HPC Bridge Views

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EXPECTATIONS FOR HPC BRIDGES

Wes Heald, Executive Director, Texas Department of Transportation

The Texas Department of Transportation (TxDOT) is promoting the use of high performance concrete (HPC) through research, construction, and technology transfer. Our first two federally funded HPC bridge research projects, which resulted in the construction of the Louetta Road overpass in Houston and the San Angelo U.S. 67 bridge, have increased our knowledge of how to use HPC.

We have modified our statewide specifications to make use of higher strength HPC beams, and we are evaluating specification requirements for improved durability of conventional strength, cast-in-place HPC in current projects. With HPC, we anticipate being able to build bridges faster, thus, reducing traffic disruption.

Quality Control and Quality Assurance

Quality control and quality assurance (QC/QA) were important aspects of the first two HPC bridge projects. The initial steps were implemented through job specifications and partnering. Researchers from The University of Texas at Austin's Center for Transportation Research performed structural and materials testing, and assisted TxDOT and the contractor as needed in solving HPC mix design, fabrication, and construction problems. This help was extremely useful and kept construction on schedule. The FHWA sent trained personnel and its mobile concrete laboratory to aid in the onsite testing. Implementation of the QC/QA program was a dynamic process with continuous updating of the program to accommodate test results and findings during construction.

Partnering

Partnering was another element in the successful production of HPC at reasonable costs. Partnership and teamwork were not accidental; they were clearly laid out as objectives of the contract and partnering agreements. Prebid, prefabrication, and preconstruction meetings were all held. These meetings allowed concerns to be expressed and options to be considered while plans could still be changed relatively easily and inexpensively. The meetings assured contractors that construction would not be hampered by the use of innovative techniques and materials, and that local materials and conventional methods would be used to the maximum possible extent. The meetings also promoted discussion and fair resolution of problems of precasting bed requirements, special HPC construction requirements, and curing concerns associated with HPC mixes.

Several notable benefits came from the collaborative process. One was TxDOT's acceptance of the precaster's redesign of the San Angelo HPC beam stressing sequence. The contract drawings required that all the strands be pretensioned. The fabricator proposed a mix of pretensioned and post-tensioned strands. The arrangement allowed the fabricator to use the company's existing precasting beds. This saved both time and money. Another benefit was the special lifting frame that the fabricator designed to help in transporting the beams safely. Working together on the hauling system and routing resulted in the successful transportation of beams with lengths up to 153 feet (46.6 m) from the fabrication site to the job sites — a journey of over 300 miles (480 km) for the San Angelo project.

Concrete Durability

In addition to allowing longer spans with fewer beams, a very attractive feature of HPC is its durability. Durable, impermeable concrete should mean lower maintenance over the life of a structure and longer life expectancy. An environmental benefit is that the researchers recommend the use of fly ash—a waste material—as 25 to 35 percent of the cementitious material in HPC to decrease permeability.

Summary

Based on what we have learned, the future looks bright for HPC. Through its use, we expect durable, reasonably priced bridges that can be built faster, last longer, and require less maintenance.

Placing concrete on New Hampshire's HPC bridge deck.

CRACK FREE HPC BRIDGE DECK—NEW HAMPSHIRE'S EXPERIENCE

Christopher M. Waszczuk, New Hampshire Department of Transportation

With the state and country's infrastructure needing greater attention, the New Hampshire Department of Transportation (NHDOT) has become proactive in the use of better quality, higher performing materials. The goals are to reduce the maintenance and repairs typically necessary during a structure's life and to try to increase the service life of structures.

To help achieve the above goals, NHDOT has become involved in the use of HPC as part of the Federal Highway Administration's (FHWA) High Performance Concrete (HPC) Bridge Showcase Program. The first HPC bridge constructed in the region specified 8000 psi (55 MPa) concrete for the girders and 6000 psi (41 MPa) concrete for the deck. In addition to the benefit of increased strength, durability properties such as low permeability and increased freeze-thaw resistance were considered extremely important. Considerable research and background investigations were performed to ensure that the specifications addressed the practicality of all aspects of the concrete construction process including batching, placing, finishing, and curing.

The following provides a brief description of NHDOT's first HPC structure with emphasis on the HPC deck construction experience. To ensure a longer life with little to no maintenance, it was essential to install a highly impermeable, crack-free, freeze-thaw resistant concrete deck.

Bridge Background

The HPC bridge is located in Bristol, New Hampshire and carries Route 104 over the Newfound River. The bridge is a 65 ft (19.8 m) single span structure with a total width of 57.5 ft (17.5 m) and was designed to accommodate three lanes of traffic and a sidewalk. The superstructure consists of a cast-in-place concrete deck composite with five precast, prestressed AASHTO Type III girders. The girders are spaced at 12.5 ft (3.8 m) on center. The deck utilizes the bare concrete as the final riding surface.

Deck Construction

The specifications necessitated that the concrete supplier perform several trial batches to refine the concrete deck mix proportions. Once the mix proportions were approved by NHDOT and prior to the actual placement of the deck concrete, a 5 cu yd (3.8 cu m) trial pour was made simulating the actual placing, finishing, and curing conditions. This trial pour was considered very important for the purpose of allowing the contractor the ability to fine tune the admixture dosage to ensure a workable mix. It also allowed the opportunity to ensure that the proper equipment was being used for good finishing practices and that the curing methodology was adequate. The criteria for the deck concrete mix are shown in Table 1. The approved mix design is listed in Table 2. A silica fume mix with a maximum water-cementitious material ratio (w/cm) of 0.38 was chosen based on research conducted at the University of New Hampshire (UNH). A 6 to 9 percent air content requirement was instituted to provide an air-void system for freeze-thaw resistance. Higher concrete strength was needed to minimize the deck thickness required to span the 12.5-ft (3.8-m) girder spacing. A permeability of 1000 coulombs or less was targeted to achieve a dense, highly impermeable concrete. A corrosion inhibitor was specified instead of NHDOT's standard practice of protecting concrete decks with a barrier membrane and an asphalt overlay. Four days of wet cure with cotton mats were specified.

The deck was built using standard deck construction techniques. The concrete was pumped for ease of placement. To limit air content loss and to prevent freefall of the concrete, the end of the hose was positioned horizontally during pumping. A standard self-propelled fin-

Table 1. Deck Concrete Specifications

Cement	Type II
Silica Fume	7.50%
w/cm max.	0.38
Air Content	6 to 9%
28-day Cylinder Strength*	7200 psi (50 MPa)
Chloride Ion Permeability	1000 coulombs
Corrosion Inhibitor	4 gal/yd^3 (20 l/m^3)
Curing Procedure	4-day wet cure w/ cotton mats

**Basis for concrete mix proportions*

Table 2. Deck Concrete Mix Design

Material	Quantities	
	per yd ^{3}	per m ^{3}
Type II Cement w/8% Silica Fume	660 lb	392 kg
Fine Aggregate	1190 lb	706 kg
Course Aggregate	1815 lb	1077 kg
Water	253 lb	150 kg
Air Entrainment	5 oz	193 ml
Water Reducer	20 oz	774 ml
High-Range Water-Reducer*	158 oz	6.11 l
Corrosion Inhibitor	4 gal	19.8 l
Water/Cementitious Material Ratio	0.38	0.38

* *Added at the site.*

ishing machine was used to strike off the concrete surface. Hand finishing was performed only in the areas adjacent to the curb line and screed rail supports. A finishing pan and burlap drag were attached to and followed behind the screed machine to simultaneously finish and texture the concrete surface. Within 15 minutes after a section of the deck was dragged, it was covered with dry cotton mats and then wetted. Bullfloating and over-finishing the surface were strongly discouraged.

Curing consisted of maintaining the wet cotton mats in direct contact with the concrete surface for a period of four days. The timely placement of the cotton mats prevented surface drying and eliminated the initiation of shrinkage cracks. Requirements to limit water evaporation based on climatic conditions at the time of the concrete placement were strictly enforced. No concrete could be placed if the evaporation rate was greater than 0.1 lb/ft^2/hr (0.45 kg/m^2/hr) or if the ambient temperature was above 85°F (29°C). Once adequate concrete strength was achieved, the hardened finish was transversely saw-cut on 1.5 in. (38 mm) centers. The grooves were 0.125 in. (3 mm) wide by approximately 0.25 in. (6 mm) deep. Tining or raking the surface was not considered due to the possibility of tearing and exposing the surface to the drying elements.

Each truck load of concrete was tested for slump, unit weight, concrete temperature, and air content. Consistency and uniformity in the values was of prime importance. Some difficulty maintaining the required air content and a consistent slump was encountered during the deck placement. A higher dosage of superplasticizer than that used in the trial pour was needed at the site in order to achieve the desired workability in the concrete. This phenomenon was largely unexplained, however it is the author's belief that the interaction of the corrosion inhibitor with the other admixtures during the travel time to the site may have contributed to the inconsistent air content and slump results. Regardless, all the other specification requirements were met.

The NHDOT deck concrete test results are listed in Table 3. The average 28-day cylinder strengths were well in excess of the 7200 psi (50 MPa) requirement and the results from the 56-day rapid chloride permeability tests performed on deck cores were outstanding. Even though the air content of the concrete fell below the specification requirement, the freeze-thaw durability tests performed on the prisms revealed excellent results after 300 test cycles.

Summary

Trial batching and the trial pour played an integral role in optimizing the development and placement of the HPC deck. Modifications were made throughout the pre-pour process to refine the mix proportions and eliminate any foreseeable problems. The concrete was placed using standard deck construction techniques and equipment. Over-finishing and bullfloating the surface were strongly discouraged. Proper curing practices were implemented immediately and were considered vital to ensure a good end result. The concrete surface was immediately covered with cotton mats and wet cured for a period of four days. The final product exceeded expectations. No visible cracks in the deck were found during several post construction reviews conducted by research, construction, and design personnel. UNH conducted an extensive "wet study" of the deck surface and concluded only microscopic longitudinal flexural cracks existed in some areas over the girder lines. No shrinkage cracks or transverse cracks were evident. The 28-day concrete strength exceeded the specification requirement. The freeze-thaw durability, chloride ion permeability, and scaling tests also produced excellent

Table 3. Deck Concrete Test Results

Test	Results	
Slump	3 to 5 in.	76 to 127 mm
Unit Weight	144 to 147 lb/ft^3	2.31 to 2.35 Mg/m^3
Air Content	4.0 to 5.8%	4.0 to 5.8%
w/cm Ratio	0.39	0.39
28-Day Cylinder Strength	8160 to 9610 psi	56.3 to 66.3 MPa
Modulus of Elasticity	4.2 to 4.3x10^6 psi	29 to 30 GPa
Chloride Ion Permeability	610 to 900 coulombs	610 to 900 coulombs
Freeze-Thaw Durability	96 to 99%	96 to 99%
Scaling	0 to 1	0 to 1

results. Based on preliminary evaluations, the concrete deck will be highly resistant to chloride intrusion and freeze-thaw deterioration and should provide superior long-term service with minimal maintenance.

Further Information

Further information about Route 104 bridge may be obtained by contacting the author at 603-271-6675 or N34CMW@dot.state.nh.us and in the following publications:

Waszczuk, Christopher M. and Juliano, Michelle L., "Application of HPC in a New Hampshire Bridge," Concrete International, February 1999, Vol. 21, No. 2, pp. 61-62.

Fratzel, Todd M., "Evaluation of High Performance Concrete Slabs Including In-Situ Testing at a Bridge Deck Testing Facility," Graduate Thesis, University of New Hampshire, May 1996, Durham, NH.

Wilson, Cheryl R. and Cook, Raymond A., "Measuring Performance: Preliminary Use of High Performance Concrete in New Hampshire Bridges," New Hampshire Journal of Civil Engineers, Vol. 1, No. 2, Autumn 1996.

Q&A

Many questions arise about HPC and its applications. If you have a question that you would like answered in HPC Bridge Views, please submit it to the Editor.

Question:

Is there a standard mix for HPC?

Answer:

As illustrated by articles in this and previous editions of *HPC Bridge Views*, the requirements for HPC differ from one state to another, from one bridge to another, and between the deck and the girders. For example, the proportions for five different HPC mixes all designed to meet a specified compressive strength of 10,000 psi (70 MPa) are given in Table 1. Even though the specified compressive strengths are the same, they are specified at different ages and the specified strengths at transfer of prestressing force are different. Different types of cements, mineral admixtures, and chemical admixtures are incorporated into the mixes.

Whereas the mix proportions for HPC in prestressed concrete bridge girders are based primarily on strength criteria, durable concrete is usually achieved because of the low permeability of high-strength concrete. On the other hand, mix proportions for HPC in cast-in-place decks are often based on durability, although a minimum concrete compressive strength is also specified. Table 2 shows mix proportions for four HPC bridge decks. In all cases, a combination of cementitious materials is used to improve the durability and not necessarily to increase the strength.

The data in the two tables indicate that there is not a standard mix for HPC for either precast, prestressed concrete girders or cast-in-place decks. Concrete mix proportions must be selected to meet the specified performance criteria using locally available materials and good construction practices.

Table 1. Concrete Mix Proportions for HPC Prestressed Girders

BRIDGE LOCATION	CO	LA	OH	VA	WA
CONCRETE COMPRESSIVE STRENGTHS					
At Initial Prestress, psi	6,500	7,000	6,000	6,600	7,400
Specified Strength, psi	10,000	10,000	10,000	10,000	10,000
Specified Age, days	56	56	56	28	56
MIXTURE INGREDIENTS					
Cement Type	III	III	III	I	III
Cement Quantity, lb/yd^3	730	691	846	752	728
Fly Ash Quantity, lb/yd^3	—	296	—	—	222
Silica Fume, lb/yd^3	35	—	100	75	50
Fine Aggregate, lb/yd^3	1,363	1,135	927	1,350	890
Coarse Aggregate, lb/yd^3	1,775	1,803	1,773	1,671	1870
Water, lb/yd^3	219	247	262	235	265
w/cm Ratio	0.30	0.25	0.28	0.28	0.27
Chemical Admixtures					
Air Entrainment, fl oz/yd^3	—	—	21	Yes	—
Water Reducer, fl oz/yd^3	15-58	60	—	—	29
Retarder, fl oz/yd^3	—	—	28	25	—
High-Range Water-Reducer, fl oz/yd^3	44-131	150	215	207	215

Table 2. Concrete Mix Proportions for HPC Bridge Decks

BRIDGE LOCATION	NE	NH	TX	VA
SPECIFIED PROPERTIES				
Strength, psi	8000	6000	4000	4000
Strength Age, days	56	28	28	28
Permeability, coulombs	1800	1000	—	2500
Permeability Age, days	56	56	—	28 (1)
MIXTURE INGREDIENTS (2)				
Cement, lb/yd^3	750	607	382	329
Fly Ash, lb/yd^3	75	—	148	—
Silica Fume, lb/yd^3	—	53	—	—
Slag, lb/yd^3	—	—	—	329
Fine Aggregate, lb/yd^3	1400	1190	1242	1173
Coarse Aggregate, lb/yd^3	1400	1815	1856	1773
Water, lb/yd^3	255	253	230	263
w/cm Ratio	0.31	0.38	0.43	0.40

(1) Includes 21 days at 100°F (38°C).

(2) The mix proportions also include various combinations of air-entraining and chemical admixtures.

FROM THREE SPANS TO ONE WITH HPC

Richard A. Miller, University of Cincinnati

Adjacent box girder bridges are frequently used in Ohio and other eastern states. These bridges have a favorable span-to-depth ratio—an important benefit when vertical clearance is a design consideration. Furthermore, with noncomposite sections the bridge can be constructed quickly because there is no need to form, cast, and cure a separate deck. With HPC adjacent box girders, savings can also be realized by using longer spans and eliminating piers.

The Ohio HPC Showcase bridge is located on U.S. 22, near Cambridge, Ohio. The existing structure was a 70-ft (21.3-m) long steel stringer bridge over a river. The Ohio Department of Transportation (ODOT) decided to widen the channel at this point and to provide sloping sides, rather than the existing vertical sides. The original replacement structure was designed as a three-span bridge using 21-in. (535-mm) deep, simply-supported boxes.

To save the cost of constructing the piers and to provide better flow characteristics by having an unobstructed channel, the bridge was redesigned as a single span. Thus, the new structure needed to span 116 ft (35.4 m). The largest box girder available is an ODOT B42-48, which is 42 in. (1.07 m) deep and 48 in. (1.22 m) wide. ODOT box girders have a 5-in. (125-mm) thick bottom flange rather than the 5.5 in. (140 mm) flange used in standard AASHTO sections. The ODOT section can only accommodate a single full row of 23 strands and several partial rows of 2 or 4 strands. With all possible strand positions used, this section can only span 105 ft (32 m) with conventional strength concrete and 0.5-in. (12.7-mm) diameter strands. With 0.6-in. (15.2-mm) diameter strands, the maximum span can be increased to 135 ft (41.1 m). Because the 0.6 in. (15.2 mm) strand provides a much higher prestressing force, high strength, high performance concrete is needed to resist the higher compressive stresses.

High performance concrete was also used in the girders because of its lower permeability. This provides better corrosion protection to the prestressed and nonprestressed reinforcement. This is particularly important with adjacent box girders as salt-laden water tends to penetrate into any longitudinal cracks that may form between adjacent girders.

One of the first steps in the design was to check the probable transportation route for weight and size restrictions and to ensure that the beams could be safely transported to the site. Next, mix designs were developed for both the beams and abutment concretes. Once the beam mix design was selected, two heavily instrumented test beams were cast. These beams provided the fabricator with production experience for the concrete mix. The two test beams were then subjected to cyclic loading and tested to destruction. This testing showed that the beam behavior was predictable using standard analysis techniques and met the provisions of the AASHTO Standard Specifications. With satisfactory results from the test beams, the production beams were cast.

Just a few weeks before site construction was due to begin, the aggregates for the abutment HPC were found to contain too much carbon. The abutment mix had to be redesigned in a very short time. After casting, differential shrinkage cracking occurred in some areas of the abutments because the wet burlap was not maintained in contact with the concrete surface. In later pours, the concrete surface was maintained completely wet and the cracking was greatly reduced.

The bridge was constructed in two phases to maintain traffic. In Phase I, one half of the old bridge was removed and seven HPC beams installed for the first half of the new bridge. Traffic was then diverted to the new half of the bridge while the remaining five beams of Phase II were installed. After both phases, the bridge was load tested by parking up to four dump trucks, each weighing 32 kip (142 kN), in various patterns on the deck. In both phases, the maximum deflection under the worst case static loading was only 0.5 in. (13 mm). Subsequent measurements of deflection under normal, moving traffic loads showed a maximum deflection of 0.25 in. (6 mm). There was concern that a bridge this long and slender would vibrate excessively, but the measured vibrations were not excessive and they damped out quickly.

This HPC structure is expected to provide a long service life, with minimal maintenance.

Further Information

Further information about the U.S. 22 HPC bridge may be obtained by contacting the author at 513-556-3744 or ramiller@uceng.uc.edu.

HPC resulted in a wider channel with no piers.

INTERNATIONAL SYMPOSIUM ON HIGH PERFORMANCE CONCRETE

The Precast/Prestressed Concrete Institute, the Federal Highway Administration and the Fédération Internationale du Béton will co-sponsor an International Symposium on High Performance Concrete to be held September 25-27, 2000 in conjunction with the PCI Annual Convention and Exhibition in Orlando, Florida.

Topics

Topics to be addressed at the Symposium will include:

General History and Definition
The history and definition of high performance concrete.

Materials and Mix Design
Material properties, mix design, use of admixtures, durability, placeability, and avoidance of delayed ettringite formation.

Research and Future Direction
Research on mix properties, strength, durability, ductility, high performance grout, reactive powder concrete, and new materials including development, testing, and applications of non-metallic corrosion-resistant reinforcement such as FRP.

Quality Concepts
Quality control, curing procedures, test methods, instrumentation, placement, and use of quality systems for durable high strength concrete products and performance based specifications.

Construction Techniques
Techniques, systems, methods, or procedures that facilitate construction, including transportation and placement of high performance concrete.

Structural Design and Concepts
Design aspects of high performance concrete, including seismic behavior of high strength structural elements, repair, rehabilitation and promising concepts for future applications.

Fabrication and Transportation
Fabrication and testing of bridge girders, prestressing techniques, delivery to the job site, and erection of prestressed concrete members.

Structural Performance and Code Requirements
Evaluation of structural performance in terms of creep, shrinkage, camber, and other long-term behavioral characteristics. Current ACI and AASHTO Code provisions including limits and required changes relevant to high strength concrete.

FHWA Showcase Projects and Case Histories
Overviews and summaries of the demonstration projects sponsored by FHWA and state departments of transportation, including follow-up reports on their performance. Highlights from projects that have incorporated high performance concrete including problems and limitations.

Cost Effectiveness, Marketing, and Implementation
Modeling service life, life-cycle cost analysis, marketing, and implementation of high performance concrete for bridges.

Call for Papers

Papers are invited on the above topics. Authors should forward a one-page abstract of their paper to PCI, together with a short career history and confirmation that they will attend and present the paper at the symposium if the abstract is accepted. The deadline for receipt of abstracts is August 31, 1999. Authors of accepted abstracts will be notified by October 31, 1999. Written papers are required by February 28, 2000.

Further Information

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