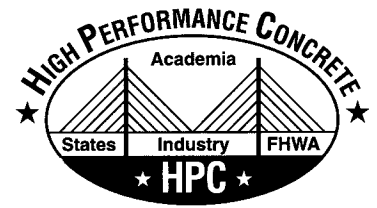




Bridge Views



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REDUCING CRACKS IN CONCRETE BRIDGE DECKS

M. Myint Lwin, Federal Highway Administration and Henry G. Russell, Henry G. Russell, Inc.

In recent years, many bridge owners have adopted the use of lower permeability concretes in bridge decks to reduce chloride penetration and extend the time before corrosion of the reinforcement begins. At the same time, more owners have reported an increase in the amount of cracking in concrete bridge decks. This issue of *HPC Bridge Views*, as well as the next issue, focuses on the experiences of several state Departments of Transportation in dealing with bridge deck cracking.

The problem of cracking is complex and, in some situations, cracking cannot be avoided. Nevertheless, cracks can be minimized by the careful selection of materials, proper design details, and appropriate construction practices. This article addresses some of the critical factors that may have contributed to bridge deck cracking, and identifies practices to reduce cracking.⁽¹⁾

Low permeability concretes are generally achieved through the use of a low water-cementitious materials ratio and supplemental cementitious materials. The use of these materials frequently results in concretes having higher concrete compressive and tensile strengths, higher moduli of elasticity, and less creep. Although the tensile strength is higher, the higher modulus of elasticity and lower creep have led to an increase in the amount of cracking, which then provides the chlorides with an easier path to the reinforcement. As a result, the increase in the number of cracks offsets the benefits of the low-permeability concrete between the cracks. As stated "We have managed to get excellent concrete between the cracks!"⁽²⁾

It is important to design a concrete mix that balances the need for low permeability with the need to minimize cracking. It may not always be desirable or even essential to specify the lowest possible permeability value for bridge deck concrete. A range of 1500 to 2500 coulombs per AASHTO T 277 along with a top cover of 2.5 in. (64 mm) and a water-cementitious materials ratio in the range of 0.40 to 0.45 have been effective for many decks.

Construction practices can have a major impact on the likelihood of cracking. In a survey of 45 bridge agencies in 2003, the most effective strategies to control cracking were identified as fogging during placement of the fresh concrete and adequate curing of the hardened concrete.⁽¹⁾ The majority of owners specified a continuous water-saturated cover for a minimum of 7 days. Curing is particularly important when supplemental cementitious materials are used because of the tendency for less bleed water on the surface.

Other practices that can reduce cracking are:

- Decrease the volume of water and cementitious paste consistent with achieving other properties
- Use the largest practical maximum size aggregate
- Use aggregates, when locally available, that result in lower concrete shrinkage
- Use the smallest transverse bar size and minimum spacing that are practical
- Avoid high concrete compressive strengths
- Design the concrete mix to produce a low modulus of elasticity and high creep
- Implement surface evaporation requirements and use windbreaks and fogging equipment, when necessary, to minimize surface evaporation from fresh concrete
- Apply wet curing immediately **after** finishing and cure continuously for at least 7 days
- Apply a curing compound after the wet curing period to slow down the shrinkage and enhance the concrete properties.

We encourage readers to let us know about other practices and innovative methods that have been used successfully for controlling cracking in concrete bridge decks.

References

1. Russell, H. G., NCHRP Synthesis of Highway Practice 333: Concrete Bridge Deck Performance, National Research Council, Transportation Research Board, Washington, DC, 2004, 101 pp.
2. Concrete Cracking Workshop, Northwestern University, Aug 18-19, 2005, <http://acbm.northwestern.edu/ccw.html>.

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EARLY AGE CRACKING IN SOUTH CAROLINA'S BRIDGE DECKS

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The South Carolina Department of Transportation (SCDOT)'s first use of high performance concrete (HPC) in bridge decks started in the early 1990s. A 1993 report⁽¹⁾ entitled "A Study of Microsilica Concrete," was used as the basis for the development of SCDOT's high performance concrete specifications. The primary purpose of the study was to find the general range of combinations of cementitious materials, aggregates, and various admixtures in a standard laboratory mixture that would yield concrete with improved durability and workability.

The resulting mixture was named Class E (later changed to Class 45) concrete and had the following ingredients per cu yd: 600 lb (356 kg/cu m) of Type I cement; 140 lb (83 kg/cu m) of Type F fly ash; 42 lb (25 kg/cu m) of silica fume; fine to coarse aggregate ratio of 35:65 for crushed stone and 36:64 for gravel; entrained air of 4.5 ± 1.5 percent; and a water-cementitious materials ratio of 0.37; with a high-range water reducer (HRWR) and corrosion inhibitor added to the mix. Specified compressive strength for the Class E concrete was 4000 psi (30 MPa) at 28 days and 6500 psi (45 MPa) at 56 days.

Class E concrete was used on several bridge decks in the upstate region of South Carolina. Most of these bridge decks experienced problems with cracking occurring both before being opened to traffic and immediately thereafter.

In an effort to determine the likely causes of cracking experienced in the new Class E HPC bridge decks, a study entitled "Review of Class E Concrete Bridge Decks in South Carolina" was conducted.⁽²⁾

From the nine bridges that were investigated, it was concluded that the observed cracking had two likely causes: poor curing practices and load-induced cracking. The load-induced cracking that appeared shortly after the spans were open to traffic may have resulted from the relatively stiff decks being placed on more flexible bridge superstructures. A summary of conclusions and key observations from the study were as follows:

1. Early age cracking is likely the result of

improper curing techniques. Curing mats were not placed as soon as they should have been and on-site inspection and quality assurance related to curing may, at times, have been substandard.

2. All inspected bridges exhibited some degree of load-induced cracking. This cracking took the form of full-width transverse cracks. In all cases, these cracks were spaced uniformly along the bridge span and were always observed over the intermediate piers.

3. The Class E concrete mix in South Carolina was, in the opinion of the investigators, a very "rich" mix, which required very stringent quality control during placing and curing. A less "rich" mix was recommended.

4. The performance aspect of concrete most important in bridge decks is durability rather than strength.

The report recommended the following changes related to the use of Class E concrete:

1. Provide improved on-site quality control/quality assurance in all aspects of mixing, placing, and curing when high performance concrete is used.
2. Develop a new concrete mix with enhanced durability characteristics.
3. Review placement sequence documentation and ensure the sequence does not lead to large tensile stresses in previously placed segments.
4. Initiate the placement sequence in the positive moment regions prior to the negative moment regions.
5. Adopt the FHWA parameter characterization for the specification of HPC mixes.
6. Include likely vibration or deflection effects associated with more flexible bridge superstructures in the design of the bridge decks.

During the last few years, the SCDOT implemented some requirements and made changes regarding the Class E HPC mix design:

1. The new mix has less cement. The new ingredients per cu yd are: 500 lb (297 kg/cu m) of Type I cement; 140 lb (83 kg/cu m) of Type F fly ash; 35 lb (21 kg/cu m) of silica fume maintained at 7 percent of the weight of cement; fine to coarse aggregate ratio of 37:63

for crushed stone and 38:62 for gravel; entrained air 4.5 ± 1.5 percent; water-cementitious materials ratio of 0.37; with a HRWR required and corrosion inhibitor added to the mix.

2. Trial mixes for HPC must be performed and approved by the SCDOT.
3. All bridge decks, regardless of the class of the mix, must be wet cured for 7 full days.
4. Wind barricades and foggers must be used during the placement of all bridge deck concrete.

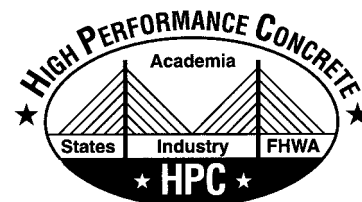
The new mix resulted in a concrete compressive strength of 4000 psi (28 MPa) at 28 days. Rapid chloride permeability values ranging between 1000 and 3000 coulombs were recommended as a means of acceptance and quality control for performance mix designs. Since the implementation of the new requirements and the changes that were incorporated, a few projects with HPC bridge decks were constructed without cracking. It appears that the rich mix was a major factor in causing the early age cracking. Additionally, during the placement of bridge decks, the operation went very smoothly due to the change of the ratio of fine aggregate to the coarse aggregate.

References

1. Mou, C. H. and Hwang, S. Y., "A Study of Microsilica Concrete," School of Engineering Technology, South Carolina State University, 1993.
2. Petrou, M. F. and Harries, K. A., "Review of Class E Concrete Bridge Decks in South Carolina," University of South Carolina, 1999.

Further Information

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MITIGATING DECK CRACKING IN PENNSYLVANIA

Bryan Spangler, Pennsylvania Department of Transportation and Paul J. Tikalsky, University of Utah

Reducing cracking and creating long-life bridge decks in Pennsylvania has become a critically important strategy in renewing the Commonwealth's aging transportation infrastructure. In spring 2001, construction commenced on the westbound lanes of the Pennsylvania State Route 56 Kernville Viaduct in Johnstown, PA, using selected concepts of high performance concrete materials. The multi-span curved composite girder bridge is a major artery through a populated valley of the Allegheny Mountains. Throughout the spring and summer of 2001, the deck was cast and cured for 7 days per job specifications. However, following the removal of the wet burlap, extensive transverse cracking was observed over the entire length of the bridge deck. Despite measures taken to determine the source of the cracks throughout the construction season, the early age cracking persisted.

The Kernville Viaduct is a 2700-ft (823-m) long, 27-span, curved, continuous steel girder bridge with an 8-in. (203-mm) thick reinforced concrete deck. The bridge is divided into six units of three to seven continuous spans with isolation joints between units. The galvanized deck reinforcement consists of No. 5 bars at 10-in. (254-mm) centers each way for the bottom mat, No. 4 bars at 12-in. (305-mm) centers each way for the top mat in the positive moment region, and No. 5 bars at 6-in. (152-mm) centers each way for the top mat in the negative moment region. Concrete cover above the top bars is 2.5 in. (64 mm).

A crack survey of the 2001 westbound lanes by the Pennsylvania Department of Transportation (PennDOT) showed that there were 237 cracks at an average spacing of 6.4 ft (1.95 m) in the positive moment regions and 227 cracks at an average spacing of 5.1 ft (1.55 m) in the negative moment region. Cracks had a width generally greater than 0.04 in. (1 mm) with numerous cracks greater than 0.12 in. (3 mm).

Prior to placement of the eastbound lanes in 2002, PennDOT entered into a sponsored collaborative research and implementation partnership with the Pennsylvania Transportation Institute at Penn State University, to identify measures that would mitigate the cracking on the remaining lanes and to assist in implemen-



Bridge deck cracking on the Kernville Viaduct was reduced by 62 percent.

tation and monitoring of bridge construction.

An investigation of the design and construction practices on the westbound lane was conducted and certain deficiencies were identified that were inconsistent with the goals for creating a bridge with minimal cracking. The following changes to the concrete mixtures were recommended:

- Increase the water-cementitious materials (w/cm) ratio from 0.40 to 0.43 and ensure that the contractor is meeting this target. This reduces the modulus of elasticity and stresses at early ages.
- Decrease the cementitious materials content from 650 to 588 lb/cu yd (386 to 349 kg/cu m) to reduce the early age heat generation and the paste component of the mixture.
- Decrease the percentage of ground granulated blast-furnace slag from 50 to 42 percent of the total cementitious material to reduce the volume of paste in the concrete mixture.
- Decrease the target slump from 6.0 to 4.5 in. (152 to 114 mm) to reduce settlement between the bars.
- Reduce the maximum concrete temperature at time of placement from 80 to 75°F (27 to 24°C) to slow the early age hydration and heat generation.

The following construction considerations were also implemented:

- Place positive moment regions successively on one day followed by the placement of negative moment regions no less than three days later. This procedure reduces the tensile stresses in the negative moment regions when the deck concrete is cast in the positive moment regions.
- Apply moist curing immediately after concrete finishing and maintain con-

tinuously for 10 days with pigmented curing compound applied thereafter to avoid any potential for rapid surface desiccation.

- Increase vigilance in quality control and quality assurance operations to improve concrete production and reject substandard concrete.

Following construction of the eastbound lanes in 2002, crack surveys made immediately after curing and in subsequent months, showed a dramatic reduction in the frequency and width of cracks. Early age cracking, documented immediately after curing, was nearly eliminated by the changes in mixture design and construction practices. At later ages, 174 total cracks were recorded on the eastbound deck, compared to 464 cracks on the westbound deck—a 62 percent reduction. The 7-month survey showed the majority of the cracks in the eastbound lanes were closed or narrower than 0.005 in. (0.13 mm) during cold weather conditions.

The success of these changes has instigated a high performance bridge deck implementation program throughout Pennsylvania. More than 25 additional major bridges have been constructed using the lessons of the Kernville Viaduct to mitigate or eliminate bridge deck cracking and to decrease the permeability and shrinkage of bridge decks. These measures are expected to extend their predicted average service life from 30 to 75 years.

Further Information

Tikalsky, P. J. and Camisa, S. J., "Field Evaluations of Early Age Bridge Deck Behavior," Report to the Pennsylvania Department of Transportation, February, 2005, 174 pp. Paul Tikalsky may be contacted at tikalsky@civil.utah.edu

Question

How do we measure the cracking tendency of concrete?

Answer

The AASHTO PP 34—Standard Practice for Estimating the Cracking Tendency of Concrete covers the determination of the cracking tendency of restrained concrete ring specimens. The procedure is mainly comparative and does not predict the cracking of concrete cast in a specific structure. It does, however, facilitate selecting concrete mixes that are less likely to crack.

The major advantage of the ring test, originally conceived in about 1940, is that all the material factors influencing cracking are present in one straightforward test procedure that simultaneously includes stress development, shrinkage, and creep at early ages, including those during the setting period.

The test method measures the strain in a steel ring as a surrounding concrete ring shrinks. Tensile stresses develop in the concrete and compressive stresses in the steel ring. The standard steel ring has a wall thickness of 0.5 in. (12.5 mm), an outside diameter of 12 in. (305 mm), and a height of 6 in. (152 mm). Strain gages are attached at four equidistant mid-height locations on the interior of the steel ring. A data acquisition unit automatically records each strain gage independently.

Typically, the samples are wet cured for 24 hours then the exterior side surfaces only are exposed to a standard drying environment with a constant air temperature of 73.4°F ±3°F (21°C ±1.7°C) and a relative humidity of 50 ±4 percent. Other curing conditions, however, can be used to simulate site conditions. Time-to-cracking is the age when strains measured by one or more of the strain gages mounted on the steel ring suddenly decrease. A strain decrease of more than 30 microstrain usually indicates cracking.

The measured stresses in the steel rings behave in one of three ways: (a) the stress in the specimen increases uniformly until cracking of the concrete occurs, (b) the stress increases initially to a given value, and then remains near a constant high value near the cracking strength, and (c) the stress increases initially, then decreases and remains nearly constant at a value well below the cracking strength. In case (c), large creep relaxation dissipates the tensile stresses. The goal is to formulate concrete mixtures that will not crack and will allow dissipation of accumulated stresses, as in case (c), since temperature and loading stresses will be superimposed during service.

More Information

For additional information about the cracking tendency of concretes, see NCHRP Report No. 380, Transverse Cracking in Newly Constructed Bridge Decks.

Answer contributed by Paul Krauss, Wiss Janney Elstner Associates, Inc. He may be contacted at pkrauss@wje.com or 847-272-7400 for further information.



Casting specimens per AASHTO PP 34.

HPC BRIDGE CALENDAR

May 14-15, 2007

ASBI Seminar on Design & Construction of Segmental Concrete Bridges, Seattle, WA. See www.asbi-assoc.org/news/events for more information.

May 22-24, 2007

2007 Concrete Technology Forum: Focus on High Performance Concrete, Dallas, TX, Organized by NRMCA. See www.concretetechnologyforum.org for more information.

June 4-6, 2007

International Bridge Conference & Exhibition, Pittsburg, PA. Organized by the Engineers' Society of Western Pennsylvania. Visit www.eswp.com/bridge/bridge_overview.htm for more information.

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