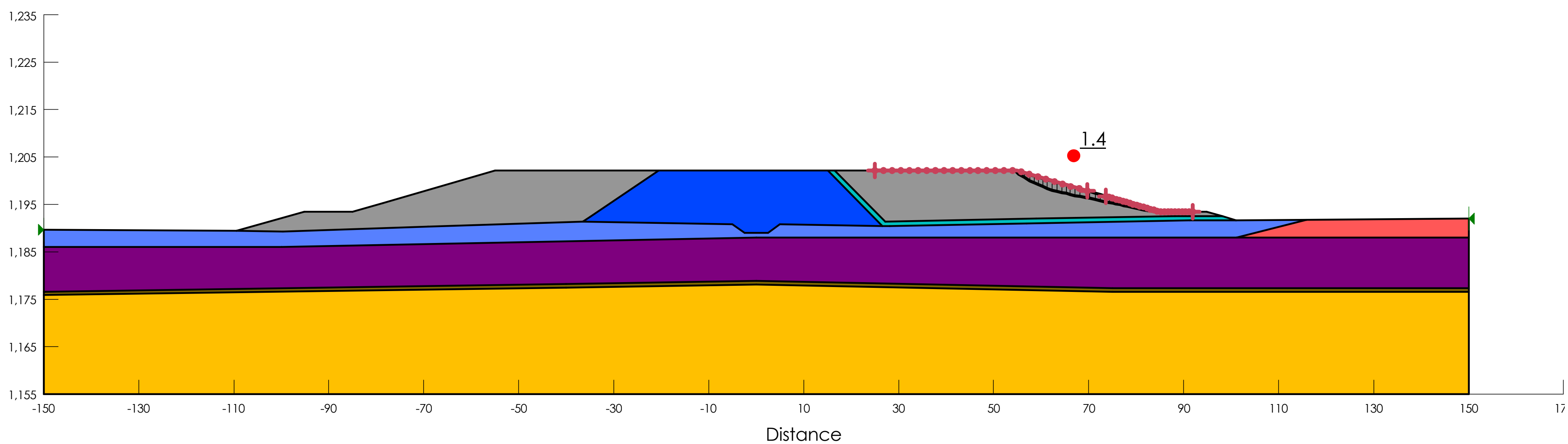


Stantec

Alberta Transportation SR1 Storage Dam

Section 22+990
Load Case: End of Construction, Year 2
Effective Stress Parameters
Incipient Motion in the Downstream Direction

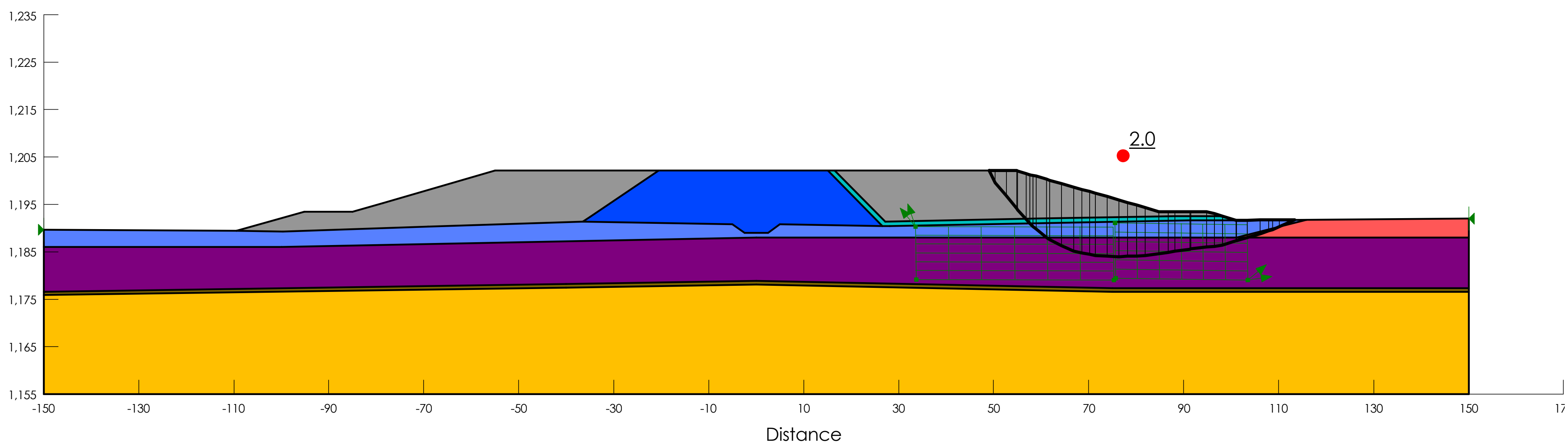
Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)
	Compacted Till (Drained)	20	0	28
	Drain	21	0	33
	Embankment Core (Drained)	20	0	28
	Embankment Shell (Drained)	20	0	24
	Glacial Till (Drained)	18	0	27
	Glacio-Lacustrine (Drained)	18	0	23
	Sandstone			
	Weathered Bedrock	21	0	35



Alberta Transportation SR1 Storage Dam

Section 22+990
Load Case: End of Construction, Year 2
Effective Stress Parameters
Incipient Motion in the Downstream Direction

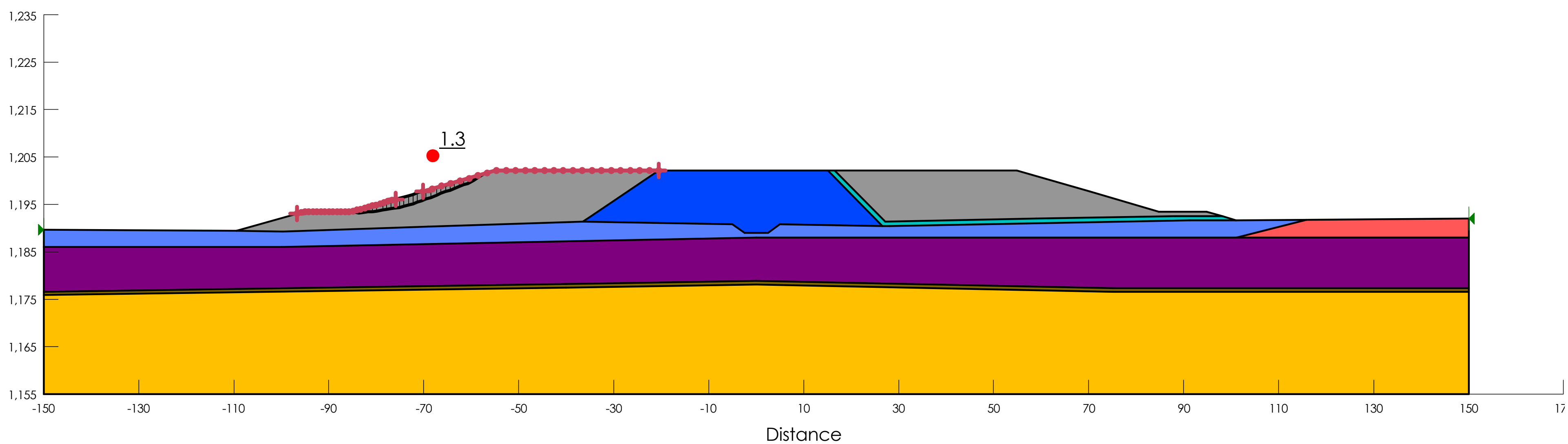
Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)
	Compacted Till (Drained)	20	0	28
	Drain	21	0	33
	Embankment Core (Drained)	20	0	28
	Embankment Shell (Drained)	20	0	24
	Glacial Till (Drained)	18	0	27
	Glacio-Lacustrine (Drained)	18	0	23
	Sandstone			
	Weathered Bedrock	21	0	35



Alberta Transportation SR1 Storage Dam

Section 22+990
Load Case: End of Construction, Year 2
Effective Stress Parameters
Incipient Motion in the Upstream Direction

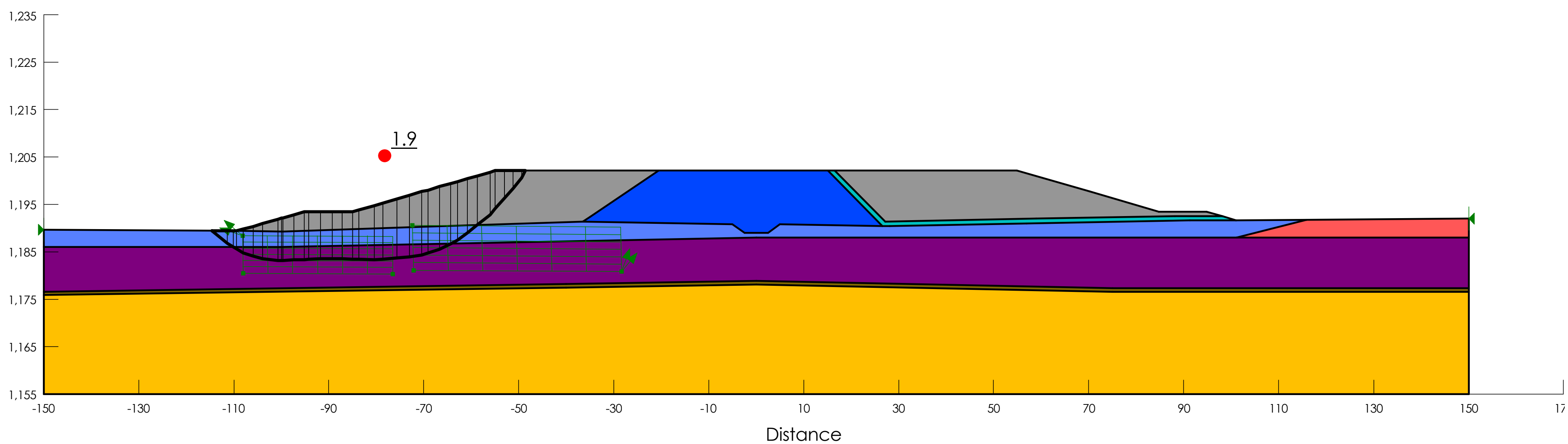
Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)
	Compacted Till (Drained)	20	0	28
	Drain	21	0	33
	Embankment Core (Drained)	20	0	28
	Embankment Shell (Drained)	20	0	24
	Glacial Till (Drained)	18	0	27
	Glacio-Lacustrine (Drained)	18	0	23
	Sandstone			
	Weathered Bedrock	21	0	35



Alberta Transportation SR1 Storage Dam

Section 22+990
Load Case: End of Construction, Year 2
Effective Stress Parameters
Incipient Motion in the Upstream Direction

Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)
	Compacted Till (Drained)	20	0	28
	Drain	21	0	33
	Embankment Core (Drained)	20	0	28
	Embankment Shell (Drained)	20	0	24
	Glacial Till (Drained)	18	0	27
	Glacio-Lacustrine (Drained)	18	0	23
	Sandstone			
	Weathered Bedrock	21	0	35

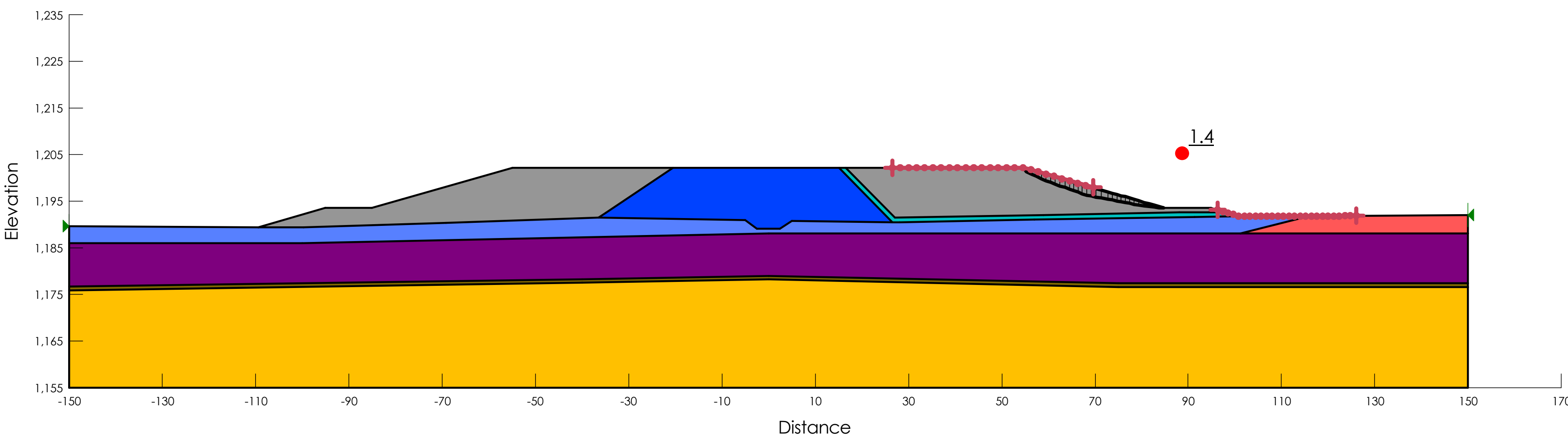


Stantec

Alberta Transportation SR1 Storage Dam

Section 22+990
Load Case: End of Construction, Year 2
Total Stress Parameters
Incipient Motion in the Downstream Direction

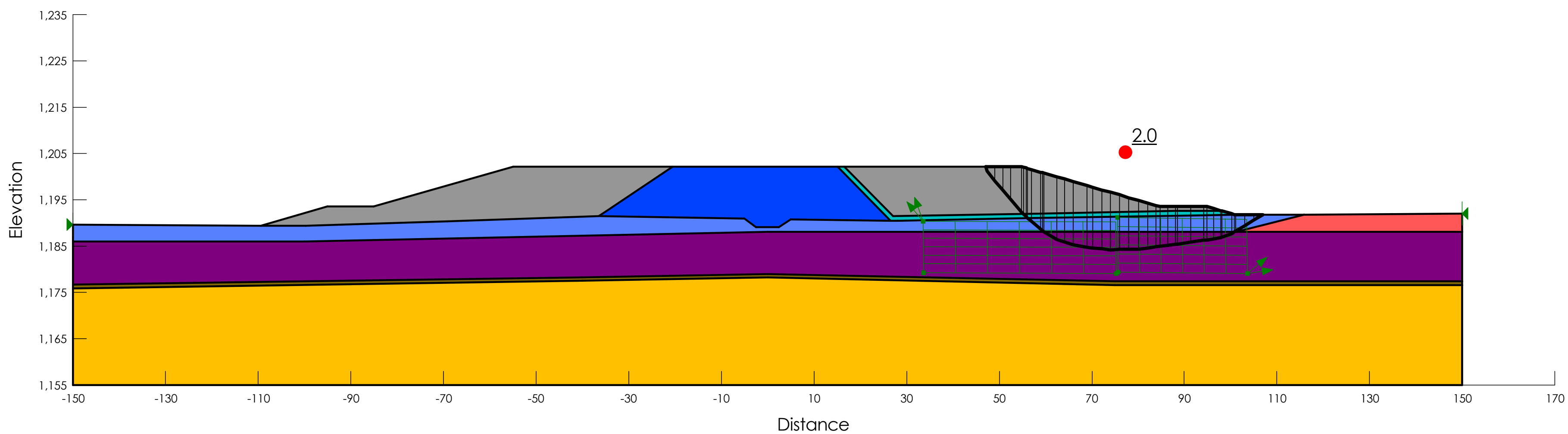
Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi' (°)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)
	Compacted Till (Undrained)	20		0		28	19	427
	Drain	21		0	33			
	Embankment Core (Undrained)	20		0		28	19	427
	Embankment Shell (Undrained)	20		0		24	15	141
	Glacial Till (Undrained)	18		0		27	19	363.2
	Glacio-Lacustrine (Undrained)	18	Undrained GL		0			
	Sandstone							
	Weathered Bedrock	21		0	35			



Alberta Transportation SR1 Storage Dam

Section 22+990
Load Case: End of Construction, Year 2
Total Stress Parameters
Incipient Motion in the Downstream Direction

Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi' (°)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)
	Compacted Till (Undrained)	20		0		28	19	427
	Drain	21		0	33			
	Embankment Core (Undrained)	20		0		28	19	427
	Embankment Shell (Undrained)	20		0		24	15	141
	Glacial Till (Undrained)	18		0		27	19	363.2
	Glacio-Lacustrine (Undrained)	18	Undrained GL		0			
	Sandstone							
	Weathered Bedrock	21		0	35			

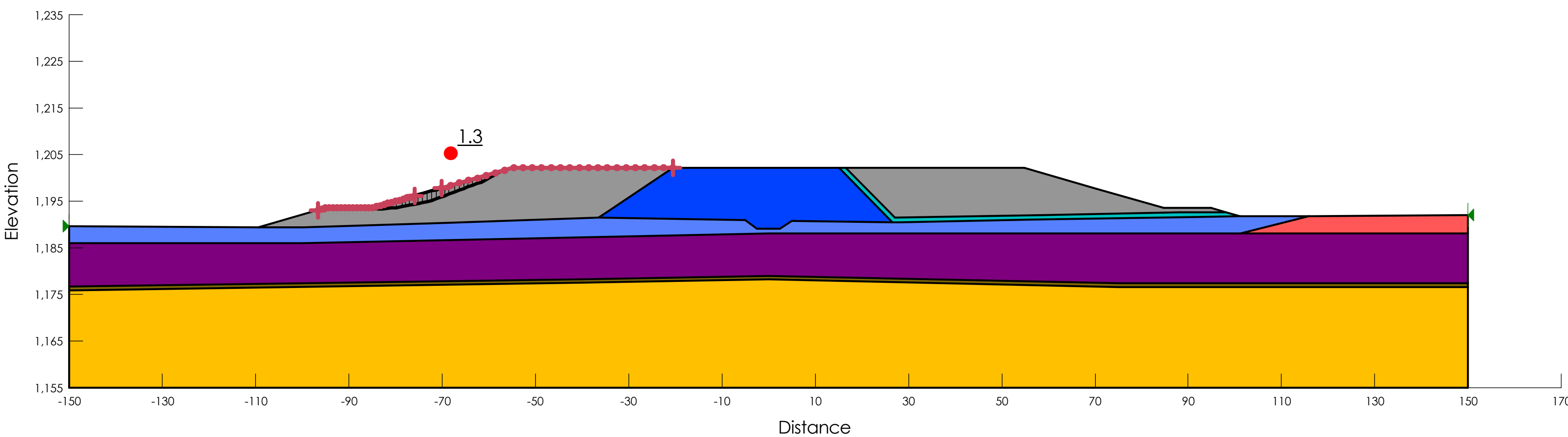


Stantec

Alberta Transportation SR1 Storage Dam

Section 22+990
Load Case: End of Construction, Year 2
Total Stress Parameters
Incipient Motion in the Upstream Direction

Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi' (°)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)
	Compacted Till (Undrained)	20		0		28	19	427
	Drain	21		0	33			
	Embankment Core (Undrained)	20		0		28	19	427
	Embankment Shell (Undrained)	20		0		24	15	141
	Glacial Till (Undrained)	18		0		27	19	363.2
	Glacio-Lacustrine (Undrained)	18	Undrained GL		0			
	Sandstone							
	Weathered Bedrock	21		0	35			

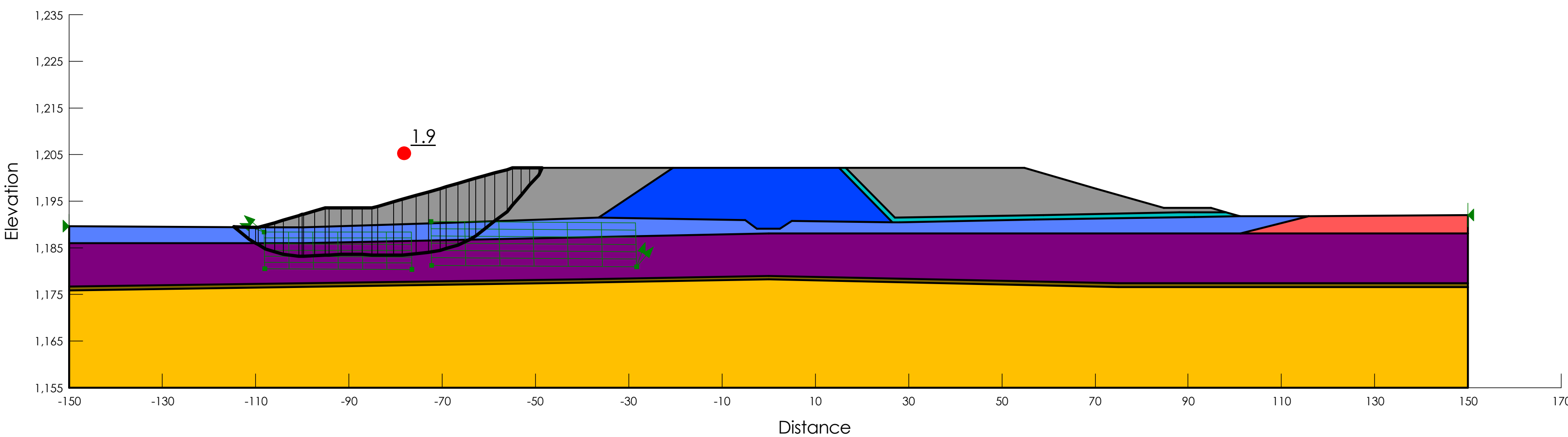


Stantec

Alberta Transportation SR1 Storage Dam

Section 22+990
Load Case: End of Construction, Year 2
Total Stress Parameters
Incipient Motion in the Upstream Direction

Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi' (°)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)
	Compacted Till (Undrained)	20		0		28	19	427
	Drain	21		0	33			
	Embankment Core (Undrained)	20		0		28	19	427
	Embankment Shell (Undrained)	20		0		24	15	141
	Glacial Till (Undrained)	18		0		27	19	363.2
	Glacio-Lacustrine (Undrained)	18	Undrained GL		0			
	Sandstone							
	Weathered Bedrock	21		0	35			



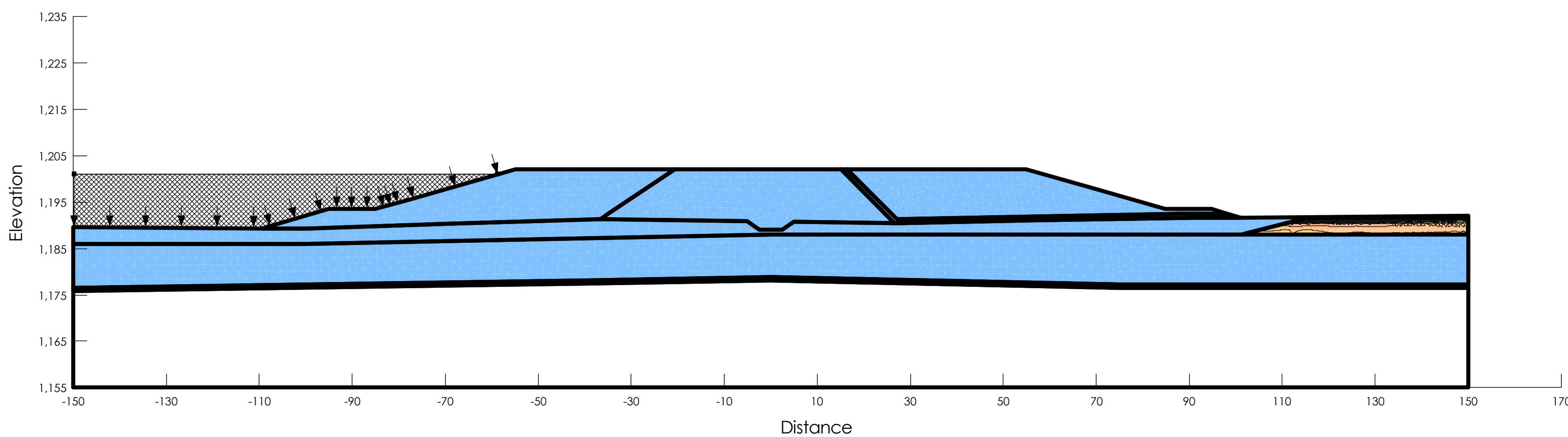
Stantec

Alberta Transportation SR1 Storage Dam

Section 22+990
Load Case: End Construction, Year 2, Flood

Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi' (°)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)
	Compacted Till (Undrained)	20		0		28	19	427
	Drain	21		0	33			
	Embankment Core (Undrained)	20		0		28	19	427
	Embankment Shell (Undrained)	20		0		24	15	141
	Glacial Till (Undrained)	18		0		27	19	363.2
	Glacio-Lacustrine (Undrained)	18	Undrained GL		0			
	Sandstone							
	Weathered Bedrock	21		0	35			

Cohesion
- 0 - 5 kPa
- 5 - 10 kPa
- 10 - 15 kPa
- 15 - 20 kPa
- 20 - 25 kPa
- 25 - 30 kPa
- 30 - 35 kPa
- 35 - 40 kPa
- 40 - 45 kPa
- 45 - 50 kPa
- 50 - 55 kPa
- 55 - 60 kPa
- 60 - 65 kPa
- 65 - 70 kPa
- 70 - 75 kPa
- 75 - 80 kPa
- 80 - 85 kPa
- 85 - 90 kPa
- 90 - 95 kPa
- 95 - 100 kPa
- 100 - 105 kPa
- 105 - 110 kPa

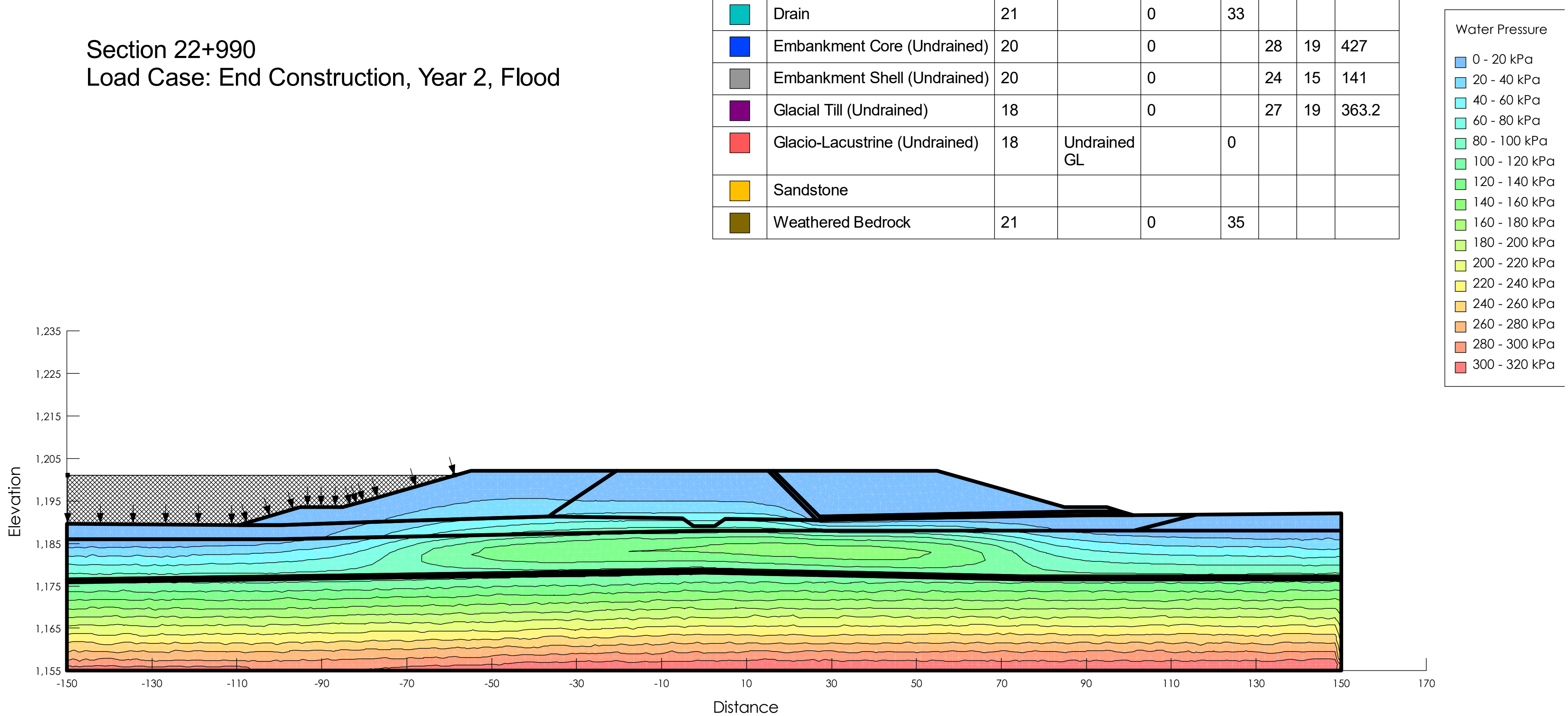


Stantec

Alberta Transportation SR1 Storage Dam

Section 22+990
Load Case: End Construction, Year 2, Flood

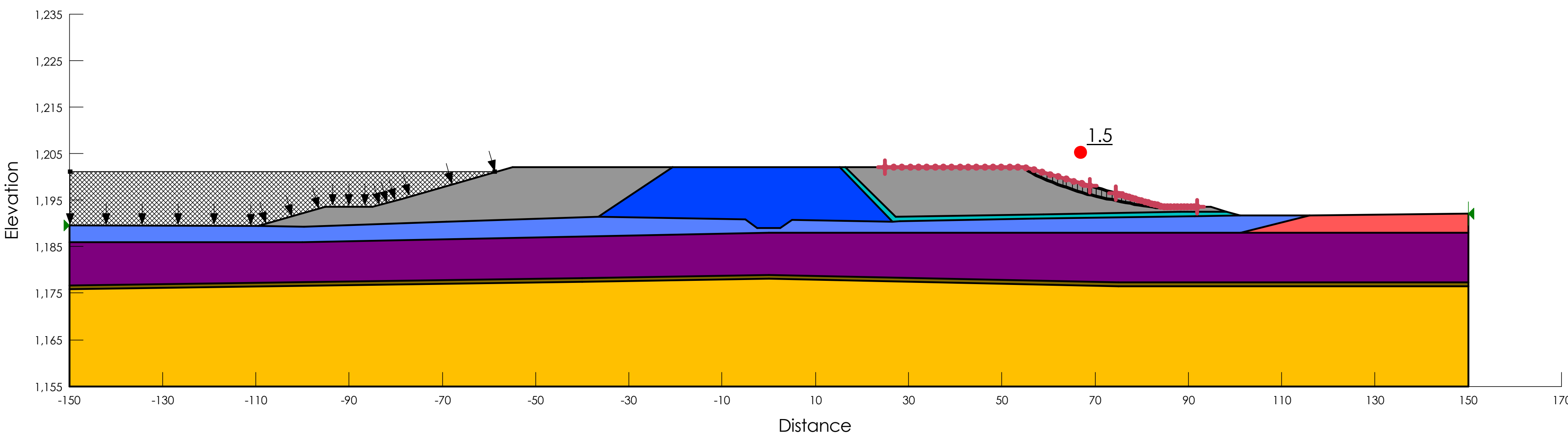
Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi' (°)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)
	Compacted Till (Undrained)	20		0		28	19	427
	Drain	21		0	33			
	Embankment Core (Undrained)	20		0		28	19	427
	Embankment Shell (Undrained)	20		0		24	15	141
	Glacial Till (Undrained)	18		0		27	19	363.2
	Glacio-Lacustrine (Undrained)	18	Undrained GL		0			
	Sandstone							
	Weathered Bedrock	21		0	35			



Alberta Transportation SR1 Storage Dam

Section 22+990
Load Case: End Construction, Year 2, Flood
Total Stress Parameters
Incipient Motion in the Downstream Direction

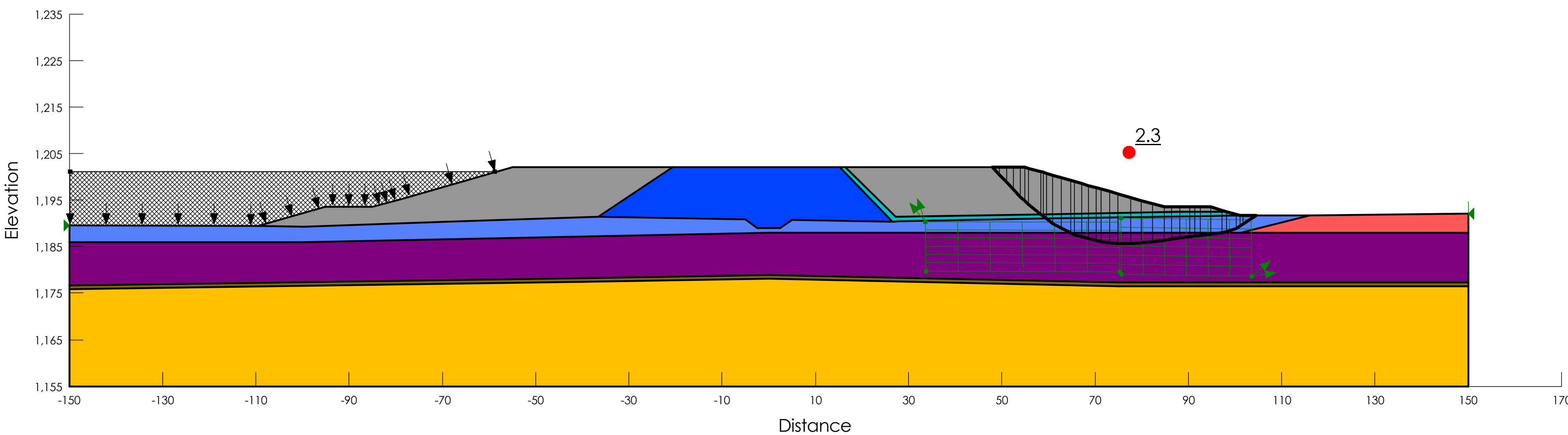
Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi' (°)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)
	Compacted Till (Undrained)	20		0		28	19	427
	Drain	21		0	33			
	Embankment Core (Undrained)	20		0		28	19	427
	Embankment Shell (Undrained)	20		0		24	15	141
	Glacial Till (Undrained)	18		0		27	19	363.2
	Glacio-Lacustrine (Undrained)	18	Undrained GL		0			
	Sandstone							
	Weathered Bedrock	21		0	35			



Alberta Transportation SR1 Storage Dam

Section 22+990
Load Case: End Construction, Year 2, Flood
Total Stress Parameters
Incipient Motion in the Downstream Direction

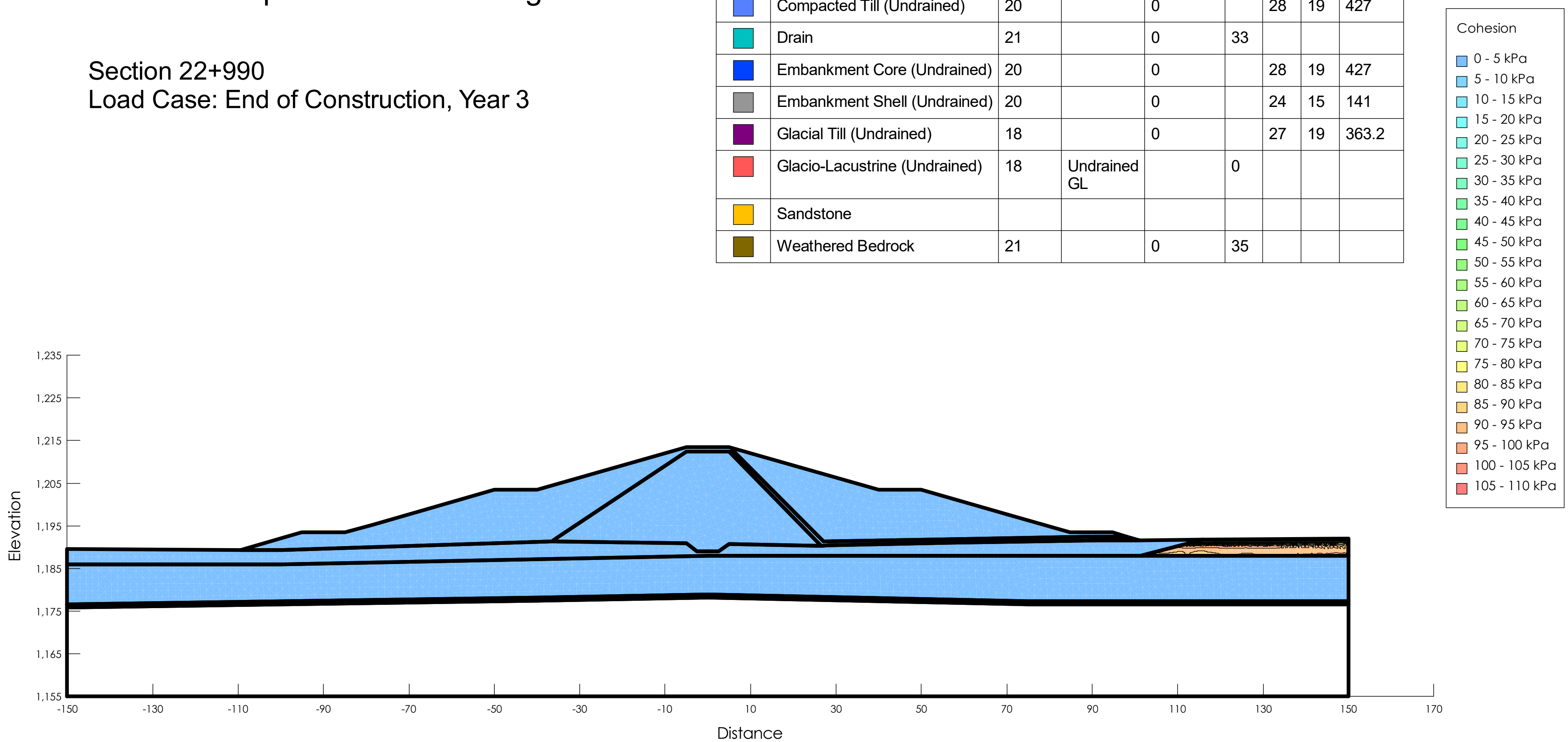
Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi' (°)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)
	Compacted Till (Undrained)	20		0		28	19	427
	Drain	21		0	33			
	Embankment Core (Undrained)	20		0		28	19	427
	Embankment Shell (Undrained)	20		0		24	15	141
	Glacial Till (Undrained)	18		0		27	19	363.2
	Glacio-Lacustrine (Undrained)	18	Undrained GL		0			
	Sandstone							
	Weathered Bedrock	21		0	35			



Alberta Transportation SR1 Storage Dam

Section 22+990
Load Case: End of Construction, Year 3

Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi' (°)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)
	Compacted Till (Undrained)	20		0		28	19	427
	Drain	21		0	33			
	Embankment Core (Undrained)	20		0		28	19	427
	Embankment Shell (Undrained)	20		0		24	15	141
	Glacial Till (Undrained)	18		0		27	19	363.2
	Glacio-Lacustrine (Undrained)	18	Undrained GL		0			
	Sandstone							
	Weathered Bedrock	21		0	35			

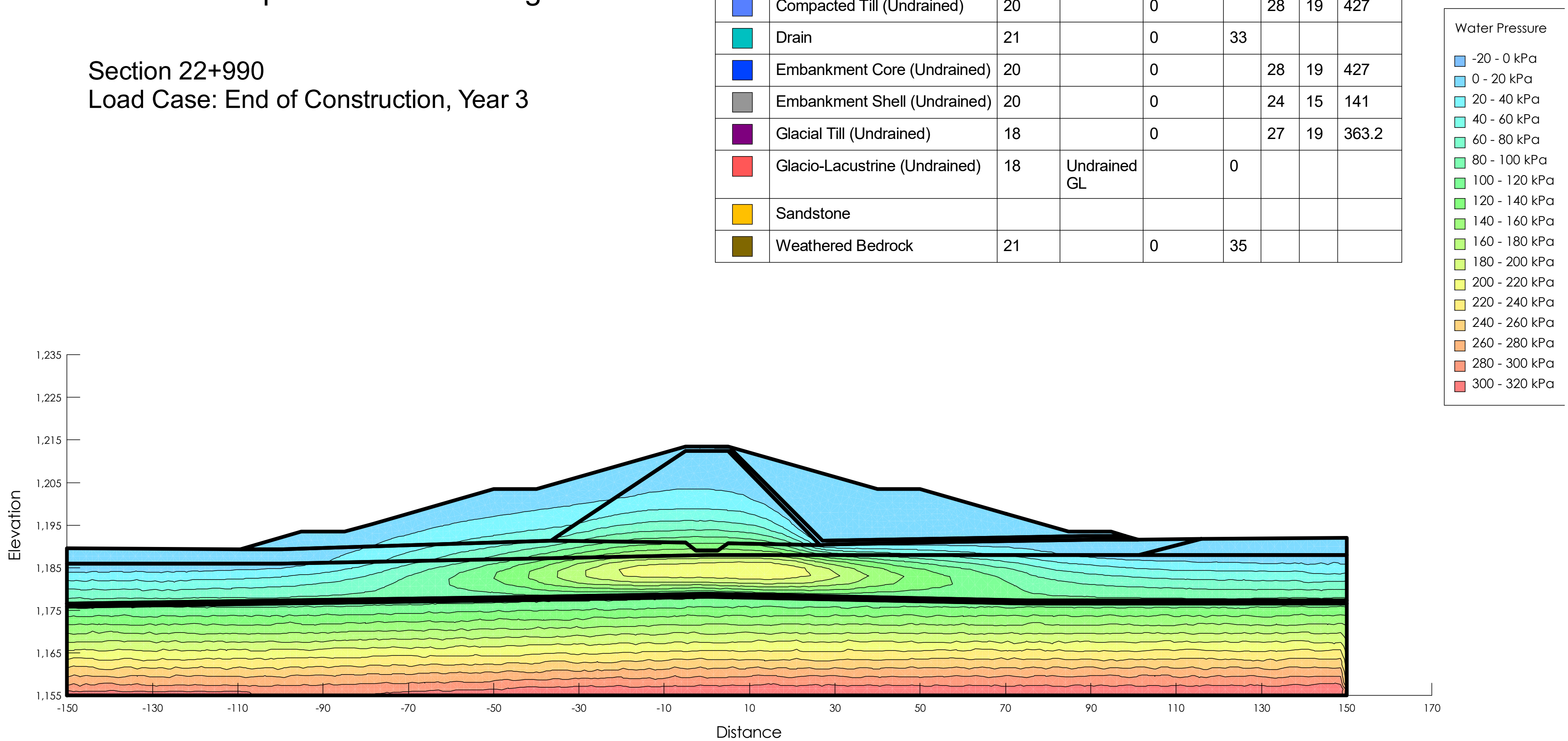


Stantec

Alberta Transportation SR1 Storage Dam

Section 22+990
Load Case: End of Construction, Year 3

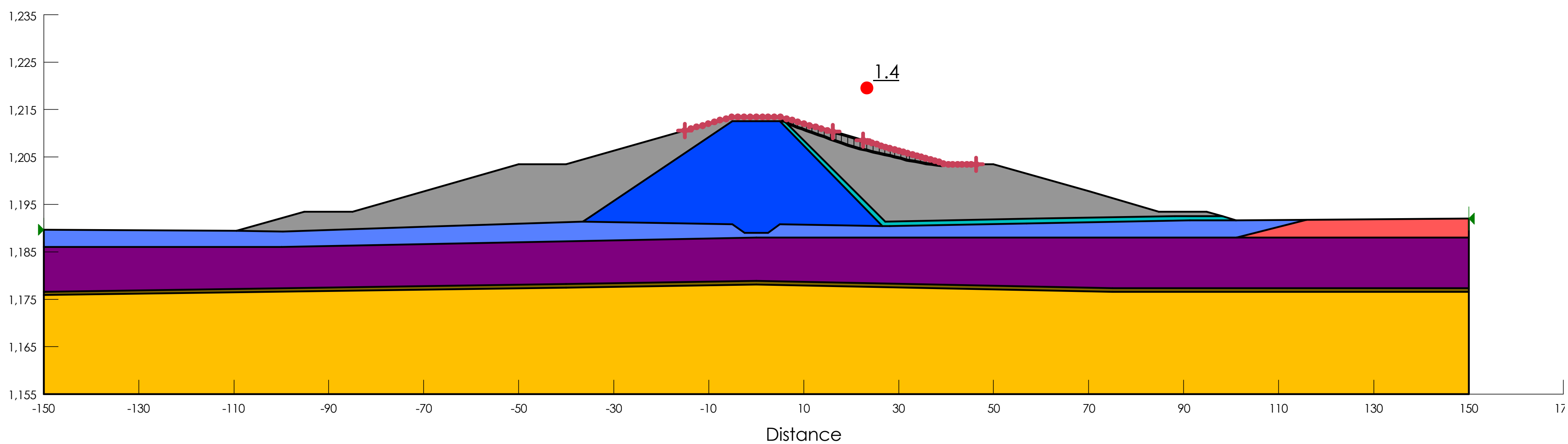
Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi' (°)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)
	Compacted Till (Undrained)	20		0		28	19	427
	Drain	21		0	33			
	Embankment Core (Undrained)	20		0		28	19	427
	Embankment Shell (Undrained)	20		0		24	15	141
	Glacial Till (Undrained)	18		0		27	19	363.2
	Glacio-Lacustrine (Undrained)	18	Undrained GL		0			
	Sandstone							
	Weathered Bedrock	21		0	35			



Alberta Transportation SR1 Storage Dam

Section 22+990
Load Case: End of Construction, Year 3
Effective Stress Parameters
Incipient Motion in the Downstream Direction

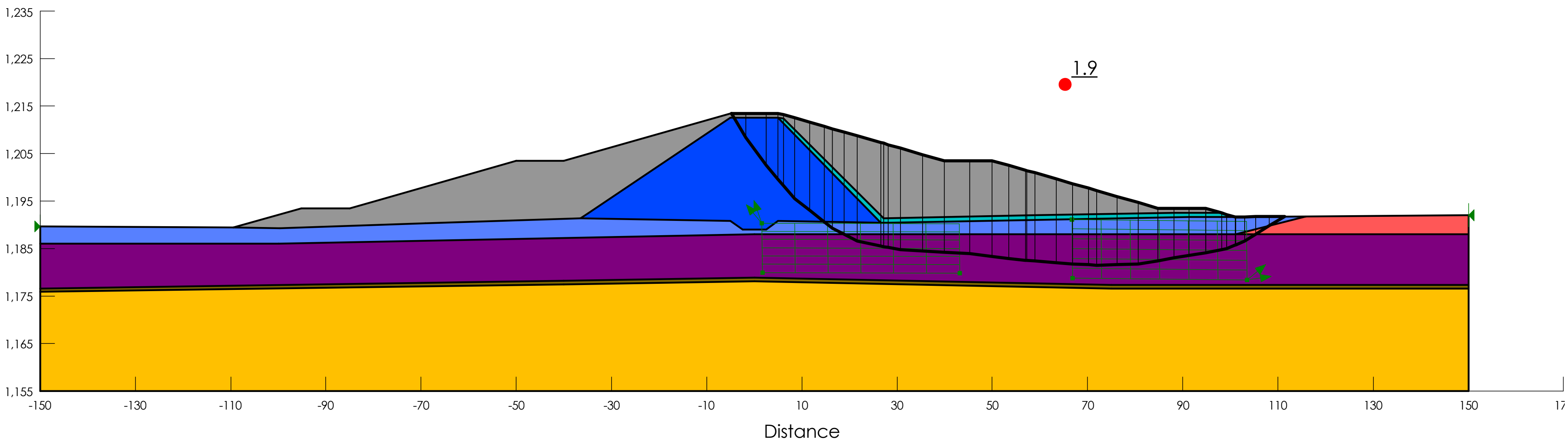
Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)
	Compacted Till (Drained)	20	0	28
	Drain	21	0	33
	Embankment Core (Drained)	20	0	28
	Embankment Shell (Drained)	20	0	24
	Glacial Till (Drained)	18	0	27
	Glacio-Lacustrine (Drained)	18	0	23
	Sandstone			
	Weathered Bedrock	21	0	35



Alberta Transportation SR1 Storage Dam

Section 22+990
Load Case: End of Construction, Year 3
Effective Stress Parameters
Incipient Motion in the Downstream Direction

Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)
	Compacted Till (Drained)	20	0	28
	Drain	21	0	33
	Embankment Core (Drained)	20	0	28
	Embankment Shell (Drained)	20	0	24
	Glacial Till (Drained)	18	0	27
	Glacio-Lacustrine (Drained)	18	0	23
	Sandstone			
	Weathered Bedrock	21	0	35

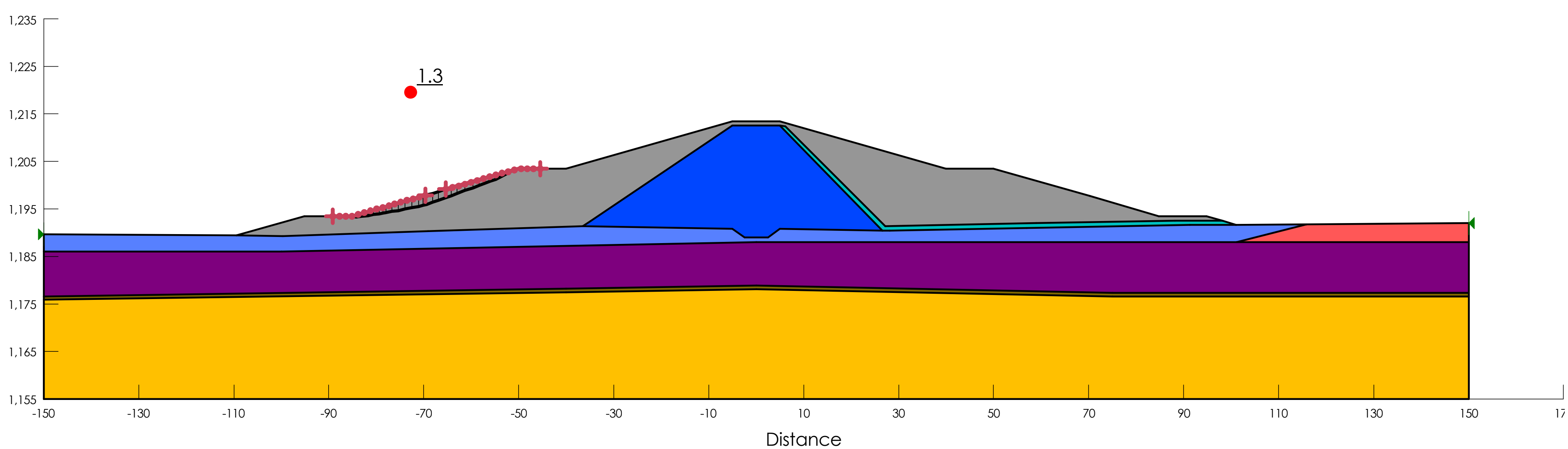


Stantec

Alberta Transportation SR1 Storage Dam

Section 22+990
Load Case: End of Construction, Year 3
Effective Stress Parameters
Incipient Motion in the Upstream Direction

Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)
	Compacted Till (Drained)	20	0	28
	Drain	21	0	33
	Embankment Core (Drained)	20	0	28
	Embankment Shell (Drained)	20	0	24
	Glacial Till (Drained)	18	0	27
	Glacio-Lacustrine (Drained)	18	0	23
	Sandstone			
	Weathered Bedrock	21	0	35

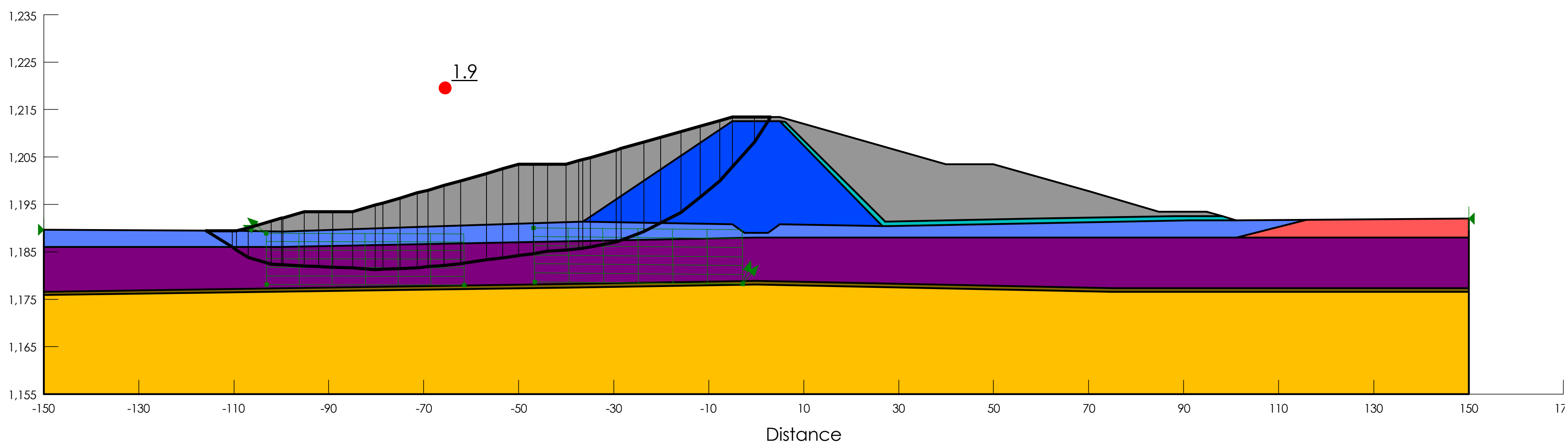


Stantec

Alberta Transportation SR1 Storage Dam

Section 22+990
Load Case: End of Construction, Year 3
Effective Stress Parameters
Incipient Motion in the Upstream Direction

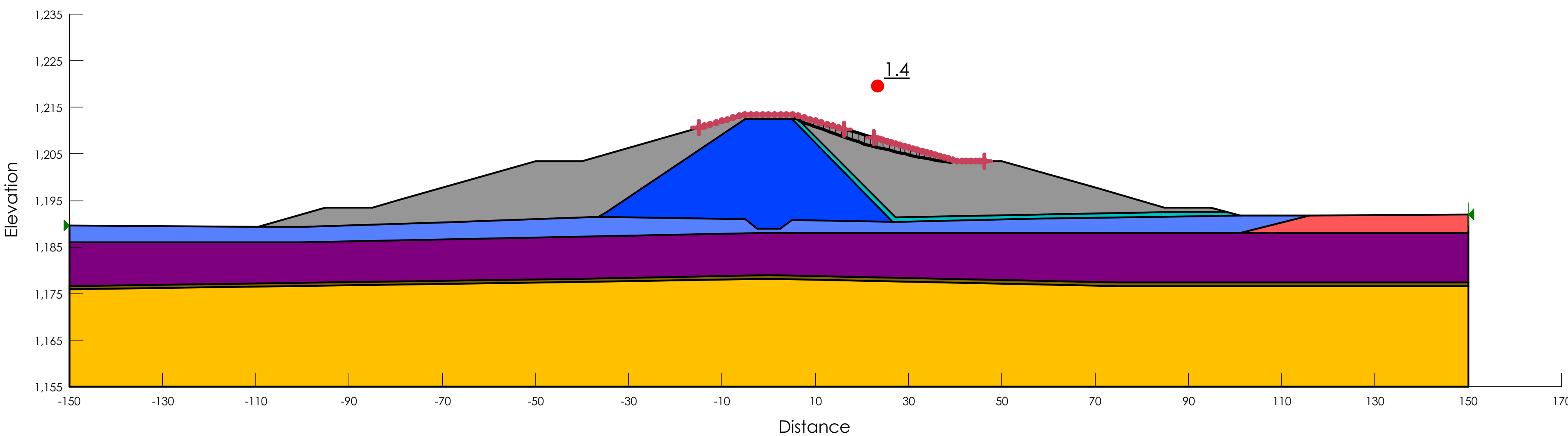
Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)
	Compacted Till (Drained)	20	0	28
	Drain	21	0	33
	Embankment Core (Drained)	20	0	28
	Embankment Shell (Drained)	20	0	24
	Glacial Till (Drained)	18	0	27
	Glacio-Lacustrine (Drained)	18	0	23
	Sandstone			
	Weathered Bedrock	21	0	35



Alberta Transportation SR1 Storage Dam

Section 22+990
Load Case: End of Construction, Year 3
Total Stress Parameters
Incipient Motion in the Downstream Direction

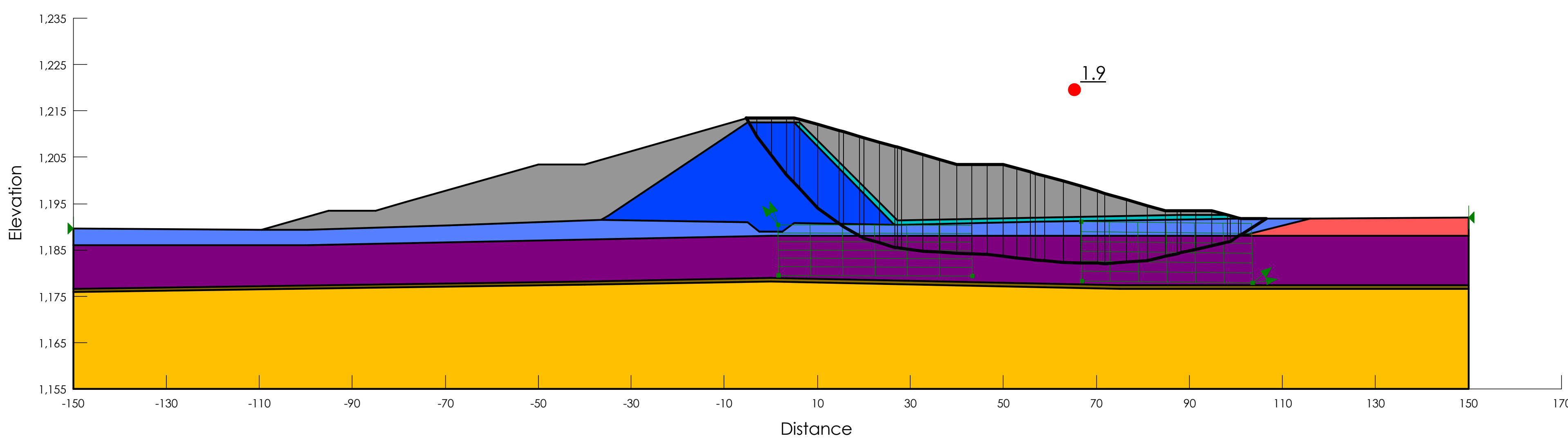
Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi' (°)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)
	Compacted Till (Undrained)	20		0		28	19	427
	Drain	21		0	33			
	Embankment Core (Undrained)	20		0		28	19	427
	Embankment Shell (Undrained)	20		0		24	15	141
	Glacial Till (Undrained)	18		0		27	19	363.2
	Glacio-Lacustrine (Undrained)	18	Undrained GL		0			
	Sandstone							
	Weathered Bedrock	21		0	35			



Alberta Transportation SR1 Storage Dam

Section 22+990
Load Case: End of Construction, Year 3
Total Stress Parameters
Incipient Motion in the Downstream Direction

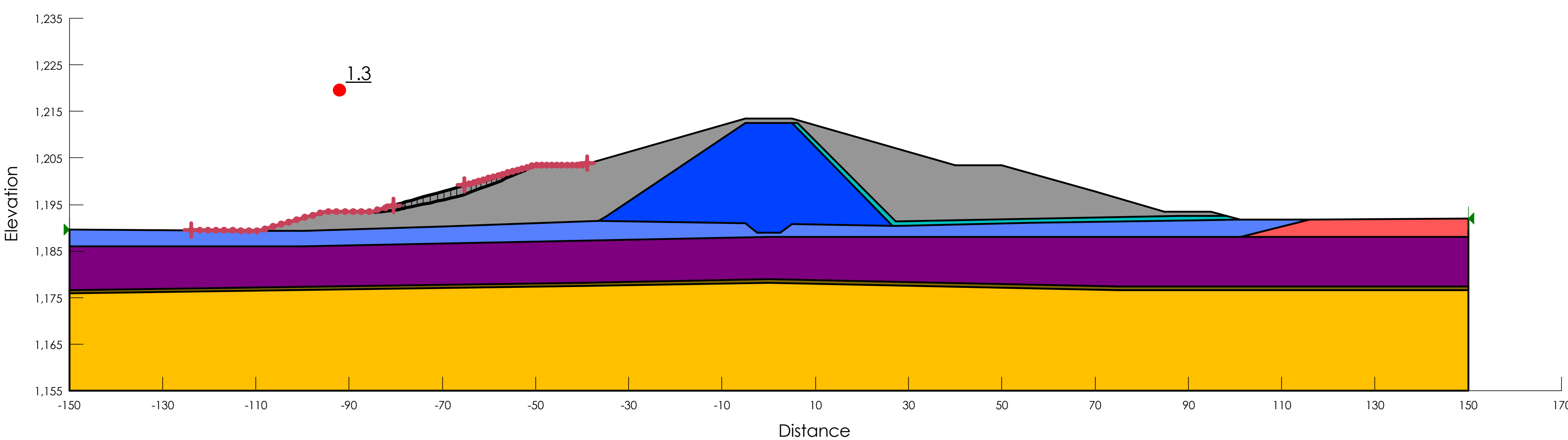
Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi' (°)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)
	Compacted Till (Undrained)	20		0		28	19	427
	Drain	21		0	33			
	Embankment Core (Undrained)	20		0		28	19	427
	Embankment Shell (Undrained)	20		0		24	15	141
	Glacial Till (Undrained)	18		0		27	19	363.2
	Glacio-Lacustrine (Undrained)	18	Undrained GL		0			
	Sandstone							
	Weathered Bedrock	21		0	35			



Alberta Transportation SR1 Storage Dam

Section 22+990
Load Case: End of Construction, Year 3
Total Stress Parameters
Incipient Motion in the Upstream Direction

Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi' (°)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)
	Compacted Till (Undrained)	20		0		28	19	427
	Drain	21		0	33			
	Embankment Core (Undrained)	20		0		28	19	427
	Embankment Shell (Undrained)	20		0		24	15	141
	Glacial Till (Undrained)	18		0		27	19	363.2
	Glacio-Lacustrine (Undrained)	18	Undrained GL		0			
	Sandstone							
	Weathered Bedrock	21		0	35			

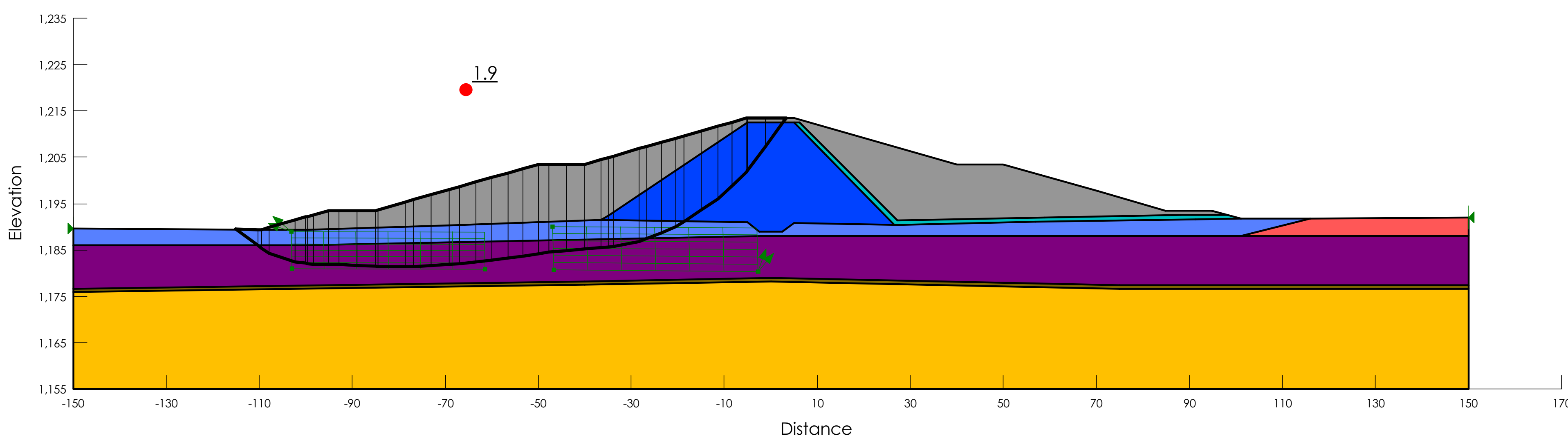


Stantec

Alberta Transportation SR1 Storage Dam

Section 22+990
Load Case: End of Construction, Year 3
Total Stress Parameters
Incipient Motion in the Upstream Direction

Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi' (°)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)
	Compacted Till (Undrained)	20		0		28	19	427
	Drain	21		0	33			
	Embankment Core (Undrained)	20		0		28	19	427
	Embankment Shell (Undrained)	20		0		24	15	141
	Glacial Till (Undrained)	18		0		27	19	363.2
	Glacio-Lacustrine (Undrained)	18	Undrained GL		0			
	Sandstone							
	Weathered Bedrock	21		0	35			

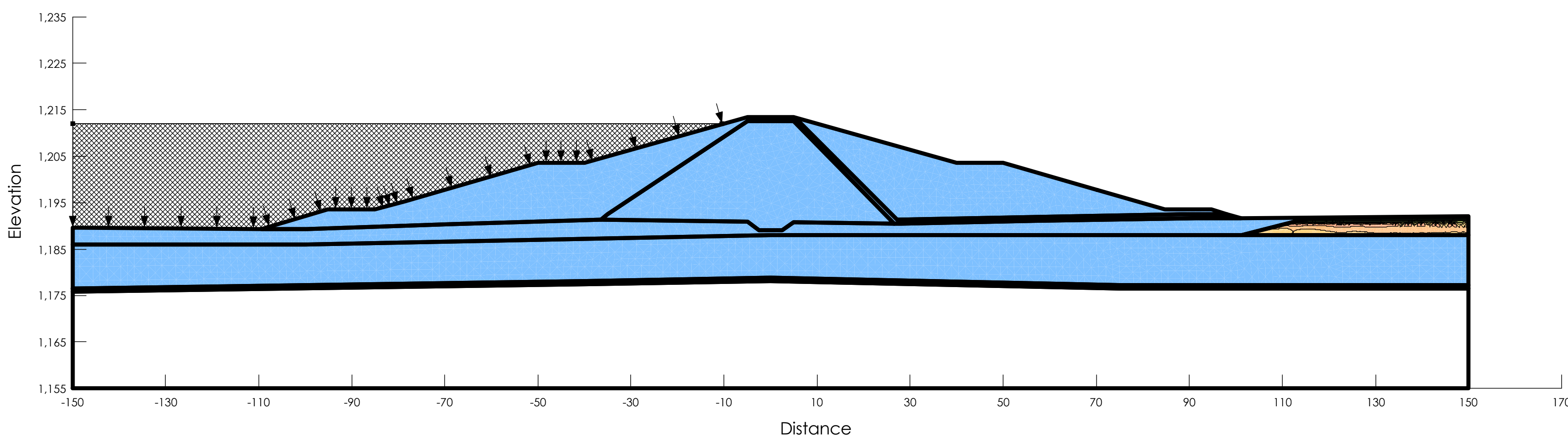


Stantec

Alberta Transportation SR1 Storage Dam

Section 22+990
Load Case: End of Construction, Year 3, Flood
Total Stress Parameters
Incipient Motion in the Downstream Direction

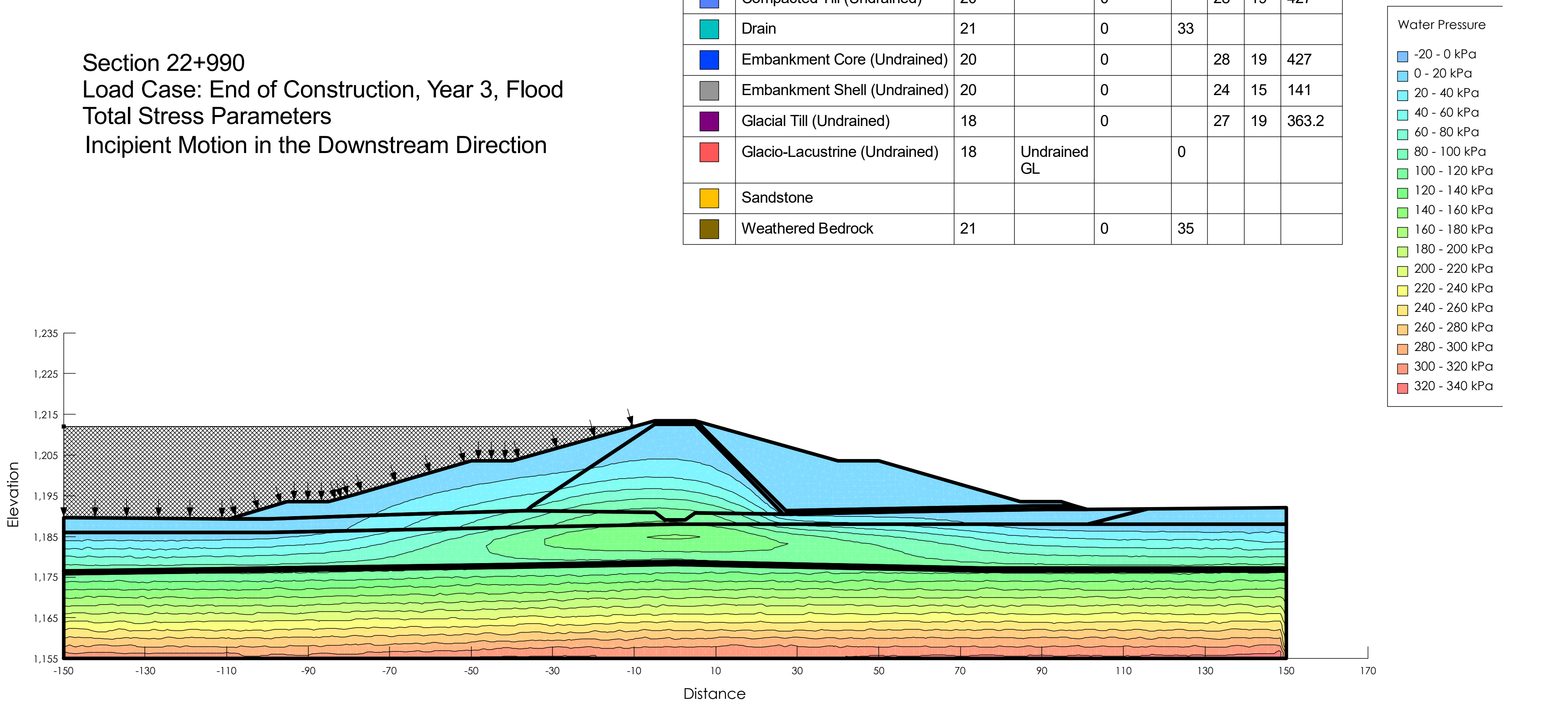
Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi' (°)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)
	Compacted Till (Undrained)	20		0		28	19	427
	Drain	21		0	33			
	Embankment Core (Undrained)	20		0		28	19	427
	Embankment Shell (Undrained)	20		0		24	15	141
	Glacial Till (Undrained)	18		0		27	19	363.2
	Glacio-Lacustrine (Undrained)	18	Undrained GL		0			
	Sandstone							
	Weathered Bedrock	21		0	35			



Alberta Transportation SR1 Storage Dam

Section 22+990
Load Case: End of Construction, Year 3, Flood
Total Stress Parameters
Incipient Motion in the Downstream Direction

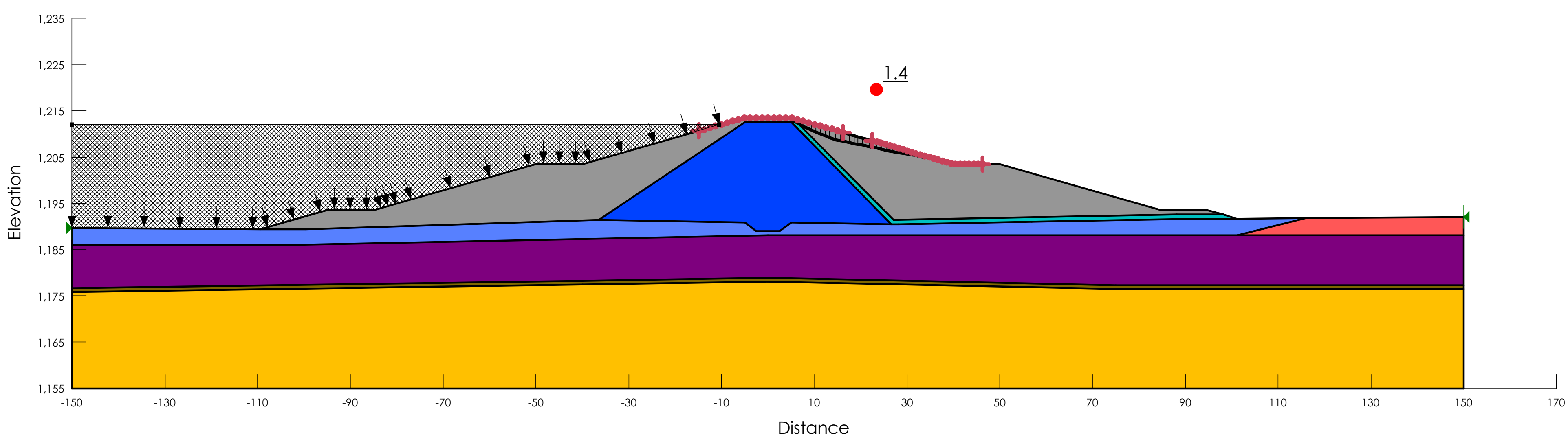
Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi' (°)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)
	Compacted Till (Undrained)	20		0		28	19	427
	Drain	21		0	33			
	Embankment Core (Undrained)	20		0		28	19	427
	Embankment Shell (Undrained)	20		0		24	15	141
	Glacial Till (Undrained)	18		0		27	19	363.2
	Glacio-Lacustrine (Undrained)	18	Undrained GL		0			
	Sandstone							
	Weathered Bedrock	21		0	35			



Alberta Transportation SR1 Storage Dam

Section 22+990
Load Case: End of Construction, Year 3, Flood
Total Stress Parameters
Incipient Motion in the Downstream Direction

Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi' (°)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)
	Compacted Till (Undrained)	20		0		28	19	427
	Drain	21		0	33			
	Embankment Core (Undrained)	20		0		28	19	427
	Embankment Shell (Undrained)	20		0		24	15	141
	Glacial Till (Undrained)	18		0		27	19	363.2
	Glacio-Lacustrine (Undrained)	18	Undrained GL		0			
	Sandstone							
	Weathered Bedrock	21		0	35			

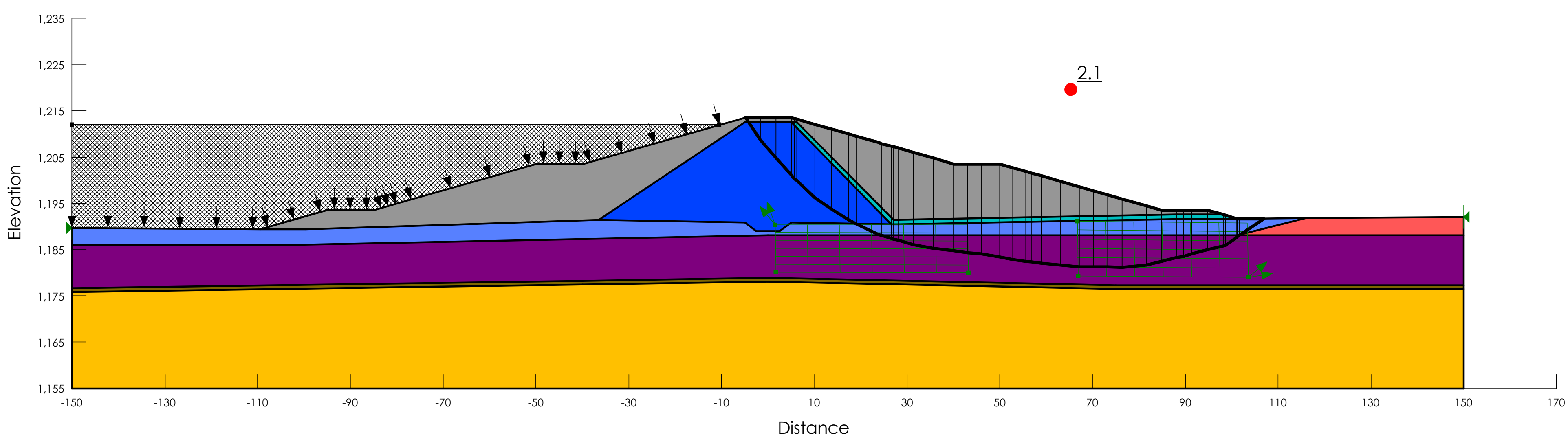


Stantec

Alberta Transportation SR1 Storage Dam

Section 22+990
Load Case: End of Construction, Year 3, Flood
Total Stress Parameters
Incipient Motion in the Downstream Direction

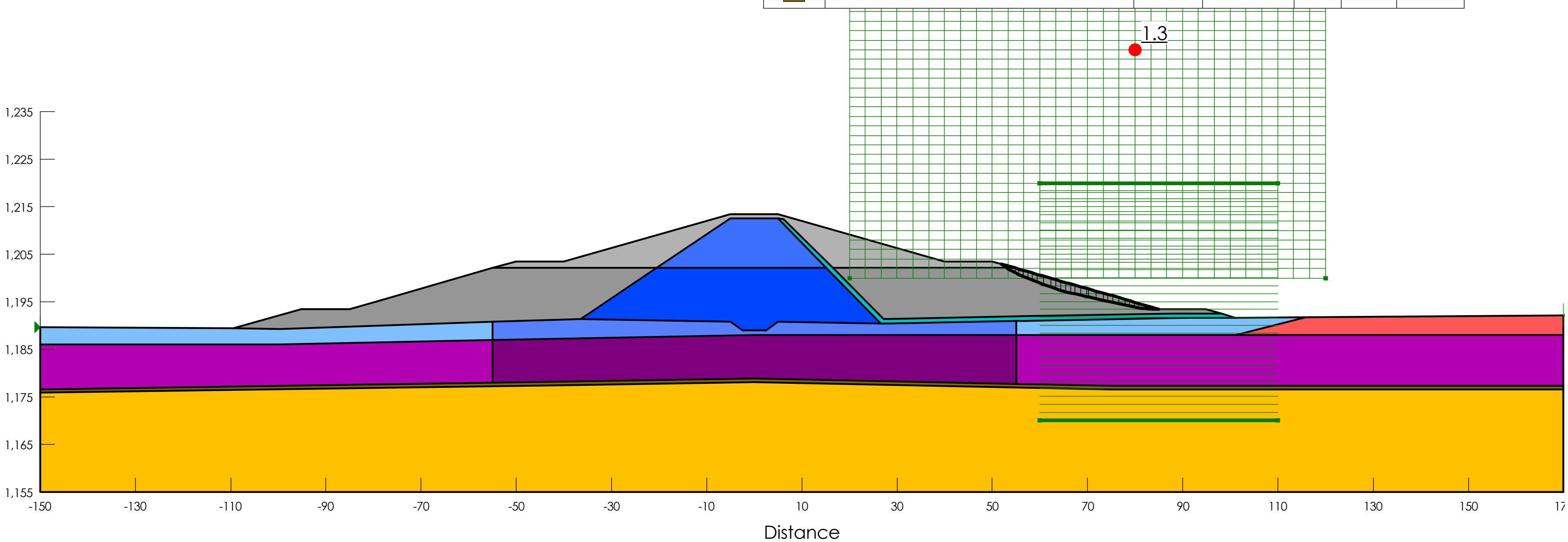
Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi' (°)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)
	Compacted Till (Undrained)	20		0		28	19	427
	Drain	21		0	33			
	Embankment Core (Undrained)	20		0		28	19	427
	Embankment Shell (Undrained)	20		0		24	15	141
	Glacial Till (Undrained)	18		0		27	19	363.2
	Glacio-Lacustrine (Undrained)	18	Undrained GL		0			
	Sandstone							
	Weathered Bedrock	21		0	35			



Alberta Transportation SR1 Storage Dam

Section 22+990
Load Case: Long Term
Effective Stress Parameters
Incipient Motion in the Downstream Direction

Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)	B-bar	Add Weight
	Compacted Till (Drained, Crest/Slope)	20	0	28	0.4	Yes
	Compacted Till (Drained, Slope/Toe)	20	0	28	0.3	Yes
	Drain	21	0	33	0	Yes
	Embankment Core (Drained, Year 2)	20	0	28	0.55	Yes
	Embankment Core (Drained, Year 3)	20	0	28	0	Yes
	Embankment Shell (Drained, Year 2)	20	0	24	0.18	Yes
	Embankment Shell (Drained, Year 3)	20	0	24	0	Yes
	Glacial Till (Drained, Crest/Slope)	18	0	27	0.4	No
	Glacial Till (Drained, Slope/Toe)	18	0	27	0.25	No
	Glacio-Lacustrine (Drained)	18	0	23	0	No
	Sandstone				0	No
	Weathered Bedrock	21	0	35	0	No

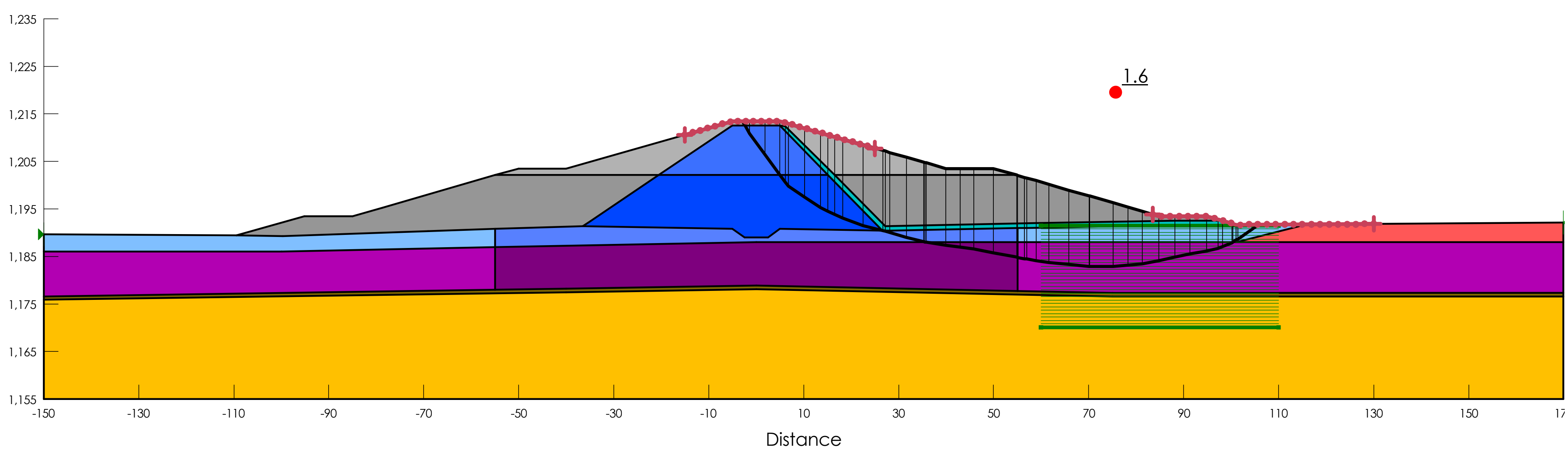


Stantec

Alberta Transportation SR1 Storage Dam

Section 22+990
Load Case: Long Term
Effective Stress Parameters
Incipient Motion in the Downstream Direction

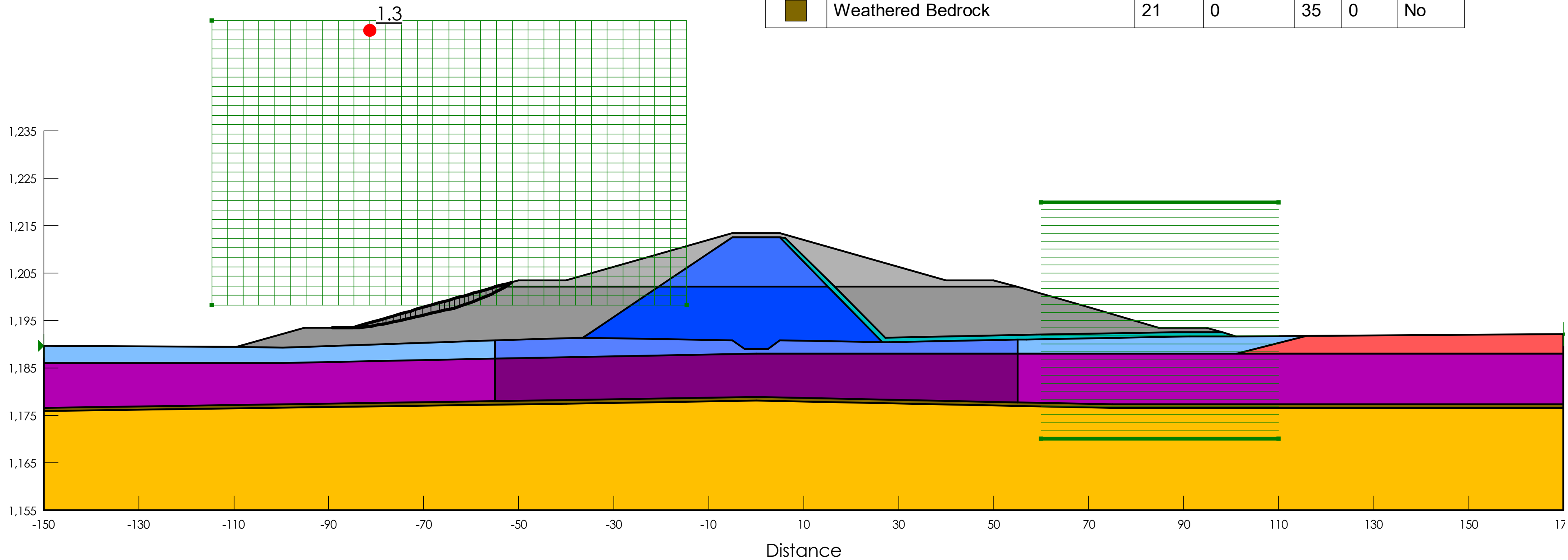
Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)	B-bar	Add Weight
	Compacted Till (Drained, Crest/Slope)	20	0	28	0.4	Yes
	Compacted Till (Drained, Slope/Toe)	20	0	28	0.3	Yes
	Drain	21	0	33	0	Yes
	Embankment Core (Drained, Year 2)	20	0	28	0.55	Yes
	Embankment Core (Drained, Year 3)	20	0	28	0	Yes
	Embankment Shell (Drained, Year 2)	20	0	24	0.18	Yes
	Embankment Shell (Drained, Year 3)	20	0	24	0	Yes
	Glacial Till (Drained, Crest/Slope)	18	0	27	0.4	No
	Glacial Till (Drained, Slope/Toe)	18	0	27	0.25	No
	Glacio-Lacustrine (Drained)	18	0	23	0	No
	Sandstone				0	No
	Weathered Bedrock	21	0	35	0	No



Alberta Transportation SR1 Storage Dam

Section 22+990
Load Case: Long Term
Effective Stress Parameters
Incipient Motion in the Downstream Direction

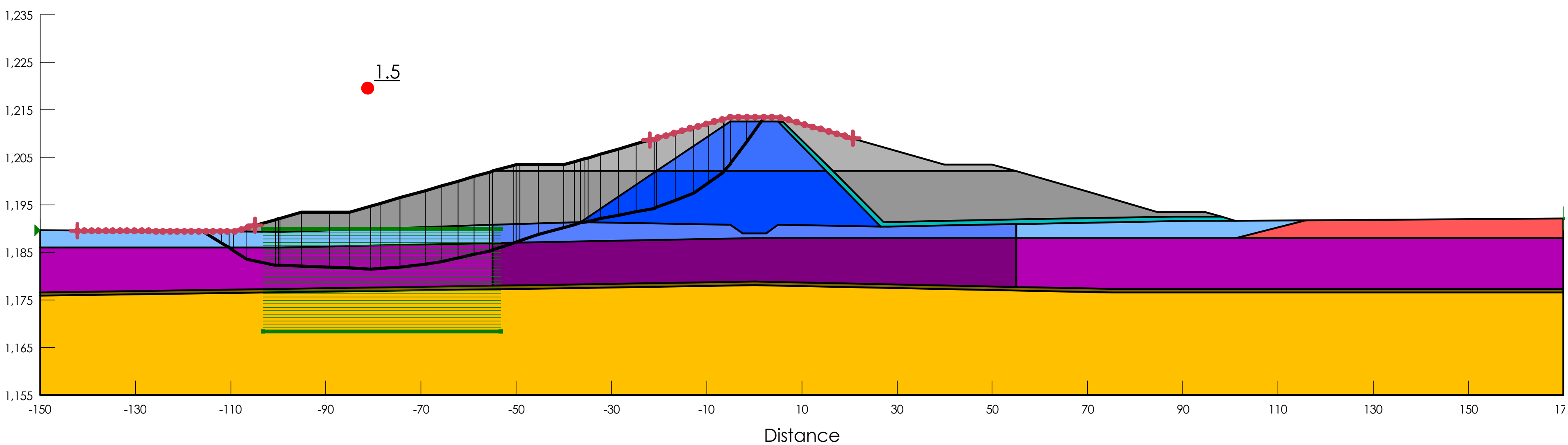
Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)	B-bar	Add Weight
	Compacted Till (Drained, Crest/Slope)	20	0	28	0.4	Yes
	Compacted Till (Drained, Slope/Toe)	20	0	28	0.3	Yes
	Drain	21	0	33	0	Yes
	Embankment Core (Drained, Year 2)	20	0	28	0.55	Yes
	Embankment Core (Drained, Year 3)	20	0	28	0	Yes
	Embankment Shell (Drained, Year 2)	20	0	24	0.18	Yes
	Embankment Shell (Drained, Year 3)	20	0	24	0	Yes
	Glacial Till (Drained, Crest/Slope)	18	0	27	0.4	No
	Glacial Till (Drained, Slope/Toe)	18	0	27	0.25	No
	Glacio-Lacustrine (Drained)	18	0	23	0	No
	Sandstone				0	No
	Weathered Bedrock	21	0	35	0	No



Alberta Transportation SR1 Storage Dam

Section 22+990
Load Case: Long Term
Effective Stress Parameters
Incipient Motion in the Downstream Direction

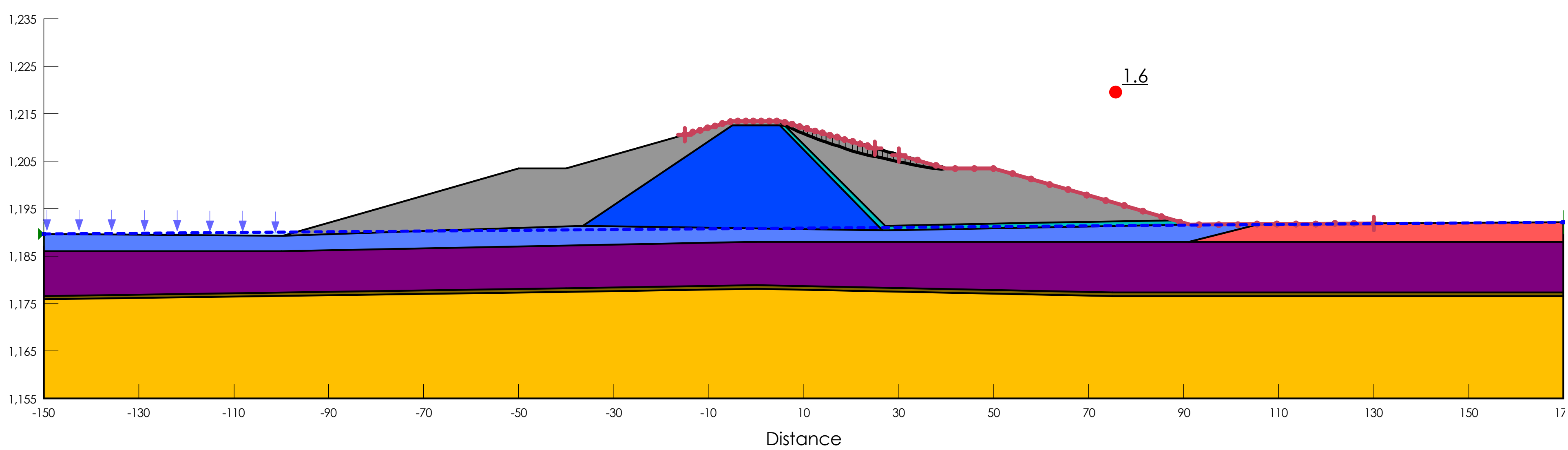
Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)	B-bar	Add Weight
	Compacted Till (Drained, Crest/Slope)	20	0	28	0.4	Yes
	Compacted Till (Drained, Slope/Toe)	20	0	28	0.3	Yes
	Drain	21	0	33	0	Yes
	Embankment Core (Drained, Year 2)	20	0	28	0.55	Yes
	Embankment Core (Drained, Year 3)	20	0	28	0	Yes
	Embankment Shell (Drained, Year 2)	20	0	24	0.18	Yes
	Embankment Shell (Drained, Year 3)	20	0	24	0	Yes
	Glacial Till (Drained, Crest/Slope)	18	0	27	0.4	No
	Glacial Till (Drained, Slope/Toe)	18	0	27	0.25	No
	Glacio-Lacustrine (Drained)	18	0	23	0	No
	Sandstone				0	No
	Weathered Bedrock	21	0	35	0	No



Alberta Transportation SR1 Storage Dam

Section 22+990
Load Case: Long Term
Effective Stress Parameters
Incipient Motion in the Downstream Direction

Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)
	Compacted Till	20	0	28
	Drain	21	0	33
	Embankment Core (Drained)	20	0	28
	Embankment Shell (Drained)	20	0	24
	Glacial Till (Drained)	18	0	27
	Glacio-Lacustrine (Drained)	18	0	23
	Sandstone			
	Weathered Bedrock	21	0	35

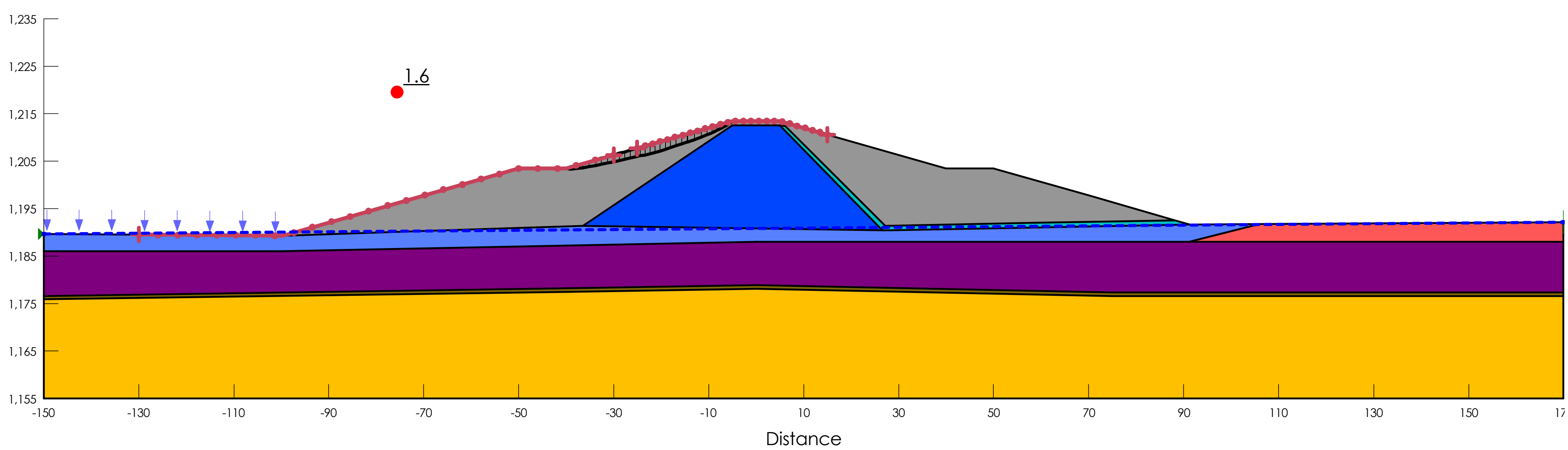


Stantec

Alberta Transportation SR1 Storage Dam

Section 22+990
Load Case: Long Term
Effective Stress Parameters
Incipient Motion in the Upstream Direction

Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)
	Compacted Till	20	0	28
	Drain	21	0	33
	Embankment Core (Drained)	20	0	28
	Embankment Shell (Drained)	20	0	24
	Glacial Till (Drained)	18	0	27
	Glacio-Lacustrine (Drained)	18	0	23
	Sandstone			
	Weathered Bedrock	21	0	35

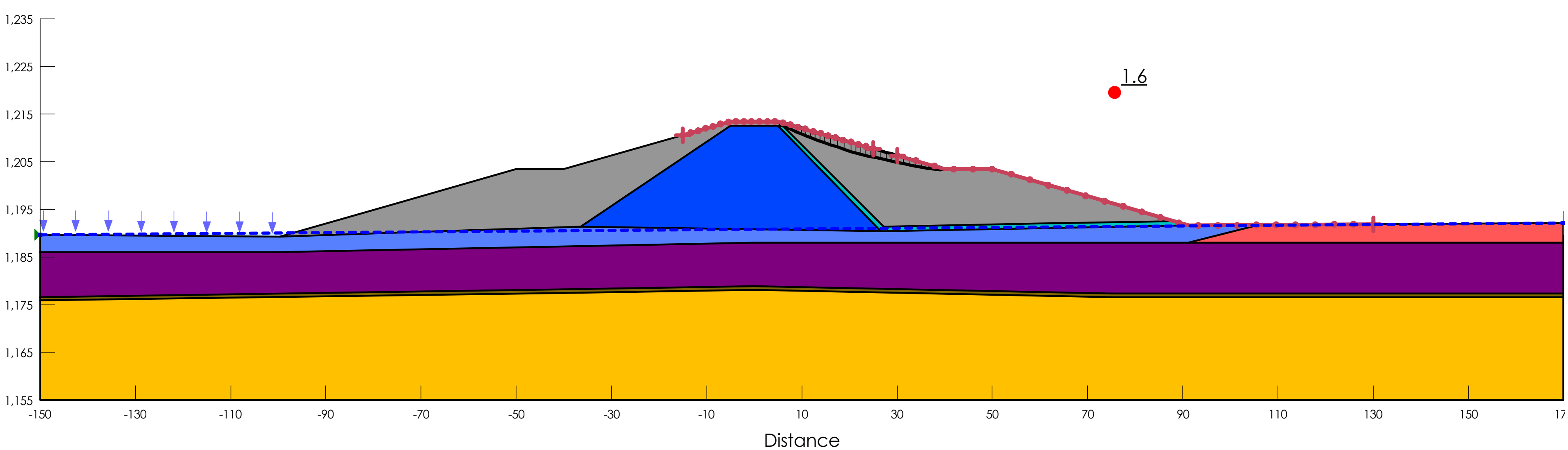


Stantec

Alberta Transportation SR1 Storage Dam

Section 22+990
Load Case: Post Earthquake
Post Earthquake Parameters
Incipient Motion in the Downstream Direction

Color	Name	Unit Weight (kN/m³)	Minimum Strength (kPa)	Tau/Sigma Ratio	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)
	Compacted Till	20			0				28
	Drain	21			0				33
	Embankment Core (EQ/Pseudo)	20			0	28	15	243	
	Embankment Shell (EQ/Pseudo)	20			0	24	12	86	
	Glacial Till (EQ/Pseudo)	18			0	27	15	199	
	Glacio-Lacustrine (EQ/Pseudo)	18	0	0.212					
	Sandstone								
	Weathered Bedrock	21			0				35

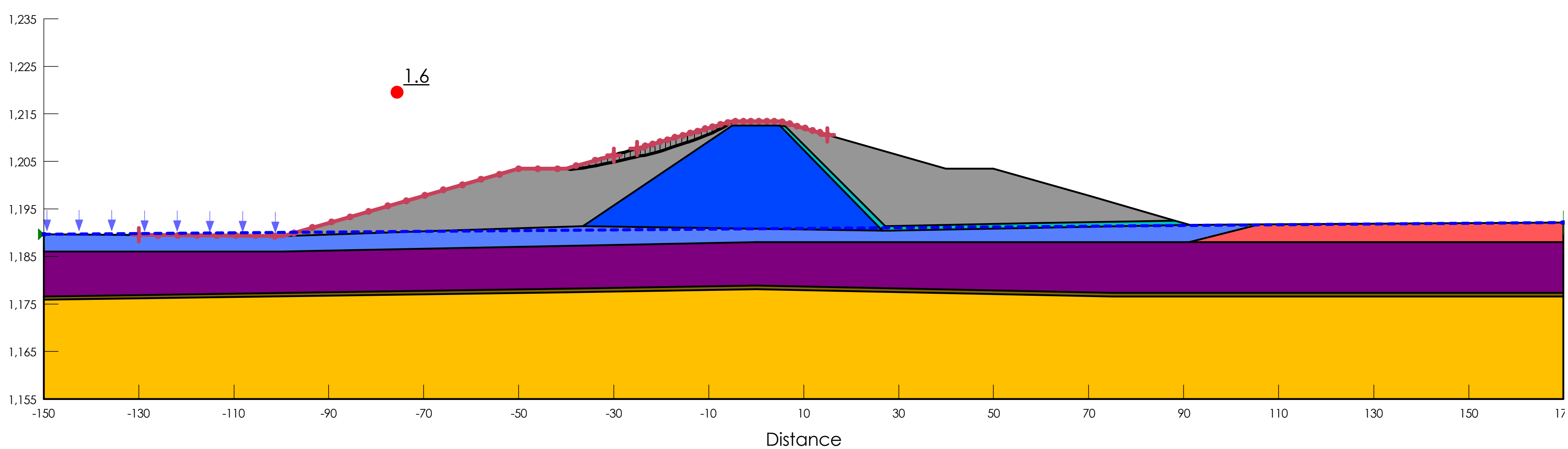


Stantec

Alberta Transportation SR1 Storage Dam

Section 22+990
Load Case: Post Earthquake
Post Earthquake Parameters
Incipient Motion in the Upstream Direction

Color	Name	Unit Weight (kN/m³)	Minimum Strength (kPa)	Tau/Sigma Ratio	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)
	Compacted Till	20			0				28
	Drain	21			0				33
	Embankment Core (EQ/Pseudo)	20			0	28	15	243	
	Embankment Shell (EQ/Pseudo)	20			0	24	12	86	
	Glacial Till (EQ/Pseudo)	18			0	27	15	199	
	Glacio-Lacustrine (EQ/Pseudo)	18	0	0.212					
	Sandstone								
	Weathered Bedrock	21			0				35

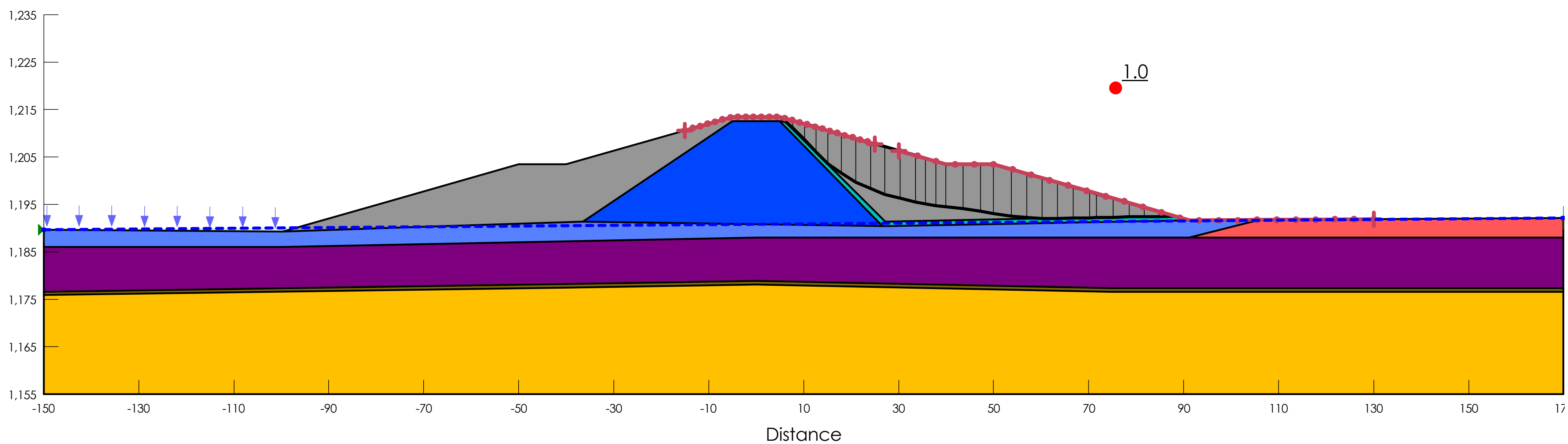


Stantec

Alberta Transportation SR1 Storage Dam

Section 22+990
Load Case: Pseudostatic
Pseudostatic Parameters
Incipient Motion in the Downstream Direction

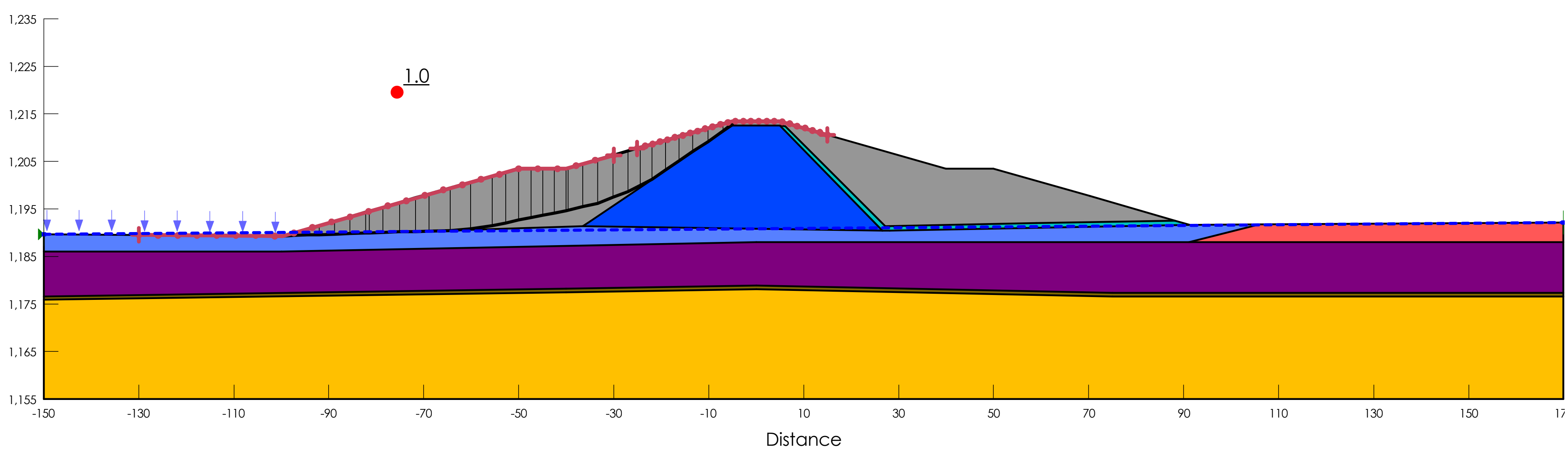
Color	Name	Unit Weight (kN/m³)	Minimum Strength (kPa)	Tau/Sigma Ratio	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)	Co R (k
	Compacted Till	20			0				28	0
	Drain	21			0				33	0
	Embankment Core (EQ/Pseudo)	20			0	28	15	243		
	Embankment Shell (EQ/Pseudo)	20			0	24	12	86		
	Glacial Till (EQ/Pseudo)	18			0	27	15	199		
	Glacio-Lacustrine (EQ/Pseudo)	18	0	0.212						
	Sandstone									
	Weathered Bedrock	21			0				35	0



Alberta Transportation SR1 Storage Dam

Section 22+990
Load Case: Pseudostatic
Pseudostatic Parameters
Incipient Motion in the Upstream Direction

Color	Name	Unit Weight (kN/m³)	Minimum Strength (kPa)	Tau/Sigma Ratio	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)	Col R (k
	Compacted Till	20			0				28	0
	Drain	21			0				33	0
	Embankment Core (EQ/Pseudo)	20			0	28	15	243		
	Embankment Shell (EQ/Pseudo)	20			0	24	12	86		
	Glacial Till (EQ/Pseudo)	18			0	27	15	199		
	Glacio-Lacustrine (EQ/Pseudo)	18	0	0.212						
	Sandstone									
	Weathered Bedrock	21			0				35	0

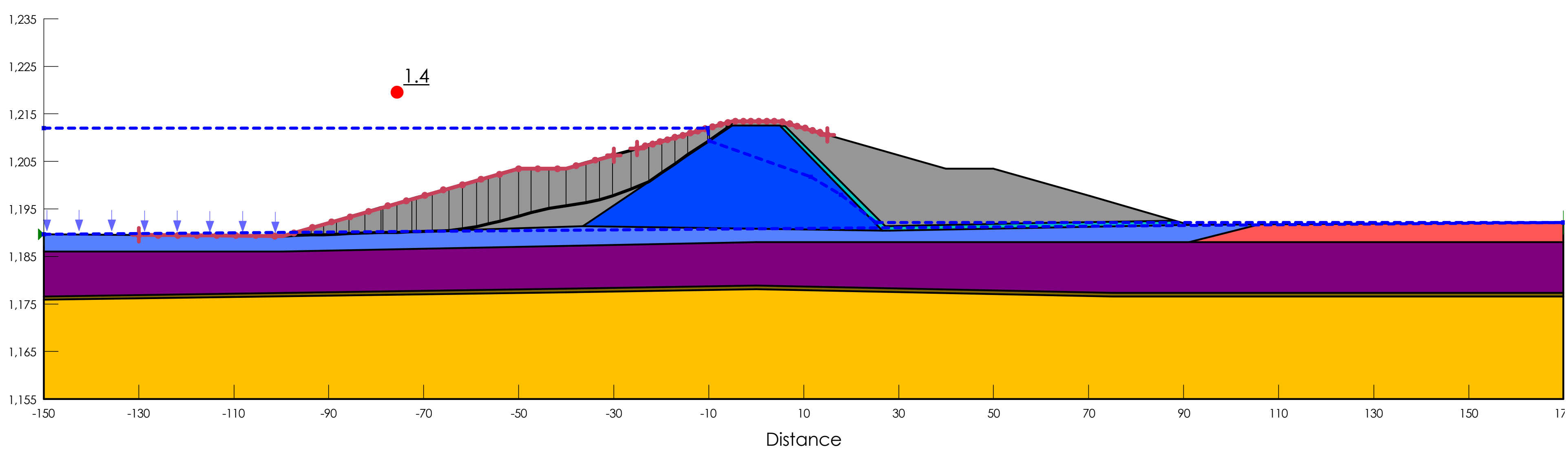


Stantec

Alberta Transportation SR1 Storage Dam

Section 22+990
Load Case: Rapid Drawdown
Effective and Total Parameters
Incipient Motion in the Upstream Direction

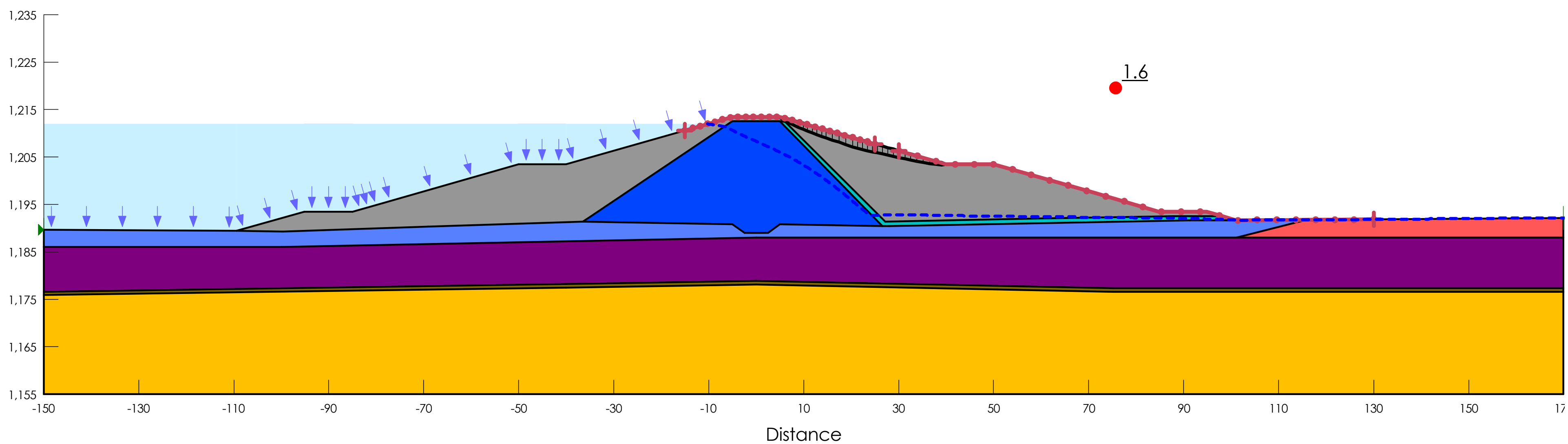
Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)	Cohesion R (kPa)	Phi R (°)	Piezometric Line After Drawdown
	Compacted Till	20	0	28	0	0	1
	Drain	21	0	33	0	0	1
	Embankment Core (RDD)	20	0	28	80	19	1
	Embankment Shell (RDD)	20	0	24	25	15	1
	Glacial Till (RDD)	18	0	27	60	19	1
	Glacio-Lacustrine (RDD)	18	0	23	15	20	1
	Sandstone						1
	Weathered Bedrock	21	0	35	0	0	1



Alberta Transportation SR1 Storage Dam

Section 22+990
Load Case: USBR Flood
Effective Parameters
Incipient Motion in the Downstream Direction

Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)
	Compacted Till	20	0	28
	Drain	21	0	33
	Embankment Core (Drained)	20	0	28
	Embankment Shell (Drained)	20	0	24
	Glacial Till (Drained)	18	0	27
	Glacio-Lacustrine (Drained)	18	0	23
	Sandstone			
	Weathered Bedrock	21	0	35

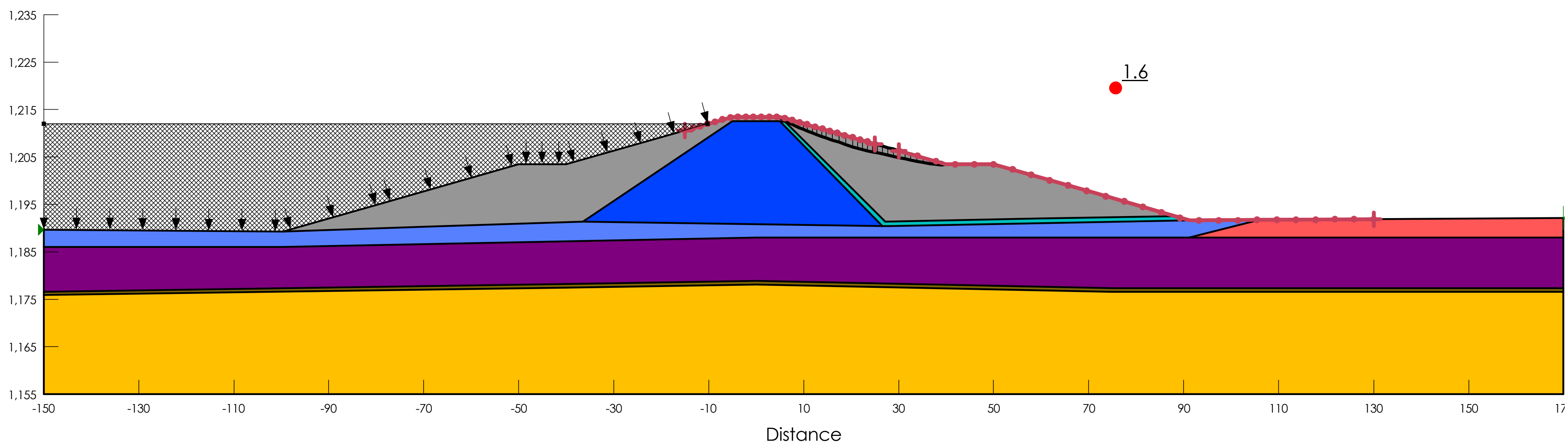


Stantec

Alberta Transportation SR1 Storage Dam

Section 22+990
Load Case: Yield Acceleration
Pseudostatic Parameters
Incipient Motion in the Downstream Direction

Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)
	Compacted Till	20	0				28
	Drain	21	0				33
	Embankment Core (Undrained)	20	0	28	19	427	
	Embankment Shell (Undrained)	20	0	24	15	141	
	Glacial Till (Undrained)	18	0	27	19	363.2	
	Glacio-Lacustrine (Undrained)	18	0				23
	Sandstone						
	Weathered Bedrock	21	0				35



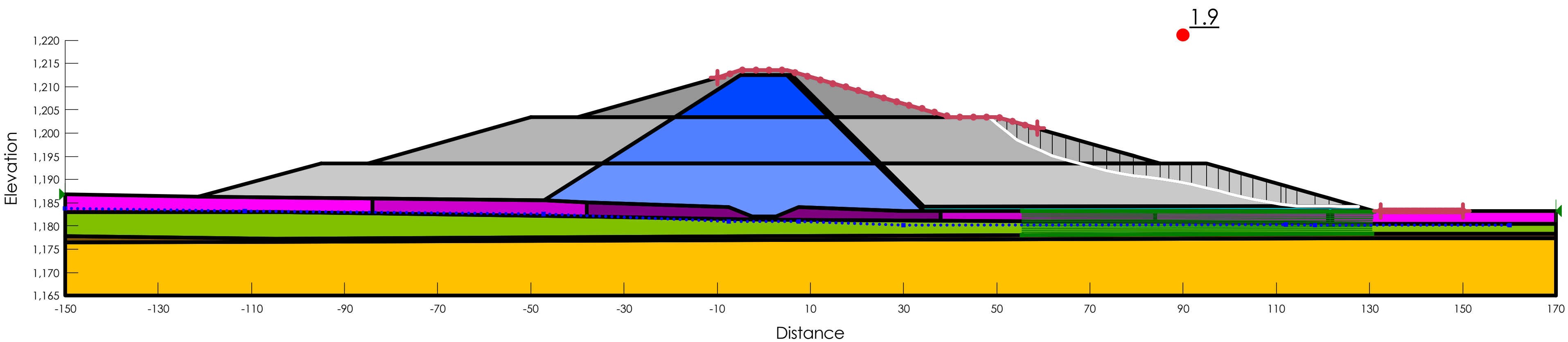
Attachment 12.1
Slope Stability and Seepage Analyses

12.1.7 Slope Stability Analyses
Sta. 23+175

Alberta Transportation SR1 Storage Dam

Section 23+175
Load Case: End of Construction, Year 3
B-bar Analysis
Effective Stress Parameters

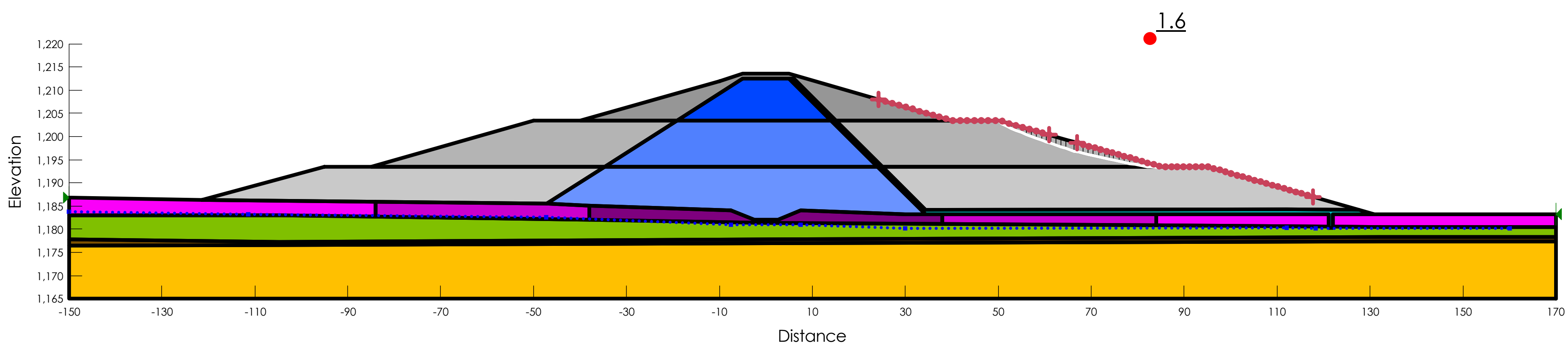
Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)	B-bar	Add Weight
	Drain	21	0	33	0	Yes
	Embankment Core (Drained, Year 1)	20	0	28	0.5	Yes
	Embankment Core (Drained, Year 2)	20	0	28	0.4	Yes
	Embankment Core (Drained, Year 3)	20	0	28	0	Yes
	Embankment Shell (Drained, Year 1)	20	0	24	0.18	Yes
	Embankment Shell (Drained, Year 2)	20	0	24	0.15	Yes
	Embankment Shell (Drained, Year 3)	20	0	24	0	Yes
	Fluvial (Unnamed Creek)	22	0	35	0	No
	Glacial Till (Drained, Crest)	18	0	27	0.4	No
	Glacial Till (Drained, Slope)	18	0	27	0.3	No
	Glacial Till (Drained, Toe)	18	0	27	0.2	No
	Sandstone				0	No
	Weathered Bedrock	21	0	35	0	No



Alberta Transportation SR1 Storage Dam

Section 23+175
Load Case: End of Construction, Year 3
B-bar Analysis
Effective Stress Parameters

Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)	B-bar	Add Weight
	Drain	21	0	33	0	Yes
	Embankment Core (Drained, Year 1)	20	0	28	0.5	Yes
	Embankment Core (Drained, Year 2)	20	0	28	0.4	Yes
	Embankment Core (Drained, Year 3)	20	0	28	0	Yes
	Embankment Shell (Drained, Year 1)	20	0	24	0.18	Yes
	Embankment Shell (Drained, Year 2)	20	0	24	0.15	Yes
	Embankment Shell (Drained, Year 3)	20	0	24	0	Yes
	Fluvial (Unnamed Creek)	22	0	35	0	No
	Glacial Till (Drained, Crest)	18	0	27	0.4	No
	Glacial Till (Drained, Slope)	18	0	27	0.3	No
	Glacial Till (Drained, Toe)	18	0	27	0.2	No
	Sandstone				0	No
	Weathered Bedrock	21	0	35	0	No

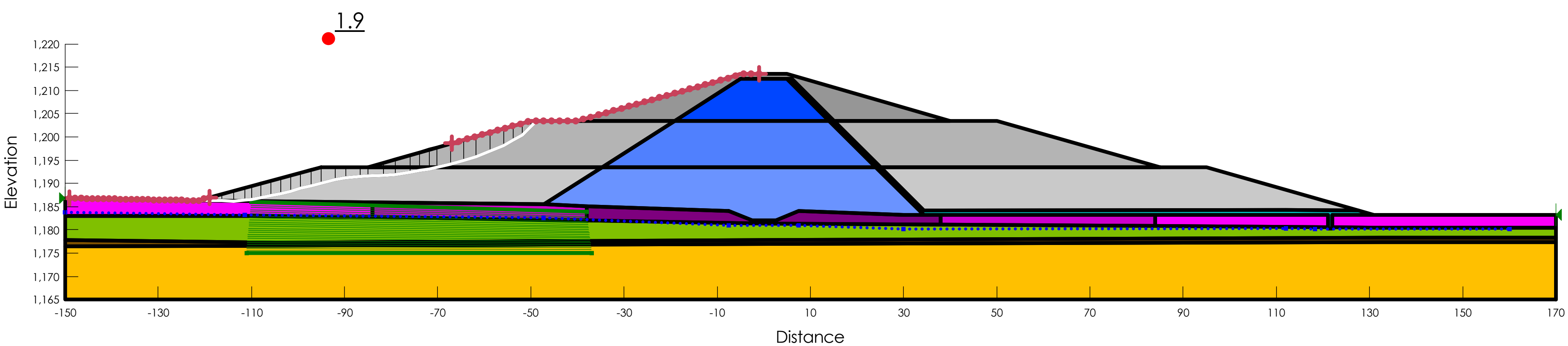


Stantec

Alberta Transportation SR1 Storage Dam

Section 23+175
Load Case: End of Construction, Year 3
B-bar Analysis
Effective Stress Parameters

Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)	B-bar	Add Weight
	Drain	21	0	33	0	Yes
	Embankment Core (Drained, Year 1)	20	0	28	0.5	Yes
	Embankment Core (Drained, Year 2)	20	0	28	0.4	Yes
	Embankment Core (Drained, Year 3)	20	0	28	0	Yes
	Embankment Shell (Drained, Year 1)	20	0	24	0.18	Yes
	Embankment Shell (Drained, Year 2)	20	0	24	0.15	Yes
	Embankment Shell (Drained, Year 3)	20	0	24	0	Yes
	Fluvial (Unnamed Creek)	22	0	35	0	No
	Glacial Till (Drained, Crest)	18	0	27	0.4	No
	Glacial Till (Drained, Slope)	18	0	27	0.3	No
	Glacial Till (Drained, Toe)	18	0	27	0.2	No
	Sandstone				0	No
	Weathered Bedrock	21	0	35	0	No

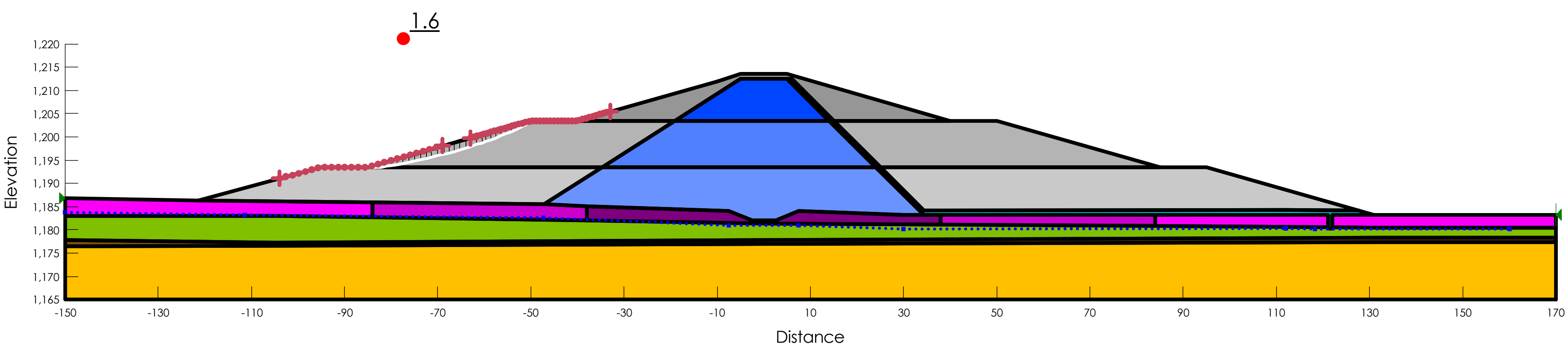


Stantec

Alberta Transportation SR1 Storage Dam

Section 23+175
Load Case: End of Construction, Year 3
B-bar Analysis
Effective Stress Parameters

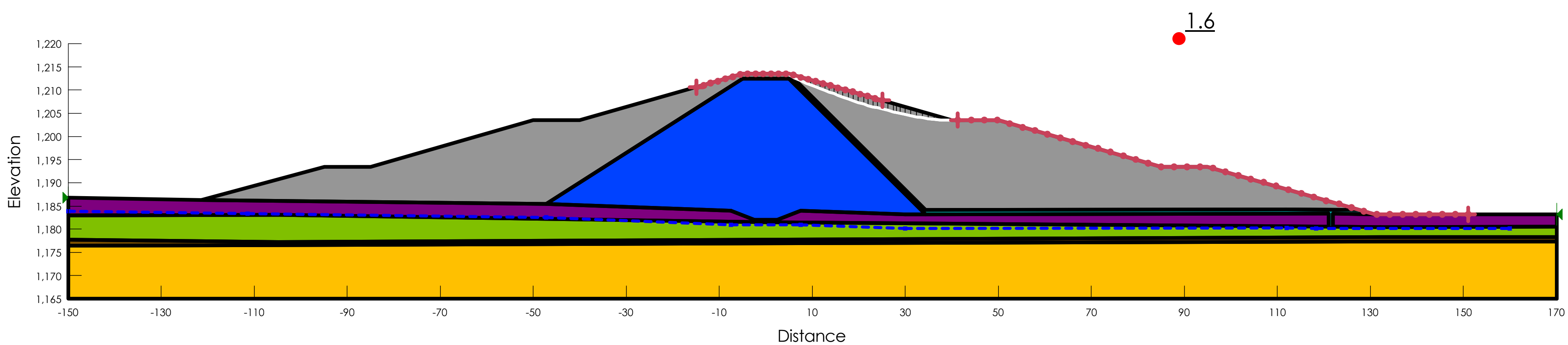
Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)	B-bar	Add Weight
	Drain	21	0	33	0	Yes
	Embankment Core (Drained, Year 1)	20	0	28	0.5	Yes
	Embankment Core (Drained, Year 2)	20	0	28	0.4	Yes
	Embankment Core (Drained, Year 3)	20	0	28	0	Yes
	Embankment Shell (Drained, Year 1)	20	0	24	0.18	Yes
	Embankment Shell (Drained, Year 2)	20	0	24	0.15	Yes
	Embankment Shell (Drained, Year 3)	20	0	24	0	Yes
	Fluvial (Unnamed Creek)	22	0	35	0	No
	Glacial Till (Drained, Crest)	18	0	27	0.4	No
	Glacial Till (Drained, Slope)	18	0	27	0.3	No
	Glacial Till (Drained, Toe)	18	0	27	0.2	No
	Sandstone				0	No
	Weathered Bedrock	21	0	35	0	No



Alberta Transportation SR1 Storage Dam

Section 23+175
Load Case: End of Construction
Total Stress Parameters
Incipient Motion in the Downstream Direction

Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)
	Drain	21	0				33
	Embankment Core (Undrained)	20	0	28	19	427	
	Embankment Shell (Undrained)	20	0	24	15	141	
	Fluvial (Unnamed Creek)	22	0				35
	Glacial Till (Undrained)	18	0	27	19	363.2	
	Sandstone						
	Weathered Bedrock	21	0				35

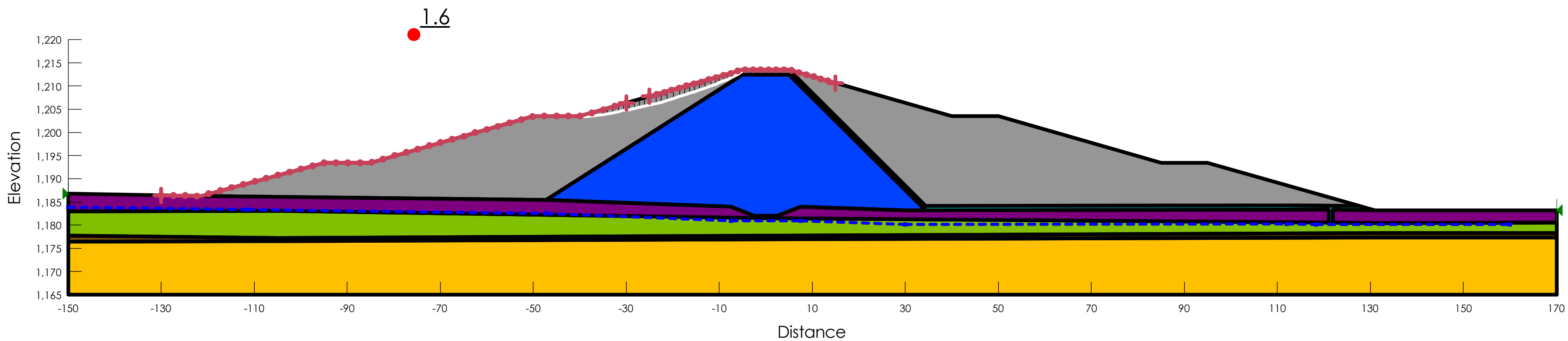


Stantec

Alberta Transportation SR1 Storage Dam

Section 23+175
Load Case: End of Construction
Total Stress Parameters
Incipient Motion in the Upstream Direction

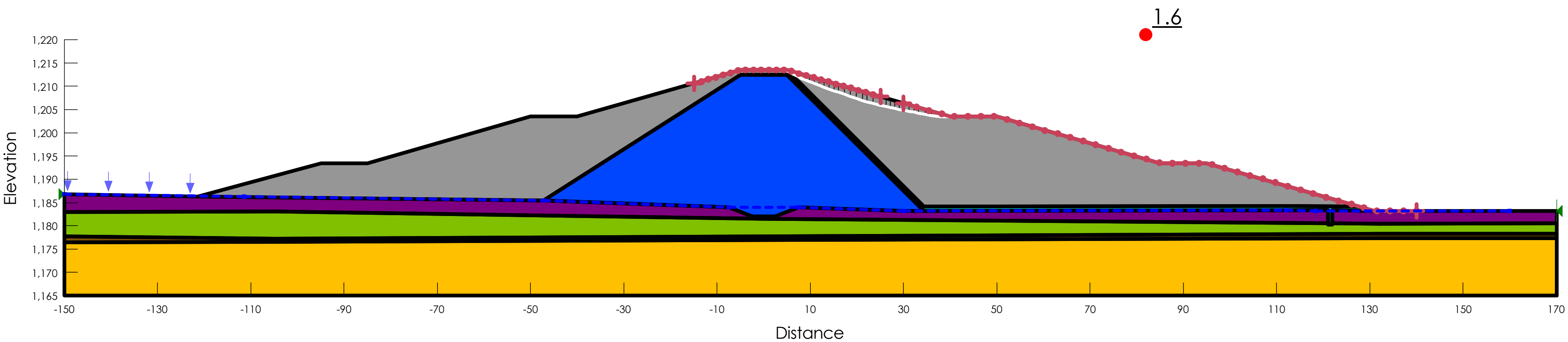
Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)
	Drain	21	0				33
	Embankment Core (Undrained)	20	0	28	19	427	
	Embankment Shell (Undrained)	20	0	24	15	141	
	Fluvial (Unnamed Creek)	22	0				35
	Glacial Till (Undrained)	18	0	27	19	363.2	
	Sandstone						
	Weathered Bedrock	21	0				35



Alberta Transportation SR1 Storage Dam

Section 23+175
Load Case: Long Term
Effective Stress Parameters
Incipient Motion in the Downstream Direction

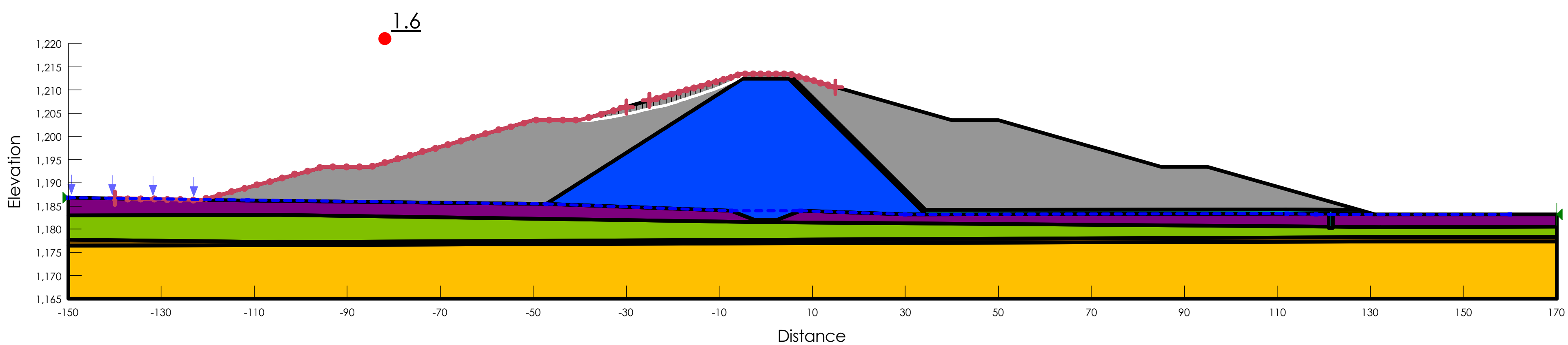
Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)
	Drain	21	0	33
	Embankment Core (Drained)	20	0	28
	Embankment Shell (Drained)	20	0	24
	Fluvial (Unnamed Creek)	22	0	35
	Glacial Till (Drained)	18	0	27
	Sandstone			
	Weathered Bedrock	21	0	35



Alberta Transportation SR1 Storage Dam

Section 23+175
Load Case: Long Term
Effective Stress Parameters
Incipient Motion in the Upstream Direction

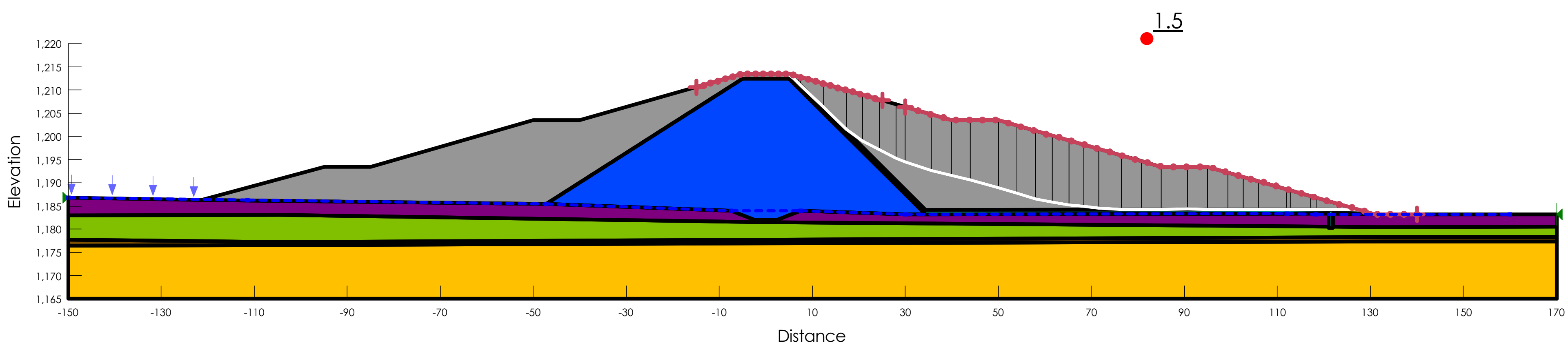
Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)
	Drain	21	0	33
	Embankment Core (Drained)	20	0	28
	Embankment Shell (Drained)	20	0	24
	Fluvial (Unnamed Creek)	22	0	35
	Glacial Till (Drained)	18	0	27
	Sandstone			
	Weathered Bedrock	21	0	35



Alberta Transportation SR1 Storage Dam

Section 23+175
Load Case: Post Earthquake
Pseudostatic Stress Parameters
Incipient Motion in the Downstream Direction

Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)
	Drain	21	0				33
	Embankment Core (EQ/Pseudo)	20	0	28	15	243	
	Embankment Shell (EQ/Pseudo)	20	0	24	12	86	
	Fluvial (Unnamed Creek)	22	0				35
	Glacial Till (EQ/Pseudo)	18	0	27	15	199	
	Sandstone						
	Weathered Bedrock	21	0				35

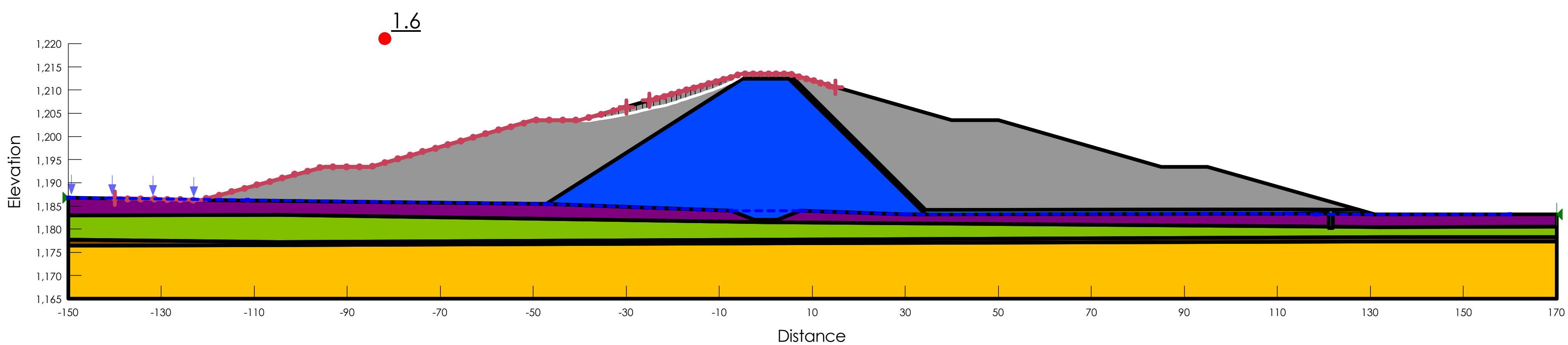


Stantec

Alberta Transportation SR1 Storage Dam

Section 23+175
Load Case: Post Earthquake
Pseudostatic Stress Parameters
Incipient Motion in the Upstream Direction

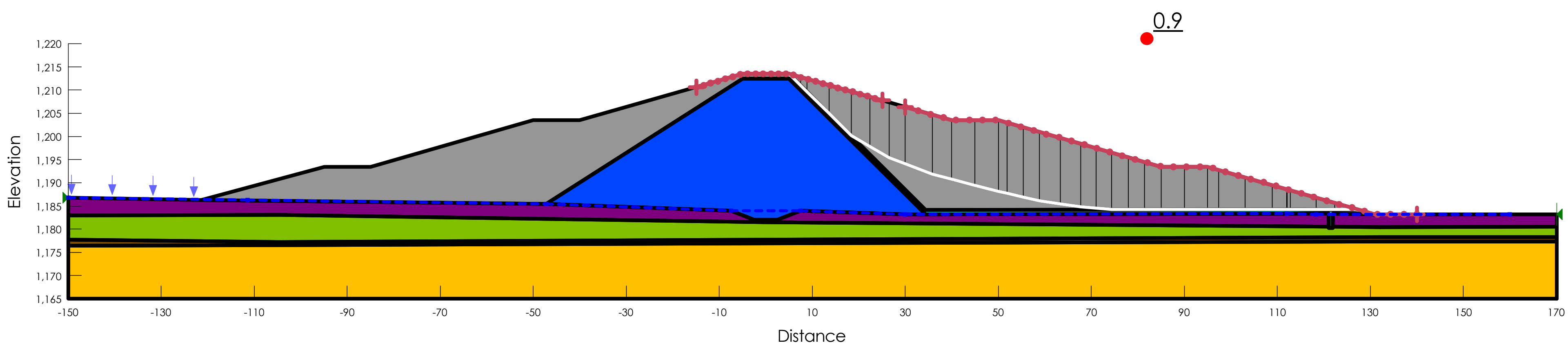
Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)
	Drain	21	0				33
	Embankment Core (EQ/Pseudo)	20	0	28	15	243	
	Embankment Shell (EQ/Pseudo)	20	0	24	12	86	
	Fluvial (Unnamed Creek)	22	0				35
	Glacial Till (EQ/Pseudo)	18	0	27	15	199	
	Sandstone						
	Weathered Bedrock	21	0				35



Alberta Transportation SR1 Storage Dam

Section 23+175
Load Case: Pseudostatic
Pseudostatic Stress Parameters
Incipient Motion in the Downstream Direction

Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)	Cohesion R (kPa)	Phi R (°)
	Drain	21	0				33	0	0
	Embankment Core (EQ/Pseudo)	20	0	28	15	243			
	Embankment Shell (EQ/Pseudo)	20	0	24	12	86			
	Fluvial (Unnamed Creek)	22	0				35	0	0
	Glacial Till (EQ/Pseudo)	18	0	27	15	199			
	Sandstone								
	Weathered Bedrock	21	0				35	0	0

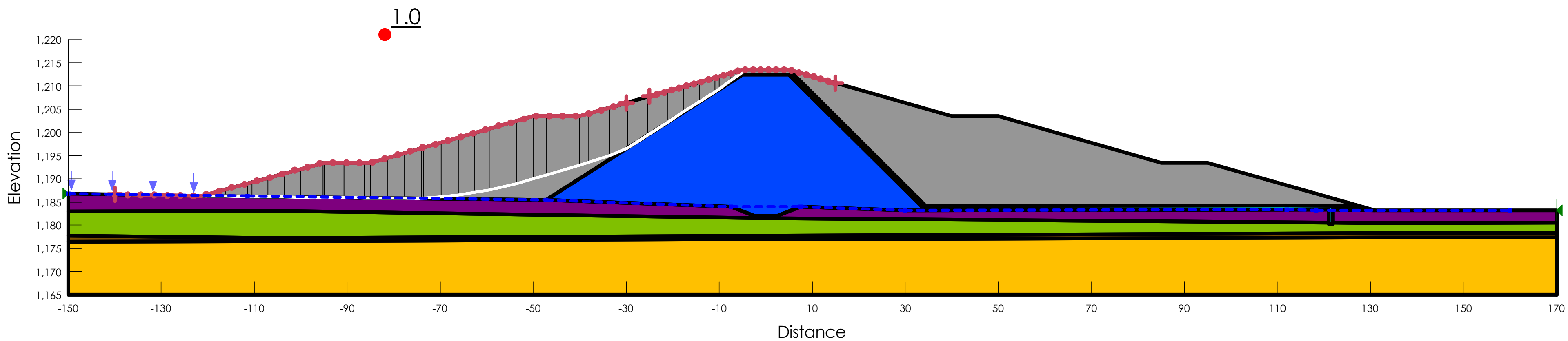


Stantec

Alberta Transportation SR1 Storage Dam

Section 23+175
Load Case: Pseudostatic
Pseudostatic Stress Parameters
Incipient Motion in the Upstream Direction

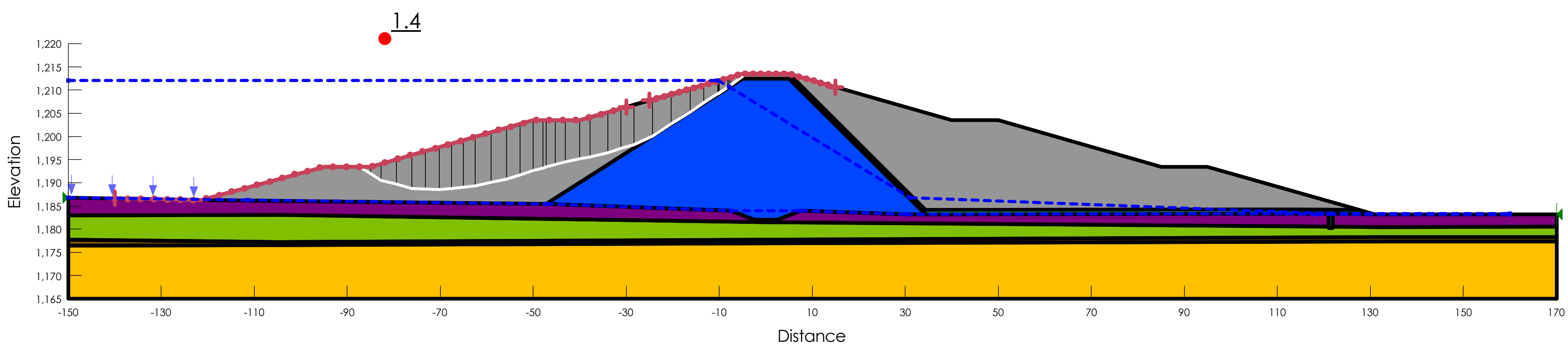
Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)	Cohesion R (kPa)	Phi R (°)
	Drain	21	0				33	0	0
	Embankment Core (EQ/Pseudo)	20	0	28	15	243			
	Embankment Shell (EQ/Pseudo)	20	0	24	12	86			
	Fluvial (Unnamed Creek)	22	0				35	0	0
	Glacial Till (EQ/Pseudo)	18	0	27	15	199			
	Sandstone								
	Weathered Bedrock	21	0				35	0	0



Alberta Transportation SR1 Storage Dam

Section 23+175
Load Case: Rapid Drawdown
Effective and Total Stress Parameters
Incipient Motion in the Upstream Direction

Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)	Cohesion R (kPa)	Phi R (°)
	Drain	21	0	33	0	0
	Embankment Core (RDD)	20	0	28	80	19
	Embankment Shell (RDD)	20	0	24	25	15
	Fluvial (Unnamed Creek)	22	0	35	0	0
	Glacial Till (RDD)	18	0	27	60	19
	Sandstone					
	Weathered Bedrock	21	0	35	0	0

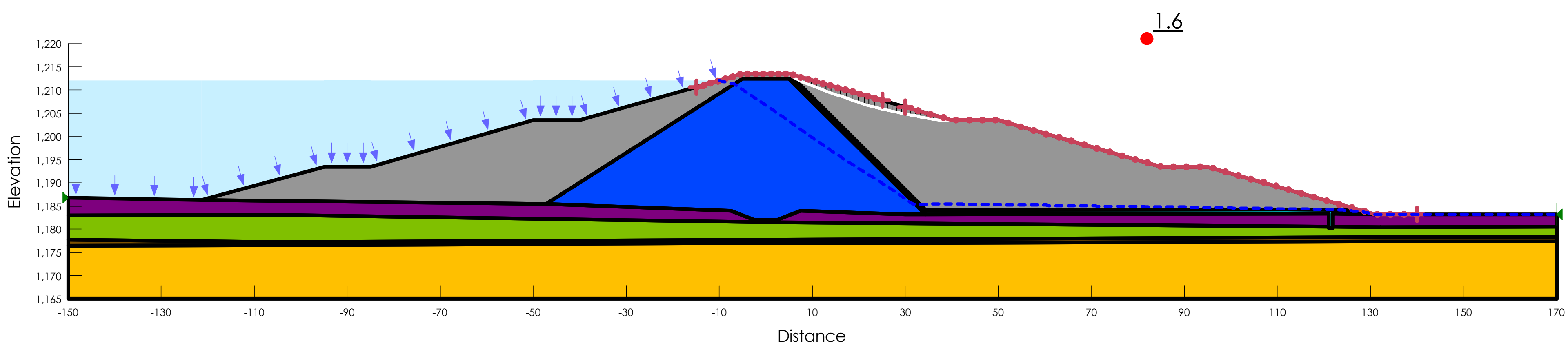


Stantec

Alberta Transportation SR1 Storage Dam

Section 23+175
Load Case: USBR Flood
Effective Stress Parameters
Incipient Motion in the Upstream Direction

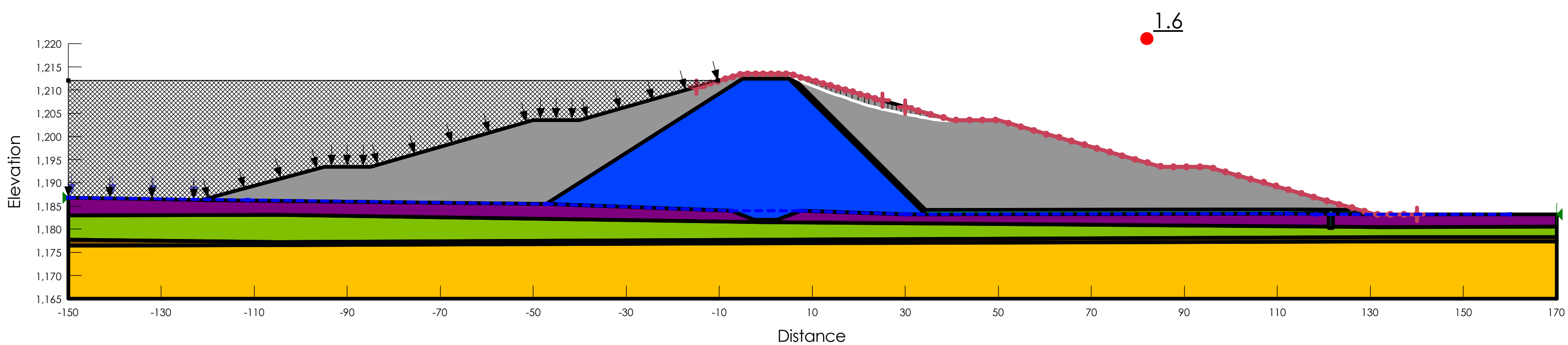
Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)
	Drain	21	0	33
	Embankment Core (Drained)	20	0	28
	Embankment Shell (Drained)	20	0	24
	Fluvial (Unnamed Creek)	22	0	35
	Glacial Till (Drained)	18	0	27
	Sandstone			
	Weathered Bedrock	21	0	35



Alberta Transportation SR1 Storage Dam

Section 23+175
Load Case: USACE Flood
Total Stress Parameters
Incipient Motion in the Downstream Direction

Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)
	Drain	21	0				33
	Embankment Core (Undrained)	20	0	28	19	427	
	Embankment Shell (Undrained)	20	0	24	15	141	
	Fluvial (Unnamed Creek)	22	0				35
	Glacial Till (Undrained)	18	0	27	19	363.2	
	Sandstone						
	Weathered Bedrock	21	0				35



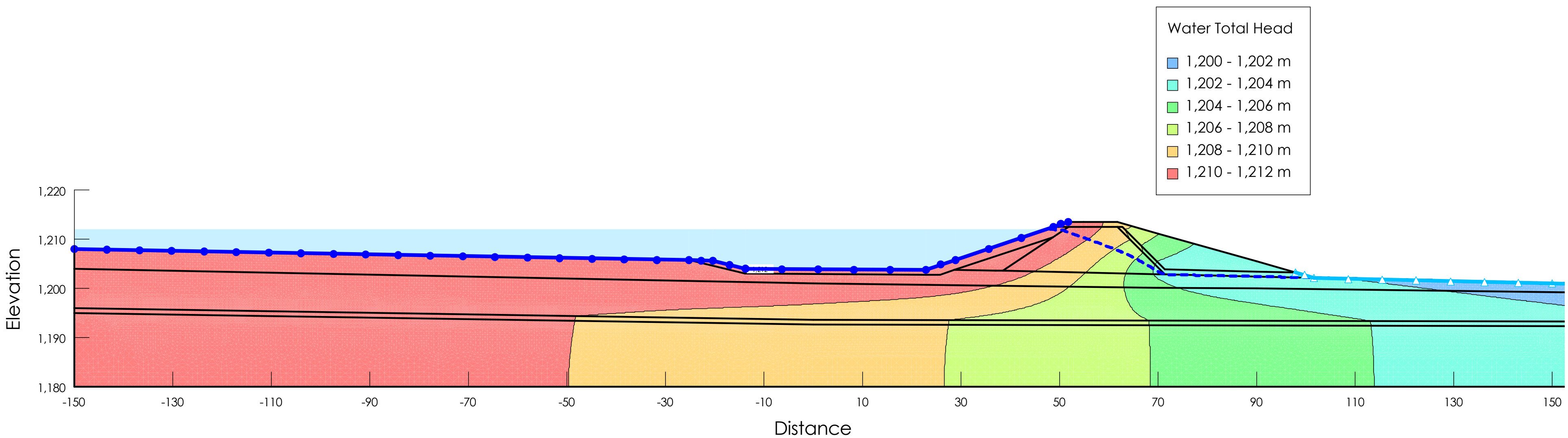
Attachment 12.1
Slope Stability and Seepage Analyses

12.1.8 Seepage Analyses
Seepage Results and Exit Gradient Calculations

Alberta Transportation SR1 Storage Dam

Section 20+000
Load Case: Seepage
Steady-State

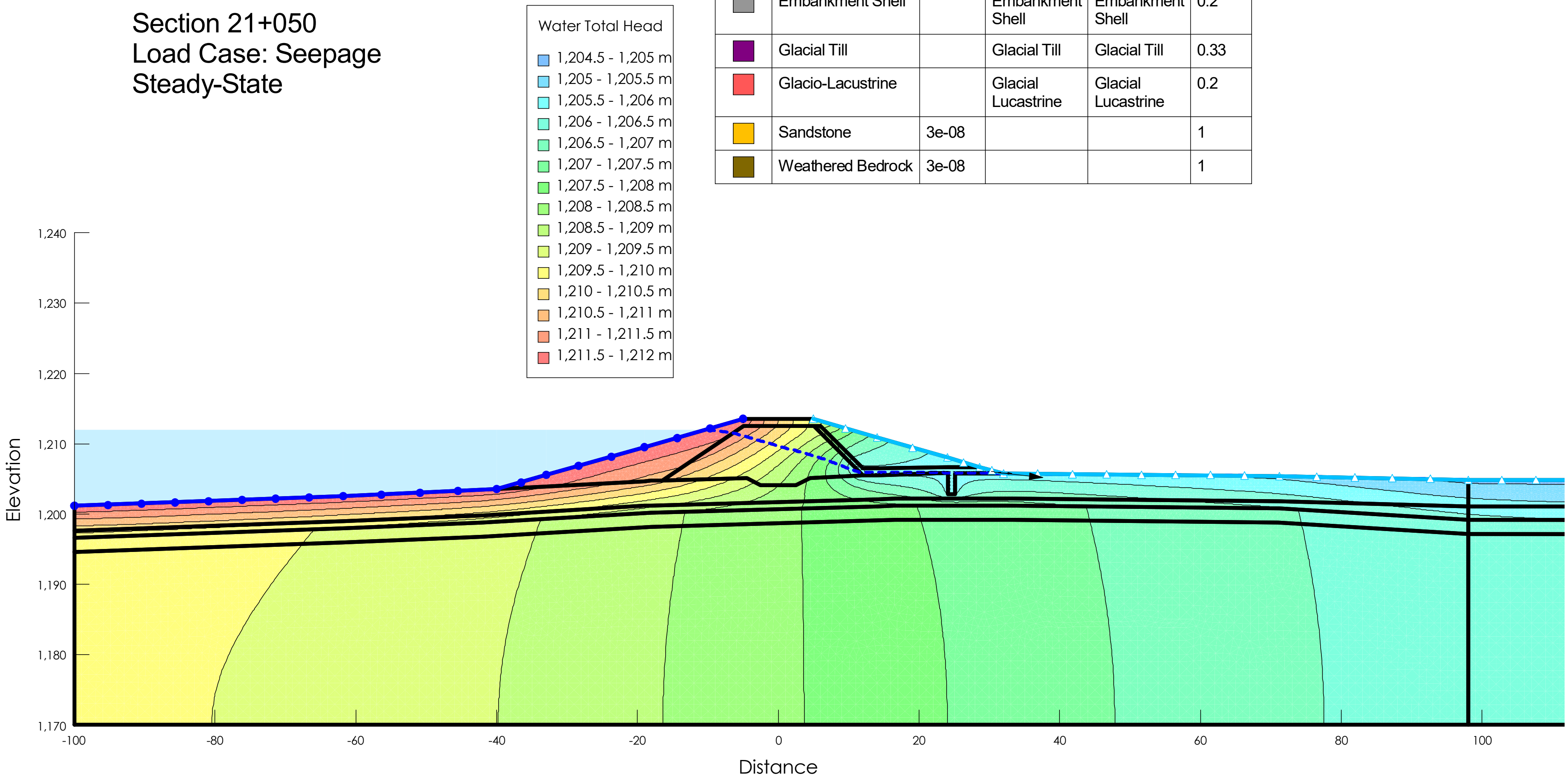
Color	Name	Sat Kx (m/sec)	Vol. WC. Function	K-Function	Ky'/Kx' Ratio
	Drain		Drain	Drain	1
	Embankment Core		Embankment Core	Embankment Core	0.2
	Embankment Shell		Embankment Shell	Embankment Shell	0.2
	Glacial Till		Glacial Till	Glacial Till	0.33
	Glacio-Lacustrine		Glacial Lucastrine	Glacial Lucastrine	0.2
	Rock Toe		Rock Toe	Rock Toe	1
	Sandstone	3e-08			1
	Weathered Bedrock	3e-08			1



Alberta Transportation SR1 Storage Dam

Section 21+050
Load Case: Seepage
Steady-State

Color	Name	Sat Kx (m/sec)	Vol. WC. Function	K-Function	Ky'/Kx' Ratio
	Drain		Drain	Drain	1
	Embankment Core		Embankment Core	Embankment Core	0.2
	Embankment Shell		Embankment Shell	Embankment Shell	0.2
	Glacial Till		Glacial Till	Glacial Till	0.33
	Glacio-Lacustrine		Glacial Lucastrine	Glacial Lucastrine	0.2
	Sandstone	3e-08			1
	Weathered Bedrock	3e-08			1

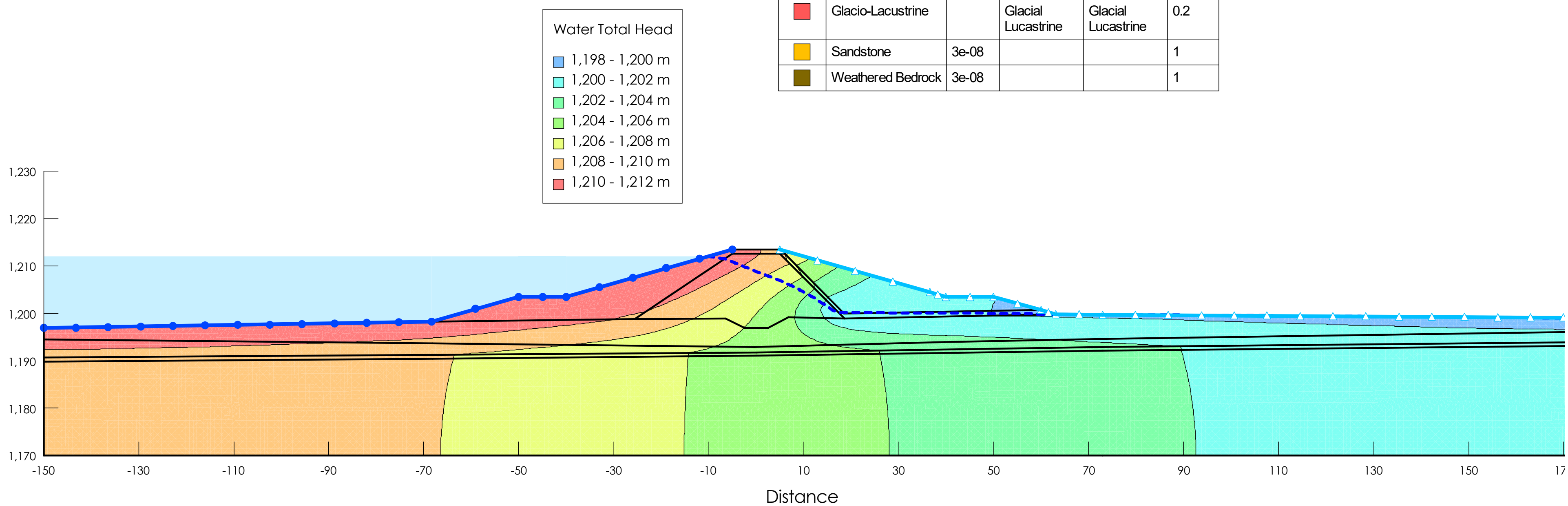


Stantec

Alberta Transportation SR1 Storage Dam

Section 21+750
Load Case: Seepage
Steady-State

Color	Name	Sat Kx (m/sec)	Vol. WC. Function	K-Function	Ky'/Kx' Ratio
	Drain		Drain	Drain	1
	Embankment Core		Embankment Core	Embankment Core	0.2
	Embankment Shell		Embankment Shell	Embankment Shell	0.2
	Glacial Till		Glacial Till	Glacial Till	0.33
	Glacio-Lacustrine		Glacial Lucastrine	Glacial Lucastrine	0.2
	Sandstone	3e-08			1
	Weathered Bedrock	3e-08			1



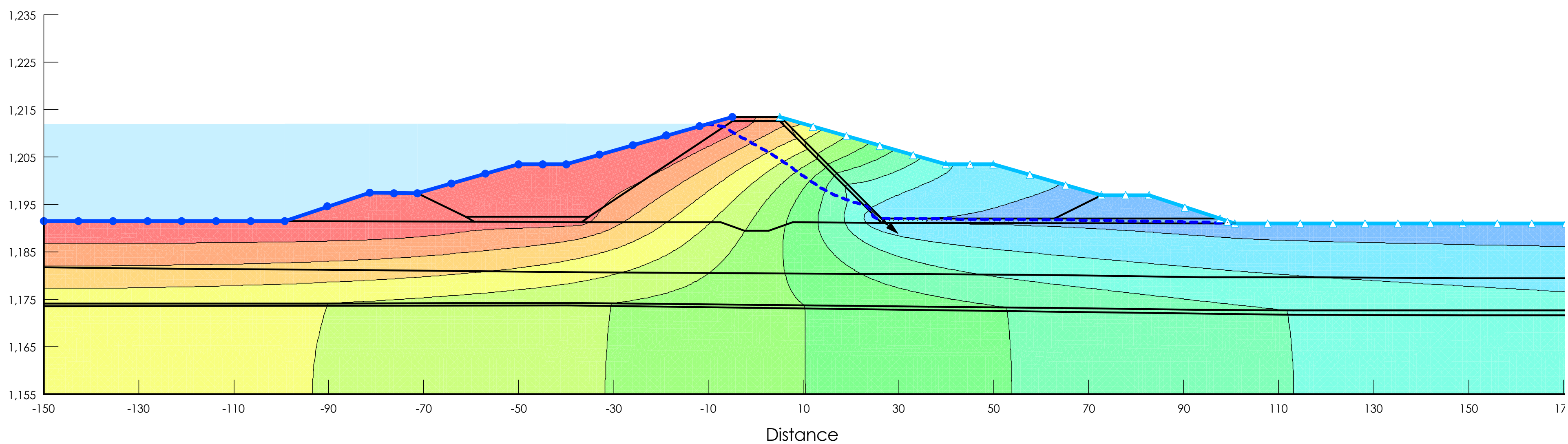
Alberta Transportation SR1 Storage Dam

Section 22+500
Load Case: Seepage
Steady-State

Color	Name	Sat Kx (m/sec)	Vol. WC. Function	K-Function	Ky'/Kx' Ratio
	Drain		Drain	Drain	1
	Embankment Core		Embankment Core	Embankment Core	0.2
	Embankment Shell		Embankment Shell	Embankment Shell	0.2
	Glacial Till		Glacial Till	Glacial Till	0.33
	Glacio-Lacustrine		Glacial Lucastrine	Glacial Lucastrine	0.2
	Granular Zone		Granular Material	Granular Material	1
	Rock Toe		Rock Toe	Rock Toe	1
	Sandstone	3e-08			1
	Weathered Bedrock	3e-08			1

Water Total Head

- 1,190 - 1,192 m
- 1,192 - 1,194 m
- 1,194 - 1,196 m
- 1,196 - 1,198 m
- 1,198 - 1,200 m
- 1,200 - 1,202 m
- 1,202 - 1,204 m
- 1,204 - 1,206 m
- 1,206 - 1,208 m
- 1,208 - 1,210 m
- 1,210 - 1,212 m



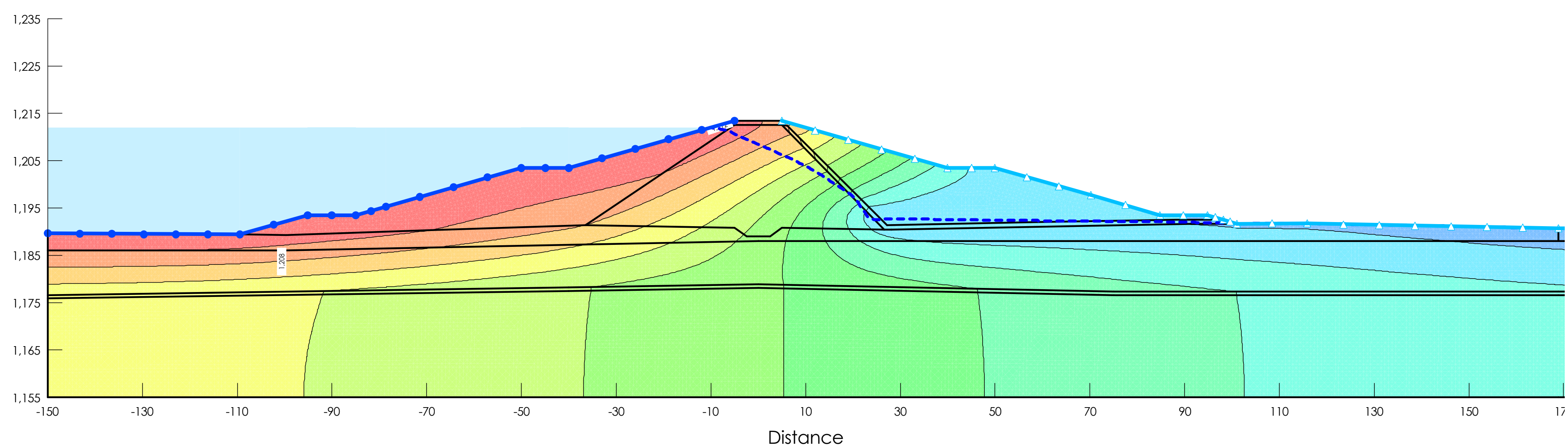
Stantec

Alberta Transportation SR1 Storage Dam

Section 22+990
Load Case: Seepage
Steady-State

Color	Name	Sat Kx (m/sec)	Vol. WC. Function	K-Function	Ky'/Kx' Ratio
	Compacted Till		Embankment Core	Embankment Core	0.2
	Drain		Drain	Drain	1
	Embankment Core		Embankment Core	Embankment Core	0.
	Embankment Shell		Embankment Shell	Embankment Shell	0.
	Glacial Till		Glacial Till	Glacial Till	0.
	Glacio-Lacustrine		Glacial Lucastrine	Glacial Lucastrine	0.
	Sandstone	3e-08			1
	Weathered Bedrock	3e-08			1

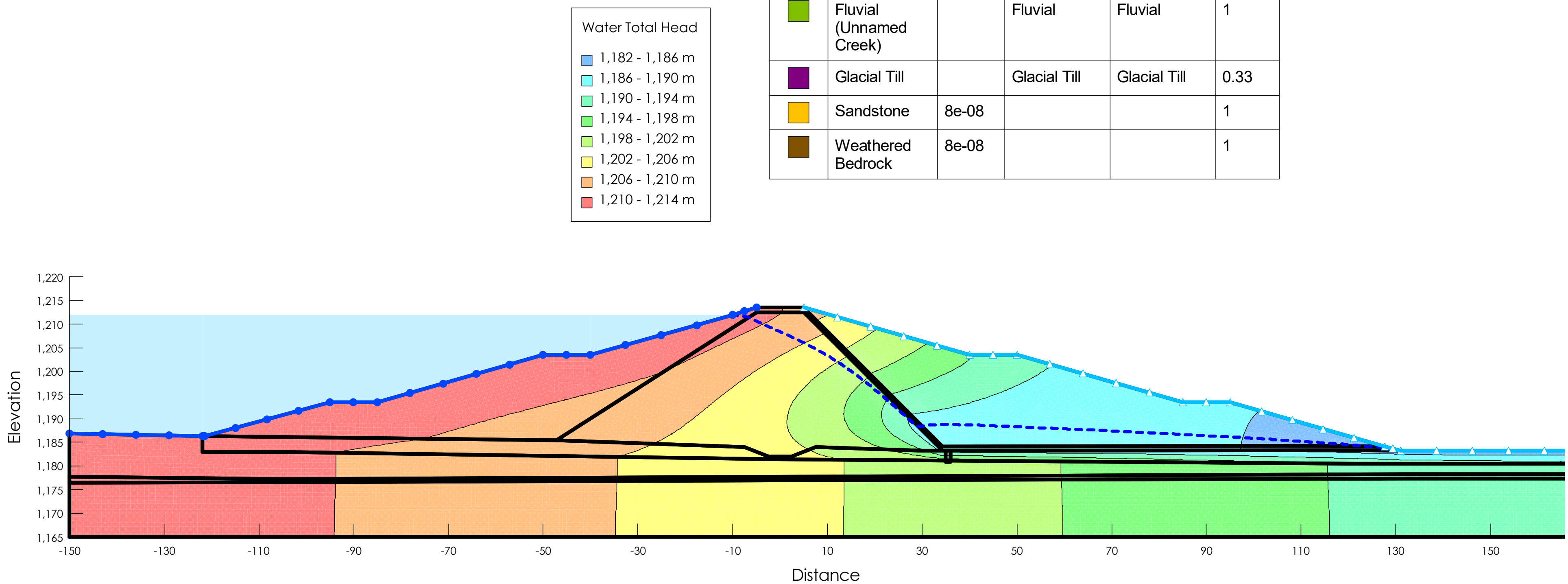
Water Total Head
- 1,190 - 1,192 m
- 1,192 - 1,194 m
- 1,194 - 1,196 m
- 1,196 - 1,198 m
- 1,198 - 1,200 m
- 1,200 - 1,202 m
- 1,202 - 1,204 m
- 1,204 - 1,206 m
- 1,206 - 1,208 m
- 1,208 - 1,210 m
- 1,210 - 1,212 m



Alberta Transportation SR1 Storage Dam

Section 23+175
Load Case: Seepage, without seepage control
Steady-State

Color	Name	Sat Kx (m/sec)	Vol. WC. Function	K-Function	Ky'/Kx' Ratio
	Drain		Drain	Drain	1
	Embankment Core		Embankment Core	Embankment Core	0.2
	Embankment Shell		Embankment Shell	Embankment Shell	0.2
	Fluvial (Unnamed Creek)		Fluvial	Fluvial	1
	Glacial Till		Glacial Till	Glacial Till	0.33
	Sandstone	8e-08			1
	Weathered Bedrock	8e-08			1

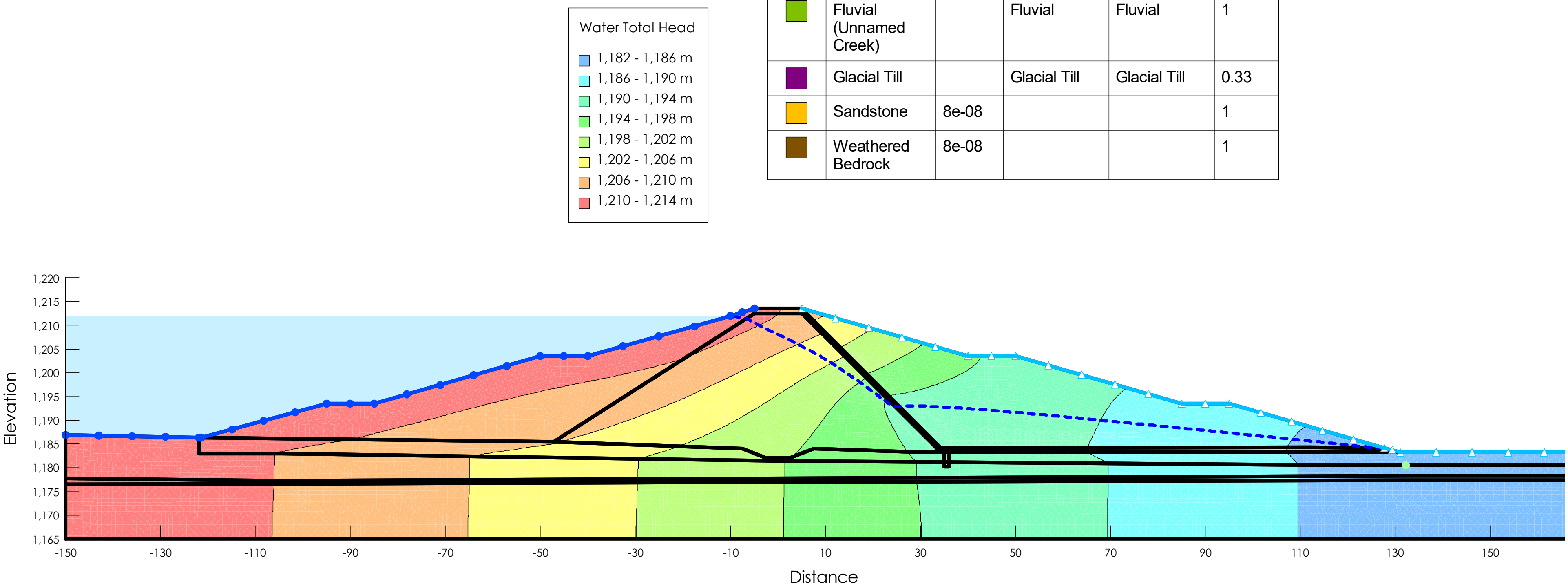


Stantec

Alberta Transportation SR1 Storage Dam

Section 23+175
Load Case: Seepage, with seepage control
Steady-State

Color	Name	Sat Kx (m/sec)	Vol. WC. Function	K-Function	Ky'/Kx' Ratio
	Drain		Drain	Drain	1
	Embankment Core		Embankment Core	Embankment Core	0.2
	Embankment Shell		Embankment Shell	Embankment Shell	0.2
	Fluvial (Unnamed Creek)		Fluvial	Fluvial	1
	Glacial Till		Glacial Till	Glacial Till	0.33
	Sandstone	8e-08			1
	Weathered Bedrock	8e-08			1



Project Name: SR1
Task Name: Exit Gradient Analyses

Soil Name	Gs	e	i-crit
Glacial Till	2.69	0.49	1.13
Glacio-Lacustrine	2.7	0.62	1.05

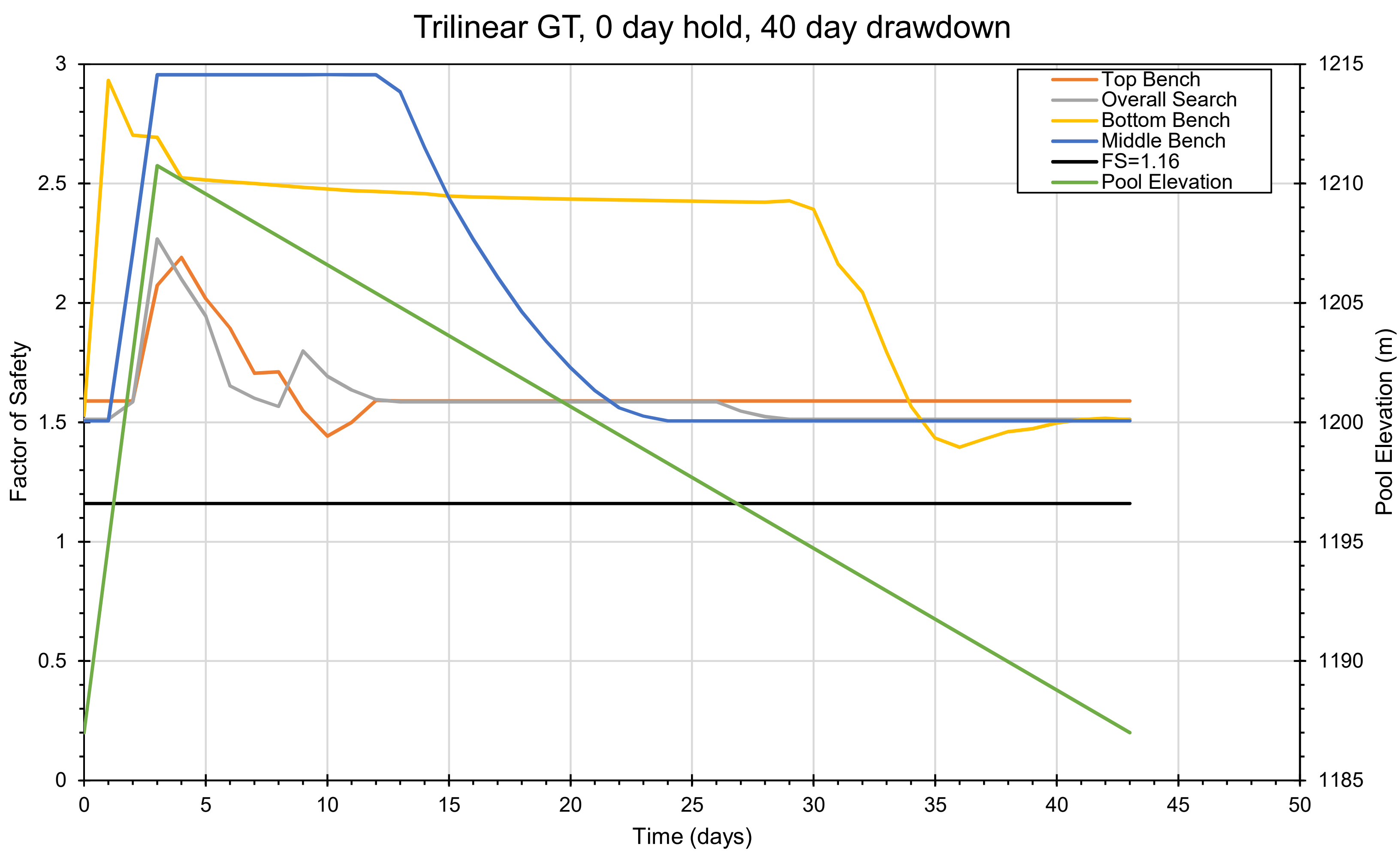
i-crit = (Gs-1)/(e+1)

Section	Surficial Material	Location (x,y)	Total Head (ft)	Elevation (ft)	Elevation at Top of Ground (ft)	Seepage Gradient (i)	Critical Gradient (i_{crit})	FS_{exit}
20+000	Glacio-Lacustrine	103.8, 1201.0	1202.4	1201.0	1202.1	0.273	1.049	3.8
21+050	Glacio-Lacustrine	35.0, 1204.7	1206.0	1204.7	1205.7	0.300	1.049	3.5
21+750	Glacio-Lacustrine	65.9, 1198.4	1200.3	1198.4	1199.8	0.347	1.049	3.0
22+500	Glacio-Lacustrine	102.3, 1189.5	1191.5	1189.5	1191.0	0.333	1.049	3.1
22+990	Glacio-Lacustrine	104.0, 1190.2	1192.2	1190.2	1191.7	0.333	1.049	3.1
23+175 (no treatment)	Glacial Till	132.3, 1181.8	1188.4	1181.8	1183.2	3.714	1.134	0.3
23+175 (with treatment)	Glacial Till	132.3, 1181.8	1183.4	1181.8	1183.2	0.143	1.134	7.9

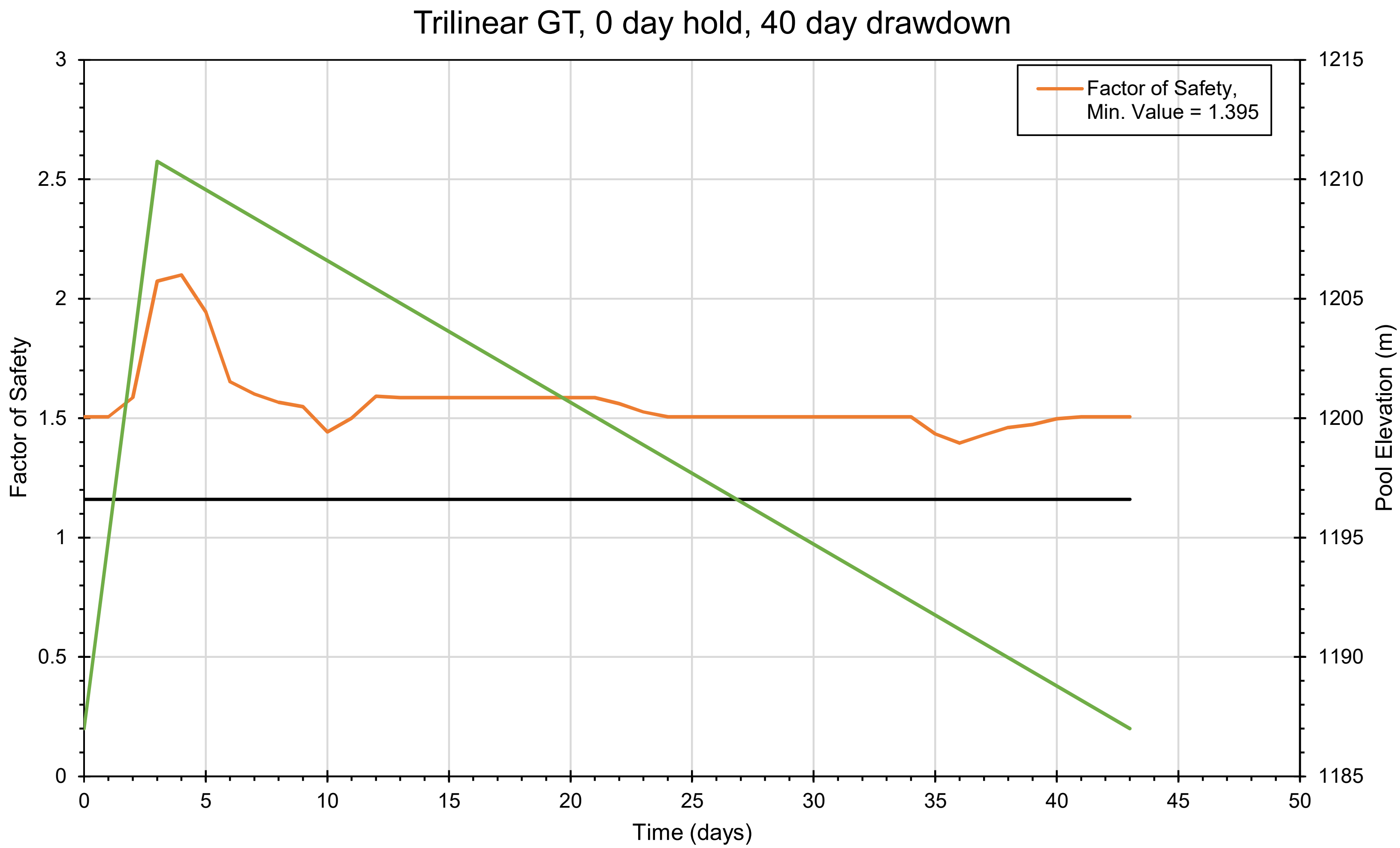
FS-exit = i-crit / i

Attachment 12.1
Slope Stability and Seepage Analyses

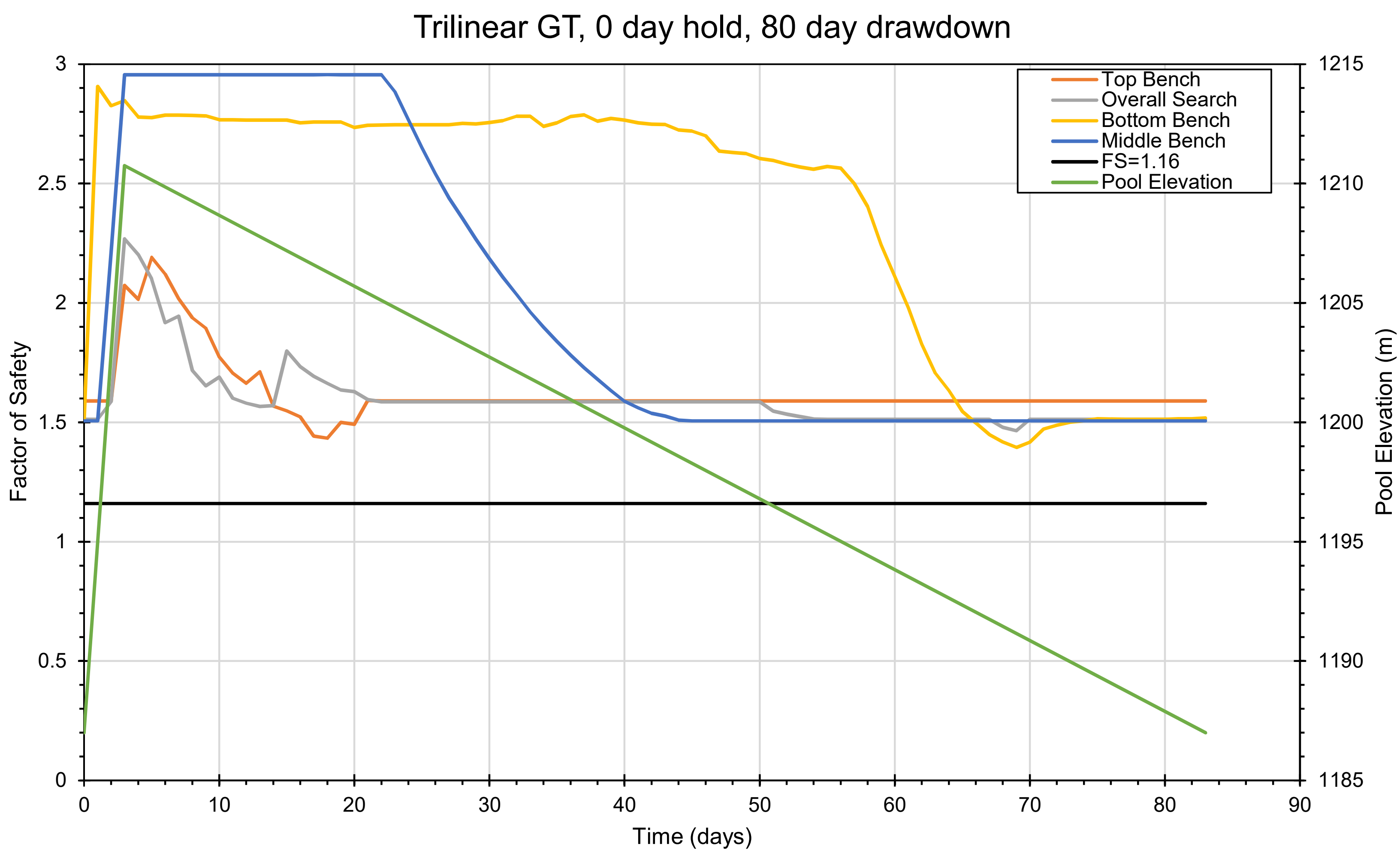
12.1.9 Transient Analysis Results
Sta. 22+990



Trilinear GT, 0 day hold, 40 day drawdown
Factor of Safety
Pool Elevation (m)
Time (days)
Top Bench
Overall Search
Bottom Bench
Middle Bench
FS=1.16
Pool Elevation
0
0.5
1
1.5
2
2.5
3
1185
1190
1195
1200
1205
1210
1215
0
5
10
15
20
25
30
35
40
45
50

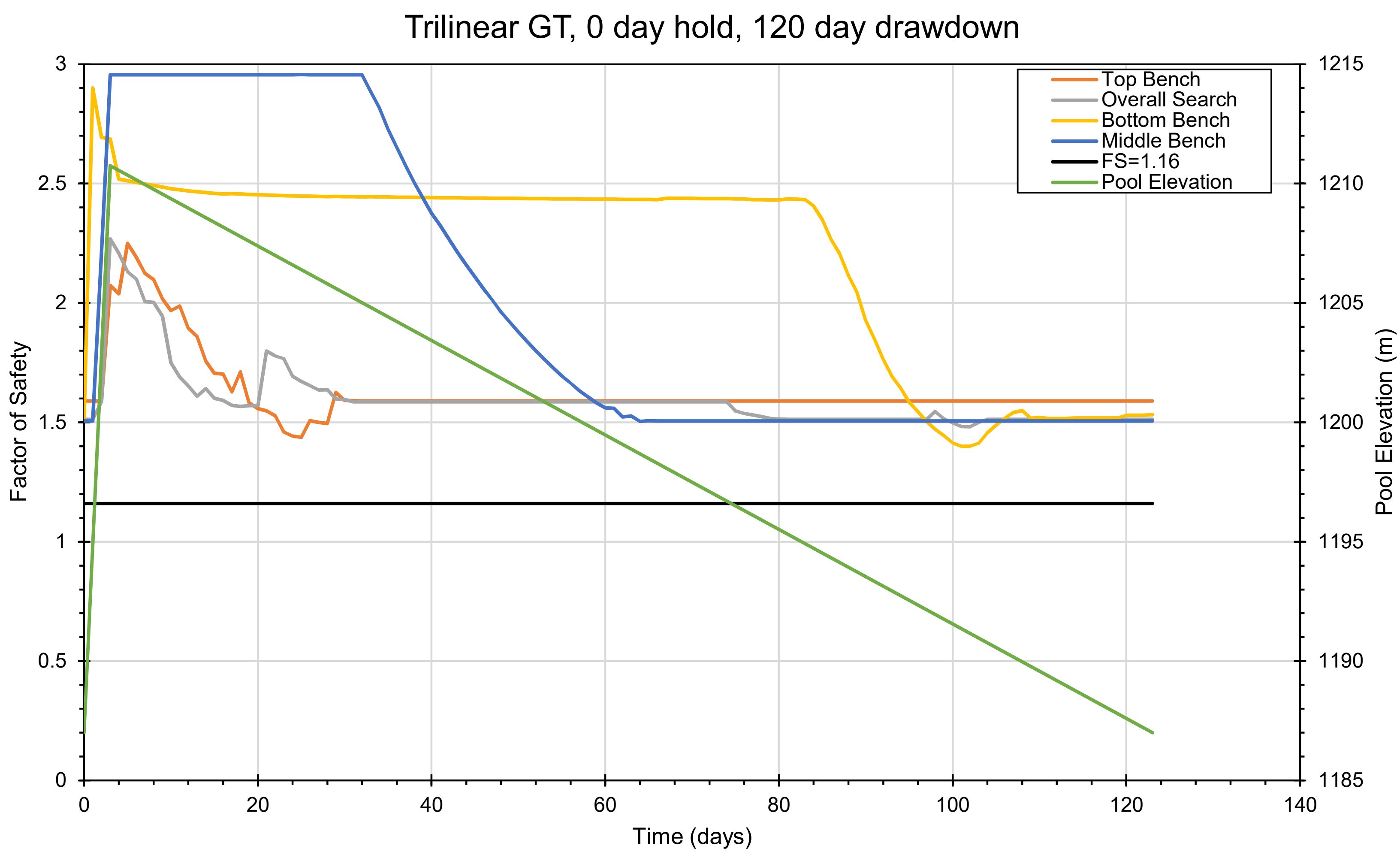


Trilinear GT, 0 day hold, 40 day drawdown
Factor of Safety,
Min. Value = 1.395
Factor of Safety
Pool Elevation (m)
Time (days)
0
0.5
1
1.5
2
2.5
3
1185
1190
1195
1200
1205
1210
1215
0
5
10
15
20
25
30
35
40
45
50

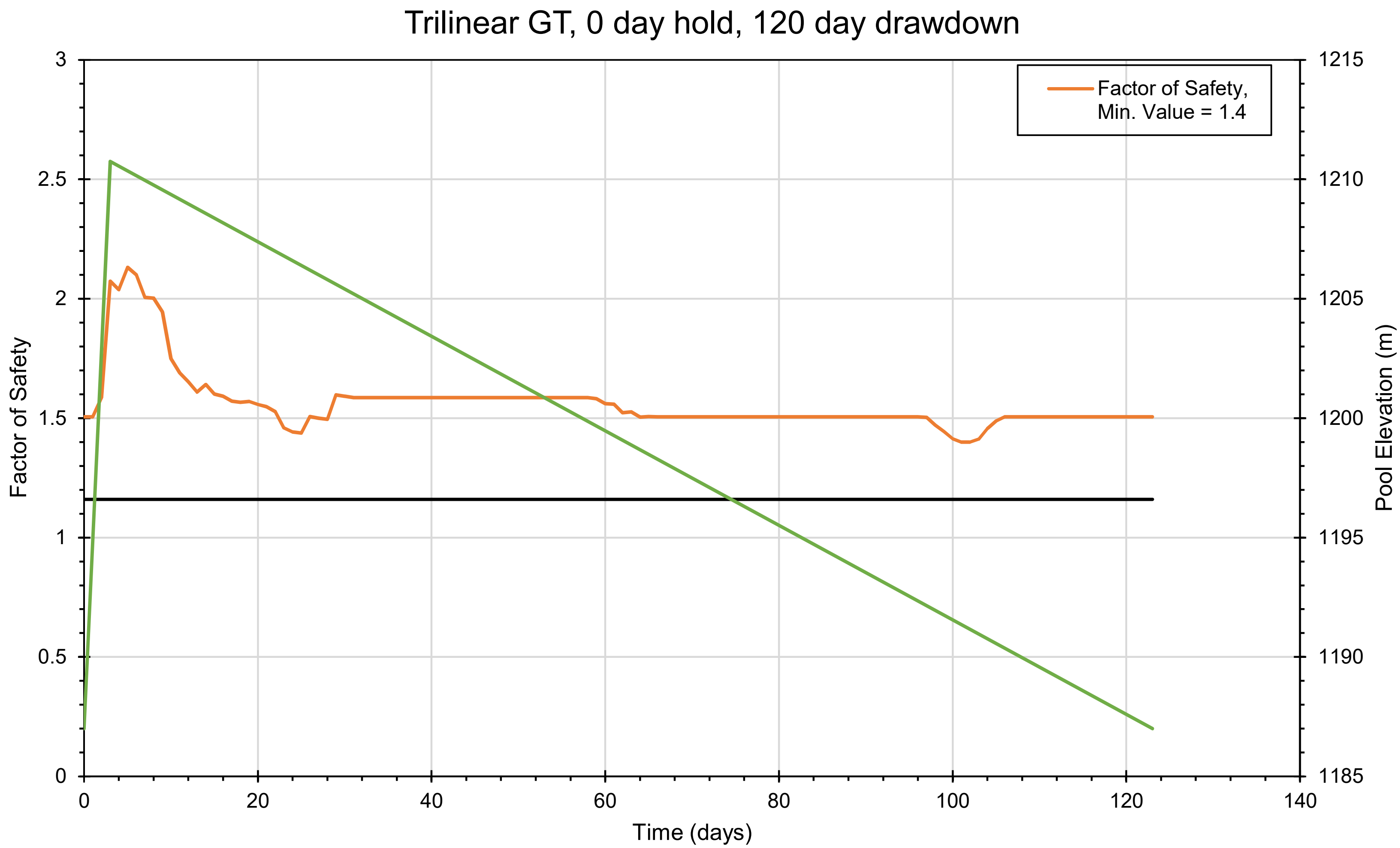


Trilinear GT, 0 day hold, 80 day drawdown
Top Bench
Overall Search
Bottom Bench
Middle Bench
FS=1.16
Pool Elevation
Factor of Safety
Pool Elevation (m)
Time (days)
0
0.5
1
1.5
2
2.5
3
1185
1190
1195
1200
1205
1210
1215
0
10
20
30
40
50
60
70
80
90

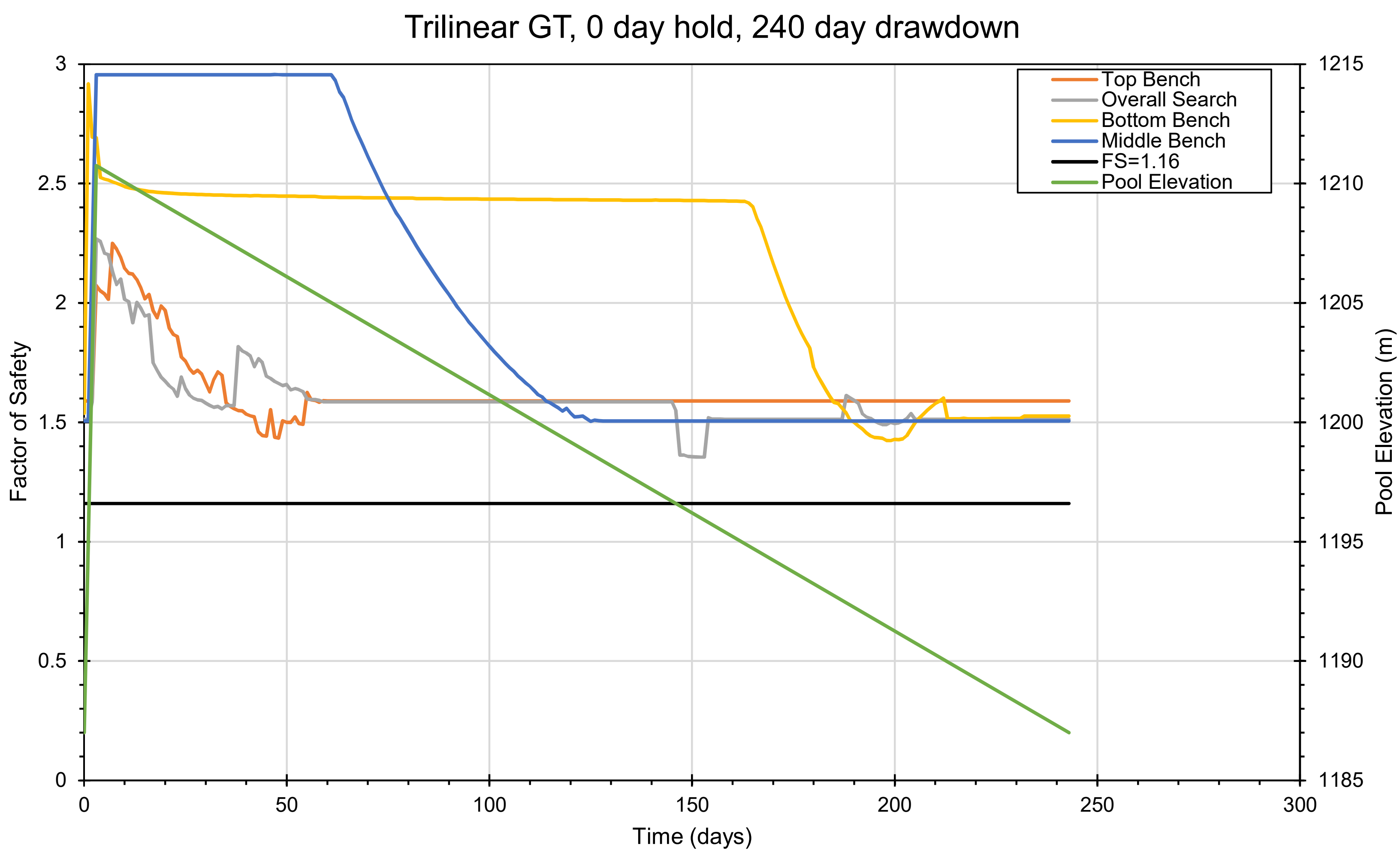

Trilinear GT, 0 day hold, 80 day drawdown
Factor of Safety,
Min. Value = 1.395
Factor of Safety
Pool Elevation (m)
Time (days)
0
0.5
1
1.5
2
2.5
3
1185
1190
1195
1200
1205
1210
1215
0
10
20
30
40
50
60
70
80
90



Trilinear GT, 0 day hold, 120 day drawdown
Factor of Safety
Pool Elevation (m)
Time (days)
Top Bench
Overall Search
Bottom Bench
Middle Bench
FS=1.16
Pool Elevation
0
0.5
1
1.5
2
2.5
3
1185
1190
1195
1200
1205
1210
1215
0
20
40
60
80
100
120
140

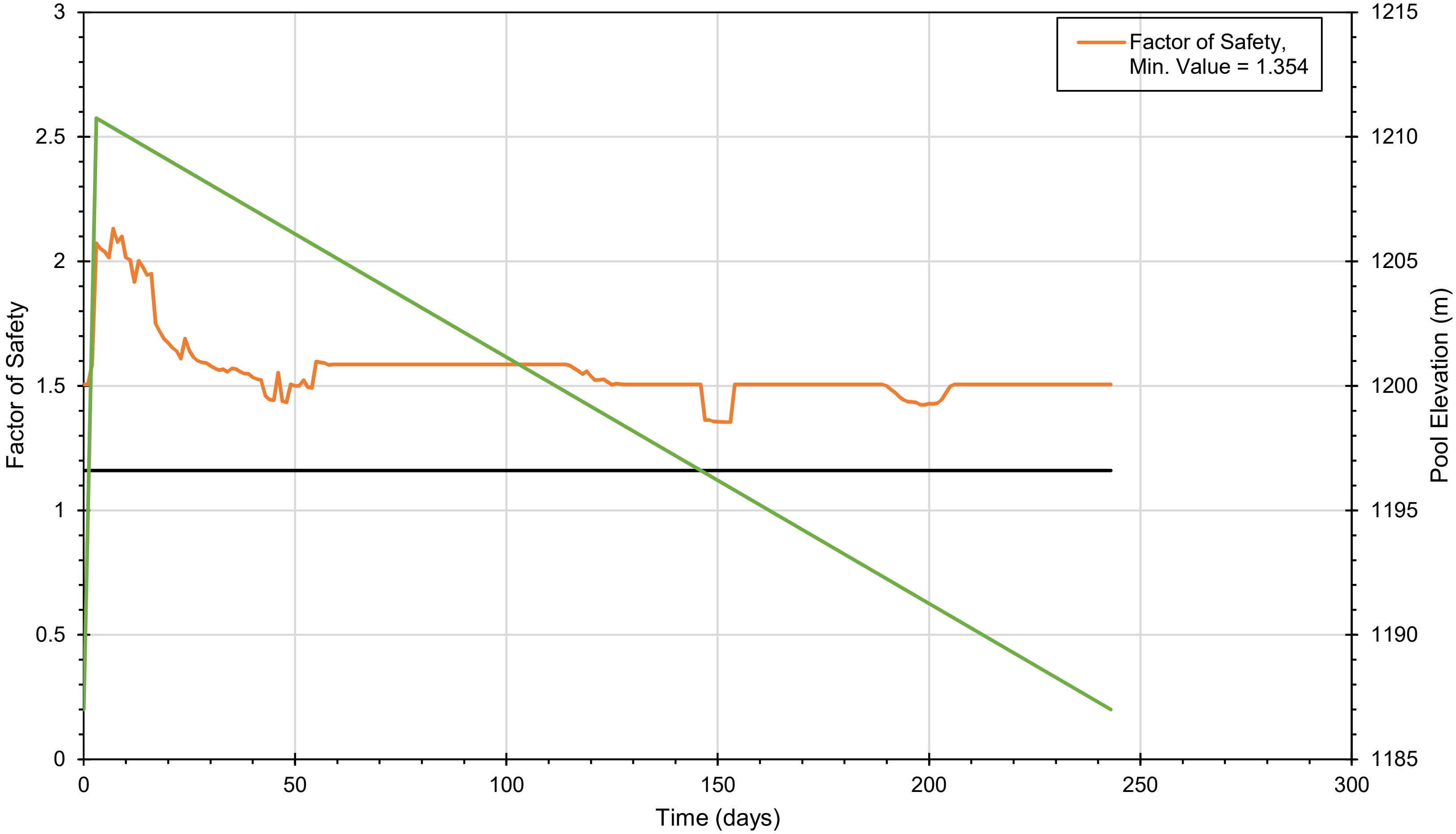


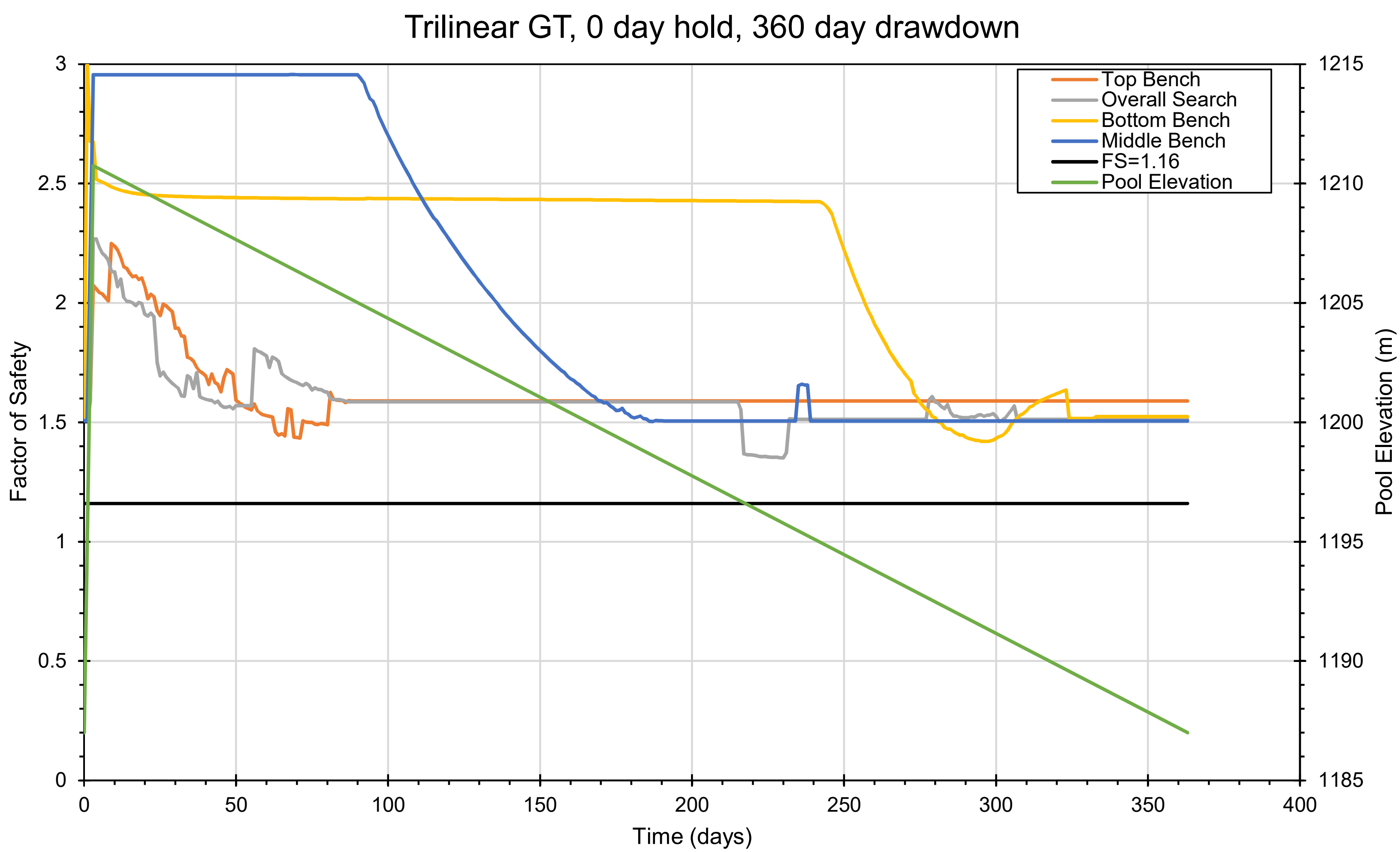
Trilinear GT, 0 day hold, 120 day drawdown
Factor of Safety,
Min. Value = 1.4
Factor of Safety
Pool Elevation (m)
Time (days)
0
0.5
1
1.5
2
2.5
3
1185
1190
1195
1200
1205
1210
1215
0
20
40
60
80
100
120
140



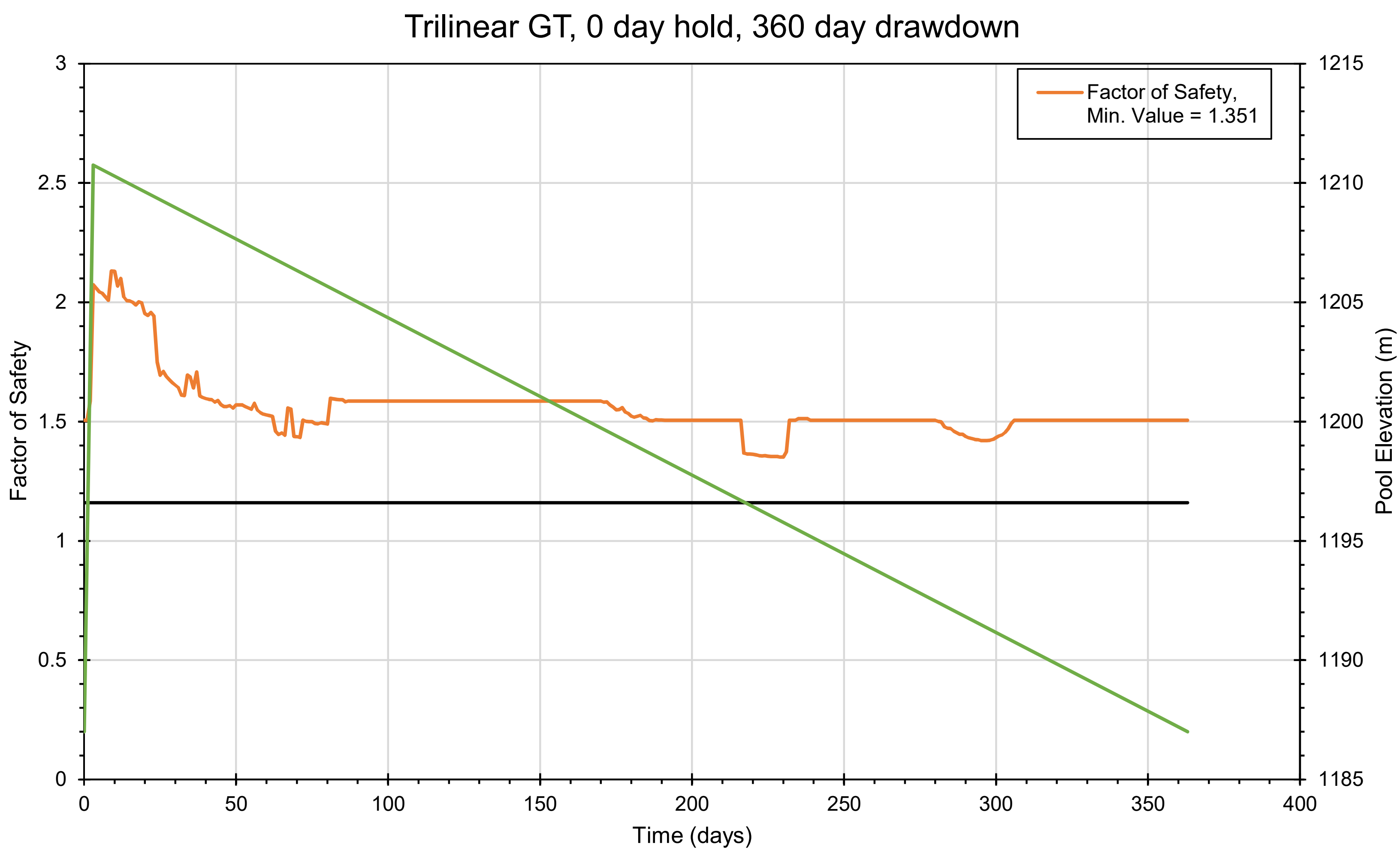
Trilinear GT, 0 day hold, 240 day drawdown
Factor of Safety
Pool Elevation (m)
Time (days)
Top Bench
Overall Search
Bottom Bench
Middle Bench
FS=1.16
Pool Elevation
0
0.5
1
1.5
2
2.5
3
1185
1190
1195
1200
1205
1210
1215
0
50
100
150
200
250
300

Trilinear GT, 0 day hold, 240 day drawdown

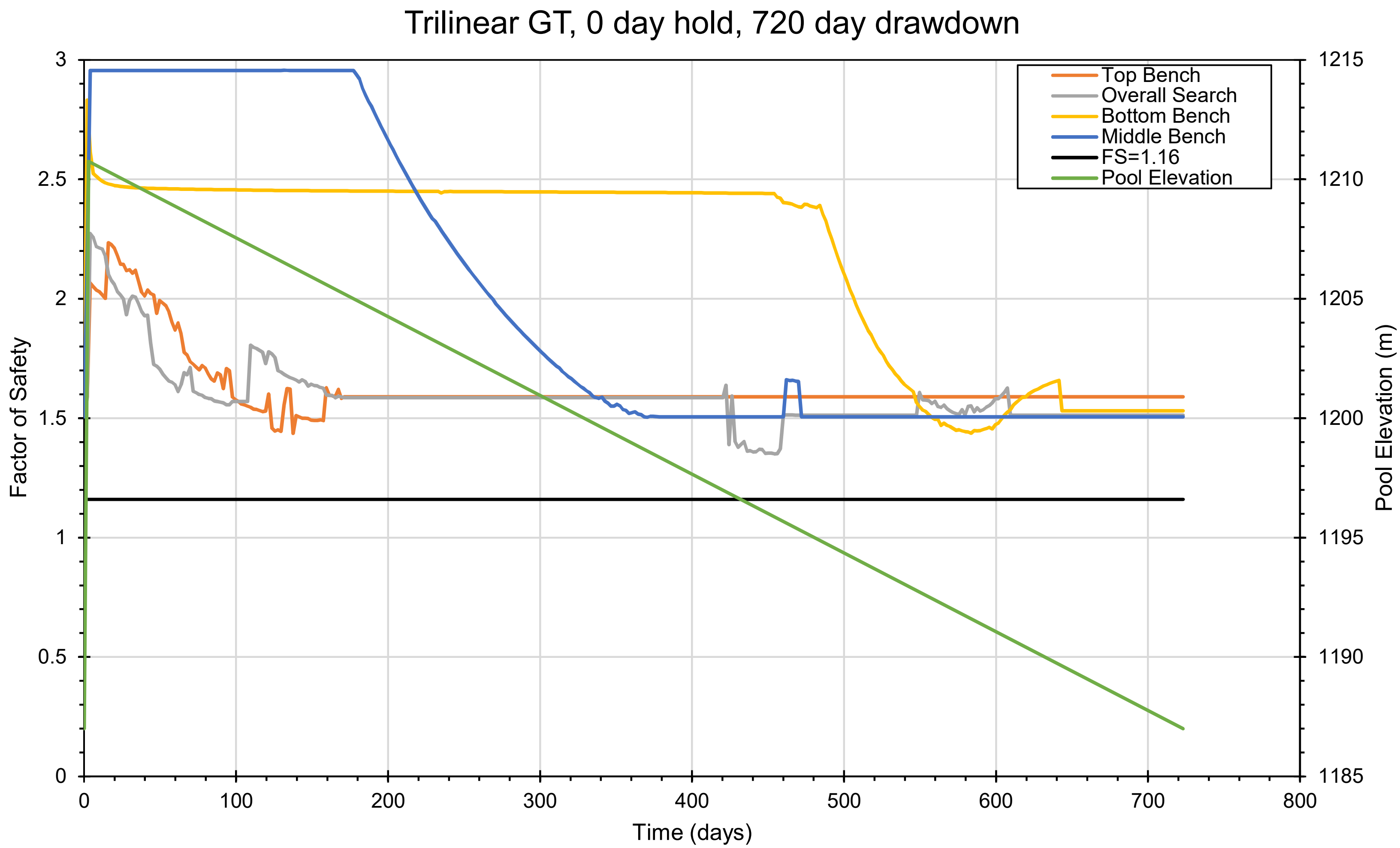




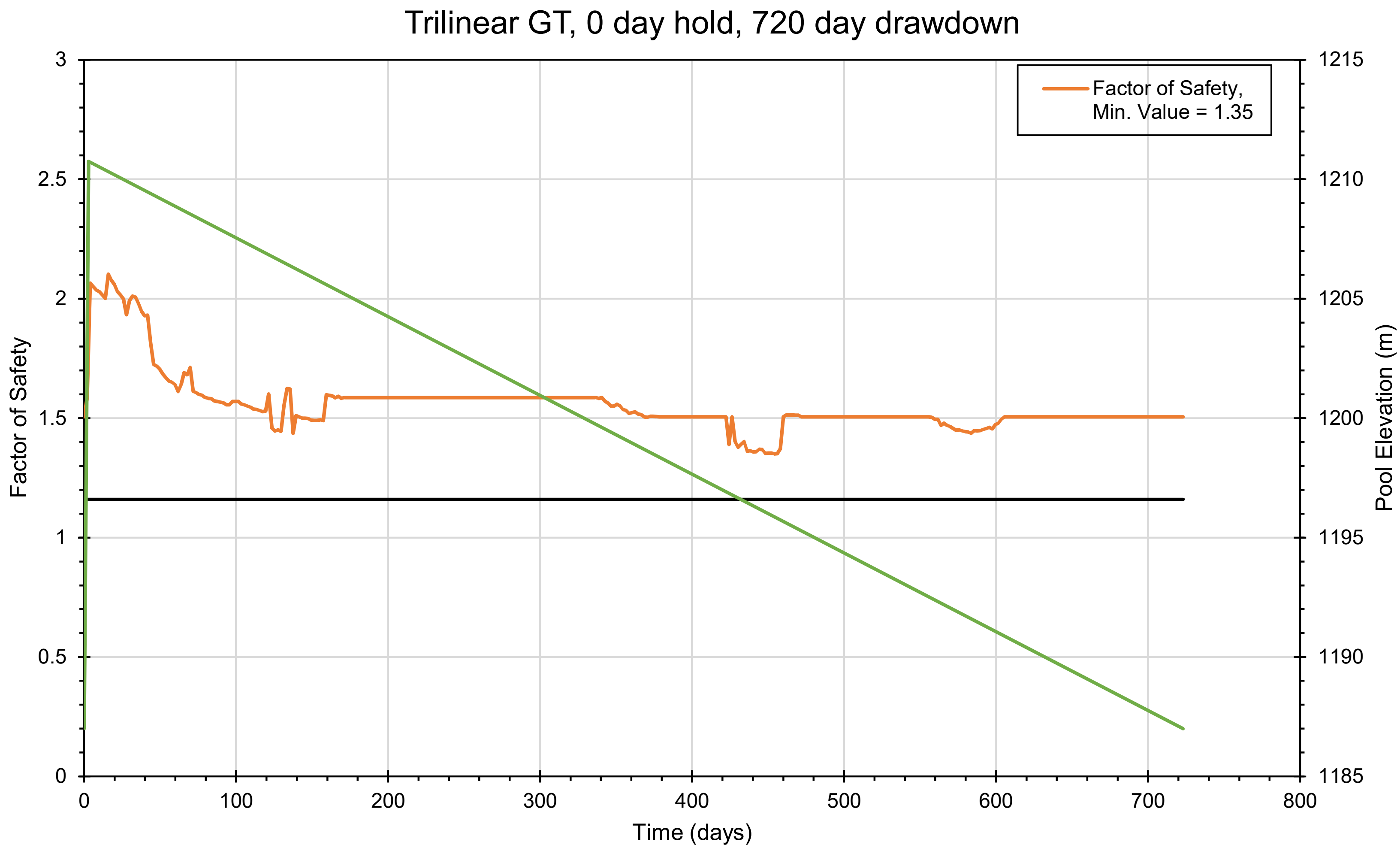
Trilinear GT, 0 day hold, 360 day drawdown
Factor of Safety
Pool Elevation (m)
Time (days)
0
0.5
1
1.5
2
2.5
3
1185
1190
1195
1200
1205
1210
1215
0
50
100
150
200
250
300
350
400
Top Bench
Overall Search
Bottom Bench
Middle Bench
FS=1.16
Pool Elevation



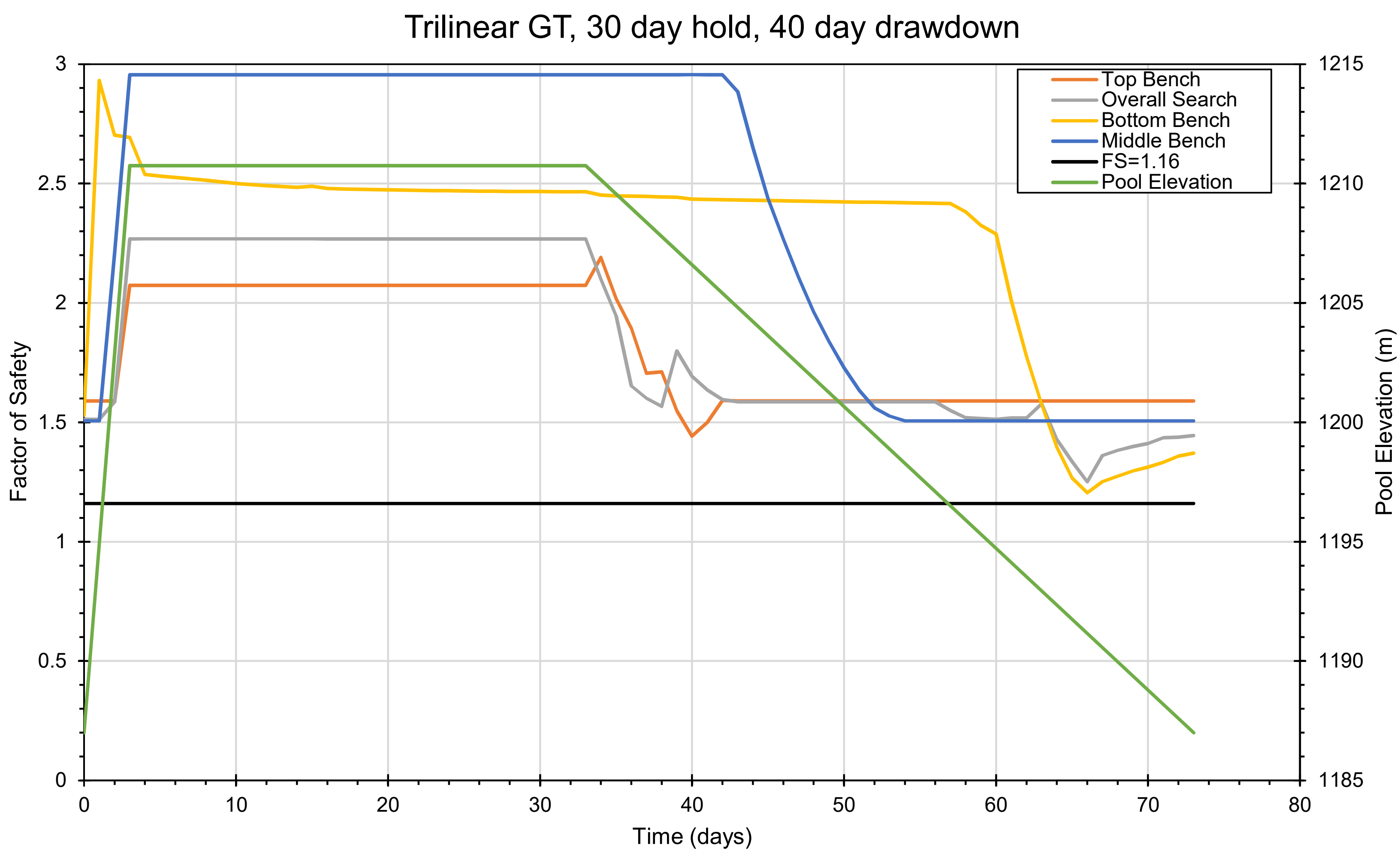
Trilinear GT, 0 day hold, 360 day drawdown
Factor of Safety,
Min. Value = 1.351
Factor of Safety
Pool Elevation (m)
Time (days)
0
0.5
1
1.5
2
2.5
3
1185
1190
1195
1200
1205
1210
1215
0
50
100
150
200
250
300
350
400



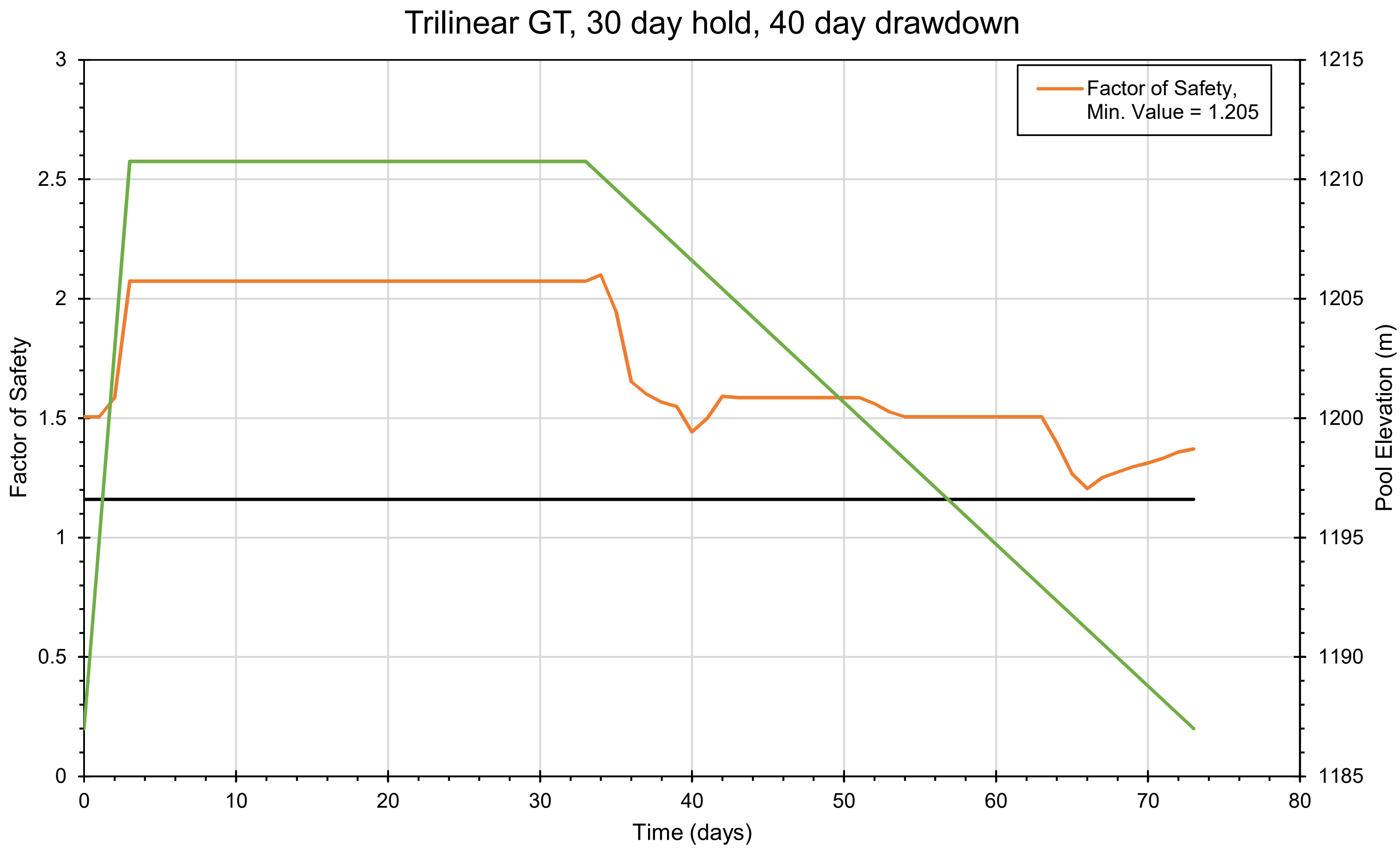
Trilinear GT, 0 day hold, 720 day drawdown
Factor of Safety
Pool Elevation (m)
Time (days)
Top Bench
Overall Search
Bottom Bench
Middle Bench
FS=1.16
Pool Elevation
0
0.5
1
1.5
2
2.5
3
1185
1190
1195
1200
1205
1210
1215
0
100
200
300
400
500
600
700
800



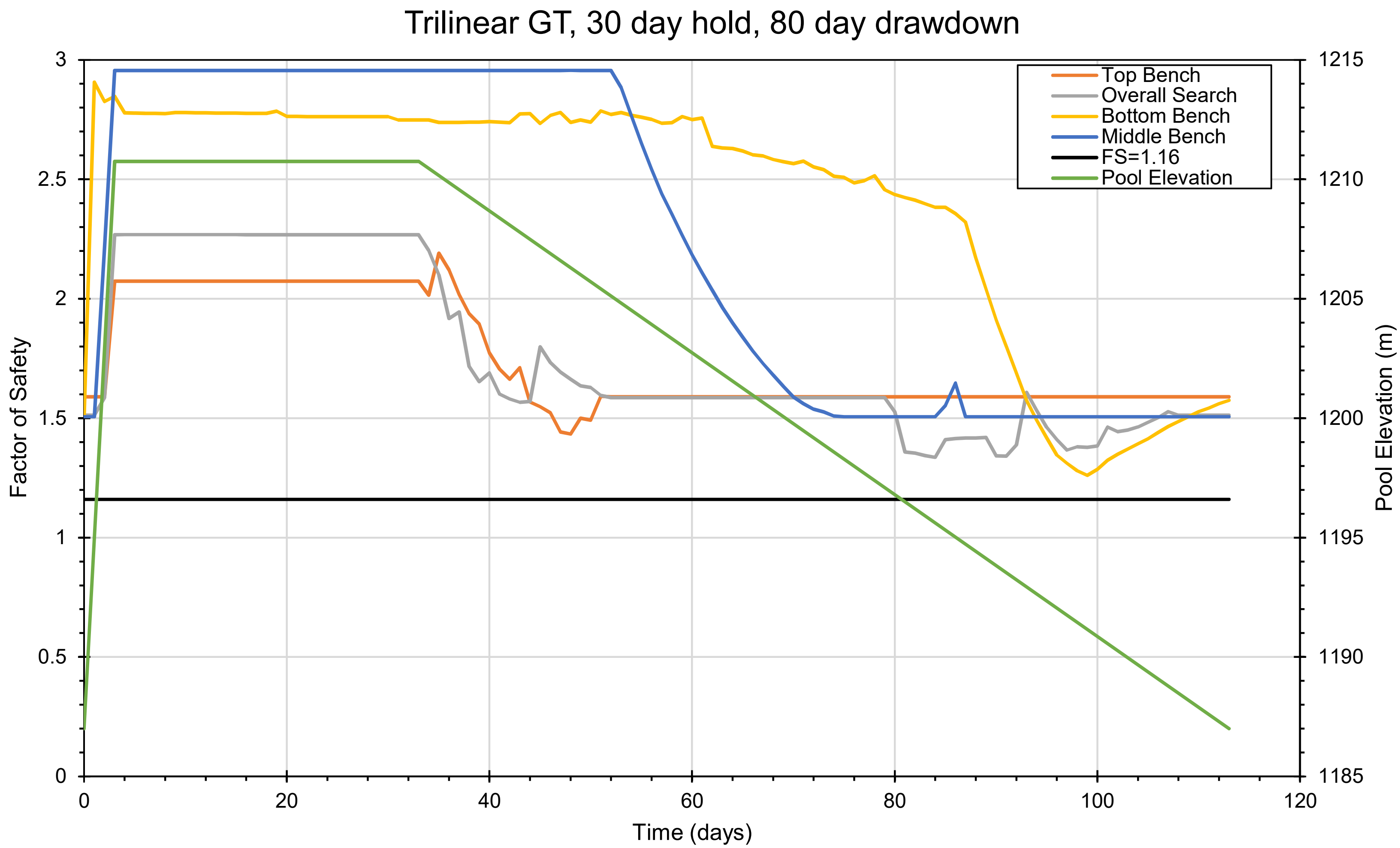
Trilinear GT, 0 day hold, 720 day drawdown
Factor of Safety,
Min. Value = 1.35
Factor of Safety
Pool Elevation (m)
Time (days)
0
0.5
1
1.5
2
2.5
3
1185
1190
1195
1200
1205
1210
1215
0
100
200
300
400
500
600
700
800

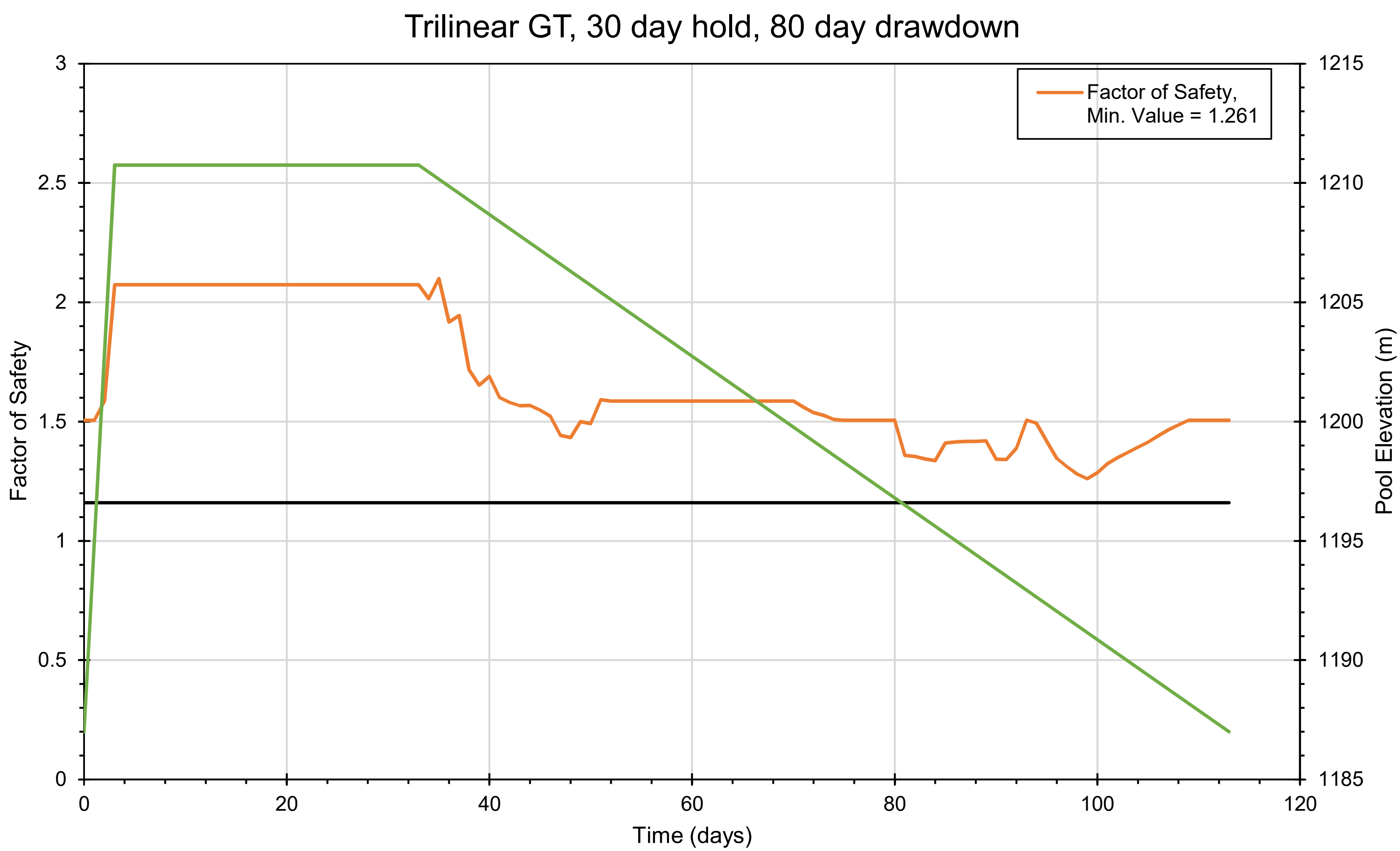


Trilinear GT, 30 day hold, 40 day drawdown
Top Bench
Overall Search
Bottom Bench
Middle Bench
FS=1.16
Pool Elevation
Factor of Safety
Pool Elevation (m)
Time (days)
0
0.5
1
1.5
2
2.5
3
1185
1190
1195
1200
1205
1210
1215
0
10
20
30
40
50
60
70
80

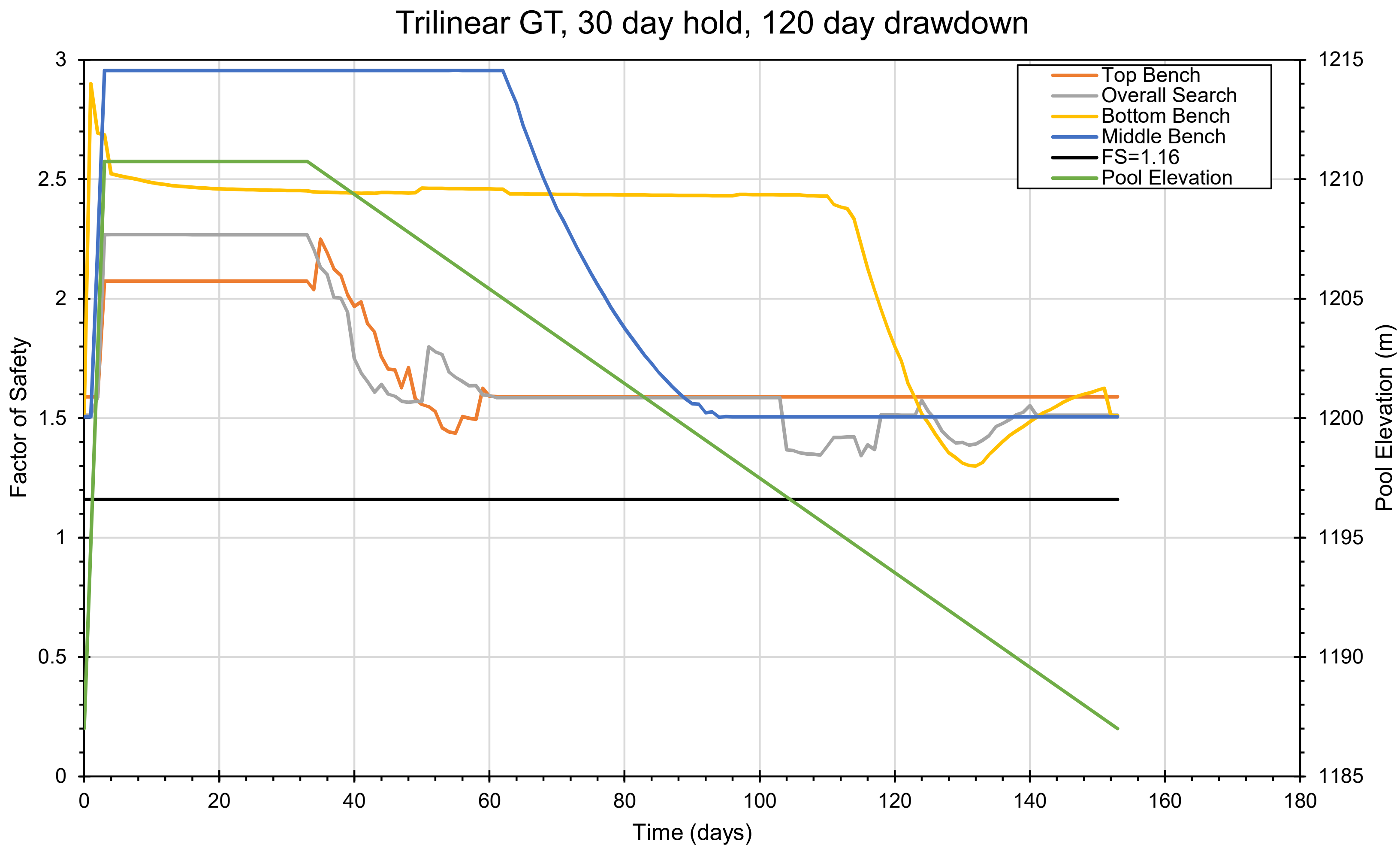


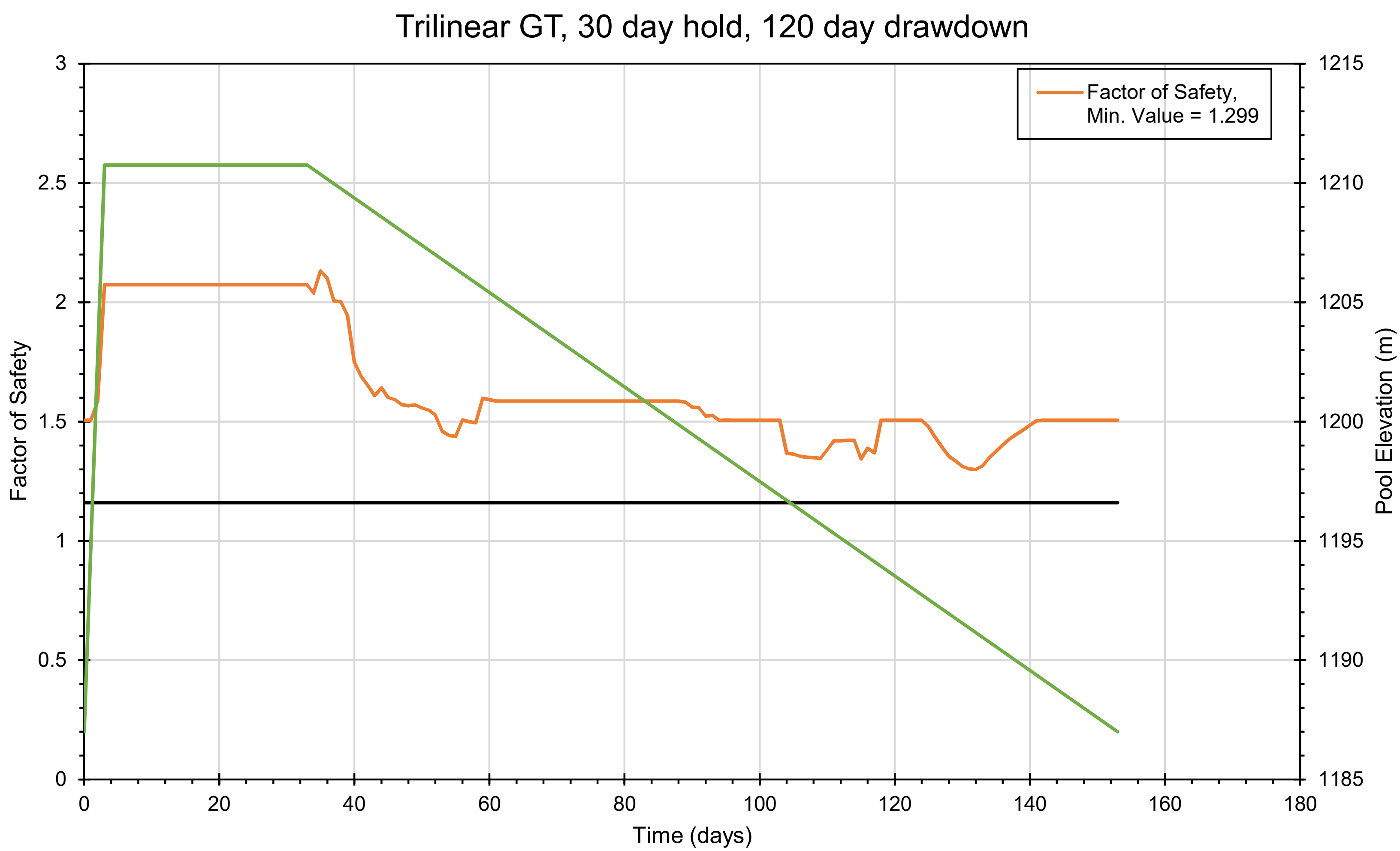
Trilinear GT, 30 day hold, 40 day drawdown
Factor of Safety,
Min. Value = 1.205
Factor of Safety
Pool Elevation (m)
Time (days)
0
0.5
1
1.5
2
2.5
3
1185
1190
1195
1200
1205
1210
1215
0
10
20
30
40
50
60
70
80

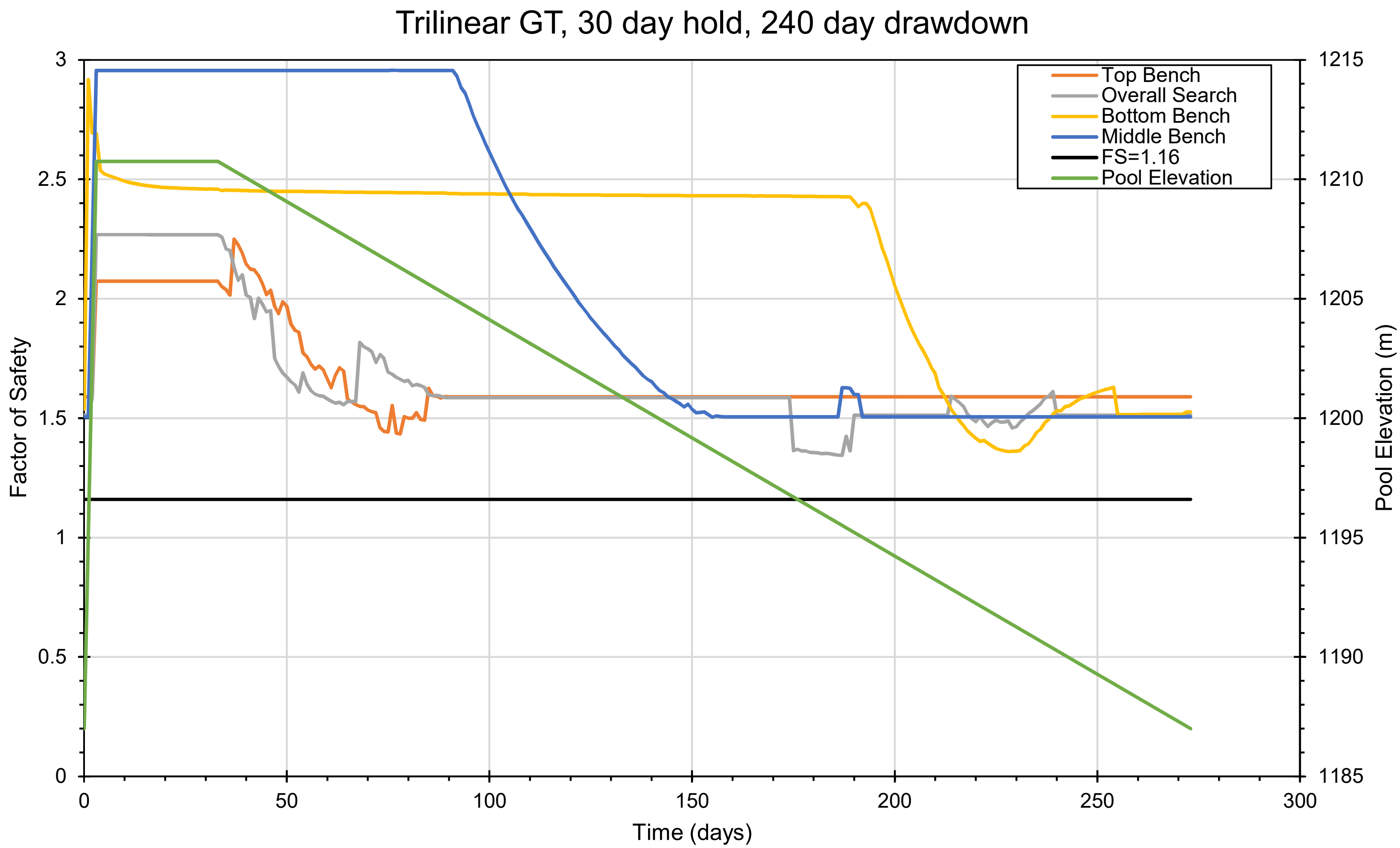

Trilinear GT, 30 day hold, 80 day drawdown
Factor of Safety
Pool Elevation (m)
Time (days)
Top Bench
Overall Search
Bottom Bench
Middle Bench
FS=1.16
Pool Elevation
0
0.5
1
1.5
2
2.5
3
1185
1190
1195
1200
1205
1210
1215
0
20
40
60
80
100
120



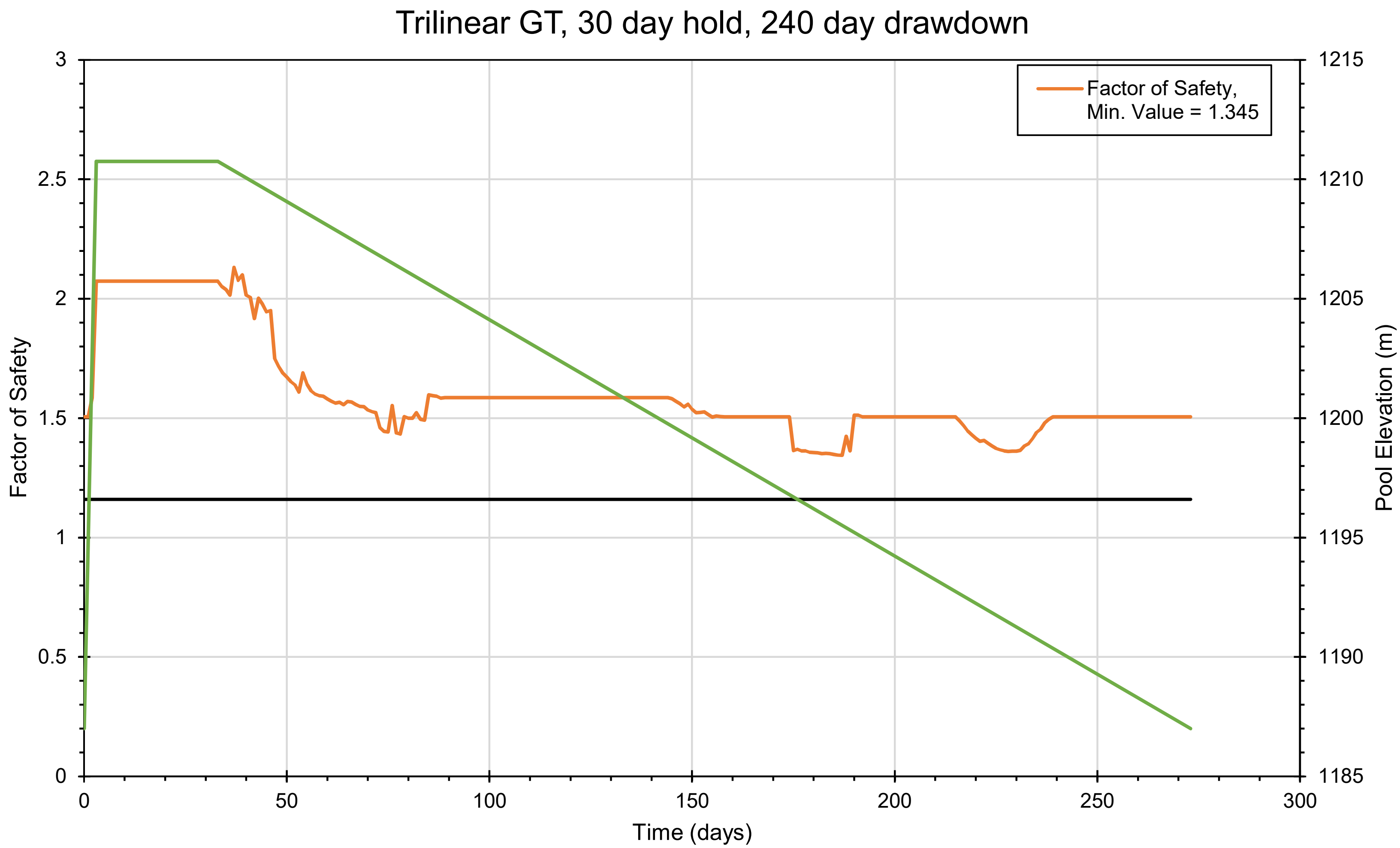
Trilinear GT, 30 day hold, 80 day drawdown
Factor of Safety,
Min. Value = 1.261
Factor of Safety
Pool Elevation (m)
Time (days)
0
0.5
1
1.5
2
2.5
3
1185
1190
1195
1200
1205
1210
1215
0
20
40
60
80
100
120


Trilinear GT, 30 day hold, 120 day drawdown
Factor of Safety
Pool Elevation (m)
Time (days)
Top Bench
Overall Search
Bottom Bench
Middle Bench
FS=1.16
Pool Elevation
0
0.5
1
1.5
2
2.5
3
1185
1190
1195
1200
1205
1210
1215
0
20
40
60
80
100
120
140
160
180

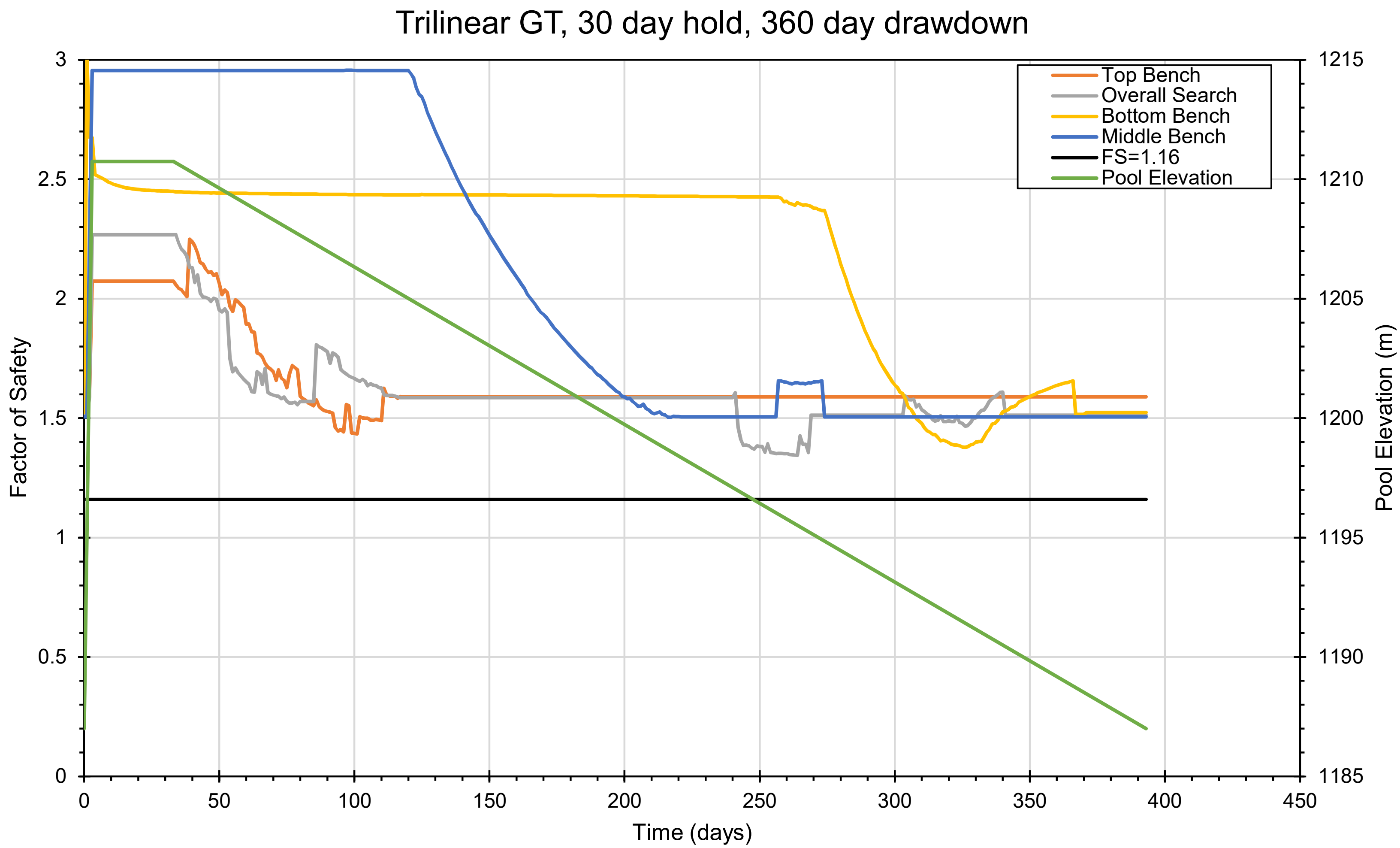

Trilinear GT, 30 day hold, 120 day drawdown
Factor of Safety,
Min. Value = 1.299
Factor of Safety
Pool Elevation (m)
Time (days)
0
0.5
1
1.5
2
2.5
3
1185
1190
1195
1200
1205
1210
1215
0
20
40
60
80
100
120
140
160
180



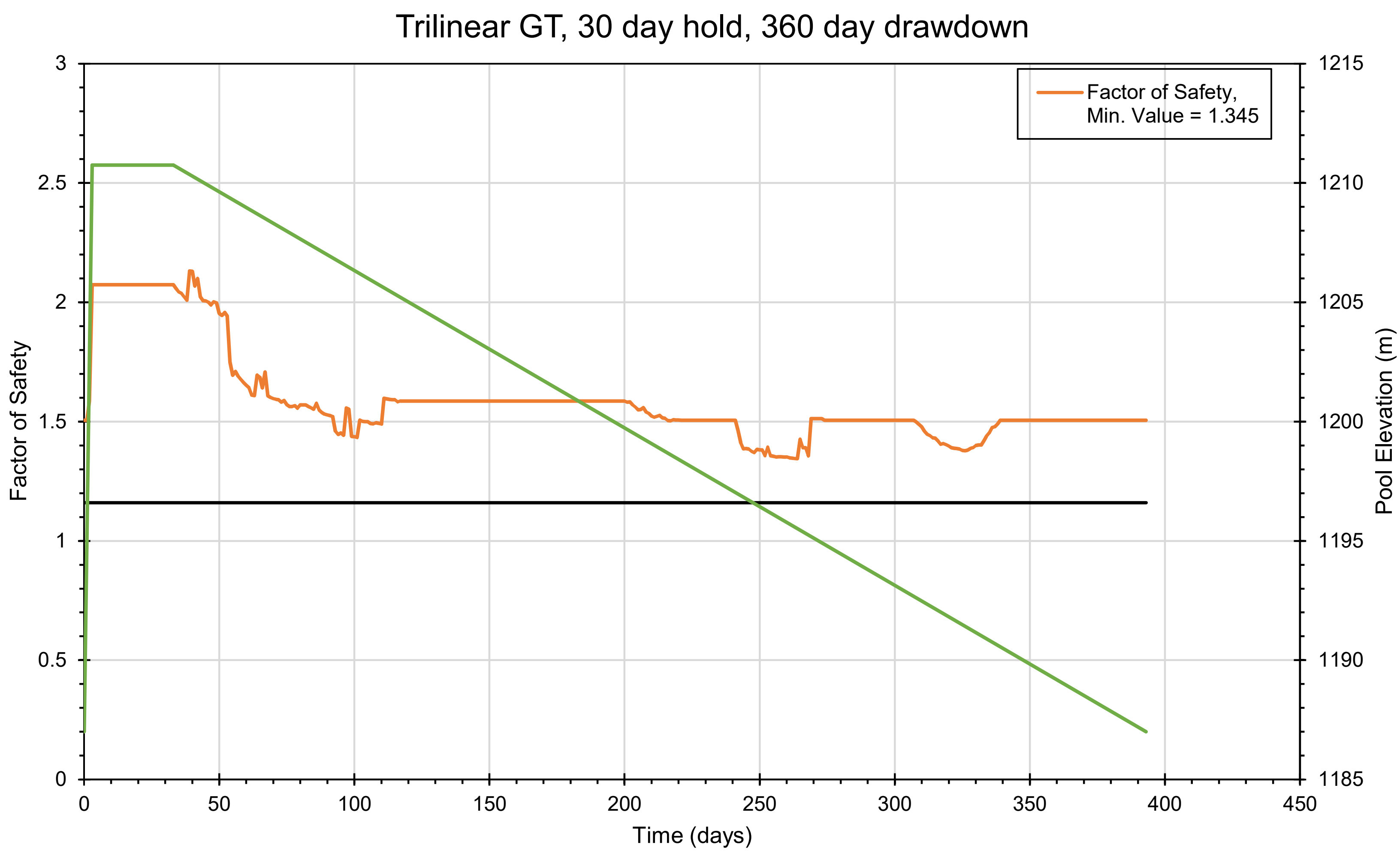
Trilinear GT, 30 day hold, 240 day drawdown
Top Bench
Overall Search
Bottom Bench
Middle Bench
FS=1.16
Pool Elevation
Factor of Safety
Pool Elevation (m)
Time (days)
0
0.5
1
1.5
2
2.5
3
1185
1190
1195
1200
1205
1210
1215
0
50
100
150
200
250
300



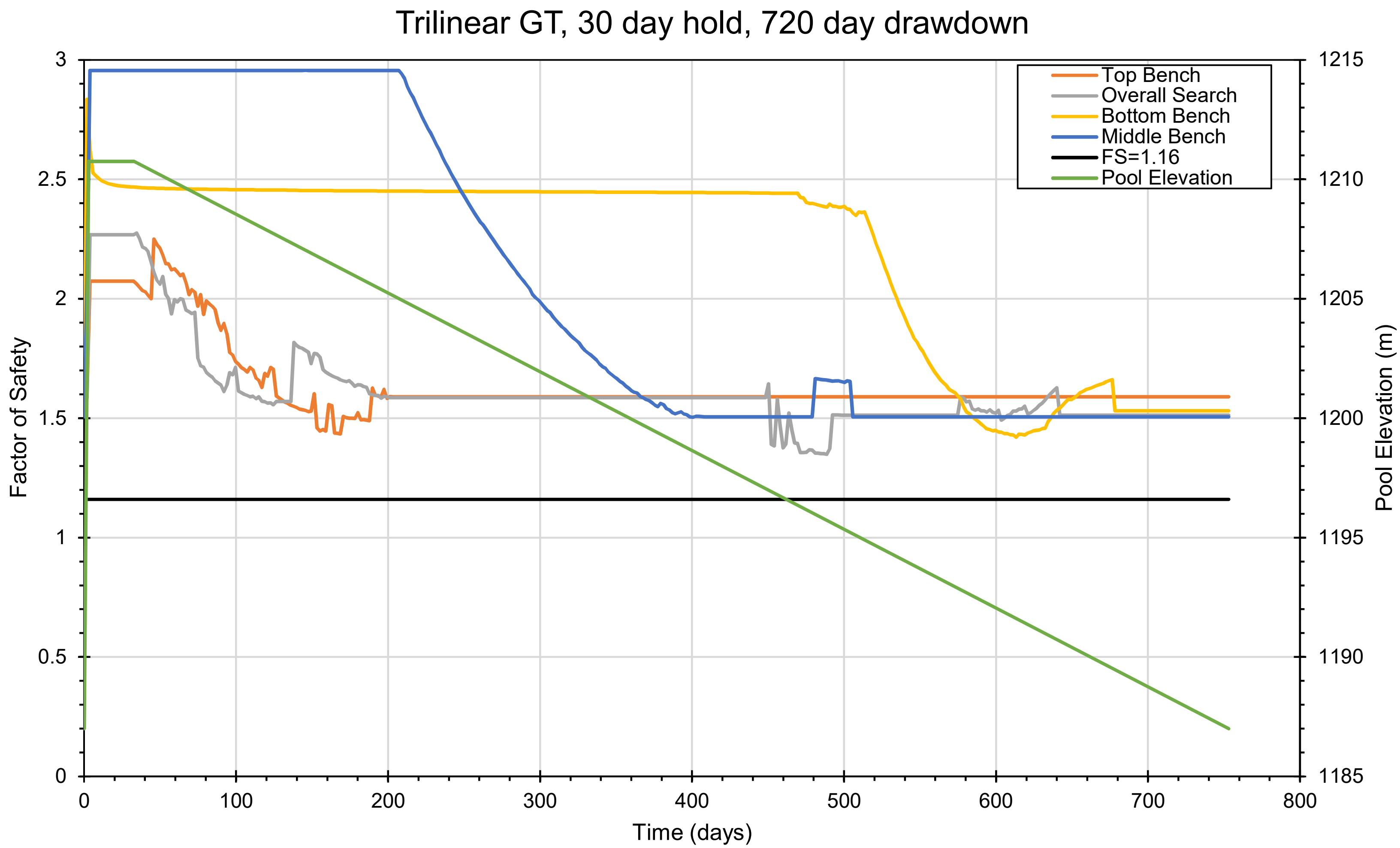
Trilinear GT, 30 day hold, 240 day drawdown
Factor of Safety,
Min. Value = 1.345
Factor of Safety
Pool Elevation (m)
Time (days)
0
0.5
1
1.5
2
2.5
3
1185
1190
1195
1200
1205
1210
1215
0
50
100
150
200
250
300



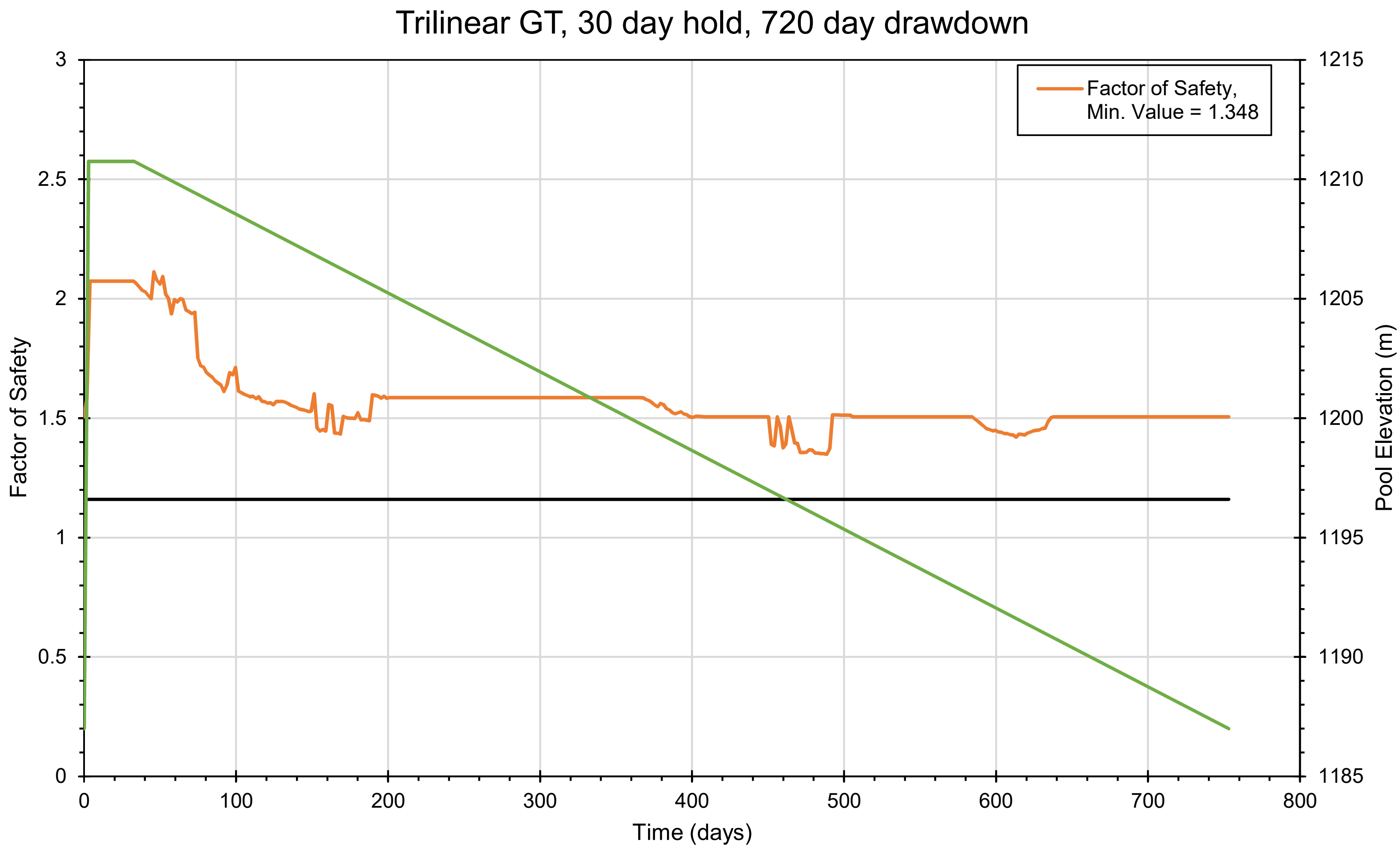
Trilinear GT, 30 day hold, 360 day drawdown
Factor of Safety
Pool Elevation (m)
Time (days)
Top Bench
Overall Search
Bottom Bench
Middle Bench
FS=1.16
Pool Elevation
0
0.5
1
1.5
2
2.5
3
1185
1190
1195
1200
1205
1210
1215
0
50
100
150
200
250
300
350
400
450



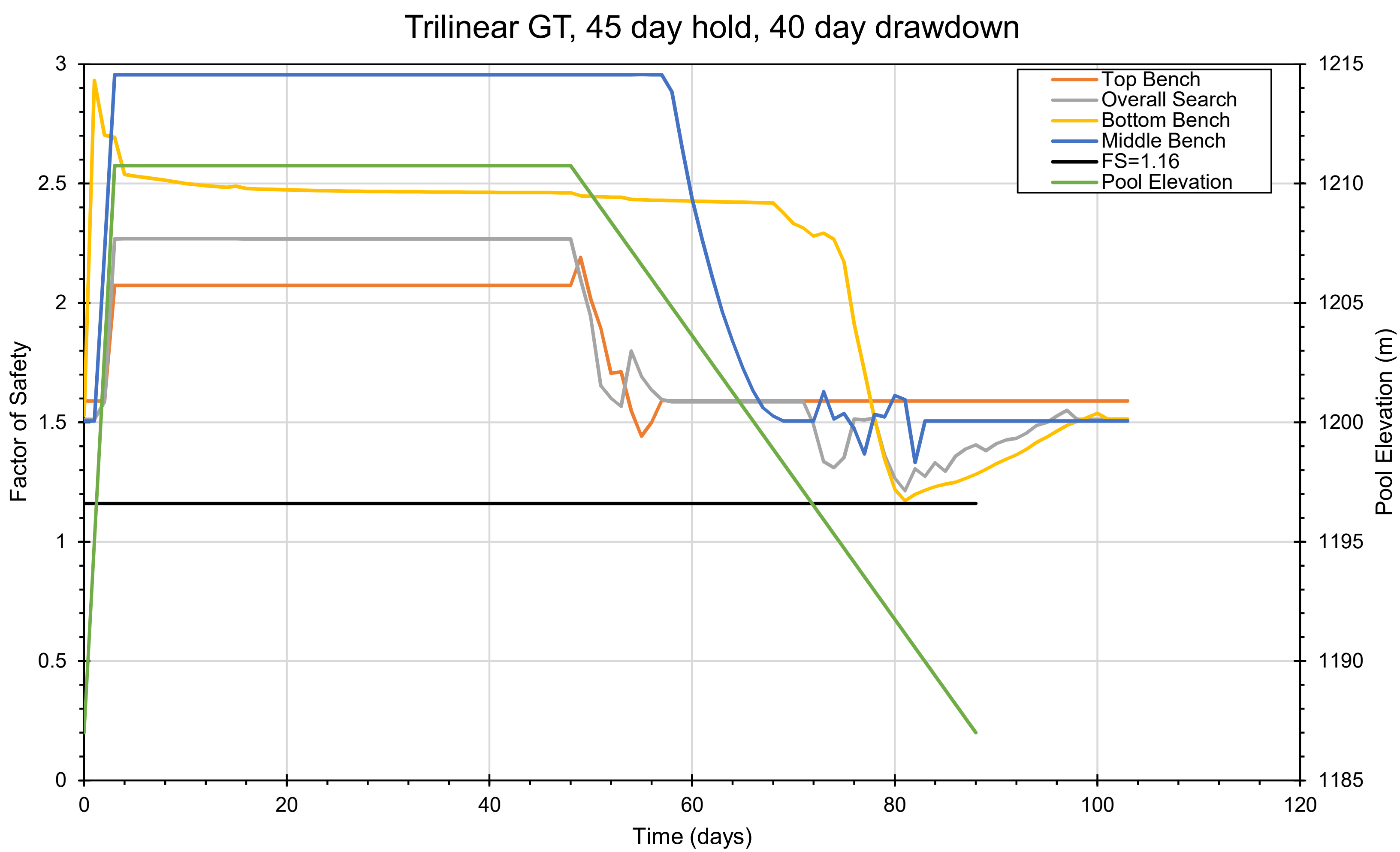
Trilinear GT, 30 day hold, 360 day drawdown
Factor of Safety,
Min. Value = 1.345
Factor of Safety
Pool Elevation (m)
Time (days)
0
0.5
1
1.5
2
2.5
3
1185
1190
1195
1200
1205
1210
1215
0
50
100
150
200
250
300
350
400
450



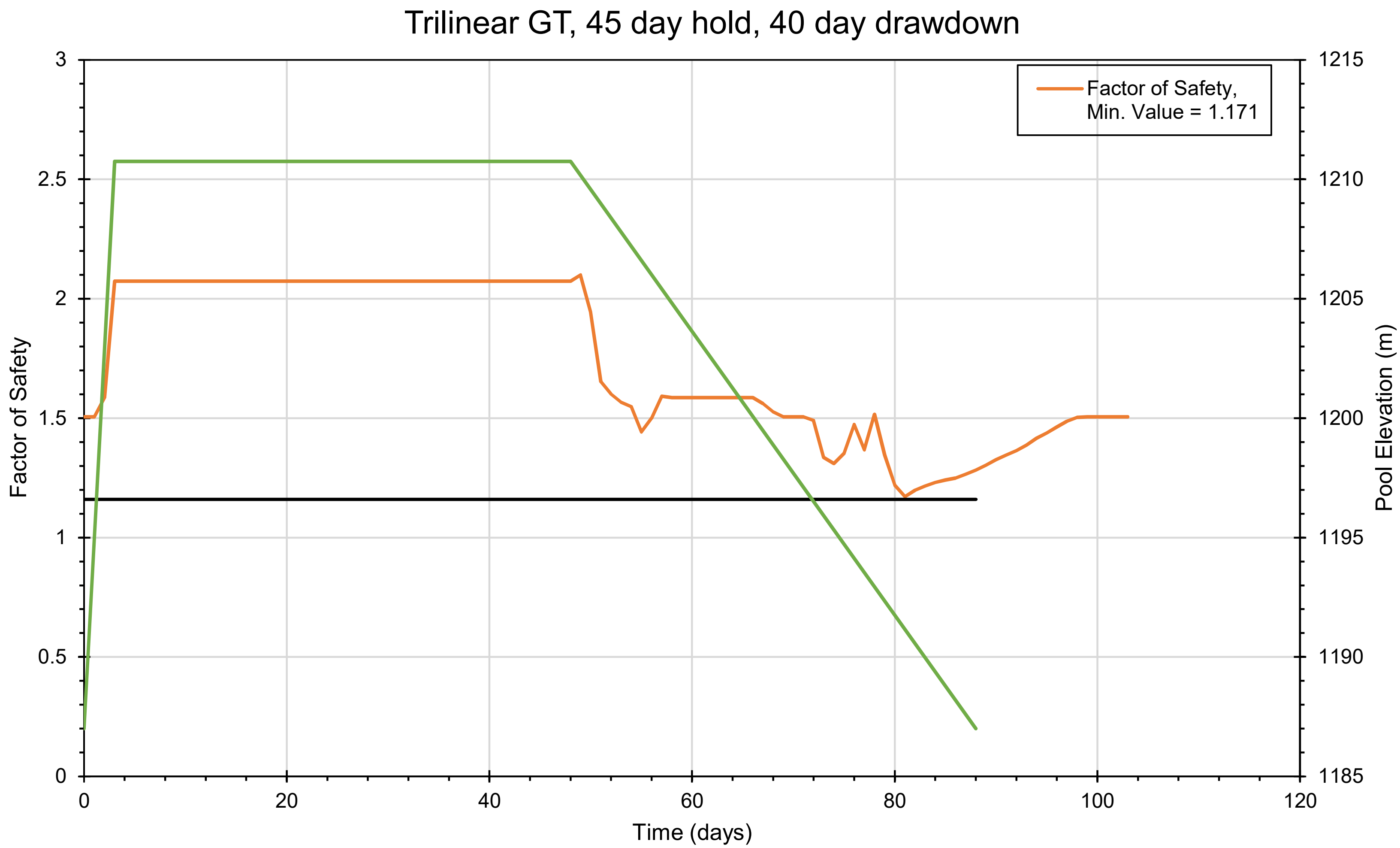
Trilinear GT, 30 day hold, 720 day drawdown
Factor of Safety
Pool Elevation (m)
Time (days)
Top Bench
Overall Search
Bottom Bench
Middle Bench
FS=1.16
Pool Elevation
0
0.5
1
1.5
2
2.5
3
1185
1190
1195
1200
1205
1210
1215
0
100
200
300
400
500
600
700
800



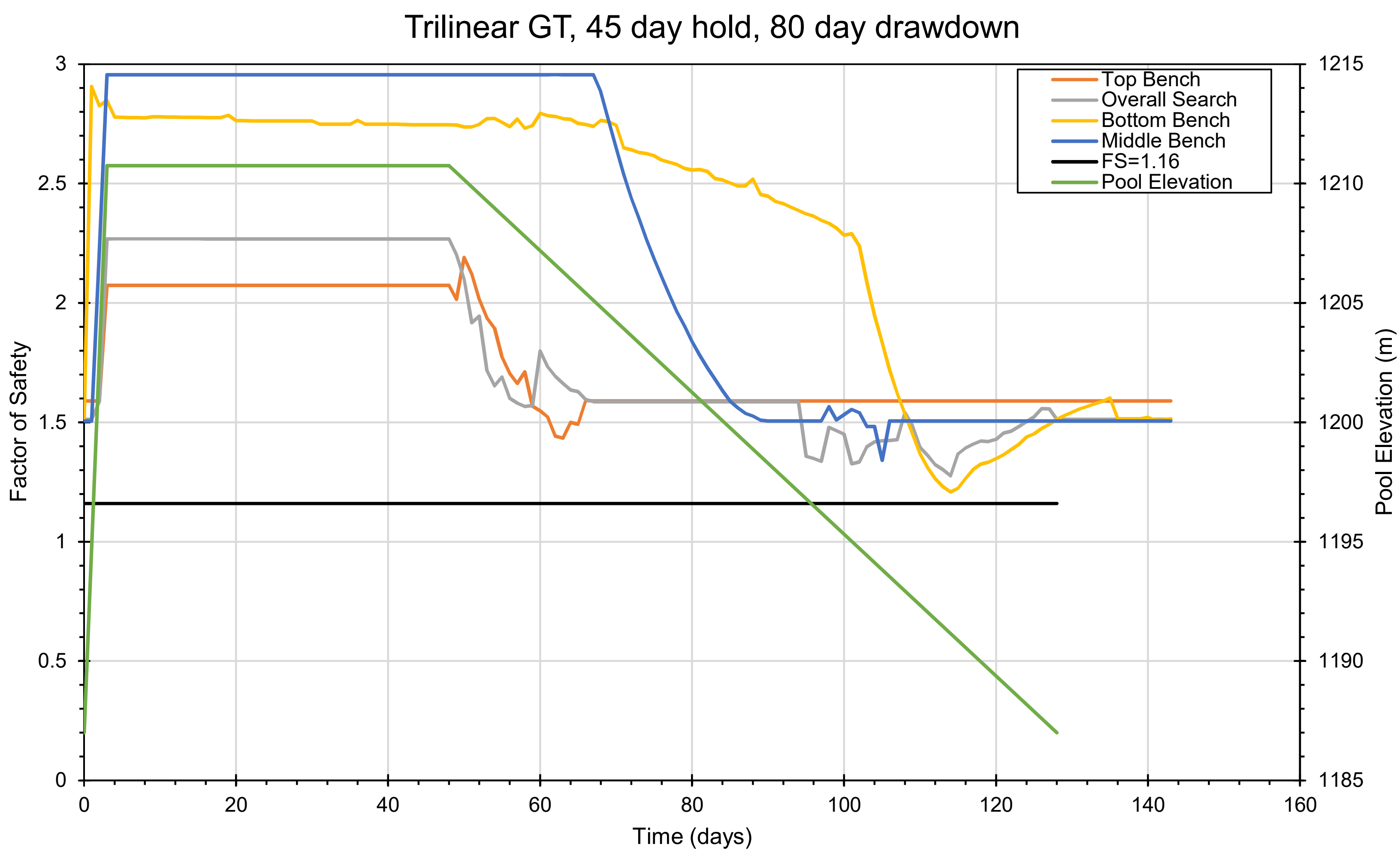
Trilinear GT, 30 day hold, 720 day drawdown
Factor of Safety,
Min. Value = 1.348
Factor of Safety
Pool Elevation (m)
Time (days)
0
0.5
1
1.5
2
2.5
3
1185
1190
1195
1200
1205
1210
1215
0
100
200
300
400
500
600
700
800



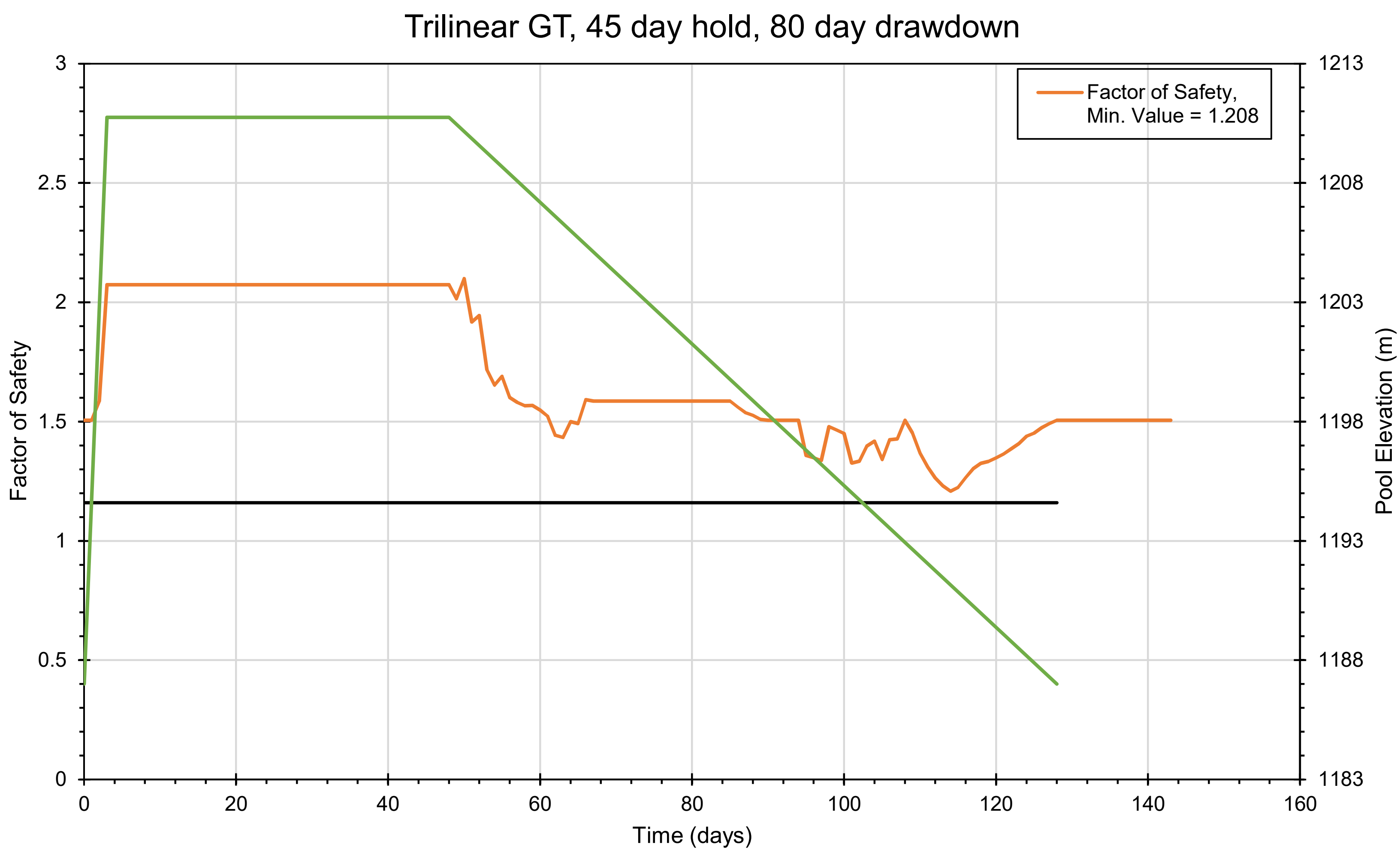
Trilinear GT, 45 day hold, 40 day drawdown
Top Bench
Overall Search
Bottom Bench
Middle Bench
FS=1.16
Pool Elevation
Factor of Safety
Pool Elevation (m)
Time (days)
0
0.5
1
1.5
2
2.5
3
1185
1190
1195
1200
1205
1210
1215
0
20
40
60
80
100
120



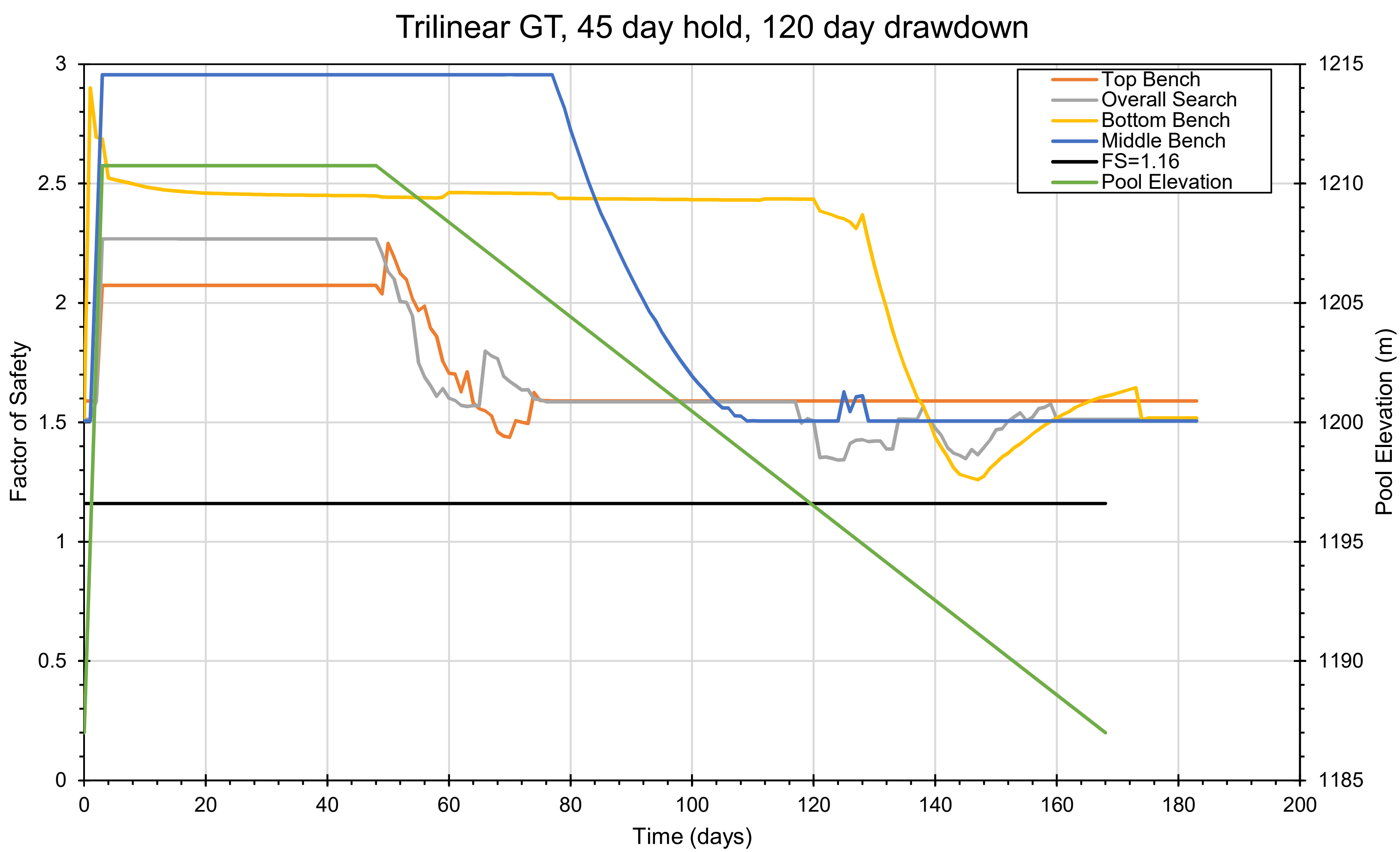
Trilinear GT, 45 day hold, 40 day drawdown
Factor of Safety,
Min. Value = 1.171
Factor of Safety
Pool Elevation (m)
Time (days)
0
0.5
1
1.5
2
2.5
3
1185
1190
1195
1200
1205
1210
1215
0
20
40
60
80
100
120

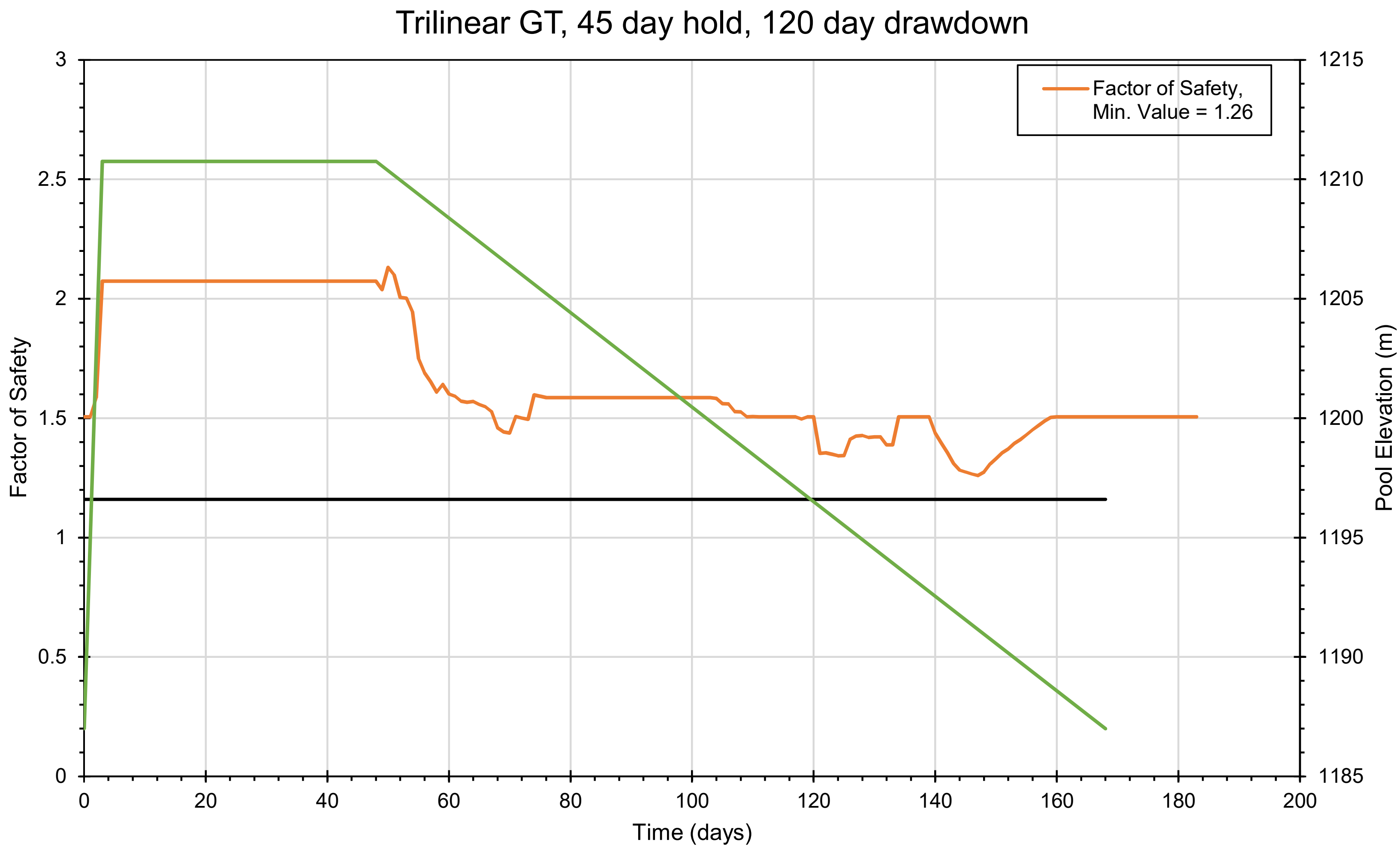


Trilinear GT, 45 day hold, 80 day drawdown
Factor of Safety
Pool Elevation (m)
Time (days)
Top Bench
Overall Search
Bottom Bench
Middle Bench
FS=1.16
Pool Elevation
0
0.5
1
1.5
2
2.5
3
1185
1190
1195
1200
1205
1210
1215
0
20
40
60
80
100
120
140
160

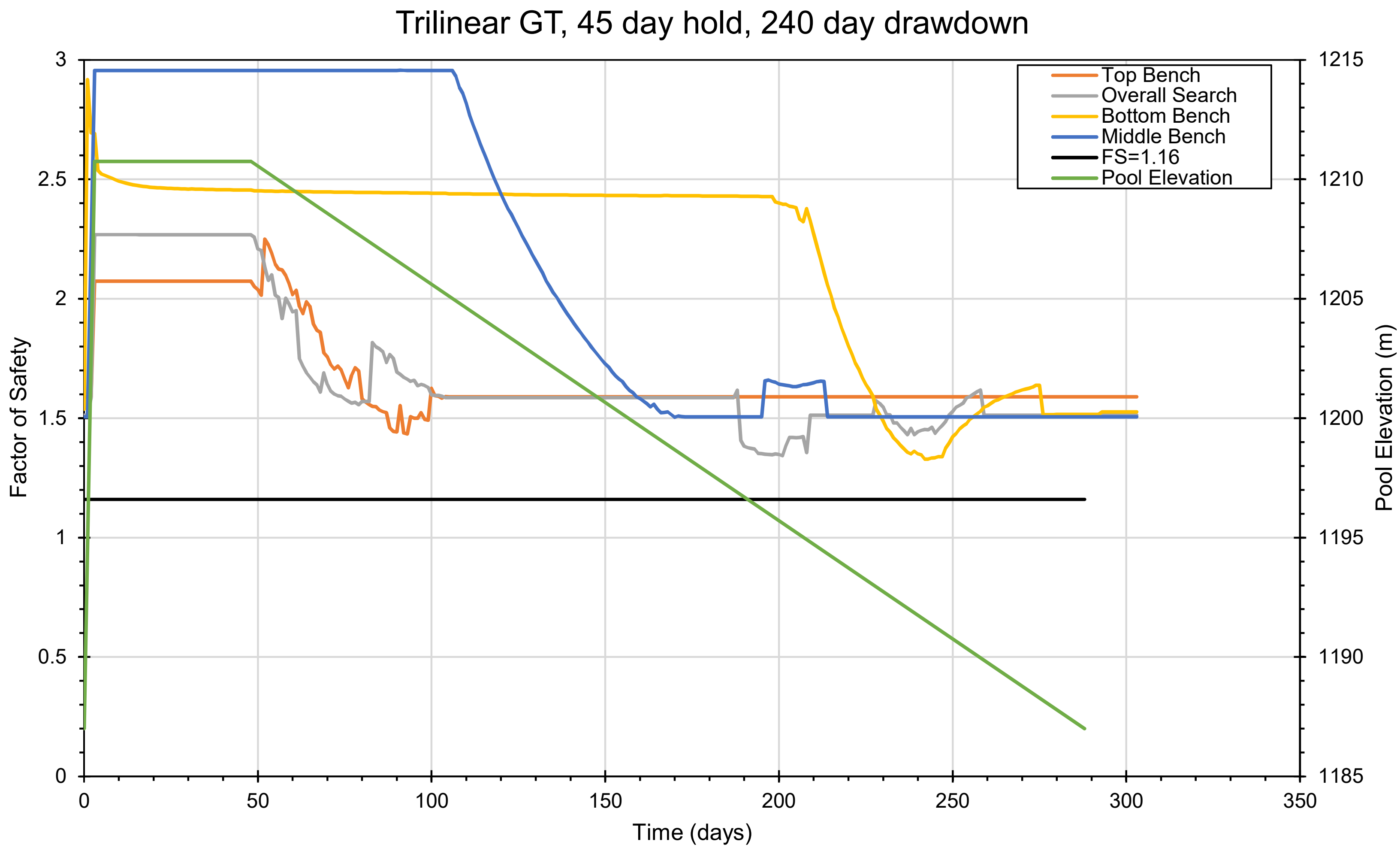


Trilinear GT, 45 day hold, 80 day drawdown
Factor of Safety,
Min. Value = 1.208
Factor of Safety
Pool Elevation (m)
Time (days)
0
0.5
1
1.5
2
2.5
3
1183
1188
1193
1198
1203
1208
1213
0
20
40
60
80
100
120
140
160

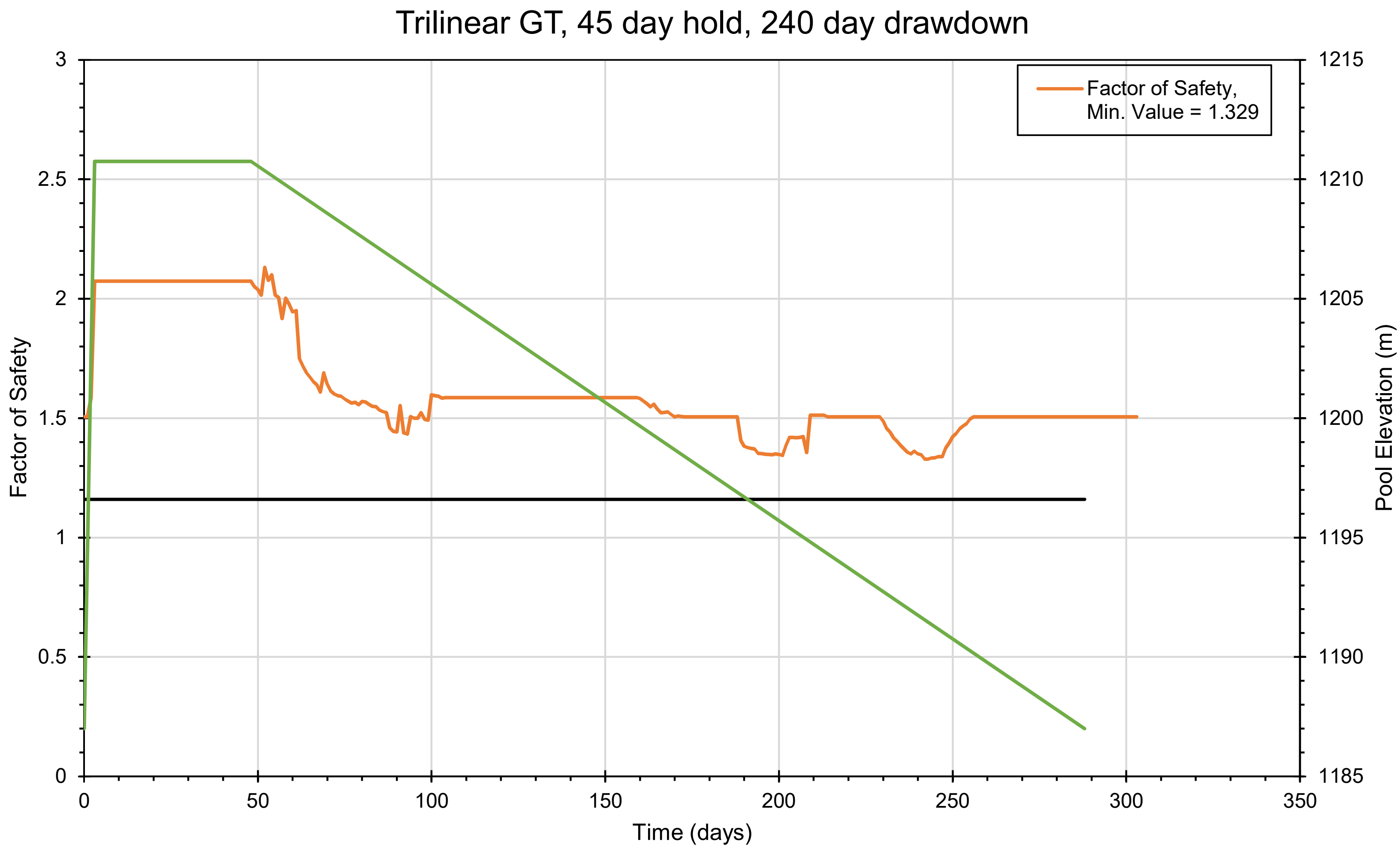

Trilinear GT, 45 day hold, 120 day drawdown
Top Bench
Overall Search
Bottom Bench
Middle Bench
FS=1.16
Pool Elevation
Factor of Safety
Pool Elevation (m)
Time (days)
0
0.5
1
1.5
2
2.5
3
1185
1190
1195
1200
1205
1210
1215
0
20
40
60
80
100
120
140
160
180
200



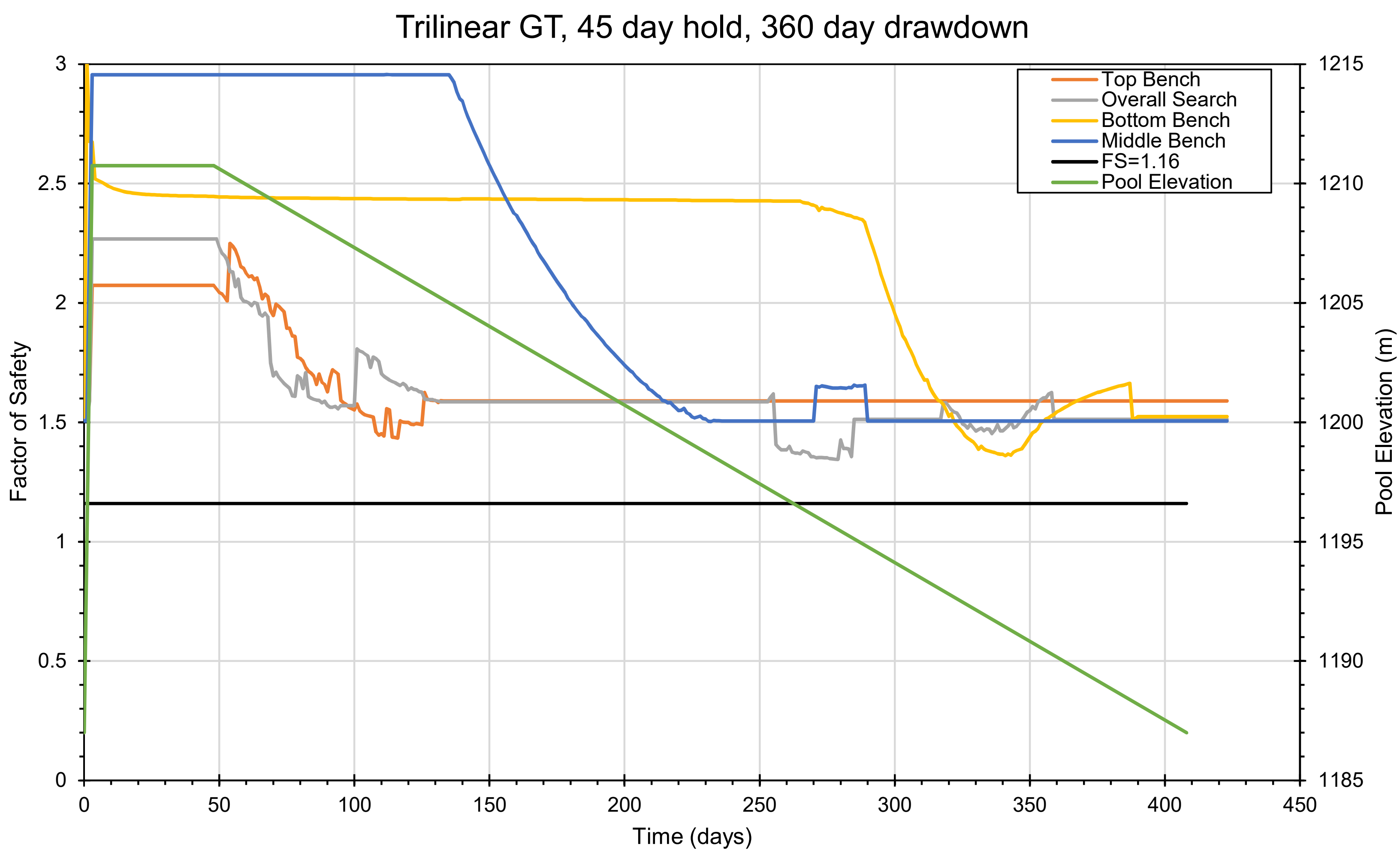
Trilinear GT, 45 day hold, 120 day drawdown
Factor of Safety,
Min. Value = 1.26
Factor of Safety
Pool Elevation (m)
Time (days)
0
20
40
60
80
100
120
140
160
180
200
0
0.5
1
1.5
2
2.5
3
1185
1190
1195
1200
1205
1210
1215



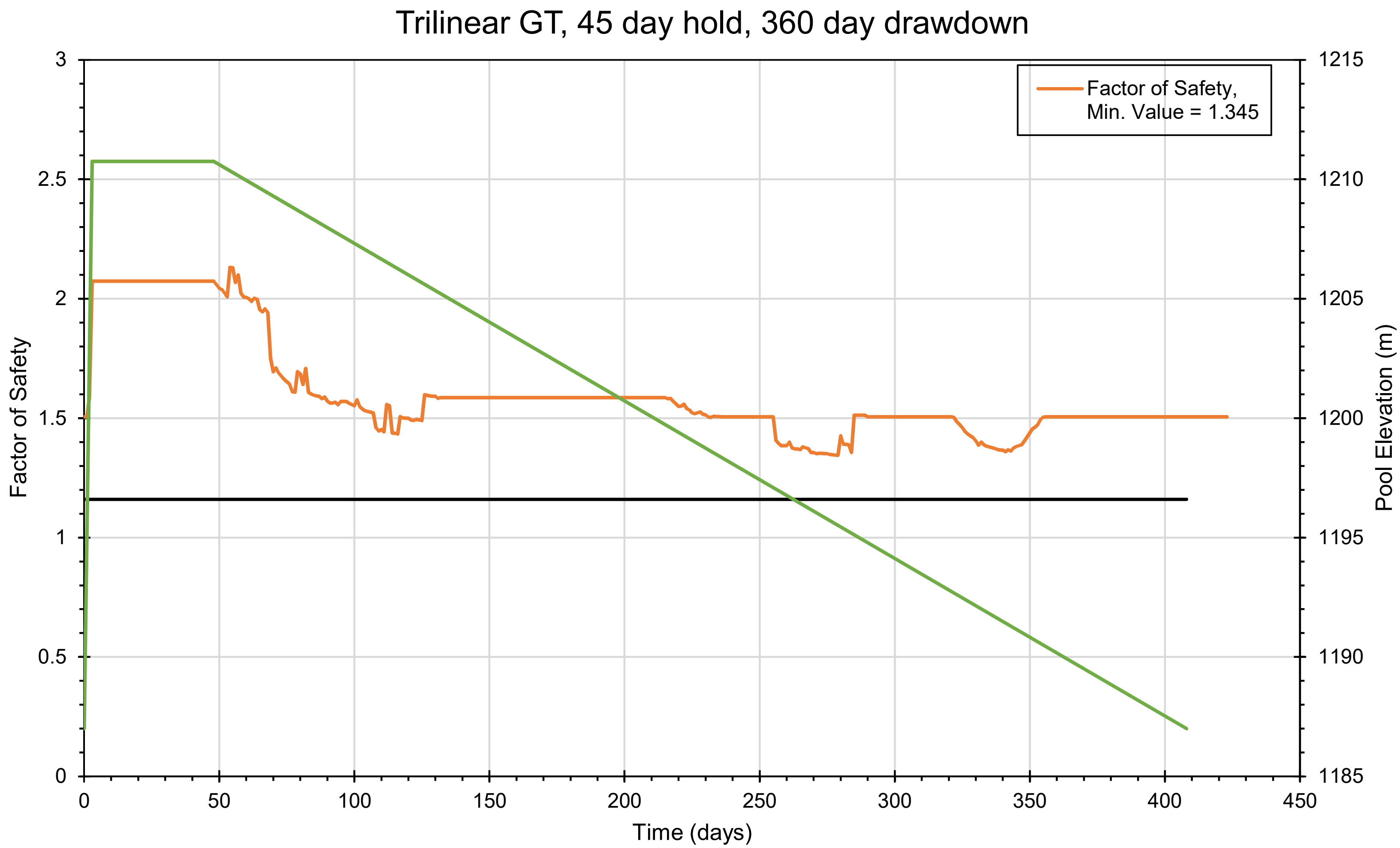
Trilinear GT, 45 day hold, 240 day drawdown
Top Bench
Overall Search
Bottom Bench
Middle Bench
FS=1.16
Pool Elevation
Factor of Safety
Pool Elevation (m)
Time (days)
0
0.5
1
1.5
2
2.5
3
1185
1190
1195
1200
1205
1210
1215
0
50
100
150
200
250
300
350

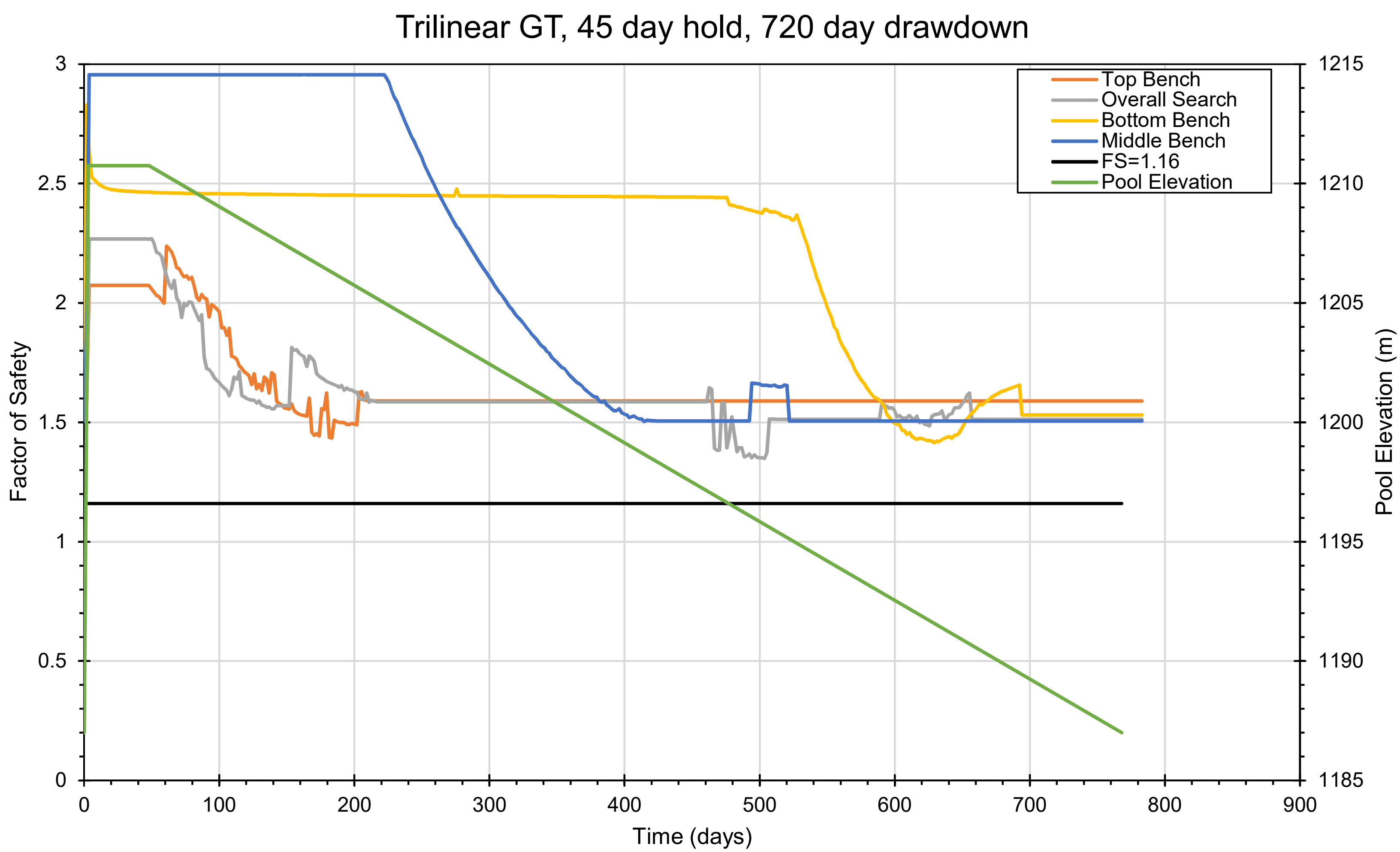


Trilinear GT, 45 day hold, 240 day drawdown
Factor of Safety,
Min. Value = 1.329
Factor of Safety
Pool Elevation (m)
Time (days)
0
0.5
1
1.5
2
2.5
3
1185
1190
1195
1200
1205
1210
1215
0
50
100
150
200
250
300
350

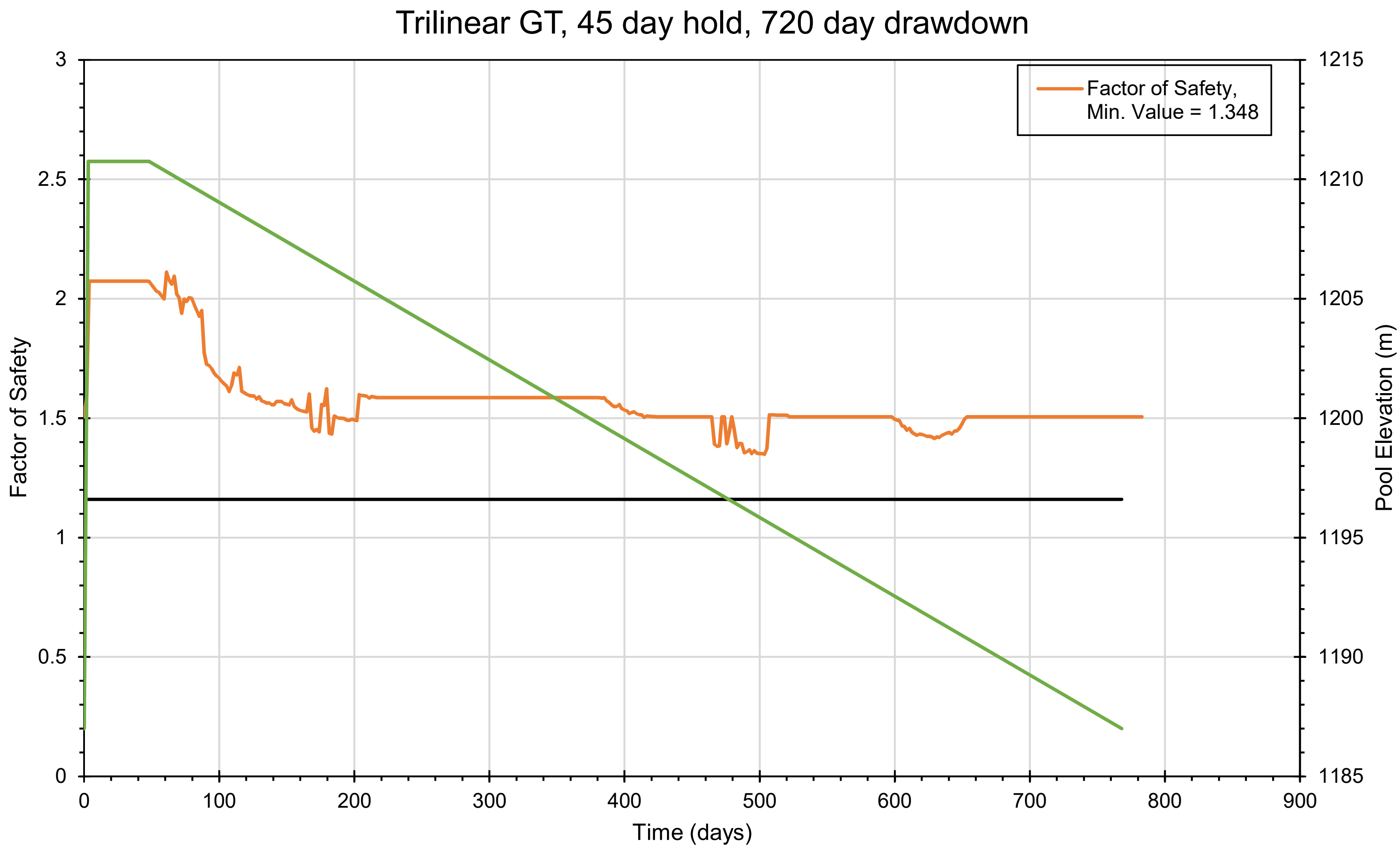


Trilinear GT, 45 day hold, 360 day drawdown
Top Bench
Overall Search
Bottom Bench
Middle Bench
FS=1.16
Pool Elevation
Factor of Safety
Pool Elevation (m)
Time (days)
0
0.5
1
1.5
2
2.5
3
1185
1190
1195
1200
1205
1210
1215
0
50
100
150
200
250
300
350
400
450

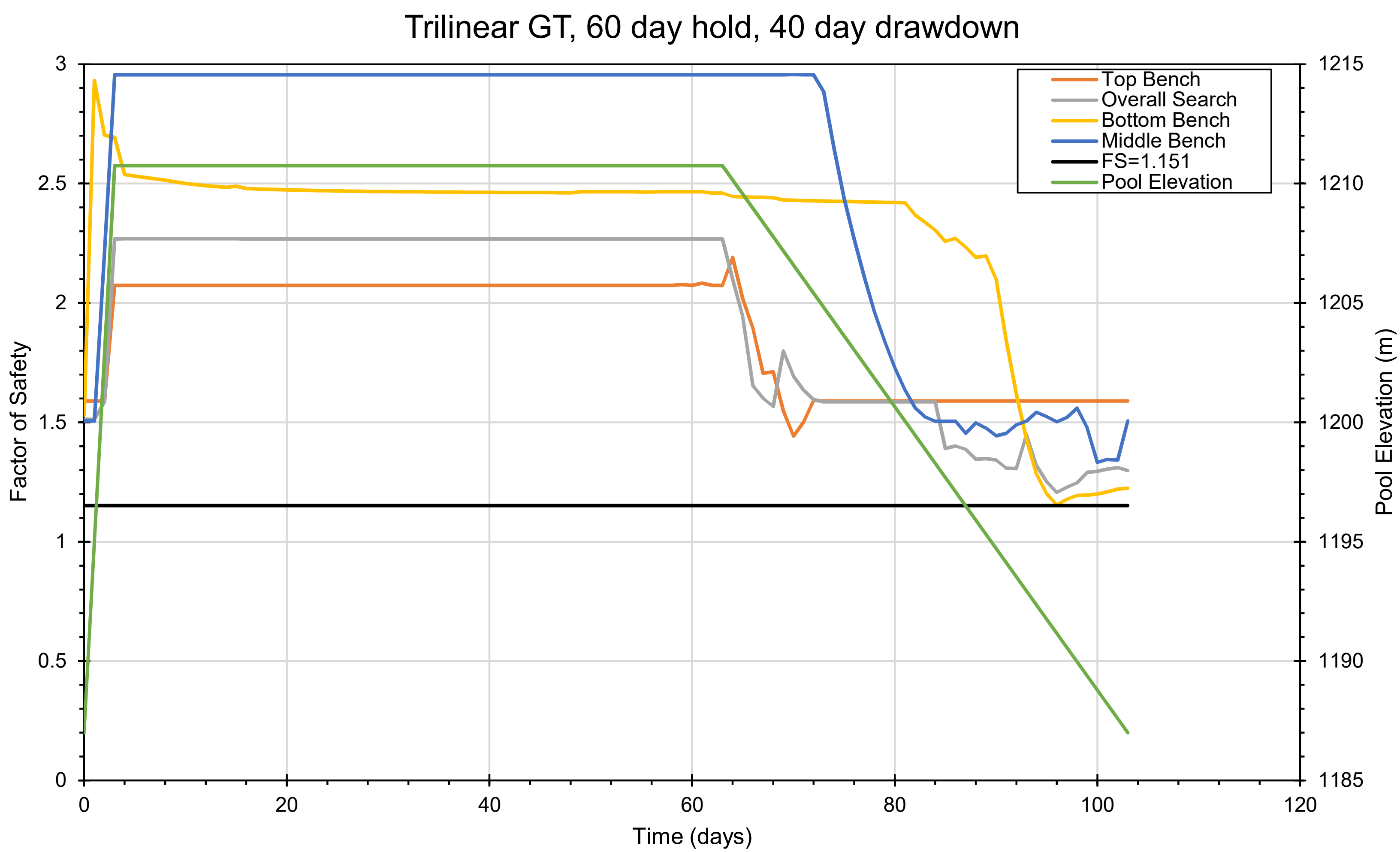

Trilinear GT, 45 day hold, 360 day drawdown
Factor of Safety,
Min. Value = 1.345
Factor of Safety
Pool Elevation (m)
Time (days)
0
0.5
1
1.5
2
2.5
3
1185
1190
1195
1200
1205
1210
1215
0
50
100
150
200
250
300
350
400
450

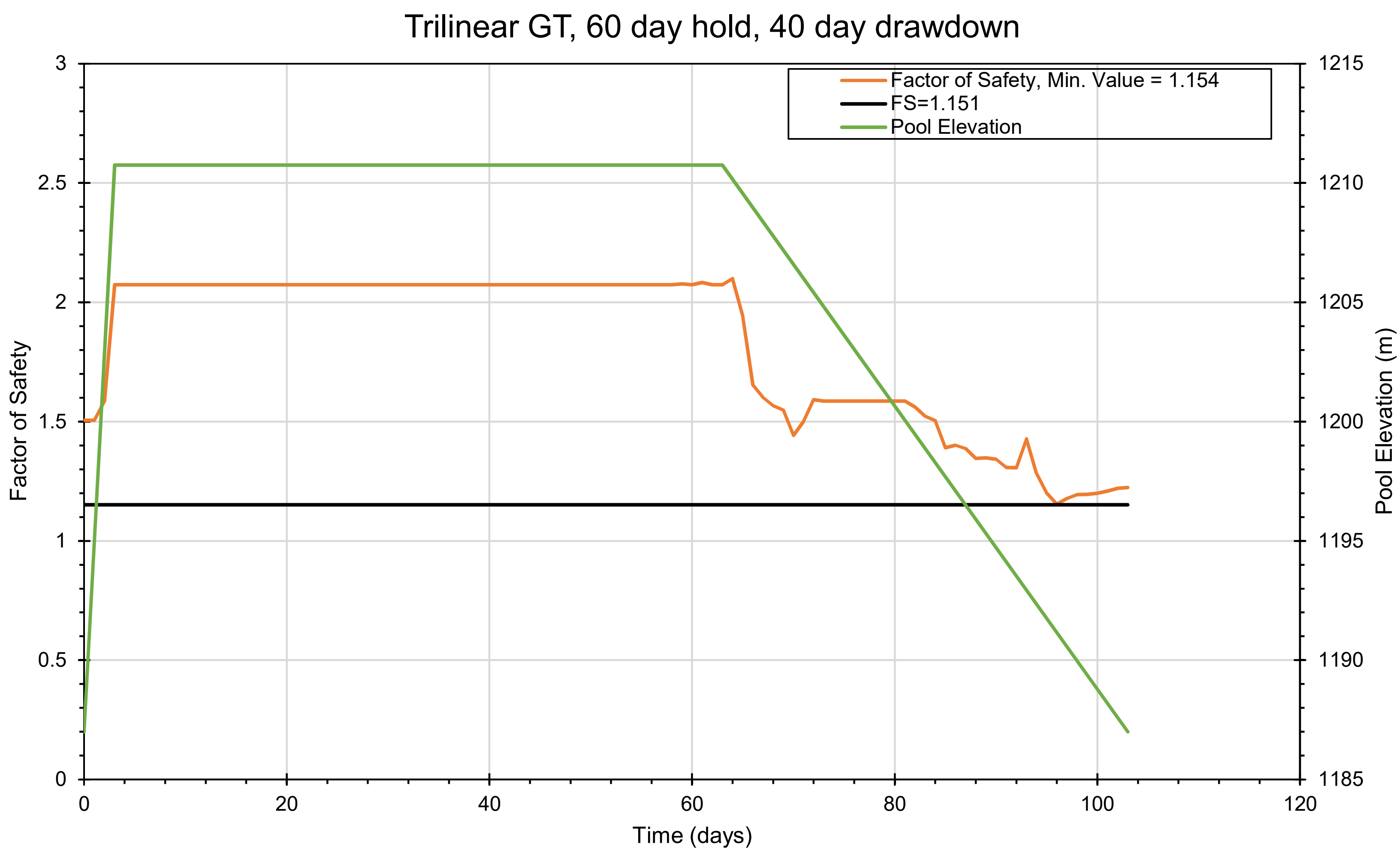


Trilinear GT, 45 day hold, 720 day drawdown
Top Bench
Overall Search
Bottom Bench
Middle Bench
FS=1.16
Pool Elevation
Factor of Safety
Pool Elevation (m)
Time (days)
0
0.5
1
1.5
2
2.5
3
1185
1190
1195
1200
1205
1210
1215
0
100
200
300
400
500
600
700
800
900

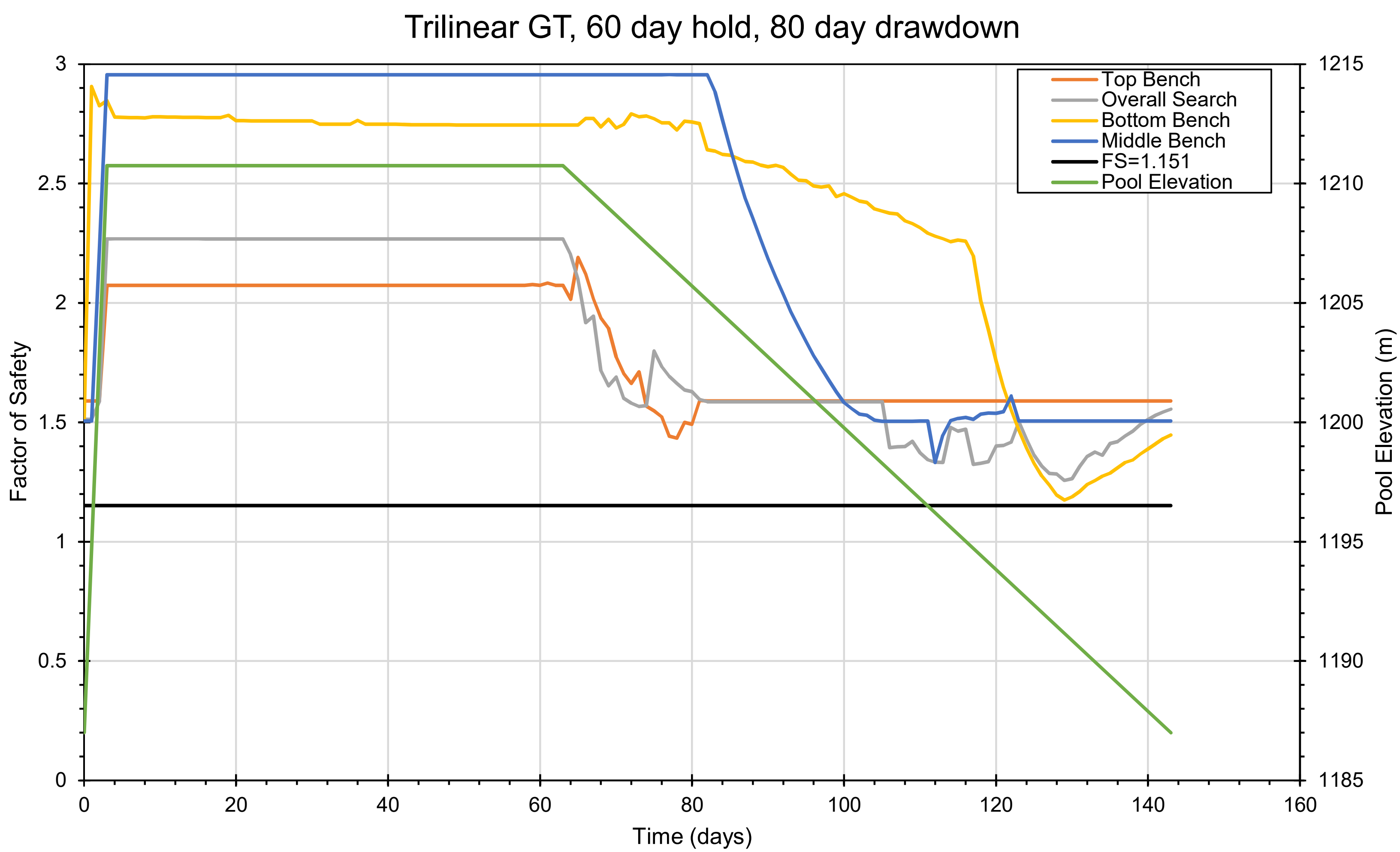


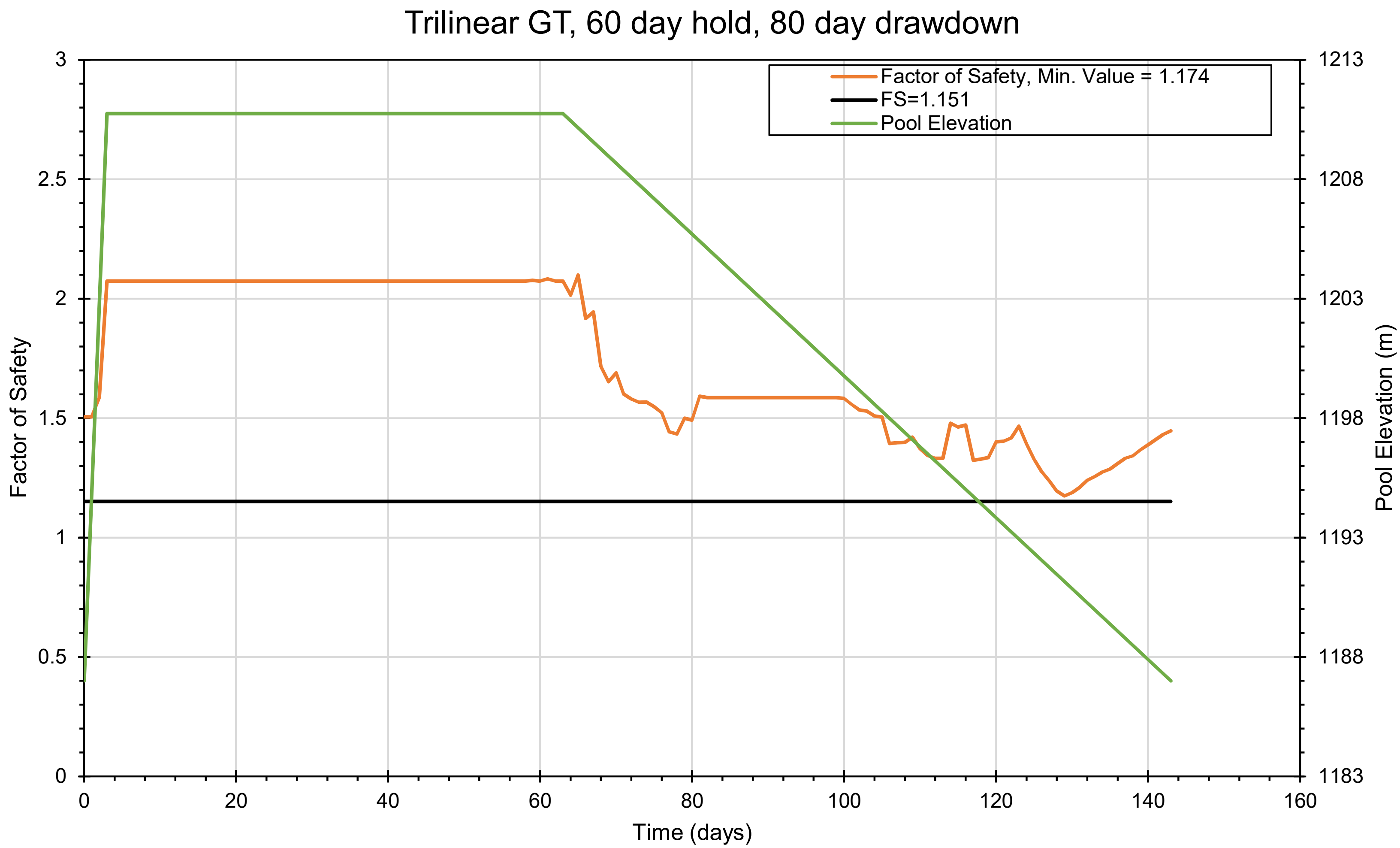
Trilinear GT, 45 day hold, 720 day drawdown
Factor of Safety,
Min. Value = 1.348
Factor of Safety
Pool Elevation (m)
Time (days)
0
0.5
1
1.5
2
2.5
3
1185
1190
1195
1200
1205
1210
1215
0
100
200
300
400
500
600
700
800
900


Trilinear GT, 60 day hold, 40 day drawdown
Top Bench
Overall Search
Bottom Bench
Middle Bench
FS=1.151
Pool Elevation
Factor of Safety
Pool Elevation (m)
Time (days)
0
0.5
1
1.5
2
2.5
3
1185
1190
1195
1200
1205
1210
1215
0
20
40
60
80
100
120

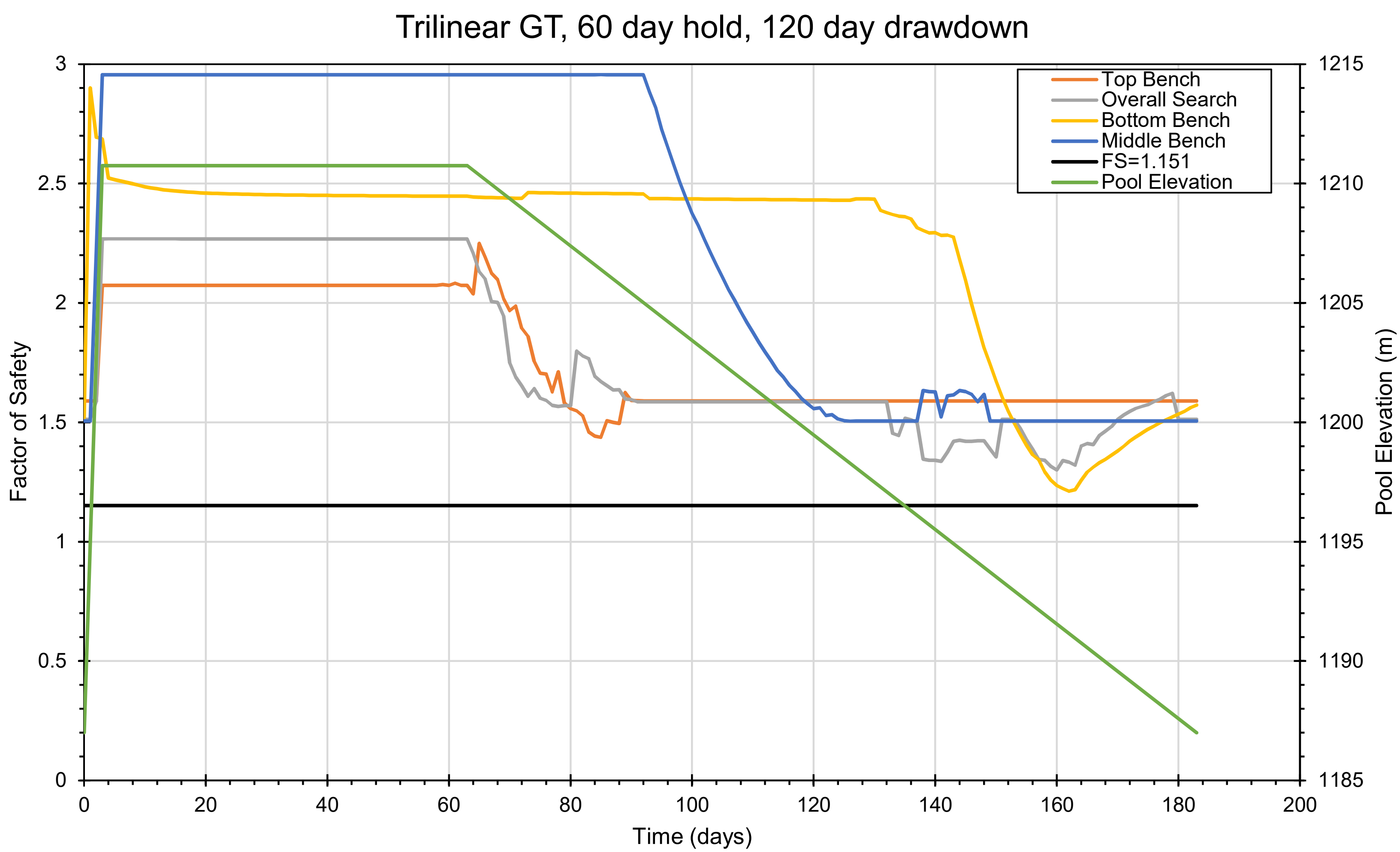


Trilinear GT, 60 day hold, 40 day drawdown
Factor of Safety, Min. Value = 1.154
FS=1.151
Pool Elevation
Factor of Safety
Pool Elevation (m)
Time (days)
0
0.5
1
1.5
2
2.5
3
1185
1190
1195
1200
1205
1210
1215
0
20
40
60
80
100
120

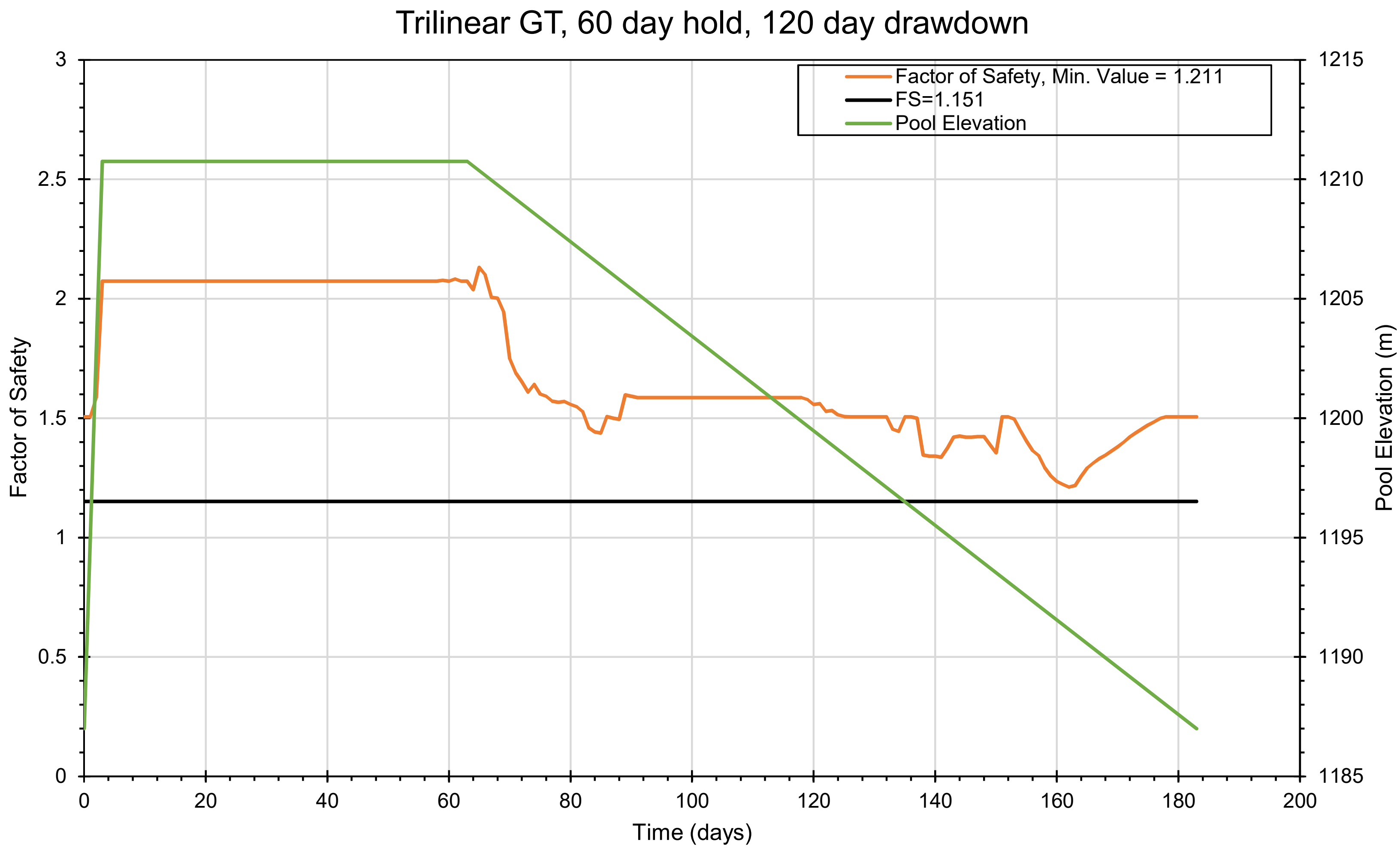

Trilinear GT, 60 day hold, 80 day drawdown
Factor of Safety
Pool Elevation (m)
Time (days)
Top Bench
Overall Search
Bottom Bench
Middle Bench
FS=1.151
Pool Elevation
0
0.5
1
1.5
2
2.5
3
1185
1190
1195
1200
1205
1210
1215
0
20
40
60
80
100
120
140
160



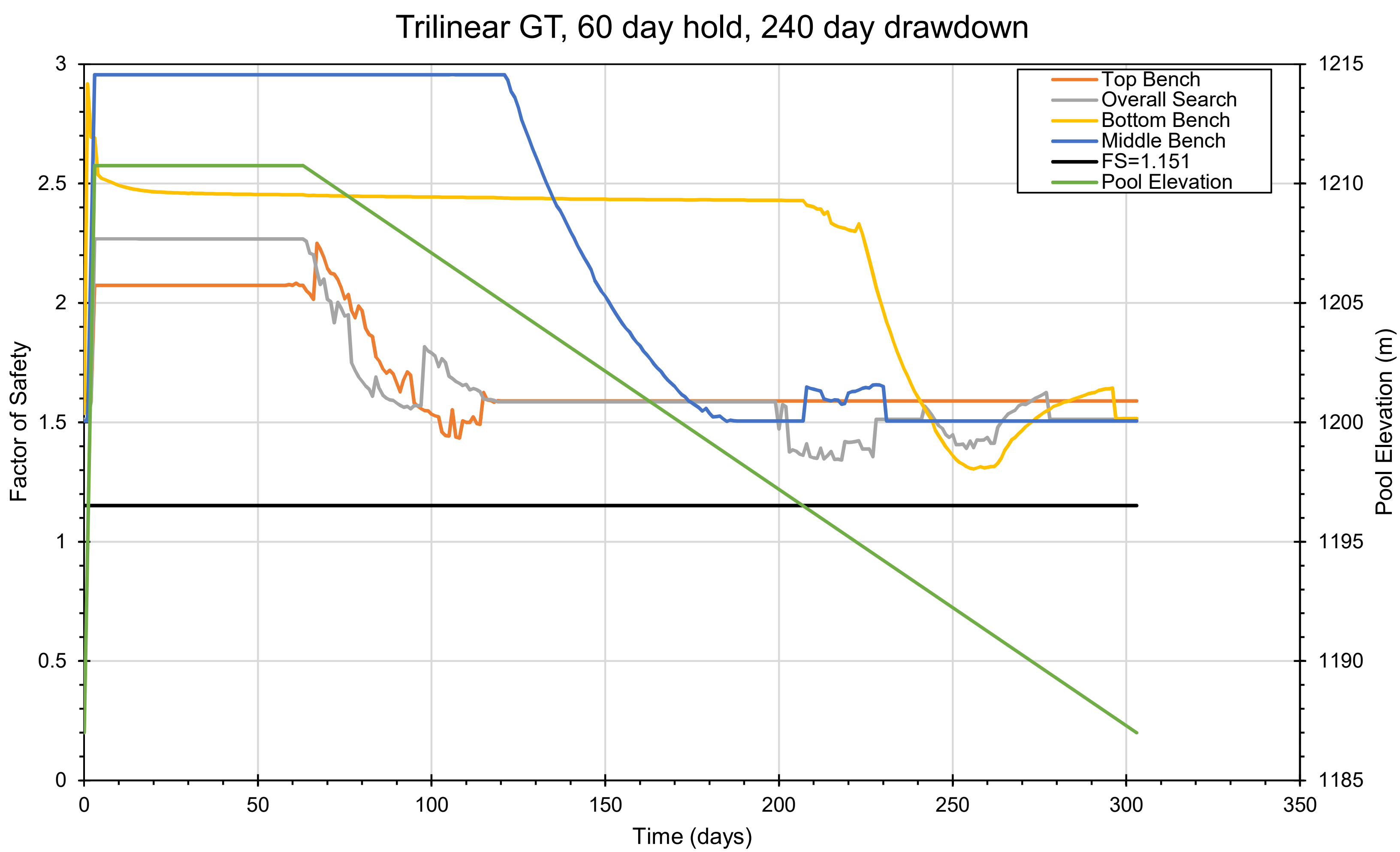
Trilinear GT, 60 day hold, 80 day drawdown
Factor of Safety, Min. Value = 1.174
FS=1.151
Pool Elevation
Factor of Safety
Pool Elevation (m)
Time (days)
0
0.5
1
1.5
2
2.5
3
1183
1188
1193
1198
1203
1208
1213
0
20
40
60
80
100
120
140
160

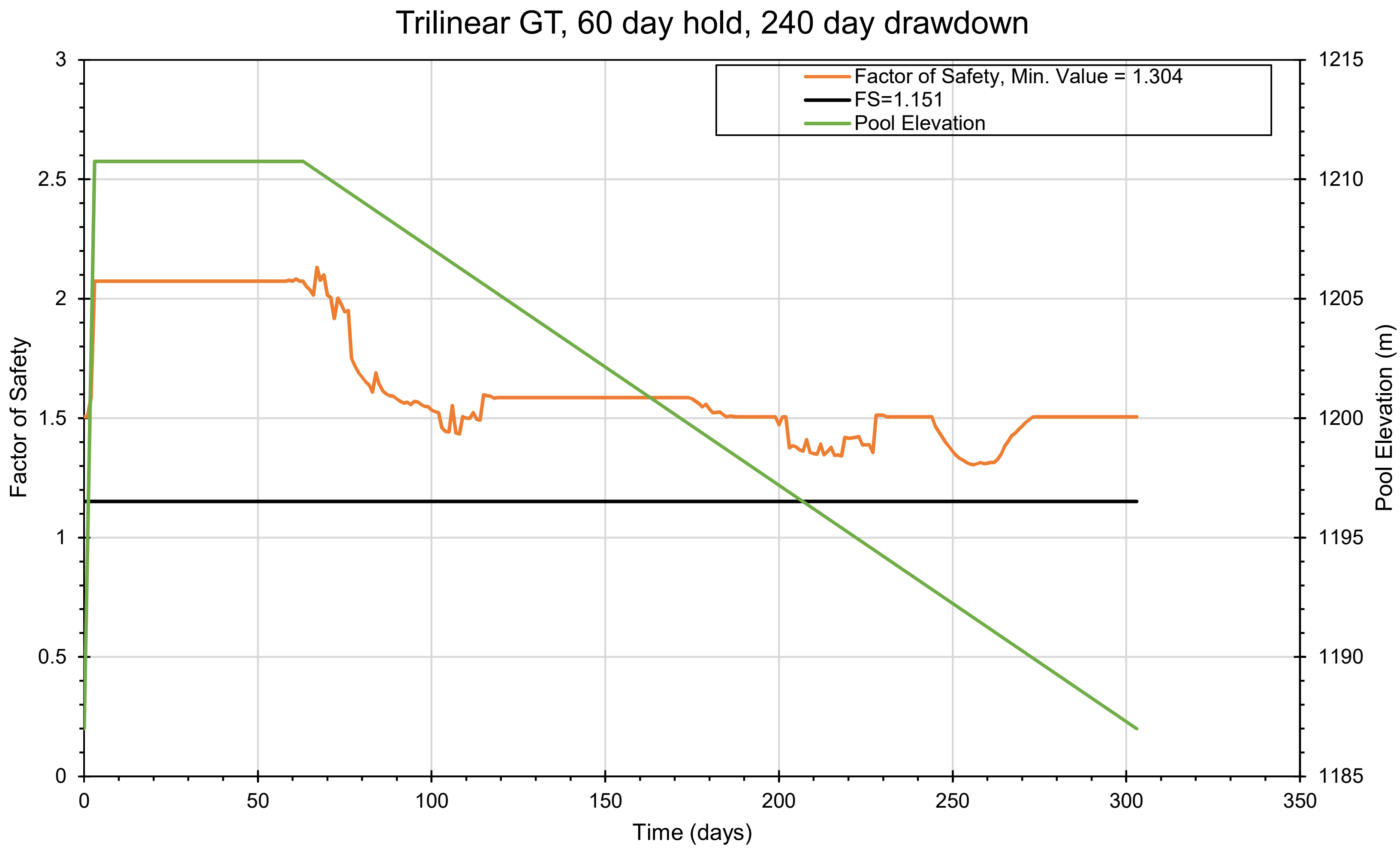


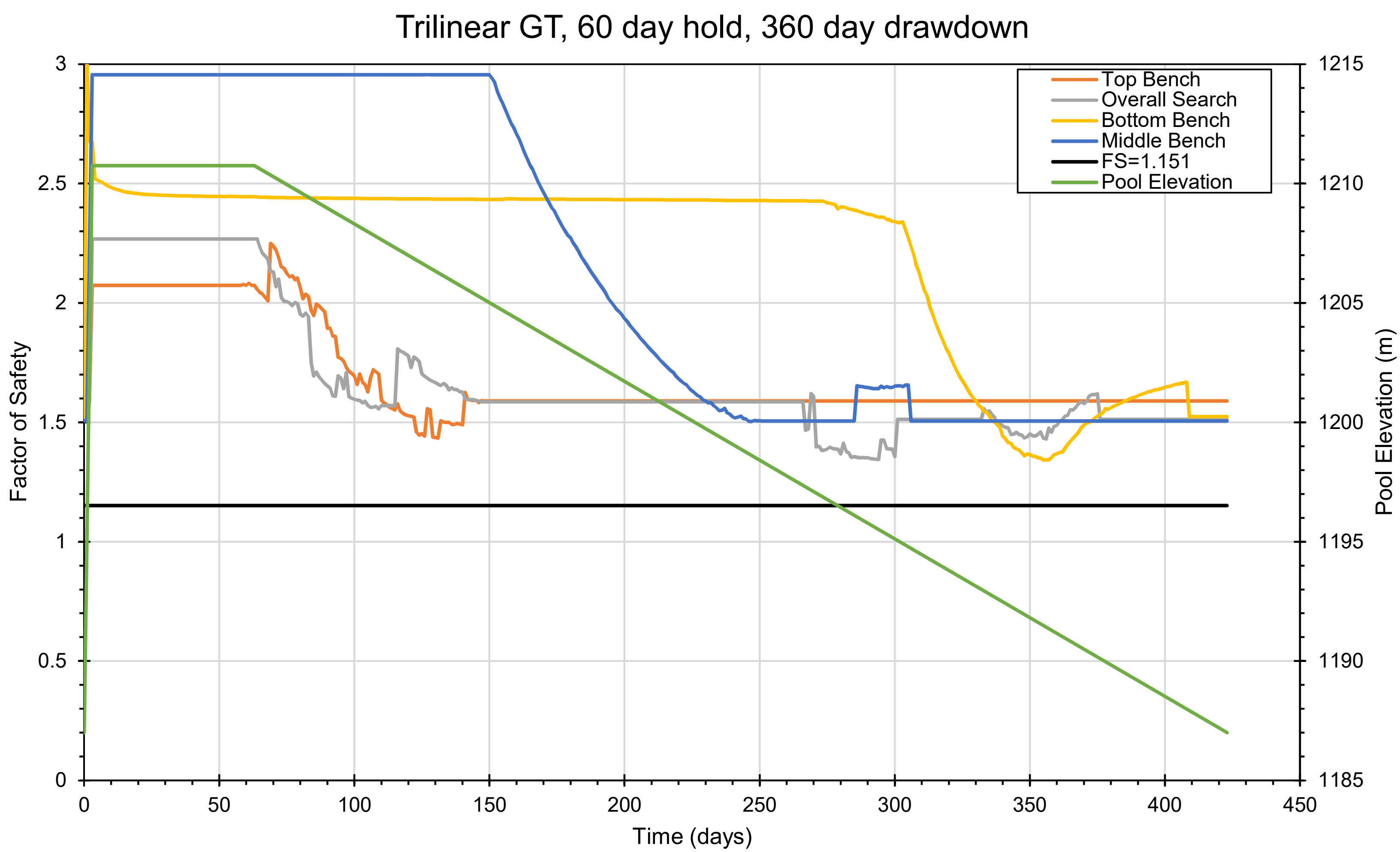
Trilinear GT, 60 day hold, 120 day drawdown
Factor of Safety
Pool Elevation (m)
Time (days)
Top Bench
Overall Search
Bottom Bench
Middle Bench
FS=1.151
Pool Elevation
0
0.5
1
1.5
2
2.5
3
1185
1190
1195
1200
1205
1210
1215
0
20
40
60
80
100
120
140
160
180
200

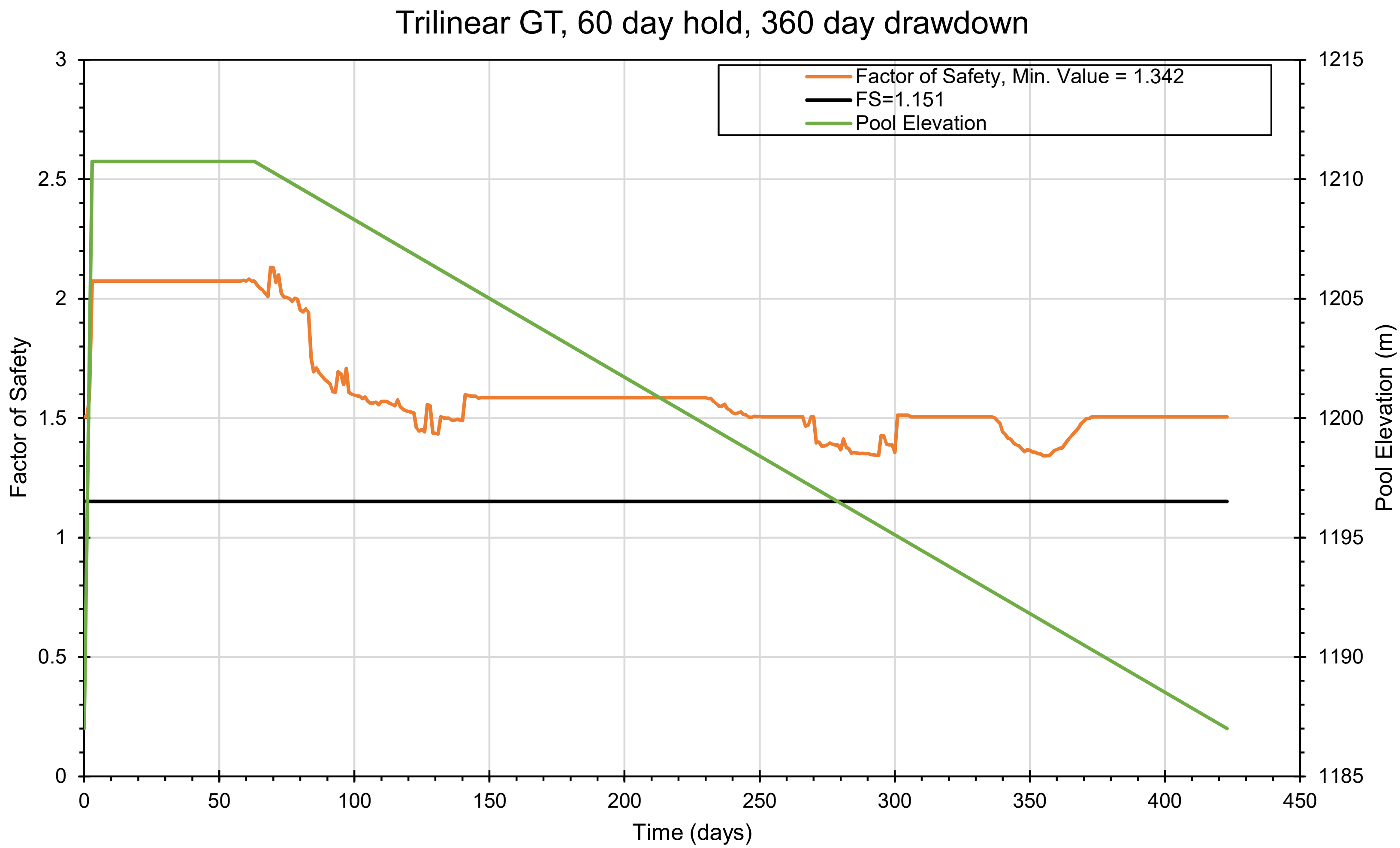


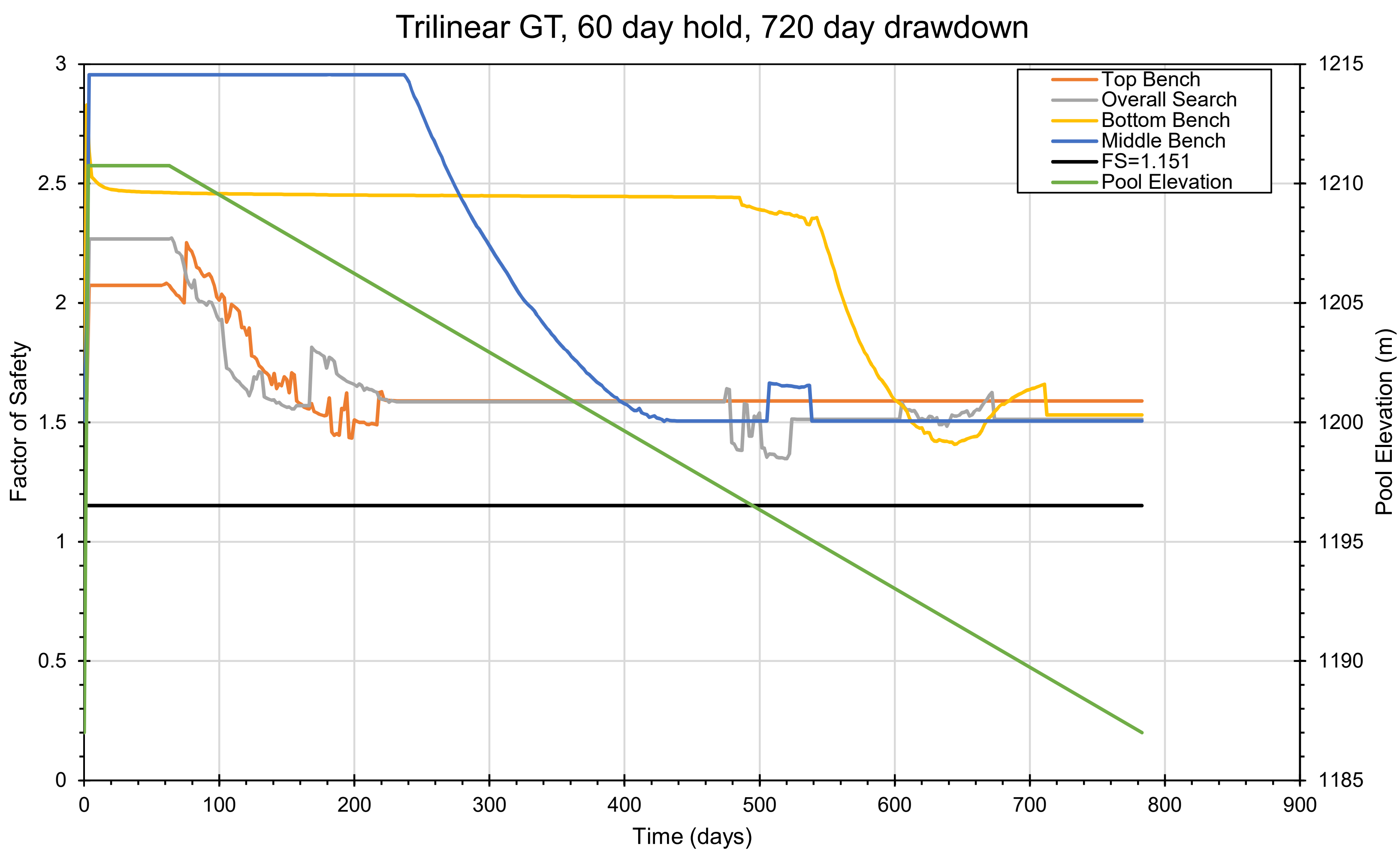
Trilinear GT, 60 day hold, 120 day drawdown
Factor of Safety, Min. Value = 1.211
FS=1.151
Pool Elevation
Factor of Safety
Pool Elevation (m)
Time (days)
0
0.5
1
1.5
2
2.5
3
1185
1190
1195
1200
1205
1210
1215
0
20
40
60
80
100
120
140
160
180
200


Trilinear GT, 60 day hold, 240 day drawdown
Factor of Safety
Pool Elevation (m)
Time (days)
0
0.5
1
1.5
2
2.5
3
1185
1190
1195
1200
1205
1210
1215
0
50
100
150
200
250
300
350
Top Bench
Overall Search
Bottom Bench
Middle Bench
FS=1.151
Pool Elevation

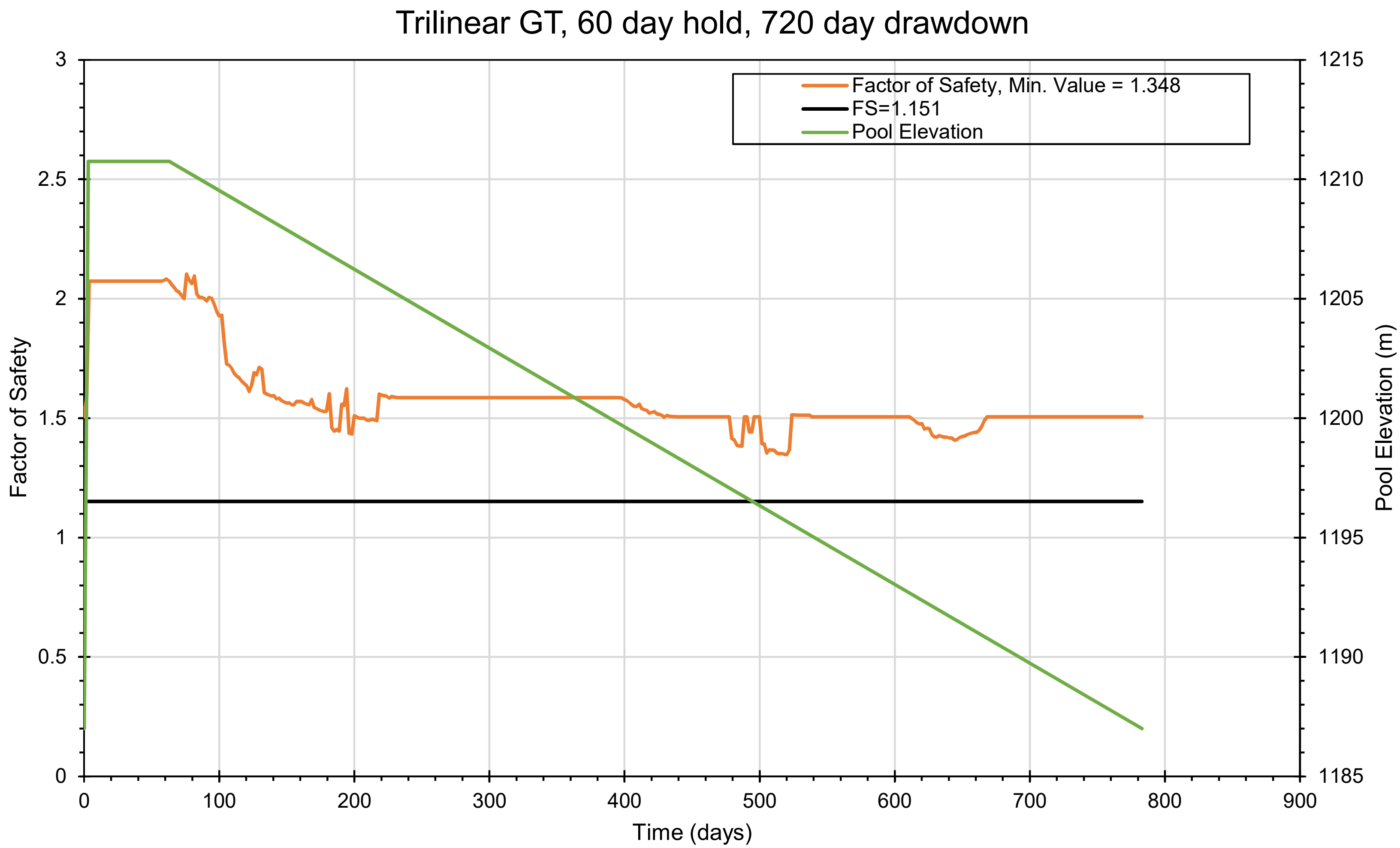

Trilinear GT, 60 day hold, 240 day drawdown
Factor of Safety, Min. Value = 1.304
FS=1.151
Pool Elevation
Factor of Safety
Pool Elevation (m)
Time (days)
0
0.5
1
1.5
2
2.5
3
1185
1190
1195
1200
1205
1210
1215
0
50
100
150
200
250
300
350

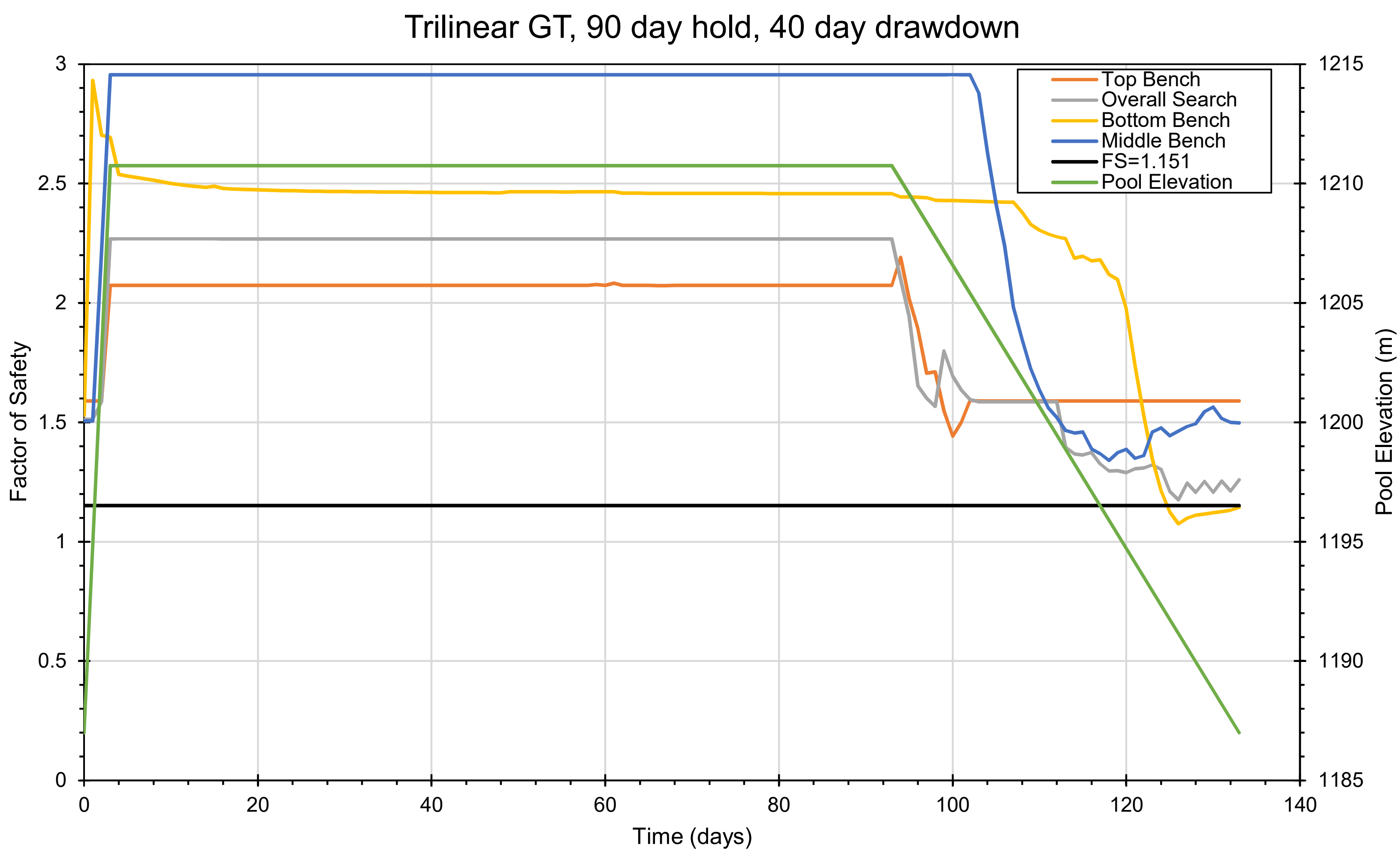

Trilinear GT, 60 day hold, 360 day drawdown
Factor of Safety
Pool Elevation (m)
Time (days)
Top Bench
Overall Search
Bottom Bench
Middle Bench
FS=1.151
Pool Elevation
0
0.5
1
1.5
2
2.5
3
1185
1190
1195
1200
1205
1210
1215
0
50
100
150
200
250
300
350
400
450


Trilinear GT, 60 day hold, 360 day drawdown
Factor of Safety, Min. Value = 1.342
FS=1.151
Pool Elevation
Factor of Safety
Pool Elevation (m)
Time (days)
0
0.5
1
1.5
2
2.5
3
1185
1190
1195
1200
1205
1210
1215
0
50
100
150
200
250
300
350
400
450

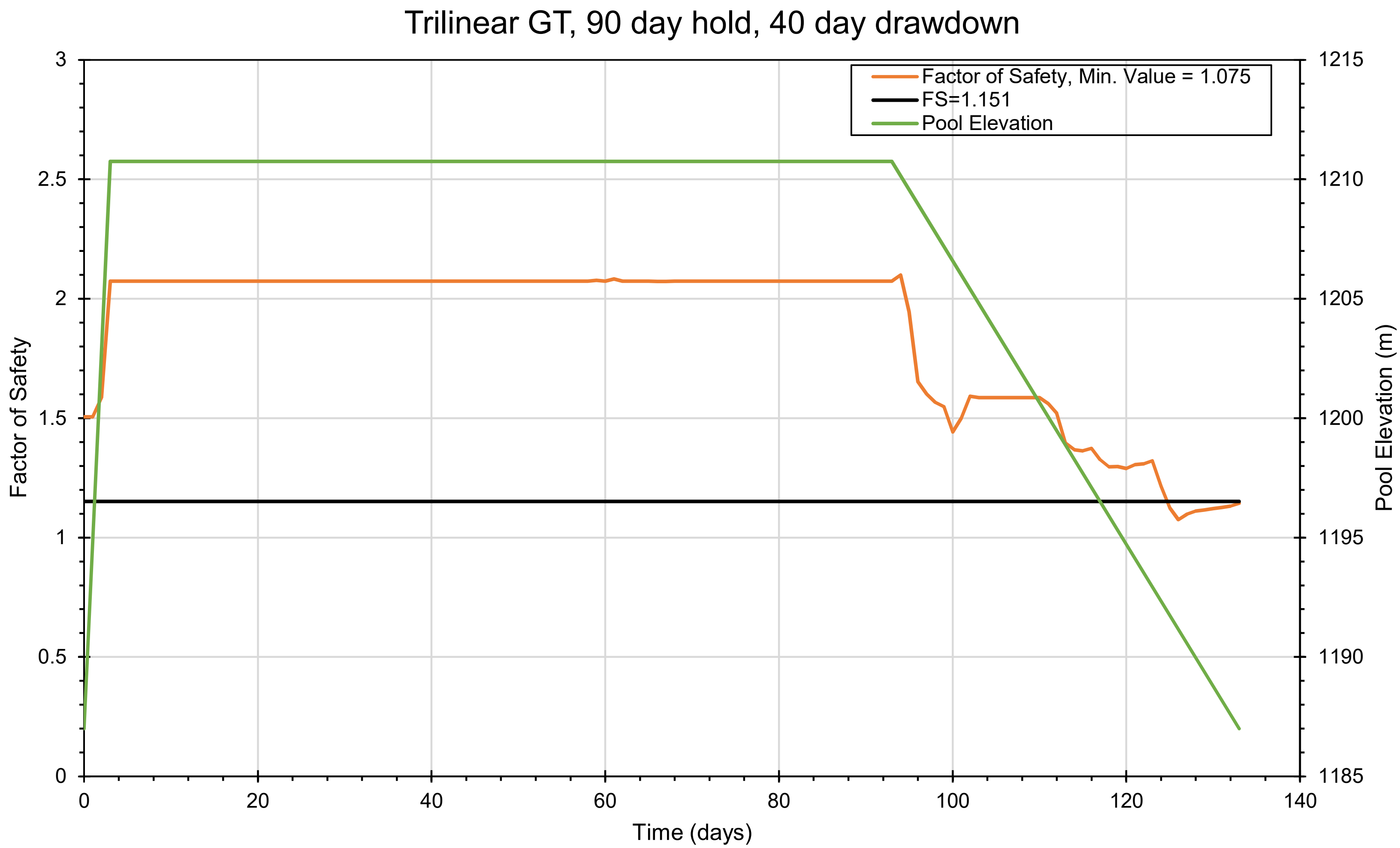


Trilinear GT, 60 day hold, 720 day drawdown
Factor of Safety
Pool Elevation (m)
Time (days)
Top Bench
Overall Search
Bottom Bench
Middle Bench
FS=1.151
Pool Elevation
0
0.5
1
1.5
2
2.5
3
1185
1190
1195
1200
1205
1210
1215
0
100
200
300
400
500
600
700
800
900

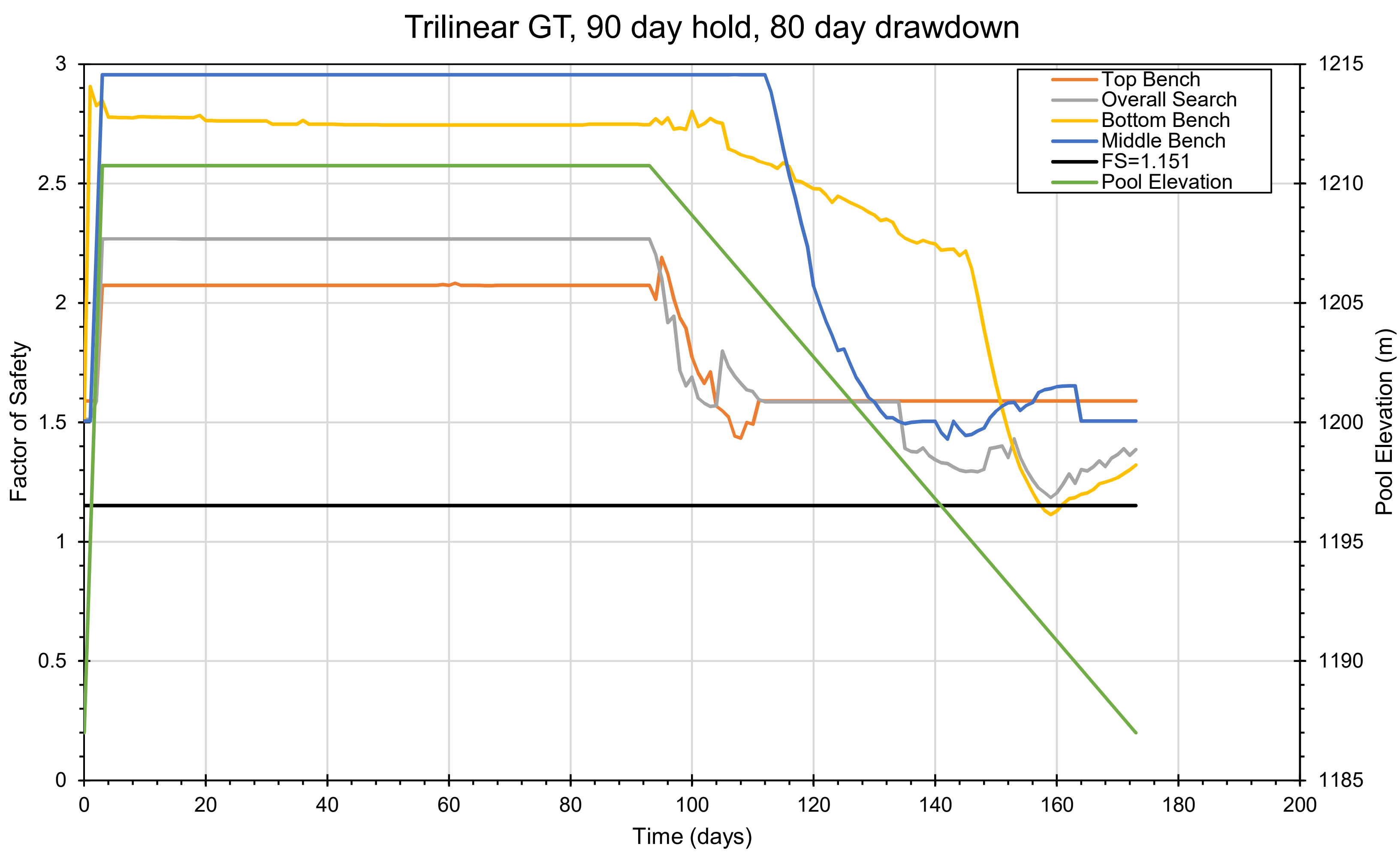

Trilinear GT, 60 day hold, 720 day drawdown
Factor of Safety, Min. Value = 1.348
FS=1.151
Pool Elevation
Factor of Safety
Pool Elevation (m)
Time (days)
0
0.5
1
1.5
2
2.5
3
1185
1190
1195
1200
1205
1210
1215
0
100
200
300
400
500
600
700
800
900



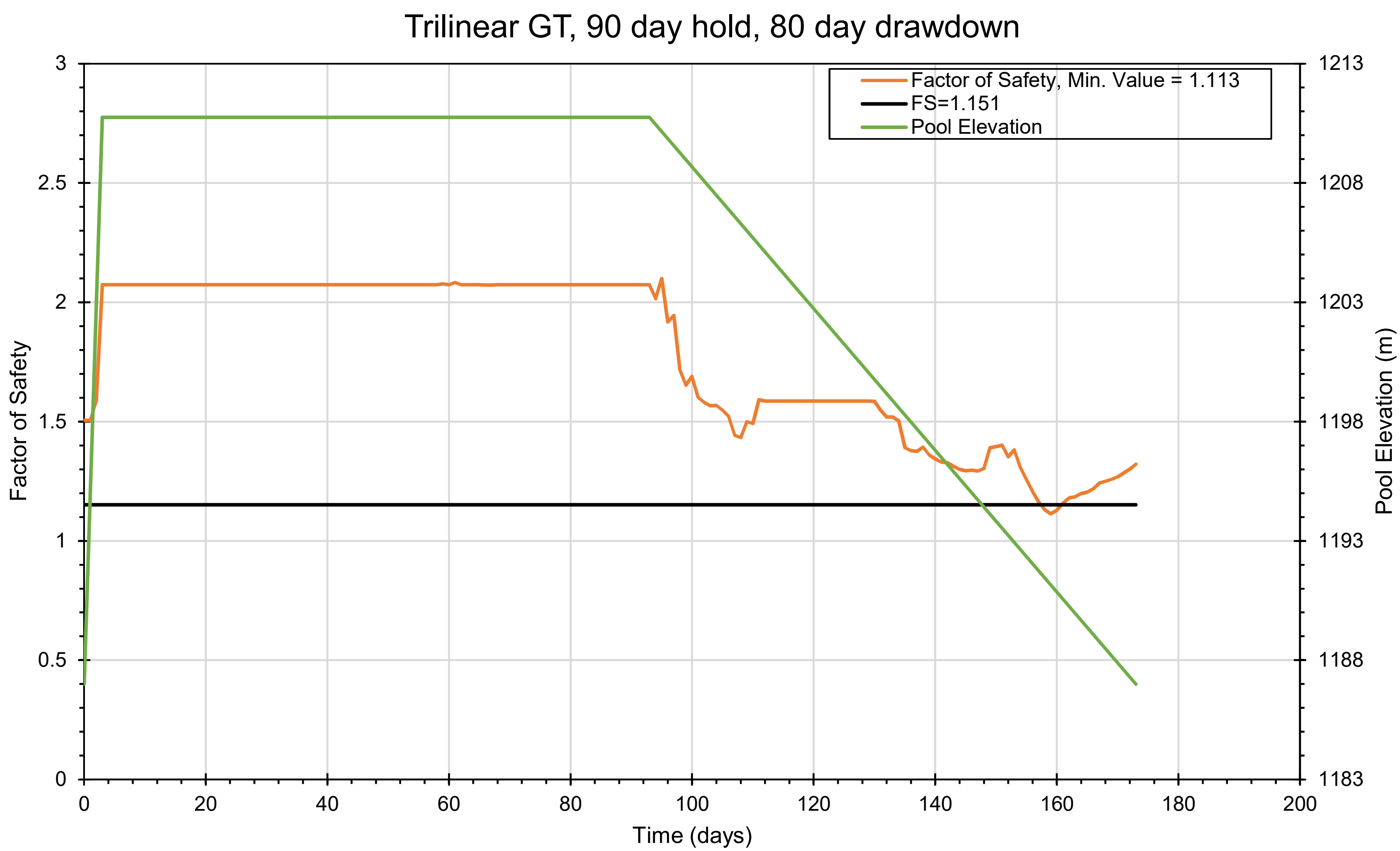
Trilinear GT, 90 day hold, 40 day drawdown
Factor of Safety
Pool Elevation (m)
Time (days)
Top Bench
Overall Search
Bottom Bench
Middle Bench
FS=1.151
Pool Elevation
0
0.5
1
1.5
2
2.5
3
1185
1190
1195
1200
1205
1210
1215
0
20
40
60
80
100
120
140



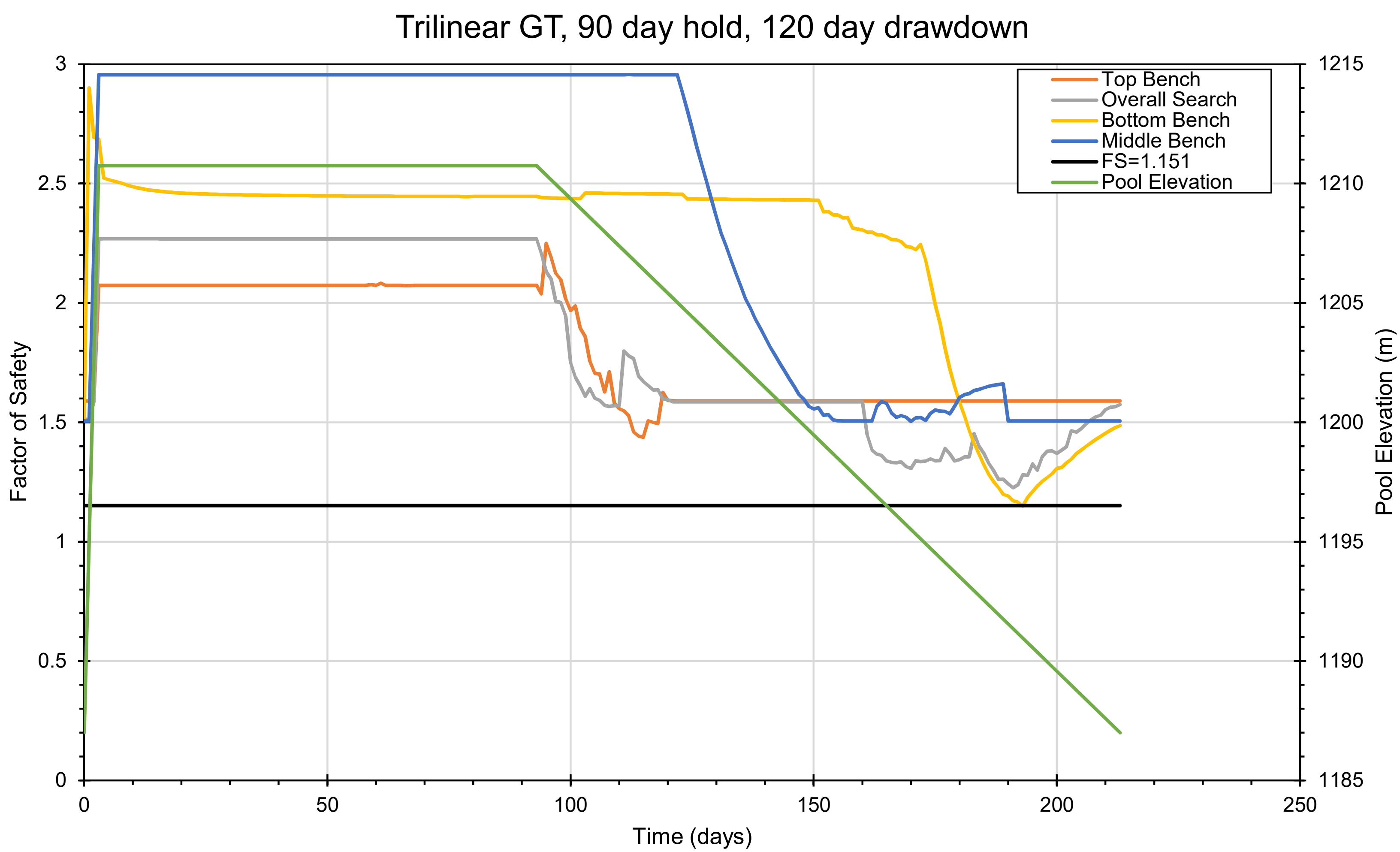
Trilinear GT, 90 day hold, 40 day drawdown
Factor of Safety, Min. Value = 1.075
FS=1.151
Pool Elevation
Factor of Safety
Pool Elevation (m)
Time (days)
0
0.5
1
1.5
2
2.5
3
1185
1190
1195
1200
1205
1210
1215
0
20
40
60
80
100
120
140



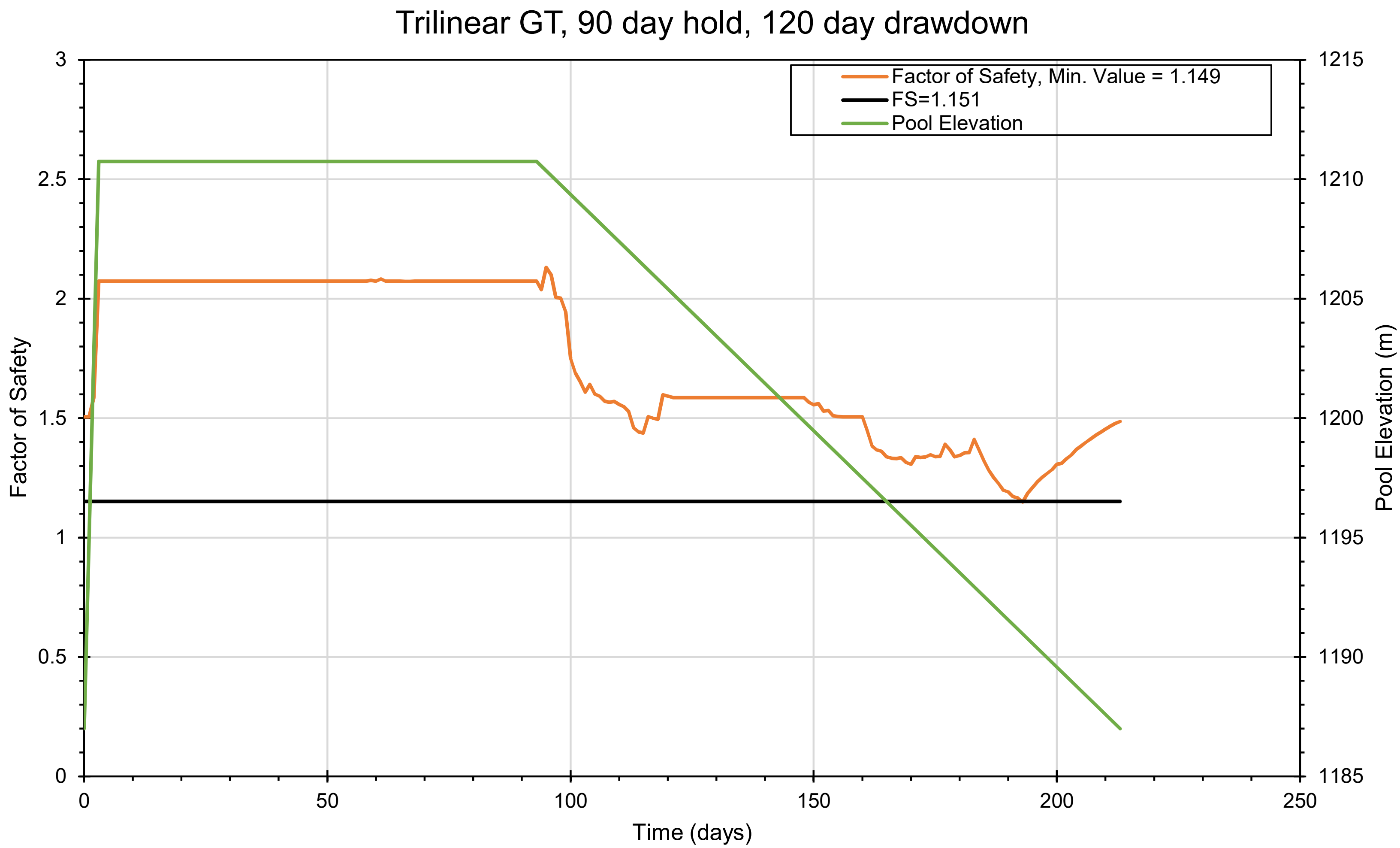
Trilinear GT, 90 day hold, 80 day drawdown
Factor of Safety
Pool Elevation (m)
Time (days)
Top Bench
Overall Search
Bottom Bench
Middle Bench
FS=1.151
Pool Elevation
0
0.5
1
1.5
2
2.5
3
1185
1190
1195
1200
1205
1210
1215
0
20
40
60
80
100
120
140
160
180
200

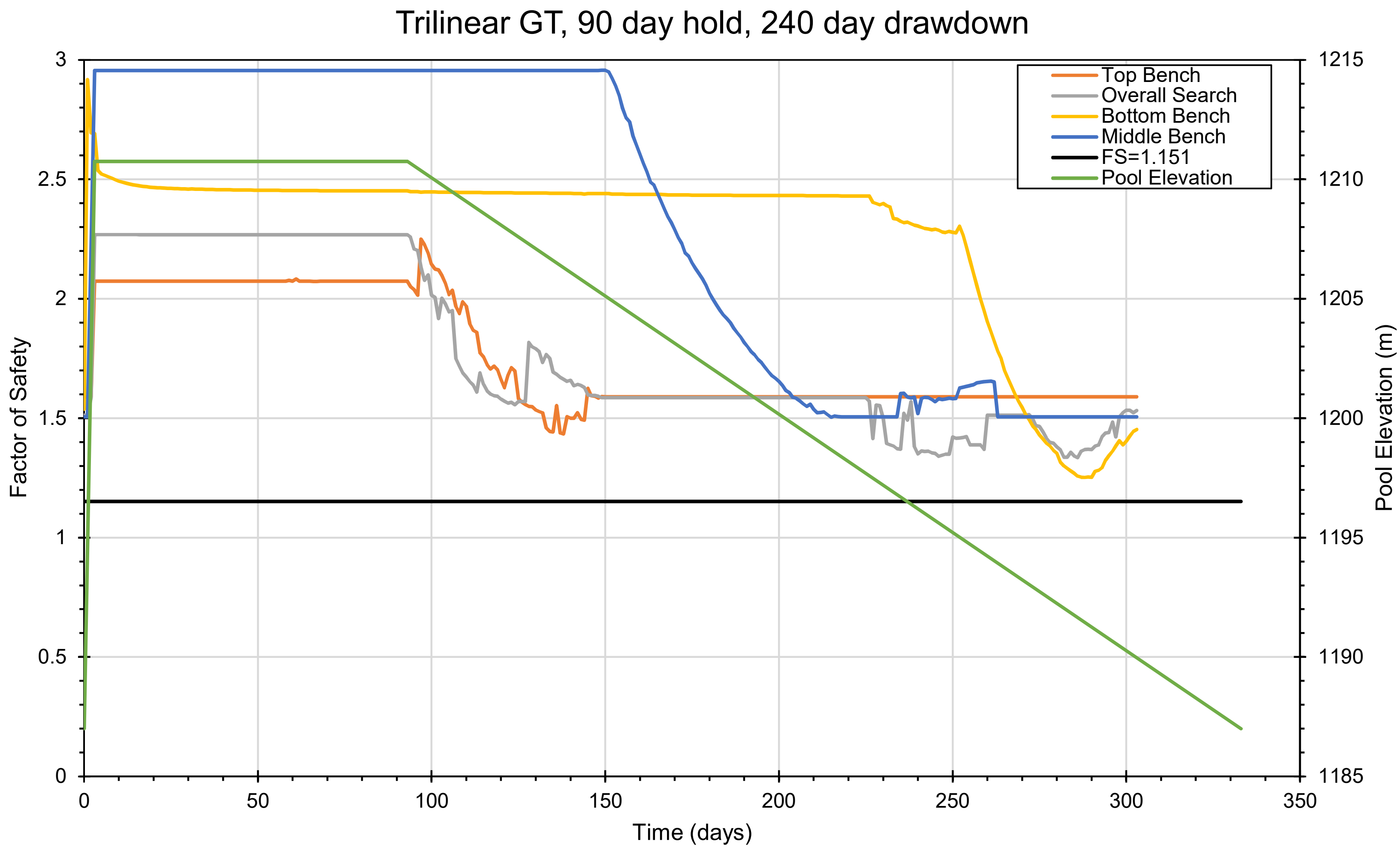


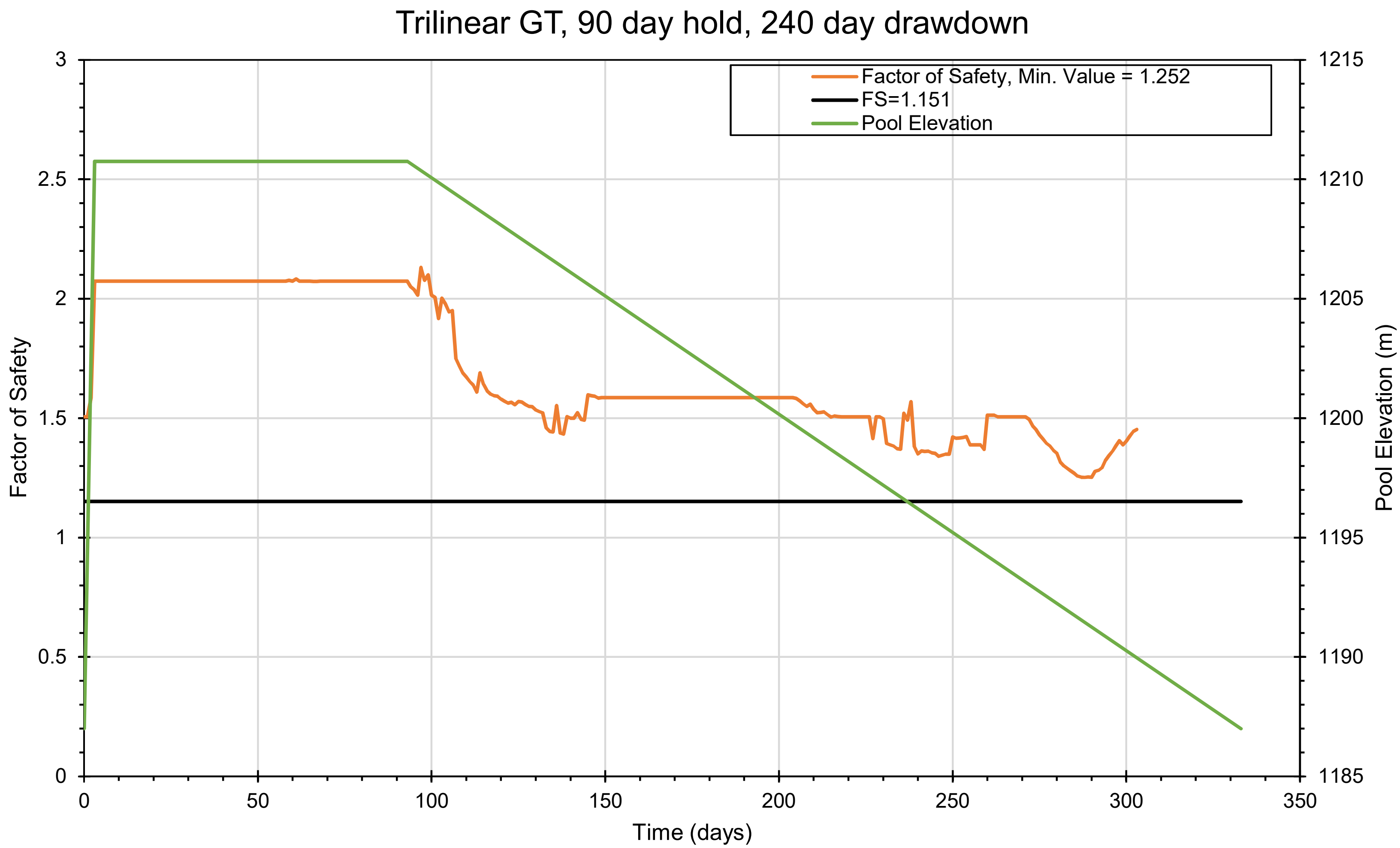
Trilinear GT, 90 day hold, 80 day drawdown
Factor of Safety, Min. Value = 1.113
FS=1.151
Pool Elevation
Factor of Safety
Pool Elevation (m)
Time (days)
0
0.5
1
1.5
2
2.5
3
1183
1188
1193
1198
1203
1208
1213
0
20
40
60
80
100
120
140
160
180
200



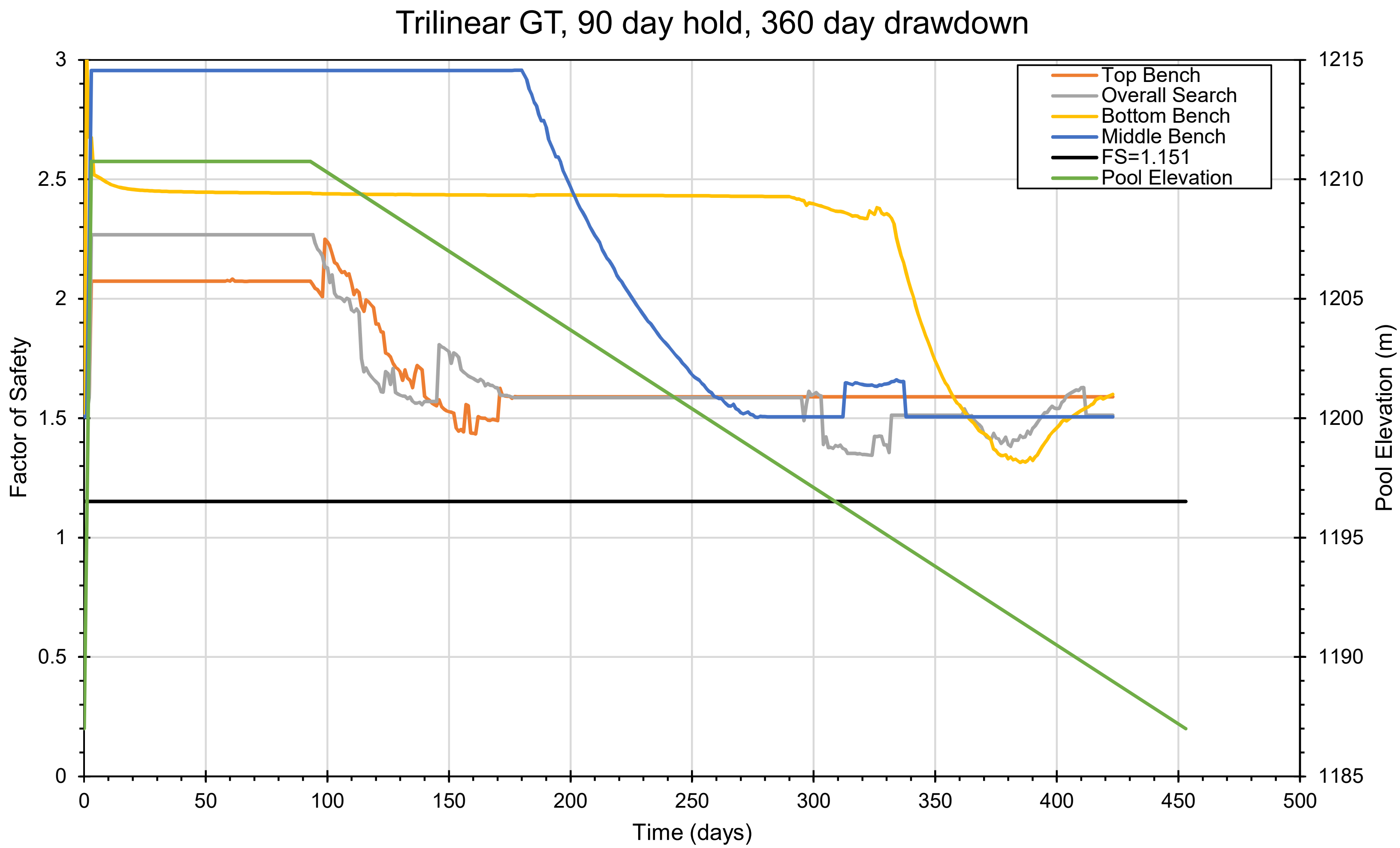
Trilinear GT, 90 day hold, 120 day drawdown
Factor of Safety
Pool Elevation (m)
Time (days)
0
0.5
1
1.5
2
2.5
3
1185
1190
1195
1200
1205
1210
1215
0
50
100
150
200
250
Top Bench
Overall Search
Bottom Bench
Middle Bench
FS=1.151
Pool Elevation


Trilinear GT, 90 day hold, 120 day drawdown
Factor of Safety, Min. Value = 1.149
FS=1.151
Pool Elevation
Factor of Safety
Pool Elevation (m)
Time (days)
0
0.5
1
1.5
2
2.5
3
1185
1190
1195
1200
1205
1210
1215
0
50
100
150
200
250

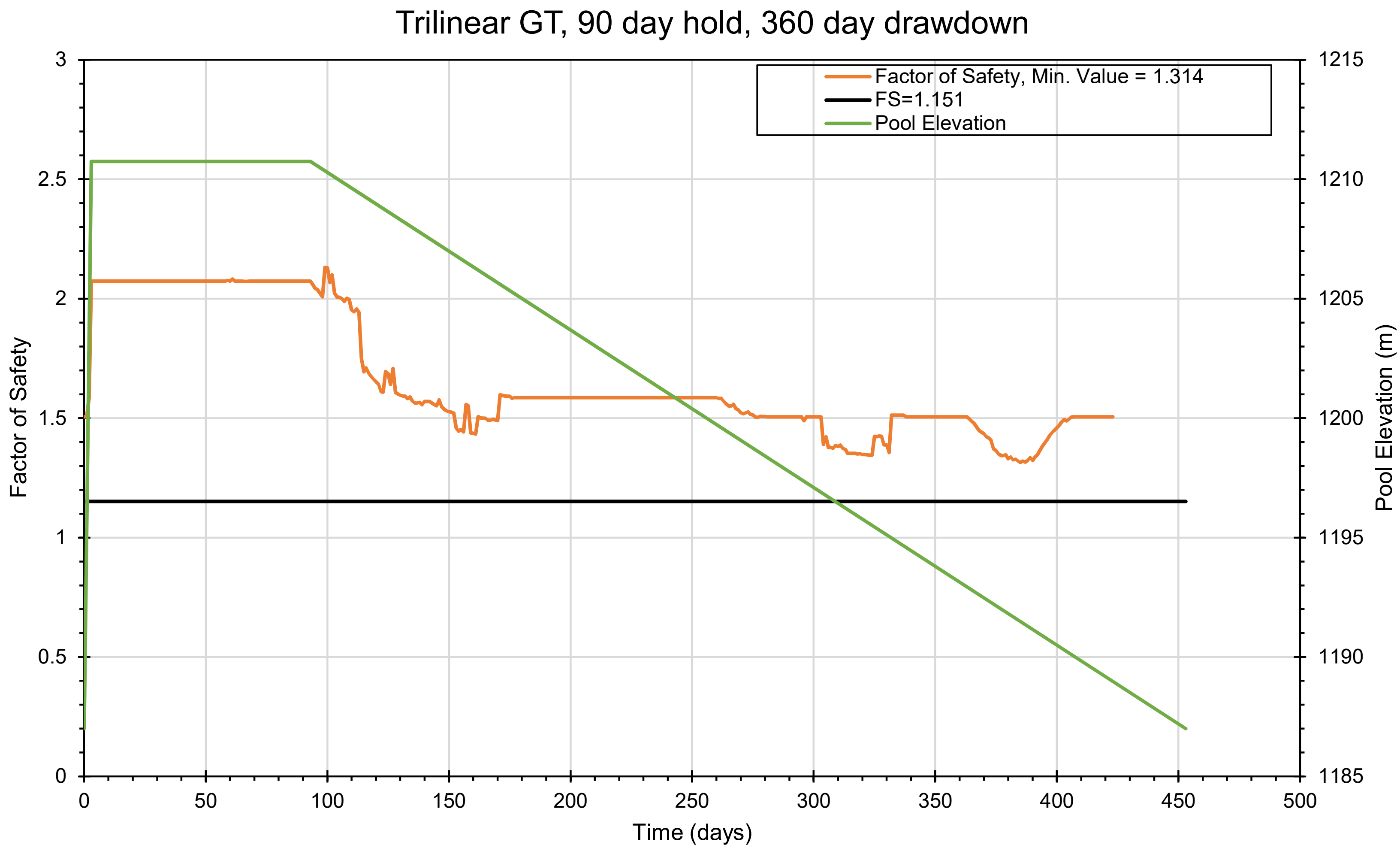

Trilinear GT, 90 day hold, 240 day drawdown
Top Bench
Overall Search
Bottom Bench
Middle Bench
FS=1.151
Pool Elevation
Factor of Safety
Pool Elevation (m)
Time (days)
0
0.5
1
1.5
2
2.5
3
1185
1190
1195
1200
1205
1210
1215
0
50
100
150
200
250
300
350

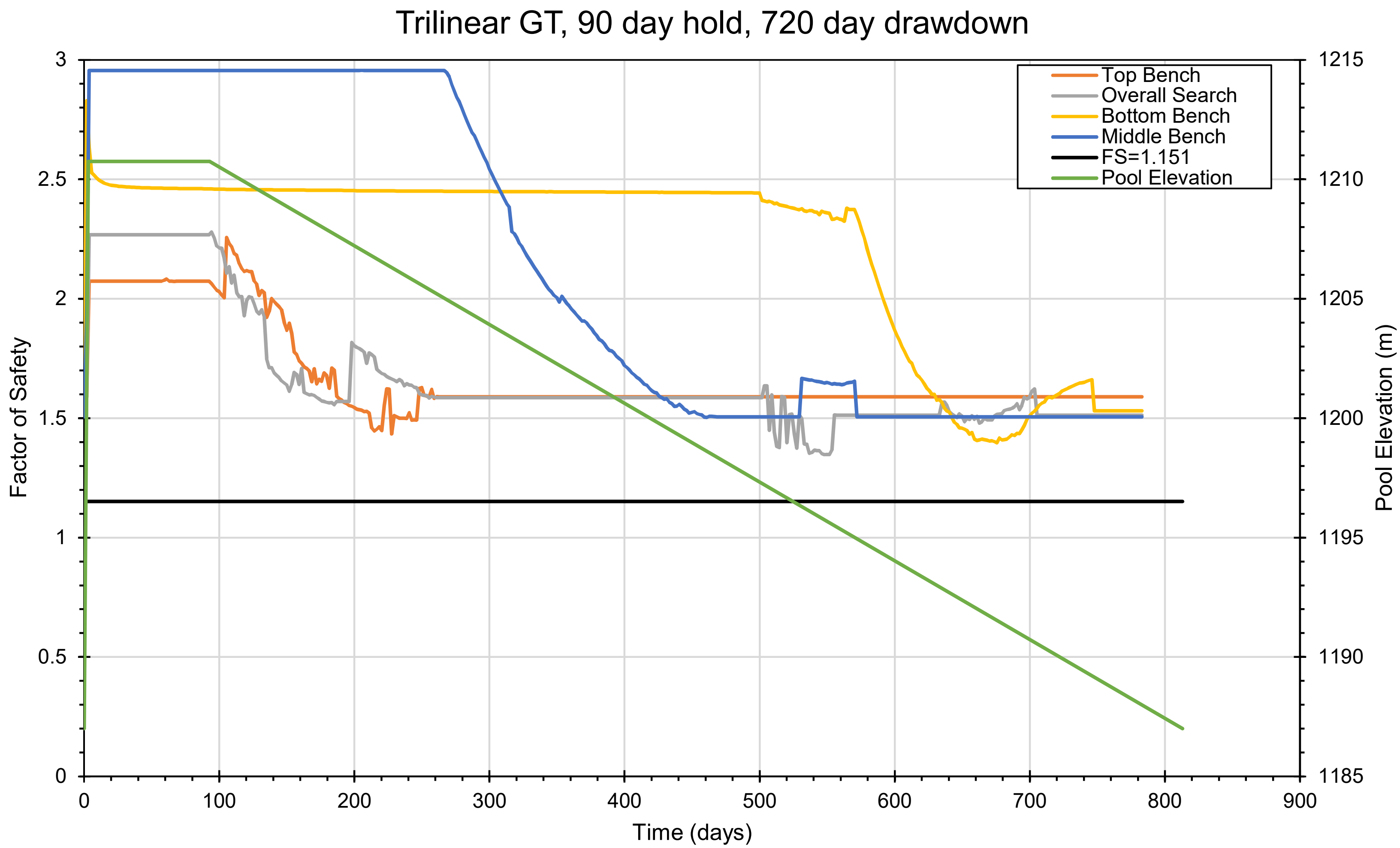


Trilinear GT, 90 day hold, 240 day drawdown
Factor of Safety, Min. Value = 1.252
FS=1.151
Pool Elevation
Factor of Safety
Pool Elevation (m)
Time (days)
0
0.5
1
1.5
2
2.5
3
1185
1190
1195
1200
1205
1210
1215
0
50
100
150
200
250
300
350

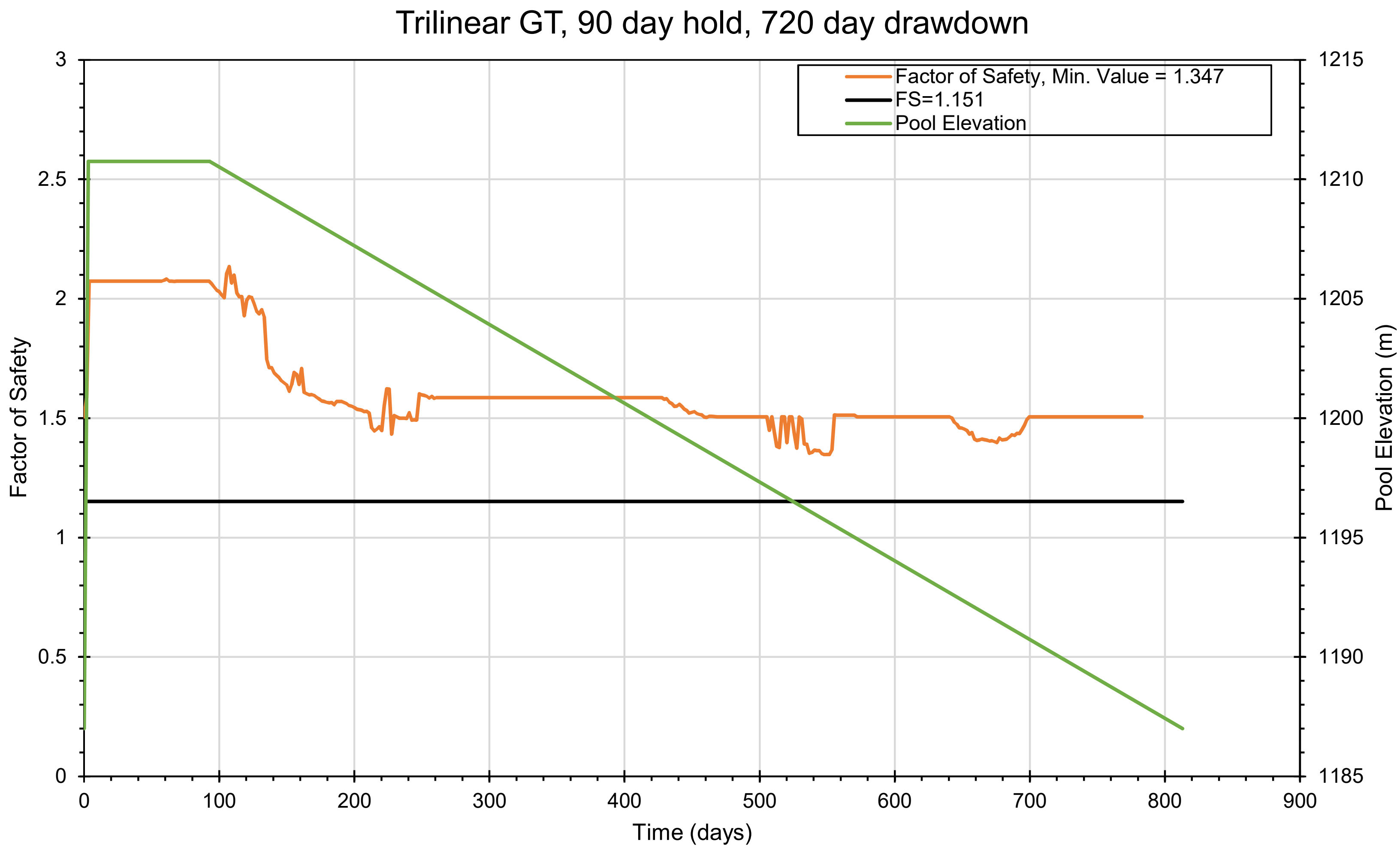


Trilinear GT, 90 day hold, 360 day drawdown
Factor of Safety
Pool Elevation (m)
Time (days)
0
0.5
1
1.5
2
2.5
3
1185
1190
1195
1200
1205
1210
1215
0
50
100
150
200
250
300
350
400
450
500
Top Bench
Overall Search
Bottom Bench
Middle Bench
FS=1.151
Pool Elevation

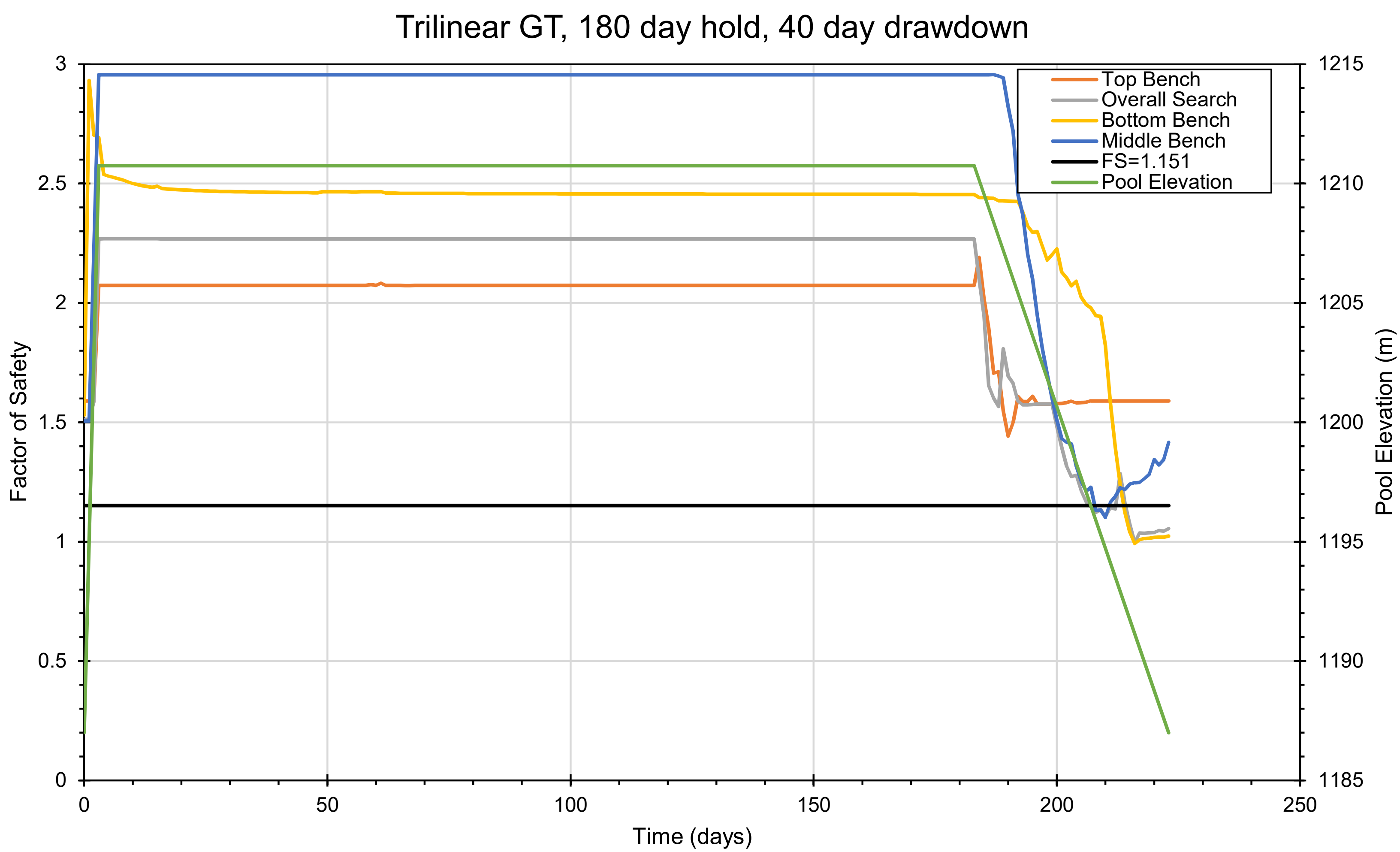

Trilinear GT, 90 day hold, 360 day drawdown
Factor of Safety, Min. Value = 1.314
FS=1.151
Pool Elevation
Factor of Safety
Pool Elevation (m)
Time (days)
0
0.5
1
1.5
2
2.5
3
1185
1190
1195
1200
1205
1210
1215
0
50
100
150
200
250
300
350
400
450
500



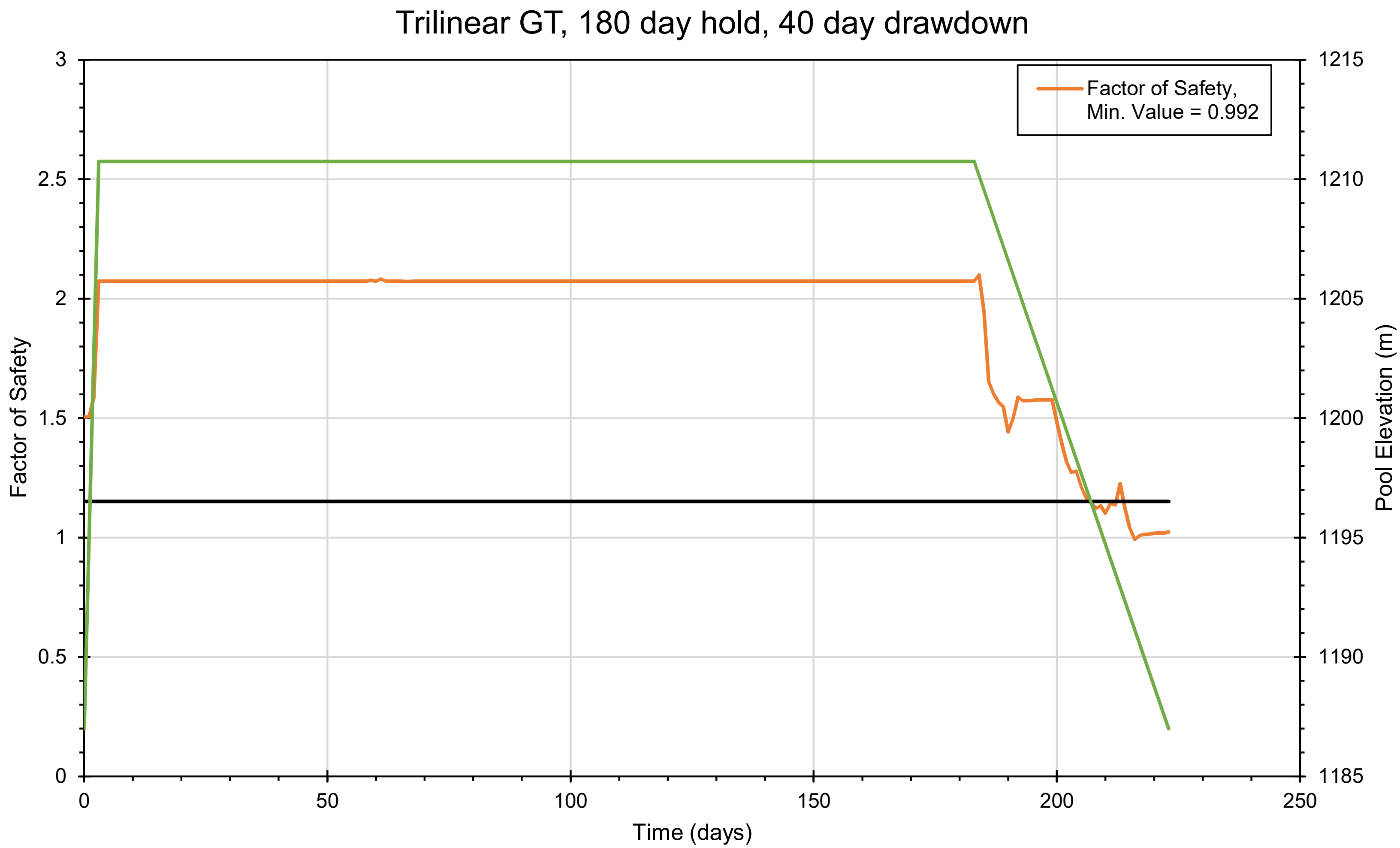
Trilinear GT, 90 day hold, 720 day drawdown
Top Bench
Overall Search
Bottom Bench
Middle Bench
FS=1.151
Pool Elevation
Factor of Safety
Pool Elevation (m)
Time (days)
0
0.5
1
1.5
2
2.5
3
1185
1190
1195
1200
1205
1210
1215
0
100
200
300
400
500
600
700
800
900



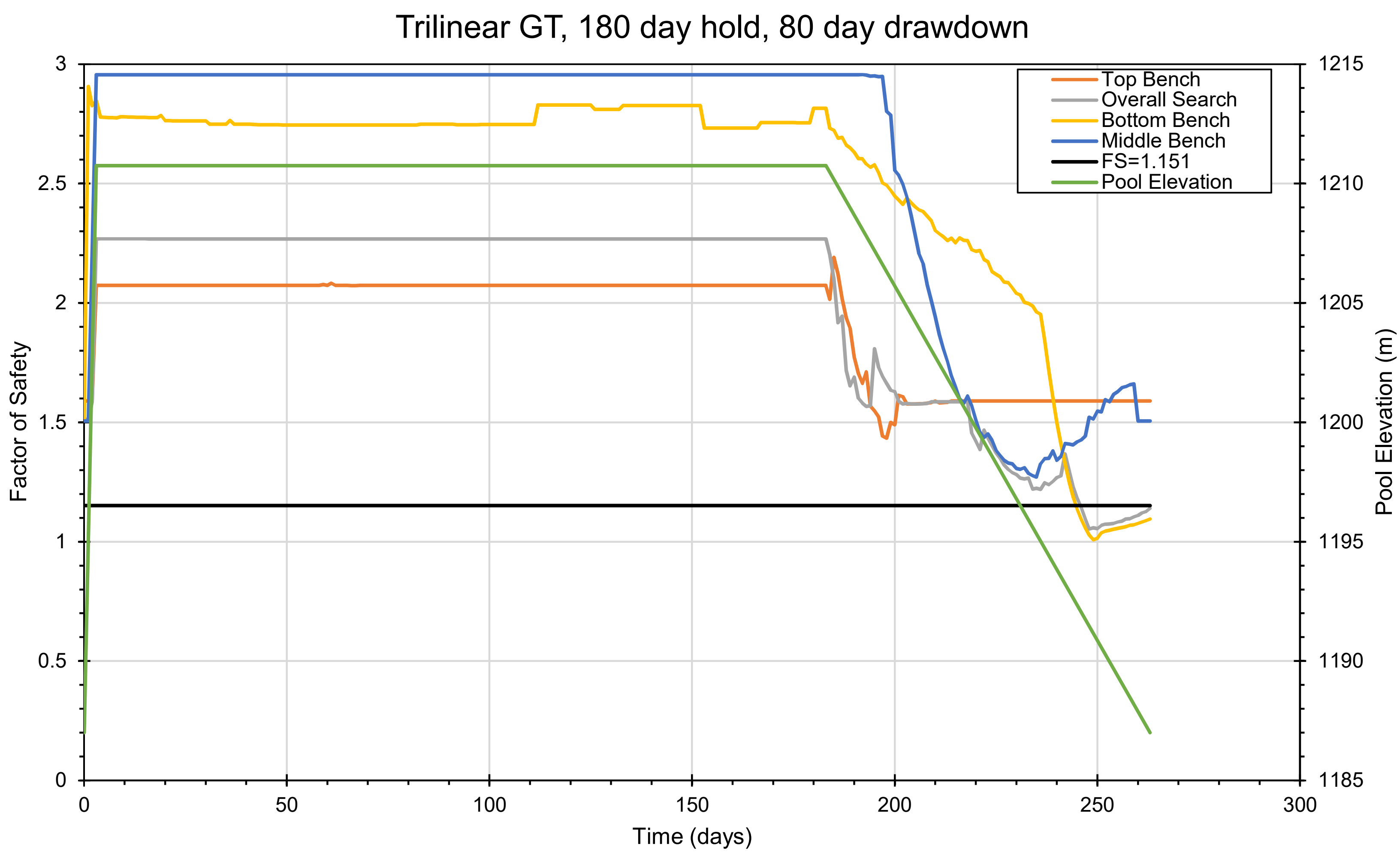
Trilinear GT, 90 day hold, 720 day drawdown
Factor of Safety, Min. Value = 1.347
FS=1.151
Pool Elevation
Factor of Safety
Pool Elevation (m)
Time (days)
0
0.5
1
1.5
2
2.5
3
1185
1190
1195
1200
1205
1210
1215
0
100
200
300
400
500
600
700
800
900



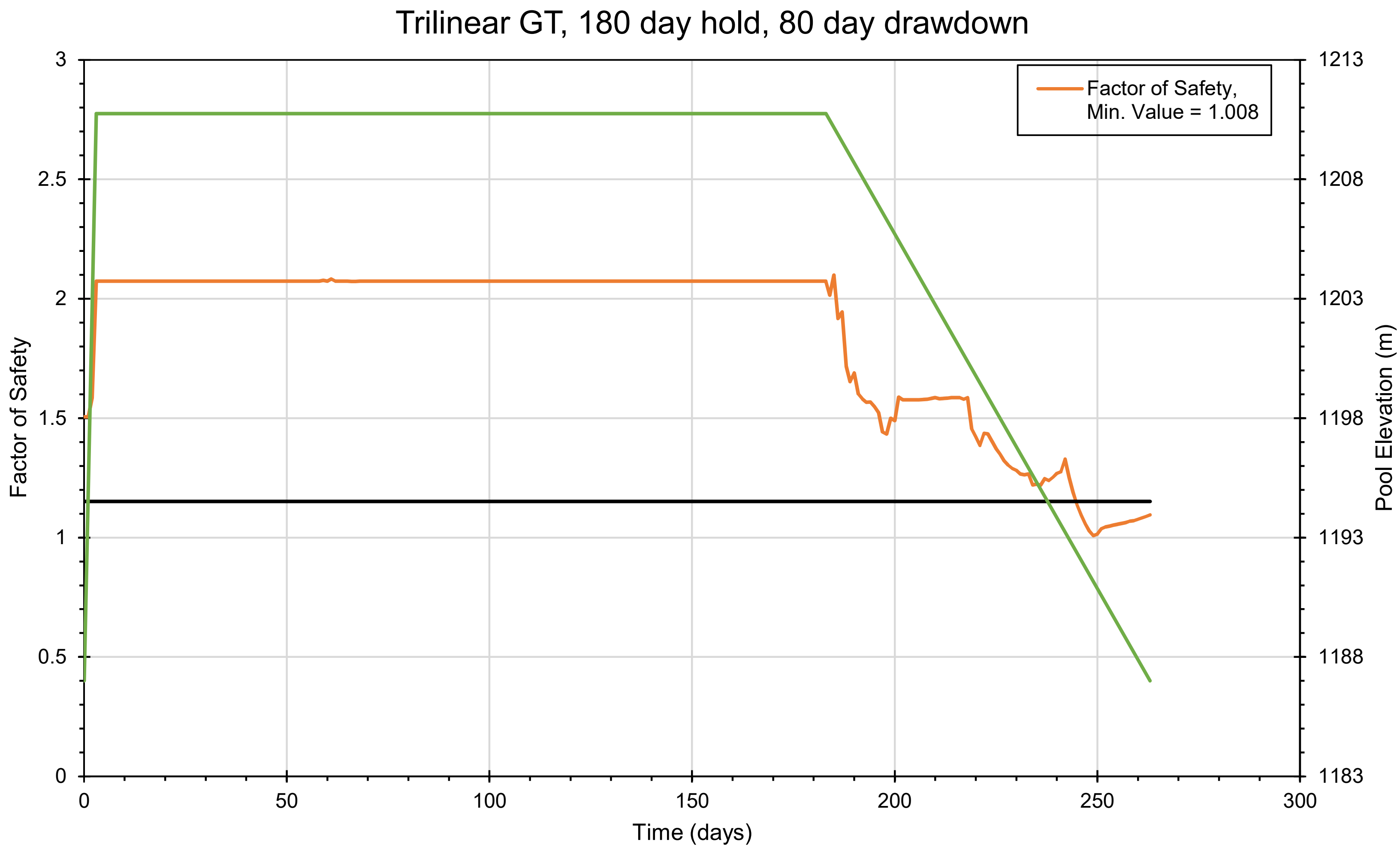
Trilinear GT, 180 day hold, 40 day drawdown
Factor of Safety
Pool Elevation (m)
Time (days)
0
0.5
1
1.5
2
2.5
3
1185
1190
1195
1200
1205
1210
1215
0
50
100
150
200
250
Top Bench
Overall Search
Bottom Bench
Middle Bench
FS=1.151
Pool Elevation



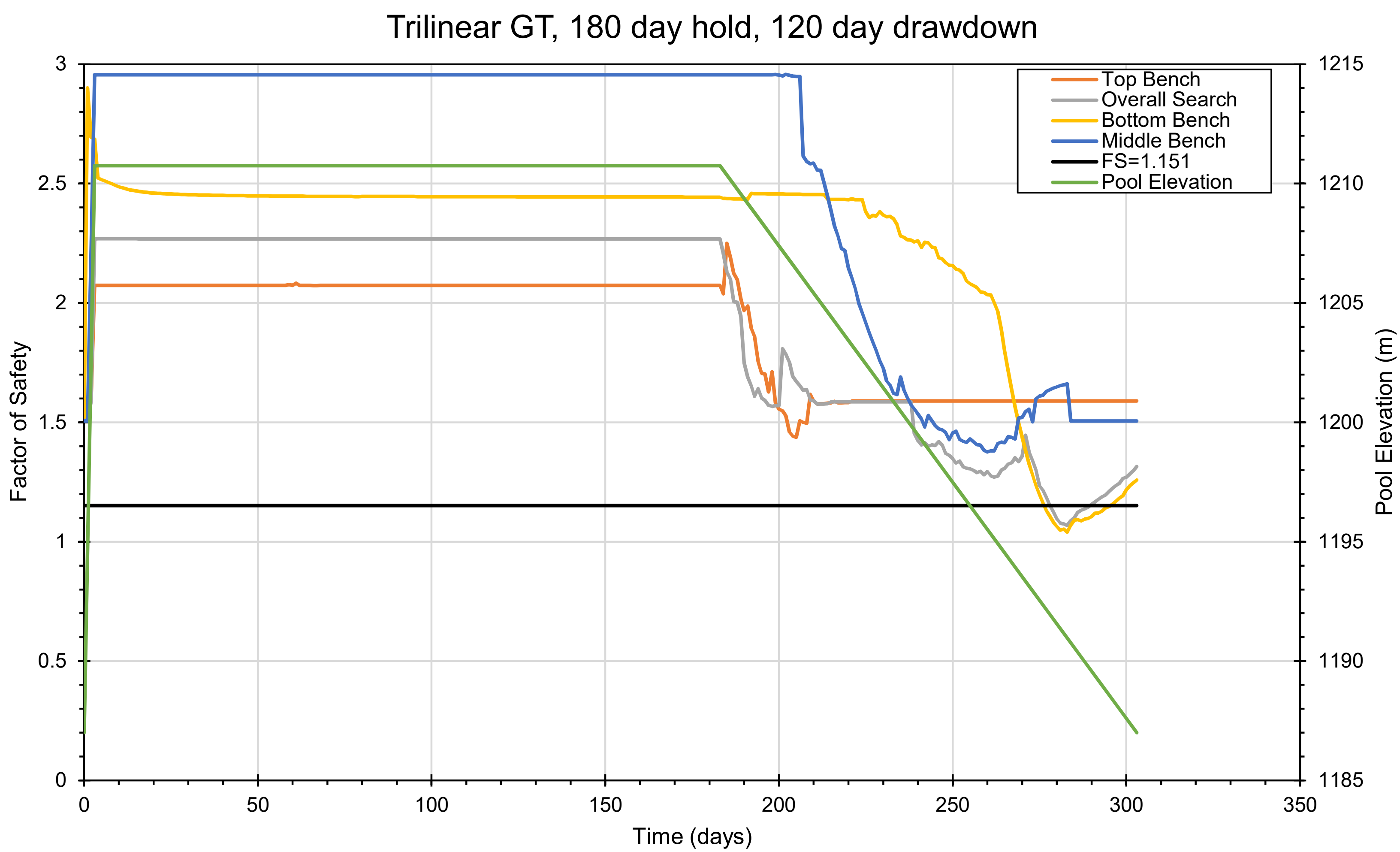
Trilinear GT, 180 day hold, 40 day drawdown
Factor of Safety,
Min. Value = 0.992
Factor of Safety
Pool Elevation (m)
Time (days)
0
0.5
1
1.5
2
2.5
3
1185
1190
1195
1200
1205
1210
1215
0
50
100
150
200
250

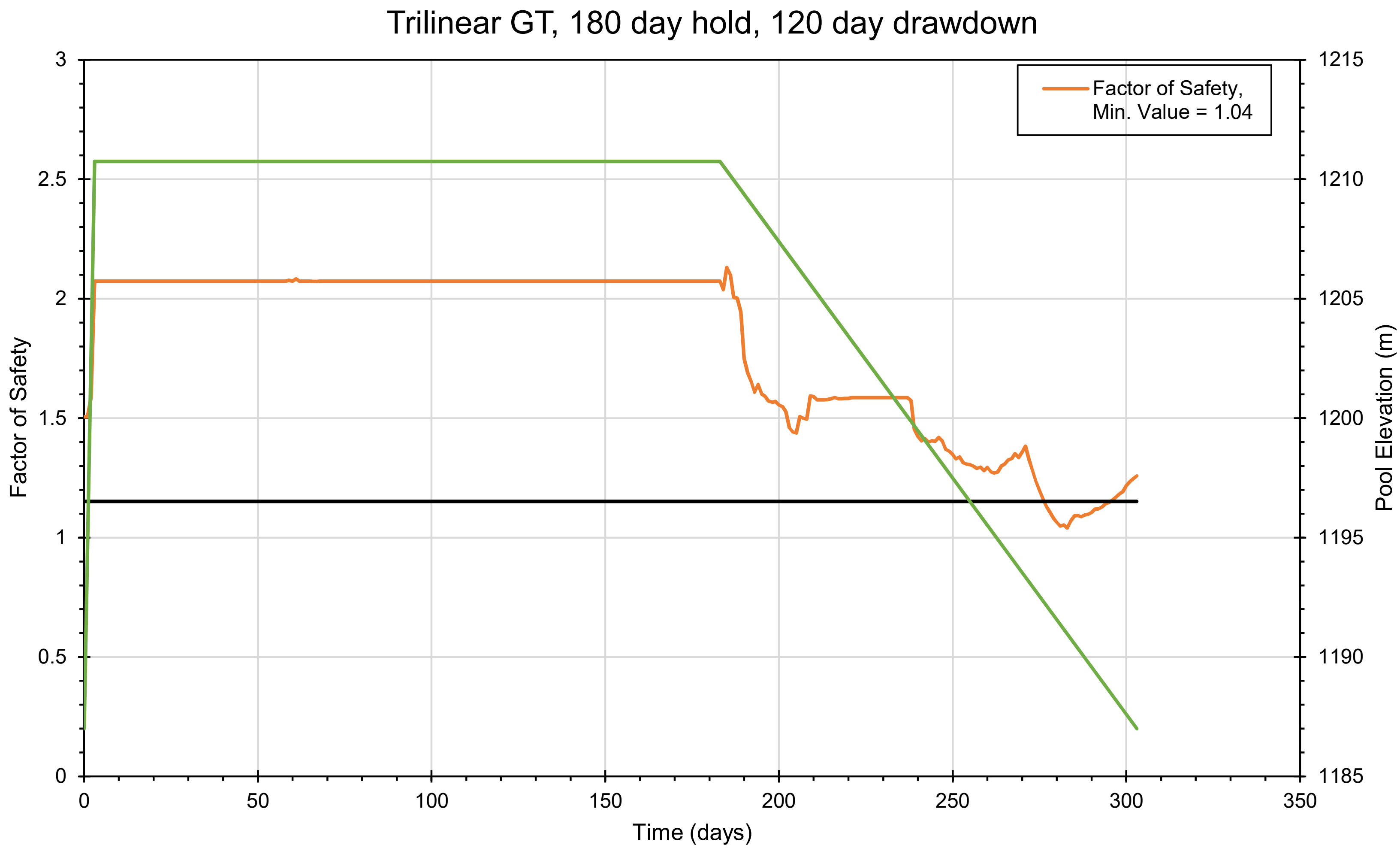


Trilinear GT, 180 day hold, 80 day drawdown
Factor of Safety
Pool Elevation (m)
Time (days)
Top Bench
Overall Search
Bottom Bench
Middle Bench
FS=1.151
Pool Elevation
0
0.5
1
1.5
2
2.5
3
1185
1190
1195
1200
1205
1210
1215
0
50
100
150
200
250
300

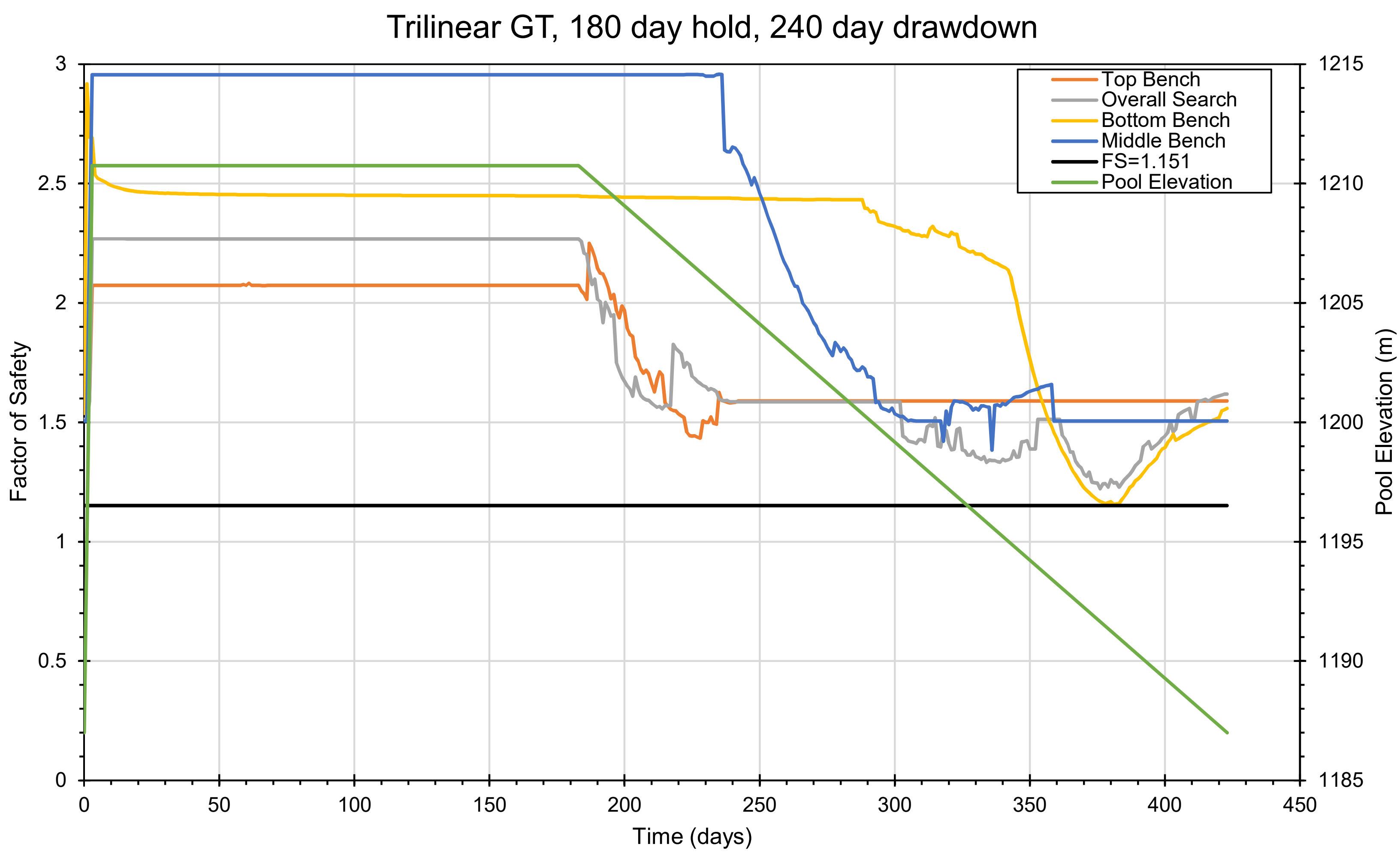


Trilinear GT, 180 day hold, 80 day drawdown
Factor of Safety
Pool Elevation (m)
Time (days)
Factor of Safety,
Min. Value = 1.008
0
0.5
1
1.5
2
2.5
3
1183
1188
1193
1198
1203
1208
1213
0
50
100
150
200
250
300

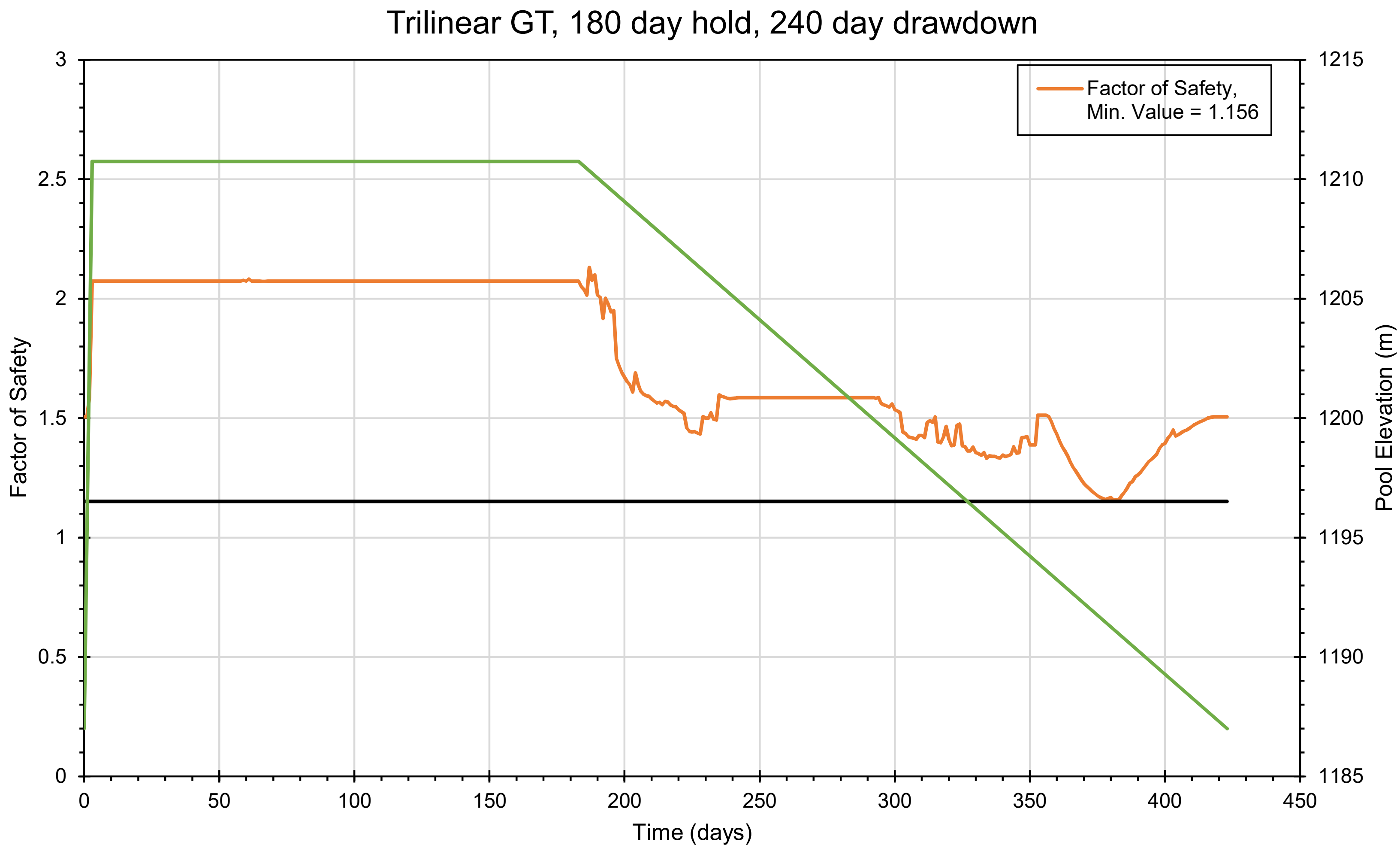

Trilinear GT, 180 day hold, 120 day drawdown
Factor of Safety
Pool Elevation (m)
Time (days)
Top Bench
Overall Search
Bottom Bench
Middle Bench
FS=1.151
Pool Elevation
0
0.5
1
1.5
2
2.5
3
1185
1190
1195
1200
1205
1210
1215
0
50
100
150
200
250
300
350



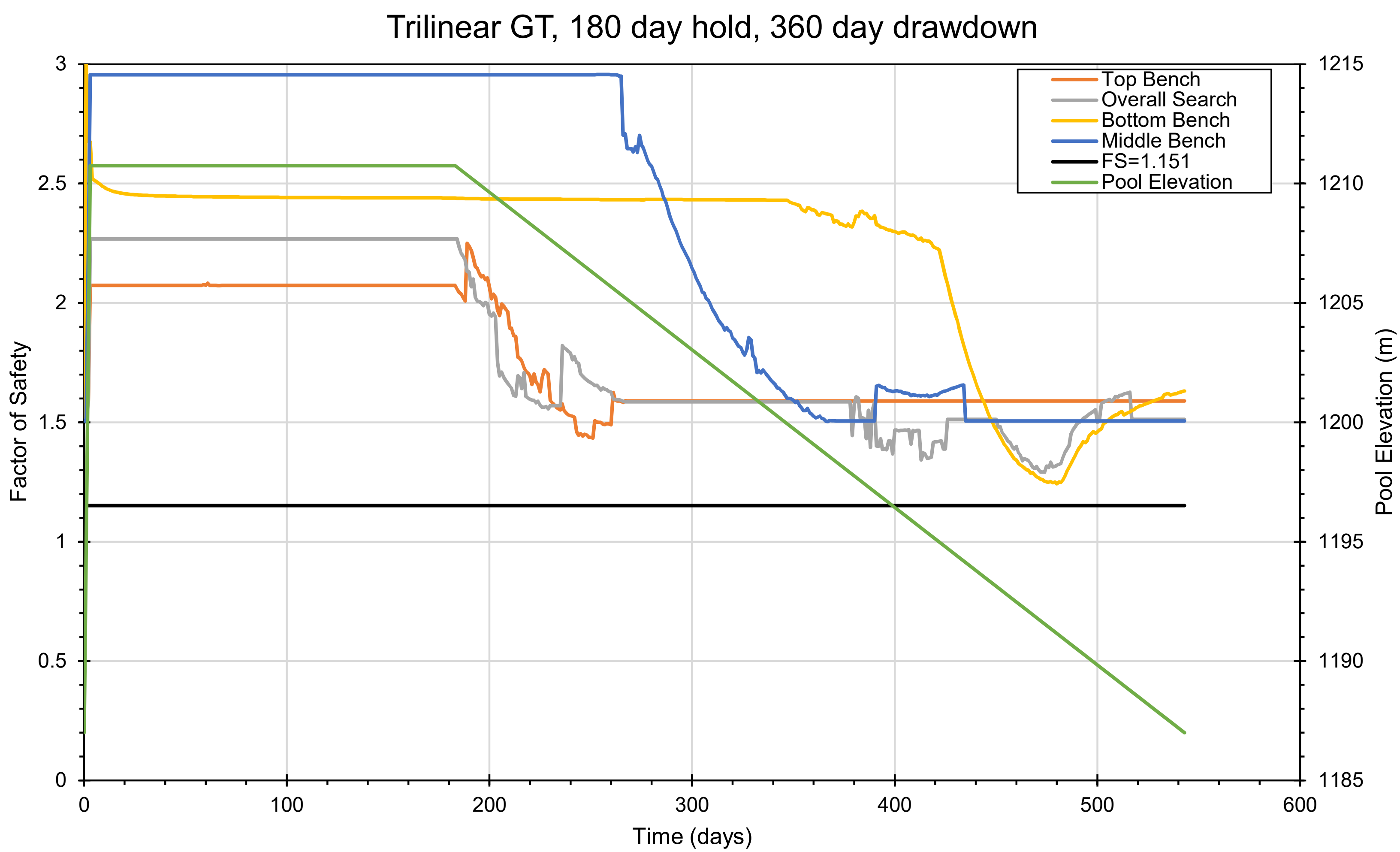
Trilinear GT, 180 day hold, 120 day drawdown
Factor of Safety,
Min. Value = 1.04
Factor of Safety
Pool Elevation (m)
Time (days)
0
0.5
1
1.5
2
2.5
3
1185
1190
1195
1200
1205
1210
1215
0
50
100
150
200
250
300
350



Trilinear GT, 180 day hold, 240 day drawdown
Factor of Safety
Pool Elevation (m)
Time (days)
Top Bench
Overall Search
Bottom Bench
Middle Bench
FS=1.151
Pool Elevation
0
0.5
1
1.5
2
2.5
3
1185
1190
1195
1200
1205
1210
1215
0
50
100
150
200
250
300
350
400
450

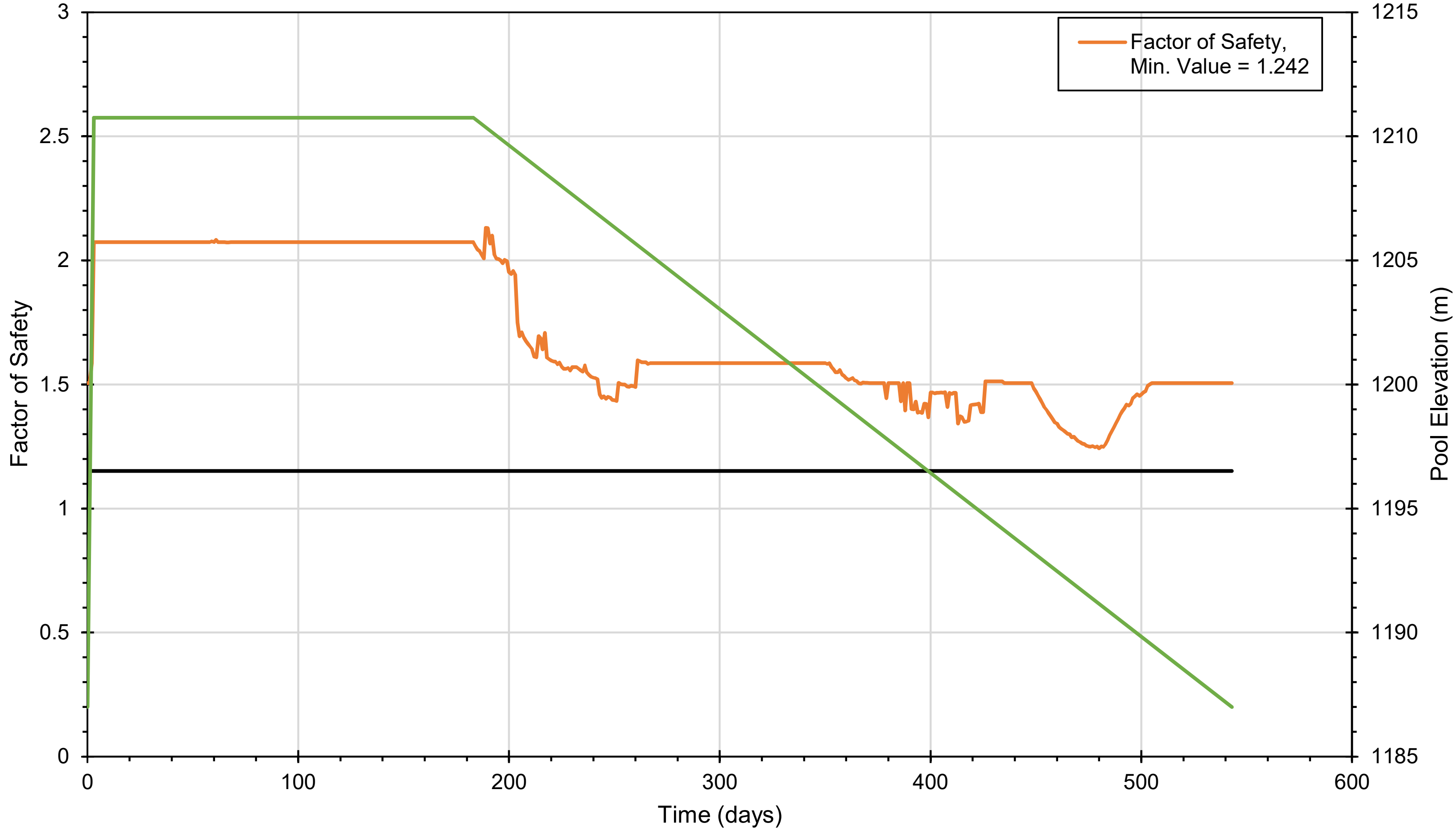


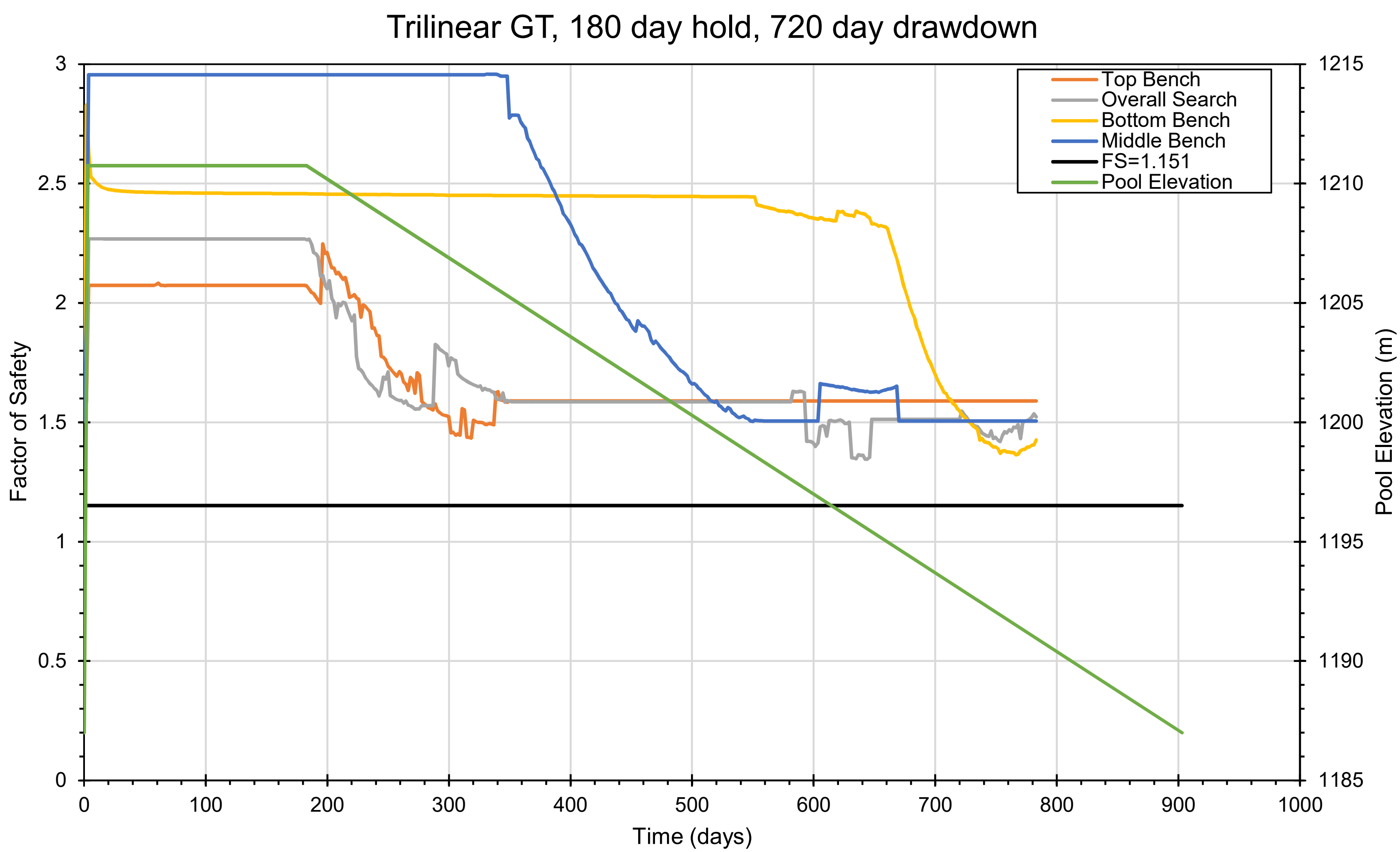
Trilinear GT, 180 day hold, 240 day drawdown
Factor of Safety,
Min. Value = 1.156
Factor of Safety
Pool Elevation (m)
Time (days)
0
0.5
1
1.5
2
2.5
3
1185
1190
1195
1200
1205
1210
1215
0
50
100
150
200
250
300
350
400
450

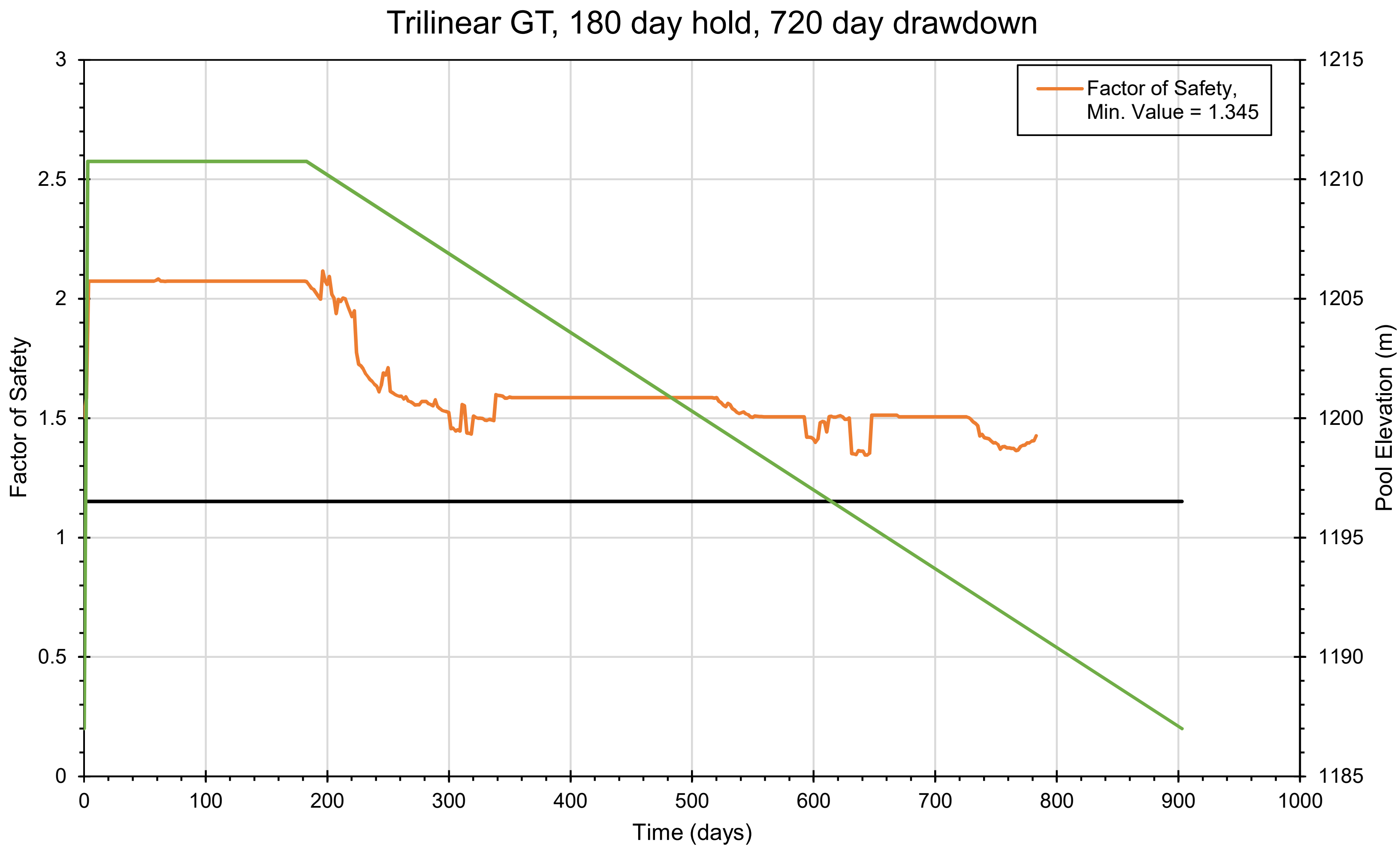


Trilinear GT, 180 day hold, 360 day drawdown
Top Bench
Overall Search
Bottom Bench
Middle Bench
FS=1.151
Pool Elevation
Factor of Safety
Pool Elevation (m)
Time (days)
0
0.5
1
1.5
2
2.5
3
1185
1190
1195
1200
1205
1210
1215
0
100
200
300
400
500
600

Trilinear GT, 180 day hold, 360 day drawdown




Trilinear GT, 180 day hold, 720 day drawdown
Factor of Safety
Pool Elevation (m)
Time (days)
Top Bench
Overall Search
Bottom Bench
Middle Bench
FS=1.151
Pool Elevation
0
0.5
1
1.5
2
2.5
3
1185
1190
1195
1200
1205
1210
1215
0
100
200
300
400
500
600
700
800
900
1000



Trilinear GT, 180 day hold, 720 day drawdown
Factor of Safety,
Min. Value = 1.345
Factor of Safety
Pool Elevation (m)
Time (days)
0
0.5
1
1.5
2
2.5
3
1185
1190
1195
1200
1205
1210
1215
0
100
200
300
400
500
600
700
800
900
1000

Attachment 12.2 Settlement Analysis

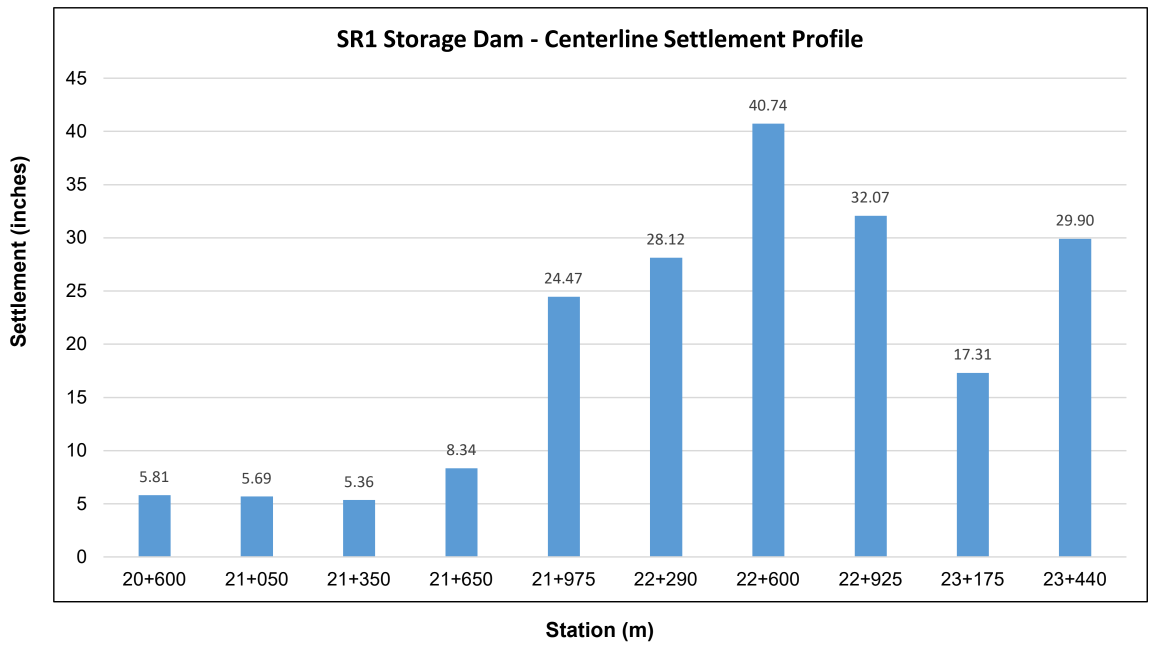
Storage Dam Settlement Calculations

Stantec

SR1 Storage Dam Centerline Profile
Settlement Calculations Summary

2/9/2017
Calculated by: J. Curd
Checked by: V. Severance

Station	Glacial Lacustrine (GL)				Glacial Till (GT)				Gravel				Total Settlement			
	in	ft	m	mm	in	ft	m	mm	in	ft	m	mm	in	ft	m	mm
20+600	3.85	0.32	0.10	98	1.96	0.16	0.05	50	0.00	0.00	0.00	0	5.81	0.48	0.15	148
21+050	5.50	0.46	0.14	140	0.19	0.02	0.00	5	0.00	0.00	0.00	0	5.69	0.47	0.14	144
21+350	4.39	0.37	0.11	112	0.97	0.08	0.02	25	0.00	0.00	0.00	0	5.36	0.45	0.14	136
21+650	6.27	0.52	0.16	159	2.07	0.17	0.05	53	0.00	0.00	0.00	0	8.34	0.69	0.21	212
21+975	21.41	1.78	0.54	544	3.06	0.25	0.08	78	0.00	0.00	0.00	0	24.47	2.04	0.62	621
22+290	18.77	1.56	0.48	477	9.35	0.78	0.24	237	0.00	0.00	0.00	0	28.12	2.34	0.71	714
22+600	14.60	1.22	0.37	371	26.13	2.18	0.66	664	0.00	0.00	0.00	0	40.74	3.39	1.03	1035
22+925	9.53	0.79	0.24	242	22.54	1.88	0.57	572	0.00	0.00	0.00	0	32.07	2.67	0.81	815
23+175	0.00	0.00	0.00	0	16.71	1.39	0.42	424	0.61	0.05	0.02	15	17.31	1.44	0.44	440
23+440	3.75	0.31	0.10	95	25.87	2.16	0.66	657	0.28	0.02	0.01	7	29.90	2.49	0.76	759



Storage Dam Settlement Calculations

SR1 Storage Dam
Settlement Calculations for Dam Centerline Sta. 20+600

Layer
24.4 ft (7.4 m) Embankment
6.2 ft (1.9 m) Fat Clay (Lacustrine)
36.1 ft (11.0 m) Lean Clay with Sand (Till)

Nearest Consolidation Test Samples:
D2 - ST4 (1.50 m - 1.95 m) Fat Clay (Lacustrine)
D8 - ST4 (1.80 m - 2.30 m) Lean Clay with Sand (Till)

D2 - ST4 (1.50 m - 1.95 m) Fat Clay (Lacustrine)
Pc = 205 kPa (4,282 psf), OCR = 6.6, Cc = 0.21, Cr = 0.09

Boring D2		
Embankment Crest Elev.	1213.50	m
Surface Elev.	1206.57	m
Top Lacust/Bottom Strip	1206.07	m
Top Till Elev.	1204.17	m
Top of Rock Elev.	1193.17	m

Top of Embankment Elevation = 1213.5 m
Embankment Thickness = 7.4 m (24.4 ft)
Embankment Unit Weight = 20 kN/m^3 (127.3 lb/ft^3)

New embankment loading does not exceed preconsolidation pressure, therefore only use Cr value.

$$\Delta H = \frac{H}{1+e_0}\left(C_r \log\frac{p_c}{p_o} + C_c \log\frac{p_f}{p_c}\right)$$

Fat Clay (Lacustrine) One Layer 1.90 m (6.2 ft)

Lacustrine Unit Weight = 18 kN/m^3 (114.6 lb/ft^3)

Location	Mid Pt. (ft)	H (ft)	Cr	Cc	e	Po (psf)	Pc (psf)	W(ft.)	ΔP(psf)	Pf = Po+ΔP	ΔH
0+000 (Crest)	3.1	6.2	0.09	0	0.8	394.63	4282.00	24.40	3106.12	3500.75	0.32

SUM = 0.32 feet
3.85 inches

Fat Clay (Lacustrine) Two Layers - 3 Feet Thick

Lacustrine Unit Weight = 18 kN/m^3 (114.6 lb/ft^3)

Location	Mid Pt. (ft)	H (ft)	Cr	Cc	e	Po (psf)	Pc (psf)	W(ft.)	ΔP(psf)	Pf = Po+ΔP	ΔH
0+000 (Crest)	3	3	0.09	0	0.8	381.90	4282.00	24.40	3106.12	3488.02	0.16
0+000 (Crest)	3.2	3.2	0.09	0	0.8	407.36	4282.00	24.40	3106.12	3513.48	0.16
		6.2									

SUM = 0.32 feet
3.85 inches

Storage Dam Settlement Calculations

Stantec

Settlement Calculations for Centerline Dam Sta. 20+600
D8 - ST4 (1.80-2.30 m) - Lean Clay with Sand (CL) Till
Pc = 310 kPa (6,474 psf), OCR = 8.4, Cr = 0.012, Cc = 0.15

New embankment loading + existing overburden does not exceed preconsolidation pressure, therefore only use Cr value.

$$\Delta H = \frac{H}{1+e_0}\left(C_r \log\frac{p_c}{p_o} + C_c \log\frac{p_f}{p_c}\right)$$

Lean Clay with Sand (Till) One Layer

Unit Weight = 18 kN/m^3 (114.6 lb/ft^3)

Location	Mid Pt. (ft)	H (ft)	Cr	Cc	e	Po (psf)	Pc (psf)	W(ft.)	ΔP(psf)	Pf = Po+ΔP	ΔH
0+000 (Crest)	18.05	36.1	0.012	0	0.624	2857.79	6474.00	24.40	3106.12	5963.91	0.09

SUM = 0.09 feet
1.14 inches

Lean Clay with Sand (Till) 12 Layers

Unit Weight = 18 kN/m^3 (114.6 lb/ft^3)

New embankment loading + existing overburden does not exceed preconsolidation pressure until a depth of 29.4 feet

Location	Mid Pt. (ft)	H (ft)	Cr	Cc	e	Po (psf)	Pc (psf)	W(ft.)	ΔP(psf)	Pf = Po+ΔP	ΔH
0+000 (Crest)	1.5	3	0.012	0	0.624	882.42	6474.00	24.40	3106.12	3988.54	0.02
0+000 (Crest)	4.5	3	0.012	0	0.624	1226.22	6474.00	24.40	3106.12	4332.34	0.02
0+000 (Crest)	7.5	3	0.012	0	0.624	1570.02	6474.00	24.40	3106.12	4676.14	0.01
0+000 (Crest)	10.5	3	0.012	0	0.624	1913.82	6474.00	24.40	3106.12	5019.94	0.01
0+000 (Crest)	13.5	3	0.012	0	0.624	2257.62	6474.00	24.40	3106.12	5363.74	0.01
0+000 (Crest)	16.5	3	0.012	0	0.624	2601.42	6474.00	24.40	3106.12	5707.54	0.01
0+000 (Crest)	19.5	3	0.012	0	0.624	2945.22	6474.00	24.40	3106.12	6051.34	0.01
0+000 (Crest)	22.5	3	0.012	0	0.624	3289.02	6474.00	24.40	3106.12	6395.14	0.01
0+000 (Crest)	25.5	3	0.012	0.15	0.624	3632.82	6474.00	24.40	3106.12	6738.94	0.01
0+000 (Crest)	28.5	3	0.012	0.15	0.624	3976.62	6474.00	24.40	3106.12	7082.74	0.02
0+000 (Crest)	31.5	3	0.012	0.15	0.624	4320.42	6474.00	24.40	3106.12	7426.54	0.02
0+000 (Crest)	33.05	3.1	0.012	0.15	0.624	4498.05	6474.00	24.40	3106.12	7604.17	0.02
		36.1									

SUM = 0.16 feet
1.96 inches

Total Settlement at Centerline Sta. 21+050 =	**3.85 inches**	**Within 9.2 feet Thick Lacustrine Layer**
+	**1.96 inches**	**Within 3.2 feet Thick Till Layer**
=	**5.81 inches**	**Total Settlement**

Storage Dam Settlement Calculations

SR1 Storage Dam
Settlement Calculations for Dam Centerline Sta. 21+050

21.6 ft (6.6 m) Embankment
9.2 ft (2.8 m) Fat Clay (Lacustrine)
3.2 ft (1.0 m) Lean Clay with Sand (Till)

Nearest Consolidation Test Samples:
D2 - ST4 (1.50 m - 1.95 m) Fat Clay (Lacustrine)
D8 - ST4 (1.80 m - 2.30 m) Lean Clay with Sand (Till)

D2 - ST4 (1.50 m - 1.95 m) Fat Clay (Lacustrine)
Pc = 205 kPa (4,282 psf), OCR = 6.6, Cc = 0.21, Cr = 0.09

Top of Embankment Elevation = 1213.5 m
Embankment Thickness = 6.58 m (21.6 ft)
Embankment Unit Weight = 20 kN/m^3 (127.3 lb/ft^3)

New embankment loading does not exceed preconsolidation pressure, therefore only use Cr value.

$$\Delta H = \frac{H}{1+e_0}\left(C_r \log\frac{p_c}{p_o} + C_c \log\frac{p_f}{p_c}\right)$$

Fat Clay (Lacustrine) Layer 2.80 m (9.2 ft)

Lacustrine Unit Weight = 18 kN/m^3 (114.6 lb/ft^3)

Location	Mid Pt. (ft)	H (ft)	Cr	Cc	e	Po (psf)	Pc (psf)	W(ft.)	ΔP(psf)	Pf = Po+ΔP	ΔH
0+000 (Crest)	4.6	9.2	0.09	0	0.8	527.16	4282.00	21.60	2749.68	3276.84	0.42

SUM = 0.42 feet
5.02 inches

Fat Clay (Lacustrine) Five Layers - 3 Feet Thick

Location	Mid Pt. (ft)	H (ft)	Cr	Cc	e	Po (psf)	Pc (psf)	W(ft.)	ΔP(psf)	Pf = Po+ΔP	ΔH
0+000 (Crest)	1.5	3	0.09	0	0.8	171.90	4282.00	21.60	2749.68	2921.58	0.21
0+000 (Crest)	4.5	3	0.09	0	0.8	515.70	4282.00	21.60	2749.68	3265.38	0.14
0+000 (Crest)	7.6	3.2	0.09	0	0.8	870.96	4282.00	21.60	2749.68	3620.64	0.11
		9.2									

SUM = 0.46 feet
5.50 inches

Storage Dam Settlement Calculations

Settlement Calculations for Centerline Dam Sta. 21+050
D8 - ST4 (1.80-2.30 m) - Lean Clay with Sand (CL) Till
Pc = 310 kPa (6,474 psf), OCR = 8.4, Cr = 0.012, Cc = 0.15

New embankment loading + existing overburden does not exceed preconsolidation pressure, therefore only use Cr value.

$$\Delta H = \frac{H}{1+e_0}\left(C_r \log\frac{p_c}{p_o} + C_c \log\frac{p_f}{p_c}\right)$$

Lean Clay with Sand (Till) - One Layer

Till Unit Weight = 18 kN/m^3 (114.6 lb/ft^3)

Location	Mid Pt. (ft)	H (ft)	Cr	Cc	e	Po (psf)	Pc (psf)	W(ft.)	ΔP(psf)	Pf = Po+ΔP	ΔH
0+000 (Crest)	1.6	3.2	0.012	0	0.624	1354.52	6474.00	21.60	2749.68	4104.20	0.02

SUM = 0.02 feet
0.19 inches

Total Settlement at Centerline Sta. 21+050 =		**5.50 inches**	**Within 9.2 feet Thick Lacustrine Layer**
	+	**0.2 inches**	**Within 3.2 feet Thick Till Layer**
	=	**5.69 inches**	**Total Settlement**

Storage Dam Settlement Calculations

Stantec

SR1 Storage Dam
Settlement Calculations for Dam Centerline Sta. 21+350

23 ft (7.0 m) Embankment
10 ft (3.0 m) Fat Clay (Lacustrine)
5 ft (1.5 m) Lean Clay with Sand (Till)

10 ft Thick Lacustrine Layer Settlement Calculations

Nearest Consolidation Test Samples:

D12 (Lacustrine) Pc = 400 kPa (8,354 psf), OCR = 7.6, Cc = 0.24, Cr = 0.06
D20 (Lacustrine) Pc = 160 kPa (3,342 psf), OCR = 3.0, Cc = 0.16, Cr = 0.05

Average D12 and D20 Consolidation Parameters:
Pc = 280 kPa (5848 psf), OCR = 5.3, Cc = 0.20, Cr = 0.06

Top of Embankment Elevation = 1213.5 m
Embankment Thickness = 7.0 m (23.0 ft)
Embankment Unit Weight = 20 kN/m^3 (127.3 lb/ft^3)

New embankment loading + existing overburden does not exceed preconsolidation pressure, therefore only use Cr value.

$$\Delta H = \frac{H}{1+e_0}\left(C_r \log\frac{p_c}{p_o} + C_c \log\frac{p_f}{p_c}\right)$$

One 10 Foot Thick Layer - Overconsolidated Lacustrine

Lacustrine Unit Weight = 18 kN/m^3 (114.6 lb/ft^3)

Location	Mid Pt. (ft)	H (ft)	Cr	Cc	e	Po (psf)	Pc (psf)	W(ft.)	ΔP(psf)	Pf = Po+ΔP	ΔH
0+000 (Crest)	5	10	0.06	0	0.8	573.00	5848.00	23.00	2927.90	3500.90	0.34

SUM = 0.34 feet
4.04 inches

Four Layers Approximately 3 feet Thick - Overconsolidated Lacustine

Location	Mid Pt. (ft)	H (ft)	Cr	Cc	e	Po (psf)	Pc (psf)	W(ft.)	ΔP(psf)	Pf = Po+ΔP	ΔH
0+000 (Crest)	1.5	3	0.06	0	0.8056	171.90	5848.00	23.00	2927.90	3099.80	0.15
0+000 (Crest)	4.5	3	0.06	0	0.8000	515.70	5848.00	23.00	2927.90	3443.60	0.11
0+000 (Crest)	7.5	3	0.06	0	0.7951	859.50	5848.00	23.00	2927.90	3787.40	0.08
0+000 (Crest)	9.5	1	0.06	0	0.7951	1088.70	5848.00	23.00	2927.90	4016.60	0.02
		10									

SUM = 0.37 feet
4.39 inches

Storage Dam Settlement Calculations

SR1 Storage Dam
Centerline Sta. 21+350
Settlement Calculations for Centerline Dam Sta. 21+350

5 ft Thick Lean Clay with Sand (Till) Layer Settlement Calculations

Nearest Consolidation Test Samples:

D8 (Till) Pc = 310 kPa (6,474 psf), OCR = 8.4, Cc = 0.15, Cr = 0.03
D11 (Till) Pc = 245 kPa (5,117 psf), OCR = 7.8, Cc = 0.18, Cr = 0.06

Average D8 and D11 Consolidation Parameters:
Pc = 278 kPa (5806 psf), OCR = 58.1, Cc = 0.165, Cr = 0.045

$$\Delta H = \frac{H}{1+e_0}\left(C_r \log\frac{p_c}{p_o} + C_c \log\frac{p_f}{p_c}\right)$$

New embankment loading + existing overburden does not exceed preconsolidation pressure, therefore only use Cr value.

One Layer 5 ft thickness

Till Unit Weight = 18 kN/m^3 (114.6 lb/ft^3)

Location	Mid Pt. (ft)	H (ft)	Cr	Cc	e	Po (psf)	Pc (psf)	W(ft.)	ΔP(psf)	Pf = Po+ΔP	ΔH
0+000 (Crest)	2.5	5	0.045	0	0.6814	1432.50	5806.00	23.00	2927.90	4360.40	0.08

SUM = 0.08 feet
0.98 inches

Two Layers Approximately 3 feet thick

Location	Mid Pt. (ft)	H (ft)	Cr	Cc	e	Po (psf)	Pc (psf)	W(ft.)	ΔP(psf)	Pf = Po+ΔP	ΔH
0+000 (Crest)	1.5	3	0.045	0	0.6814	1317.90	5806.00	23.00	2927.90	4245.80	0.05
0+000 (Crest)	4	2	0.045	0	0.6814	1680.00	5806.00	23.00	2927.90	4607.90	0.03
		5									

SUM = 0.08 feet
0.97 inches

Total Settlement at Centerline Sta. 21+350

Lacustrine Layer		4.39 inches
Till Layer	+	0.97 inches
	=	5.36 inches Total Settlement

Storage Dam Settlement Calculations

Stantec

SR1 Storage Dam
Settlement Calculations for Dam Centerline Sta. 21+650

45 ft (13.7 m) Embankment
14 ft (4.3 m) Fat Clay (Lacustrine)
7 ft (2.1 m) Lean Clay with Sand (Till)

14 ft Thick Lacustrine Layer Settlement Calculations

Nearest Consolidation Test Samples:

D12 (Lacustrine) Pc = 400 kPa (8,354 psf), OCR = 7.6, Cc = 0.24, Cr = 0.06
D20 (Lacustrine) Pc = 160 kPa (3,342 psf), OCR = 3.0, Cc = 0.16, Cr = 0.05

Average D12 and D20 Consolidation Parameters:
Pc = 280 kPa (5848 psf), OCR = 5.3, Cc = 0.20, Cr = 0.06

Top of Embankment Elevation = 1213.5 m
Embankment Thickness = 13.7 m (45.0 ft)
Embankment Unit Weight = 20 kN/m^3 (127.3 lb/ft^3)

$$\Delta H = \frac{H}{1+e_0}\left(C_r \log\frac{p_c}{p_o} + C_c \log\frac{p_f}{p_c}\right)$$

One Layer 14 ft thickness

Lacustrine Unit Weight = 18 kN/m^3 (114.6 lb/ft^3)

Location	Mid Pt. (ft)	H (ft)	Cr	Cc	e	Po (psf)	Pc (psf)	W(ft.)	ΔP(psf)	Pf = Po+ΔP	ΔH
0+000 (Crest)	7	14	0.06	0.20	0.7867	802.20	5848.00	45.00	5728.50	6530.70	0.48

SUM = 0.48 feet
5.77 inches

Five Layers Approximately 3 feet thick

New embankment loading + existing overburden does not exceed preconsolidation pressure in first layer, therefore only use Cr value.

Location	Mid Pt. (ft)	H (ft)	Cr	Cc	e	Po (psf)	Pc (psf)	W(ft.)	ΔP(psf)	Pf = Po+ΔP	ΔH
0+000 (Crest)	1.5	3	0.06	0.00	0.8056	171.90	5848.00	45.00	5728.50	5900.40	0.15
0+000 (Crest)	4.5	3	0.06	0.20	0.800	515.70	5848.00	45.00	5728.50	6244.20	0.11
0+000 (Crest)	7.5	3	0.06	0.20	0.795	859.50	5848.00	45.00	5728.50	6588.00	0.10
0+000 (Crest)	10.5	3	0.06	0.20	0.795	1203.30	5848.00	45.00	5728.50	6931.80	0.09
0+000 (Crest)	13	2	0.06	0.20	0.790	1489.80	5848.00	45.00	5728.50	7218.30	0.06
		14									

SUM = 0.52 feet
6.27 inches

Storage Dam Settlement Calculations

Stantec

SR1 Storage Dam
Centerline Sta. 21+350
Settlement Calculations for Centerline Dam Sta. 21+350

5 ft Thick Lean Clay with Sand (Till) Layer Settlement Calculations

Nearest Consolidation Test Samples:

D8 (Till) Pc = 310 kPa (6,474 psf), OCR = 8.4, Cc = 0.15, Cr = 0.03
D11 (Till) Pc = 245 kPa (5,117 psf), OCR = 7.8, Cc = 0.18, Cr = 0.06

Average D8 and D11 Consolidation Parameters:
Pc = 278 kPa (5806 psf), OCR = 8.1, Cc = 0.165, Cr = 0.045

$$\Delta H = \frac{H}{1+e_0}\left(C_r \log\frac{p_c}{p_o} + C_c \log\frac{p_f}{p_c}\right)$$

7 ft Thick Lean Clay with Sand (Till) Layer Settlement Calculations

Till Unit Weight = 18 kN/m^3 (114.6 lb/ft^3)

Location	Mid Pt. (ft)	H (ft)	Cr	Cc	e	Po (psf)	Pc (psf)	W(ft.)	ΔP(psf)	Pf = Po+ΔP	ΔH
0+000 (Crest)	3.5	7	0.045	0.165	0.6814	2005.50	5806.00	45.00	5728.50	7734.00	0.17

SUM = 0.17 feet
2.06 inches

Three Layers Approximately 3 feet thick

Location	Mid Pt. (ft)	H (ft)	Cr	Cc	e	Po (psf)	Pc (psf)	W(ft.)	ΔP(psf)	Pf = Po+ΔP	ΔH
0+000 (Crest)	1.5	3	0.045	0.165	0.6814	1776.30	5806.00	45.00	5728.50	7504.80	0.07
0+000 (Crest)	4.5	3	0.045	0.165	0.6814	2120.10	5806.00	45.00	5728.50	7848.60	0.07
0+000 (Crest)	6.5	1	0.045	0.165	0.6814	2349.30	5806.00	45.00	5728.50	8077.80	0.02
		7									

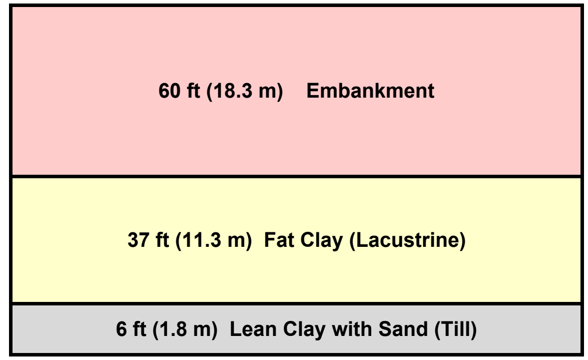
SUM = 0.17 feet
2.07 inches

Total Settlement at Centerline Sta. 21+650

Lacustrine Layer		6.27 inches
Till Layer	+	2.07 inches
	=	8.34 inches Total Settlement

Storage Dam Settlement Calculations

SR1 Storage Dam
Settlement Calculations for Dam Centerline Sta. 21+975



37 ft Thick Lacustrine Layer Settlement Calculations

Nearest Consolidation Test Samples:

D14 (Lacustrine) Pc = 265 kPa (5,535 psf), OCR = 3.0, Cc = 0.20, Cr = 0.05
D20 (Lacustrine) Pc = 285 kPa (5,952 psf), OCR = 2.8, Cc = 0.24, Cr = 0.08

Average D14 and D20 Consolidation Parameters:
Pc = 275 kPa (5,743 psf), OCR = 2.9, Cc = 0.22, Cr = 0.065

Top of Embankment Elevation = 1213.5 m
Embankment Thickness = 18.3 m (60.0 ft)
Embankment Unit Weight = 20 kN/m^3 (127.3 lb/ft^3)

$$\Delta H = \frac{H}{1+e_0}\left(C_r \log\frac{p_c}{p_o} + C_c \log\frac{p_f}{p_c}\right)$$

One Layer 37 ft thickness

Location	Mid Pt. (ft)	H (ft)	Cr	Cc	e	Po (psf)	Pc (psf)	W(ft.)	ΔP(psf)	Pf = Po+ΔP	ΔH
0+000 (Crest)	18.5	37	0.065	0.22	0.7867	2120.10	5743.00	60.00	7638.00	9758.10	1.63

SUM = 1.63 feet
19.58 inches

Thirteen Layers Approximately 3 feet thick

Location	Mid Pt. (ft)	H (ft)	Cr	Cc	e	Po (psf)	Pc (psf)	W(ft.)	ΔP(psf)	Pf = Po+ΔP	ΔH
0+000 (Crest)	1.5	3	0.065	0.22	0.8056	171.90	5743.00	60.00	7638.00	7809.90	0.21
0+000 (Crest)	4.5	3	0.065	0.22	0.8000	515.70	5743.00	60.00	7638.00	8153.70	0.17
0+000 (Crest)	7.5	3	0.065	0.22	0.7951	859.50	5743.00	60.00	7638.00	8497.50	0.15
0+000 (Crest)	10.5	3	0.065	0.22	0.7951	1203.30	5743.00	60.00	7638.00	8841.30	0.14
0+000 (Crest)	13.5	3	0.065	0.22	0.7900	1547.10	5743.00	60.00	7638.00	9185.10	0.14
0+000 (Crest)	16.5	3	0.065	0.22	0.7867	1890.90	5743.00	60.00	7638.00	9528.90	0.13
0+000 (Crest)	19.5	3	0.065	0.22	0.7867	2234.70	5743.00	60.00	7638.00	9872.70	0.13
0+000 (Crest)	22.5	3	0.065	0.22	0.7867	2578.50	5743.00	60.00	7638.00	10216.50	0.13
0+000 (Crest)	25.5	3	0.065	0.22	0.7700	2922.30	5743.00	60.00	7638.00	10560.30	0.13
0+000 (Crest)	28.5	3	0.065	0.22	0.7700	3266.10	5743.00	60.00	7638.00	10904.10	0.13
0+000 (Crest)	31.5	3	0.065	0.22	0.7700	3609.90	5743.00	60.00	7638.00	11247.90	0.13
0+000 (Crest)	34.5	3	0.065	0.22	0.7183	3953.70	5743.00	60.00	7638.00	11591.70	0.14
0+000 (Crest)	36.5	1	0.065	0.22	0.7183	4182.90	5743.00	60.00	7638.00	11820.90	0.05
		37									1.78

SUM = 1.78 feet
21.41 inches

Storage Dam Settlement Calculations

SR1 Storage Dam
Settlement Calculations for Dam Centerline Sta. 21+975

6 ft Thick Lean Clay with Sand (Till) Layer Settlement Calculations

Nearest Consolidation Test Sample:

D11 (Till) Pc = 245 kPa (5,117 psf), OCR = 7.8, Cc = 0.18, Cr = 0.06

$$\Delta H = \frac{H}{1+e_0}\left(C_r \log\frac{p_c}{p_o} + C_c \log\frac{p_f}{p_c}\right)$$

One Layer 6 ft thickness

Location	Mid Pt. (ft)	H (ft)	Cr	Cc	e	Po (psf)	Pc (psf)	W(ft.)	ΔP(psf)	Pf = Po+ΔP	ΔH
0+000 (Crest)	3	6	0.06	0.18	0.6713	4584.00	5117.00	60.00	7638.00	12222.00	0.25

SUM = 0.25 feet
3.06 inches

Two Layers 3 feet thick

Location	Mid Pt. (ft)	H (ft)	Cr	Cc	e	Po (psf)	Pc (psf)	W(ft.)	ΔP(psf)	Pf = Po+ΔP	ΔH	
0+000 (Crest)	1.5	3	0.06	0.18	0.6713	4412.10	5117.00	60.00	7638.00	12050.10	0.13	
0+000 (Crest)	4.5	3	0.06	0.18	0.6713	4755.90	5117.00	60.00	7638.00	12393.90	0.13	
												0.25

SUM = 0.25 feet
3.06 inches

Total Settlement at Centerline Sta. 21+975 = **21.41 inches**
+ 3.1 inches
= 24.47 inches Total Settlement

Storage Dam Settlement Calculations

SR1 Storage Dam
Settlement Calculations for Dam Centerline Sta. 21+290

67 ft (20.4 m) Embankment
33 ft (10.1 m) Fat Clay (Lacustrine)
17 ft (5.2 m) Lean Clay with Sand (Till)

33 ft Thick Lacustrine Layer Settlement Calculations

Nearest Consolidation Test Samples:

D14 (Lacustrine) Pc = 265 kPa (5,535 psf), OCR = 3.0, Cc = 0.20, Cr = 0.05
D28 (Lacustrine) Pc = 275 kPa (5,743 psf), OCR = 4.1, Cc = 0.21, Cr = 0.04

Average D14 and D28 Consolidation Parameters:
Pc = 270 kPa (5,639 psf), OCR = 3.6, Cc = 0.205, Cr = 0.045

Top of Embankment Elevation = 1213.5 m
Embankment Thickness = 20.4 m (67.0 ft)
Embankment Unit Weight = 20 kN/m^3 (127.3 lb/ft^3)

$$\Delta H = \frac{H}{1+e_0}\left(C_r \log\frac{p_c}{p_o} + C_c \log\frac{p_f}{p_c}\right)$$

One Layer 33 ft thickness

Location	Mid Pt. (ft)	H (ft)	Cr	Cc	e	Po (psf)	Pc (psf)	W(ft.)	ΔP(psf)	Pf = Po+ΔP	ΔH
0+000 (Crest)	16.5	33	0.045	0.205	0.7122	1890.90	5639.00	67.00	8529.10	10420.00	1.47

SUM = 1.47 feet
17.58 inches

Eleven Layers Approximately 3 feet thick

Location	Mid Pt. (ft)	H (ft)	Cr	Cc	e	Po (psf)	Pc (psf)	W(ft.)	ΔP(psf)	Pf = Po+ΔP	ΔH
0+000 (Crest)	1.5	3	0.045	0.205	0.7108	171.90	5639.00	67.00	8529.10	8701.00	0.19
0+000 (Crest)	4.5	3	0.045	0.205	0.7108	515.70	5639.00	67.00	8529.10	9044.80	0.16
0+000 (Crest)	7.5	3	0.045	0.205	0.7108	859.50	5639.00	67.00	8529.10	9388.60	0.14
0+000 (Crest)	10.5	3	0.045	0.205	0.7108	1203.30	5639.00	67.00	8529.10	9732.40	0.14
0+000 (Crest)	13.5	3	0.045	0.205	0.7111	1547.10	5639.00	67.00	8529.10	10076.20	0.13
0+000 (Crest)	16.5	3	0.045	0.205	0.7122	1890.90	5639.00	67.00	8529.10	10420.00	0.13
0+000 (Crest)	19.5	3	0.045	0.205	0.7122	2234.70	5639.00	67.00	8529.10	10763.80	0.13
0+000 (Crest)	22.5	3	0.045	0.205	0.7000	2578.50	5639.00	67.00	8529.10	11107.60	0.13
0+000 (Crest)	25.5	3	0.045	0.205	0.7000	2922.30	5639.00	67.00	8529.10	11451.40	0.13
0+000 (Crest)	28.5	3	0.045	0.205	0.7000	3266.10	5639.00	67.00	8529.10	11795.20	0.13
0+000 (Crest)	31.5	3	0.045	0.205	0.6994	3609.90	5639.00	67.00	8529.10	12139.00	0.14
		33									

SUM = 1.56 feet
18.77 inches

Storage Dam Settlement Calculations

Stantec

Settlement Calculations for Centerline Dam Sta. 22+290
17 ft Thick Lean Clay with Sand (Till) Layer Settlement Calculations

Nearest Consolidation Test Sample:

D11 (Till) Pc = 245 kPa (5,117 psf), OCR = 7.8, Cc = 0.18, Cr = 0.06

$$\Delta H = \frac{H}{1+e_0}\left(C_r \log\frac{p_c}{p_o} + C_c \log\frac{p_f}{p_c}\right)$$

One Layer 17 ft thickness

Location	Mid Pt. (ft)	H (ft)	Cr	Cc	e	Po (psf)	Pc (psf)	W(ft.)	ΔP(psf)	Pf = Po+ΔP	ΔH
0+000 (Crest)	8.5	17	0.06	0.18	0.6713	4755.90	5117.00	67.00	8529.10	13285.00	0.78

SUM = 0.78 feet
9.34 inches

Six Layers Approximately 3 feet thick

Location	Mid Pt. (ft)	H (ft)	Cr	Cc	e	Po (psf)	Pc (psf)	W(ft.)	ΔP(psf)	Pf = Po+ΔP	ΔH
0+000 (Crest)	1.5	3	0.06	0.18	0.6713	3953.70	5117.00	67.00	8529.10	12482.80	0.14
0+000 (Crest)	4.5	3	0.06	0.18	0.6713	4297.50	5117.00	67.00	8529.10	12826.60	0.14
0+000 (Crest)	7.5	3	0.06	0.18	0.6713	4641.30	5117.00	67.00	8529.10	13170.40	0.14
0+000 (Crest)	10.5	3	0.06	0.18	0.6713	4985.10	5117.00	67.00	8529.10	13514.20	0.14
0+000 (Crest)	13.5	3	0.06	0.18	0.6713	5328.90	5117.00	67.00	8529.10	13858.00	0.14
0+000 (Crest)	16	2	0.06	0.18	0.6713	5615.40	5117.00	67.00	8529.10	14144.50	0.09
		17									

SUM = 0.78 feet
9.35 inches

Total Settlement at Centerline Sta. 22+290 = **18.77 inches**
+ 9.35 inches
= 28.12 inches Total Settlement

Storage Dam Settlement Calculations

Stantec

SR1 Storage Dam
Centerline Sta. 22+600
Settlement Calculations

Nearest Lacaustine Consolidation Test Results:

D-30, 1.70 m - 2.15 m (5.6 ft - 7.1 ft)
Pc = 100 kPa (2089 psf), OCR = 2.9, Cc = 0.13, Cr = 0.03

D-30, 4.40 m - 4.85 m (14.4 ft - 15.9 ft)
Pc = 120 kPa (2506 psf), OCR = 1.4, Cc = 0.12, Cr = 0.03

Average Values:

Pc = 110 kPa (2298 psf), OCR = 2.2, Cc = 0.125, Cr = 0.03

70.5 ft (21.5 m)	**Embankment**
20 ft (6.1 m)	**Fat Clay (Lacustine)**
44.9 ft (13.7 m)	**Lean Clay with Sand (Till)**

Top of Embankment Elevation = 1213.5 m
Embankment Thickness = 21.5 m (70.5 ft)
Embankment Unit Weight = 20 kN/m^3 (127.3 lb/ft^3)

$$\Delta H = \frac{H}{1+e_0}\left(C_r \log\frac{p_c}{p_o} + C_c \log\frac{p_f}{p_c}\right)$$

One Layer 20 ft thickness

Location	Mid Pt. (ft)	H (ft)	Cr	Cc	e	Po (psf)	Pc (psf)	W(ft.)	ΔP(psf)	Pf = Po+ΔP	ΔH
0+000 (Crest)	10	20	0.03	0.125	0.5151	1146.00	2298.00	70.50	8974.65	10120.65	1.18

SUM = 1.18 feet
14.18 inches

Seven Layers Approximately 3 feet thick

Location	Mid Pt. (ft)	H (ft)	Cr	Cc	e	Po (psf)	Pc (psf)	W(ft.)	ΔP(psf)	Pf = Po+ΔP	ΔH
0+000 (Crest)	1.5	3	0.03	0.125	0.5408	171.90	2298.00	70.50	8974.65	9146.55	0.21
0+000 (Crest)	4.5	3	0.03	0.125	0.5392	515.70	2298.00	70.50	8974.65	9490.35	0.19
0+000 (Crest)	7.5	3	0.03	0.125	0.5332	859.50	2298.00	70.50	8974.65	9834.15	0.18
0+000 (Crest)	10.5	3	0.03	0.125	0.5151	1203.30	2298.00	70.50	8974.65	10177.95	0.18
0+000 (Crest)	13.5	3	0.03	0.125	0.5151	1547.10	2298.00	70.50	8974.65	10521.75	0.17
0+000 (Crest)	16.5	3	0.03	0.125	0.5151	1890.90	2298.00	70.50	8974.65	10865.55	0.17
0+000 (Crest)	19	2	0.03	0.125	0.5000	2177.40	2298.00	70.50	8974.65	11152.05	0.12
		20									

SUM = 1.22 feet
14.60 inches

Storage Dam Settlement Calculations

Settlement Calculations for Centerline Dam Sta. 22+600

D11 (Till) Pc = 245 kPa (5,117 psf), OCR = 7.8, Cc = 0.18, Cr = 0.06

$$\Delta H = \frac{H}{1+e_0}\left(C_r \log\frac{p_c}{p_o} + C_c \log\frac{p_f}{p_c}\right)$$

One Layer 44.9 ft thickness

Location	Mid Pt. (ft)	H (ft)	Cr	Cc	e	Po (psf)	Pc (psf)	W(ft.)	ΔP(psf)	Pf = Po+ΔP	ΔH
0+000 (Crest)	22.45	44.9	0.06	0.18	0.6713	4865.92	5117.00	70.50	8974.65	13840.57	2.12

SUM = 2.12 feet
25.50 inches

Fifteen Layers Approximately 3 feet thick

Location	Mid Pt. (ft)	H (ft)	Cr	Cc	e	Po (psf)	Pc (psf)	W(ft.)	ΔP(psf)	Pf = Po+ΔP	ΔH
0+000 (Crest)	1.5	3	0.06	0.18	0.6713	2463.90	5117.00	70.50	8974.65	11438.55	0.15
0+000 (Crest)	4.5	3	0.06	0.18	0.6713	2807.70	5117.00	70.50	8974.65	11782.35	0.15
0+000 (Crest)	7.5	3	0.06	0.18	0.6713	3151.50	5117.00	70.50	8974.65	12126.15	0.14
0+000 (Crest)	10.5	3	0.06	0.18	0.6713	3495.30	5117.00	70.50	8974.65	12469.95	0.14
0+000 (Crest)	13.5	3	0.06	0.18	0.6713	3839.10	5117.00	70.50	8974.65	12813.75	0.14
0+000 (Crest)	16.5	3	0.06	0.18	0.6713	4182.90	5117.00	70.50	8974.65	13157.55	0.14
0+000 (Crest)	19.5	3	0.06	0.18	0.6713	4526.70	5117.00	70.50	8974.65	13501.35	0.14
0+000 (Crest)	22.5	3	0.06	0.18	0.6374	4870.50	5117.00	70.50	8974.65	13845.15	0.14
0+000 (Crest)	25.5	3	0.06	0.18	0.6374	5214.30	5117.00	70.50	8974.65	14188.95	0.15
0+000 (Crest)	28.5	3	0.06	0.18	0.6374	5558.10	5117.00	70.50	8974.65	14532.75	0.15
0+000 (Crest)	31.5	3	0.06	0.18	0.6374	5901.90	5117.00	70.50	8974.65	14876.55	0.15
0+000 (Crest)	34.5	3	0.06	0.18	0.6374	6245.70	5117.00	70.50	8974.65	15220.35	0.15
0+000 (Crest)	37.5	3	0.06	0.18	0.6374	6589.50	5117.00	70.50	8974.65	15564.15	0.15
0+000 (Crest)	40.5	3	0.06	0.18	0.6033	6933.30	5117.00	70.50	8974.65	15907.95	0.15
0+000 (Crest)	41.95	2.9	0.06	0.18	0.6033	7099.47	5117.00	70.50	8974.65	16074.12	0.15
		44.9									

SUM = 2.18 feet
26.13 inches

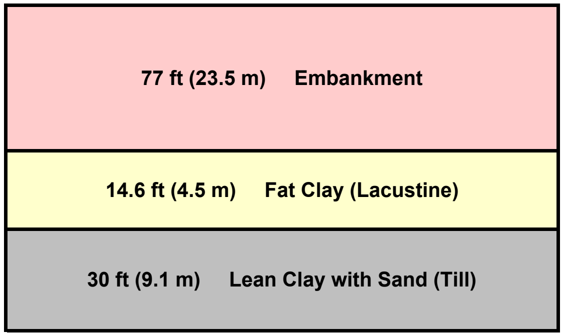
Total Settlement at Centerline Sta. 22+600 =

	14.60 inches
+	**26.13 inches**
=	**40.74 inches** **Total Settlement**

Storage Dam Settlement Calculations

SR1 Storage Dam
Centerline Station 22+925
Settlement Calculations

Nearest Consolidation Test Samples:
D36 - ST10 (4.50 m to 4.95 m) Fat Clay (Lucustrine)
D62 - ST6 (4.60 m to 5.05 m) Lean Clay with Sand (Till)



Settlement Calculations for Centerline Dam Sta. 22+950
D36 - ST10 (4.50-4.95m) - Lacustrine (CL)
Pc = 280 kPa (5,848 psf), OCR = 3.3, Cc = 0.23, Cr = 0.03

Top of Embankment Elevation = 1213.5 m
Embankment Thickness = 23.5 m (77.0 ft)
Embankment Unit Weight = 20 kN/m^3 (127.3 lb/ft^3)

$$\Delta H = \frac{H}{1+e_0}\left(C_r \log\frac{p_c}{p_o} + C_c \log\frac{p_f}{p_c}\right)$$

Fat Clay (Lacustrine) Layer 4.45 m (14.6 ft)

Location	Mid Pt. (ft)	H (ft)	Cr	Cc	e	Po (psf)	Pc (psf)	W(ft.)	ΔP(psf)	Pf = Po+ΔP	ΔH
0+000 (Crest)	7.3	14.6	0.03	0.23	0.619	836.58	5848.00	77.00	9802.10	10638.68	0.77

SUM = 0.77 feet
9.21 inches

Fat Clay (Lacustrine) Five Layers - 3 Feet Thick

Location	Mid Pt. (ft)	H (ft)	Cr	Cc	e	Po (psf)	Pc (psf)	W(ft.)	ΔP(psf)	Pf = Po+ΔP	ΔH
0+000 (Crest)	1.5	3	0.03	0.23	0.619	171.90	5848.00	77.00	9802.10	9974.00	0.18
0+000 (Crest)	4.5	3	0.03	0.23	0.619	515.70	5848.00	77.00	9802.10	10317.80	0.16
0+000 (Crest)	7.5	3	0.03	0.23	0.619	859.50	5848.00	77.00	9802.10	10661.60	0.16
0+000 (Crest)	10.5	3	0.03	0.23	0.619	1203.30	5848.00	77.00	9802.10	11005.40	0.16
0+000 (Crest)	13.3	2.6	0.03	0.23	0.619	1524.18	5848.00	77.00	9802.10	11326.28	0.13
		14.6									

SUM = 0.79 feet
9.53 inches

Storage Dam Settlement Calculations

Settlement Calculations for Centerline Dam Sta. 22+925
D62 - ST6 (4.60-5.05 m) - Lean Clay with Sand (CL) Till
Pc = 87 kPa (1,808 psf), OCR = 1.0, Cc = 0.15, Cr = 0.02

$$\Delta H = H\left(\frac{C_c}{1+e_o}\right)\log\frac{p_o+\Delta p}{p_o}$$

Lean Clay with Sand (Till) - One Layer 30 feet thick

Location	Mid Pt. (ft)	H (ft)	Cc	e	Po (psf)	W(ft.)	ΔP(psf)	Pf = Po+ΔP	ΔH
0+000 (Crest)	15	30	0.15	0.44	3392.16	77	9802.10	13194.26	1.84

SUM = 1.84 feet
22.1 inches

Lean Clay with Sand (Till) Ten Layers, 3 Feet Thick

Location	Mid Pt. (ft)	H (ft)	Cc	e	Po (psf)	W(ft.)	ΔP(psf)	Pf = Po+ΔP	ΔH
0+000 (Crest)	1.5	3	0.15	0.4900	1845.06	77	9802.10	11647.16	0.24
0+000 (Crest)	4.5	3	0.15	0.4822	2188.86	77	9802.10	11990.96	0.22
0+000 (Crest)	7.5	3	0.15	0.4744	2532.66	77	9802.10	12334.76	0.21
0+000 (Crest)	10.5	3	0.15	0.4667	2876.46	77	9802.10	12678.56	0.20
0+000 (Crest)	13.5	3	0.15	0.4589	3220.26	77	9802.10	13022.36	0.19
0+000 (Crest)	16.5	3	0.15	0.4511	3564.06	77	9802.10	13366.16	0.18
0+000 (Crest)	19.5	3	0.15	0.4433	3907.86	77	9802.10	13709.96	0.17
0+000 (Crest)	22.5	3	0.15	0.4356	4251.66	77	9802.10	14053.76	0.16
0+000 (Crest)	25.5	3	0.15	0.4278	4595.46	77	9802.10	14397.56	0.16
0+000 (Crest)	28.5	3	0.15	0.4200	4939.26	77	9802.10	14741.36	0.15
		30							

SUM = 1.88 feet
22.5 inches

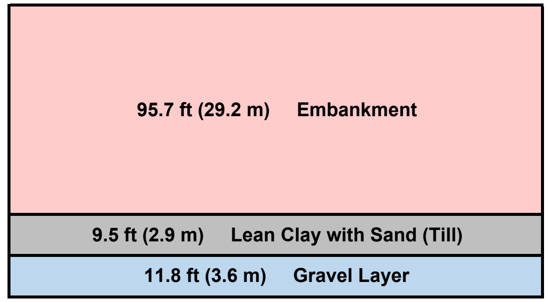
Total Settlement at Centerline Sta. 22+925 = 9.53 inches
\+ 22.54 inches
= 32.07 inches Total Settlement

Storage Dam Settlement Calculations

SR1 Storage Dam
Centerline Sta. 23+175 Low Level Outlet
Settlement Calculations

Nearest Consolidation Test Samples:
D62 - ST6, (4.60 m to 5.05 m)

Top of Embankment Elevation = 1213.5 m
Embankment Thickness = 29.2 m (95.7 ft)
Embankment Unit Weight = 20 kN/m^3 (127.3 lb/ft^3)



Settlement Calculations for Centerline Dam, Gravel Layer (GW) - Non-Cohesive

$$\Delta H = H\left(\frac{1}{c'}\right)\log\frac{p_o + \Delta p}{p_o}$$

Location	Mid Pt. (ft)	H (ft)	W(ft.)	Po(psf)	Po+ΔP(psf)	ΔP(psf)	c'	H(ft.)	ΔH(ft.)	ΔH(in.)
0+000 (Crest)	5.9	11.8	95.7	1764.84	13947.45	12182.61	210	11.8	0.0504	0.61

SUM = 0.050 feet
0.61 inches

Settlement Calculations for Centerline Dam
D62 - ST6 (4.60-5.05 m) - Lean Clay with Sand (CL) Till
Pc = 88 kPa (1,838 psf), OCR = 1.0, Cc = 0.15

$$\Delta H = H\left(\frac{C_c}{1 + e_o}\right)\log\frac{p_o + \Delta p}{p_o}$$

<u>One Layer 9.512 feet thick</u>

Location	Mid Pt. (ft)	H (ft)	Cc	e	Po (psf)	W(ft.)	ΔP(psf)	Pf = Po+ΔP	ΔH
0+000 (Crest)	4.756	9.5	0.15	0.49	545.04	95.7	12182.61	12727.65	1.31

SUM = 1.31 feet
15.7 inches

<u>Three Layers Approximately 3 feet thick</u>

Location	Mid Pt. (ft)	H (ft)	Cc	e	Po (psf)	W(ft.)	ΔP(psf)	Pf = Po+ΔP	ΔH
0+000 (Crest)	1.5	3	0.15	0.49	171.90	95.7	12182.61	12354.51	0.56
0+000 (Crest)	4.5	3	0.15	0.49	515.70	95.7	12182.61	12698.31	0.42
0+000 (Crest)	7.756	3.5	0.15	0.49	888.84	95.7	12182.61	13071.45	0.41
		9.5							

SUM = 1.39 feet
16.7 inches

Total Settlement at Centerline Sta.23+175 =

	0.61	inches	
+	16.71	inches	
=	17.31	inches	Total Settlement

Storage Dam Settlement Calculations

SR1 Storage Dam
Centerline Station 23+440
Settlement Calculations

Nearest Consolidation Test Samples:

64.3 ft (19.6 m) Embankment
4.3 ft (1.3 m) Silt (Till?)
37.1 ft (11.3 m) Lean Clay with Sand (Till)
5.6 ft (1.7 m) Gravel Layer

Settlement Calculations for Centerline Dam Sta. 23+440
D51 - ST6 (2.70 m - 3.15 m) Lean Clay with Sand (Till)
Pc = 270 kPa (5639 psf), OCR = 5.1, Cc = 0.21, Cr = 0.06

Top of Embankment Elevation = 1213.5 m
Embankment Thickness = 19.6 m (64.3 ft)

$$\Delta H = \frac{H}{1+e_0}\left(C_r \log\frac{p_c}{p_o} + C_c \log\frac{p_f}{p_c}\right)$$

Silt (Till) Layer 1.30 m (4.3 ft)

Location	Mid Pt. (ft)	H (ft)	Cr	Cc	e	Po (psf)	Pc (psf)	W(ft.)	ΔP(psf)	Pf = Po+ΔP	ΔH
0+000 (Crest)	2.15	4.3	0.06	0.21	0.6	246.39	5639.00	64.30	8185.39	8431.78	0.32

SUM = 0.32 feet
3.81 inches

Silt (Till) Two Layers - 3 Feet Thick

Location	Mid Pt. (ft)	H (ft)	Cr	Cc	e	Po (psf)	Pc (psf)	W(ft.)	ΔP(psf)	Pf = Po+ΔP	ΔH
0+000 (Crest)	2	2	0.0627	0.21	0.6	229.20	5639.00	64.30	8185.39	8414.59	0.15
0+000 (Crest)	3.15	2.3	0.06	0.21	0.6	360.99	5639.00	64.30	8185.39	8546.38	0.16
		4.3									

SUM = 0.31 feet
3.75 inches

Storage Dam Settlement Calculations

Settlement Calculations for Centerline Dam Sta. 23+440
D51 - ST6 (2.70 m - 3.15 m) Lean Clay with Sand (Till)
Pc = 230 kPa (4804 psf), OCR = 4.4, Cc = 0.21, Cr = 0.06

$$\Delta H = \frac{H}{1+e_0}\left(C_r \log\frac{p_c}{p_o} + C_c \log\frac{p_f}{p_c}\right)$$

Lean Clay with Sand (Till) One Layer 37.1 ft. thick

Location	Mid Pt. (ft)	H (ft)	Cr	Cc	e	Po (psf)	Pc (psf)	W(ft.)	ΔP(psf)	Pf = Po+ΔP	ΔH
0+000 (Crest)	18.55	37.1	0.06	0.21	0.624	2618.61	4804.00	64.30	8185.39	10804.00	2.05

SUM = 2.05 feet
24.60 inches

Lean Clay with Sand (Till) Twelve Layers 3 ft. thick

Location	Mid Pt. (ft)	H (ft)	Cr	Cc	e	Po (psf)	Pc (psf)	W(ft.)	ΔP(psf)	Pf = Po+ΔP	ΔH
0+000 (Crest)	1.5	3	0.0627	0.21	0.6	664.68	4804.00	64.30	8185.39	8850.07	0.21
0+000 (Crest)	4.5	3	0.06	0.21	0.6	1008.48	4804.00	64.30	8185.39	9193.87	0.19
0+000 (Crest)	7.5	3	0.06	0.21	0.6	1352.28	4804.00	64.30	8185.39	9537.67	0.18
0+000 (Crest)	10.5	3	0.06	0.21	0.6	1696.08	4804.00	64.30	8185.39	9881.47	0.17
0+000 (Crest)	13.5	3	0.06	0.21	0.6	2039.88	4804.00	64.30	8185.39	10225.27	0.17
0+000 (Crest)	16.5	3	0.06	0.21	0.6	2383.68	4804.00	64.30	8185.39	10569.07	0.17
0+000 (Crest)	19.5	3	0.06	0.21	0.6	2727.48	4804.00	64.30	8185.39	10912.87	0.17
0+000 (Crest)	22.5	3	0.06	0.21	0.6	3071.28	4804.00	64.30	8185.39	11256.67	0.17
0+000 (Crest)	25.5	3	0.06	0.21	0.6	3415.08	4804.00	64.30	8185.39	11600.47	0.17
0+000 (Crest)	28.5	3	0.06	0.21	0.6	3758.88	4804.00	64.30	8185.39	11944.27	0.17
0+000 (Crest)	31.5	3	0.06	0.21	0.6	4102.68	4804.00	64.30	8185.39	12288.07	0.17
0+000 (Crest)	33.55	4.1	0.06	0.21	0.6	4337.61	4804.00	64.30	8185.39	12523.00	0.23
		37.1									

SUM = 2.16 feet
25.87 inches

Settlement Calculations for Centerline Dam Sta. 23+440 Sand/Gavel Layer - Non Cohesive
5.6 ft Thick Gravel/Sand Layer

$$\Delta H = H\left(\frac{1}{c'}\right)\log\frac{p_o + \Delta p}{p_o}$$

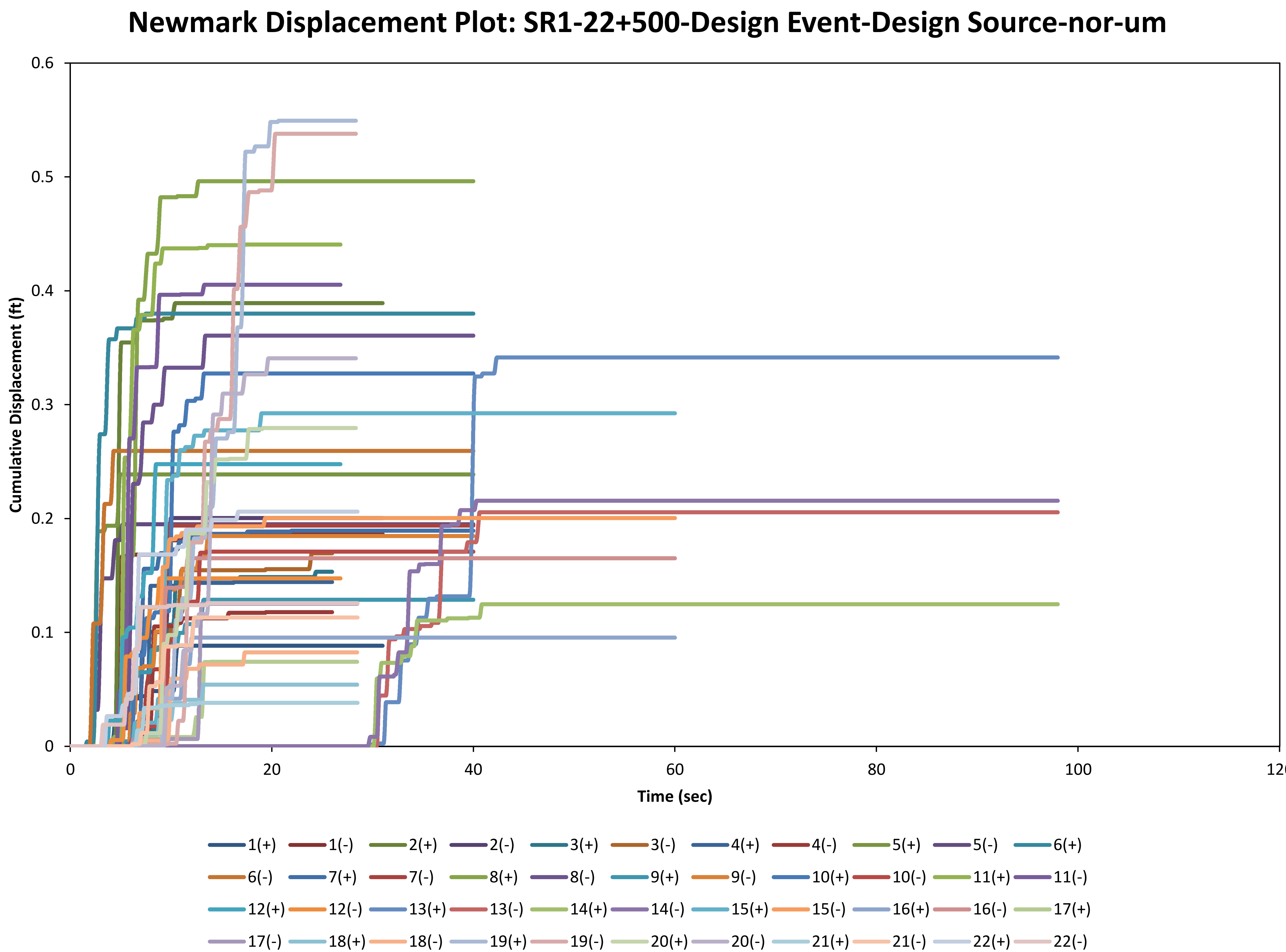
Location	Mid Pt. (ft)	H (ft)	W(ft.)	Po(psf)	Po+ΔP(psf)	ΔP(psf)	c'	H(ft.)	ΔH(ft.)	ΔH(in.)
0+000 (Crest)	44.1	5.6	64.3	5053.86	13239.25	8185.39	210	11.8	0.0235	0.28

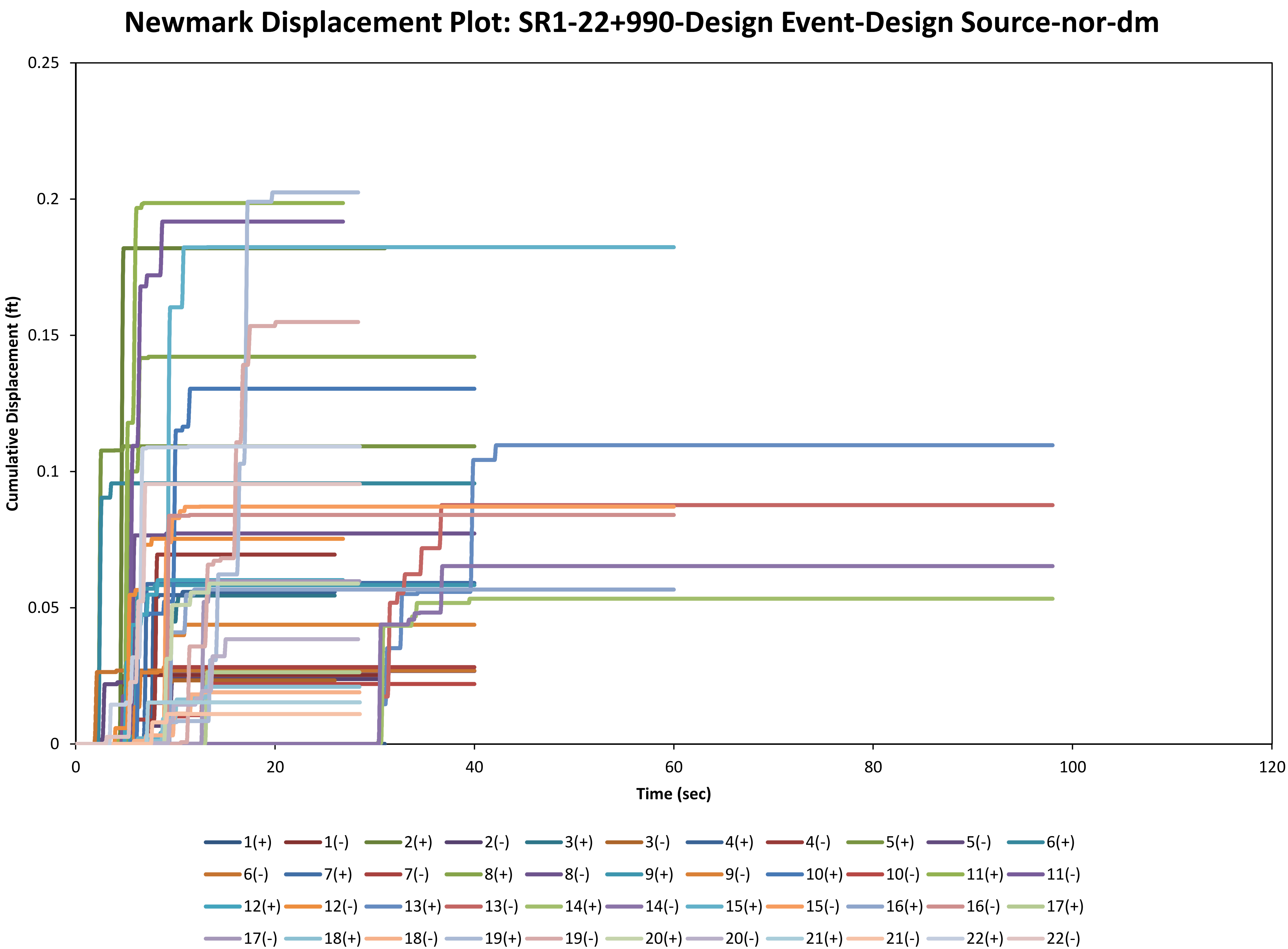
SUM = 0.024 feet
0.28 inches

Total Settlement at Centerline LLO Profile =		**3.75 inches**	**Within 4.3 feet Thick Silt Till Layer**
	+	**25.87 inches**	**Within 37.1 feet Thick Till Layer**
		0.28 inches	**Within 5.6 feet Thick Gravel/Sand Layer**
	=	**29.90 inches**	**Total Settlement**

Attachment 12.3
Seismic Analyses

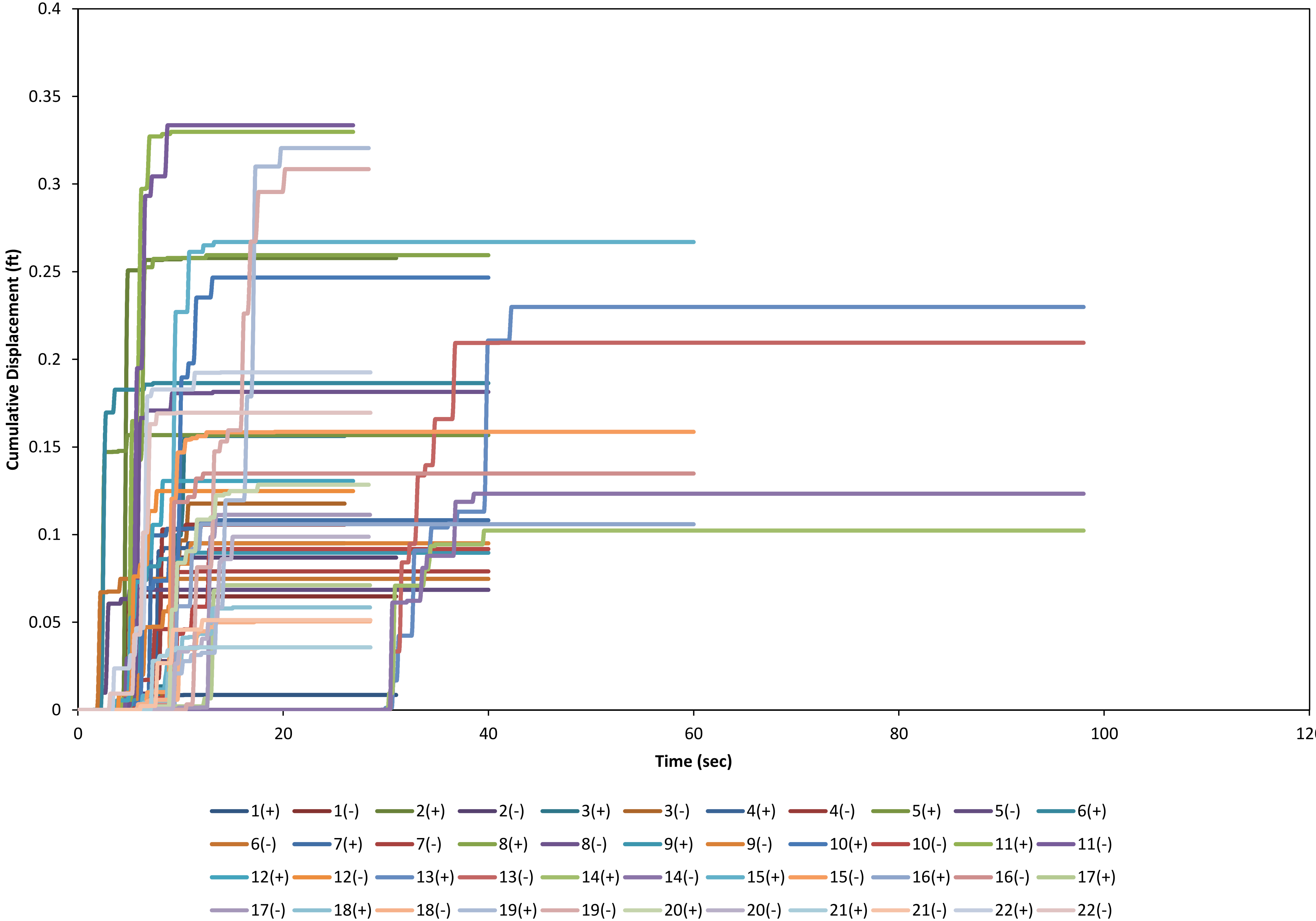
12.3.1 Newmark Displacement Plots


Newmark Displacement Plot: SR1-22+500-Design Event-Design Source-nor-um
Cumulative Displacement (ft)
0
0.1
0.2
0.3
0.4
0.5
0.6
0
20
40
60
80
100
120
Time (sec)
1(+) 1(-) 2(+) 2(-) 3(+) 3(-) 4(+) 4(-) 5(+) 5(-) 6(+)
6(-) 7(+) 7(-) 8(+) 8(-) 9(+) 9(-) 10(+) 10(-) 11(+) 11(-)
12(+) 12(-) 13(+) 13(-) 14(+) 14(-) 15(+) 15(-) 16(+) 16(-) 17(+)
17(-) 18(+) 18(-) 19(+) 19(-) 20(+) 20(-) 21(+) 21(-) 22(+) 22(-)

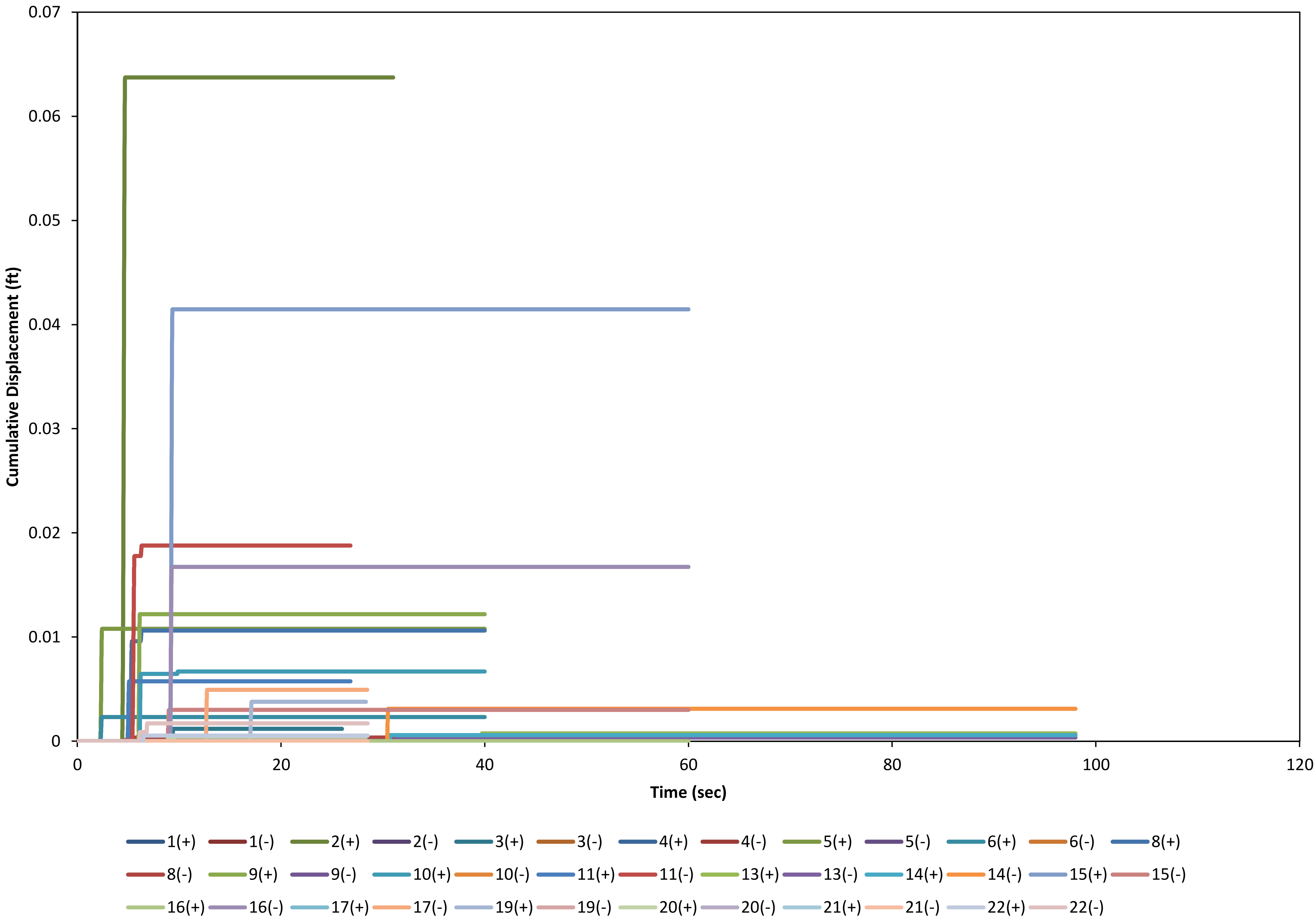


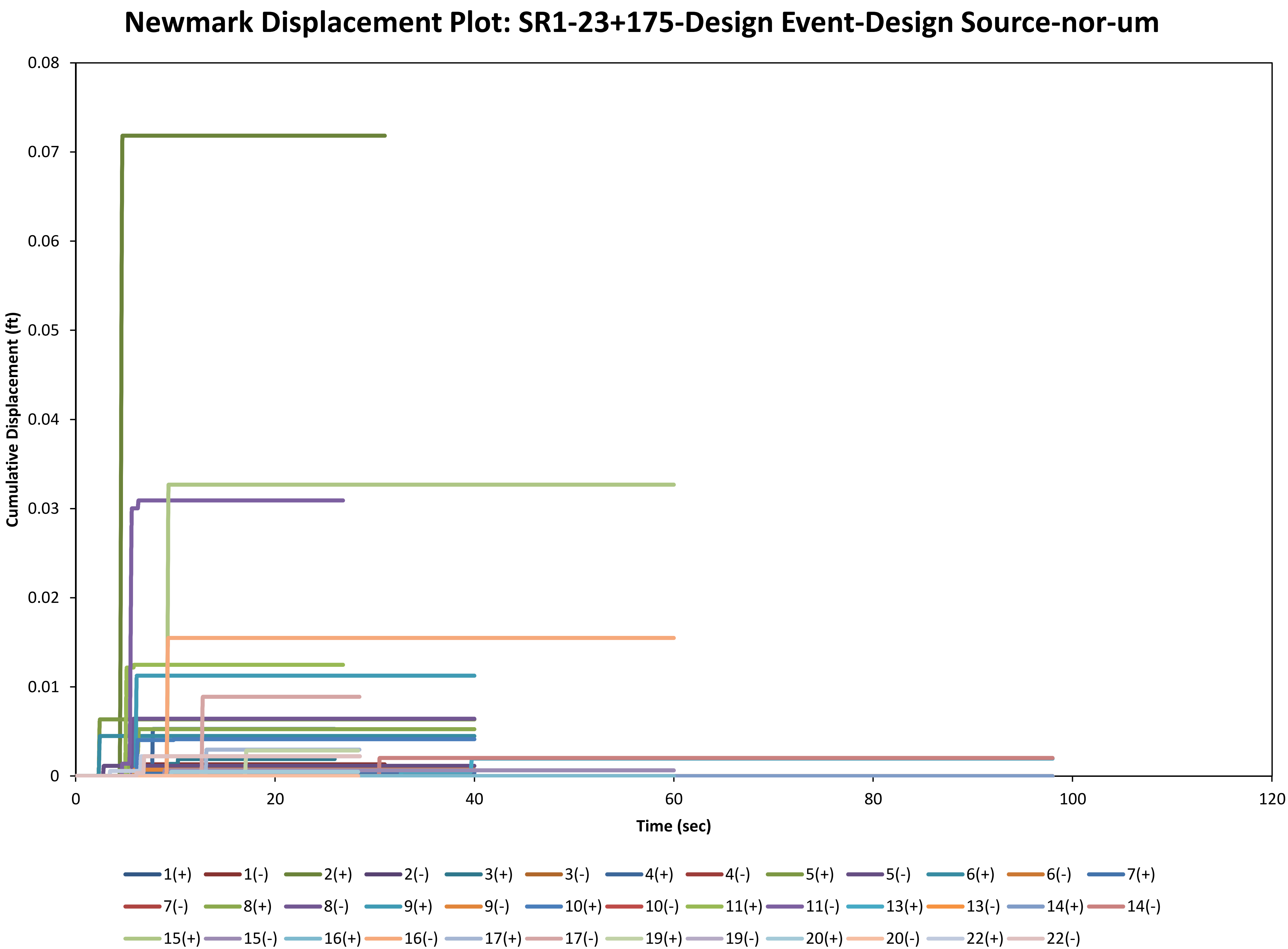
Newmark Displacement Plot: SR1-22+990-Design Event-Design Source-nor-dm
Cumulative Displacement (ft)
0.25
0.2
0.15
0.1
0.05
0
0
20
40
60
80
100
120
Time (sec)
1(+) 1(-) 2(+) 2(-) 3(+) 3(-) 4(+) 4(-) 5(+) 5(-) 6(+)
6(-) 7(+) 7(-) 8(+) 8(-) 9(+) 9(-) 10(+) 10(-) 11(+) 11(-)
12(+) 12(-) 13(+) 13(-) 14(+) 14(-) 15(+) 15(-) 16(+) 16(-) 17(+)
17(-) 18(+) 18(-) 19(+) 19(-) 20(+) 20(-) 21(+) 21(-) 22(+) 22(-)

Newmark Displacement Plot: SR1-22+990-Design Event-Design Source-nor-um



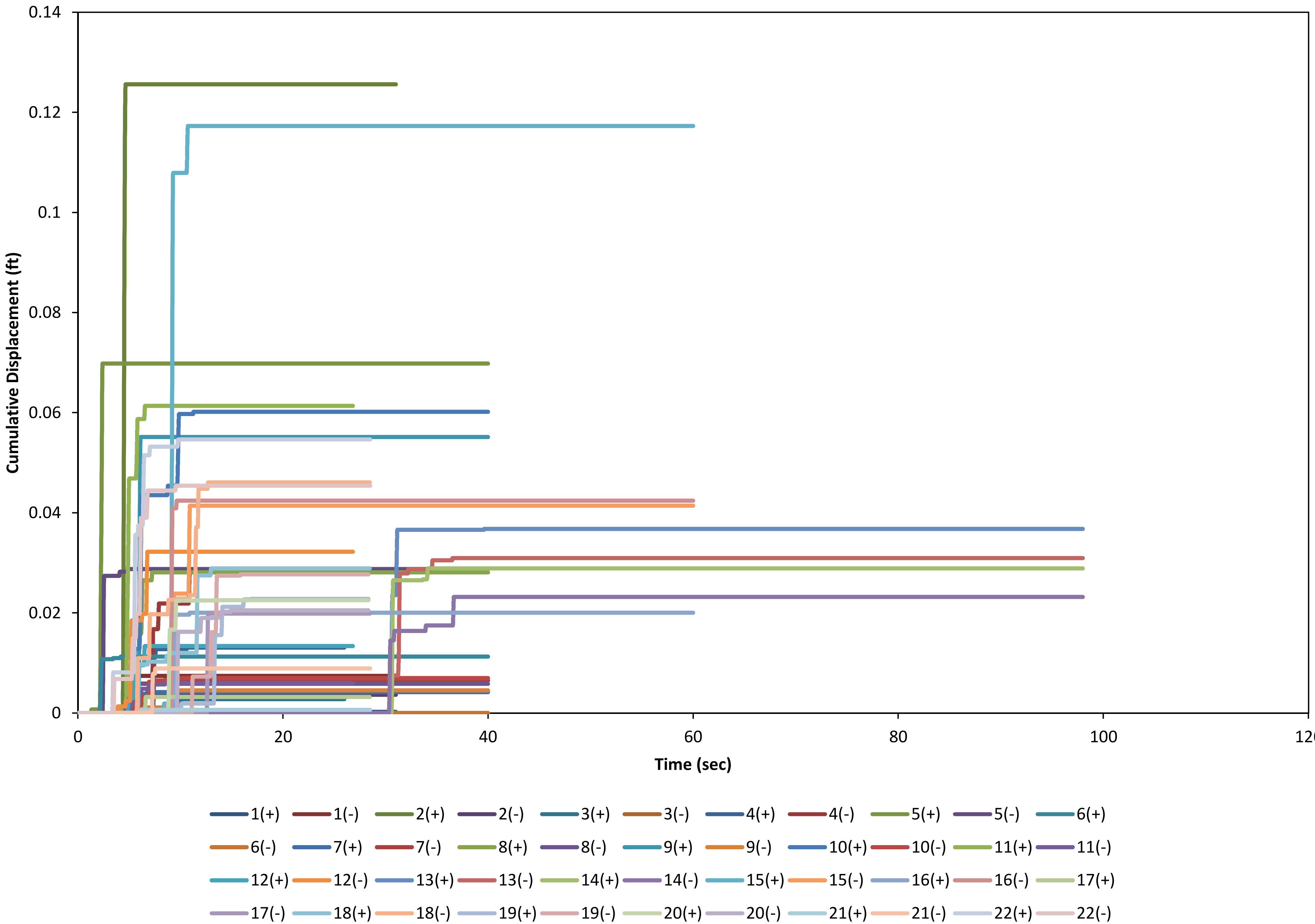
Newmark Displacement Plot: SR1-23+175-Design Event-Design Source-nor-dm



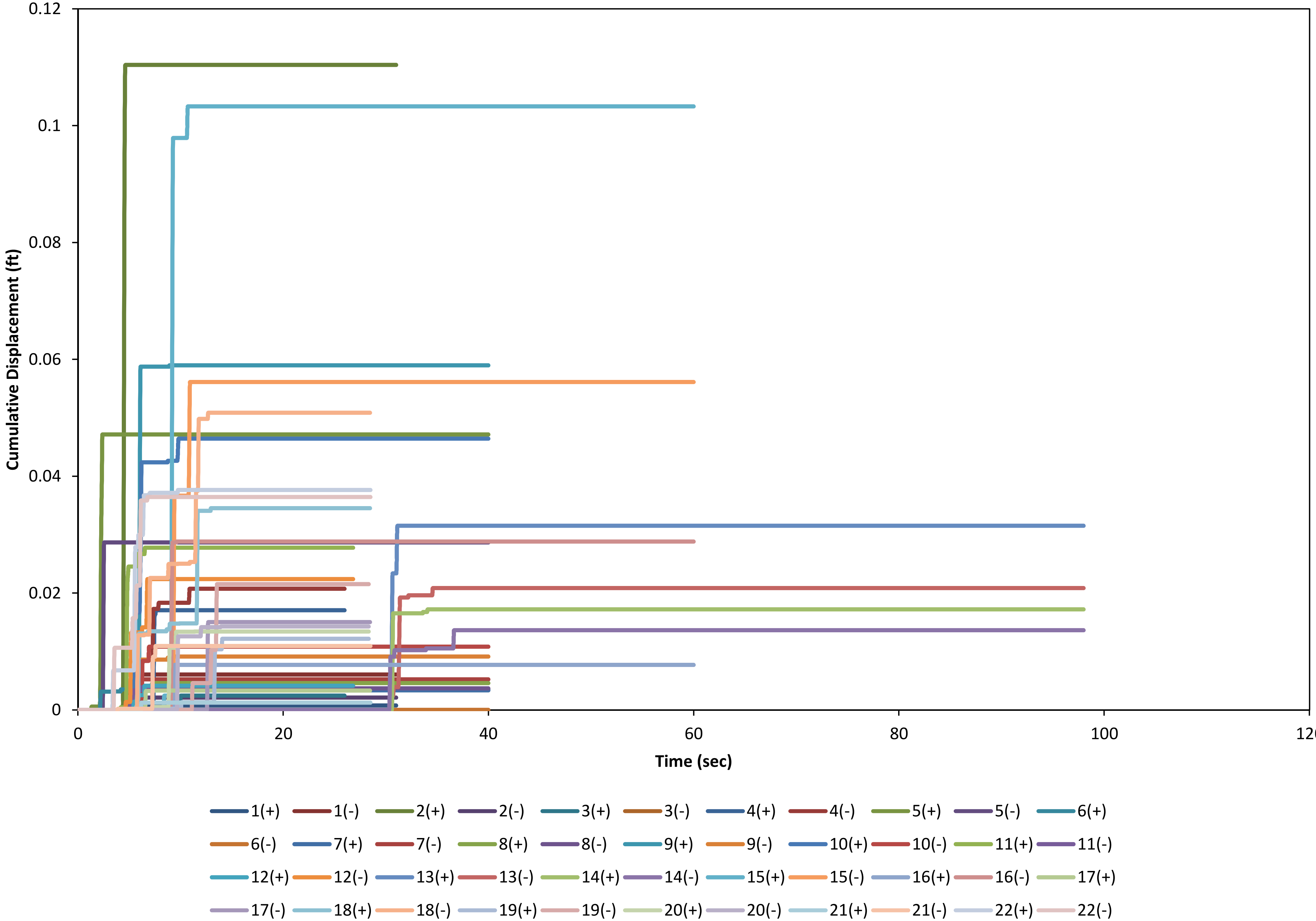


Newmark Displacement Plot: SR1-23+175-Design Event-Design Source-nor-um
Cumulative Displacement (ft)
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
0
20
40
60
80
100
120
Time (sec)
1(+) 1(-) 2(+) 2(-) 3(+) 3(-) 4(+) 4(-) 5(+) 5(-) 6(+) 6(-) 7(+)
7(-) 8(+) 8(-) 9(+) 9(-) 10(+) 10(-) 11(+) 11(-) 13(+) 13(-) 14(+) 14(-)
15(+) 15(-) 16(+) 16(-) 17(+) 17(-) 19(+) 19(-) 20(+) 20(-) 22(+) 22(-)

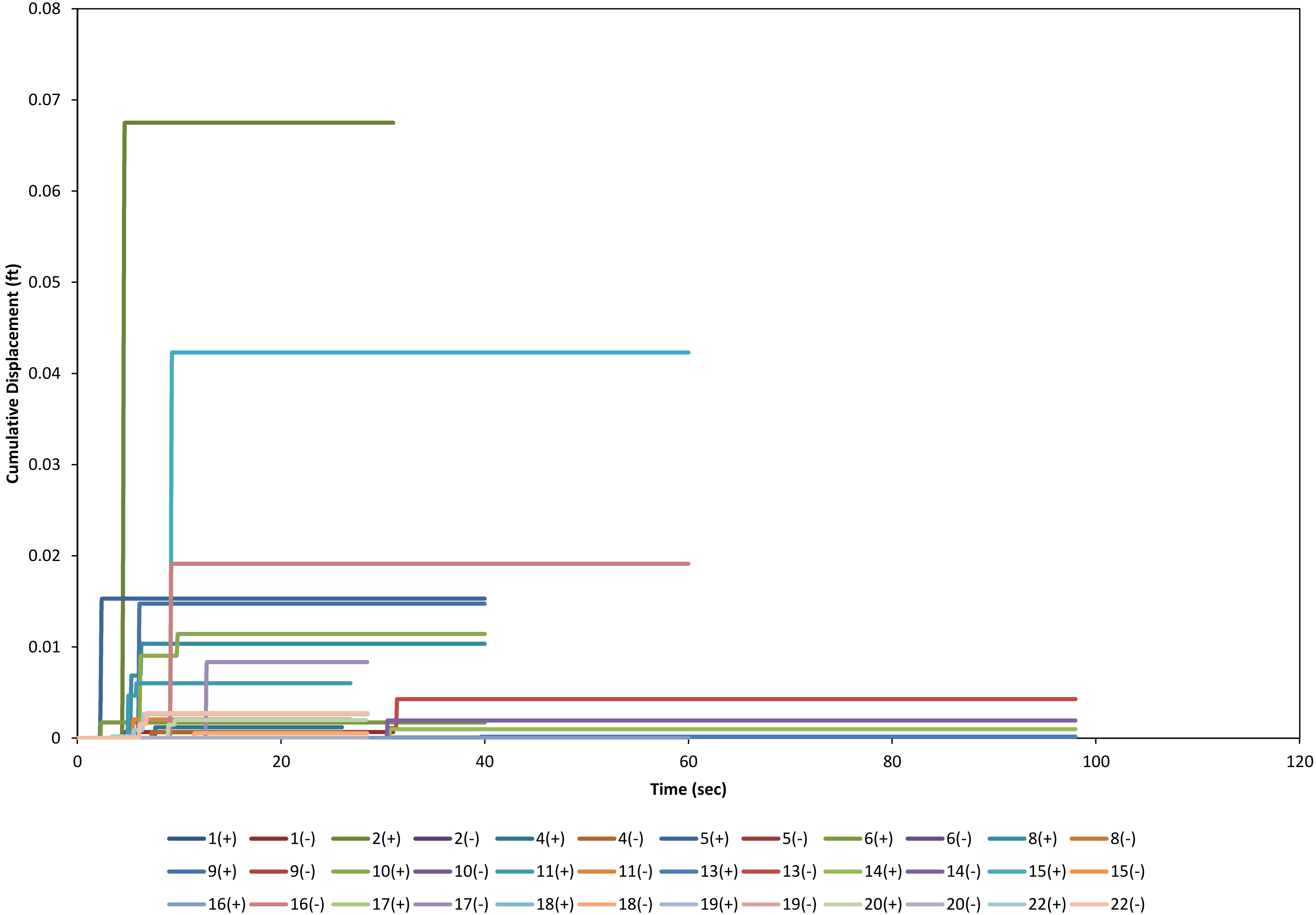
Newmark Displacement Plot: SR1-20+000-Design Event-Design Source-nor-dm

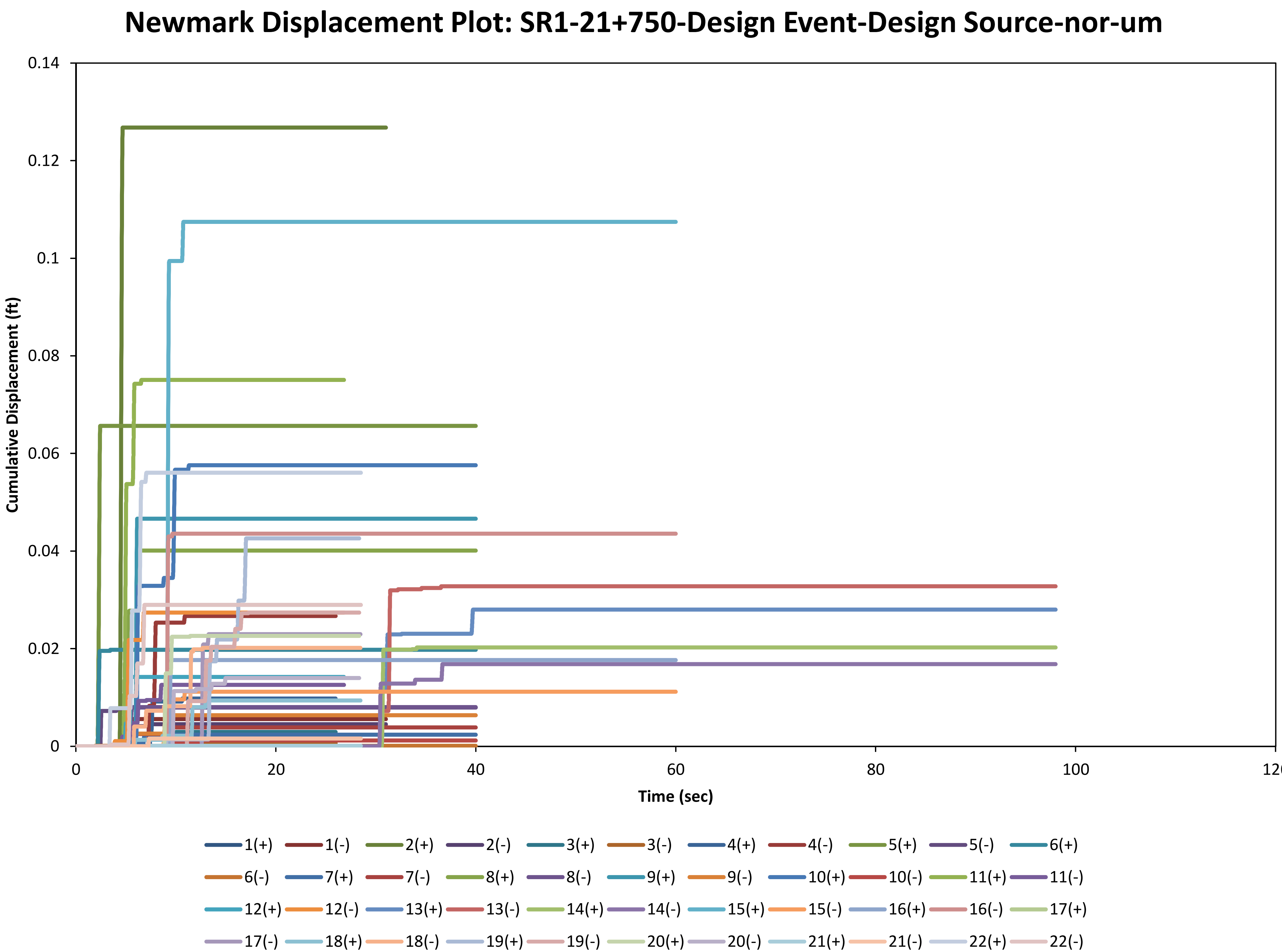


Newmark Displacement Plot: SR1-20+000-Design Event-Design Source-nor-um

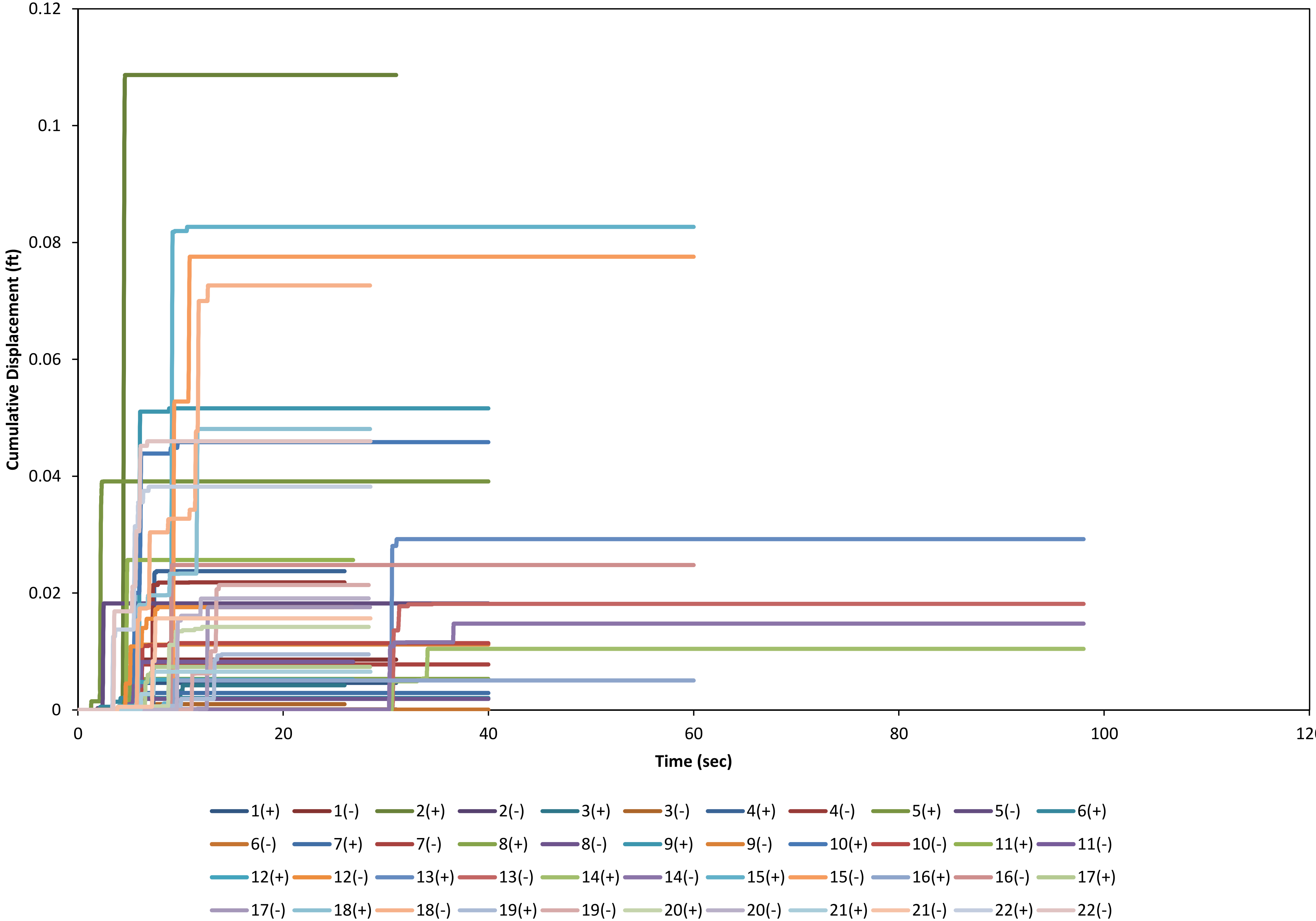


Newmark Displacement Plot: SR1-21+750-Design Event-Design Source-nor-dm

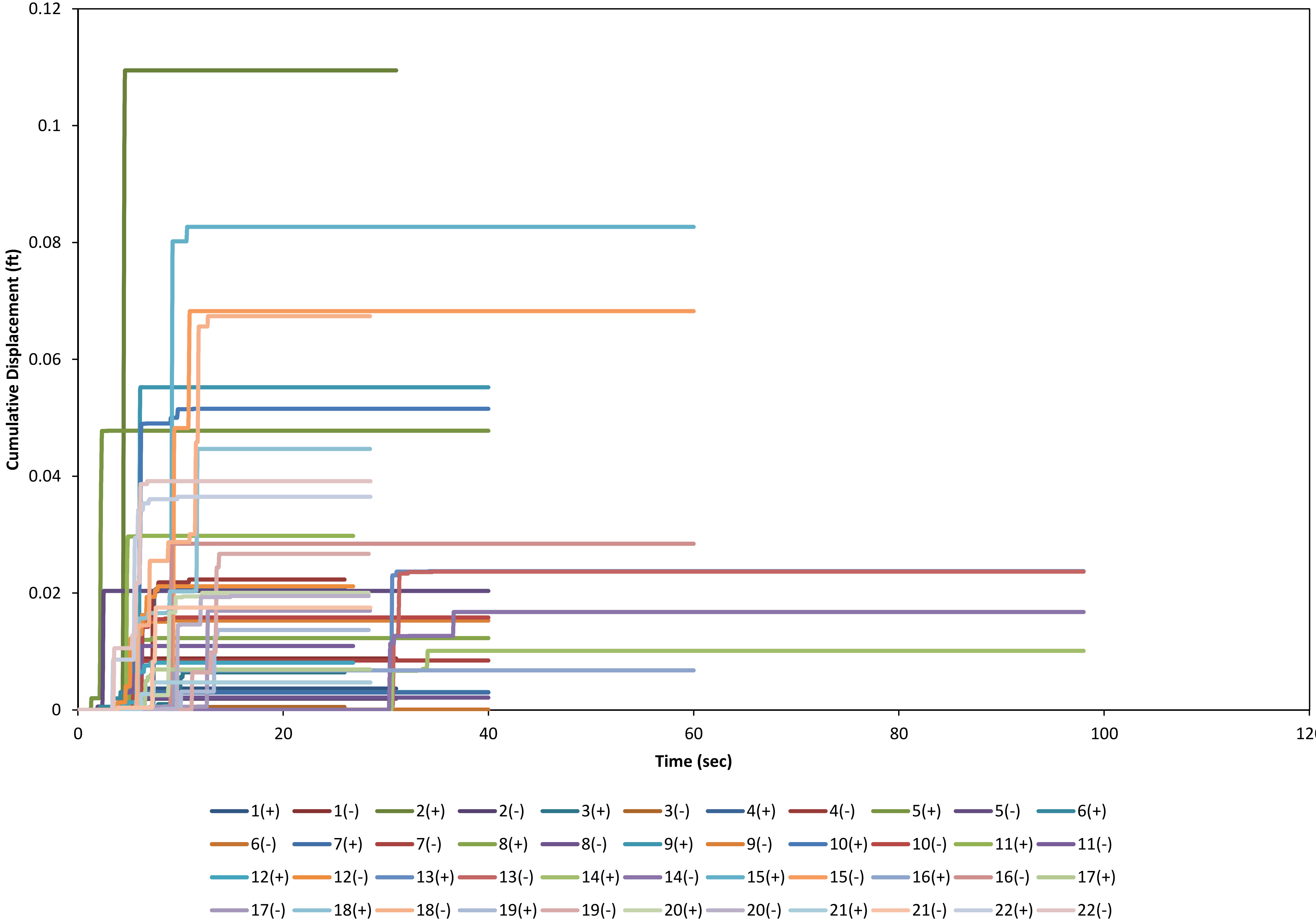



Newmark Displacement Plot: SR1-21+750-Design Event-Design Source-nor-um
Cumulative Displacement (ft)
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0
20
40
60
80
100
120
Time (sec)
1(+) 1(-) 2(+) 2(-) 3(+) 3(-) 4(+) 4(-) 5(+) 5(-) 6(+)
6(-) 7(+) 7(-) 8(+) 8(-) 9(+) 9(-) 10(+) 10(-) 11(+) 11(-)
12(+) 12(-) 13(+) 13(-) 14(+) 14(-) 15(+) 15(-) 16(+) 16(-) 17(+)
17(-) 18(+) 18(-) 19(+) 19(-) 20(+) 20(-) 21(+) 21(-) 22(+) 22(-)

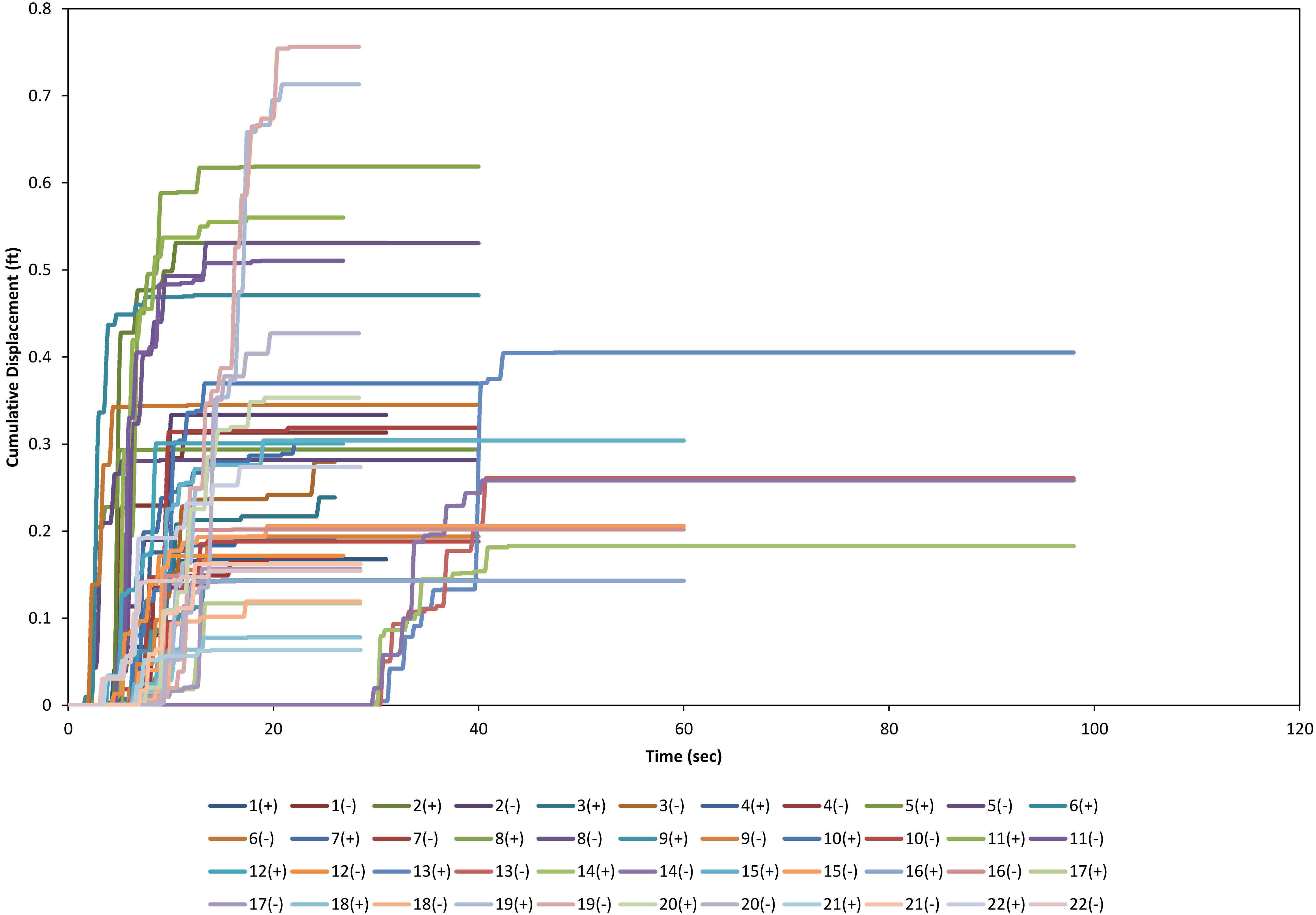
Newmark Displacement Plot: SR1-21+050-Design Event-Design Source-nor-dm



Newmark Displacement Plot: SR1-21+050-Design Event-Design Source-nor-um

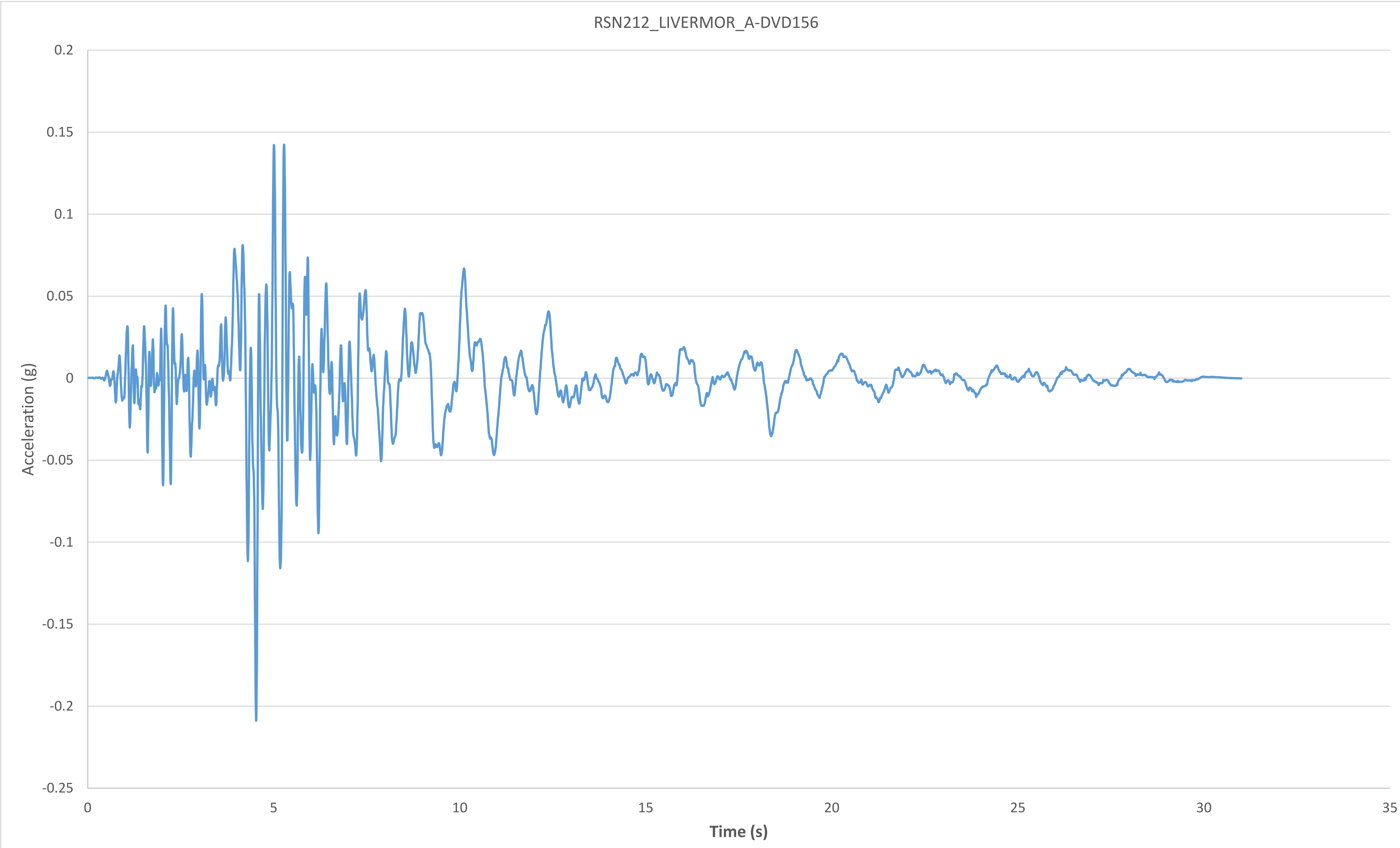


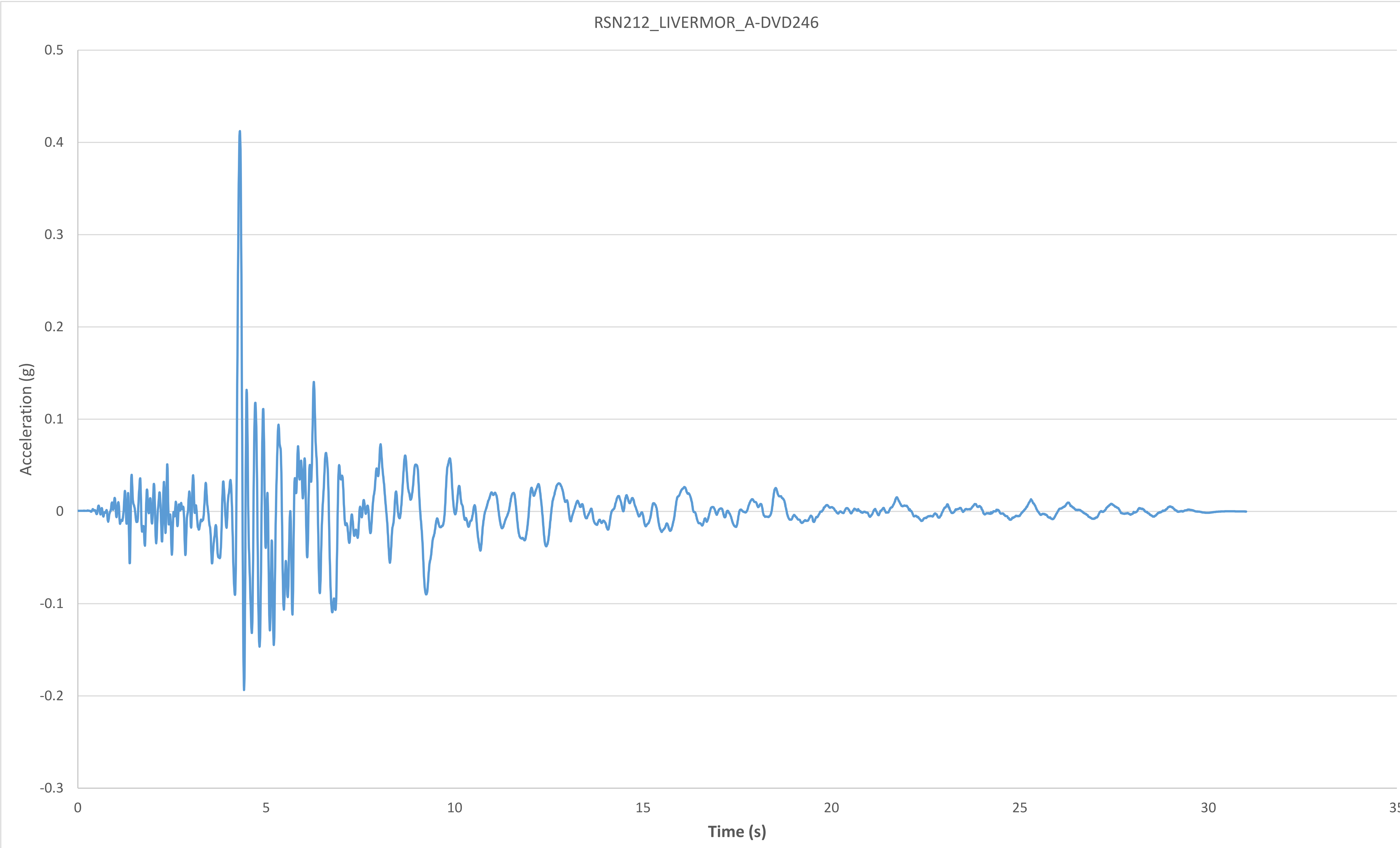
Newmark Displacement Plot: SR1-22+500-Design Event-Design Source-nor-dm

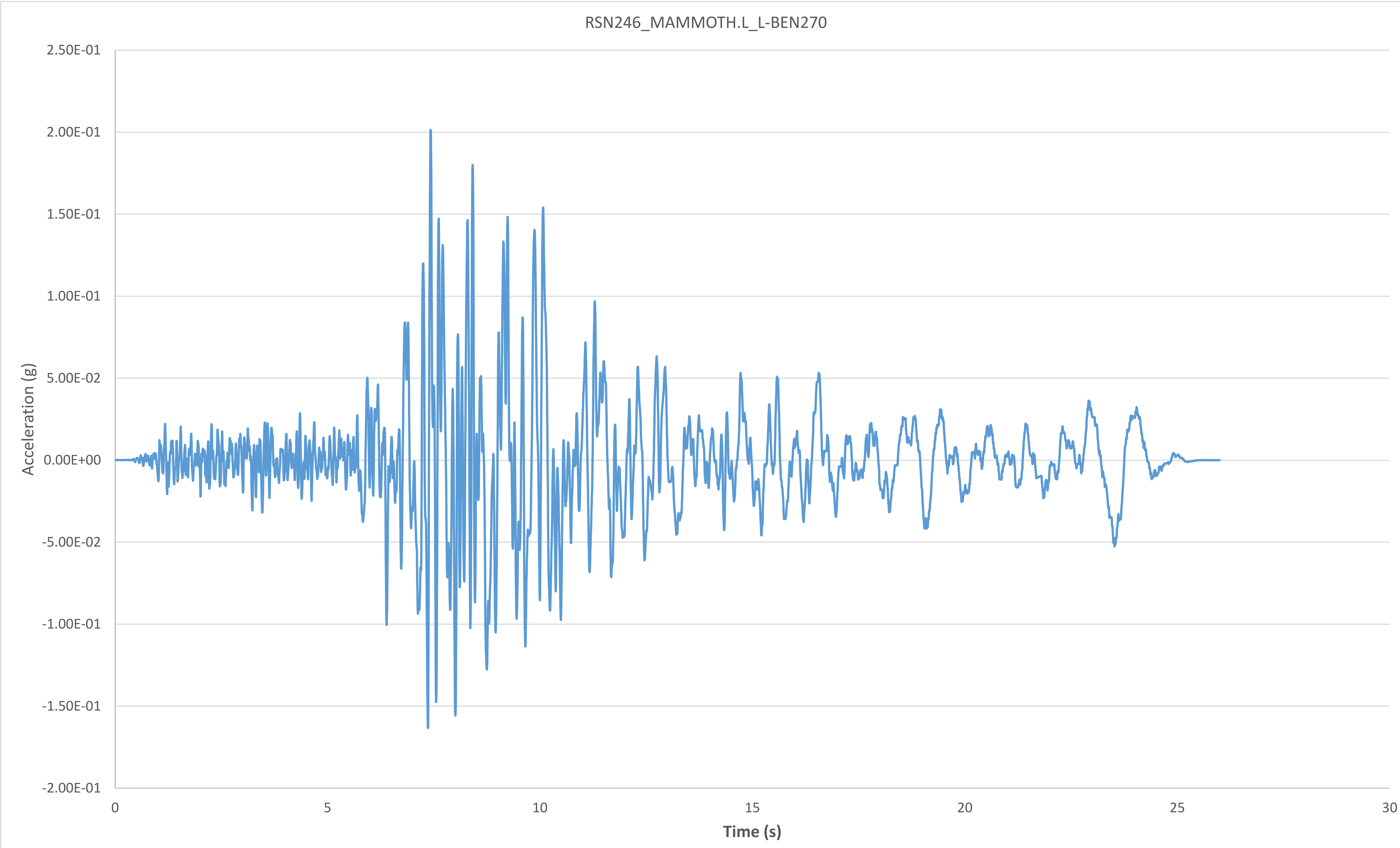


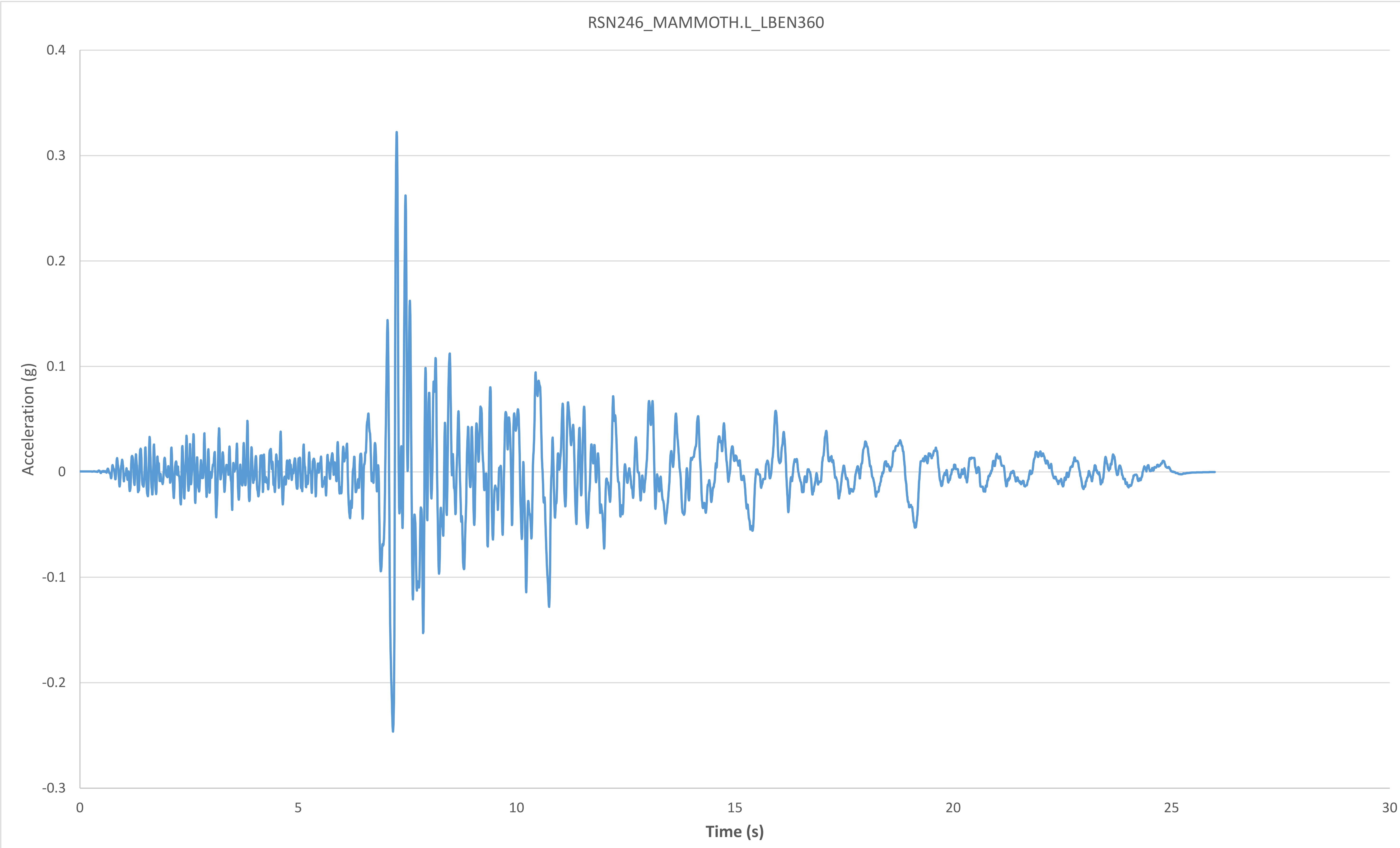
Attachment 12.3
Seismic Analyses

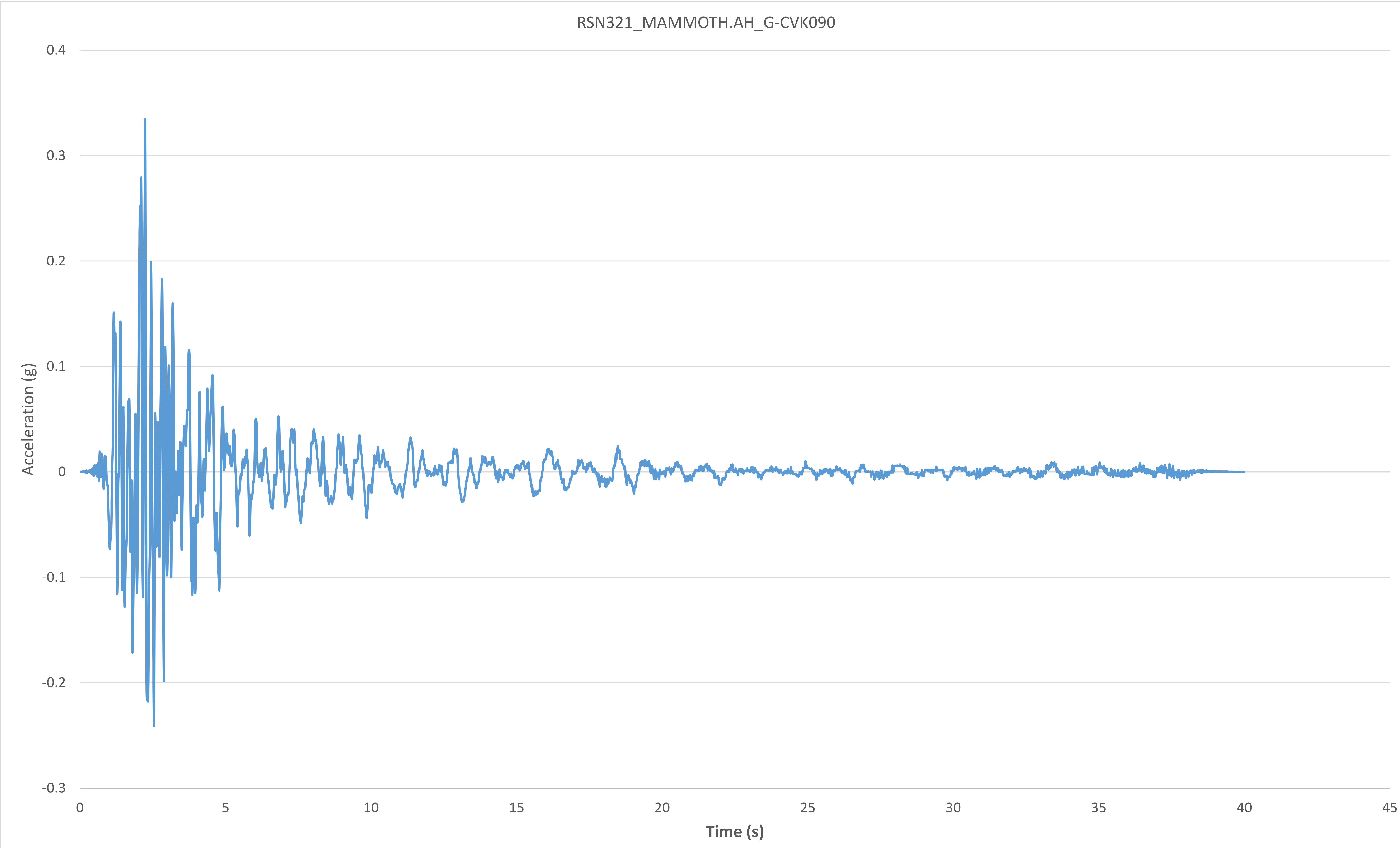
12.3.2 Time Histories

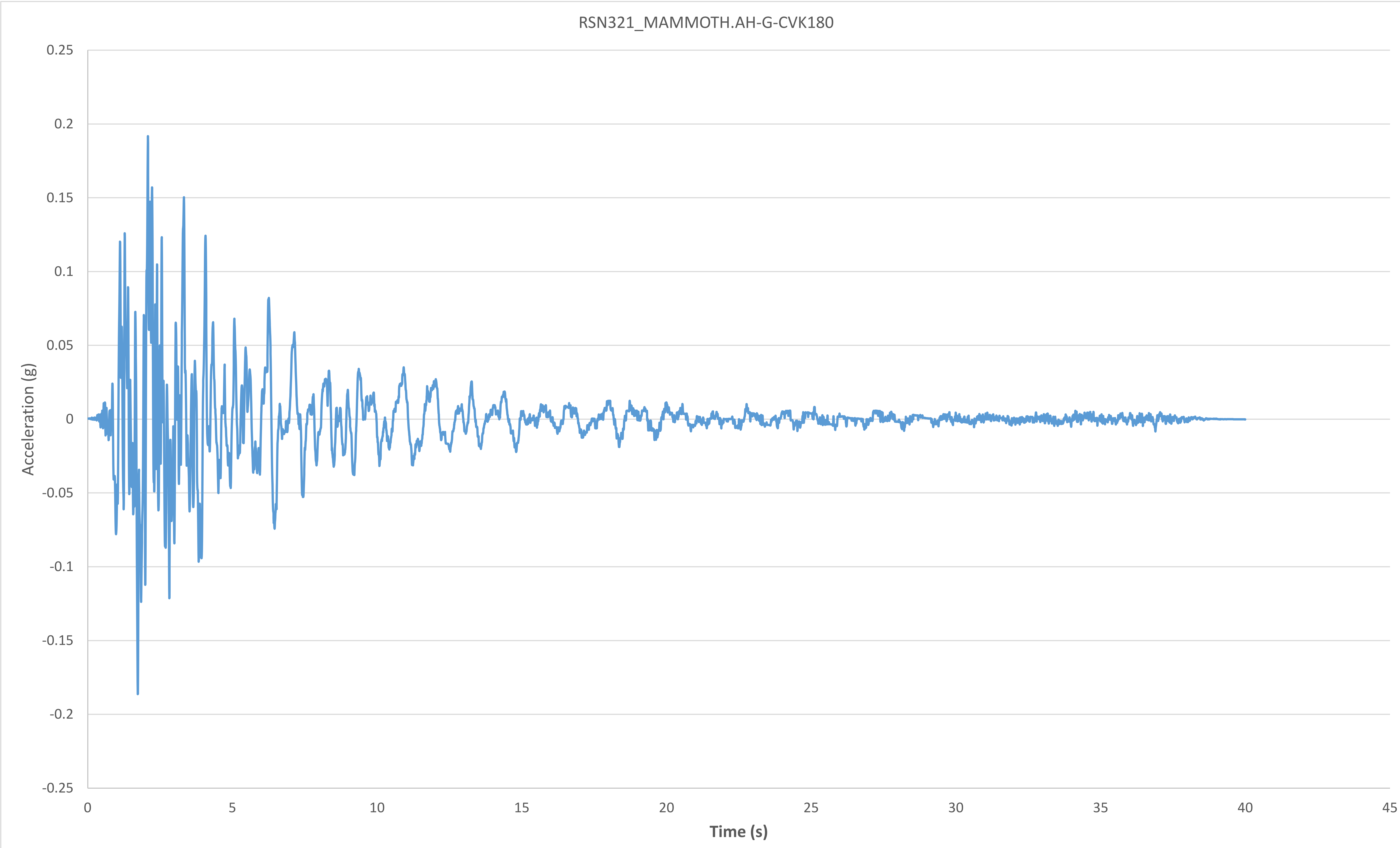

RSN212_LIVERMOR_A-DVD156
0.2
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
-0.2
-0.25
Acceleration (g)
0
5
10
15
20
25
30
35
Time (s)

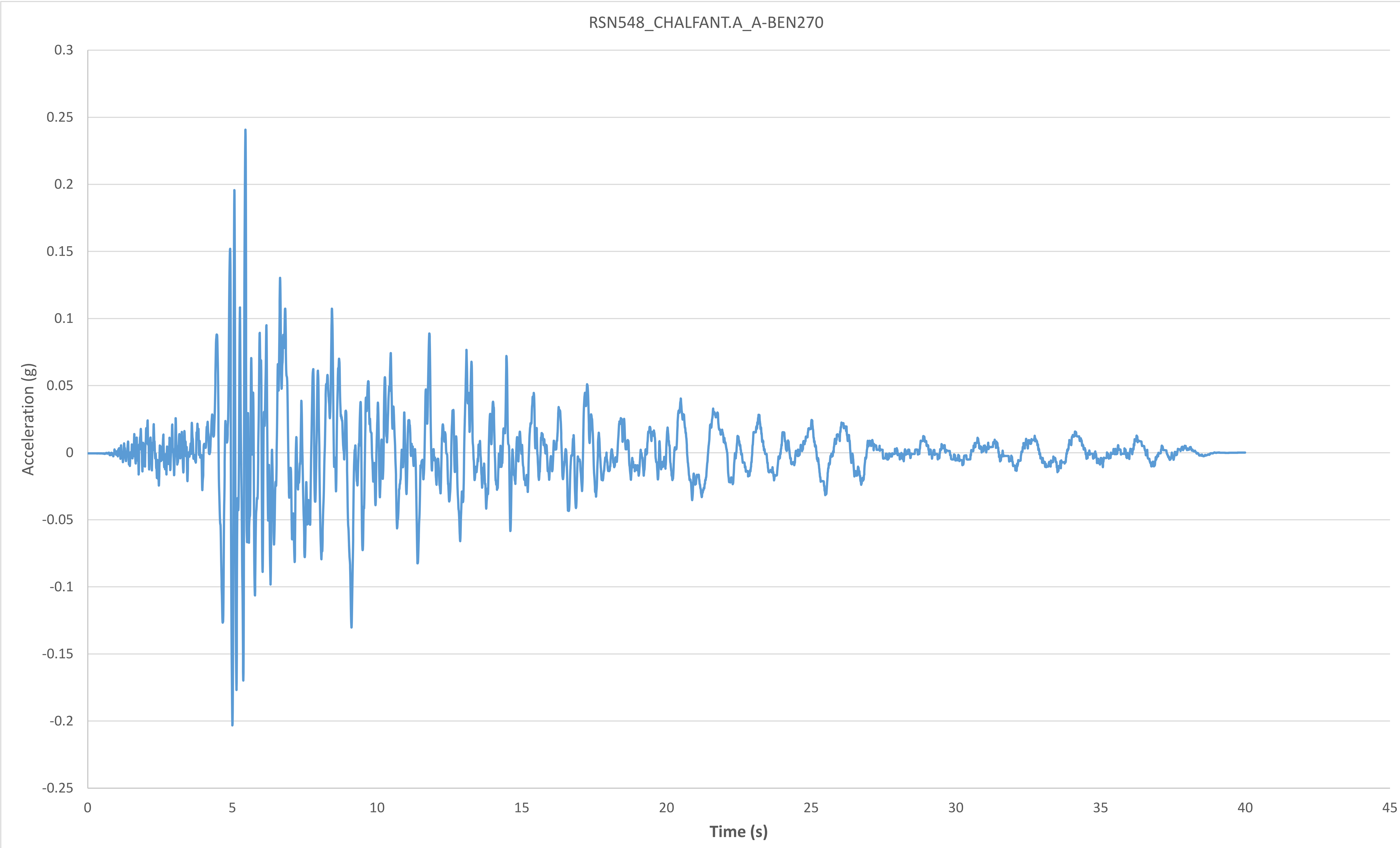

RSN212_LIVERMOR_A-DVD246
Acceleration (g)
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
0
5
10
15
20
25
30
35
Time (s)


RSN246_MAMMOTH.L_L-BEN270
Acceleration (g)
2.50E-01
2.00E-01
1.50E-01
1.00E-01
5.00E-02
0.00E+00
-5.00E-02
-1.00E-01
-1.50E-01
-2.00E-01
0
5
10
15
20
25
30
Time (s)

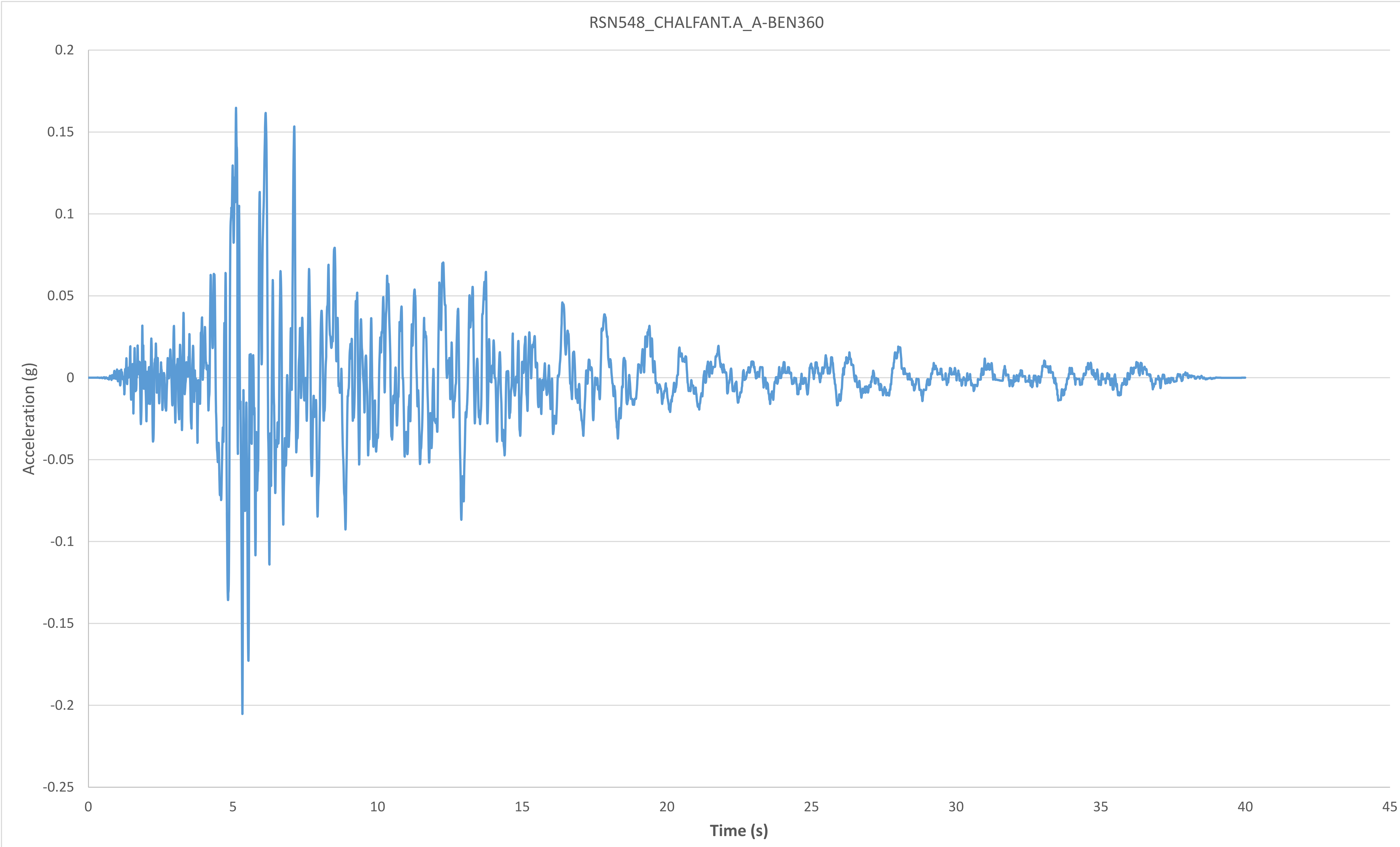

RSN246_MAMMOTH.L_LBEN360
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
Acceleration (g)
0
5
10
15
20
25
30
Time (s)

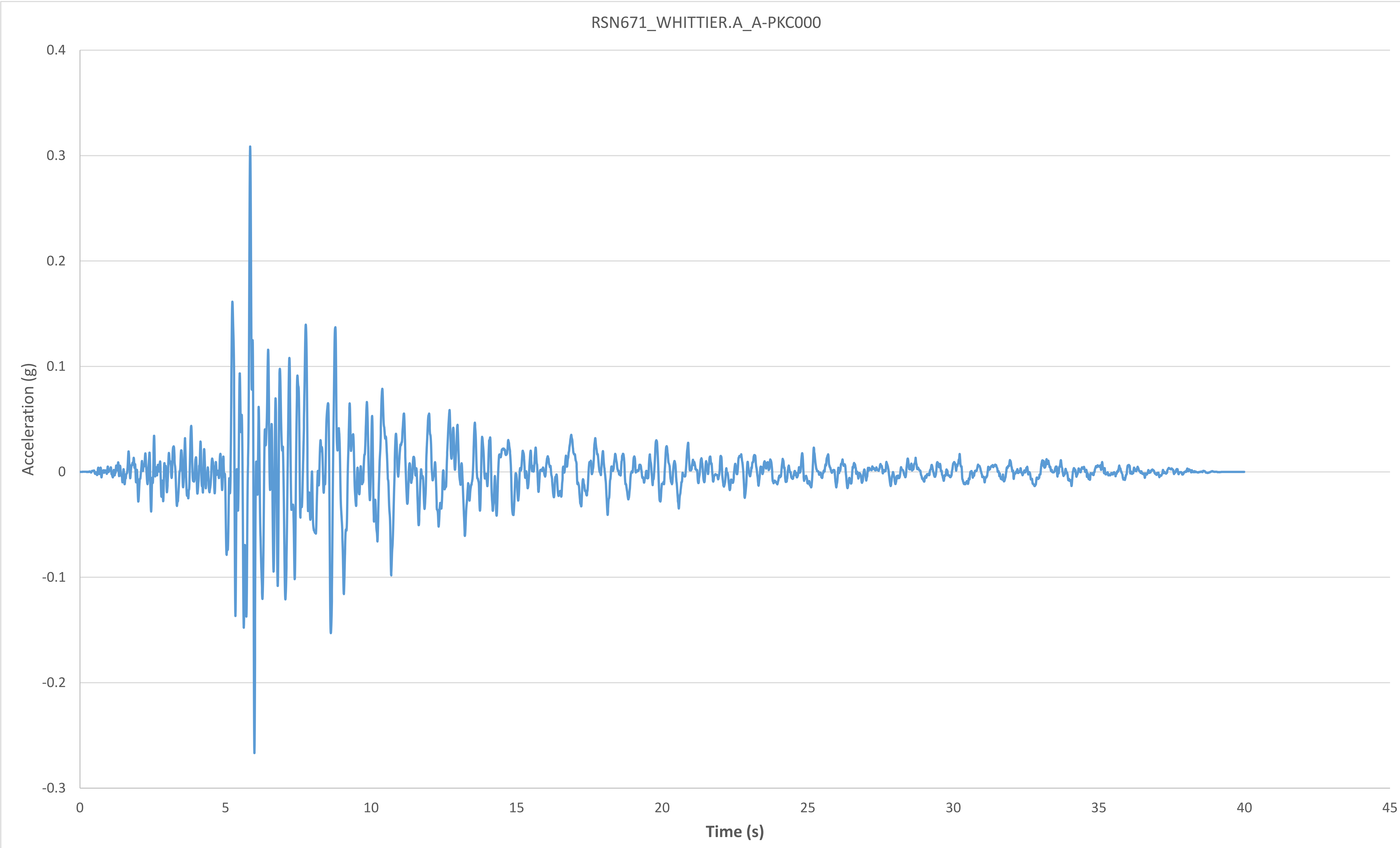

RSN321_MAMMOTH.AH_G-CVK090
Acceleration (g)
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
0
5
10
15
20
25
30
35
40
45
Time (s)

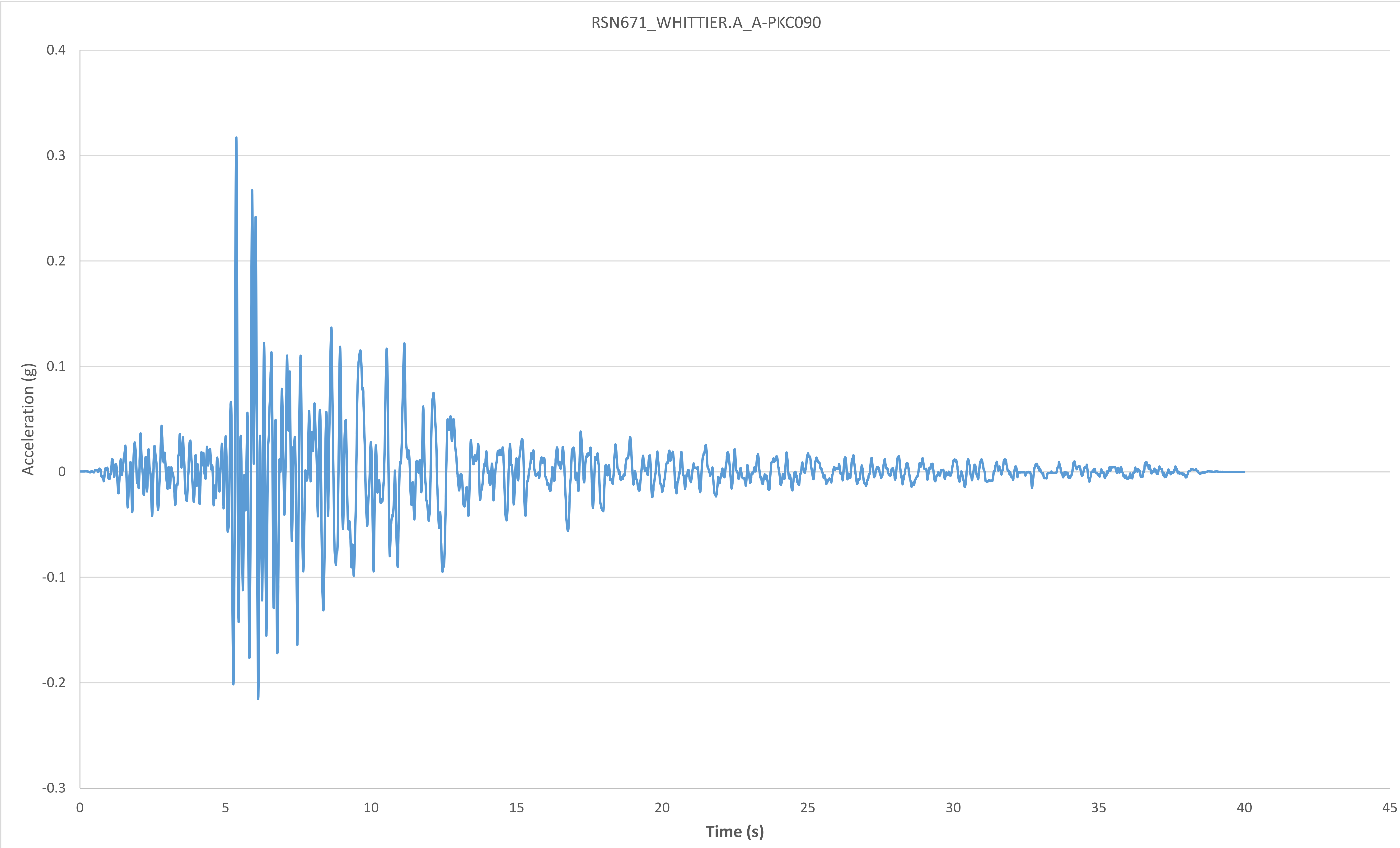

RSN321_MAMMOTH.AH-G-CVK180
Acceleration (g)
0.25
0.2
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
-0.2
-0.25
0
5
10
15
20
25
30
35
40
45
Time (s)

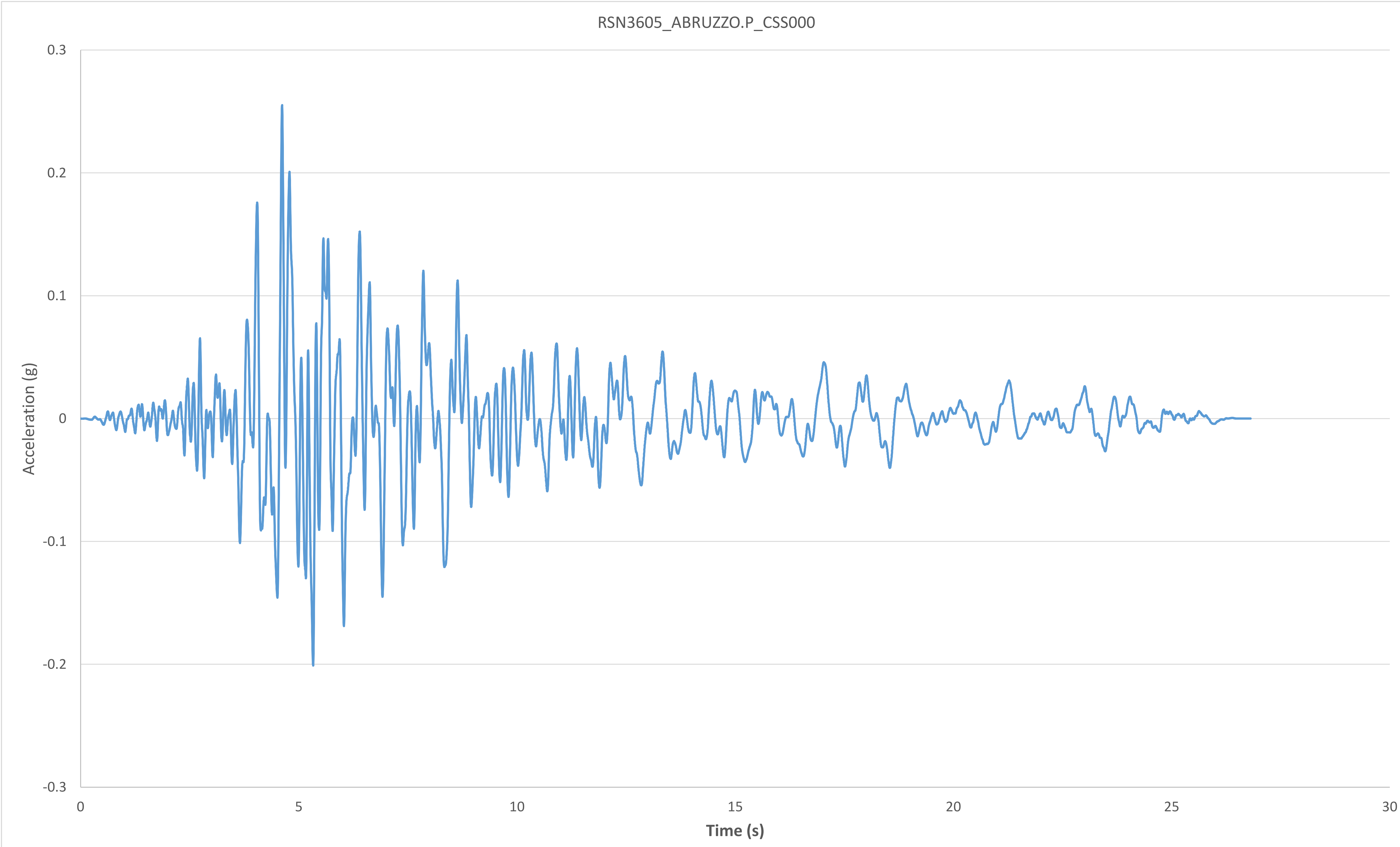


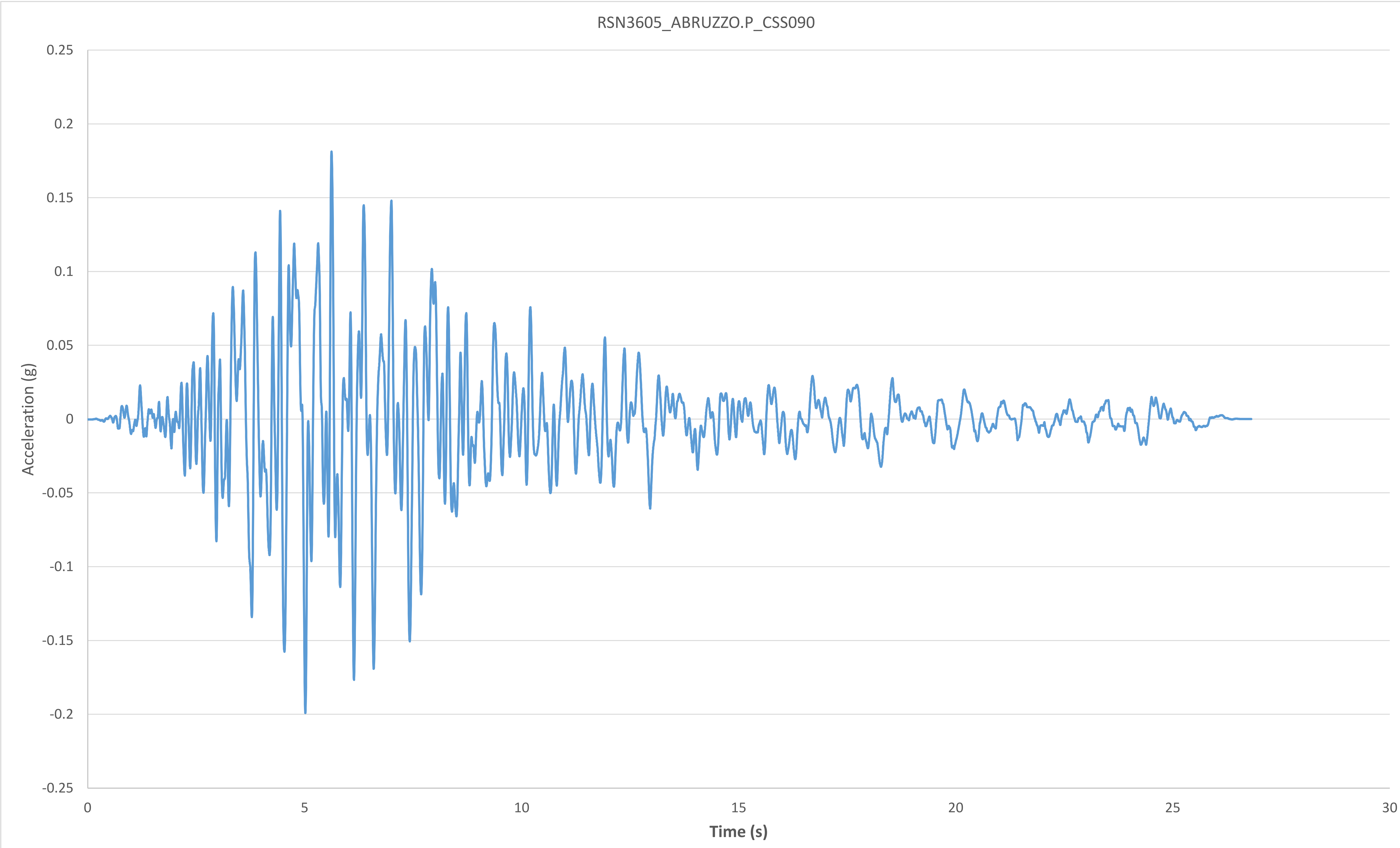
RSN548_CHALFANT.A_A-BEN270
Acceleration (g)
0.3
0.25
0.2
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
-0.2
-0.25
0
5
10
15
20
25
30
35
40
45
Time (s)

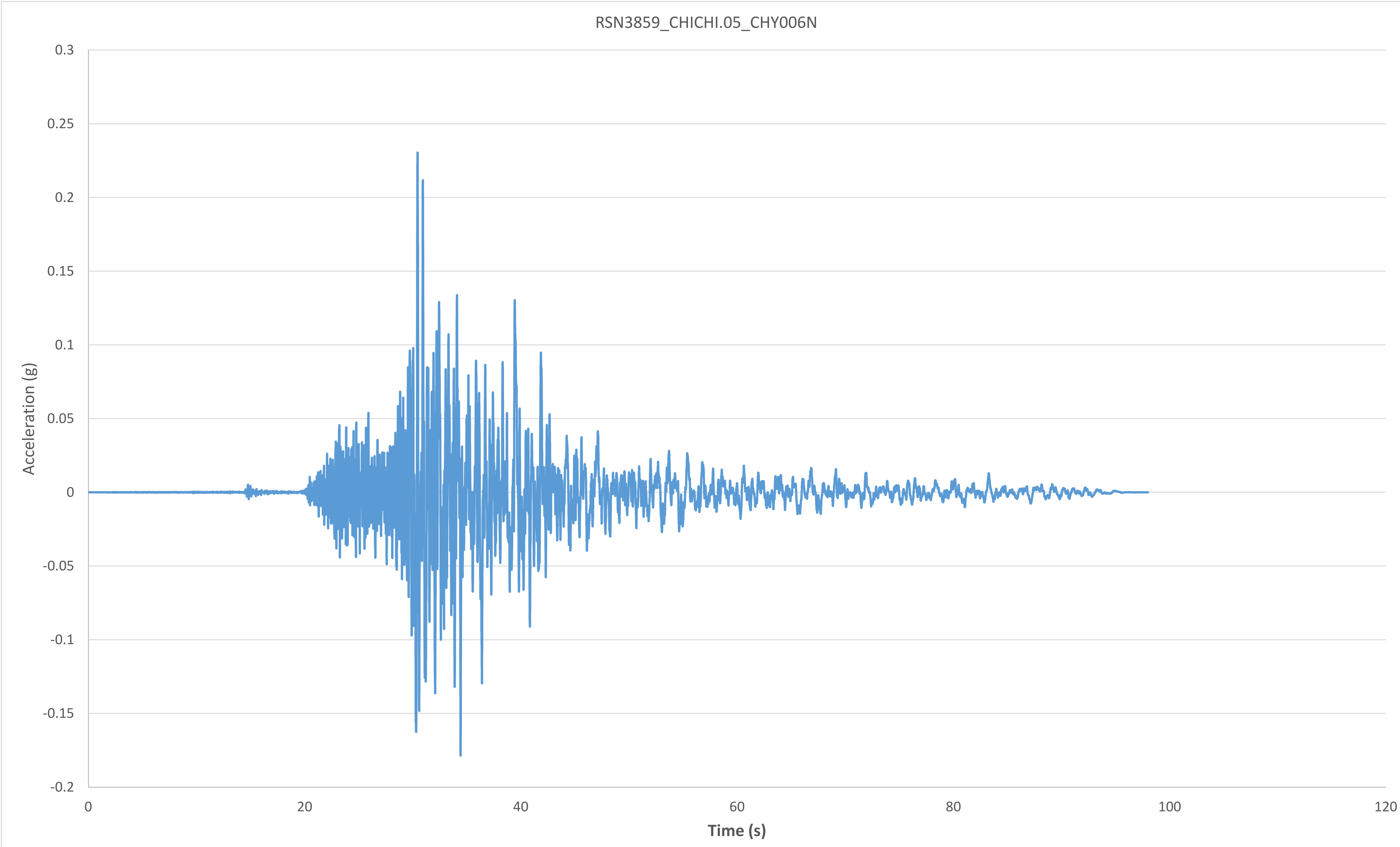

RSN548_CHALFANT.A_A-BEN360
Acceleration (g)
0.2
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
-0.2
-0.25
0
5
10
15
20
25
30
35
40
45
Time (s)

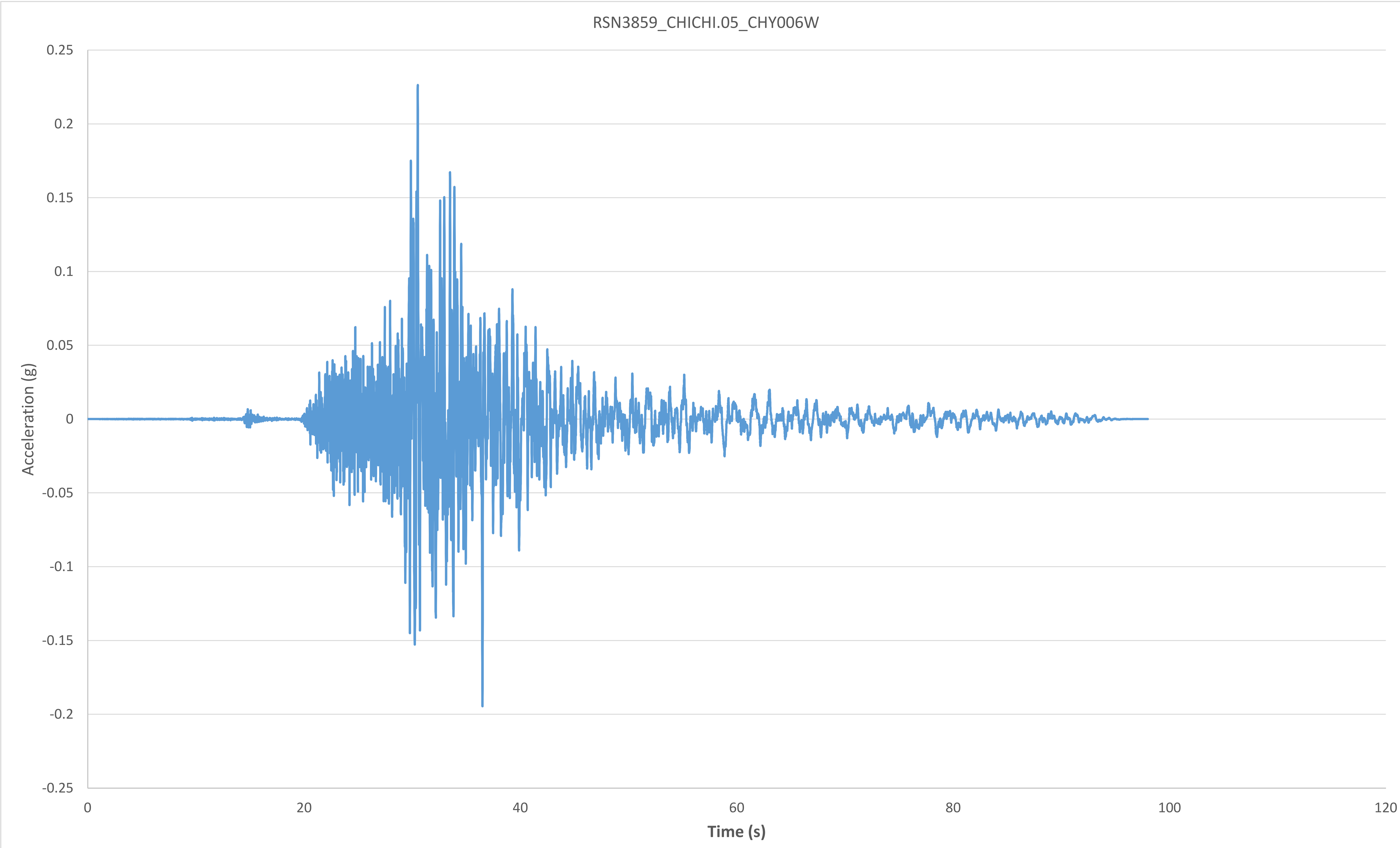

RSN671_WHITTIER.A_A-PKC000
Acceleration (g)
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
0
5
10
15
20
25
30
35
40
45
Time (s)

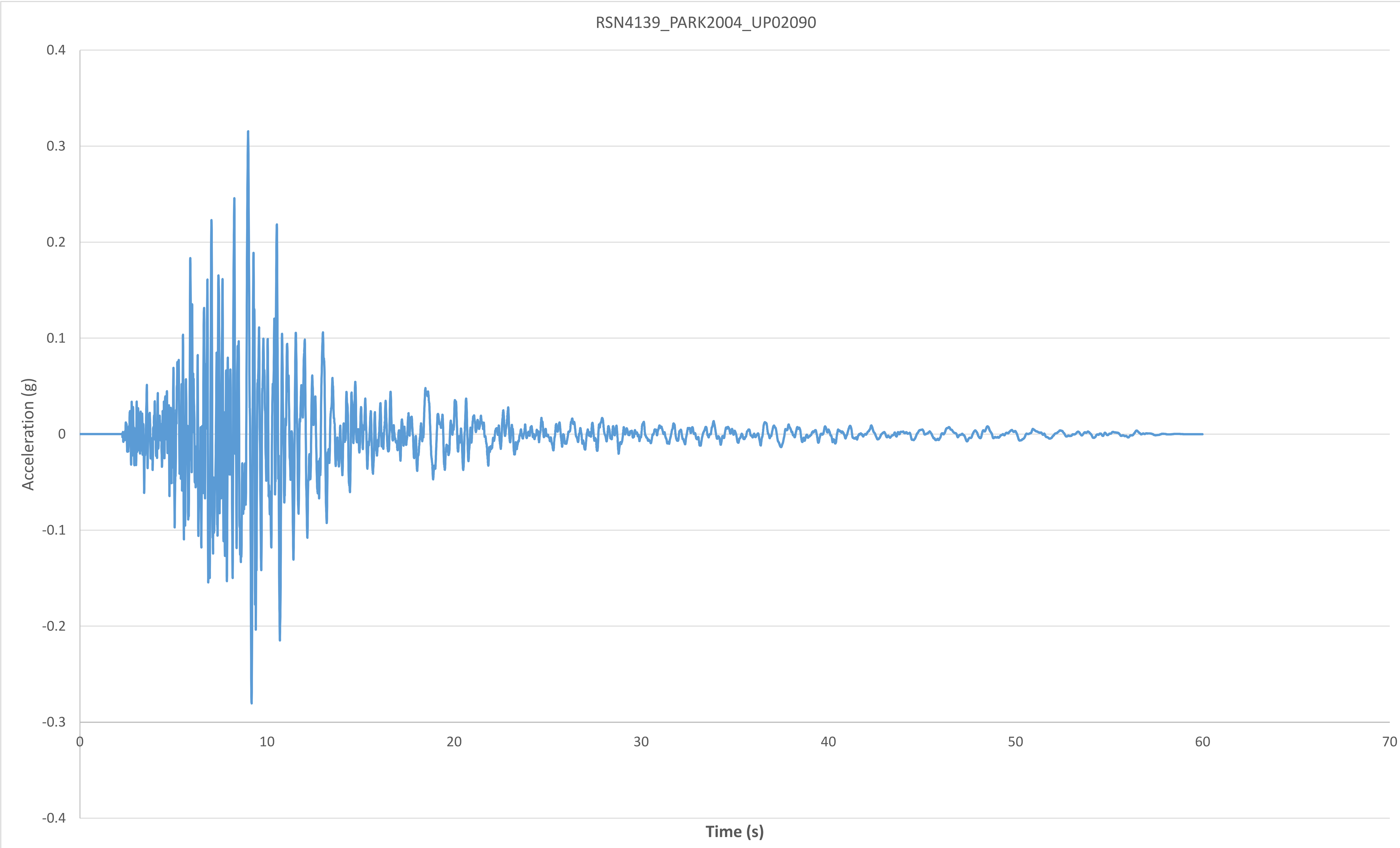

RSN671_WHITTIER.A_A-PKC090
Acceleration (g)
Time (s)
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
0
5
10
15
20
25
30
35
40
45

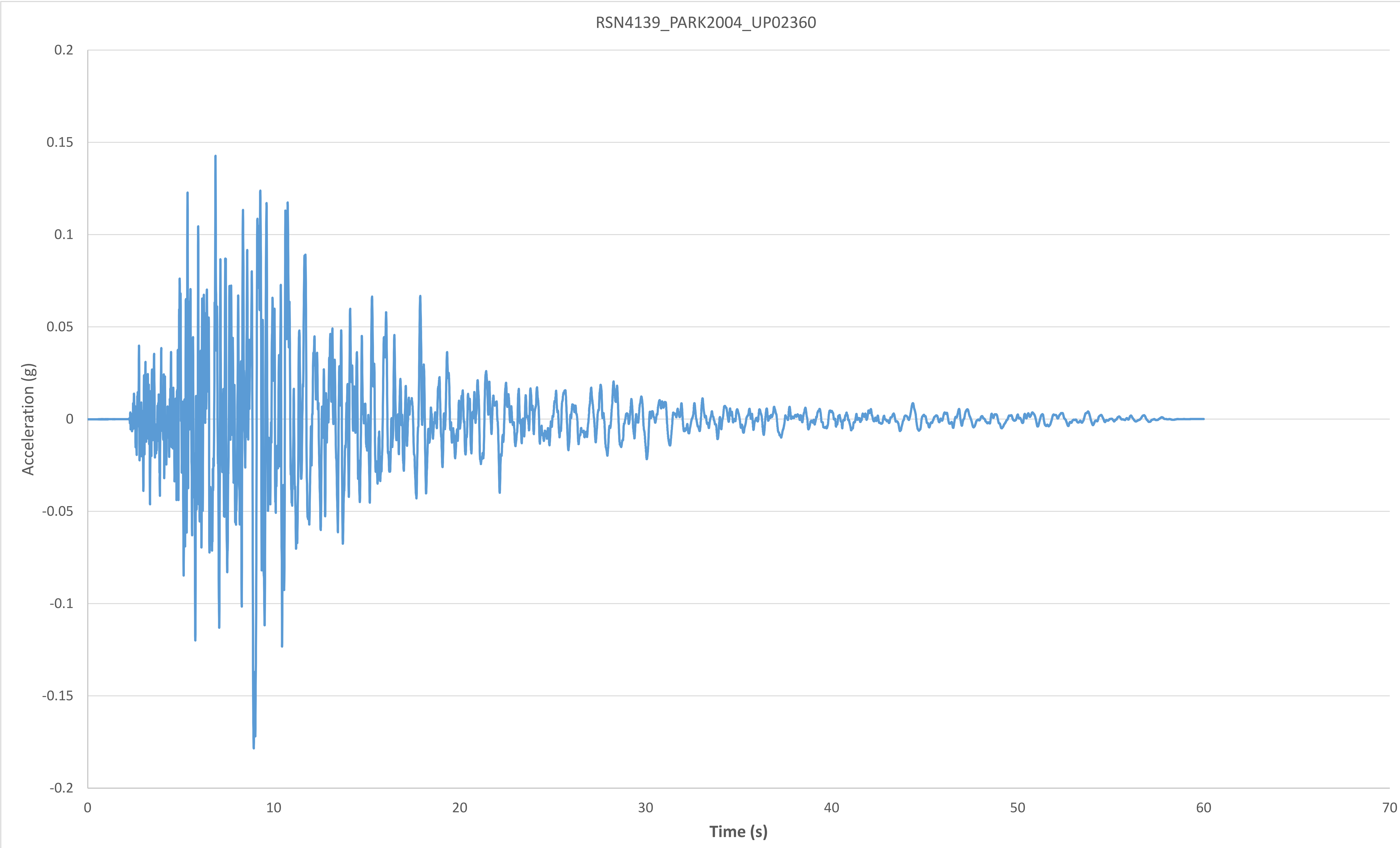

RSN3605_ABRUZZO.P_CSS000
Acceleration (g)
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
0
5
10
15
20
25
30
Time (s)

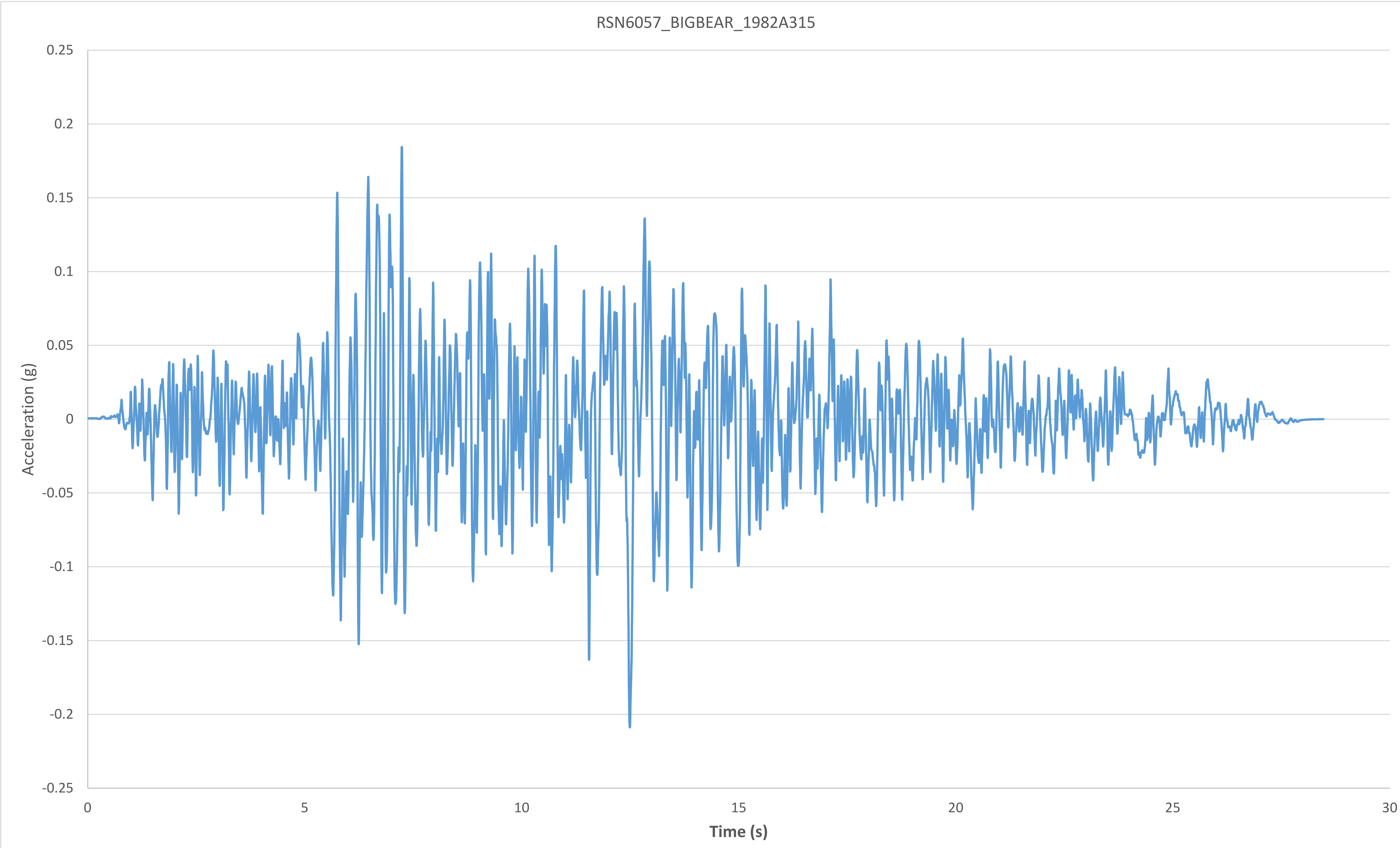

RSN3605_ABRUZZO.P_CSS090
Acceleration (g)
0.25
0.2
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
-0.2
-0.25
0
5
10
15
20
25
30
Time (s)

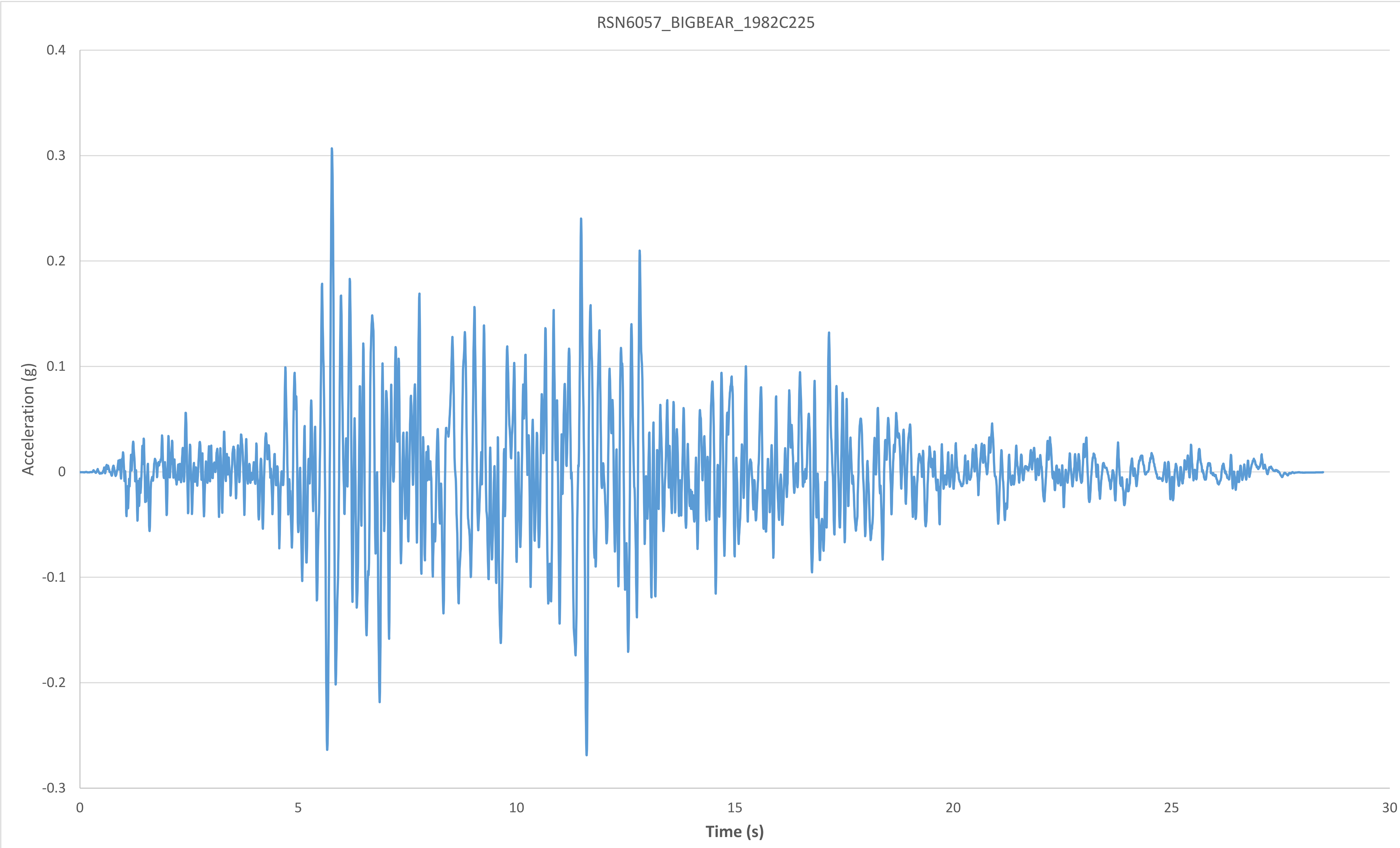

RSN3859_CHICHI.05_CHY006N
Acceleration (g)
0.3
0.25
0.2
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
-0.2
0
20
40
60
80
100
120
Time (s)


RSN3859_CHICHI.05_CHY006W
Acceleration (g)
0.25
0.2
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
-0.2
-0.25
0
20
40
60
80
100
120
Time (s)

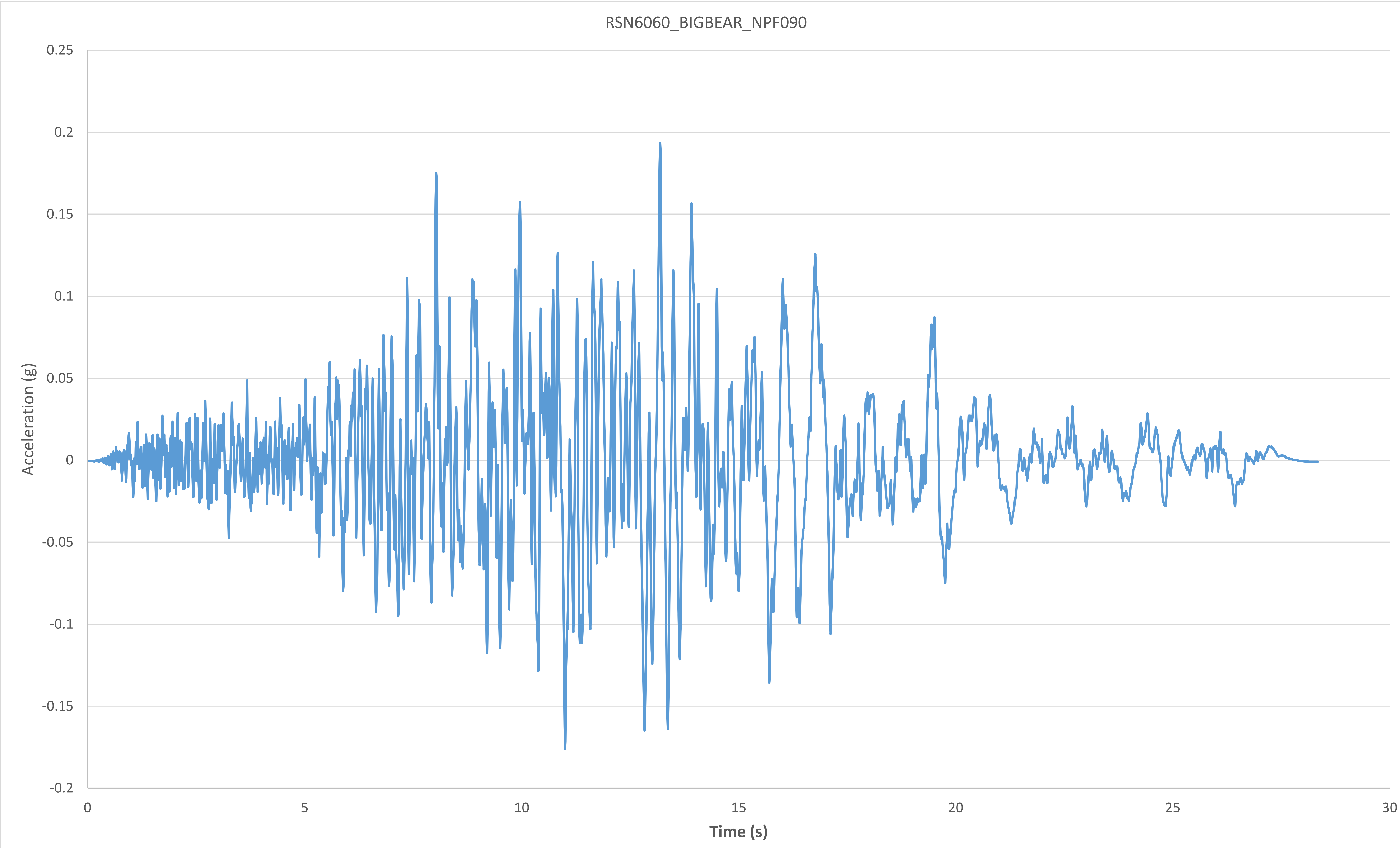

RSN4139_PARK2004_UP02090
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
Acceleration (g)
0
10
20
30
40
50
60
70
Time (s)

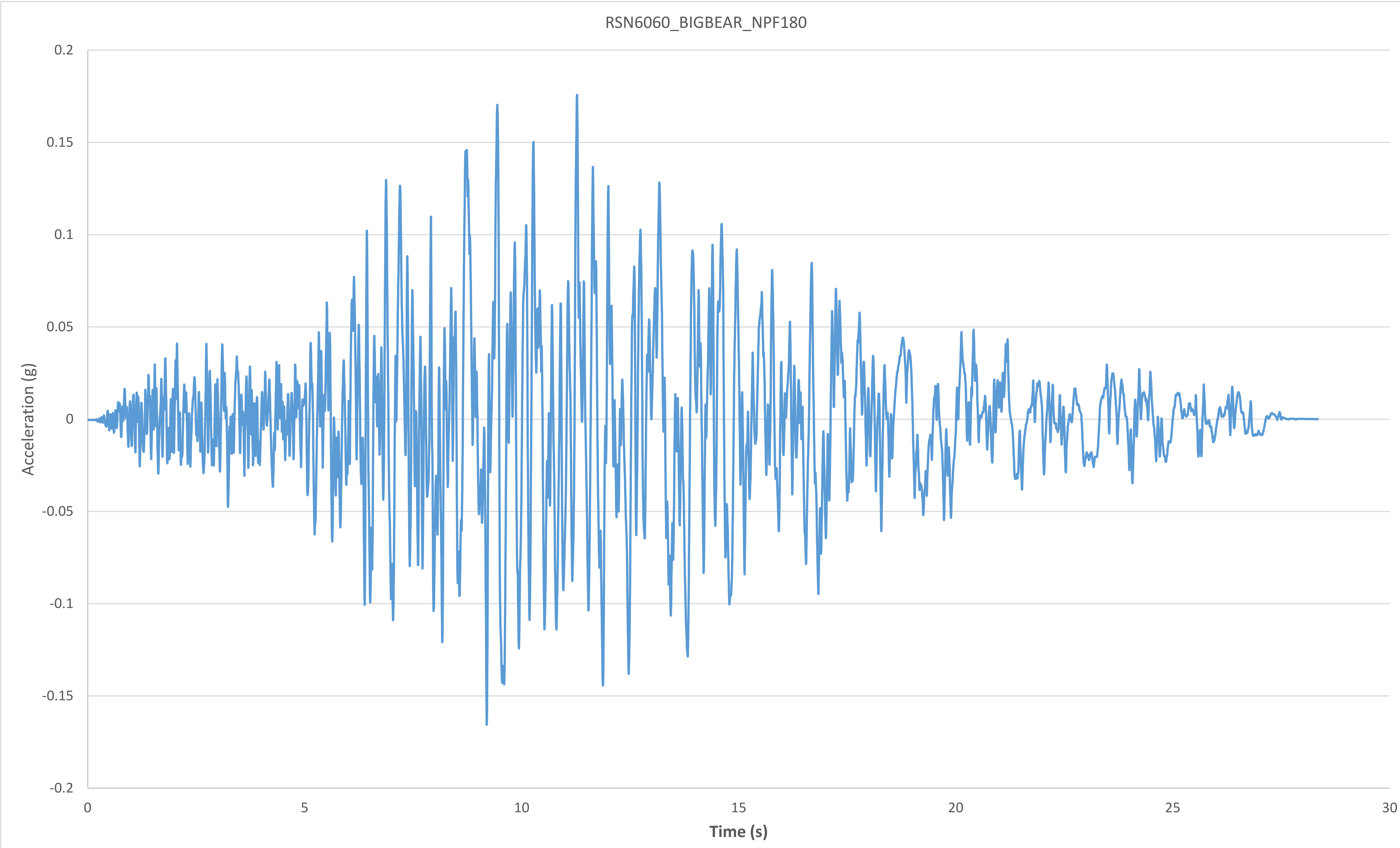

RSN4139_PARK2004_UP02360
Acceleration (g)
0.2
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
-0.2
0
10
20
30
40
50
60
70
Time (s)

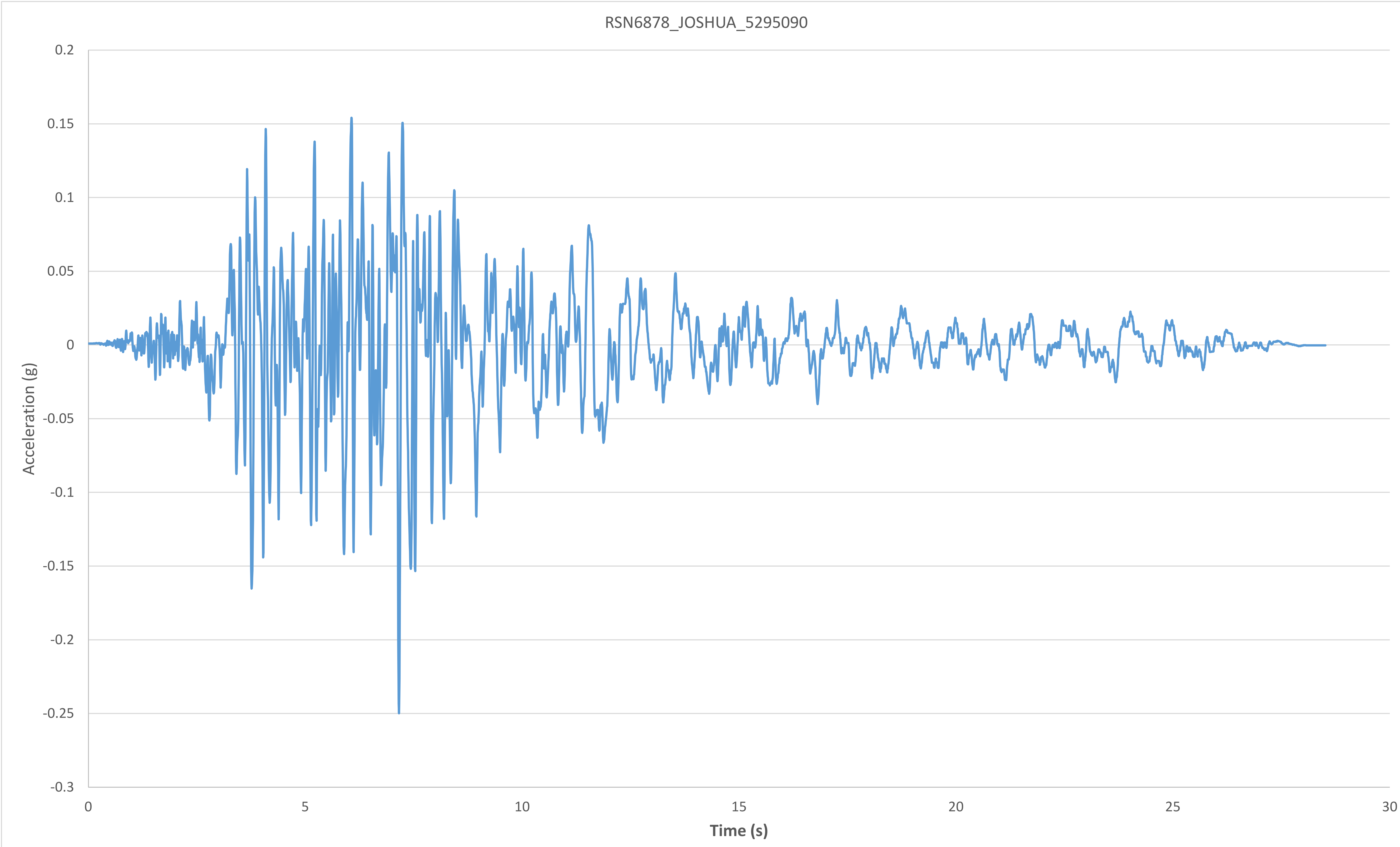

RSN6057_BIGBEAR_1982A315
Acceleration (g)
0.25
0.2
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
-0.2
-0.25
0
5
10
15
20
25
30
Time (s)



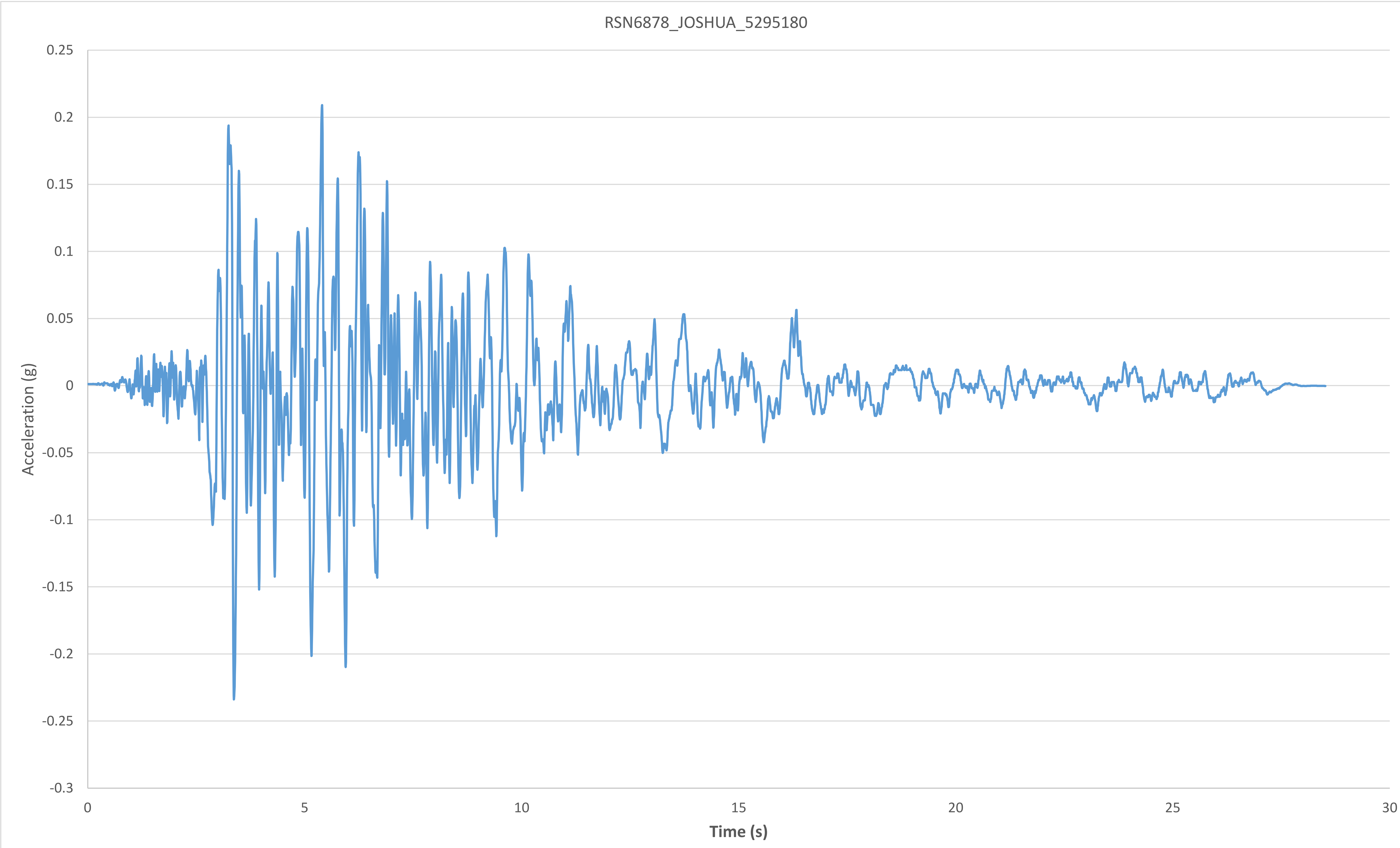
RSN6057_BIGBEAR_1982C225
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
Acceleration (g)
0
5
10
15
20
25
30
Time (s)


RSN6060_BIGBEAR_NPF090
Acceleration (g)
0.25
0.2
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
-0.2
0
5
10
15
20
25
30
Time (s)


RSN6060_BIGBEAR_NPF180
Acceleration (g)
0.2
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
-0.2
0
5
10
15
20
25
30
Time (s)



RSN6878_JOSHUA_5295090
Acceleration (g)
0.2
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
-0.2
-0.25
-0.3
0
5
10
15
20
25
30
Time (s)



RSN6878_JOSHUA_5295180
0.25
0.2
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
-0.2
-0.25
-0.3
Acceleration (g)
0
5
10
15
20
25
30
Time (s)

Attachment 12.3
Seismic Analyses

12.3.3 Yield Acceleration Analysis

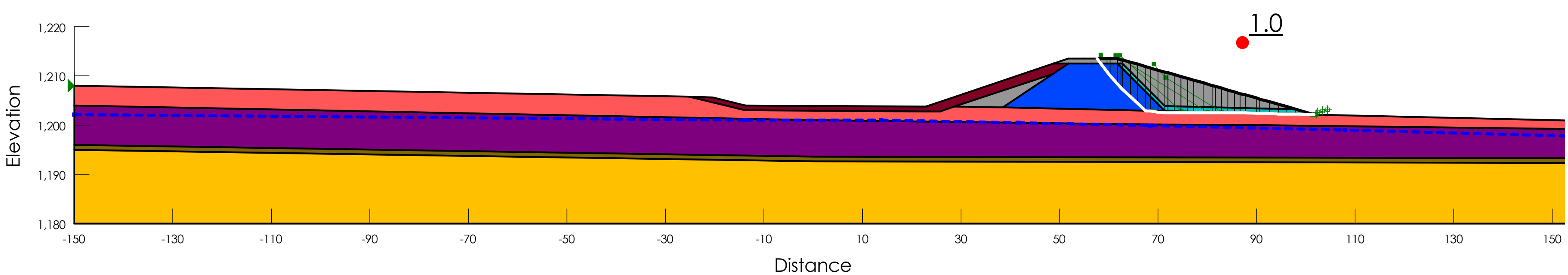
Stantec

Alberta Transportation SR1 Storage Dam

Section 20+000
Load Case: Yield Acceleration
Pseudostatic Parameters
Incipient Motion in the Downstream Direction

Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)	Cohesion R (kPa)	Phi R (°)
	Drain	21		0				33	0	0
	Embankment Core (EQ/Pseudo)	20		0	28	15	243			
	Embankment Shell (EQ/Pseudo)	20		0	24	12	86			
	Glacial Till (EQ/Pseudo)	18		0	27	15	199			
	Glacio-Lacustrine (EQ/Pseudo)	18	Glacio-Lacustrine (Seismic)					0	0	0
	Rock Toe	20		0				33	0	0
	Sandstone									
	Weathered Bedrock	21		0				35	0	0

Yield Acceleration = 0.14 g

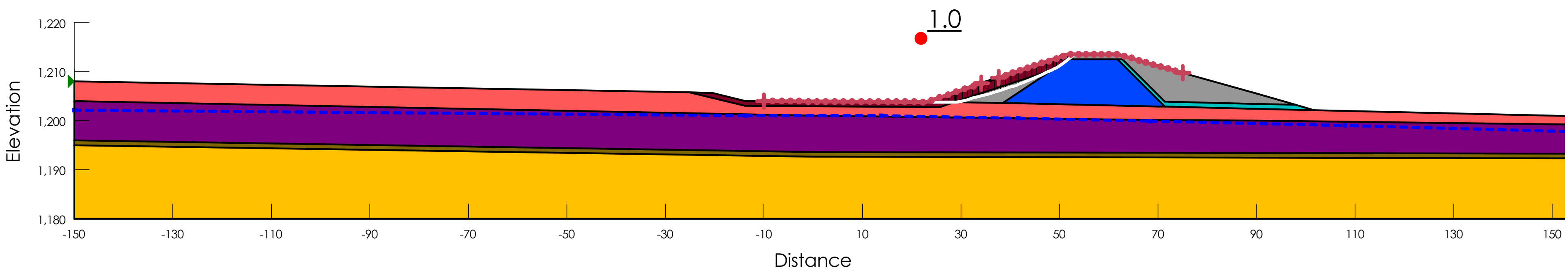


Alberta Transportation SR1 Storage Dam

Section 20+000
Load Case: Yield Acceleration
Pseudostatic Parameters
Incipient Motion in the Upstream Direction

Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)	Cohesion R (kPa)	Phi R (°)
	Drain	21		0				33	0	0
	Embankment Core (EQ/Pseudo)	20		0	28	15	243			
	Embankment Shell (EQ/Pseudo)	20		0	24	12	86			
	Glacial Till (EQ/Pseudo)	18		0	27	15	199			
	Glacio-Lacustrine (EQ/Pseudo)	18	Glacio-Lacustrine (Seismic)					0	0	0
	Rock Toe	20		0				33	0	0
	Sandstone									
	Weathered Bedrock	21		0				35	0	0

Yield Acceleration = 0.17 g

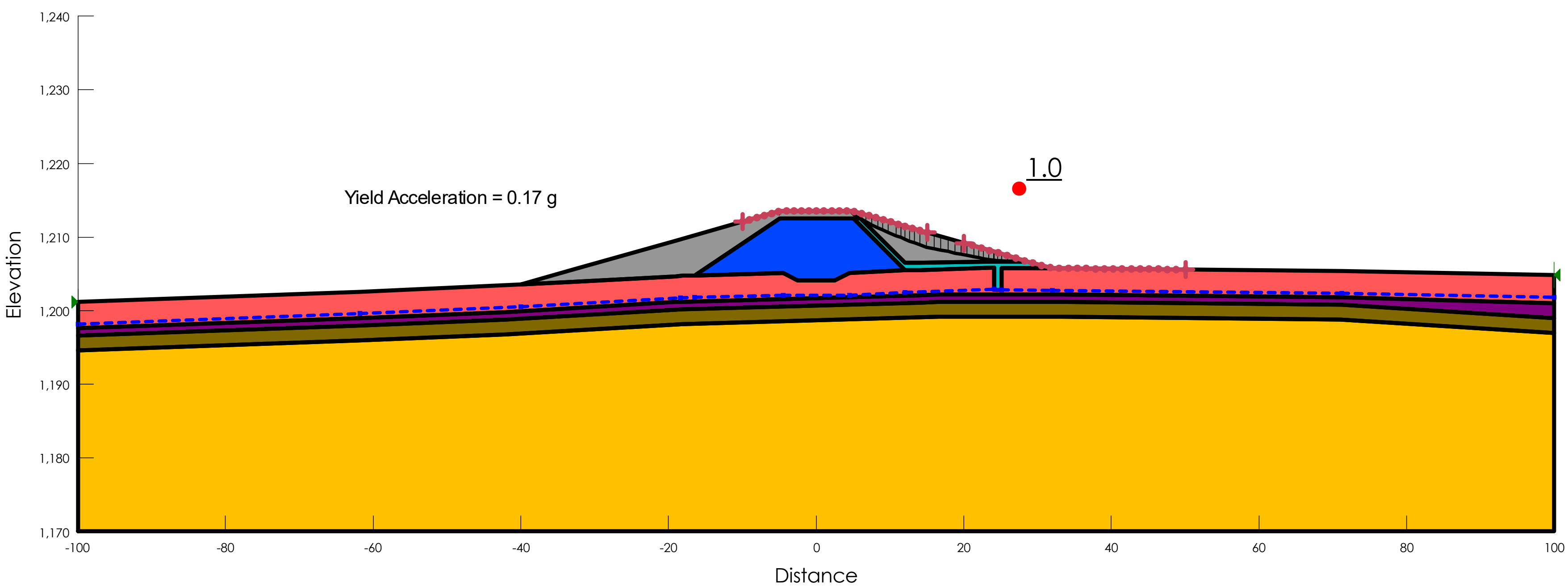


Stantec

Alberta Transportation SR1 Storage Dam

Section 21+050
Load Case: Yield Acceleration
Pseudostatic Parameters
Incipient Motion in the Downstream Direction

Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)	Cohesion R (kPa)	Phi R (°)
	Drain	21		0				30	0	0
	Embankment Core (EQ/Pseudo)	20		0	28	15	243			
	Embankment Shell (EQ/Pseudo)	20		0	24	12	86			
	Glacial Till (EQ/Pseudo)	18		0	27	15	199			
	Glacio-Lacustrine (EQ/Pseudo)	18	Glacio-Lacustrine (Seismic)					0	0	0
	Sandstone									
	Weathered Bedrock	21		0				35	0	0

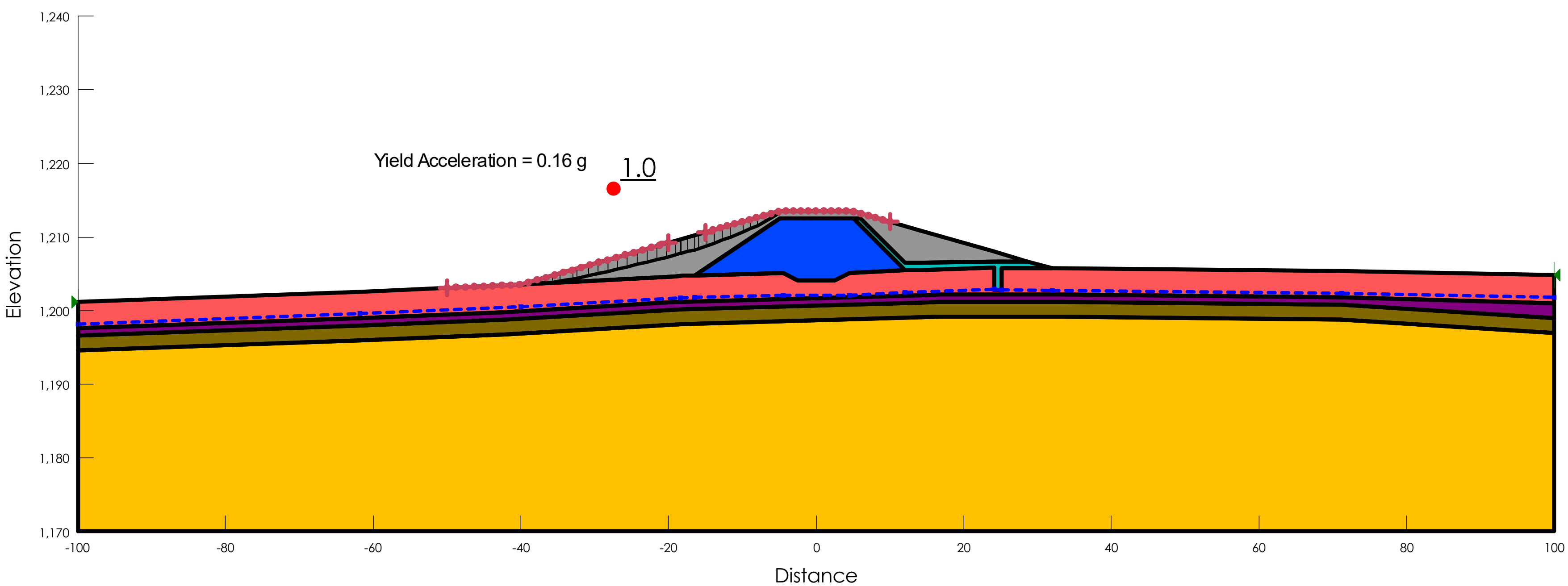


Stantec

Alberta Transportation SR1 Storage Dam

Section 21+050
Load Case: Yield Acceleration
Pseudostatic Parameters
Incipient Motion in the Upstream Direction

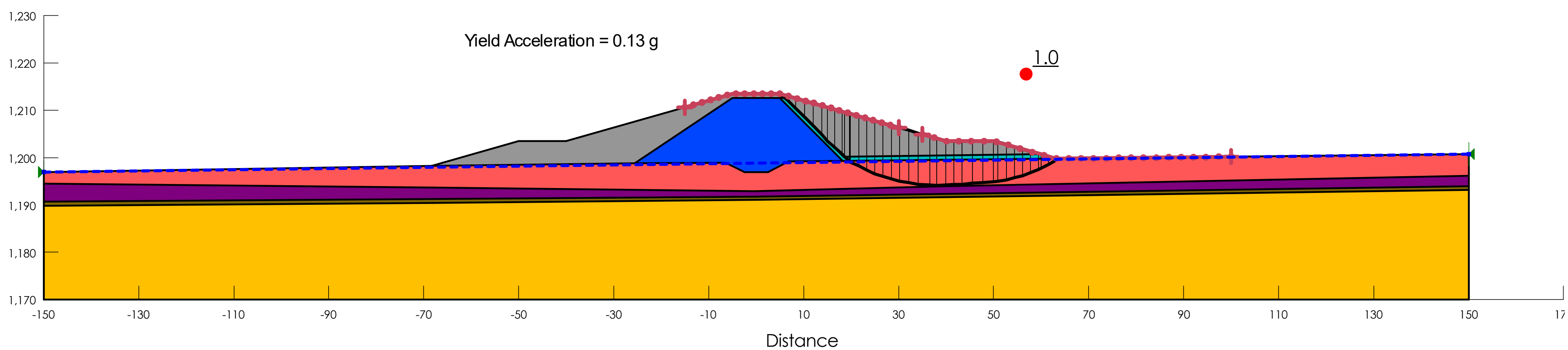
Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)	Cohesion R (kPa)	Phi R (°)
	Drain	21		0				30	0	0
	Embankment Core (EQ/Pseudo)	20		0	28	15	243			
	Embankment Shell (EQ/Pseudo)	20		0	24	12	86			
	Glacial Till (EQ/Pseudo)	18		0	27	15	199			
	Glacio-Lacustrine (EQ/Pseudo)	18	Glacio-Lacustrine (Seismic)					0	0	0
	Sandstone									
	Weathered Bedrock	21		0				35	0	0



Alberta Transportation SR1 Storage Dam

Section 21+750
Load Case: Yield Acceleration
Pseudostatic Parameters Parameters
Incipient Motion in the Downstream Direction

Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)	Cohesion R (kPa)	Phi R (°)
	Drain	21		0				33	0	0
	Embankment Core (EQ/Pseudo)	20		0	28	15	243			
	Embankment Shell (EQ/Pseudo)	20		0	24	12	86			
	Glacial Till (EQ/Pseudo)	18		0	27	15	199			
	Glacio-Lacustrine (EQ/Pseudo)	18	Glacio-Lacustrine (Seismic)					0	0	0
	Sandstone									
	Weathered Bedrock	21		0				35	0	0

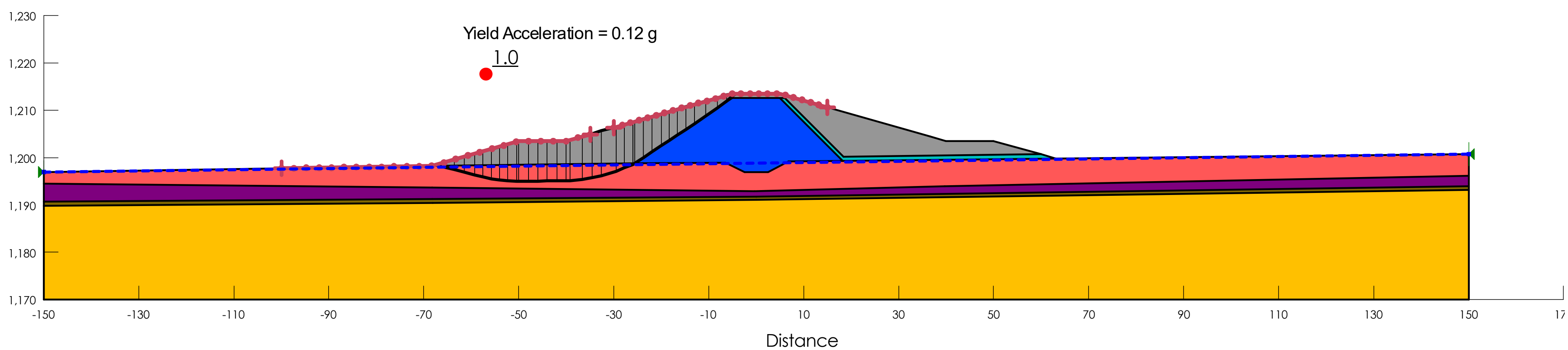


Stantec

Alberta Transportation SR1 Storage Dam

Section 21+750
Load Case: Yield Acceleration
Pseudostatic Parameters Parameters
Incipient Motion in the Upstream Direction

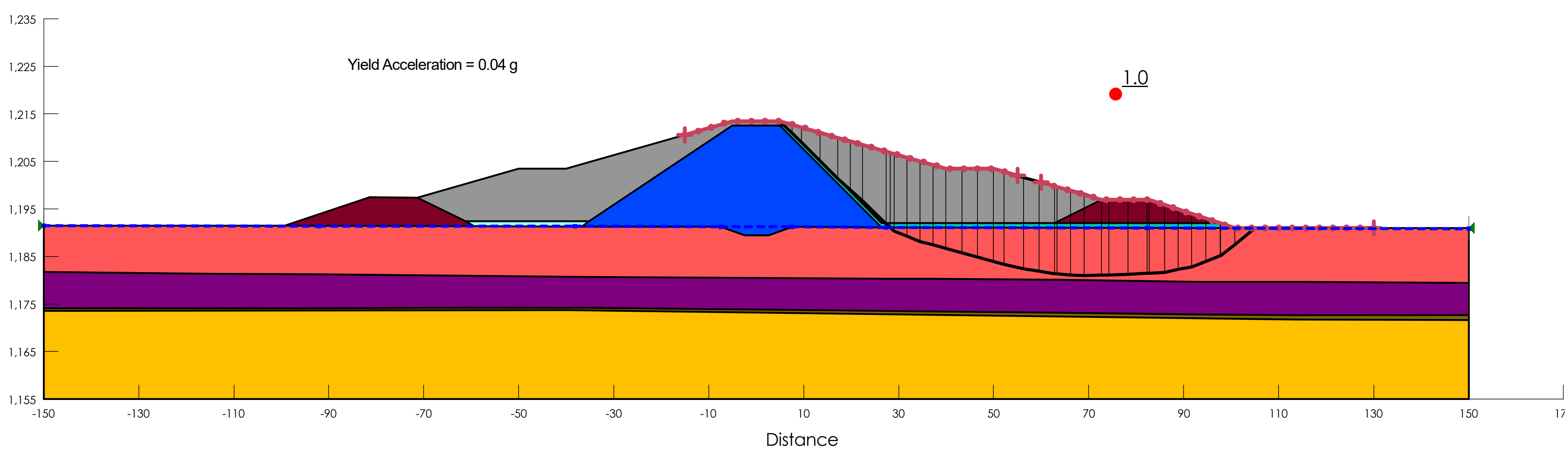
Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)	Cohesion R (kPa)	Phi R (°)
	Drain	21		0				33	0	0
	Embankment Core (EQ/Pseudo)	20		0	28	15	243			
	Embankment Shell (EQ/Pseudo)	20		0	24	12	86			
	Glacial Till (EQ/Pseudo)	18		0	27	15	199			
	Glacio-Lacustrine (EQ/Pseudo)	18	Glacio-Lacustrine (Seismic)					0	0	0
	Sandstone									
	Weathered Bedrock	21		0				35	0	0



Alberta Transportation SR1 Storage Dam

Section 22+500
Load Case: Yield Acceleration
Pseudostatic Parameters
Incipient Motion in the Downstream Direction

Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)	Cohesion R (kPa)	Phi R (°)
	Drain	21		0				33	0	0
	Embankment Core (EQ/Pseudo)	20		0	28	15	243			
	Embankment Shell (EQ/Pseudo)	20		0	24	12	86			
	Glacial Till (EQ/Pseudo)	18		0	27	15	199			
	Glacio-Lacustrine (EQ/Pseudo)	18	Glacio-Lacustrine (Seismic)					0	0	0
	Granular Zone	21		0				33	0	0
	Rock Toe	20		0				33	0	0
	Sandstone									
	Weathered Bedrock	21		0				35	0	0

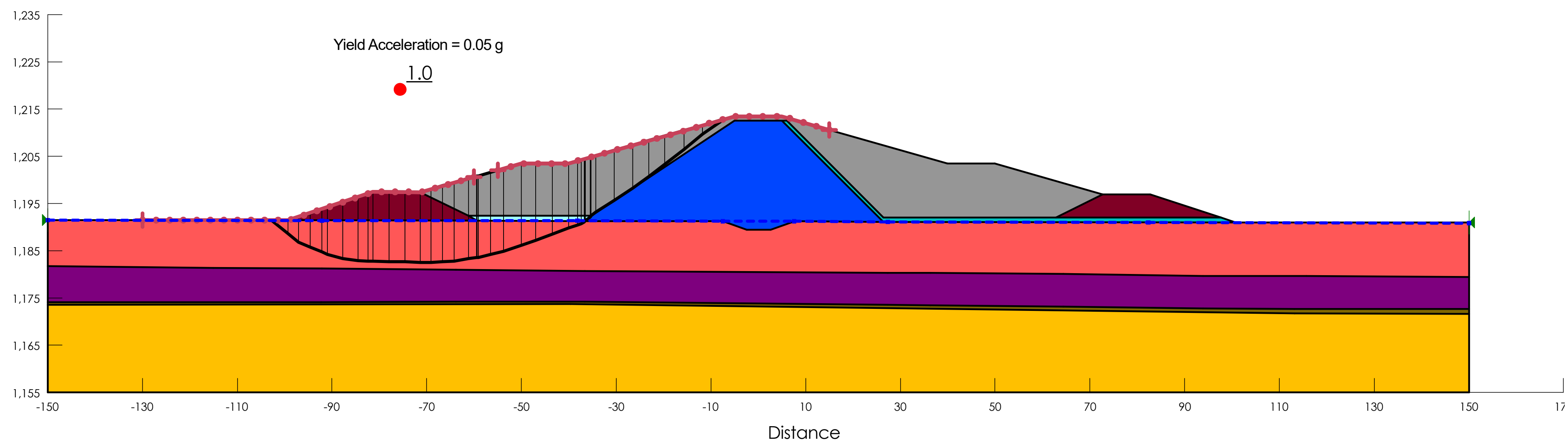


Stantec

Alberta Transportation SR1 Storage Dam

Section 22+500
Load Case: Yield Acceleration
Pseudostatic Parameters
Incipient Motion in the Upstream Direction

Color	Name	Unit Weight (kN/m³)	Cohesion Spatial Fn	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)	Cohesion R (kPa)	Phi R (°)
	Drain	21		0				33	0	0
	Embankment Core (EQ/Pseudo)	20		0	28	15	243			
	Embankment Shell (EQ/Pseudo)	20		0	24	12	86			
	Glacial Till (EQ/Pseudo)	18		0	27	15	199			
	Glacio-Lacustrine (EQ/Pseudo)	18	Glacio-Lacustrine (Seismic)					0	0	0
	Granular Zone	21		0				33	0	0
	Rock Toe	20		0				33	0	0
	Sandstone									
	Weathered Bedrock	21		0				35	0	0

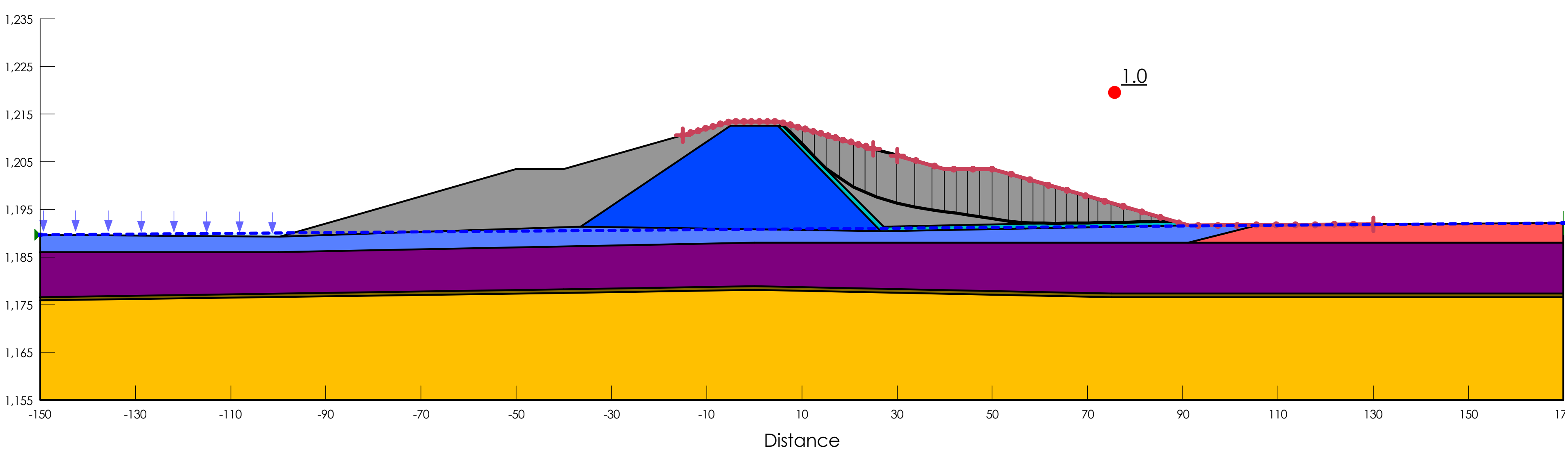


Stantec

Alberta Transportation SR1 Storage Dam

Section 22+990
Load Case: Yield Acceleration
Pseudostatic Parameters
Incipient Motion in the Downstream Direction

Color	Name	Unit Weight (kN/m³)	Minimum Strength (kPa)	Tau/Sigma Ratio	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)	Co… R (…
	Compacted Till	20			0				28	0
	Drain	21			0				33	0
	Embankment Core (EQ/Pseudo)	20			0	28	15	243		
	Embankment Shell (EQ/Pseudo)	20			0	24	12	86		
	Glacial Till (EQ/Pseudo)	18			0	27	15	199		
	Glacio-Lacustrine (EQ/Pseudo)	18	0	0.212						
	Sandstone									
	Weathered Bedrock	21			0				35	0

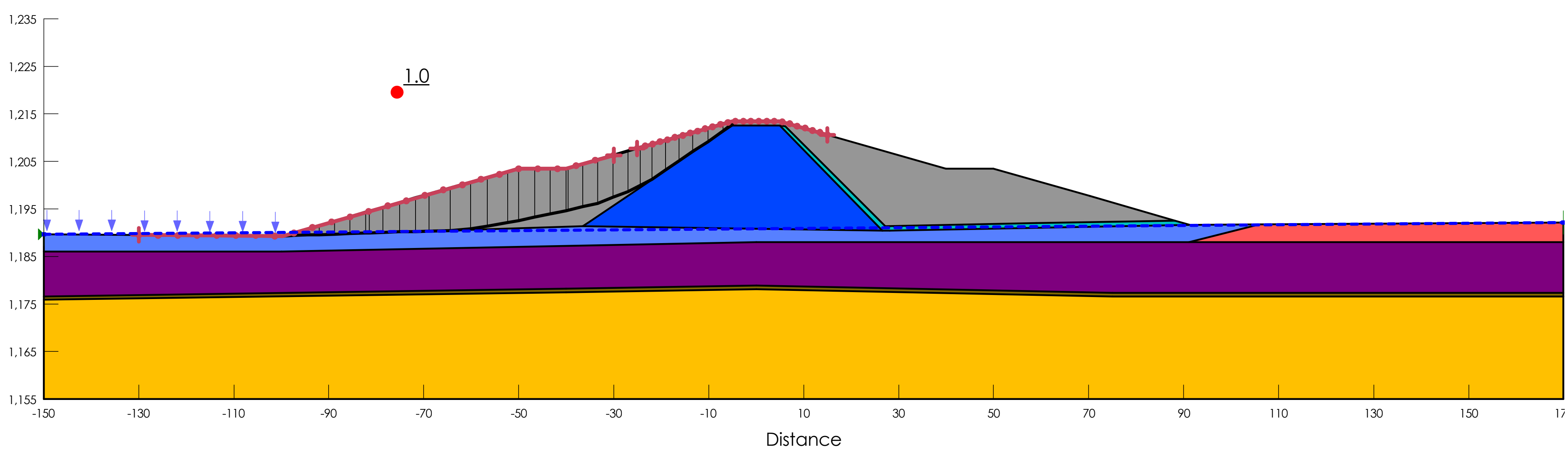


Stantec

Alberta Transportation SR1 Storage Dam

Section 22+990
Load Case: Yield Acceleration
Pseudostatic Parameters
Incipient Motion in the Upstream Direction

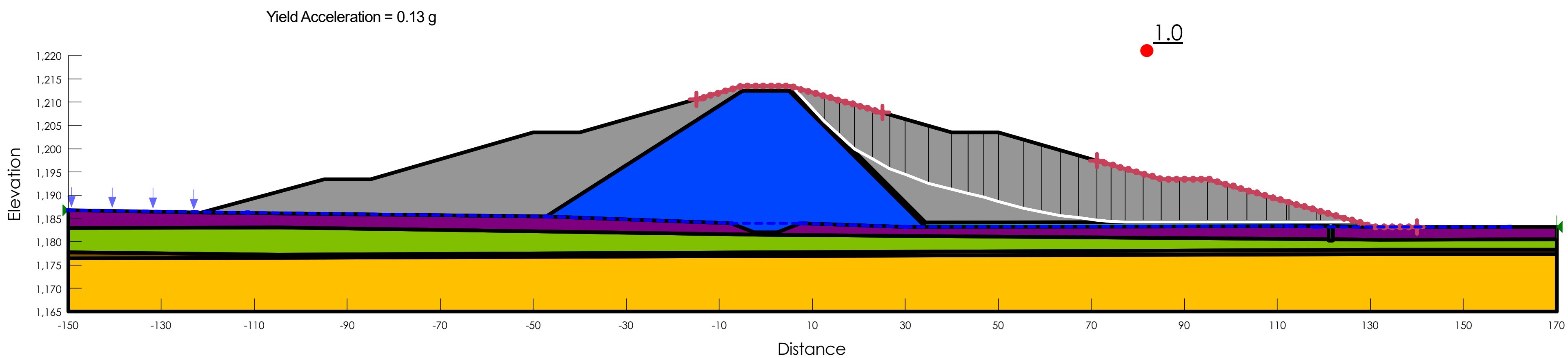
Color	Name	Unit Weight (kN/m³)	Minimum Strength (kPa)	Tau/Sigma Ratio	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)	Col R (k
	Compacted Till	20			0				28	0
	Drain	21			0				33	0
	Embankment Core (EQ/Pseudo)	20			0	28	15	243		
	Embankment Shell (EQ/Pseudo)	20			0	24	12	86		
	Glacial Till (EQ/Pseudo)	18			0	27	15	199		
	Glacio-Lacustrine (EQ/Pseudo)	18	0	0.212						
	Sandstone									
	Weathered Bedrock	21			0				35	0



Alberta Transportation SR1 Storage Dam

Section 23+175
Load Case: Yield Acceleration
Pseudostatic Stress Parameters
Incipient Motion in the Downstream Direction

Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)	Cohesion R (kPa)	Phi R (°)
	Drain	21	0				33	0	0
	Embankment Core (EQ/Pseudo)	20	0	28	15	243			
	Embankment Shell (EQ/Pseudo)	20	0	24	12	86			
	Fluvial (Unnamed Creek)	22	0				35	0	0
	Glacial Till (EQ/Pseudo)	18	0	27	15	199			
	Sandstone								
	Weathered Bedrock	21	0				35	0	0

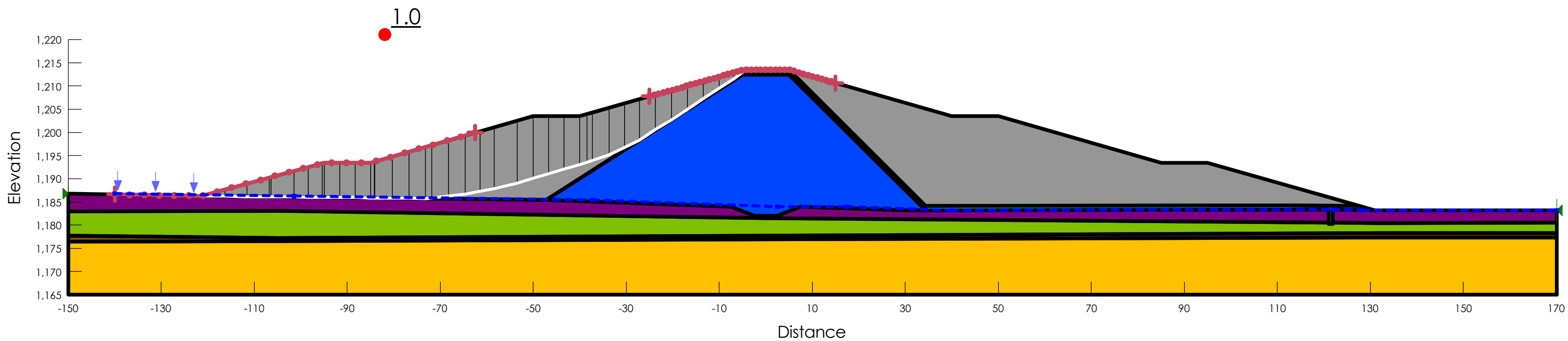


Alberta Transportation SR1 Storage Dam

Section 23+175
Load Case: Yield Acceleration
Pseudostatic Stress Parameters
Incipient Motion in the Upstream Direction

Color	Name	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi 1 (°)	Phi 2 (°)	Bilinear Normal (kPa)	Phi' (°)	Cohesion R (kPa)	Phi R (°)
	Drain	21	0				33	0	0
	Embankment Core (EQ/Pseudo)	20	0	28	15	243			
	Embankment Shell (EQ/Pseudo)	20	0	24	12	86			
	Fluvial (Unnamed Creek)	22	0				35	0	0
	Glacial Till (EQ/Pseudo)	18	0	27	15	199			
	Sandstone								
	Weathered Bedrock	21	0				35	0	0

Yield Acceleration = 0.13 g



Attachment 12.3
Seismic Analyses

12.3.4 Liquefaction Screening Analysis

Liquefaction Susceptibility of Fine-Grained Soils

Stantec Project Number: 110773396
Project Name: SR1
Site/Structure Name: Diversion Channel, Storage Dam

Note: NP = Non-Plastic

Sand-like versus Clay-like Behavior (-1 indicates result does not meet criteria, green shading indicates result does meet criteria, no results shown for non-plastic material)

Lab ID	Boring	Depth (m)	Soil Classification	NMC (w_c) (%)	% Passing #200	% Passing #40	LL	PI	Seed et al (2003): Meets criteria for sand-like behavior: LL in Zone A (see plot)	Seed et al (2003): Meets criteria for sand-like behavior: PI in Zone A (see plot)	Seed et al (2003): In Zone B: LL	Seed et al (2003): In Zone B: PI	Seed et al (2003): in B with w >= .85LL: LL	Seed et al (2003): in B with w >= .85LL: PI	Seed et al (2003): Meets criteria for clay-like behavior: LL in Zone B (see plot)	Seed et al (2003): Meets criteria for clay-like behavior: PI in Zone B (see plot)	Seed et al (2003): Meets criteria for clay-like behavior: LL in Zone C (see plot)	Seed et al (2003): Meets criteria for clay-like behavior: PI in Zone C (see plot)	Idriss and Boulanger (2008): Meets criteria for sand-like behavior: PI < 7	Idriss and Boulanger (2008): Meets criteria for clay-like behavior: PI >= 7	MSHA (2010): Meets criteria for sand-like behavior: PI <= 7	MSHA (2010): Meets criteria for clay-like behavior: P40>=35%, P200>=20%, and PI>=10	MSHA (2010): Borderline soils (treat as sand-like): 7 < PI < 10, or does not meet P40 or P200	Overall Judgement based on 3 methods (sand-like or clay-like)
GL-1	D2 ST4	1.50	CH	28.8	99.7	100	66	45	-1	-1	-1	-1	-1	-1	-1	-1	66	45	-1	45	-1	45	-1	Clay-like
GT-2	D2 BS15	7.00	CL	14.6	70.8	86.2	31	16	-1	-1	31	16	-1	-1	31	16	-1	-1	-1	16	-1	16	-1	Clay-like
GL-1	D5 BS2	0.60	CH	28.3	99.4	100	54	34	-1	-1	-1	-1	-1	-1	-1	-1	54	34	-1	34	-1	34	-1	Clay-like
GT-3	D5 BS9	4.20	CL	16.5	64.4	77.8	36	21	-1	-1	-1	-1	-1	-1	-1	-1	36	21	-1	21	-1	21	-1	Clay-like
GL-2	D3 ST2	0.90	CL	19.3	99.5	100	43	24	-1	-1	-1	-1	-1	-1	-1	-1	43	24	-1	24	-1	24	-1	Clay-like
GL-2	D11 ST8	4.25	CL	30.5	99.3	100	43	25	-1	-1	-1	-1	-1	-1	-1	-1	43	25	-1	25	-1	25	-1	Clay-like
GT-1	D 11 ST 11	6.10	CL	15.8	68.3	87.3	30	15	-1	-1	30	15	-1	-1	30	15	-1	-1	-1	15	-1	15	-1	Clay-like
GL-1	D12 ST6	2.25	CH	28.1	98.2	100	59	39	-1	-1	-1	-1	-1	-1	-1	-1	59	39	-1	39	-1	39	-1	Clay-like
GT-1	D19 ST21	9.90	CL	11.8	69.4	89.3	30	16	-1	-1	30	16	-1	-1	30	16	-1	-1	-1	16	-1	16	-1	Clay-like
GL-2	D20 ST6	2.70	CL	28.6	88.4	100	41	24	-1	-1	-1	-1	-1	-1	-1	-1	41	24	-1	24	-1	24	-1	Clay-like
GT-1	D20 BS D	10.30	CL	15	68.7	89.8	34	19	-1	-1	34	19	-1	-1	34	19	-1	-1	-1	19	-1	19	-1	Clay-like
GL-1	D27 ST4	1.70	CH	22.1	96.2	99.8	55	38	-1	-1	-1	-1	-1	-1	-1	-1	55	38	-1	38	-1	38	-1	Clay-like
GL-1	D28 ST4	1.70	CH	27.1	92	98.2	46	30	-1	-1	-1	-1	-1	-1	-1	-1	46	30	-1	30	-1	30	-1	Clay-like
GT	D28 BS21	13.30	CL	14.3	60.8	79.2	28	14	-1	-1	28	14	-1	-1	28	14	-1	-1	-1	14	-1	14	-1	Clay-like
GT-1	D58 SS15	9.10	CL	10.5	63.7	82.7	29	15	-1	-1	29	15	-1	-1	29	15	-1	-1	-1	15	-1	15	-1	Clay-like
GT-1	D58 ST21	13.70	CL	22.2	79	98.3	29	15	-1	-1	29	15	-1	-1	29	15	-1	-1	-1	15	-1	15	-1	Clay-like
GL-2	D59 SS21	10.70	CL	21.8	81.6	89.7	41	25	-1	-1	-1	-1	-1	-1	-1	-1	41	25	-1	25	-1	25	-1	Clay-like
GR-1	D45 SS13	7.60	SC	12.9	48.6	76.5	31	15	-1	-1	31	15	-1	-1	31	15	-1	-1	-1	15	-1	15	-1	Clay-like
	D45 SS7	2.70	CL	14	74.4	96.6	40	26	-1	-1	-1	-1	-1	-1	-1	-1	40	26	-1	26	-1	26	-1	Clay-like
	D45 ST2	0.90	CL	29.3	70.1	94.2	43	24	-1	-1	-1	-1	-1	-1	-1	-1	43	24	-1	24	-1	24	-1	Clay-like
	D46 ST4	1.80	CL	12.1	51.1	79	30	15	-1	-1	30	15	-1	-1	30	15	-1	-1	-1	15	-1	15	-1	Clay-like
GT	D48 ST11	7.70	CL	11.3	70.1	90.6	31	17	-1	-1	31	17	-1	-1	31	17	-1	-1	-1	17	-1	17	-1	Clay-like
--	D51 ST8	3.60	CL	18.5	75.9	90.7	39	23	-1	-1	-1	-1	-1	-1	-1	-1	39	23	-1	23	-1	23	-1	Clay-like

Liquefaction Susceptibility of Fine-Grained Soils

Stantec Project Number: 110773396
Project Name: SR1
Site/Structure Name: Diversion Channel, Storage Dam

Note: NP = Non-Plastic

									Susceptibility of Clay-like Soils to Cyclic Softening (-1 indicates result does not meet criteria, green shading indicates result does meet criteria, no results shown for Sand-like materials)								
									Using Criteria published by Seed et al (2003)		Using Criteria published by Bray and Sancio (2006)						Overall Judgement based on 2 methods (susceptibility)
									Meets all criteria for B (clay-like and potentially liquefiable, -2 indicates zone A but susceptible, -3 indicates not applicable due to fines content		Clay-like soil is susceptible (must meet both)		Clay-like soil is not susceptible (must meet one or both)		Clay-like soil is moderately susceptible		
Lab ID	Boring	Depth (m)	Soil Classification	NMC (w_c) (%)	% Passing #200	% Passing #40	LL	PI	LL	PI	w_c/LL >= 0.85	PI <= 12	w_c/LL < 0.80	PI > 18	Intermediate w_c/LL (see plot)	Intermediate PI (see plot)	
GL-1	D2 ST4	1.50	CH	28.8	99.7	100	66	45	-1	-1	-1.00	-1	0.44	45	-1.00	-1	Not Susceptible
GT-2	D2 BS15	7.00	CL	14.6	70.8	86.2	31	16	-1	-1	-1.00	-1	0.47	16	-1.00	-1	Not Susceptible
GL-1	D5 BS2	0.60	CH	28.3	99.4	100	54	34	-1	-1	-1.00	-1	0.52	34	-1.00	-1	Not Susceptible
GT-3	D5 BS9	4.20	CL	16.5	64.4	77.8	36	21	-1	-1	-1.00	-1	0.46	21	-1.00	-1	Not Susceptible
GL-2	D3 ST2	0.90	CL	19.3	99.5	100	43	24	-1	-1	-1.00	-1	0.45	24	-1.00	-1	Not Susceptible
GL-2	D11 ST8	4.25	CL	30.5	99.3	100	43	25	-1	-1	-1.00	-1	0.71	25	-1.00	-1	Not Susceptible
GT-1	D 11 ST 11	6.10	CL	15.8	68.3	87.3	30	15	-1	-1	-1.00	-1	0.53	15	-1.00	-1	Not Susceptible
GL-1	D12 ST6	2.25	CH	28.1	98.2	100	59	39	-1	-1	-1.00	-1	0.48	39	-1.00	-1	Not Susceptible
GT-1	D19 ST21	9.90	CL	11.8	69.4	89.3	30	16	-1	-1	-1.00	-1	0.39	16	-1.00	-1	Not Susceptible
GL-2	D20 ST6	2.70	CL	28.6	88.4	100	41	24	-1	-1	-1.00	-1	0.70	24	-1.00	-1	Not Susceptible
GT-1	D20 BS D	10.30	CL	15	68.7	89.8	34	19	-1	-1	-1.00	-1	0.44	19	-1.00	-1	Not Susceptible
GL-1	D27 ST4	1.70	CH	22.1	96.2	99.8	55	38	-1	-1	-1.00	-1	0.40	38	-1.00	-1	Not Susceptible
GL-1	D28 ST4	1.70	CH	27.1	92	98.2	46	30	-1	-1	-1.00	-1	0.59	30	-1.00	-1	Not Susceptible
GT	D28 BS21	13.30	CL	14.3	60.8	79.2	28	14	-1	-1	-1.00	-1	0.51	14	-1.00	-1	Not Susceptible
GT-1	D58 SS15	9.10	CL	10.5	63.7	82.7	29	15	-1	-1	-1.00	-1	0.36	15	-1.00	-1	Not Susceptible
GT-1	D58 ST21	13.70	CL	22.2	79	98.3	29	15	-1	-1	-1.00	-1	0.77	15	-1.00	-1	Not Susceptible
GL-2	D59 SS21	10.70	CL	21.8	81.6	89.7	41	25	-1	-1	-1.00	-1	0.53	25	-1.00	-1	Not Susceptible
GR-1	D45 SS13	7.60	SC	12.9	48.6	76.5	31	15	-1	-1	-1.00	-1	0.42	15	-1.00	-1	Not Susceptible
	D45 SS7	2.70	CL	14	74.4	96.6	40	26	-1	-1	-1.00	-1	0.35	26	-1.00	-1	Not Susceptible
	D45 ST2	0.90	CL	29.3	70.1	94.2	43	24	-1	-1	-1.00	-1	0.68	24	-1.00	-1	Not Susceptible
	D46 ST4	1.80	CL	12.1	51.1	79	30	15	-1	-1	-1.00	-1	0.40	15	-1.00	-1	Not Susceptible
GT	D48 ST11	7.70	CL	11.3	70.1	90.6	31	17	-1	-1	-1.00	-1	0.36	17	-1.00	-1	Not Susceptible
--	D51 ST8	3.60	CL	18.5	75.9	90.7	39	23	-1	-1	-1.00	-1	0.47	23	-1.00	-1	Not Susceptible

Attachment 12.4 Filter Design

November 27, 2019
Calculated by: Vince Severance
Checked by: Dan Back

Filter Design – Embankment Core Soil and Fine Filter 3A

Core – The embankment core will be constructed of glacial till (GT) material obtained from the borrow areas. Filter design was performed in accordance with USACE publication EM 1110-2-2300. Thirteen gradation/hydrometer tests were used to characterize the GT lean clay borrow soils. Fine and coarse gradations were developed to define a gradation envelope of the GT borrow soil.

The core soil upper and lower (coarse and fine) gradation limits of the thirteen GT borrow soil gradations are presented in Table 1 and plotted on the attached grainsize log chart.

Table 1. Embankment Core Soil Gradation

Shell Soil Gradation			
Opening (mm)	**Sieve No.**	**Upper (Coarser) Limit (%)**	**Lower (Finer) Limit (%)**
25	-	100.00	
12.5	-	93.9	100.00
9.5	-	91.9	100.00
4.75	4	88.6	99.50
2.36	8	86.0	98.4
2	10	85.4	98.2
1.18	16	83.6	97.8
0.6	30	81.6	97.2
0.3	50	79.4	96.2
0.15	100	74.4	95.9
0.075	200	64.0	91.6
0.053	270	63.0	86.0
0.02	-	45.0	76.0
0.006	-	30.0	63.0
0.0005	-	15.00	57.00
0.00007	-	12.00	30.00
0.000002	-	5.00	15.00

The following values were obtained from the attached borrow soil gradation envelope plot:

d_{85} (max.) = 0.020 mm
d_{85} (min.) = 0.053 mm

d_{15} (max.) = 0.0012 mm
d_{15} (min.) = 0.00005 mm

November 27, 2019
Calculated by: Vince Severance
Checked by: Dan Back

Fine Filter 3A Sand – The filter will be constructed of Fine Filter 3A sand material. The upper and lower (coarse and fine) gradation limits of the Fine Filter 3A sand are presented in Table 2 and plotted on the attached grainsize log chart.

Table 2. Fine Filter 3A - Chimney and Blanket Drain/Filter

Fine Filter 3A			
Opening (mm)	**Sieve No.**	**Upper Limit (%)**	**Lower Limit (%)**
10		100	-
5		90	100
2.5		70	95
1.25		50	80
0.630		25	55
0.315		10	25
0.160		0	10
0.080	#200	0	3

The following values were obtained from the attached Fine Filter 3A gradation envelope plot:

$$D_{15} \text{ (max.)} = 0.40 \text{ mm}$$
$$D_{15} \text{ (min.)} = 0.18 \text{ mm}$$

From EM 1110-2-2300, Table B-1 the GT core soil is classified best as USACE soil category 2. The soil 2 category, consisting of clays with 40 to 85 percent passing a #200 sieve, requires a filter material D_{15} size of $\leq$ 0.7 mm. The Fine Filter 3A material D_{15} size ranges from 0.18 mm to 0.40 mm and passes the required stability filter criteria.

Filter criteria was also performed for an USACE category 1 soil consisting of clays with 85 percent passing a #200 sieve. This criteria requires a D_{15} (filter) size $\leq$ 9 x d_{85} (core soil). The Fine Filter 3A material D_{15} size of 0.40 mm is less than the required 1.8 mm and 0.48 mm values and passes soil 1 category stability filter criteria.

USACE permeability criteria requires a D_{15} (filter) / d_{15} (soil) value $\geq$ 3 to 5. This value for the Fine Filter 3A and core soil is 150 or greater and passes the permeability criteria.

Based on this evaluation, the defined Fine Filter 3A sand material passed both stability and permeability filter criteria to provide a suitable filter for the GT embankment core material.

① $D_{15} = 0.40\text{ mm} \leq 0.7\text{ mm}$ (PASS)

② $D_{15} \leq 9 \times d_{85}$

$0.40\text{ mm} \leq 9 \times 0.20\text{ m}$

$0.40\text{ mm} \leq 1.80\text{ mm}$ (PASS)

FILTER DESIGN FOR SOIL CATEGORIES ① AND ②

OFFICE
325 - 25th Street SE
Suite 200
Calgary, Alberta
Canada T2A 7H8
Tel: (403) 716-8000

LABORATORY
10830 - 46th Street SE
Calgary, Alberta
Canada T2C 1G4
Tel: (403) 253-7876

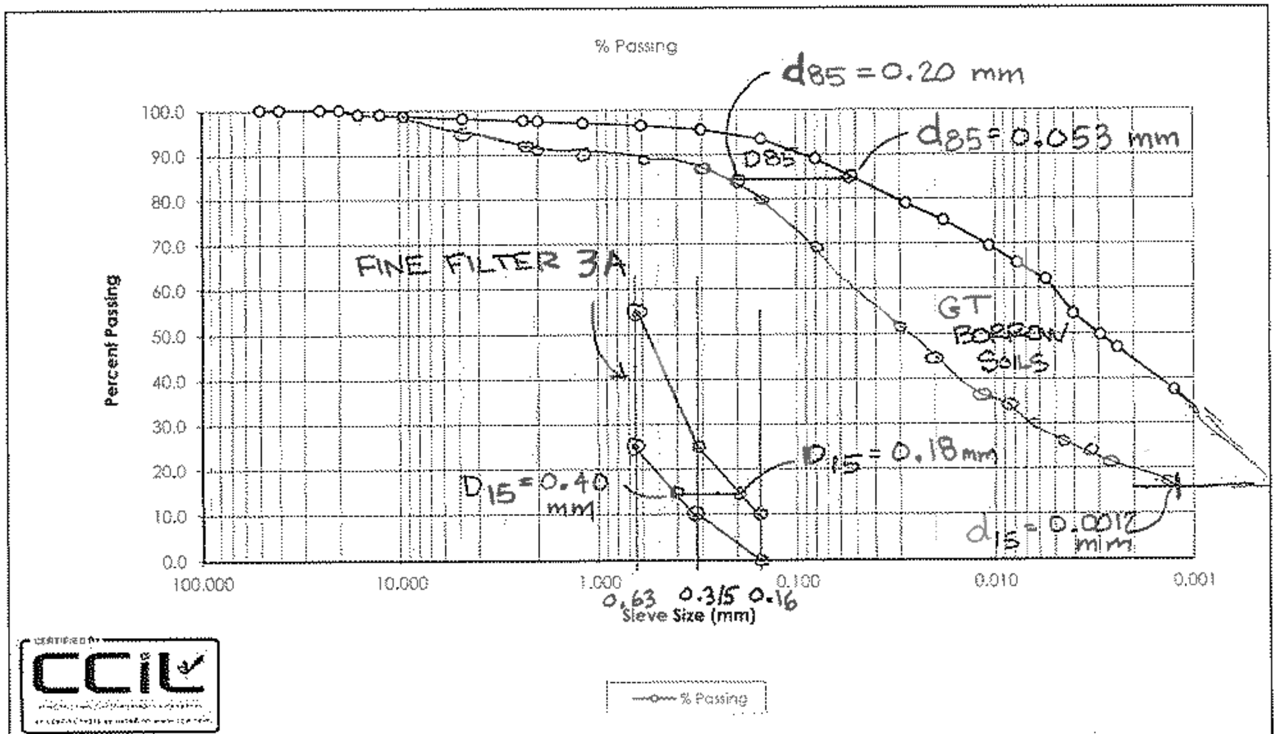
Stantec

Grain Size Analysis
Hydrometer Report
ASTM D422
CANFEM

Client: Alberta Transportation
Project Name: SR1
Project No: 110773396.302.702.250

SAMPLE No.: BSF
SOURCE: BS3
TESTED BY: B.Pelkey

DATE TESTED: October 3, 2016
DATE RECEIVED: August 19, 2016
SAMPLE DESCRIPTION: Clay (CI), Trace Sand, Trace Gravel



Sieve (mm)	Sample % Passing	Sieve (mm)	Sample % Passing
50.0	100.0	0.0055	61.9
40.0	100.0	0.0040	54.4
25.0	100.0	0.0029	49.6
20.0	100.0	0.0024	46.8
16.0	99.0	0.0012	37.4
12.5	99.0		
9.5	98.6		
4.75	98.1		
2.36	97.5		
2.00	97.4		
1.18	97.0		
0.600	96.4		
0.300	95.5		
0.150	93.3		
0.080	88.9		
0.0279	78.9		
0.0181	75.1		
0.0107	69.5		
0.0077	65.7		

Gravel:	1.9%	D_{10}:	-
Sand:	9.2%	D_{30}:	-
Silt:	44.7%	D_{60}:	0.0052
Clay:	44.2%	C_u:	-
		C_c:	-

Comments: Sample description (MUSCS) derived from both the Grain Size and Atterberg Limit test results.

Reviewed by:

PERMEABILITY CRITERIA $\frac{D_{15}\text{ (FILTER)}}{d_{15}\text{ (SOIL)}} \geq 3 \text{ TO } 5 \Rightarrow \frac{0.18\text{ mm}}{0.0012\text{ mm}} = 150 \geq 3 \text{ TO } 5$ (PASS)

Sieve Size	Percent Passing by Mass
[10 mm	100%
5 mm	90% – 100%
2.5 mm	70% – 95%
1.25 mm	50% – 80%
630µm	25% – 55%
315µm	10% – 25%
160µm	0% – 10%
80µm	0% – 3%]

✓OK

D_{15} = 0.315 mm < 0.70mm

.2 Less than 12% loss of weight after 5 cycles in accordance with the requirements of CAN/CSA-A23.2–9A.

.3 Natural sand with no crushed or otherwise manufactured component.

.3 Coarse Filter Zone 3B:

.1 Well graded gravel with sand with a gradation that falls completely within the upper and lower bounds of the envelope defined by straight lines drawn directly between the following points plotted on a standard semi-log soil grain size distribution plot:

Sieve Size	Percent Passing by Mass
[40 mm	100%
20 mm	80% – 100%
10 mm	40% – 80%
5 mm	5% – 40%
2.5 mm	0% – 3%
80µm	0% – 2%]

OR

Sieve Size	Percent Passing by Mass
[28 mm	100%
20 mm	75% – 100%
10 mm	40% – 85%
5 mm	5% – 50%
2.5 mm	0% – 3%
80µm	0% – 2%]

.2 Less than 12% loss of weight after 5 cycles in accordance with the requirements of CAN/CSA-A23.2–9A.

.3 At least [40%] by mass of the particles retained on the 10 mm and larger sieves to have 2 or more fractured faces.

.4 Base Gravel Zone 4A:

.1 Reasonably well graded crushed gravel and sand with a gradation that falls completely within the upper and lower bounds of the envelope defined by straight lines drawn directly between the following points plotted on a standard semi-log soil grain size distribution plot:

(2) Multiply the percentage passing each sieve size of the base soil smaller than No. 4 (4.75 mm) by the correction factor from step *c*(1).

(3) Plot these adjusted percentages to obtain a new gradation curve.

(4) Use the adjusted curve to determine the percent passing the No. 200 (0.075 mm) sieve in step *d*.

d. Place the base soil in a category based on the percent passing the No. 200 (0.075 mm) sieve in accordance with Table B-1.

Table B-1
Categories of Base Soil Materials

Category	Percent finer than the No. 200 (0.075 mm) sieve
1	85
2	40-85
3	15-39
4	15

e. Determine the maximum D_{15} size for the filter in accordance with Table B-2. Note that the maximum D_{15} is not required to be smaller than 0.20 mm.

Table B-2
Criteria for Filters

Base soil category	Base soil description, and percent finer than No. 200 (0.075 mm) sieve[1]	Filter criteria in terms of maximum D_{15} size[2]	Note
1	Fine silts and clays; more than 85% finer	$D_{15} \leq 9 \times d_{85}$	(1)
2	Sands, silts, clays, and silty and clayey sands; 40 to 85% finer.	$D_{15} \leq 0.7$ mm	
3	Silty and clayey sands and gravels; 15 to 39% finer	$D_{15} \leq \frac{40-A}{40-15}$ $((4 \times d_{85}) - 0.7\text{ mm}) + 0.7\text{ mm}$	(2),(3)
4	Sands and gravels; less than 15% finer.	$D_{15} \leq 4$ to $5 \times d_{85}$	(4)

[1] Category designation for soil containing particles larger than 4.75 mm is determined from a gradation curve of the base soil which has been adjusted to 100% passing the No. 4 (4.75 mm) sieve.
[2] Filters are to have a maximum particle size of 3 in. (75 mm) and a maximum of 5% passing the No. 200 (0.075 mm) sieve with the plasticity index (PI) of the fines equal to zero. PI is determined on the material passing the No. 40 (0.425 mm) sieve in accordance with EM 1110-2-1906. To ensure sufficient permeability, filters are to have a D_{15} size equal to or greater than $4 \times d_{15}$ but no smaller than 0.1 mm.

NOTES:
(1) When $9 \times d_{85}$ is less than 0.2 mm, use 0.2 mm.
(2) A = percent passing the No. 200 (0.075 mm) sieve after any regrading.
(3) When $4 \times d_{85}$ is less than 0.7 mm, use 0.7 mm.
(4) In category 4, the d_{85} can be based on the total base soil before regrading. In category 4, the $D_{15} \leq 4 \times d_{85}$ criterion should be used in the case of filters beneath riprap subject to wave action and drains which may be subject to violent surging and/or vibration.

ATTACHMENT 14
LOW LEVEL OUTLET

Attachment 14.1
Settlement Analyses

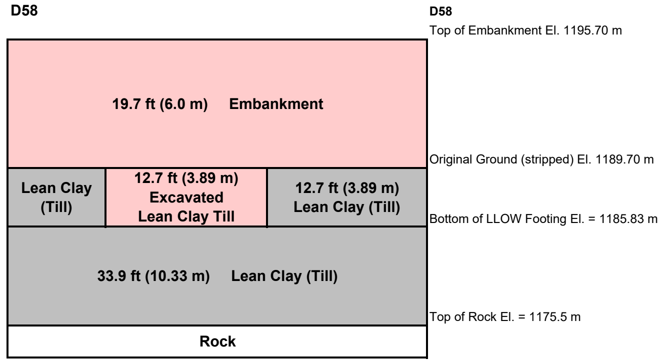
SR1 Storage Dam
Settlement Calculations

106 m Left West Low Level Outlet Alignment @ Sta. 23+022
Nearest Consolidation Test Samples:
D62 - ST6, (4.60 m to 5.05 m)
LLOW08 - ST7 (4.60 m to 5.05 m)

Top of Embankment Elevation = 1195.7 m
Embankment Thickness = 6.0 m (19.7 ft)
Embankment Unit Weight = 20 kN/m^3 (127.3 lb/ft^3)

Till Excavation = 12.7 ft (Excavated Overburden)

D58



D58

Embankment Crest	1195.70	m			
Surface	1190.20	m			
Top Till / Bottom Strip	1189.70	m	6.00	m Embankment	19.7 ft
LLOW Flowline	1186.73	m			
Bottom LLOW Slab	1185.83	m	3.87	m Till Excavation	12.7 ft
Top of Rock	1175.50	m	10.33	m Till Below LLOW	33.9 ft

LLO08 - ST7 (4.60-5.05 m) - Lean Clay with Sand (CL) Till
Pc = 115 kPa (2,402 psf), OCR = 1.3, Cc = 0.15, Cr = 0.04, e = 0.5757, depth = 4.83 m

$$\Delta H = H\left(\frac{C_c}{1+e_o}\right)\log\frac{p_o+\Delta p}{p_o}$$

One Layer 33.9 feet thick

Location	Mid Pt. (ft)	H (ft)	Cc	e	Po (psf)	W(ft.)	ΔP(psf)	Pf = Po+ΔP	ΔH
0+000 (Crest)	16.95	33.9	0.15	0.5757	3397.89	19.7	2507.81	5905.70	0.77

Note Po = (12.7 ft + 16.95 ft) x 114.6 pcf = 3397.89 psf

SUM = 0.77 feet
9.3 inches

11 Layers Approximately 3 feet thick

Location	Mid Pt. (ft)	H (ft)	Cc	e	Po (psf)	W(ft.)	ΔP(psf)	Pf = Po+ΔP	ΔH
0+000 (Crest)	1.5	3	0.15	0.5757	1627.32	19.7	2507.81	4135.13	0.12
0+000 (Crest)	4.5	3	0.15	0.5757	1971.12	19.7	2507.81	4478.93	0.10
0+000 (Crest)	7.5	3	0.15	0.5757	2314.92	19.7	2507.81	4822.73	0.09
0+000 (Crest)	10.5	3	0.15	0.5757	2658.72	19.7	2507.81	5166.53	0.08
0+000 (Crest)	13.5	3	0.15	0.5757	3002.52	19.7	2507.81	5510.33	0.08
0+000 (Crest)	16.5	3	0.15	0.5757	3346.32	19.7	2507.81	5854.13	0.07
0+000 (Crest)	19.5	3	0.15	0.5757	3690.12	19.7	2507.81	6197.93	0.06
0+000 (Crest)	22.5	3	0.15	0.5757	4033.92	19.7	2507.81	6541.73	0.06
0+000 (Crest)	25.5	3	0.15	0.5757	4377.72	19.7	2507.81	6885.53	0.06
0+000 (Crest)	28.5	3	0.15	0.5757	4721.52	19.7	2507.81	7229.33	0.05
0+000 (Crest)	31.95	3.9	0.15	0.5757	5116.89	19.7	2507.81	7624.70	0.06
		33.9							

SUM = 0.83 feet
10.00 inches

Total Settlement at Sta. 23+022, 106 m Lt = 10.00 inches

254 mm

Consider soil recompression back to 3,398 psf after excavation using Cr and Cc values

$$\Delta H = \frac{H}{1+e_0}\left(C_r\log\frac{p_c}{p_o}+C_c\log\frac{p_f}{p_c}\right)$$

One Layer 33.9 ft

Lacustrine Unit Weight = 18 kN/m^3 (114.6 lb/ft^3)

Location	Mid Pt. (ft)	H (ft)	Cr	Cc	e	Po (psf)	Pc (psf)	W(ft.)	ΔP(psf)	Pf = Po+ΔP	ΔH
0+000 (Crest)	16.95	33.9	0.04	0.15	0.5757	1942.47	3397.89	19.70	2507.81	4450.28	0.59

SUM = 0.59 feet
7.05 inches (Less than above)

7/19/2019
Determine additional load required to result in additional 0.75 inch settlement

11 Layers Approximately 3 feet thick

Location	Mid Pt. (ft)	H (ft)	Cc	e	Po (psf)	W(ft.)	ΔP(psf)	Pf = Po+ΔP	ΔH
0+000 (Crest)	1.5	3	0.15	0.5757	1627.32	21.70	2762.41	4389.73	0.12
0+000 (Crest)	4.5	3	0.15	0.5757	1971.12	21.70	2762.41	4733.53	0.11
0+000 (Crest)	7.5	3	0.15	0.5757	2314.92	21.70	2762.41	5077.33	0.10
0+000 (Crest)	10.5	3	0.15	0.5757	2658.72	21.70	2762.41	5421.13	0.09
0+000 (Crest)	13.5	3	0.15	0.5757	3002.52	21.70	2762.41	5764.93	0.08
0+000 (Crest)	16.5	3	0.15	0.5757	3346.32	21.70	2762.41	6108.73	0.07
0+000 (Crest)	19.5	3	0.15	0.5757	3690.12	21.70	2762.41	6452.53	0.07
0+000 (Crest)	22.5	3	0.15	0.5757	4033.92	21.70	2762.41	6796.33	0.06
0+000 (Crest)	25.5	3	0.15	0.5757	4377.72	21.70	2762.41	7140.13	0.06
0+000 (Crest)	28.5	3	0.15	0.5757	4721.52	21.70	2762.41	7483.93	0.06
0+000 (Crest)	31.95	3.9	0.15	0.5757	5116.89	21.70	2762.41	7879.30	0.07
		33.9							

SUM = 0.89 feet
10.73 inches

	W(ft.)	ΔP(psf)	Settle (in)	Target (in)
Original	19.70	2507.81	10.0	
New Load	**21.70**	2762.41	10.7	10.75
Difference	2.00	254.60	**0.74**	

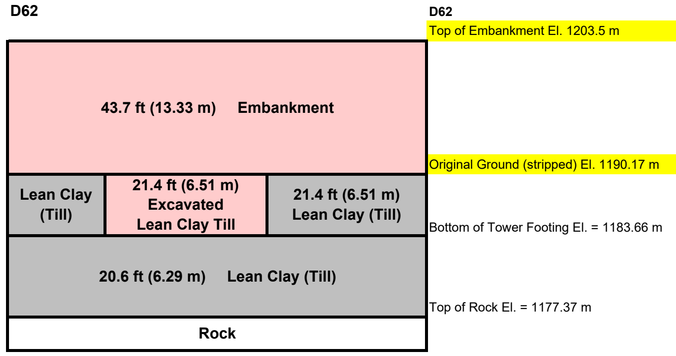
SR1 Storage Dam
Settlement Calculations

45 m Left West Low Level Outlet Alignment @ Sta. 23+022
Nearest Consolidation Test Samples:
D62 - ST6, (4.60 m to 5.05 m)
LLOW08 - ST7 (4.60 m to 5.05 m)

Top of Embankment Elevation = 1203.0 m
Embankment Thickness = 23.2 m (76.5 ft)
Embankment Unit Weight = 20 kN/m^3 (127.3 lb/ft^3)

Till Excavation = 21.35 ft (Excavated Overburden)

D62



D62

Embankment Crest	1203.50	m			
Surface	1190.67	m			
Top Till / Bottom Strip	1190.17	m	13.33 m Embankment	43.7 ft	
LLOW Flowline		m			
Bottom Tower Slab	1183.66	m	6.51 m Till Excavation	21.4 ft	
Top of Rock	1177.37	m	6.29 m Till Below LLOW	20.6 ft	

LLOW08 - ST7 (4.60-5.05 m) - Lean Clay with Sand (CL) Till
Pc = 115 kPa (2,402 psf), OCR = 1.3, Cc = 0.15, e = 0.5757, depth = 4.83 m

$$\Delta H = H\left(\frac{C_c}{1+e_o}\right)\log\frac{p_o+\Delta p}{p_o}$$

One Layer 20.6 feet thick

Location	Mid Pt. (ft)	H (ft)	Cc	e	Po (psf)	W(ft.)	ΔP(psf)	Pf = Po+ΔP	ΔH
0+000 (Crest)	10.3156	20.6	0.15	0.5757	3629.20	43.7	5563.01	9192.21	0.79

Note Po = (16.24 ft + 12.85 ft) x 114.6 pcf = 3,333.26 ps

SUM = 0.79 feet
9.5 inches

Nine Layers Approximately 3 feet thick

Location	Mid Pt. (ft)	H (ft)	Cc	e	Po (psf)	W(ft.)	ΔP(psf)	Pf = Po+ΔP	ΔH
0+000 (Crest)	1.5	3	0.15	0.5757	2618.93	43.7	5565.86	8184.79	0.14
0+000 (Crest)	4.5	3	0.15	0.5757	2962.73	43.7	5565.86	8528.59	0.13
0+000 (Crest)	7.5	3	0.15	0.5757	3306.53	43.7	5565.86	8872.39	0.12
0+000 (Crest)	10.5	3	0.15	0.5757	3650.33	43.7	5565.86	9216.19	0.11
0+000 (Crest)	13.5	3	0.15	0.5757	3994.13	43.7	5565.86	9559.99	0.11
0+000 (Crest)	16.5	3	0.15	0.5757	4337.93	43.7	5565.86	9903.79	0.10
0+000 (Crest)	19.3	2.6	0.15	0.5757	4658.81	43.7	5565.86	10224.67	0.08
		20.6							

SUM = 0.80 feet
9.7 inches

Total Settlement at Sta.23+022, 45 m Lt = 9.66 inches

245 mm

7/19/2019
Determine additional settlement from estimated LLOW Tower load of load required to result in additional 0.75 inch settlemen

Five Layers Approximately 3 feet thick

Location	Mid Pt. (ft)	H (ft)	Cc	e	Po (psf)	W(ft.)	ΔP(psf)	Pf = Po+ΔP	ΔH
0+000 (Crest)	1.5	3	0.15	0.5757	2618.93	49.20	6263.16	8882.09	0.15
0+000 (Crest)	4.5	3	0.15	0.5757	2962.73	49.20	6263.16	9225.89	0.14
0+000 (Crest)	7.5	3	0.15	0.5757	3306.53	49.20	6263.16	9569.69	0.13
0+000 (Crest)	10.5	3	0.15	0.5757	3650.33	49.20	6263.16	9913.49	0.12
0+000 (Crest)	13.5	3	0.15	0.5757	3994.13	49.20	6263.16	10257.29	0.12
0+000 (Crest)	16.5	3	0.15	0.5757	4337.93	49.20	6263.16	10601.09	0.11
0+000 (Crest)	19.3	2.6	0.15	0.5757	4658.81	49.20	6263.16	10921.97	0.09
		20.6							

SUM = 0.87 feet
10.4 inches

	W(ft.)	ΔP(psf)	Settle (in)	Target (in)
Original	43.72	5565.86	9.7	
New Load	**49.20**	6263.16	10.4	10.41
Difference	5.48	**697.30**	**0.75**	

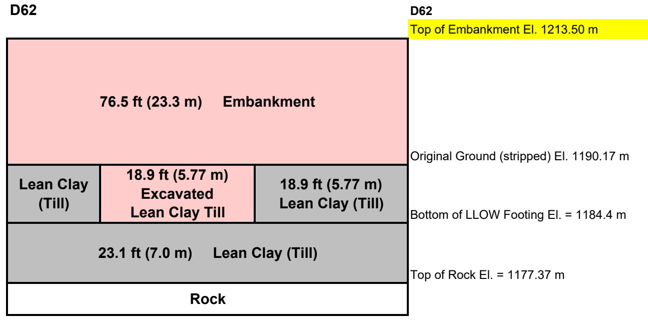
SR1 Storage Dam
Settlement Calculations

Centerline West Low Level Outlet Alignment @ Sta. 23+022
Nearest Consolidation Test Samples:
D62 - ST6, (4.60 m to 5.05 m)
LLOW08 - ST7 (4.60 m to 5.05 m)

Top of Embankment Elevation = 1213.5 m
Embankment Thickness = 23.2 m (76.5 ft)
Embankment Unit Weight = 20 kN/m^3 (127.3 lb/ft^3)

Till Excavation = 18.9 ft (Excavated Overburden)

D62



D62						
Embankment Crest	1213.50	m				
Surface	1190.67	m				
Top Till / Bottom Strip	1190.17	m	23.33	m Embankment	76.5	ft
LLOW Flowline	1185.5	m				
Bottom LLOW Slab	1184.4	m	5.77	m Till Excavation	18.9	ft
Top of Rock	1177.37	m	7.03	m Till Below LLOW	23.1	ft

LLOW08 - ST7 (4.60-5.05 m) - Lean Clay with Sand (CL) Till
Pc = 115 kPa (2,402 psf), OCR = 1.3, Cc = 0.15, e = 0.5757, depth = 4.83 m

$$\Delta H = H\left(\frac{C_c}{1+e_o}\right)\log\frac{p_o+\Delta p}{p_o}$$

One Layer 23.1 feet thick

Location	Mid Pt. (ft)	H (ft)	Cc	e	Po (psf)	W(ft.)	ΔP(psf)	Pf = Po+ΔP	ΔH
0+000 (Crest)	11.55	23.1	0.15	0.5757	3489.57	76.5	9738.45	13228.02	1.27
							SUM =	1.27 feet	
								15.3 inches	

Eight Layers Approximately 3 feet thick

Location	Mid Pt. (ft)	H (ft)	Cc	e	Po (psf)	W(ft.)	ΔP(psf)	Pf = Po+ΔP	ΔH
0+000 (Crest)	1.5	3	0.15	0.5757	2337.84	76.5	9738.45	12076.29	0.20
0+000 (Crest)	4.5	3	0.15	0.5757	2681.64	76.5	9738.45	12420.09	0.19
0+000 (Crest)	7.5	3	0.15	0.5757	3025.44	76.5	9738.45	12763.89	0.18
0+000 (Crest)	10.5	3	0.15	0.5757	3369.24	76.5	9738.45	13107.69	0.17
0+000 (Crest)	13.5	3	0.15	0.5757	3713.04	76.5	9738.45	13451.49	0.16
0+000 (Crest)	16.5	3	0.15	0.5757	4056.84	76.5	9738.45	13795.29	0.15
0+000 (Crest)	19.5	3	0.15	0.5757	4400.64	76.5	9738.45	14139.09	0.14
0+000 (Crest)	22.05	2.1	0.15	0.5757	4692.87	76.5	9738.45	14431.32	0.10
		23.1							
							SUM =	1.29 feet	
								15.5 inches	

Consider soil recompression back to 3,489 psf after excavation using Cr and Cc values

$$\Delta H = \frac{H}{1+e_0}\left(C_r\log\frac{p_c}{p_o} + C_c\log\frac{p_f}{p_c}\right)$$

One Layer 16.5 ft

Lacustrine Unit Weight = 18 kN/m^3 (114.6 lb/ft^3)

Location	Mid Pt. (ft)	H (ft)	Cr	Cc	e	Po (psf)	Pc (psf)	W(ft.)	ΔP(psf)	Pf = Po+ΔP	ΔH
0+000 (Crest)	11.55	23.1	0.04	0.15	0.5757	1323.63	3489.57	76.50	9738.45	11062.08	1.35
								SUM =	1.35 feet		
									16.18 inches	MORE THAN ABOVE	

Total Settlement at Centerline Sta.23+022 = 16.18 inches

411 mm

Consider soil recompression back to 3,489 psf after excavation using Cr and Cc values

$$\Delta H = \frac{H}{1+e_0}\left(C_r\log\frac{p_c}{p_o} + C_c\log\frac{p_f}{p_c}\right)$$

One Layer 16.5 ft

Lacustrine Unit Weight = 18 kN/m^3 (114.6 lb/ft^3)

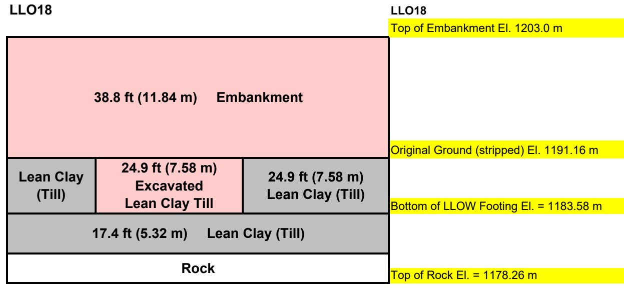
Location	Mid Pt. (ft)	H (ft)	Cr	Cc	e	Po (psf)	Pc (psf)	W(ft.)	ΔP(psf)	Pf = Po+ΔP	ΔH
0+000 (Crest)	11.55	23.1	0.04	0.15	0.5757	1323.63	3489.57	82.40	10489.52	11813.15	1.41
								SUM =	1.41 feet		
									16.94 inches		

	W(ft.)	ΔP(psf)	Settle (in)	Target (in)
Original	76.50	9738.45	16.18	
New Load	82.40	10489.52	16.94	16.93
Difference	5.90	**751.07**	**0.75**	

SR1 Storage Dam
Settlement Calculations

45 m Right West Low Level Outlet Alignment @ Sta. 23+022
Nearest Consolidation Test Samples:
D62 - ST6, (4.60 m to 5.05 m)
LLOW08 - ST7 (4.60 m to 5.05 m)

Top of Embankment Elevation = 1203.0 m
Embankment Thickness = 23.2 m (76.5 ft)
Embankment Unit Weight = 20 kN/m^3 (127.3 lb/ft^3)



Till Excavation = 24.9 ft (Excavated Overburden)

LLO18

Embankment Crest	1203.00	m				
Surface	1191.66	m				
Top Till / Bottom Strip	1191.16	m	11.84	m Embankment	38.8	ft
LLOW Flowline	1184.68	m				
Bottom LLOW Slab	1183.58	m	7.58	m Till Excavation	24.9	ft
Top of Rock	1178.26	m	5.32	m Till Below LLOW	17.4	ft

LLOW08 - ST7 (4.60-5.05 m) - Lean Clay with Sand (CL) Till
Pc = 115 kPa (2,402 psf), OCR = 1.3, Cc = 0.15, Cr = 0.04, e = 0.5757, depth = 4.83 m

$$\Delta H = H\left(\frac{C_c}{1+e_o}\right)\log\frac{p_o+\Delta p}{p_o}$$

One Layer 17.4 feet thick

Location	Mid Pt. (ft)	H (ft)	Cc	e	Po (psf)	W(ft.)	ΔP(psf)	Pf = Po+ΔP	ΔH
0+000 (Crest)	8.7	17.4	0.15	0.5757	3850.56	38.8	4943.72	8794.28	0.59

SUM = 0.59 feet
7.1 inches

Five Layers Approximately 3 feet thick

Location	Mid Pt. (ft)	H (ft)	Cc	e	Po (psf)	W(ft.)	ΔP(psf)	Pf = Po+ΔP	ΔH
0+000 (Crest)	1.5	3	0.15	0.5757	3025.44	38.8	4939.24	7964.68	0.12
0+000 (Crest)	4.5	3	0.15	0.5757	3369.24	38.8	4939.24	8308.48	0.11
0+000 (Crest)	7.5	3	0.15	0.5757	3713.04	38.8	4939.24	8652.28	0.10
0+000 (Crest)	10.5	3	0.15	0.5757	4056.84	38.8	4939.24	8996.08	0.10
0+000 (Crest)	14.7	5.4	0.15	0.5757	4538.16	38.8	4939.24	9477.40	0.16
		17.4							

SUM = 0.60 feet
7.2 inches

Total Settlement at Centerline Sta.23+050 = 7.20 inches
183 mm

Consider recompression up to 3,850 psf:

One Layer 17.4 feet thick

$$\Delta H = \frac{H}{1+e_0}\left(C_r \log\frac{p_c}{p_o} + C_c \log\frac{p_f}{p_c}\right)$$

Lacustrine Unit Weight = 18 kN/m^3 (114.6 lb/ft^3)

Location	Mid Pt. (ft)	H (ft)	Cr	Cc	e	Po (psf)	Pc (psf)	W(ft.)	ΔP(psf)	Pf = Po+ΔP	ΔH
0+000 (Crest)	8.7	17.4	0.04	0.15	0.5757	997.02	3850.56	38.80	4939.24	5936.26	0.57

SUM = 0.57 feet
6.85 inches Less than above

7/19/2019
Determine additional load required to result in additional 0.75 inch settlement

38.80

Five Layers Approximately 3 feet thick

Location	Mid Pt. (ft)	H (ft)	Cc	e	Po (psf)	W(ft.)	ΔP(psf)	Pf = Po+ΔP	ΔH
0+000 (Crest)	1.5	3	0.15	0.5757	3025.44	45.7	5817.61	8843.05	0.13
0+000 (Crest)	4.5	3	0.15	0.5757	3369.24	45.7	5817.61	9186.85	0.12
0+000 (Crest)	7.5	3	0.15	0.5757	3713.04	45.7	5817.61	9530.65	0.12
0+000 (Crest)	10.5	3	0.15	0.5757	4056.84	45.7	5817.61	9874.45	0.11
0+000 (Crest)	14.7	5.4	0.15	0.5757	4538.16	45.7	5817.61	10355.77	0.18
		17.4							

SUM = 0.67 feet
8.03 inches

Total Settlement at Centerline Sta.23+050 = 8.03 inches

	W(ft.)	ΔP(psf)	Settle (in)	Target (in)
Original	38.80	4939.24	7.28	
New Load	**45.70**	5817.61	8.03	8.03
Difference	6.90	878.37	**0.75**	

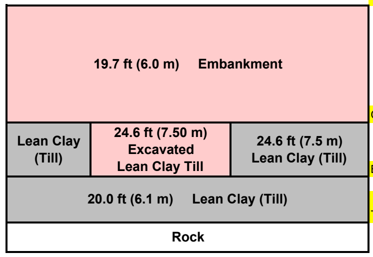
SR1 Storage Dam
Settlement Calculations

106 m Right West Low Level Outlet Alignment @ Sta. 23+022
Nearest Consolidation Test Samples:
D62 - ST6, (4.60 m to 5.05 m)
LLOW08 - ST7 (4.60 m to 5.05 m)

Top of Embankment Elevation = 1203.0 m
Embankment Thickness = 23.2 m (76.5 ft)
Embankment Unit Weight = 20 kN/m^3 (127.3 lb/ft^3)

Till Excavation = 24.6 ft (Excavated Overburden)

D36



D36
Top of Embankment El. 1196 m
Original Ground (stripped) El. 1190.0 m
Bottom of LLOW Footing El. = 1185.83 m
Top of Rock El. = 1176.4 m

D36

Embankment Crest	1196.00	m				
Surface	1190.50	m				
Top Till / Bottom Strip	1190.00	m	6.00	m Embankment	19.7	ft
LLOW Flowline	1183.6	m				
Bottom LLOW Slab	1182.5	m	7.50	m Till Excavation	24.6	ft
Top of Rock	1176.40	m	6.10	m Till Below LLOW	20.0	ft

LLOW08 - ST7 (4.60-5.05 m) - Lean Clay with Sand (CL) Till
Pc = 115 kPa (2,402 psf), OCR = 1.3, Cc = 0.15, e = 0.5757, depth = 4.83 m

$$\Delta H = H\left(\frac{C_c}{1+e_o}\right)\log\frac{p_o+\Delta p}{p_o}$$

One Layer 20 feet thick

Location	Mid Pt. (ft)	H (ft)	Cc	e	Po (psf)	W(ft.)	ΔP(psf)	Pf = Po+ΔP	ΔH
0+000 (Crest)	10	20	0.15	0.5757	3965.16	19.7	2507.81	6472.97	0.41

SUM = 0.41 feet
4.9 inches

Seven Layers Approximately 3 feet thick

Location	Mid Pt. (ft)	H (ft)	Cc	e	Po (psf)	W(ft.)	ΔP(psf)	Pf = Po+ΔP	ΔH
0+000 (Crest)	1.5	3	0.15	0.5757	2991.06	19.7	2507.81	5498.87	0.08
0+000 (Crest)	4.5	3	0.15	0.5757	3334.86	19.7	2507.81	5842.67	0.07
0+000 (Crest)	7.5	3	0.15	0.5757	3678.66	19.7	2507.81	6186.47	0.06
0+000 (Crest)	10.5	3	0.15	0.5757	4022.46	19.7	2507.81	6530.27	0.06
0+000 (Crest)	13.5	3	0.15	0.5757	4366.26	19.7	2507.81	6874.07	0.06
0+000 (Crest)	16.5	3	0.15	0.5757	4710.06	19.7	2507.81	7217.87	0.05
0+000 (Crest)	19	2	0.15	0.5757	4996.56	19.7	2507.81	7504.37	0.03
		20							

SUM = 0.41 feet
5.0 inches

Total Settlement at Centerline Sta.23+050 = 4.95 inches

126 mm

Consider recompression up to 3398 psf:

$$\Delta H = \frac{H}{1+e_0}\left(C_r\log\frac{p_c}{p_o} + C_c\log\frac{p_f}{p_c}\right)$$

One Layer 20 ft

Lacustrine Unit Weight = 18 kN/m^3 (114.6 lb/ft^3)

Location	Mid Pt. (ft)	H (ft)	Cr	Cc	e	Po (psf)	Pc (psf)	W(ft.)	ΔP(psf)	Pf = Po+ΔP	ΔH
0+000 (Crest)	10	20	0.04	0.15	0.5757	1146.00	3398.00	19.70	2507.81	3653.81	0.30

SUM = 0.30 feet
3.60 inches (Less than above)

7/19/2019
Determine additional load required to result in additional 0.75 inch settlement
Seven Layers Approximately 3 feet thick

Location	Mid Pt. (ft)	H (ft)	Cc	e	Po (psf)	W(ft.)	ΔP(psf)	Pf = Po+ΔP	ΔH
0+000 (Crest)	1.5	3	0.15	0.5757	2991.06	23.70	3017.01	6008.07	0.09
0+000 (Crest)	4.5	3	0.15	0.5757	3334.86	23.70	3017.01	6351.87	0.08
0+000 (Crest)	7.5	3	0.15	0.5757	3678.66	23.70	3017.01	6695.67	0.07
0+000 (Crest)	10.5	3	0.15	0.5757	4022.46	23.70	3017.01	7039.47	0.07
0+000 (Crest)	13.5	3	0.15	0.5757	4366.26	23.70	3017.01	7383.27	0.07
0+000 (Crest)	16.5	3	0.15	0.5757	4710.06	23.70	3017.01	7727.07	0.06
0+000 (Crest)	19	2	0.15	0.5757	4996.56	23.70	3017.01	8013.57	0.04
		20							

SUM = 0.48 feet
5.7 inches

Total Settlement at Centerline Sta.23+050 = 5.71 inches

145 mm

	W(ft.)	ΔP(psf)	Settle (in)	Target (in)
Original	19.70	2507.81	4.95	
New Load	**23.70**	3017.01	5.71	5.70
Difference	4.00	509.20	**0.76**	

Attachment 14.2
Lateral Earth Movement

LLO Conduit Movement Calculations

Lateral Bulging of Earth Dams									
Delta-x	**F**	**C**	**e50**	**Gamma**	**Height**	**S**	**m**	**Ks**	**Km**
feet	**Factor of Safety**	**Su in psf (UU)**	**Strain at 50% strength**	**lb/ft^3**	**feet**	**Degree of saturation**	**slope**	**factor**	**factor**
2.4	1.3	2500	0.01	127	96	100	3.5	0.95	0.9
2.0	1.3	2500	0.01	127	96	95	3.5	0.82	0.9
1.7	1.3	2500	0.01	127	96	90	3.5	0.7	0.9
1.5	1.3	2500	0.01	127	96	85	3.5	0.59	0.9
1.2	1.3	2500	0.01	127	96	80	3.5	0.47	0.9
2.5	1.3	1500	0.01	127	96	85	3.5	0.59	0.9
1.8	1.3	2000	0.01	127	96	85	3.5	0.59	0.9
1.5	1.3	2500	0.01	127	96	85	3.5	0.59	0.9
1.2	1.3	3000	0.01	127	96	85	3.5	0.59	0.9
1.1	1.3	3500	0.01	127	96	85	3.5	0.59	0.9
0.7	1.3	2500	0.005	127	96	85	3.5	0.59	0.9
1.2	1.3	2500	0.008	127	96	85	3.5	0.59	0.9
1.8	1.3	2500	0.012	127	96	85	3.5	0.59	0.9
2.2	1.3	2500	0.015	127	96	85	3.5	0.59	0.9
2.6	1.3	2500	0.018	127	96	85	3.5	0.59	0.9
1.7	1.2	2500	0.01	127	96	85	3.5	0.59	0.9
1.5	1.3	2500	0.01	127	96	85	3.5	0.59	0.9
1.3	1.4	2500	0.01	127	96	85	3.5	0.59	0.9
1.1	1.5	2500	0.01	127	96	85	3.5	0.59	0.9
1.0	1.6	2500	0.01	127	96	85	3.5	0.59	0.9

Walker and Duncan, (1984). Lateral bulging of earth dams, ASCE Journal of Geotechnical Engineering

Delta-x	Mid-height horizontal movement (feet)
	Sensitivity variable

C (UU-TXC) Sigma3 = 0.25(gamma)H
Ks and Km from Tables 4 and 5

1.5 to 1.8 Best Estimate

Low Level Outlet – Joint Extensibility

Reference: USDA Technical Release No. 18 (Rev.) Aug. 27, 1969

Purpose: Estimate LLO extension due to lateral deformation of dam and foundation

Parameters in Procedure:

δ = Foundation settlement = 1.4′ (1/20/17 Memo)
B = Dam Width = 748′ (1/20/17 Memo)
D_o = O.D. Conduit = 14.9′ (1/20/17 Memo)
D = I.D. Conduit = 9.2′ (1/20/17 Memo)
H = Dam height = 96′ (1/20/17 Memo)
γ_m = Dam unit weight = 127.3 lb/ft^3
d = Compressible foundation depth = 21′ (1/20/17 Memo)
s = Undrained foundation shear strength = 2,088 psf (prelim. report)
L = Monolithic conduit length = 29.5′ (Sketch from V.S. 2/13/17).
P = Vertical pressure at base of dam = $H \times \gamma_m$ = 12,221 psf
R_1 = Strain ratio = 0.082 (from chart in procedure)
R_2 = Stress ratio
g_s = Joint opening due to strain
g_r = Joint opening due to rotation
S = Safety margin
J = Required joint extensibility

$B/d = 747.8'/21.5' = 34.8 \qquad B/H = 747.8'/96' = 7.8$

R_1 = 0.082 for B/d and B/H from chart in procedure

$$R_2 = \frac{2 \cdot p \cdot d}{s \cdot B} = 2 \cdot 12{,}221\,\text{psf} \cdot 1.4' / 2{,}088\,\text{psf} \cdot 748' = 0.44$$

Low Level Outlet - Joint Extensibility (Cont'd)

$\varepsilon_{hm} = R_1 \cdot R_2 \cdot \delta/d = 0.082 \cdot 0.44 \cdot 1.4'/21' = 0.0023$

$g_s = \varepsilon_{hm} \cdot L \cdot 12 = 0.0023 \cdot 29.5' \cdot 12 = 0.83''$

$g_r = 2.5 \cdot D_o \cdot \delta / B = 2.5 \cdot (14.9' \times 12) \cdot 1.4'/748' = 0.84''$

$S = \frac{1}{2} \cdot 2 \cdot p \cdot d/(s \cdot B) + C_H + C_D$ $(C_H = 0\ (H < 100'))$

$S = 0.5 \cdot 2 \cdot 12{,}221\,psf \cdot 21'/(2{,}088\,psf \cdot 748')$ $(C_D = 0\ (H > 30'))$ } $S_{min} = 0.5''$

$S = 0.17 \rightarrow S_{min} = 0.5$

$J = g_s + g_r + S = 0.83'' + 0.84'' + 0.5'' = 2.16''$

* Checked Exel spreadsheet with example in procedure.

Low Level Outlet – Joint Extensibility

Reference: Lateral Bulging of Earth Dams, Walker & Duncan, 1984

Purpose: Estimate LLO extension due to lateral deformation of dam

Simplified procedure to estimate amount of lateral bulging at midpoint height of dam. Since we are interested in deformation at lower 15' of dam where LLO is located, we will need to take a percentage of the estimated amount.

$$\Delta x = K_S \cdot K_m \cdot \varepsilon_{50} \cdot \frac{\gamma \cdot H^2}{C \cdot F^2} \quad \text{(feet)}$$

K_s = function of saturation (from 75% to 100%) of embankment material

K_m = function of embankment side-slope = 0.9 for 3.5H:1V.

ε_{50} = Strain level at 50% strength from UU-TX test of embankment material with $\sigma_3 = 0.25 \cdot \gamma_m \cdot H$
H = Dam height, γ_m = Dam Unit Weight

H = 96', γ_m = 127.3 pcf

Based on UU Tests completed on foundation materials, ε_{50} varied from 0.5% to 3.0%.

Compacted foundation materials are assumed to have similar strength/strain characteristics.

Designed by: Maurice Amendolagine Checked by:

Low Level Outlet – Joint Extensibility (Cont'd)

C = Undrained shear strength (UU-TX) of compacted clay foundation material, with $\sigma_3 = 0.25 \cdot \gamma_M \cdot H$
$= 3{,}048$ psf

S_U from UU-TX Tests on undisturbed clay foundation material varies from: 2,700 psf to 13,580 psf. Most below 5,000 psf. σ_3 varies from 1,566 psf to 13,575 psf, most above 6,000 psf.

∴ I selected an average $S_U = 2{,}500$ psf, and varied from 1,500 psf to 3,500 psf.

F = Factor of safety for embankment stability at the end of construction.

F = 1.3

For Base Case Conditions, I selected the following:

$F = 1.3$, $S_U = 2{,}500$ psf, $\varepsilon_{50} = 1\%$, $S = 85\%$

$$\Delta z_{\text{Base Case}} = K_S \cdot K_M \cdot \varepsilon_{50} \frac{\gamma H^2}{C F^2} = 0.59 \cdot 0.9 \cdot 0.01 \cdot \frac{127.3 \cdot 96^2}{2{,}500 \cdot 1.3^2}$$

$$= 1.5'$$

Each of the variable parameters were varied individually, and the resulting deformation varied between 1.0' and 2.6'.
(See spreadsheet for calculations).

Low Level Outlet - Joint Extensibility (Cont'd)

The estimated deformation is at the dam mid-height, which is where the maximum deformation is estimated.

We are interested in the lower 15'. The USBR (DS13-9) states the lateral deformation is maximum at mid-height, and decreases to Ø at thes base of the dam. Therefore, we consider a relatively conservative estimate at the base of the dam would be ~ 1/3 of the predicted mid-height lateral deformation.

Therefore: $\Delta_x = 1/3 \cdot 1.5' = 0.5'$ (6")

at the LLO.

United States Department of Agriculture
Soil Conservation Service
Engineering Division
Design Branch

Technical Release No. 18 (Rev.)
August 27, 1969

COMPUTATION OF JOINT EXTENSIBILITY REQUIREMENTS

This technical release presents the procedure and working tools required for the computation of the joint extensibility that may be required in a drop inlet barrel constructed of articulated segments which are essentially free to move with the adjacent parts of the embankment or earth foundation. The discussion and procedures that are established for determining the depth "d" in which foundation compression occurs, the average foundation shear strength "s" as used to compute foundation stress ratio, and the corresponding foundation settlement "δ" relate only to the computation of the required joint extensibility of conduits on yielding foundations. The foundation is considered as a body and conduit cuts or pads are not considered as influencing the total foundation deformations. These procedures do not necessarily apply to situations involving a determination of total foundation settlement.

An explanation of the strains produced at or near the interface of an earth dam embankment and its compressible foundation is contained in two reports. They are (1) "Report on Investigation of Deformations in Foundations of Earth Embankments Containing Concrete Pressure Pipe Conduits" by Moran, Proctor, Mueser and Rutledge, Consulting Engineers, dated September 1960 and (2) "Report on Study of Movements of Articulated Conduits Under Earth Dams on Compressible Foundations" by Mueser, Rutledge, Wentworth and Johnston, Consulting Engineers, dated June 1968. These reports provide the basic data and procedure which are used herein to estimate joint extensibility requirements.

The depth of the compressible foundation, d, will be obvious in some cases but in others it may be obscure until consolidation computations based on proper evaluation of foundation conditions and laboratory tests indicate the depth below which consolidation may be neglected. When the compressive unit strain in feet per foot in any stratum under the center of the embankment and at a depth of about 0.25H or more becomes less than 10 percent of the compressive unit strain of the strata above, and strata with a higher compressive unit strain do not exist below the stratum in question, it may be assumed that the depth of the compressible foundation has been attained. Obviously judgment is required in estimating d and the consolidation potential of the foundation. Relatively large consolidation can be expected on loessial soils which have not been preloaded, medium stiff residual soils or special fine grained material such as glacial lake deposits whereas relatively low or insignificant consolidation should be anticipated from ordinary SCS dams on glacial till, stream terraces, or alluvial coarse sands and gravels.

It is important that the maximum settlement, δ, be estimated with reasonable accuracy. A quotation from page 39 of the 1968 report reads as follows, "It is recommended that the settlement analysis concentrate attention on the evaluation of the probable preconsolidation condition determined from consolidation tests, but also utilizing geological evidence and data from undrained shear tests. If it can be estimated that the foundation is overconsolidated, a nominal value of recompression index should be used in computing settlements, rather than to estimate Δe directly from the e - log p curve." The straight-line semi-log recompression index ordinarily may be estimated within the range from 0.04 for lightly over-consolidated plastic clays to 0.015 for heavily over-consolidated hard or dense mixtures of silt and clay with sand or gravel. The recompression index is a dimensionless parameter which equals the void-ratio decrement for one cycle of increase of effective stress.

The shear strength of the foundation, s, must be estimated as realistically as possible. The shear strength in question is an average strength of the weakest stratum in the foundation at or near the interface with the embankment. Mr. Homer Cappleman estimated in a paper titled "Movements in Pipe Conduits Under Earth Dams" published in Journal, Soil Mechanics and Foundations Division, ASCE, November 1967, that foundation strata at a depth of more than 0.1B could be ignored in this determination.

If the size of the earth dam justifies fairly extensive testing of undisturbed samples of foundation soils, the shear strength may be estimated as follows. The probable average shear strength at the end of construction under a small earth dam is obtained from a consolidated-undrained triaxial test in which the chamber pressure is set equal to about two-thirds the average effective stress, $\bar{p}$, at the depth in question.

The average effective stress, $\bar{p}$, at the completion of the embankment is

$$\bar{p} = \frac{H}{2}\gamma_m + y\gamma_f' \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

Where

$\bar{p}$ = average effective stress on stratum in lb./ft.^{2}

y = depth into the foundation from the embankment-foundation interface to the stratum in question in feet.

γ_f' = submerged weight of foundation material in lb./ft.^{3}

If detailed strength testing is not justified, the shear strengths may be estimated from preconsolidation data in the following manner. The preconsolidation stress, P, has a very significant effect on shear strength and may be used to determine the average shear strength for silts, clays and other fine grained soils with a high percentage of silt or clay or both. For soils in which the preconsolidation stress exceeds the load to be applied by the embankment, the shear strength, s, should be taken as 0.3P. For underconsolidated soils where the preconsolidated stress is less than applied load, the shear strength should be taken as 0.3 of the effective stress at the stratum in question and under the midheight of the earth dam embankment (the average effective stress) multiplied by a factor C which ranges between 0.75 and 0.9.

$$s = 0.3\bar{p}C \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

The factor C is estimated between 0.75 and 0.9 from a consideration of the depth of the stratum and the strength of the material between it and the interface. If the stratum under consideration is just below the interface the factor C should be taken as 0.75 where as if it is a depth y which approaches 0.1B and the strength of foundation strata above are significantly greater, then C should be taken as 0.9.

Consolidation tests of undisturbed samples from the various foundation strata will indicate the preconsolidation stress. Geologic history of the site is valuable in predicting the possibility of preconsolidation and its order of magnitude as a check against the consolidation test data. Recent alluviums may indicate moderate preconsolidation to a depth of several feet due to dessication, having strata below with little preconsolidation and low shear strength that were deposited in water and have had little opportunity to dry out.

Compute joint extensibility requirements in conformance with the following procedure.

<u>Step 1</u>. Compute the following ratios, $B \div d$, $B \div H$, $\delta \div d$, $(2pd) \div sB$ and $p = H\gamma_m$

<u>Step 2</u>. From ES-146 read, R_1, the theoretical ratio of maximum unit horizontal strain to average unit vertical strain, $\delta \div d$.

<u>Step 3</u>. Compute R_2, a factor which corrects for the effect of the foundation stress ratio, $\frac{2pd}{sB}$, on the theoretical ratio R_1.

$$R_2 = \frac{2pd}{sB} + 0.10 \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

<u>Step 4</u>. Compute ϵ_{hm}, the maximum unit horizontal strain.

$$\epsilon_{hm} = R_1 \cdot R_2 \cdot \frac{\delta}{d} \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

Step 5. Compute g_s, the maximum probable joint opening due to foundation and embankment strain

$$g_s = \epsilon_{hm} \cdot 12 \cdot L \qquad (5)$$

where L is the length of a section of conduit in feet. It is assumed that the articulated conduit under the major part of embankment is made up of sections of equal length, L.

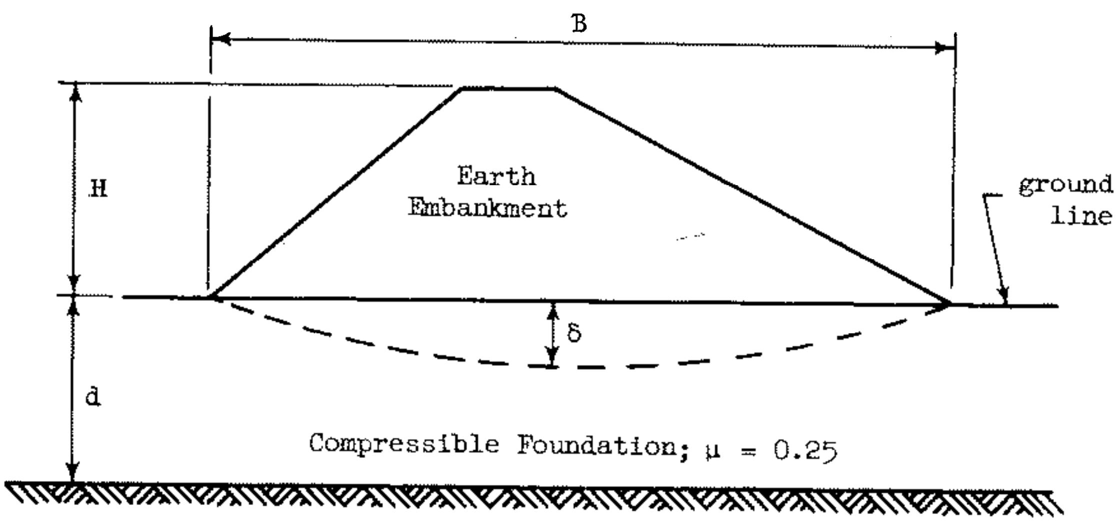


Fig. 1 Definition sketch

Available evidence indicates that, as the conduit (barrel) settles, the induced rotation in the joints is not consistent but rather is quite irregular to the extent that in some cases the rotation is opposite to the anticipated direction. This situation probably is due to localized irregularities in the foundation, its consolidation potential, and the effect of anti-seep collars on differential settlement of the conduit.

Step 6. The probable joint opening due to joint rotation, g_r, in inches may be computed from the following equation which was derived from experimental data

$$g_r = \frac{2.5 D_o \delta}{B} \qquad (6)$$

where D_o = outside diameter or vertical height of conduit in inches.

Step 7. The required joint extensibility, J, in inches is given by the following equation

$$J = g_s + g_r + S \qquad (7)$$

where S is the safety margin in inches. The safety margin, S, is the larger value given by equation (8) or the requirements of Engineering Memorandum-27.

$$S = \frac{1}{2} \cdot \frac{2pd}{sB} + C_H + C_D \quad . \quad . \quad . \quad . \quad . \quad (8)$$

where

$$C_H = \frac{h - 100}{100} \text{ for } (H > 100)$$

$$= 0 \text{ for } (H \leq 100) \quad . \quad . \quad . \quad . \quad . \quad (9)$$

$$C_D = \frac{30 - D}{30} \text{ for } (D < 30)$$

$$= 0 \text{ for } (D \geq 30) \ . \quad . \quad . \quad . \quad . \quad . \quad (10)$$

The required joint length (EM-27) is equal to the required joint extensibility plus the maximum joint gap permitted when the pipe is installed.

Nomenclature Summary:

B = equivalent base width of embankment in feet.

C = coefficient (see equation 2)

C_H = a part of the safety margin in inches (see equation 9)

C_D = a part of the safety margin in inches (see equation 10)

d = depth of the compressible foundation, i.e. that depth in the foundation below the interface, below which additional significant settlement does not occur, in feet.

D = internal diameter or inside vertical height of conduit in inches

D_o = maximum outside diameter or vertical height of conduit in inches

g_s = maximum probable joint opening due to foundation and embankment strain in inches (see equation 5)

g_r = probable joint opening due to joint rotation in inches (see equation 6)

H = height of earth embankment in feet

J = required joint extensibility in inches (see equation 7)

L = length of a monolithic section of conduit in feet

P = preconsolidation stress in pounds per square foot

p = $H\gamma_m$ = maximum vertical pressure at the interface in pounds per square foot

$\bar{p}$ = average effective stress on stratum at depth y in pounds per square foot

R_1 = theoretical ratio of maximum unit horizontal strain to average unit vertical strain, $\delta \div d$

R_2 = a correction factor for the effect of the foundation stress ratio on R_1 (see equation 3)

s = average consolidated undrained foundation shear strength at the condition of completion of the embankment in pounds per square foot

S = safety margin in inches (see equation 8)

y = depth into the foundation from the embankment-foundation interface to the stratum in question in feet

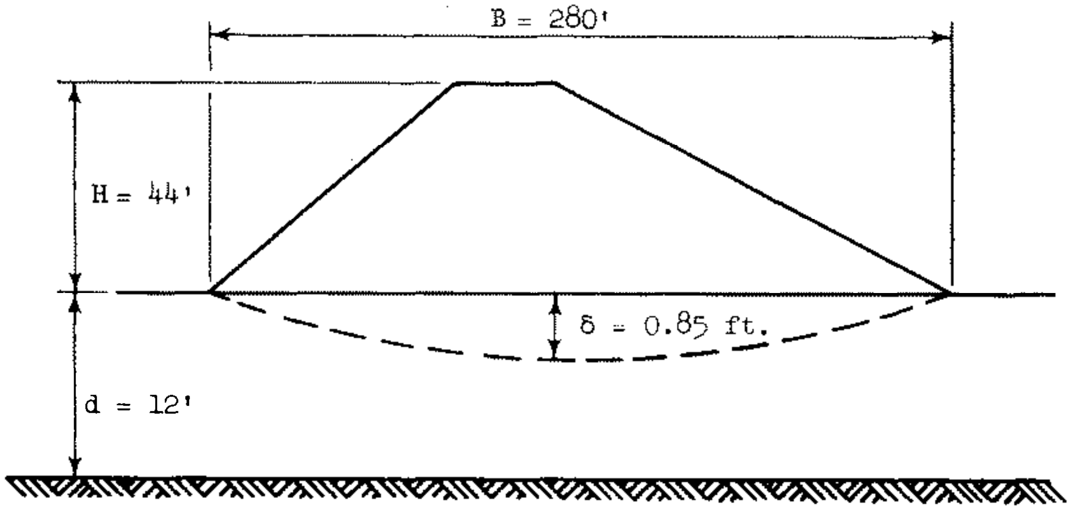
ϵ_{hm} = maximum unit horizontal strain

δ = maximum anticipated settlement of the foundation surface in the vicinity of the conduit in feet

γ_m = moist weight of the embankment as built in pounds per cubic foot

γ_f' = average submerged weight of foundation material above depth y in pounds per cubic foot

Example No. 1



Given: B = 280. ft.; H = 44. ft.; d = 12. ft.; δ = 0.85 ft.

γ_m = 115. lb./ft.^{3}; s = 1800. lb./ft.^{2}; L = 16. ft.; D = 48. in.

D_o = 54. in.; class (a) dam;

Find: Required joint extensibility

Procedure:

Step 1. Compute $\frac{B}{d} = \frac{280}{12} = 23.3$; $\frac{B}{H} = \frac{280}{44} = 6.4$; $\frac{\delta}{d} = \frac{0.85}{12} = 0.071$;

$p = H\gamma_m = (44)(115) = 5060.$ lb./ft.^{2};

$$\frac{2pd}{sB} \quad \frac{(2)(5060)(12)}{(1800)(280)} = 0.24$$

Step 2. From ES-146 for $\frac{B}{d} = 23.3$ and $\frac{B}{H} = 6.4$ read $R_1 = 0.123$

Step 3. $R_2 = 0.24 + 0.10 = 0.34$

Step 4. $\epsilon_{hm} = (0.123)(0.34)(0.071) = 0.00297$

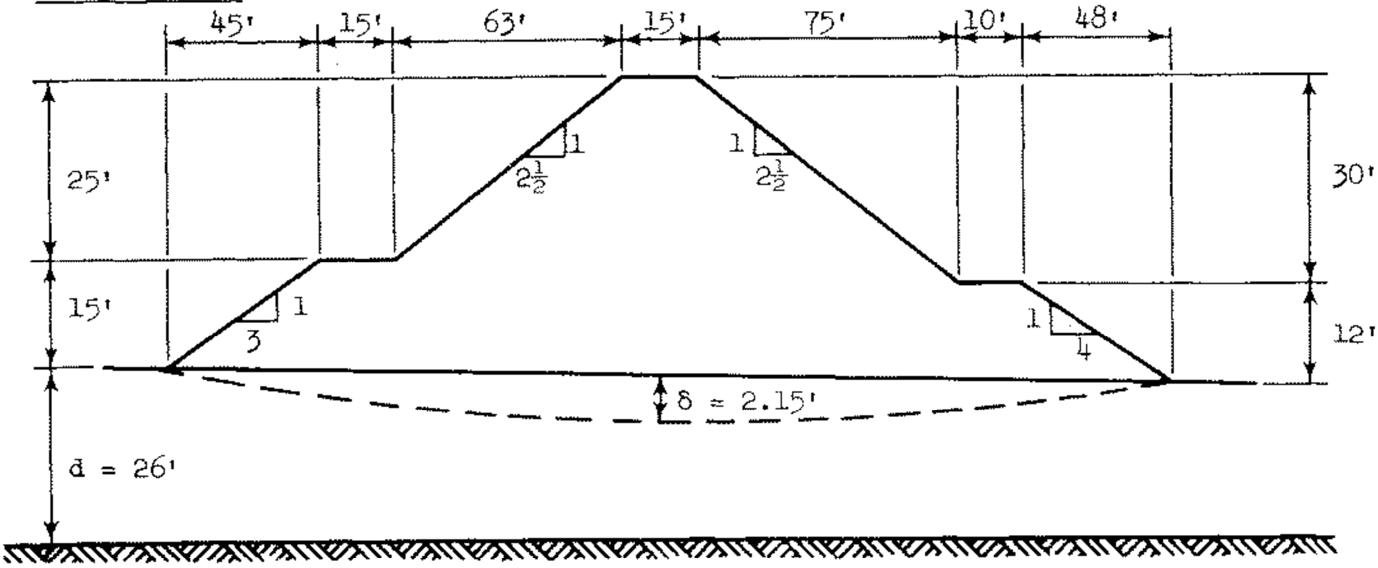
Step 5. $g_s = (0.00297)(12)(16) = 0.57$ inch

Step 6. $g_r = \frac{(2.5)(54)(0.85)}{280.} = 0.41$

Step 7. $S = \left(\frac{1}{2}\right)(0.24) + 0 + 0 = 0.12 < 0.5$ hence use S = 0.5

J = 0.57 + 0.41 + 0.50 = 1.48 inches

Example No. 2



Given: Cross section of earth dam embankment as shown; d = 26. ft.; δ = 2.15 ft.; γ_m = 125. lb./ft.^{3}; s = 1000. lb./ft.^{2}; L = 10. ft.; D_o = 35. in.; D = 30. in. class (c) dam.

Find: Effective B and H and J

H = 41. ft. by inspection

$$B = \frac{\text{2 times cross-sectional area of dam}}{H} = \frac{(2)(5333)}{41} = 260.\ \text{ft.}$$

Procedure:

Step 1. $\frac{B}{d} = \frac{260}{26} = 10$; $\frac{B}{H} = \frac{260}{41} = 6.3$; $\frac{\delta}{d} = \frac{2.15}{26} = 0.083$

$p = H\gamma_m = (125)(41) = 5125.$ lb. per ft.^{2}

Foundation stress ratio, $\frac{2pd}{sB} = \frac{(2)(5125)(26)}{(1000)(260)} = 1.03$

Step 2. From ES-146 for $\frac{B}{d} = 10$ and $\frac{B}{H} = 6.3$ read $R_1 = 0.213$

Step 3. $R_2 = 1.03 + 0.10 = 1.13$

Step 4. $\epsilon_{hm} = (R_1)(R_2)\left(\frac{\delta}{d}\right) = (0.213)(1.13)(0.083) = 0.020$

Step 5. $g_s = (\epsilon_{hm})(L)(12) = (0.020)(10)(12) = 2.40$ inches

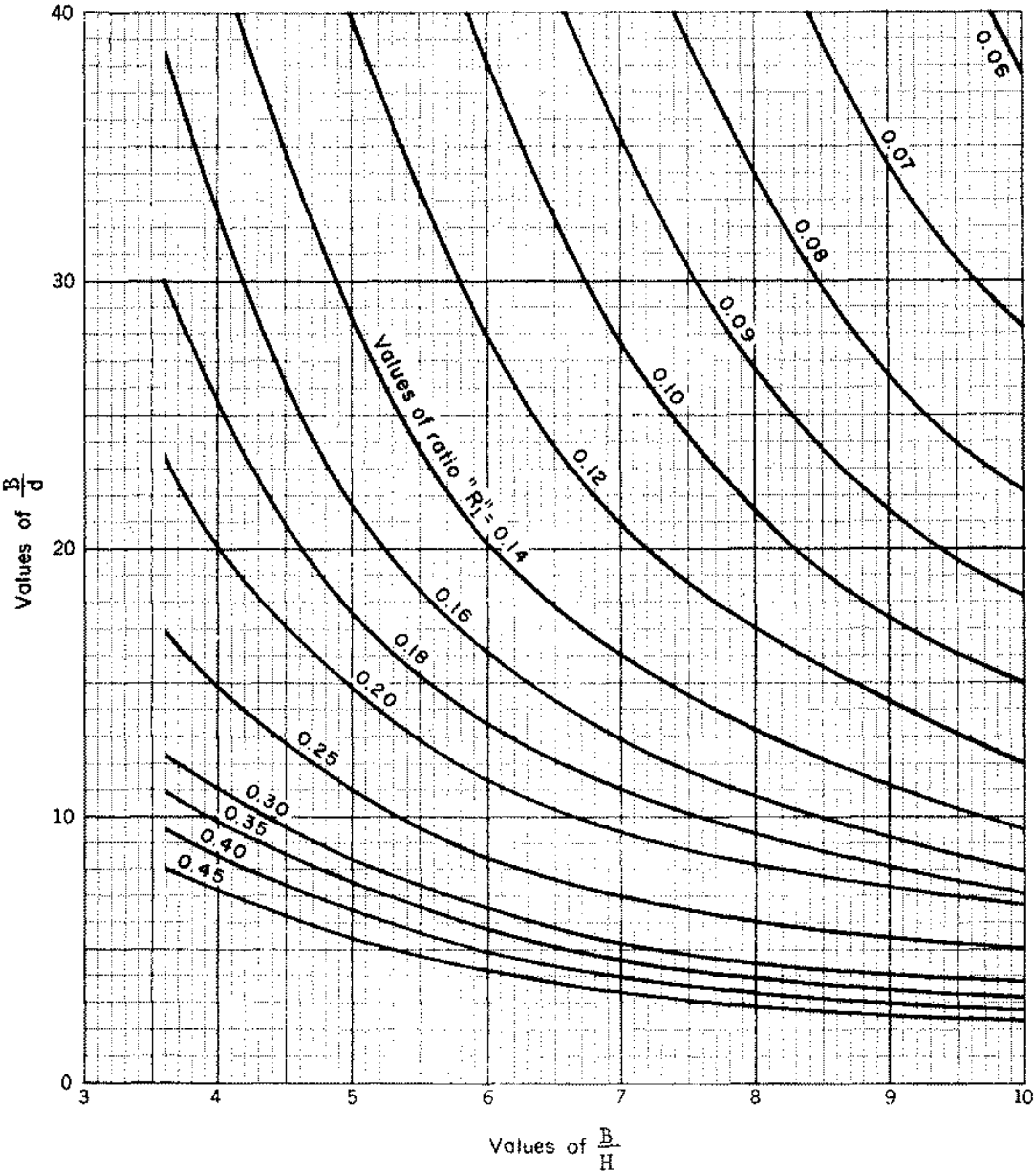
Step 6. $g_r = \frac{2.5 D_o \delta}{B} \quad \frac{(2.5)(35)(2.15)}{260} = 0.72$ inches

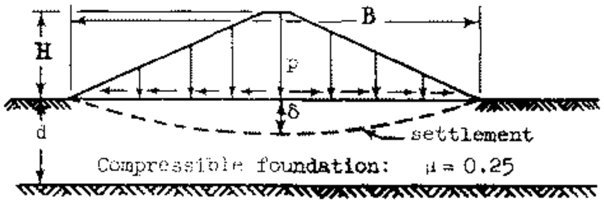
Step 7. $S = \frac{1}{2} \cdot \frac{2pd}{sB} + C_H + C_D$

$= \left(\frac{1}{2}\right)(1.03) + 0 + 0 = 0.52 > 0.5$ use S = 0.52

Step 8. $J = g_s + g_r + S = 2.40 + 0.72 + 0.52 = 3.64$ inches

SOIL MECHANICS: Values of theoretical ratio of maximum unit horizontal strain to average unit vertical strain = R_1 μ=0.25





Maximum average unit vertical strain $\epsilon_{vm} = \delta/d$

REFERENCE "Report on Investigation of Deformatations in Foundations of Earth Embankments Containing Concrete Pressure Pipe Conduits" by Moran, Proctor, Mueser, and Rutledge.	U. S. DEPARTMENT OF AGRICULTURE SOIL CONSERVATION SERVICE ENGINEERING DIVISION - DESIGN SECTION	STANDARD DWG. NO. ES-146 SHEET 1 OF 1 DATE 3-24-61

Attachment 14.3
LLOW Soil Parameters

Recommended Geotechnical Soil Parameters
SR-1 Low Level Outlet Works (LLOW) Structures
25-September-2019

Geotechnical information required for the LLO structural design.

1. <u>Foundation Parameters</u>

- 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: Φ = 27 degrees
  - Lean/Fat Lacustrine Clay: Φ = 23 degrees
- Effective cohesion (c)
  - c = 0 kPa (both soil layers)
- Coefficient of sliding friction (μ)
  - Lean Clay Glacial Till with Sand: μ = 0.51
  - Lean/Fat Lacustrine Clay: μ = 0.42
- Settlement
  - See attachment LLOW settlement profile
- Subgrade Modulus
  - Lean Clay Glacial Till with Sand: 125 lb/in^3
  - Lean/Fat Lacustrine Clay: 100 lb/in^3

2. <u>Bedding, Backfill and Embankment Fill Parameters</u>

- Y_{sat}
  - Embankment Soils: 2039 kg/m^3 or 20.0 kN/m^3 (127.3 lb/ft^3)
- Y_{moist}
  - Embankment Soils: 2039 kg/m^3 or 20.0 kN/m^3 (127.3 lb/ft^3)
- Φ_{eff}
  - Embankment Shell: Φ = 24 degrees
  - Embankment Core: Φ = 28 degrees
- K_o
  - Embankment Shell: K_o = 0.59
  - Embankment Core: K_o = 0.53
- K_a
  - Embankment Shell: K_a = 0.42
  - Embankment Core: K_a = 0.36
- K_p
  - Embankment Shell: K_p = 2.37
  - Embankment Core: K_p = 2.77

- Permeability
  - Embankment Shell: k_v = 1.0 E -07 cm/sec
  - Embankment Core: k_v = 5.0 E -08 cm/sec
  - Lean Clay Till Foundation Soils: k_v = 5.0 E -08 cm/sec
  - Lean/Fat Lacustrine Foundation Soils: k_v = 5.0 E -08 cm/sec

3. <u>Seepage Parameters and Uplift Assumptions</u>

- Relatively minor but unknown uplift due to non-steady state conditions upon first filling/short-term pool

4. <u>Frost Considerations</u>

- Frost depth
  - Recommended design frost depth = 2.0 meters
- Non-frost susceptible backfill
  - Gravel and clean sands

5. <u>Soil Moduli Parameters</u>

- Glacial Till Foundation (Φ = 27 degrees)
- Glacial Till Embankment Core (Φ = 28 degrees)
  - Young's Modulus (E) = 30 MPa
  - Shear Modulus (G) = 10 Mpa
  - Bulk Modulus (K') = 100 Mpa
  - Poisson's Ratio (v') = 0.45

- Lacustrine Foundation (Φ = 23 degrees)
- Lacustrine Embankment Shell (Φ = 24 degrees)
  - Young's Modulus (E) = 20 MPa
  - Shear Modulus (G) = 7 MPa
  - Bulk Modulus (K') = 65 MPa
  - Poisson's Ratio (v') = 0.45
- Weathered Bedrock
  - Young's Modulus (E) = 600 MPa
  - Shear Modulus (G) = 300 MPa
  - Bulk Modulus (K') = 200 MPa
  - Poisson's Ratio (v') = 0.10

6a. <u>Allowable Bearing Capacity - Shallow Continuous Footings</u>

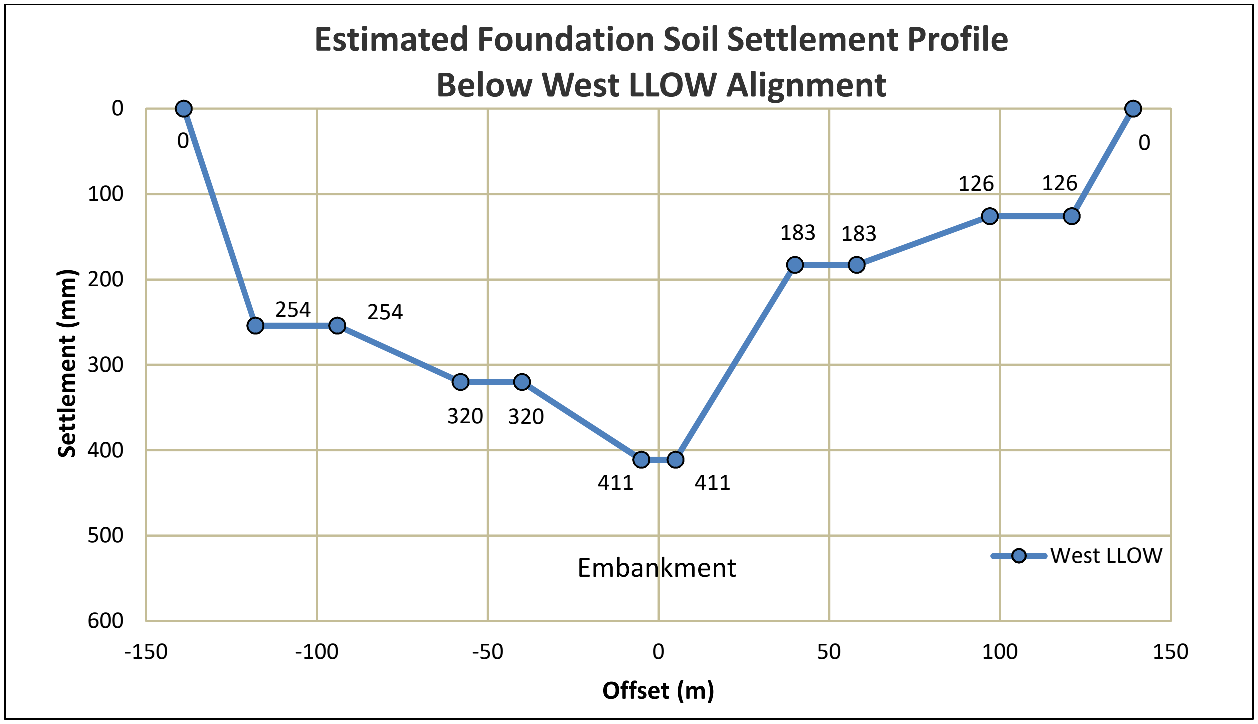
$q_{allowable}$ = 150 kPa (3,133 psf) Long Term (SF = 3.0)

$q_{allowable}$ = 200 kPa (4,177 psf) Short Term (Wind and Seismic Loading)

6b. <u>Allowable Bearing Capacity – LLOW Tower Footing on Stiff Glacial Till</u>

$q_{allowable}$ = 250 kPa (5,221 psf) (Structure Loads Only, No Backfill) (SF = 3.0)

NOTE: Foundation bearing pressures for adjacent spillway conduit and spillway tower structures are recommended to vary no more than 30 kPa (627 psf) within 10 m horizontally to limit potential differential settlement to 1: 480.



Estimated Foundation Soil Settlement Profile
Below West LLOW Alignment
Settlement (mm)
0
100
200
300
400
500
600
-150
-100
-50
0
50
100
150
Offset (m)
0
254
254
320
320
411
411
183
183
126
126
0
Embankment
West LLOW