Performance of Concrete Rehabilitation using Rapid Setting CalciumSulfoAluminate Cement at the Seattle-Tacoma Airport

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Abstract

This paper summarizes the results from an experimental study on the behavior of concrete pavement in a controlled environment. The test program characterizes the volume change or dimensional properties of selected concrete materials, evaluating their performance as real pavements in that they are exposed to the controlled environment on the top surface and to the ground moisture on the bottom surface. The concrete mix designs examined included normal-strength Portland cement concrete (PCC), high-strength concrete (HSC), concrete using shrinkage reducing admixtures (SRA), and concrete using Calcium sulfoaluminate cement (CSA). The data includes standard concrete material characterization test results, joint movements, internal relative humidity and temperature over the pavement depth. It was found that the concrete using CSA was very stable with no long term shrinkage, cracking or warping, while typical PCC and HSC continued to show crack growth at over 600 days of age. The concrete using SRA had a minor decrease in shrinkage and crack growth at an early age, and while this decrease extended for the length of the testing no further decrease in the shrinkage growth or sectional stability was noted when compared to normal PCC at the end of approximately two years.
1. Introduction

Drying shrinkage is one of the common causes of cracking in concrete slabs-on-ground including pavements. As concrete dries, the water mix in concrete begins to evaporate from the top surface of concrete. Therefore, a moisture difference is generated between the top and bottom surface of the slabs. This causes a dimensional or “shrinkage” gradient to develop into the slabs (Carlson, 1938; Tremper and Spellman, 1963; Ytterberg, 1987). Because the concrete surface is restrained by many factors such as friction between bottom surface of slab and subgrade, form work or surrounding objects and moisture difference through the depth of the slab, it resists the effects of shrinkage. Therefore, an additional tension applies to the concrete. As the tensile stress in the concrete exceeds the tensile strength of the concrete, cracking and warping occurs (ACI, 2008).

Shrinkage is the most important factor influencing warping, curling and cracking of slabs or pavements (Mailvaganam et al., 2002). In this research, warping is defined as a phenomenon occurring due to uneven moisture conditions in the slab, whereas curling is defined as a phenomenon occurring due to the uneven temperature through the depth of a slab. Warping and curling have major effects on serviceability and performance of the concrete slabs-on-ground, necessitating their maintenance and repair. Drying shrinkage, a type of shrinkage in concrete, is one of the major causes of cracks in concrete particularly in slabs-on-ground. Shrinkage does not begin at the time of loading or drying; rather, it starts immediately after cement and water come in contact during the concrete mix (Ramseyer, 1999; Holt, 2001).

Prediction of drying shrinkage in concrete is difficult because many affecting factors are involved. According to many researchers (Tremper and Spellman, 1963; Hansen, 1987; Hart, 1928; Meininger, 1966; Neville, 2000; Powers, 1959; Washa, 1955), the amount of water per unit volume of concrete or the ratio of water to cement has a significant effect on the shrinkage process of concrete. Also, the amount of cement per unit volume is one of the most important factors contributing to shrinkage (Mailvaganam et al., 2002; Troxell et al., 1968; Nagataki, 1970). Thus, concrete shrinkage increases with using more water and cement (paste) in concrete. The moisture content of the sub-base has also an important effect on the drying shrinkage and curling moment of the concrete (Nagataki, 1970; Suprenant, 2002). As the shrinkage gradient rises the curling moment of concrete increases (Carlson, 1938; Keeton, 1979). Also, temperature and relative humidity at the surface of the slab, along with moisture content in the sub-base, greatly affects the amount of curling at slab edges (Mailvaganam et al., 2002; Suprenant, 2002).
As described in the preceding paragraphs, there have been numerous analytical and experimental investigations to characterize drying shrinkage as a material property. There, however, are not enough data to evaluate the strains and stresses within concrete subjected to moisture gradients and restrained shrinkage. Given this gap, this research provides an opportunity to improve our understanding of warping and our ability to predict its effects.

The general objectives of this research are:

(1) To provide reliable warping data in a controlled environment for typical Portland cement concrete, high-strength concrete, Portland cement concrete with shrinkage reducing admixture, and Portland cement concrete with calcium sulfoaluminate cement (also known as “shrinkage compensating concrete”);

(2) To investigate a representative selection of shrinkage magnitude for concrete;

(3) To develop a better understanding of ASTM C 157 and C 878 test methods (ASTM, 2008) versus the “shrinkage from time zero” test method; and

(4) To characterize behavior of slabs-on-ground for the selected materials where shrinkage and warping are a concern.

This paper summarizes the research for seven large-scale test specimens of slabs-on-ground with the six selected concrete mixtures monitored for approximately 2 years. This research follows the test protocol of Bissonnette et al. (2007) for slabs-on-ground with more realistic conditions. The main variables of the investigation are the concrete composition (Portland cement concrete, high-strength concrete, concrete with shrinkage reducing admixtures, and concrete with calcium sulfoaluminate cement). The items monitored for the investigation include visual observation of cracks; surface strains obtained using Demec target strain gauges; interior relative humidity and interior temperature in 12.7 mm increments through the depth of a slab; compressive strength; unrestrained and restrained expansion; and shrinkage from time zero test results. This was done in order to obtain as much information as possible for a better understanding of warping and shrinkage, to enhance the prediction of its effects, and to compare the dimensional stability sensitivity of various materials.
2. Experimental program

2.1 Concrete mixtures and materials

Six concrete mixtures were selected for the investigation: normal-strength Portland Cement Concrete (PCC), High-Strength Concrete (HSC), normal concrete mixes with two types of Calcium SulfoAluminate cement [Komp I and Rapid Setting CSA Cement] (CSA and RSCC), and normal concrete mixes with two types of common Shrinkage Reducing Admixtures [Eclipse and Tetraguard] (SRA #1 and SRA #2). The only difference between PCC and concrete mixes with SRAs is adding SRAs to the same PCC mixes. The concrete mixes used in this research are summarized in Table 1. The mixtures (CSA and RSCC) using two types of calcium sulfoaluminate cement, Komp I(CSA), a so-called shrinkage compensating concrete and Rapid setting CSA cement (RSCC) which were made in the mixer at the laboratory. The rest of the concrete mixtures (PCC and HSC) using normal-strength and high-strength concrete were provided by a local ready mix concrete company in Oklahoma.

Table 1 Concrete mixes for slab specimens.

<table>
<thead>
<tr>
<th>Materials (kg/m³)</th>
<th>SRA #1</th>
<th>SRA #2</th>
<th>PCC</th>
<th>HSC</th>
<th>CSA-a</th>
<th>CSA-b</th>
<th>RSCC</th>
</tr>
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<tbody>
<tr>
<td>Komp I</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>71.2</td>
<td>71.2</td>
<td>-</td>
</tr>
<tr>
<td>Portland Cement</td>
<td>211.1</td>
<td>210.5</td>
<td>210.5</td>
<td>322</td>
<td>219.4</td>
<td>219.4</td>
<td>-</td>
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<tr>
<td>Fly Ash</td>
<td>52.2</td>
<td>52.2</td>
<td>52.2</td>
<td>106.7</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Rapid setting CSA Cement</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>390.2</td>
</tr>
<tr>
<td>Citric Acid</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>2.97</td>
</tr>
<tr>
<td>Course Aggregate 57</td>
<td>1097.1</td>
<td>1097.1</td>
<td>1097.1</td>
<td>1097.1</td>
<td>1037.8</td>
<td>1037.8</td>
<td>1050.8</td>
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<tr>
<td>Sand</td>
<td>867.6</td>
<td>867.6</td>
<td>867.6</td>
<td>709.2</td>
<td>779.8</td>
<td>779.8</td>
<td>775.1</td>
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<tr>
<td>Water</td>
<td>157.7</td>
<td>157.7</td>
<td>157.7</td>
<td>156.6</td>
<td>160.1</td>
<td>161.3</td>
<td>172</td>
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<tr>
<td>MR (Polyheed 1020 (L/m³))</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>2.48</td>
<td>2.5</td>
<td>2.04</td>
</tr>
<tr>
<td>MR (Pozzolith 80 (L/m³))</td>
<td>0.5</td>
<td>0.54</td>
<td>0.54</td>
<td>1.12</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Eclipse (L/m³)</td>
<td>4.95</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Tetruguard (L/m³)</td>
<td>-</td>
<td>4.95</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Water-to-cement ratio (MPa)</td>
<td>0.023</td>
<td>0.023</td>
<td>0.023</td>
<td>0.014</td>
<td>0.021</td>
<td>0.021</td>
<td>0.017</td>
</tr>
<tr>
<td>28 day compressive strength (MPa)</td>
<td>26.2</td>
<td>23.8</td>
<td>21.7</td>
<td>36.2</td>
<td>41</td>
<td>39</td>
<td>69</td>
</tr>
</tbody>
</table>
2.2 Characterization tests for materials

A number of characterization tests, as listed in Table 2, were developed in the investigation to typify the materials. The characterization tests followed ASTM standard tests such as compressive strength test (ASTM C 39), length change test (ASTM C 157), and restrained expansion test (ASTM C 878). Therefore, cylinders and prism test specimens were filled with the concrete from each batch. The ASTM test measurements began at the first few hours after placing concrete into the form according to the test method description. Also, the shrinkage from time zero method was used for the purpose of characterizing the materials. Test specimens were made 75 x 75 x 325 mm. A 25 mm plastic block was placed at one end of the specimen. Therefore, concrete was free to move due to shrinkage at this end (free end). A steel plate (form) on the other end of specimen restrained the concrete in shrinkage and expansion provided fixed end (Figure 1). Two bolts were screwed at the center of the ends. The bolts were 279 mm apart and were used as the original length of specimens for calculating the strain.

<table>
<thead>
<tr>
<th>Test description</th>
<th>Lab RH &amp; T</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>60% RH 21 °C</td>
</tr>
<tr>
<td>Compressive strength (ASTM C 39)</td>
<td>+</td>
</tr>
<tr>
<td>Length change (ASTM C 157)</td>
<td>+</td>
</tr>
<tr>
<td>Restrained expansion (ASTM C 878)</td>
<td>+</td>
</tr>
<tr>
<td>shrinkage from time zero test method</td>
<td>+</td>
</tr>
</tbody>
</table>

(Figure 1). A dial gauge was installed at the free end (the end with the plastic block) of each specimen and the length change was recorded at the time “zero” which was immediately after placing concrete into the form (Figure 1) and were continued for 110 days. The dial gauge was connected to the bar and bar went through the hole and touched the back of the nut (bolt). The specimens were placed in the chamber at 21°C and 60% relative humidity and were wet cured by placing wet sponges on top of specimens for 7 days. Then the specimens were demolded from the sides (not the ends). The concrete mixes used for the shrinkage from time zero method were similar to the large-scale slab concrete used in this study with the minor exception being due to the type of water reducer used on 4 of the samples.
Figure 1 Shrinkage from time zero test mold and shrinkage from time zero test specimen.

2.3 Slab experiments

Seven slab test specimens of 75 mm x 900 mm x 6000 mm were cast on 100 mm moist compacted sand on the ground (Figure 2). Two slabs (CSA-a and CSA-b) produced with calcium sulfoaluminate cement of Komp I and one slab per other combination of concrete mixes (PCC, HSC, RSCC, SRA #1 and SRA #2) was cast. The slab specimens were located in the test facility with a controlled environmental chamber. The laboratory relative humidity and temperature are generally 60% and 21 ºC. The relative humidity was dropped to 30% for the second year of the investigation as part of the experiment. The purpose of reducing ambient relative humidity was to increase the moisture gradient into the slab due to a lower relative humidity at the top surface of the slab. Slabs were cast in specially designed pits, truly on-grade. The idea was that while the base is kept moist by ground water, the top of the slabs are exposed to the low ambient relative humidity environment in the lab; this increases the moisture gradient in the slab and increases warping.

Figure 2 (a) Slab on 102 mm moist-compacted sand on grade and (b) 225 mm of concrete slab edge restrained by trusses
The slabs were fully restrained longitudinally by casting the test slabs around a transverse steel truss that was attached to the edges and the test pits. The steel trusses shown in Figure 2 transfer all the loads to two D25 reinforcing bars (diameter = 25 mm), cast previously in the existing floor along each edge of the test specimen. The test slab ends were thickened to 230 mm to accommodate this detail (Figure 2). A minimum longitudinal reinforcing steel for temperature ($\varepsilon_s = 0.0015$) was used for all of the slabs. Four 6.35 mm diameter longitudinal reinforcing bars were continuous through the joints. Upon casting the slabs, contraction joints were saw cut 25 mm deep at 1500 mm from each end to provide a 3000 mm long central test section. All the slab specimens except one (RSCC) were cured with wet burlap and a plastic sheet for 7 days. The slab (RSCC) made with Rapid setting CSA cement was cured with spraying water for 4 ~ 5 hours after casting.

Slab monitoring began after 7 days of moist curing. The monitoring consisted of the following: (1) visual observation for surface cracking; (2) surface strain and joint opening measurement in the longitudinal direction using Demec target strain gauges with 178 mm gauge length; (3) internal relative humidity at 12.7 mm increments through the depth of the slab (ASTM F 2170); (4) internal temperature at 12.7 mm increments through the depth of the slab; and (5) ambient relative humidity and temperature. The slab monitoring represented the behavior of slab exposed to the low relative humidity at the top surface and high relative humidity at the bottom surface of the slab. Figure 3(a) shows the location of Demec target strain gauges at mid-span at 1500 mm from the ends and the location of the RH (Relative Humidity) meter at 375 mm from mid-span of the slab. Figure 3(b) shows a profile of the slab deformation due to warping. It displays the end restraints and warping at joint opening.
3. Test results and discussion

3.1 Characterization test results

The ASTM C 39 compressive strength results were recorded for one year, the ASTM C 157 length change results were recorded for approximately 2 years (Figure 4(a)), and the ASTM C 878 restrained expansion results for CSA were recorded during the time the concrete expanded due to the test method description. The ASTM C 157 method is a standard test method for length change of hardened hydraulic-cement mortar and concrete, and the ASTM C 878 method is a standard test method for restrained expansion of shrinkage compensating concrete (CSA). Upon curing the specimens into the limestone and water (saturated water with lime) for 7 days, measurement of length variations was initiated. From Figure 4(a), the comparison between PCC and SRA #1 results represents that SRA #1 had a minimal impact on shrinkage at short term and almost no impact at long term. Therefore, it can be concluded that the shrinkage reducing admixture did not provide a noticeable improvement on reducing over all shrinkage in normal concrete. The HSC shrank in a greater rate in comparison to the other concrete mixes used in this research. The difference between HSC and PCC was due to many issues that affect the shrinkage in HPC, like all types of concrete shrinkage (e.g.,
autogenous shrinkage, porous system, capillary size, paste quantity, etc.) but the increased paste volume in HSC is generally referenced as a leading contributor to the increase in shrinkage (Mailvaganam et al., 2002; Troxell et al., 1968; Nagataki, 1970).

**Figure 4** (a) Unrestrained expansion ASTM C 157 versus time (*PCC, HSC* and *SRA #1*) and (b) restrained expansion ASTM C 878 versus time (*CSA*).

On the other hand, the *CSA* expanded more than 4 times greater than the other concrete mixtures during the first 7 days of curing (Figure 4(b)). It can be expected that the large expansion of *CSA* is able to offset the restrained shrinkage caused by drying shrinkage of concrete at the long term and that the possibility of warping and cracking caused by drying shrinkage is reduced. Note that shrinkage compensating cement concrete (*CSA*) was used for two of the concrete specimens (*CSA-a* and *CSA-b*), and both concrete mixes exhibited similar characteristics. Therefore, all the results showing *CSA* are the average of the data from the two concrete specimens using *CSA*. It is noted that the ASTM C 878 method provides data only for expansion of *CSA*; therefore, the *shrinkage from time zero* tests were additionally conducted for an equal basis comparison as described in the following paragraphs.

The *shrinkage from time zero* test results were recorded for 28 days and 110 days. Comparing the results from the *shrinkage from time zero* method to the ASTM C 157 unrestrained
expansion results shows that the trend after 7 days was the same for both testing methods (Figure 5). The concrete specimens for the *shrinkage from time zero* method did not show expansion in the first 7 days of curing because the expansion was restrained due to the steel plate at the fixed end of the specimens (Figure 3), while the expansion was unrestrained for the ASTM C 157 method. It is noted that the *shrinkage from time zero* method was found easier to perform in comparison with the ASTM C 157 and C 878 methods. Figure 5 is a representative result comparing two testing methods for PCC and SRA #1.

![Figure 5](image)

**Figure 5** *Shrinkage from time zero* test results for SRA #1 in comparison with those obtained from ASTM C 157

The *shrinkage from time zero* test results are also compared with those of the ASTM C 878 method for CSA in Figure 6. The *shrinkage from time zero* test results show the same general trend when compared to that of the ASTM C 878 method. Both testing methods showed expansion for the first 7 days of curing; however, the amount of expansion was different due to the smaller stiffness of the rod used to restrain expansion of concrete for the ASTM C 878 method.

![Figure 6](image)

**Figure 6** *Shrinkage from time zero* test results for CSA in comparison with those obtained from ASTM C 878
method, compared with the stiffness of the steel frame used to restrain expansion of concrete for the *shrinkage from time zero* method. Overall, there was little shrinkage in CSA for about 110 days of curing after the initial expansion, which verified the effectiveness of shrinkage compensating concrete in reducing the drying shrinkage.

### 3.2 Slab monitoring results

#### 3.2.1 Surface measurements and joint opening

The average joint opening data for the six concrete mixtures of seven slabs are represented in Figure 7, with complete surface measurements for all the slabs provided in Figure 3. The average of the east and west opening strains were used. The shrinkage was measured from the point of initial set and continued for 600 days. This measurement is not exactly the same as those from the ASTM C 157 and C 878 methods, because the slab bottom is exposed to the moisture in the soil and the slab top is exposed to the relatively low humidity in a controlled environment, while for the ASTM C 157 and C 878 methods, all sides of the specimens are exposed to the controlled relative humidity. The relative humidity of the lab (air above the top of the slab) was 60% for the first year and then was reduced to 30%.

![Figure 7 Width of joint opening versus time](image)

Figure 7 shows the average width of the joint opening versus time and illustrates that the use of *SRA* only reduced shrinkage in the first week. After the first week the slope of the line representing the SRA data matches the slope of the line for PCC. This once again indicates that the use of *SRA* reduced shrinkage at short term but did not impact the shrinkage at long term. Figure 7 also shows that *HSC* had the largest expansion/crack at the joints and *CSA* had the smallest expansion/crack at the joints. When comparing the strain of control joints for *CSA* with *SRAs*, it is found that shrinkage compensating concrete (*CSA*) had a positive effect on reducing shrinkage of concrete at both short and long terms compared with all concretes.
including SRAs. Conversely, joint opening expansion continued over the long term (over 600 days) with PCC, HSC and SRAs. The comparison between HSC and PCC shows that the cracks of HSC were wider than those of PCC, and HSC also shrank quicker than normal concrete (PCC). The HSC shrank at a faster rate than other mixes during the first few weeks (early age) after curing. Based on the discussion in this and the preceding paragraphs, it is concluded that the use of CSA reduces warping in comparison to the other types of concrete used in this research.

Table 3 summarizes the joint expansion (crack growth) for the mixes after 574 days. It can be seen that, the slab using SRAs shows join expansion 2.1 to 2.4 times greater than CSA, PCC’s joint expansion was 3.7 times greater than CSA, and HSC’s joint expansion was 4.6 times greater than CSA. Therefore, it can be concluded that CSA is very stable with less crack and warping at long term compared to other mixes in this research.

**Table 3** Joint expansion at 574 days,

<table>
<thead>
<tr>
<th>Mix</th>
<th>Joint expansion (mm)</th>
<th>Compared to CSA</th>
</tr>
</thead>
<tbody>
<tr>
<td>CSA</td>
<td>1.6</td>
<td>-</td>
</tr>
<tr>
<td>SRA #1</td>
<td>3.4</td>
<td>231%</td>
</tr>
<tr>
<td>SRA #1</td>
<td>3.9</td>
<td>244%</td>
</tr>
<tr>
<td>PCC</td>
<td>5.9</td>
<td>367%</td>
</tr>
<tr>
<td>HSC</td>
<td>7.4</td>
<td>459%</td>
</tr>
</tbody>
</table>

### 3.2.2 Comparing slab monitoring with ASTM C 157

Figure 8 shows the slab behavior in comparison with the ASTM C 157 method for SRA #1, PCC and HSC. A significant difference was observed between the slab behavior and the ASTM C 157 results. Again, this might be due to the different conditions of humidity on each face of the slab. In light of that, it appears that the ASTM C 157 method does not provide accurate results for predicting slab-on-ground behavior. Conversely, the current slab-on-ground experiment reflects the realistic exposure conditions and actual dimensional and material properties of concrete.
Figure 8 Strains at mid-span for SRA #1, PCC and HSC in comparison with those obtained from ASTM C 157

3.2.3 Interior relative humidity and temperature

This subsection presents general results for internal temperature and relative humidity of slabs-on-ground, measured after 1 year. Figure 9(a) shows that there were no temperature changes through the depth of the slabs which means the ambient temperature remained constant, whereas Figure 9(b) presents that the RH of the slabs within the top 12.5 mm of concrete slab was higher than the ambient relatively humidity in the air. From the internal relative humidity of slabs (Figure 9(b)), it is found that HSC had the highest moisture gradient and CSA had the least moisture gradient. The PCC, SRA #1, SRA #2 and RSCC
moisture gradients were between CSA and HSC. There were almost no changes in the moisture content at 63.5 mm depth in the slab. Most of the moisture content changes occurred between 25 and 63.5 mm depth from the top surface of the slab. Similar trends were observed after reducing the ambient RH (in the air) to 30% from 60%. The measured interior relative humidity (RH) of the slabs-on-ground is directly related to warping. The materials RH gradient is related to a strain gradient due to the materials tendency to swell or shrink due to moisture. In this case CSA has less of a RH gradient which indicates it has less of a strain gradient and as such it is less sensitive to warping than typical Portland cement concrete or high-strength concrete, Shadravan (2011) reports the complete results for the slabs’ interior temperature and relative humidity, as well as ambient temperature and relative humidity in the air.

![Figure 9](image)

**Figure 9** Interior slab temperature and relative humidity as a function of depth from slab top surface, measured after 1 year of curing.

The discussion in the preceding paragraph brings up two possible hypotheses. The first possible hypothesis is that the porosity of the HPC is low since it is hard for moisture to get in to the concrete from the bottom surface of the slab and it is much easier to dry it out from the top. Thus, the least porous material has the lowest average relative humidity. The second possible hypothesis is that HPC is the most porous material that has the lowest relative humidity at the top surface (i.e., the concrete is drying further into its core). These two hypotheses, however, would require further research to validate and may be influenced by other factors such as the amount of paste in each mix.
4. Conclusions

The main objective of this research was to provide reliable warping data based on the internal strain measurements of pavement, ASTM C 157, ASTM C 878, and shrinkage from time zero drying shrinkage measurements for the selected concrete mixtures in a controlled environment. The main conclusions of the investigation are summarized as follows:

(1) Typical Portland cement concrete, high-strength concrete and concrete with SRAs continued to exhibit increased crack growth at approximately 2 years.

(2) The shrinkage from time zero test method gets the same results, measures shrinkage more accurately, and is easier to perform when compared to ASTM C 157 and C 878 method. However, the shrinkage from time zero tests provide less accurate results for the prediction of slabs-on-ground behavior when compared to the large-scale tests of actual slab-on-ground exposed to realistic conditions.

(3) The ASTM C 157 method appears inadequate to assess slab shrinkage behavior because the ASTM C 157 method and the actual slab-on-ground test method show significant differences in the results.

(4) Based on the measured interior relative humidity of the slabs-on-ground, shrinkage compensating concrete or concrete using calcium sulfoaluminate cement (CSA) was inherently less sensitive to warping than typical Portland cement concrete or high-strength concrete.

(5) Shrinkage compensating concrete or concrete using calcium sulfoaluminate cement was extremely stable, with little or no long-term shrinkage, cracking or warping. This stability was noted at both early age and at approximately 2 years.

(6) Shrinkage reducing admixtures decreased shrinkage and crack growth a small amount at an early age but did not impact the rate of shrinkage growth or sectional stability after that period of time.
Acknowledgements

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