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Predicting Shrinkage Induced Cracking in Roller Compacted Concrete

Preamble:

The prediction of shrinkage induced cracking in concrete is a relatively conclusive science and is well documented throughout industry. Concrete shrinkage is a significant factor causing internal stresses within concrete. These stresses have the effect of inducing cracks when the stresses exceed the tensile strength of the concrete at often what appears to be random intervals. Concrete shrinkage is a result of a loss in volume precipitated generally by chemical reactions decreasing total volume and dehydration decreasing moisture content. The frequency and widths of shrinkage induced cracks can be understood to be determined by the degree of shrinkage, the location and effect of restraint (forces preventing shrinkage), and the maturity of the concrete when the shrinkage induced forces exceed the tensile strength of the concrete.

Introduction:

Much of the discussion taking place with respect to shrinkage induced cracking in concrete used for feeding pen hydraulic conductivity reduction surface liners is in relation to Roller Compacted Concrete. It should be understood that traditional slump concrete and roller compacted concrete have most of the same physical properties. The raw materials are essentially the same, consisting of: well graded aggregates; Portland cement; water; and may contain admixtures and supplemental cementing materials. Proportions of materials are similar with a general rule that roller compacted concrete can have a lower cement content when compared to traditional slump concrete for the same compressive and flexural strength. The density of roller compacted concrete is generally higher than traditional slump concrete. The permeability of roller compacted concrete is considered to be almost identical to traditional slump concrete. The chemical reactions that occur in traditional slump concrete are identical to those in roller compacted concrete. The complete crystalline structure forming the mechanical properties of traditional slump concrete and roller compacted concrete are essentially the same. The significant difference between traditional slump concrete and roller compacted concrete is the method of consolidation. Traditional slump concrete is (normally) consolidated through internal vibration using internal mass to settle the homogenized mixture. Roller compacted concrete is consolidated with external compaction forces using externally applied masses and often vibrator forces. These high compaction forces generally succeed in compacting roller compacted concrete more than is possible with internal consolidation of traditional slump concrete. As a result, it should be concluded that principles relative to traditional slump concrete are applicable to roller compacted concrete. Therefore, correctly produced, and installed concrete will be free of voids, have a consistent density and have consistent mechanical properties including low permeability. This is the case for roller compacted concrete and traditional slump concrete similarly.

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Shrinkage Considerations:

For clarity, some of the factors affecting shrinkage induced cracking within concrete are:

- Age of concrete at time of placement
- Age of concrete when drying starts, usually taken as the age at the end of moist curing
- Age of concrete at loading
- Aggregate content in concrete
- Cement content in concrete
- Cement type – shrinkage constant
- Concrete mean compressive strength at 28 days
- Curing method
- Relative humidity
- Shape of specimen
- Volume-surface ratio
- Water / Cement ratio
- Air Content
- Creep Coefficient
- Unit Density
- Aggregate Geological qualities
- Aggregate Classification
- Aggregate Geometry
- Supporting surface qualities
- Constraining embedment's

There are two preferred methods to estimate shrinkage of concrete:

- ACI 209.2 Guide for Modeling and Calculating Shrinkage and Creep in Concrete is a reference tool to accomplish this and utilizes most of the factors affecting shrinkage induced cracking.
- Calculating Creep *EN 1992-1-1:2004, Annex B, B.1 (1)* and Concrete shrinkage according to *EN 1992-1-1:2004, 3.1.4 (6) and EN 1992-1-1:2004, Annex B, B.2 (1)*.

Both ACI 209.2 and EN 1992-1:2004 are considered reliable enough to complete accurate calculations. It should be noted that both calculations will identify the shrinkage in a percent of the total area. The attached graph depicts the potential shrinkage for two separate samples of concrete identified below.

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Conclusions:

The following conclusions can be made, many from the calculated results:

- Time during transport of concrete increases the total shrinkage.
- The distance between cracks across a surface is somewhat inversely proportional to the crack width, in other words, the further the cracks are apart the wider the cracks will be.
- The crack width is quite proportional to concrete strength, in other words, stronger concrete means larger cracking and wider cracks.
    - the higher the cement content, it is assumed the higher the water content resulting in a greater loss in mass and a greater degree of chemical shrinkage
    - Roller compacted concrete should be expected to have lower degree of cracking when compared to traditional slump concrete because of the reduced cement content and often reduced water content.
    - The larger the loss in mass due to drying shrinkage and autogenous shrinkage, resulting in more cracking.
- Approximately 50% of shrinkage is induced during initial 28 days
    - It is predictable that most cracks induced by shrinkage induced stresses occur in the first 48 hours.
    - Most of the shrinkage cracks would grow from micro cracks (not visible) to macro cracks (visible) within the first 28 days.
- Approximately 85% of shrinkage is induced during the first 5 years.
    - It would predictable that any further shrinkage cracking would be minimal during the remainder of the life of the concrete surface.
- It is readily predictable that a crack width of 15mm caused by shrinkage is realistically impractical and therefore improbable.

Table 1 Shrinkage VS Age at 25 MPa

Concrete Strength of 25 MPa at 28 days				
AGE	Crack	3 meters between cracks	6 meters between cracks	12 meters between cracks
Days	Percentage	Crack Width mm	Crack Width mm	Crack Width mm
28	0.025%	0.41	0.82	1.65
365	0.037%	0.62	1.25	2.50
1825	0.041%	0.68	1.36	2.71
3650	0.044%	0.73	1.46	2.92
7300	0.049%	0.83	1.65	3.31

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Table 2 Shrinkage VS Age at 40 MPa

Concrete Strength of 40 MPa at 28 days				
AGE	Crack	3 meters between cracks	6 meters between cracks	12 meters between cracks
Days	Percentage	Crack Width mm	Crack Width mm	Crack Width mm
28	0.049%	0.82	1.64	3.28
365	0.074%	1.23	2.47	4.94
1825	0.078%	1.30	2.60	5.19
3650	0.080%	1.34	2.68	5.36
7300	0.085%	1.42	2.85	5.69

Factors used in Calculations:

Concrete Strength	See Graph
Age of Concrete	See Graph
Cement Type	Normal HS
Relative Humidity	50%
Cross Section of Concrete	3728 m2
Perimeter of cross Section	246 m
Age of Concrete when loaded	28 days
Age of Concrete at drying	7 days.

For more information please contact the author

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