# DURABILITY PERFORMANCE CRITERIA OF CLOSURE POUR MATERIALS FOR CIP CONNECTIONS

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## ABSTRACT

*With the public's demands for reduced construction time and traveling delays, full-depth precast deck panels and/or decked bulb tees (DBTs) are currently becoming a more viable solution. For these systems, the selection of closure pour materials (joint materials) is critical. Under the current NCHRP Project 10-71, the proposed durability performance criteria are being developed under two categories: overnight cure and 7-day cure. The short-term tests, including compressive strength and flow and workability, were performed to select candidate closure pour materials. Then, long-term tests were performed on the four selected candidate materials. These long-term tests include freeze-thaw durability, shrinkage, bond, and permeability. The performance criteria are finalized based on the test results. These testing results will be discussed in the paper.*

**Keywords**: Closure Pour Material, Performance Criteria, Accelerated Construction, Grout, HPC, Bond Strength, Shrinkage, Chloride Penetration, Freezing-and-thawing Durability

## FOREWORD

The research reported in this paper has been performed under the ongoing National Cooperative Highway Research Program (NCHRP) 10-71 project, “Cast-in-Place Reinforced Concrete Connections for Precast Deck Systems”. The PI (Principal Investigator) of the project is Prof. Catherine French at University of Minnesota (UMN). Other research team members include R. Eriksson, Z. J. Ma, C. Prussack, A. Schultz, S. Seguirant, and C. Shield. Robert Gulyas of BASF Construction Chemicals, LLC provided valuable comments in our testing program. The authors gratefully acknowledge the support by BASF Construction Chemicals, LLC, CTS Cement Manufacturing Corporation, Enco Materials, Inc., Lafarge North America, Inc., and etc. Publication of this paper does not necessarily indicate acceptance by the Academy, the Federal Highway Administration or by AASHTO.

## INTRODUCTION

The use of prefabricated bridge systems can minimize traffic disruption, improve work-zone safety, minimize impact to the environment, and improve constructability, increase quality, and lower life-cycle costs. This technology is applicable and needed for both existing and new bridge construction. For the precast bridge deck system with CIP connection, precast elements are brought to the construction site ready to be set in place and quickly joined together. A concrete closure pour completes the deck connection and ties the individual units together in a manner that is intended to emulate monolithic behavior.

Traditionally, different grouts as closure pour materials for the precast bridge deck system with CIP connection have been tried and summarized below. Mrinmay (1986) documented a wide variety of materials used after 1973 to avoid joint failure/distress in closure pours (i.e., longitudinal and transverse joints), grout pockets and keyways of precast deck panel bridges. These materials include sand-epoxy mortars, latex modified concrete, cement-based grout, non-shrink cement grout, epoxy mortar grout, calcium aluminate cement mortar and concrete, methylmethacrylate polymer concrete and mortar, and polymer mortar. Cementitious grouts have been used more in precast construction than epoxy or polymer-modified grouts (Matsumoto, E., et al 2001). Epoxy or polymer modified grouts can have significant advantages, such as a high strength in a shorter time (e.g., 6 ksi in 6 hours), better bond, reduced chloride permeability, improved freeze-thaw durability, and lower creep. However, they are often significantly more expensive and less compatible with surrounding concrete. In addition, if the resin is used in too large a volume, the heat of reaction may cause it to boil, and thereby develop less strength and loose bond. A primary disadvantage of cementitious grouts is the shrinkage and cracking that result from the use of hydraulic cement. Non-shrink grout compensates for the shrinkage by incorporating expansive agents into the mix. With non-shrink grout, the effects of shrinkage cracks or entrapped air on the transfer of forces and bond are minimized, though not eliminated. ASTM C 1107 establishes strength, consistency, and expansion criteria for prepackaged, hydraulic-cement, non-shrink grout.

Dennis Nottingham (1996) reported that the very nature of portland cement grouts virtually assures some shrinkage cracks in grout joints, regardless of quality control. Prepackaged magnesium ammonium phosphate based grout often extended with pea gravel can meet requirements, like high quality, low shrinkage, impermeable, high bond, high early strength, user friendly and low temperature curing ability. Set® 45 pockets and joints showed complete bond after two years in a heavily used arctic bridge. Gulyas et al (1995) undertook a laboratory study to compare composite grouted keyway specimens using two different grouting materials: non-shrink grouts and magnesium ammonium phosphate (MAP) mortars, in which Mg-$NH_4$-$PO_4$ materials perform better than non-shrink grouts. Gulyas and Champa (1997) further examined inadequacies in the selection of a traditional non-shrink grout for use in shear key ways. The MAP grout outperformed the non-shrink in all areas tested, including direct vertical shear, direct tension, longitudinal shear, bond, shrinkage, etc. Badie and Tadros (2006) considered several commercial grout materials for use in the proposed systems. Issa et al. (2003) evaluated the behavior of a female-to-female joint detail using Set® 45, Set® 45 HW, Set Grout and EMACO® 2020 (polymer concrete). The shear, tensile and flexural strength of joints made with EMACO® 2020 were the highest among all 4 types of grouting materials, and EMACO® 2020 was significantly less permeable and showed lower shrinkage deformation compared to other grout materials. Menkulasi and Roberts-Wollmann (2005) presented a study of the horizontal shear resistance of the connection between full-depth precast concrete bridge deck panels and prestressed concrete girders. Two types of grout were evaluated: a latex modified grout and a magnesium phosphate grout (Set® 45 HW formulation). For both types of grout, an angular pea gravel filler was added. The Set® 45 formulation developed slightly higher peak shear stresses than the latex modified grout.

Grout without coarse aggregate extension is usually referred to as neat grout, while grout with coarse aggregate extension, typically 1/2-in. or 3/8-in. coarse aggregate, is extended grout. Comparing with neat grout, extended grout has the following potential benefits: (1) more compatible with concrete; (2) better interlock between connection components; (3) denser, less permeable; (4) less drying shrinkage and creep; and (5) larger grout volume per bag, hence less expensive.

Based on the research performed in Texas (Matsumoto et al, 2001), however, the following conclusions were made regarding the use of extended grouts. (1) The excessive surface area of mixes with 50 lbs of pea gravel required more cement paste than available in prepackaged bags, leading to lower strengths and poor workability. (2) Using coarse aggregate larger than 3/8-in. would reduce segregation and improve workability, compared to extended grouts with 3/8-in. pea gravel. Use of extended grouts or concrete with small aggregate should be used with caution. And (3) Neat grouts are preferable from a constructability and economic perspective. Ralls (2004) reports that for grouts, concretes and sealants for joints, non-shrink grouts are typically specified for the smaller closure joints, and standard or special concrete mixtures for larger joints. It was indicated that alternate materials such as magnesium ammonium phosphate mortars and polymer modified concretes exhibit superior bond strength, compressive strength and lower permeability. More information on the long-term durability and ease of construction is needed to implement these materials. More concerns are related to the interface between the precast deck and the cast-in-place closure, since cracks can develop due to shrinkage or poor bonding from the outset.

Varieties of materials are available for the joint materials. And the selection of joint materials for precast deck systems in this paper is based on the performance specification. Performance-based specifications focus on properties such as consistency, strength, durability, and aesthetics, rewarding quality, innovation, and technical knowledge, in addition to promoting better use of materials, and thus present an immense opportunity to optimize the design of materials. The industry is evolving specifications from prescriptive requirements to performance-based concepts.

In this paper, for rapid construction purpose, two categories of materials (overnight cure and 7-day cure) are studied. For the overnight cure, published performance data from different grout materials were collected through contacts with material suppliers and users. For the 7-day cure, standard or special concrete mixtures and their performance data were collected through contacts with HPC (High Performance Concrete) showcase states as well as with material suppliers. Four grouts were firstly selected as candidate overnight cure materials, and four special concrete mixes as candidate 7-day cure materials. The preliminary selection was based on some strength tests of selected materials or prediction model to narrow the choices down to two different materials in each of the two joint material classifications, as discussed by Zhu and Ma (2008). Then long-term tests were performed on the four final selected materials, including freeze-thaw durability, shrinkage, bond, and permeability tests. The research in this paper is part of the NCHRP 10-71 project, "Cast-in-Place Reinforced Concrete Connections for Precast Deck Systems", and is focused on the long-term tests and the performance criteria of closure pour materials.

## SIGNIFICANCE

Joints between adjacent precast decks or flanges are filled with joint materials to bond the two precast members, thus making the joints structural elements of the bridge. As such, longitudinal and transverse joints must be able to resist shear and moment induced by vehicular loads. Shrinkage of joint materials and transverse shorting of precast members further subject the joints to direct tension. Freeze thaw resistance and low permeability of joints are also important. The joints are important because the whole bridge performance is manifested in the behavior of its joint. The best joints should provide high flexural and shear resistance, full bond and complete tightness. However, there have been cases of unsatisfactory performances of such joints as evidenced by cracking in asphalt surfacing directly over the joints and moisture leakage. Issa et. al. (1995) concluded that material quality, construction procedures and maintenance are the main reasons for the problems associated with joints. The closure pour/precast unit interface is of concern in the area of durability. The focus must be on minimizing cracking in this location to reduce intrusion of water that may result in corrosion. An ideal connection detail emulates monolithic behavior and results in a more durable and longer lasting structure. When selecting bonding materials, performance based specifications for durability in the form of performance criteria need to be developed to be able to proportion concrete mixtures or other grouting materials that are capable of protecting structures against a given degradation for a specified service life in given environmental conditions. The selection of joint materials is critical.

## CANDIDATE MATERIALS

The candidate overnight cure and 7-day cure materials after the preliminary selection based on some strength tests or prediction model are listed in Table 1 and 2, as discussed by Zhu and Ma (2008).

TABLE 1 Candidate Overnight Cure Materials and Mixing Information

| Product Name | Mixing Quantities per 50-lb, Bag | | | | |
|---|---|---|---|---|---|
| | Initial Water, pints | Additional Water, pints | Aggregate Extension, % by weight | Aggregate Extension, lb | Yield Volume, cu. ft. |
| EUCO-SPEED MP | 3.10 | 0.50 | 0 | 0 | 0.42 |
| Set® 45 HW | 3.25 | 0.50 | 0 | 0 | 0.39 |

TABLE 2 Candidate 7-day Cure Materials Mix Proportions

| MIX NUMBER | HPC Mix 1 | RSLP Mix 2 |
|---|---|---|
| W/CM Ratio | 0.31 | 0.40 |
| Cement Type | I | CTS RSLP |
| Cement Quantity, lb/yd$^3$ | 750 | 658 |
| Fly Ash Type | C | |
| Fly Ash Type Quantity, lb/yd$^3$ | 75 | |
| Fine Aggregate, lb/yd$^3$ | 1400 | 1695 |
| Coarse Aggregate | #8 | #8 |
| Coarse Aggregate Quantity, lb/yd$^3$ | 1400 | 1454 |
| Water, lb/yd$^3$ | 255 | 263 |
| Air Entrainment, fl oz/yd$^3$ | 5 | |
| Water reducer, fl oz/yd$^3$ | 30 | |
| High-Range Water Reducer, fl oz/yd$^3$ | 135 | |

## LONG-TERM TESTS

Long-term tests were performed on the four candidate materials, including freeze-thaw durability, shrinkage, bond, and permeability tests.

BOND STRENGTH TEST

The ASTM C882 is used. And Li (2009) finished parametric study for joints of some DBT bridges and found that the maximum shear at joints is 6.024 kips/ft, which is 84 psi for joints of 6-in. depth. Since this result is for one certain type of DBT bridges, a higher limit, 200-psi, is proposed as the preliminary performance limit for bond strength considering the variability of the DBT bridge type.

The bond strength test was prepared per ASTM C882. Scholz et al, (2007) investigated slant cylinder bond strength of eight grouts with varying concrete surface preparations, a) smooth, b) exposed aggregate, c) raked, and d) raked and sandblasted. There was not a particular preparation found that consistently provided the best bond strength for all the tested grouts. The smooth interface performed better than anticipated, providing the worst or second worst bond strength for only half of the candidate grouts. For the trouble and cost involved with the other surface preparations (i.e., exposed aggregate, raked and sand blasting), these three preparations were not considered, and the smooth interface was used for the study.

The concrete half-cylinders were made using the mold and dummy section shown in Figure 1a. After they cured for at least 28 days, they were inserted into a whole 4 in. by 8 in. cylinder mold. Then for the overnight cure materials, the grout was poured into the mold to complete the cylinder (see Figure 1b). For the 7-day cure materials, a layer of cement paste was firstly applied onto the slanted face of the half-cylinder and then the test material was poured into the mold to complete the cylinder. Specimens for two overnight cure materials were air cured for 8 hours, while specimens for two 7-day cure materials were cured for 7 days by both the membrane-forming compound method and the water method with burlap (which is required by the TDOT specification for curing bridge decks).

After curing, cylinders were tested in compression in order to investigate the bond strength of each material. The test setup is shown in Figure 1c. Observations were made regarding whether the cylinder failed along the shear plane or if failure was due to significant cracking in the grout or concrete. The failure modes are shown in Figure 2.

In each case, the maximum load was recorded and converted to stress by dividing by the elliptical area of the bonded interface, as suggested by Scholz et al, (2007). The maximum load was multiplied by the cosine of $30^{o}$ to obtain the true shear stress component acting along the bonded interface. Results for the slant cylinder tests are presented in Table 3. The strength results represent the average of three cylinders.

(a) Test Mold and Dummy Section (b) Completed Slant Shear Cylinders (c) Test Setup

Figure 1 ASTM C882 Test

(a) (b) (c)

Figure 2 ASTM C882 Test Failure Modes (a), (b) and (c)

Table 3 Slant Cylinder Bond Strength and Failure Mode

| Material Type | Specimen Number | Test Age | Shear Stress (psi) | Average Shear Stress (psi) | Mode of Failure* |
|---|---|---|---|---|---|
| EUCO-SPEED MP | 1 | 8 hours | 456 | 397 | b |
| | 2 | | 159 | | b |
| | 3 | | 576 | | b |
| SET 45 HW | 1 | 8 hours | 1161 | 1176 | b |
| | 2 | | 1121 | | b |
| | 3 | | 1240 | | b |
| HPC#1 | 1 | 7 days | 1607 | 1817 | c |
| | 2 | | 1917 | | a |
| | 3 | | 1925 | | a |
| RSLP | 1 | 7 days | 659 | 705 | a |
| | 2 | | 634 | | a |
| | 3 | | 823 | | a |

*a) clean shearing of bond along slanted interface (Figure 2-a)

b) grout and/or concrete cracking before interface bond failure, grout cracking was not too severe and it was possible to load the specimen until the bonded interface failed (Figure 2-b)

c) grout cracked and split in a vertical manner so that it was not possible to continue loading the specimen (Figure 2-c)

PERMEABILITY TEST

The ASTM C1543 ponding test is used. For the chloride threshold level (CTL) for steel corrosion in concrete, Glass and Buenfeld (1995) summarized various research studies and found CTLs to vary from 0.17 to 2.5% (by mass of cement) with a value of 0.2% chosen as a good prediction of CTL for harsh environments. Also, a depth of 1.5-in is specified which is the minimum concrete cover for concrete exposed to earth or weather by ACI 318-08. And thus, the preliminary criterion for the chloride penetration is proposed as the depth for percent chloride of 0.2% by mass of cement after 90-day ponding is less than 1.5-in.

The ponding test was prepared in accordance with ASTM C1543 modified. Three specimens (10×10×3 in.) for each of the selected overnight cure materials, EUCO-SPEED MP and Set 45 HW, and 7-day cure materials, HPC #1 and RSLP, were cast. Specimens for two overnight cure materials were air cured for 8 hours, while specimens for two 7-day cure materials were cured for 7 days by both the membrane-forming compound method and the water method with burlap. After curing, the sides of the specimens were coated with rubber coating material, 1 in-high closed-cell polystyrene foams were bonded to the specimens with silicone sealant, and then the specimen were subjected to continuous ponding with a 3% sodium chloride solution to a depth of approximate 20mm for 90 days, as shown in Figure 3.

The specimen surfaces were then brushed with a wire brush to remove the salt, and 4 in. cores were taken as shown in Figure 4. The core cylinders were then cut into slices. Four slices were cut from different depths, as shown in Figure 5. The concrete slices obtained were then dried at 105 °C to constant mass and ground to pass an 850-μm sieve [No. 20] sieve, using a pulverizer. Powder samples for different depths of different samples were collected. The solution was made with each powder sample following the ASTM C 1152 modified procedure.

The titration test is introduced in the ASTM C 1152 to determine the chloride concentration. However, this method is very time-consuming. The tests by Ghanem et al. (2008) showed that the chloride ion selective electrode (ISE) matched titration readings, and suggested that the chloride concentration can be taken directly using the ISE. Consequently, the chloride ISE was used in this project rather than the titration test.

The ISE was calibrated using chloride solutions with five different concentrations. These solutions were obtained by diluting a 100 ppm solution two, five, ten, and 100 times to get solutions with concentrations ranging from 1 to 100 ppm. A calibration curve was constructed with the measured electrode potential in mV (linear axis) plotted against the concentration (log axis). The mV readings of the sample solution were taken, as shown in Figure 6, and the concentration was then determined from the calibration curve. The chloride concentrations were analyzed and are shown in Figure 7. Each result is the average of three samples.

Figure 3 Ponding of Specimens

Figure 4 Specimen coring

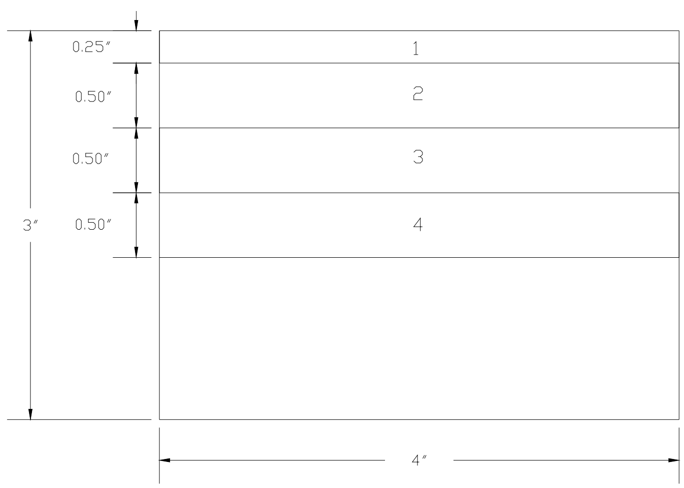


Figure 5 Sampling Depths

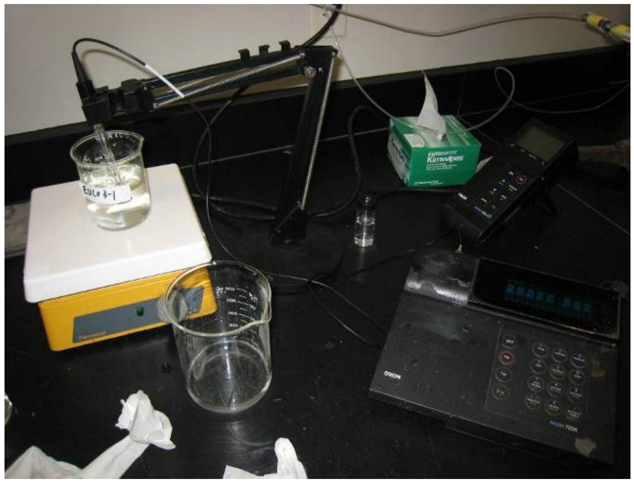

Figure 6 Chloride Concentration Determination with ISE

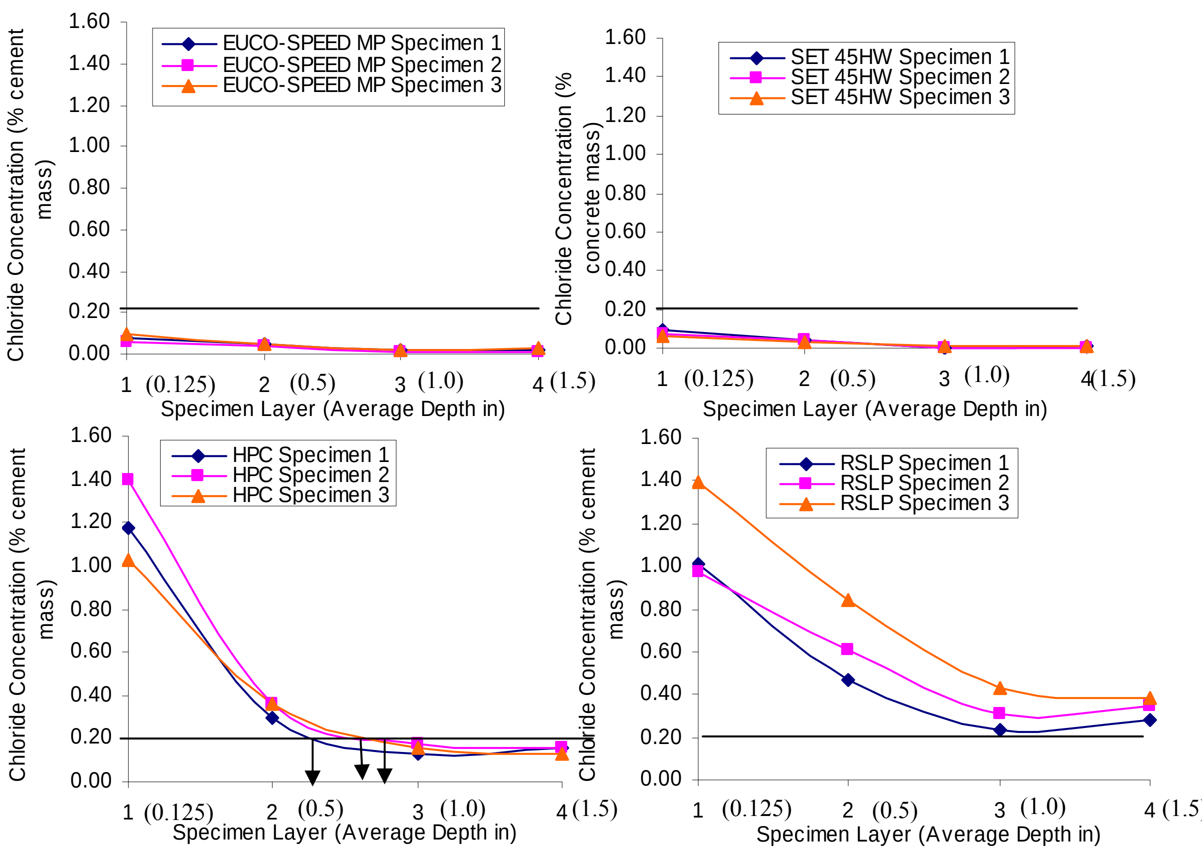


Figure 7 Chloride content profile after 90-day ponding test
(Layer 1: 0-0.25 in.; Layer 2: 0.25-0.75 in.; Layer 3: 0.75-1.25 in. and Layer 4: 1.25-1.75 in. as shown in Figure 3)

The depths for 0.2% chloride content (by mass of cement) for the four materials were calculated based on Figure 7, as listed in Table 4. For calculating the depths, the average depth of 0.125 in, 0.5 in, 1.0 in and 1.5 in is taken for Layer 1, 2, 3 and 4 respectively. The two overnight cure of CP materials have the depths for 0.2% chloride content less than 0.125 in. For the 7-day cure of CP materials, HPC Mix 1 is less than 1.0 in, and RSLP Mix 2 is greater than 1.5 in.

Table 4 Depths (in.) for 0.2% chloride content (by mass of cement)

| Materials | Sample | | |
|---|---|---|---|
| | 1 | 2 | 3 |
| EUCO-SPEED MP | <0.125 | <0.125 | <0.125 |
| Set 45 HW | <0.125 | <0.125 | <0.125 |
| HPC Mix 1 | <1.0 | <1.0 | <1.0 |
| RSLP Mix 2 | >1.5 | >1.5 | >1.5 |

FREEZING-AND-THAWING TEST

The ASTM C666 Procedure A modified is used. And performance characteristic grades by Russell and Ozyildirim (2006) is proposed as the preliminary performance limit, which is the relative dynamic modulus of elasticity after 300 cycles greater than 70% for Grade 1, greater than 80% for Grade 2, and greater than 90% for Grade 3.

The freeze thaw test was prepared in accordance with ASTM C666 Procedure A modified. Specimens for two overnight cure materials were air cured for 8 hours, while specimens for two 7-day cure materials were cured for 7 days by both the membrane-forming compound method and the water method with burlap. After curing, specimens were moisture-conditioned in saturated lime water at 73.4±3$^{o}$F for 48 hours prior to testing, as is used on specimens sawed from hardened concrete by the ASTM C666. After curing and 48-hour moisture-conditioning, the test was started as shown in Figure 8. After 76 cycles, the RSLP Mix 2 specimens failed as shown in Figure 9. The test results are listed in Table 5. Each result is the average of three specimens. EUCO-SPEED MP, Set 45 HW and HPC Mix 1 performed very well.

(a) Freezing-and-Thawing Apparatus (b) Fundamental Transverse Frequency Test

Figure 8 ASTM C666 Freezing-and-thawing Durability Test

Figure 9 Failure of RSLP Mix 2 Specimens

Table 5 Freezing-and-thawing Durability by ASTM C666 Procedure A

| | EUCO-SPEED MP | Set 45 HW | HPC Mix 1 | RSLP Mix 2 |
|---|---|---|---|---|
| Relative dynamic modulus of elasticity after 300 cycles | 92% | 96% | 96% | Fail after 70 cycles |

SHRINKAGE TEST

The AASHTO PP34-99 (1998) Restrain Shrinkage Ring test is used. And CDOT Specifications Committee (2005) specified Class H concrete used for bare concrete bridge decks must not exhibit a crack at or before 14 days in the cracking tendency test (AASHTO PP 34), which is proposed as the preliminary performance limit here.

The test was prepared in accordance with AASHTO PP34 modified as shown in Figure 10. Strain gages were bond at four equidistant midheight locations on the interior of the steel ring. Three ring specimens were fabricated for each material, and were immediately transferred to the cure room after completion of casting. The strain gages were connected to the data acquisition system to start monitoring the strain development in the steel ring. Specimens for two overnight cure materials were air cured, while specimens for two 7-day cure materials were cured by both the membrane-forming compound method and the water method with burlap till the age of 24 hours ± 1 hour. Then the outer ring was removed and the top surface was sealed.

Cracks were found for specimens of the HPC #1 at the age of 20.5 days. No crack was observed to occur for the EUCO-SPEED MP, Set 45 HW and RSLP Mix 2 throughout the tests which were terminated at the ages of 58, 62 and 61 days, respectively.

Figure 10 AASHTO PP34 Test Setup

## PROPOSED PERFORMANCE CRITERIA AND CONCLUSIONS

The performance criteria are proposed after all the tests, as listed in Table 6 and 7. Table 7 was developed by Tepke and Tikalsky (2007). For all the candidate materials tested, including both overnight cure and 7-day cure, all the tests gave results better than the performance criteria developed, except one material failed in the freezing-and-thawing test and one material did not perform very good in the ponding test, which means there are certain materials available meeting performance criteria.

Table 6 Proposed Performance Criteria of CP Materials

<table>
<tr><th>Performance Characteristic</th><th>Test Method</th><th colspan="3">Performance Criteria</th></tr>
<tr><td>Compressive Strength (CS), ksi</td><td>ASTM C39 modified</td><td colspan="3">$6.0 \le CS$<br>@ 8 hours (overnight cure)<br>@ 7 days (7-day cure)</td></tr>
<tr><td>Shrinkage[a](S),<br>(Crack age, days)</td><td>AASHTO PP34 modified</td><td colspan="3">$20 < S$</td></tr>
<tr><td>Bond Strength (BS), psi</td><td>ASTM C882 modified</td><td colspan="3">$300 < BS$</td></tr>
<tr><td>Chloride Penetration[b](ChP),<br>(Depth for Percent Chloride of 0.2% by mass of cement after 90-day ponding, in.)</td><td>ASTM C1543 modified</td><td colspan="3">$ChP < 1.5$</td></tr>
<tr><td rowspan="2">Freezing-and-thawing Durability (F/T), (relative modulus after 300 cycles)</td><td rowspan="2">ASTM C666 Procedure A modified</td><td>Grade[c] 1</td><td>Grade 2</td><td>Grade 3</td></tr>
<tr><td>$70\% \le F/T$</td><td>$80\% \le F/T$</td><td>$90\% \le F/T$</td></tr>
</table>

*a: No S criterion need be specified if the CP material is not exposed to moisture, chloride salts or soluble sulfate environments.*
*b: No ChP criterion need be specified if the CP material is not exposed to chloride salts or soluble sulfate environments.*
*c: Grades are defined in Table 7.*

Table 7 Application of CP Material Grades for Freezing-and-thawing Durability

<table>
<tr><td rowspan="4">Freezing-and-thawing Durability (F/T)</td><td rowspan="4">Is the concrete exposed to freezing-and-thawing environments?</td><td rowspan="3">Yes</td><td rowspan="3">Is the member exposed to deicing salts?</td><td rowspan="2">Yes</td><td rowspan="2">Will the member be saturated during freezing?</td><td>Yes.<br>Specify F/T-Grade 3</td></tr>
<tr><td>No.<br>Specify F/T-Grade 2</td></tr>
<tr><td colspan="3">No. Specify F/T- Grade 1</td></tr>
<tr><td colspan="5">No. F/T grade should not be specified.</td></tr>
</table>

Based on extensive literature reviews and experimental investigation carried out in this paper, the following conclusions were made.

1. The selection of CP materials is critical. For rapid construction, two categories of materials, overnight cure of CP materials and 7-day cure of CP materials, were studied. Candidate materials were compared by lab tests and software analysis, and two CP materials were selected for each category. The performance criteria for selecting durable CP materials is developed based on durability tests of selected candidate materials. These durability tests include freezing-and-thawing durability, shrinkage, bond, and permeability tests.
2. Performance characteristics, compressive strength, shrinkage, chloride penetration, freezing-and-thawing durability and bond strength, are investigated as performance criteria to control cracking and corrosion, as for the closure pour/precast unit interface the focus must be on minimizing cracking in this location to reduce intrusion of water that may result in corrosion. Table 6 shows the final proposed performance criteria.

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