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Specifications to Reduce Bridge Deck Cracking

JoAnn Browning and David Darwin, University of Kansas and Kenneth F. Hurst, Kansas Department of Transportation

Wet burlap is placed within 10 minutes of strike-off for LC-HPC bridge decks.

A pooled-fund study is being implemented in two phases under the direction of the Kansas Department of Transportation in conjunction with 18 other state departments of transportation and the Federal Highway Administration to construct 40 low-cracking, high performance concrete (LC-HPC) bridge decks in Kansas and partner states. In the first phase of the project, new concrete materials and construction specifications were developed and implemented to construct the first 20 LC-HPC bridge decks. These decks, which did not contain any supplementary cementitious materials, are now being evaluated and compared with conventional decks for cost and cracking performance.

The LC-HPC specifications require the use of a concrete with a paste content (total volume of water and cement) less than 25%, low slump of 1.5 to 3.0 in. (40 to 75 mm), moderate water-cement (w/c) ratio of 0.43 to 0.45, controlled concrete placement temperature of 55 to 70°F (13 to 21°C), and an elevated air content of 6.5 to 9.5%. In combination with an optimized combined aggregate gradation, the mix must be workable, placeable, and finishable on the bridge deck. The construction specifications focus on the implementation of a thorough 14-day wet cure. This is started within 10 minutes of concrete strike-off. The concrete is protected following the 14-day wet curing period through the application of a curing compound to slow the rate of drying for the next 7 days at least. This limits the rate of development of tensile stresses in the young concrete. A qualification slab with dimensions equal to the bridge width, full depth, and 33 ft (10 m) in length is cast by the contractor prior to bridge placement to demonstrate competency in working with the concrete and meeting the curing guidelines with the available equipment. The requirement for the qualification slab may be waived on a case-by-case basis if the contractor has cast an LC-HPC bridge deck within the previous few months. More details about the specifications and goals of Phase I of the project can be found HPC Bridge Views Issue No. 46. This article focuses on the lessons learned during the first phase of the project and the broadened scope of work for Phase II.

Low-Cracking, High Performance Concrete Specifications

Two of the primary lessons from Phase I are that the concrete specifications can be implemented at a reasonable cost and that the low-paste concrete mix is workable, placeable, and finishable in the field. For the first 13 bridges bid, the costs of LC-HPC decks and conventional bridge decks in Kansas were similar when the same coarse aggregates having a maximum absorption of 0.7% were used. In terms of the concrete properties, working within the parameters of the concrete specifications has led to good workability and placeability, even with pumping, in most cases. Working with manufactured sands, however, which tend to be more angular than natural aggregates, may hamper the pumpability of an LC-HPC mix.

Practices that promote higher concrete strengths in the field are undesirable as they lead to increased cracking in bridge decks. Experience has shown that the target w/c ratio 0.43 to 0.45, when combined with the prescribed lower paste content, provides concrete strength in the range of 4000 psi (28 MPa) in the field. Any practice that lowers this ratio (e.g., inaccurate moisture contents of the aggregate or holding water out of the mix at the plant) may not only prevent easy placement of the concrete but also raise the concrete strength to undesirable levels. High strength concrete is not needed in bridge decks and results in increased cracking. Higher strength concretes creep less than moderate strength concretes as tensile stresses develop due to restrained drying shrinkage and thermal contraction. The use of high-range water-reducing admixtures is also discouraged as their usage leads to increased concrete strength.

Construction Methods

The relationships developed between owners, inspectors, contractors, and concrete suppliers are of prime importance. It might be argued, in fact, that they are the most important factors in successfully constructing an LC-HPC bridge deck. All participants need to be onboard to achieve the project goals and work to clearly communicate their expectations and needs to successfully meet the specifications. The construction parameter that leads to the most successful placements of LC-HPC bridge decks is a consistent, uninterrupted supply of concrete that meets the specifications. Only in this way can the consolidation and finishing operations proceed in a manner that will allow curing to start within 10 minutes of strike-off. Delaying the process by 10 to 30 minutes has been shown to increase the surface crack density by 0.06 to 0.08 ft/ft2 (0.20 to 0.25 m/m2), a value that is more than five times the total crack density of a properly executed LC-HPC deck.

Many elements contribute to the efficiency of the LC-HPC bridge deck placement operation. A clear understanding of the concrete testing schedule and agreement on how to handle out-of-specification concrete is the first element. In addition, the contractor needs to have two pumps or conveyor belts on site in case of equipment failure and to avoid delays from relocating equipment during placement. Over-finishing of the concrete should be discouraged. Minor corrections are applied by grinding the surface of the hardened deck. If diaphragms or abutments are cast integrally with the bridge deck, crews should begin filling the forms ahead of the finishing equipment as the deck placement approaches these larger concrete elements to limit delays in the finishing operation. Finally, careful estimates of the total quantity of concrete needed to complete the structure will eliminate costly delays when placing the last concrete on the bridge deck.

Experience continues to show that construction of the qualification slab yields great returns in terms of successful placement of LC-HPC bridge decks. For one reason, contractors have the opportunity to demonstrate competency in meeting the 10-minute curing initiation requirement with their crews and equipment. But an even more critical aspect has proven to be the ability to check the equipment that the contractor intends to use at the site with the qualified concrete mix. The pumpability of the mix can be verified and finishing techniques improved or simplified during the placement of the qualification slab.

Post-construction procedures have also been improved based on experiences during the first phase of the project. Formwork should be removed within 2 to 4 weeks after the end of the 14-day curing period. This is to ensure even drying of the concrete from the bottom as well as the top surface and thus avoid large moisture gradients through the deck. And for ease of application and inspection, the curing compound that is applied to slow the rate of drying of the top surface should be opaque rather than clear.

The implementation of the LC-HPC specifications has worked in the field by producing decks with less than 10% of the cracking found in traditional bridge decks. Phase II of the study will expand the scope with the construction of another 20 bridge decks, some of which will include the use of supplementary cementitious materials, internal curing agents, and shrinkage-reducing admixtures.

Further Information

For further information about this project, please contact the first author at jpbrown@ku.edu.

Experiences with Ohio HPC Bridge Decks with Warranty Program

Jim Welter, Ohio Department of Transportation

High strength concrete was used in the box beams to achieve a span-to-depth ratio of 29.

In response to House Bill 163 of the Ohio State General Assembly, the Ohio Department of Transportation (ODOT) established warranty specifications for various items of work in highway construction projects. Warranties are to guarantee the quality and durability of selected items of work for a specific period of time after construction, resulting in lower life-cycle costs. Supplemental Specification 894 was originally written in October 1999 requiring contractors to warrant new bridge decks with high performance concrete (HPC). There were also supplemental specifications for Quality Control/Quality Assurance Concrete and ODOT Class S (superstructure) Concrete for New Bridge Decks with Warranty. The original specification was written for the HPC to be warranted for 7 years. This warranty period was reduced to 2 years in 2005 due to a change in the state law.

The Supplemental Specification 894 applies to the structural bridge deck concrete for the entire deck. The warranty items include scaling, spalling, and alligator or map cracking. Meeting the minimum requirements and guidelines of the applicable specification are not to be construed as a warranty, expressed or implied, as to the material properties and workmanship efforts required to meet the performance criteria. The intent of the contract is for the contractor to provide a maintenance free bridge. The contractor may perform routine maintenance during the warranty period. The design of the superstructure and the design of the concrete mix are not part of the warranty. The contractor is required to mix and place the HPC per normal specifications.

Review Process and Remedial Actions

According to Supplemental Specification 894, High Performance Concrete For New Bridge Decks With Warranty, dated April 15, 2005, at least two reviews performed by an ODOT District Review Team (DRT) are required as follows for the 2-year warranty:

1. At the end of the first year, a review for alligator or map cracking.
2. Final review, 1 month before the end of the warranty period for scaling and spalling only.

Supplemental Specification 894 lists the following thresholds and required remedial actions for alligator or map cracking, scaling, and spalling.

Defect Found during Review	Required Remedial Action
Alligator or map cracking on 20% or less of deck area	Apply high molecular weight methacrylate resin (HMWM)
Alligator or map cracking on greater than 20% of deck area	Hydrodemolition of the surface of the entire deck, 1 in. (25 mm) deep and the placement of nominal 1 in. (25 mm) inlay with either latex modified concrete (LMC) or microsilica modified concrete (MSC).
Scaling less than 1/4 in. (6 mm) deep but greater than 1/8 in. (3 mm) deep and no more than 20% of deck area	Grind the defective area, saw cut transverse grooves, and seal the surface with a non-epoxy sealer.
Scaling greater than 1/4 in. (6 mm) deep or spalling less than 32 yd^2 (27 m^2)	Diamond saw cut perimeter, hydrodemolition 1 in. (25 mm) deep, patch with LMC or MSC, and seal edges with HMWM.
Scaling is more than 20% of deck area or spalling greater than 32 yd^2 (27 m^2)	Hydrodemolition of the entire deck 1 in. (25 mm) deep and place LMC or MSC.

Alligator or map cracks in bridge decks are often due to improper curing of the concrete. In our experience, scaling in bridge decks is caused by water added to the surface of the deck to aid in finishing, or the uncured concrete was allowed to freeze. Spalling can occur in bridge decks because the concrete was not mixed properly and the cementitious materials formed into balls.

Maintenance Bond and Appeal Process

In addition to the normal performance and payment bonds, the contractor furnishes a maintenance bond for 50% of the total price bid for the HPC for a period of 2 years. The contractor may appeal the DRT's bridge deck review findings within 15 days after receiving the written review results. The ODOT District Construction Engineer (DCE) will evaluate the contractor's appeal and inform the contractor of his determination within 45 days. If the contractor disagrees with the DCE's determination, the contractor may appeal.

Experience

Since January 2000, ODOT has let 149 projects with pay items for a total of 227 individual HPC bridge decks with warranty. There have been 41 decks that required corrective work for alligator or map cracking. There have been two decks that required corrective work for major spalling. According to the ODOT Division of Construction Management, 2006 Status Report of the Warranty Program, the warranty program has declined in recent years.

Feedback concerning warranty work from the ODOT Districts was that contractors, while being more conscientious about their work, were not producing significantly better products. Warranties do not necessarily reduce the need for inspection, in that extensive documentation of preexisting conditions and construction methods were required by both parties. Some contractors voiced concerns about issues over which they had no control during the warranty period.

These included the design of the bridges, overloads traveling on the bridges, and salt applications for snow and ice control. ODOT has experienced mixed results in effecting warranty repairs. At this time, ODOT is limiting the use of warranties on its projects. A cost comparison showed warranty concrete bridges cost about 5.6% more than non-warranty concrete bridges. ODOT has found that its basic contract provisions provided essentially the same rights of recovery for defective work as are provided by warranty.

ODOT will continue to use HPC in their bridge decks but not in HPC with Warranty Items.

More Information and References

The supplemental specifications are available at www.dot.state.oh.us. or contact the author at 614-444-6628. Further information is available in the ODOT Innovative Contracting Manual, dated 4/10/06 and the ODOT 2006 Status of the Warranty Program, dated 2/1/07.

Richmond Hill Bridge, Conifer, CO. Photo: Steve Yip, CDOT

High Performance Concrete in Colorado

Andrew Pott and Jamal Elkaissi, Colorado Department of Transportation

The definition of high performance concrete continues to evolve in Colorado. Technological advances, as well as performance requirements, continue to raise the bar for what we consider "high performance."

High Performance Concrete

Back in the 1930s, high performance was sought by using a higher concrete strength, 3000 psi (21 MPa) Class A concrete for bridge structures as opposed to the 2000 psi (14 MPa) Class B concrete. As the effects of freezing and thawing cycles became better known, air entrainment was required for the portions of bridges and structures exposed to the environment. This "high performance concrete" is now considered standard practice. As tight urban environments forced us to increase our span lengths while decreasing our structure depths, increased concrete strength again was the goal of our higher performance concrete. An article in HPC Bridge Views Issue No. 3 on the I-25 over Yale Avenue Bridge is a good example of this.

Some higher performance concrete results simply from technology changes in the industry. As cement particles were ground finer and finer, we found ourselves with higher earlier strength concretes. Along with these concretes came the potential for increased thermal cracking and higher setting temperatures.

The Colorado Department of Transportation's (CDOT) latest foray into higher performance concrete was an attempt to decrease permeability and achieve less cracking in our bridges decks that use Class H and HT concretes. These concretes are used for bridge decks that do not receive a waterproofing membrane. Although having the same minimum strength of 4500 psi (31 MPa) as our Class D and DT mixes, the timing for strength requirements was changed from 28 to 56 days and cementitious requirements were reduced to a range of 580 to 640 lb/yd3 (344 to 380 kg/m3) in order to achieve the desired characteristics. Lower permeability was obtained with the addition of fly ash and silica fume and lower cement content. The lower permeability helps slow the ingress of moisture and chlorides thus protecting the reinforcing steel. The lower cement content helps reduce shrinkage cracking. The addition of fly ash and silica fume also provided higher strength to offset the lower cement content.

Class H mixes have achieved the objective of less cracking, but at a cost. The specification for Class H concrete requires testing for cracking tendency per AASHTO provisional standard PP34 Standard Practice for Estimating the Cracking Tendency of Concrete. (See HPC Bridge Views, Issue No. 45) With test capabilities available at only two facilities in the state, this presented a challenge for the first projects. This challenge has now been reduced with the addition of new capabilities at other testing facilities.

Another unforeseen challenge of the Class H mixes is the silica fume content. The availability of silica fume in 25 lb (11 kg) bags only, does not lend itself readily to large batch mixes. In addition, because of the small particle size, the silica fume can be a hazard to the workers exposed to it. A study is currently underway to develop a new mix design to remove or at least reduce the silica fume content. An alternate testing method to the AASHTO PP34 test is also being sought to ease the testing requirements for this mix class.

High Strength Concrete

CDOT's requirements for higher strength, cast-in-place concretes are found in the Class S mixes including S35 at 5000 psi (35 MPa), S40 at 5800 psi (40 MPa), and S50 at 7250 psi (50 MPa). In order to gain the extra strength, the cement content range was extended. Unfortunately with increased cement content comes the risk of increased cracking tendency. A task force is looking at how to optimize the mix designs for best overall performance, e.g. increase the strength without increasing the cracking tendency. Class PS concrete is used for precast items such as girders and deck panels and is typically high strength as well, with strengths reaching up to 14,000 psi (97 MPa). This is attained by controlling aggregate size, water-cementitious materials ratio, and admixtures. The challenges for the mixes with the higher strengths are in achieving consistent properties. Fortunately, CDOT enjoys a great working rapport with local precasters in overcoming these problems.

Lessons Learned

One important lesson learned from research and experience is to use high performance concrete teamed with proper design and construction practices. A "high performance concrete" installed with poor construction practices will generally only result in a poorly performing concrete. The Class H concrete in bridge decks cracks less than the Class D concrete mix when installed properly. If installed improperly, it will crack just as much as a Class D mix, if not worse.

As part of improving construction practices, pre-placement conferences and test placements are critical, especially when using new concrete mix designs. Mixes with silica fume or other admixtures may finish differently and test placements provide the contractor with experience. At a minimum, a pre-placement conference can make the contractor aware of potential differences. Curing methods are crucial to reducing cracking.

Completely crack-free bridge decks, curbs, and sidewalks are difficult to obtain due to the restrained drying shrinkage. Even with the elimination of negative moment cracking at the piers through alternative structural designs, shrinkage cracking will still create challenges. High performance concrete can mitigate this cracking, but is only one component to making deck systems last 75 to 100 years. Secondary protection systems such as reinforcement corrosion protection and bridge deck waterproofing systems are important components as well.

Continuing research is also crucial in this holistic approach to longer lasting deck systems. This research needs to consider not only concrete mix design, but design details, construction details and practices, and supplementary protection systems as well.

The Challenge

Like other states, Colorado is challenged to develop high performance concretes to achieve the reliability and dependability necessary to meet the desired 75- to 100-year service life for our bridges. Combined with proper design and construction techniques, these materials will help achieve this goal. CDOT looks forward to the process of properly implementing the high performance concretes of today, while developing the high performance concretes of tomorrow.

Additional Information

Specifications for the classes of concrete and their intended use are available in Section 601 of the CDOT Standard Specifications for Roads and Bridge Construction.