HPC Bridge Views

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HPC STRUCTURAL DESIGNERS' GUIDE

Louis N. Triandafilou, Federal Highway Administration

The January/February 2002 issue of *HPC Bridge Views* described the renewal of the Federal Highway Administration's (FHWA) High Performance Concrete (HPC) Technology Delivery Team, with a focus on the field delivery of HPC technology. The team has been very busy with many activities since then. They have coordinated and presented workshops to assist state departments of transportation (DOT) with HPC implementation. They have developed and are maintaining a Community of Practice website. In 2004, they completed a comprehensive national survey of state DOT implementation of HPC. The survey results have been distributed to all states and Local Transportation Assistance Program Centers and are posted on the FHWA HPC website.

The latest product developed by the team* is an extensive HPC Structural Designers' Guide. Each section of the guide is authored by the facilitators of the respective topic areas that appear on the HPC website. The result is a thorough state-of-the-practice document covering all elements of HPC technology for bridges.

Objective

The main objective of the guide is to provide a source of information to structural designers for the design and construction of highway bridges and related structures using HPC. The guide will be updated periodically to keep pace with the latest developments in HPC, particularly those of the American Association of State Highway and Transportation Officials and industry organizations such as the American Concrete Institute, the American Segmental Bridge Institute, the National Concrete Bridge Council, the Portland Cement Association, the Post-Tensioning Institute, and the Precast/Prestressed Concrete Institute.

Scope

The scope of the guide includes all aspects of developing and producing HPC with desirable and beneficial characteristics for the transportation community.

After the introduction, Section 2 discusses the topic of HPC implementation in the United States highway infrastructure and provides an historical review of its development. Section 3 addresses the characteristics and grades of HPC for various applications and environments. Section 4 is devoted to recently completed national research and ongoing testing into the next generation of HPC, along with web links to state DOT research reports. Section 5 highlights the material properties of HPC that are important to owners and designers in assuring long-term structural performance. Section 6 provides guidelines for developing HPC mix designs and proportioning of materials.

Section 7 focuses on the fabrication, transportation, and erection of precast, prestressed HPC beams. Section 8 applies to cast-in-place HPC construction in substructures and superstructures, with special attention to the construction of bridge decks. Section 9 identifies the most suitable instrumentation that can be used for field measurements and recording of strains, deflections, rotations, accelerations, and temperatures of HPC members. Section 10 provides cost information and methods for assessing the cost-effectiveness of HPC with guidelines for estimating initial construction cost and life-cycle cost. Finally, Section 11 provides an overview of several HPC projects across the United States with lessons learned and contact information or web links for further details.

More Information

The HPC guide is available on CD-ROM from the author at 410-962-3648 or lou.triandafilou@fhwa.dot.gov and has been posted on the FHWA HPC website. Questions or comments on the guide are welcomed and may be directed to the author. The FHWA web site address is http://knowledge.fhwa.dot.gov/hpc.

**The author gratefully acknowledges the substantial effort made by HPC Team members, and by Ms. Deborah Vocke, Marketing Specialist of the FHWA Resource Center – Baltimore, in completing the guide.*

GUIDE SPECIFICATION FOR HPC BRIDGE ELEMENTS

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To assist specifiers in selecting important criteria for HPC in bridges, the Portland Cement Association, in conjunction with the concrete industry, has developed a Guide Specification for High Performance Concrete for Bridge Elements. This document provides mandatory language that the specifier can cut and paste into project specifications. It also includes guidance on the characteristics to be specified in a given case and the performance limits needed to ensure satisfactory performance for a given element or environment. In cases where two performance criteria are in conflict, the commentary advises the user how to balance these conflicting requirements. Using the guide, specifiers should be able to select all criteria necessary for their structures, and then, using the commentary, apply appropriate performance limits for each element.

Specifiers are often tempted to select the highest grade for every parameter with the intention of achieving "high performance concrete." This practice is undesirable and, in some cases, produces mutually incompatible requirements and can lead to unnecessarily excessive costs. For instance, low permeability is normally achieved by using a high cementitious materials content and low water-cementitious materials ratio. This, however, will increase the modulus of elasticity and heat of hydration and thus increase the risk of thermally induced cracking. It is, therefore, not advisable to specify extremely low permeability for concrete in a massive element that is not exposed to an aggressive environment.

Criteria

Durability- and strength-related criteria that may need to be specified are as follows:

- Abrasion Resistance. For bridge decks and perhaps for piers exposed to waterborne abrasion.
- Chloride Ion Penetration. For bridge decks and other structural elements exposed to deicing salts or seawater.
- Compressive Strength. For structural requirements. Strength should not be used as a control parameter for other criteria unless a correlation has been established for the specific concrete mix.
- Creep and Modulus of Elasticity. May be necessary for structural elements, particularly long-span members.
- Freeze-Thaw Durability. For concrete exposed to freezing and thawing in saturated or near-saturated conditions.
- Scaling Resistance. For bridge decks, and possibly other elements, exposed to deicing salts.
- Drying Shrinkage. For control of deflection and shrinkage-related cracking.
- Sulfate Resistance. For foundations and substructures in areas where sulfates are present in the soil or groundwater.
- Consistency. To allow the contractor to select an appropriate value with limits on variability.
- Alkali-Silica Reactivity. In areas where aggregates are potentially reactive.

The guide specification covers submissions that should be considered part of the pre-construction verification program such as mix designs, certifications, material sample retention, and plans for temperature monitoring, curing, and crack control. It also addresses and defines quality management issues, assigning responsibility for quality control and quality assurance tasks, and spelling out particular steps to be taken at each stage of construction. The guide specification lists production-related issues that can increase the likelihood of acceptable performance in the finished concrete such as equipment quality, mixing procedures and timing, temperature limits, trial batches, site addition of water or chemicals, delivery tickets and records, and measurement methods and tolerances.

Bridge Deck Example

A bridge deck exposed to deicing salts needs to resist chloride ion penetration in order to delay the onset of chloride-induced corrosion. Both freeze/thaw durability and scaling resistance are also necessary if the bridge is in a cold region. Depending on structural requirements, the concrete may need to have some minimum compressive strength; however, a strength that is too high with a correspondingly high modulus of elasticity will increase the tendency of the deck to crack. Cracking is detrimental to durability, particularly in an environment conducive to corrosion. In such a case, the specifier might elect to include only the minimum strength requirement. The concrete specification would then be as follows:

Abrasion Resistance. The coarse aggregate shall be tested according to AASHTO T 96. The loss shall not exceed 40 percent. For bridge decks or surface courses, aggregates known to polish shall not be used.

Chloride Ion Penetration. The concrete shall have a charge passed in six hours of 1500 coulombs or less when tested according to AASHTO T 277 at age 56 days. The specimens shall be moist-cured to age 7 days, after which they shall be stored at 73.4 ± 3°F and 50 ± 4 percent relative humidity until the time of test.

Compressive Strength. The concrete shall have a compressive strength of at least 4000 psi when tested according to AASHTO T 22 at age 28 days. The specimens shall be moist-cured to age 7 days, after which they shall be stored at 73.4 ± 3°F and 50 ± 4 percent relative humidity until the time of test. Either 4x8-in. or 6x12-in. cylinders may be used.

Freeze/Thaw Durability. The concrete shall have a durability factor of 90 percent or greater when tested according to AASHTO T 161, Procedure A.

Scaling Resistance. The concrete shall have a visual rating of 1 or less when tested in accordance with ASTM C 672, except that the concrete shall be moist-cured to an age of 28 days, after which it shall be stored in air for 14 days at 73.4 ± 3°F and 50 ± 4 percent relative humidity, before being exposed to deicing chemicals.

Further Information

The guide specification will be published by the Portland Cement Association later this year. For more information, the second author may be contacted at sbhide@cement.org or 847-972-9100.

HPC OVERLAY FOR GREEN RIVER BRIDGE, UTAH

Tarif Jaber, Jaber Engineering Consulting, Inc.

In many states, it is widely believed that the use of advanced materials such as high performance concrete (HPC) is only feasible near large cities. Many engineers, contractors, and the industry in general believe that the special training, workmanship, and supervision required are only available in populous areas.

The Green River Bridge project illustrates that you can successfully place HPC in remote areas, provided that you are willing to handle the materials properly and use weather conditions, such as temperature, to your advantage. Performance results to date show that the choice and methods of application were a success. The Utah Department of Transportation (UDOT) will reap the benefits of HPC for years to come in an extended service life of the bridge and reduced life-cycle costs.

Green River Bridge

Located at Ouray (Uintah County with a population of 26,000) in northeastern Utah at an elevation of 4666 ft (1422 m), the Green River Bridge is a two lane, five span bridge with a concrete deck originally 7-1/2 in. (190 mm) thick supported by four lines of steel girders. It has a total length of 405 ft (123 m) and was constructed in 1960. The bridge is used primarily by oil tankers that are suspected of frequently exceeding the posted load limits. The bridge deck surface had deteriorated significantly and needed repair.

The UDOT considered several options and chose to install a 2-in. (50-mm) thick HPC overlay to restore the integrity of the bridge deck surface and extend its service life. A full-depth replacement was not used because of the cost and environmental impact on the Green River. An HPC overlay was selected to provide an economic rehabilitation method, stiffen the superstructure, and provide 1-1/2 in. (38 mm) of additional cover to the original reinforcing steel. Silica fume was included in the concrete to reduce the permeability and steel fibers were used to control shrinkage cracking.

To obtain the best conditions, the project team chose a cool evening on May 17, 2003, for the HPC placement. The work took place at night to lessen problems with wind and temperature. On a cloudy night, with no wind and an air temperature of 60°F (16°C) at 1:30 a.m., the conditions were ideal for bridge deck placement.

Deck Preparation

The old concrete deck surface was first milled down approximately 1/2 in. (13 mm) to achieve a good rough, clean surface. Deteriorated areas in the old deck were outlined with a saw cut then chipped out with a 16 lb (7.3 kg) pneumatic hammer. These "cutouts" varied in size from 18x18 in. to 2x4 ft (460x460 mm to 610x1220 mm). The exposed reinforcement was sandblasted and the sand removed. The specifications called for keeping the deck wet for three hours prior to the placement. Subsequently, it was decided to soak the deck earlier and then let it dry out for three hours to achieve a saturated surface dry condition. Prior to concrete placement, a slurry of cement, silica fume, sand, and water was scrubbed vigorously into the deck and the cutout areas.

HPC

The batch plant was approximately 40 miles (64 km) from the project. The first truck arrived on site at 2:00 a.m. with concrete having a 6 percent air content, 5 in. (125 mm) slump, and a temperature of 60°F (16°C). Subsequent trucks arrived at 30 to 45 minute intervals. The concrete was screeded with a vibrating triangular-shaped screed. It was then bull floated and steel troweled. The first tining of the finished surface began at about 3:45 a.m. and by 6 a.m. half of the deck had been placed, tined, and received a curing compound. Between noon and 1:00 p.m., the crew placed wet burlap, wetted down the entire deck area, and covered it with plastic sheeting, which remained in place for 7 days.

Human Resources are Key

An evident contributor to the success of this project was the dedication by everyone at the site to doing their jobs well. The placement crew was large enough to match the size of the job, the foremen had good concrete experience, the finishers were diligent, and the other workers were energetic. At times when the placement was going slowly, the finishers had too much time. The crew worked hard at doing a good job and were proud of their work. Although some normal HPC practices were not followed, the final product was successful. In the end, the attention to the project and the willingness to do a good job prevailed.

End Result

The decision made by the UDOT district office to take on the challenge of an HPC project has paid off. Six months after construction, the entire bridge deck overlay showed no signs of cracking. It is expected that the use of HPC with its increased durability will prolong the life of the bridge beyond that anticipated for the original structure.

While many state departments of transportation claim they cannot do HPC in remote areas, this project speaks to the contrary. This may seem like another simple HPC application on a bridge deck, but in fact it underscores the reality that achieving HPC is only a matter of selecting the right material for the project and following good concrete practices ... and nothing more.

Concrete Mix Proportions

Material	Quantities	
	per yd^3	per m^3
Cement, Type 1	658 lb	390 kg
Fly Ash, Class F	70 lb	42 kg
Silica Fume	50 lb	30 kg
Fine Aggregate	1120 lb	665 kg
Course Aggregate	1572 lb	933 kg
Total Water	232 lb	138 kg
Steel Fiber	90 lb	53 kg
Air Entrainment	6 fl oz	232 mL
Water Reducer	15 fl oz	580 mL
HRWR	7.5 fl oz	290 mL
w/cm ratio	0.30	

DECK CRACKING REPAIR CRITERIA IN TEXAS

William R. Cox, Texas Department of Transportation

Bridge deck cracking provides access for oxygen, moisture, and chlorides to reach and corrode steel reinforcement. The resulting corrosion can cause deck deterioration, increased maintenance, and shorter service life. Repairing cracks in new and existing bridge decks is a means to achieve the planned service life of a bridge deck that has suffered significant cracking.

In Texas, the decision to repair bridge deck cracking is based on the severity of the environment, crack width, and extent of cracking. Moisture in the form of rainfall increases from the western portion of the state, where El Paso experiences an average annual rainfall of about 8 in. (200 mm), to southeastern Texas, where Beaumont receives about 57 in. (1.45 m). Winter applications of deicing chemicals are common in the northern regions of the state while structures along the Gulf Coast experience a marine environment. In these regions, the Texas Department of Transportation (TxDOT) responds to inquiries about the acceptability of deck cracks by recommending that cracks greater than 0.005 in. (0.13 mm) in width be sealed. In other areas of the state, TxDOT recommends crack sealing when crack widths exceed 0.01 in. (0.25 mm). However, in areas of the state that receive little rainfall and chloride exposure is of little concern, TxDOT recommends crack sealing only when crack widths exceed 0.02 in. (0.50 mm).

TxDOT has used the following methods and materials to seal new and existing deck cracks:

- Small, localized areas of cracking are easily repaired by cleaning the cracks with pressurized air free of oil and moisture, followed by hand dispensing of super-low-viscosity epoxy into visible cracks. Plastic condiment bottles, similar to the red ketchup containers found at fast-food restaurants, can be used to dispense and control the amount of epoxy applied.
- For larger areas of cracking, a flood coat of super-low-viscosity epoxy or high-molecular-weight methacrylate monomer effectively seals cracks too numerous to spot treat. Before flood coating, the bridge deck is prepared by abrasive blasting followed by a pressurized air blast to remove laitance and other contaminants. After the epoxy or monomer is applied, the excess is removed by brooming, and fine aggregate is broadcast onto the treated area for skid resistance.
- When an entire deck has extensive cracking, application of a multi-layer thin polymer overlay is considered. The first step prepares the deck surface by shot or abrasive blasting followed by a pressurized air blast to remove laitance and other contaminants that could compromise the bond of the overlay. Two separate polymer/aggregate layers are then placed for a minimum total thickness of 0.25 in. (6.4 mm).

Using these methods and materials limits the direct access of oxygen, moisture, and chlorides to the steel reinforcement and increases the probability that the bridge deck will achieve its expected service life.

Editor's Note

This article describes Texas's approach to repair of cracks in bridge decks. Other owners have different criteria. The Editor of *HPC Bridge Views* would like to hear about other practices.

HPC BRIDGE CALENDAR

June 20-24, 2005
Seventh International Symposium on Utilization of High Strength/High Performance Concrete, Washington, DC. Organized by ACI. See www.concrete.org and click on Events and International Conferences for more information.

July 17-20, 2005
Sixth International Bridge Engineering Conference: Reliability, Security, and Sustainability in Bridge Engineering, Boston, MA. Organized by the Transportation Research Board. See www.trb.org/conferences/IBEC/ for more information.

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