HPC Bridge Views

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NEW YORK STATE—FULL-SCALE IMPLEMENTATION OF HPC

Mathew Royce, New York State Department of Transportation

New York State Department of Transportation (NYSDOT) implemented the use of high performance concrete (HPC) for bridge beams with the completion of three bridges in 2001. An additional 19 bridges are now in various stages of design or construction. More than half these bridges will be completed by the end of 2002; the remainder will be completed in 2003.

Based on the experience with concrete Class HP for bridge decks* and with HPC for precast, prestressed concrete beams, NYSDOT is convinced that the use of HPC in bridge beams is good value based on life-cycle costs. NYSDOT is starting with a few HPC bridges with the plan of using HPC for all prestressed concrete bridge beams within a few years.

NYSDOT developed the specification for HPC in bridge beams, in consultation with the Precast Concrete Association of New York. Their main concern was the potential for rejection of beams due to test results slightly outside the specified range. The specification reduced this problem without impacting the quality and performance of the final product by allowing precasters to develop mix designs and to demonstrate in preproduction testing that the required performance criteria are met.

Precasters who are interested in producing HPC bridge beams for NYSDOT are expected to develop their own mix designs and submit them for approval. To initiate the process, a mix design sheet showing the proposed HPC mix design, proposed curing method during production, details of test specimen preparation, and information about the independent AASHTO accredited testing laboratory must be submitted to the NYSDOT. The test specimens are then prepared at the precasting plant and tested by the independent laboratory using the specified test method. The results are compared with the acceptance criteria and, if found acceptable, the mix design is approved for producing HPC bridge beams for any future NYSDOT projects.

For preproduction acceptance, the test mix must meet the following criteria:

Compressive strength (f'_c) at 56 days (AASHTO T 22) ≥ 10,150 psi (70 MPa)
Modulus of elasticity when f'_c ≥ 10,150 psi (ASTM C 469) ≥ 4351 ksi (30 GPa)
Shrinkage at 56 days (AASHTO T 160) < 600 millionths
Specific creep at 56 days (ASTM C 512) ″ 0.41 millionths/psi (60 millionths/MPa)
Freeze-thaw durability (AASHTO T 161 Proc. A) ≥ 80%
Scaling resistance (ASTM C 672) ″ Rating 3
Chloride penetration (AASHTO T 259 Modified) ″ 0.025% at 1 in. (25 mm)
Air content selected by contractor ≥ 3%
Water-cementitious materials ratio selected by contractor < 0.40

For acceptance of HPC during production, each batch ticket is examined to ascertain that mix ingredients and mix proportions are according to the approved mix design; AASHTO TP 23 is performed to ascertain that the water-cementitious materials ratio conforms to that of the approved mix design; air content is verified to be within tolerance; and the average concrete compressive strength for each beam is at least 10,150 psi (70 MPa) with no individual value less than 9650 psi (66.5 MPa). Monitoring of the other properties for the production concrete is an ongoing project by NYSDOT.

In addition to enhancing the durability, our designers are using the 10,150 psi (70 MPa) compressive strength concrete to design bridges with fewer girders to reduce cost or to design shallower superstructures to overcome vertical clearance limitations.

In conclusion, the overall experience of NYSDOT with HPC for prestressed concrete bridge beams is a positive one. If this success continues, NYSDOT will start specifying HPC for all prestressed concrete bridge beams within a year or two. The end result will be full-scale implementation of HPC in both beams and decks.

**See HPC Bridge Views Issue Nos. 6 and 7.*

HPC ON THE I-15 RECONSTRUCTION PROJECT

Raymond D. Cook, Utah Department of Transportation

The 17-mile (27-km) long, $1.59 billion I-15 Reconstruction Project in Salt Lake City, Utah, was the nation's largest design-build highway project awarded to a single contractor. The project included the design and construction of 142 bridges with 1783 prestressed concrete girders and more than 445,000 cu yd (340,000 cu m) of structural concrete. The project's scope and fast-track schedule, which involved complete design and construction within 4-1/2 years, required that the Utah Department of Transportation (UDOT) and Wasatch Constructors use a number of innovative engineering solutions including the following:

- Precast, prestressed concrete girders with high strength concrete
- Spliced post-tensioned concrete girders
- Cast-in-place (CIP) concrete bridge decks with 5 percent silica fume (SF) for all bridges
- Precast, prestressed concrete deck form panels topped with CIP SF concrete
- Girder spacings up to 20 ft (6 m) and transversely post-tensioned concrete decks to minimize the number of steel girders

Precast, prestressed concrete girders were the design-builder's preferred bridge members due to their lower construction and maintenance costs. The designers developed modified Nebraska bulb-tee girders with depths of 41.3, 57.1, and 72.8 in. (1050, 1450, and 1850 mm). The top flange width for all girders was 50 in. (1275 mm) and the bottom flange width was 38.4 in. (975 mm). A concrete compressive strength of 7500 psi (52 MPa) at 28 days was used to minimize the number of girders. Multi-span girders were made continuous at intermediate supports.

Eight interchanges were reconstructed as single point urban interchanges. The ramp geometry at these locations required bridges with clear spans up to 230 ft (70 m). At these locations, Wasatch Constructors chose to use spliced post-tensioned concrete girders. The girders were modified Nebraska bulb-tees similar to the pretensioned concrete girders, but with a depth of 94.5 in. (2400 mm). Each girder was cast in three sections. Each section was pretensioned to support dead loads and construction loads applied prior to post-tensioning. Intermediate girder ends were temporarily supported by falsework bents at the splice locations until the splice diaphragms and concrete deck were placed. The girder and deck composite section was then post-tensioned and the falsework bents removed to provide a single span bridge.

All structures required a predicted 75-year service life. To reduce corrosion potential, deck expansion joints were eliminated wherever possible and all reinforcing steel was epoxy coated. In addition, UDOT required that all CIP concrete bridge decks include 5 percent SF by weight of cementitious materials or an initial overlay. The design-builder chose to use SF concrete. In addition to SF, the structural concrete mixes included air entrainment, Class F fly ash, and a low range water-reducing admixture. Post-tensioned concrete decks required a 28-day compressive strength of 5000 psi (35 MPa). All other CIP concrete required a 28-day compressive strength of 4000 psi (28 MPa). After finishing, curing compound was applied to the deck surface followed by a seven-day water cure. Concrete temperature was maintained above 50°F (10°C) for at least the first seven days after placement.

Early in the project, the SF concrete mix caused difficulties with workability and finishing due to the stickiness of the surface. Placement procedures and specifications were evaluated and modified to reflect the needs of the SF. The allowable slump was increased to improve the ability to work with and finish the concrete. Controlled fogging was allowed to increase the humidity above the fresh concrete and minimize moisture loss from evaporation until the deck could be finished and the curing compound added. Fogging helped prevent drying of the concrete surface and the formation of a "skin" on the concrete. This had occurred early in the project leading to difficulties with finishing. Whenever possible, decks were placed during the cooler temperatures at night to reduce the evaporation of surface water.

Precast, prestressed concrete deck form panels were used on most precast, prestressed concrete girder bridges. Panels were 3.5 to 5.5 in. (90 to 145 mm) thick and were topped with CIP SF concrete to make an 8- to 10-in. (205- to 255-mm) total deck thickness. Panels were temporarily supported on the girder flanges using medium density polystyrene or preformed joint filler until the CIP concrete provided permanent support to the edges of the panels.

A research project is currently underway to evaluate the deck cracking that occurred on some of the I-15 bridges and to identify potential causes and remedies.

High strength concrete helped achieve long spans. High performance concrete was used to provide a predicted 75-year service life.

Further Information

For further information, see "I-15 Project Paves Way for Hybrid Precast Girder," ASCENT®, Spring 1999, pp 24-27; or contact the author at 801-951-1026 ext. 319 or raycook@utah.gov.

BENEFITS OF AIR ENTRAINMENT IN HPC

Beatrix Kerkhoff, Portland Cement Association

The development of air-entrained concrete in the mid-1930s was one of the greatest advances in concrete technology. Air-entrained concrete contains small and stable air bubbles that are uniformly distributed throughout the cement paste. Air-entrained concrete is produced through the use of either air-entraining portland cement or air-entraining admixtures. Benefits of entrained air are apparent in both the fresh and hardened concrete. The most important benefit in concrete is the improved freeze-thaw resistance of hardened concrete that is exposed to freezing and to deicing chemicals while critically saturated. In fresh concrete, workability is improved and bleeding is reduced.

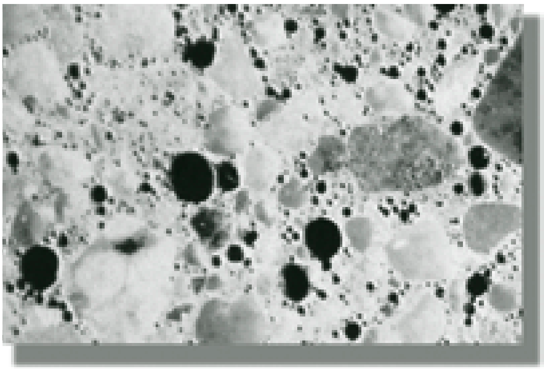
Total Air Content

Current U.S. field quality control practice usually involves the measurement of only total air volume in freshly mixed concrete. The most common test methods are the pressure method (AASHTO T 152) and the volumetric method (AASHTO T 196). It is important to note that these tests refer only to the total air content and do not address the air-void size in any way. The AASHTO Bridge Specifications for Class A(AE) concrete require a total air content of 6 percent with a tolerance of ± 1.5 percent and a maximum aggregate size of 1 in. (25 mm). For Class P concrete, the air content is to be specified in the contract documents.

Air-Void System

The total air content can be misleading. Spacing, size, and number of air voids are very important factors. They determine the quality of the air-void system. As the water in concrete freezes, it needs to find an empty space in a bubble within a short distance. Thus, as the water freezes, it can expand freely, eliminating any buildup of internal pressure—the principal cause of freeze-thaw damage such as scaling. Therefore, properly air-entrained concrete needs to have closely spaced air voids that are extremely small in size. The majority of voids in normal air-entrained concrete are between 10 µm and 100 µm in diameter.(1)

Cross-section of an air-entrained concrete.



Spacing Factor and Specific Surface

The following two air-void characteristics are considered a prime requirement of a good air-void system: (1, 2)

1. Calculated spacing factor, $\bar{L}$, (an index related to the distance between bubbles but not the actual average spacing in the system): less than 0.008 in. (0.200 mm)
2. Specific surface, a, (surface area of the air voids): 600 $in.^2/in.^3$ (24 mm^2/mm^3) of air-void volume, or greater

The standard test for air-void parameters is ASTM C 457, Standard Test Method for Microscopical Determination of Parameters of the Air-Void System in Hardened Concrete.

Durability vs. Strength

Air entrainment greatly increases concrete durability but reduces concrete strength. Compressive strength is generally reduced by 2 to 9 percent for each percentage point increase in air content.(3) Therefore, adequate strength and maximum durability are achieved by establishing optimum air contents and spacing factors.

Air Entrainment for HPC

For bridge decks, piles, piers, and parking structures, where durability in a freeze-thaw environment is required, air entrainment is mandatory. However, for certain high performance concretes with low water-cement ratios, the requirements for total air content might be too conservative.(2) Certain high strength concretes do not need as much air as conventional strength concretes to be frost resistant due to reduced porosity and less freezable water within the high strength concrete. Pinto and Hover found that non-air-entrained concretes had good frost and deicer-scaling resistance at a water to portland cement ratio of 0.25.(2) Other research has indicated excellent durability of certain non-air-entrained high performance concretes to freeze-thaw damage and salt scaling.(3)

Attention should be paid to air-entraining admixture types and their dosage rates, since certain properties of supplementary cementing materials used in HPC, such as the carbon content of fly ash, greatly influence air-void system stability. Trial mixes to ensure adequate concrete air entrainment are important.

While high performance concrete with very low water-cementitious materials ratio is widely believed to be resistant to scaling and physical breakup due to freezing and thawing, it is still considered prudent to use air entrainment.(3) No well-documented field experiments have been made to prove that air entrainment is not needed in HPC. Until such data are available, current practice for air entrainment should be followed for all concrete—conventional and high performance.

References

1. Whiting, D. A., and Nagi, M. A., "Manual on Control of Air Content in Concrete," EB116, National Ready Mixed Concrete Association and Portland Cement Association, 1998, 42 pp.
2. Pinto, R. C. A. and Hover, K. C., "Frost and Scaling Resistance of High-Strength Concrete," RD122, Portland Cement Association, Skokie, Illinois, 2001, 75 pp.
3. Kosmatka, S. H., Kerkhoff, B., and Panarese, W. C., "Design and Control of Concrete Mixtures," EB001, Portland Cement Association, Skokie, Illinois, 2002, 368 pp.

Editor's Note

This article is the eighth in a series that addresses the benefits of specific materials used in HPC. The benefits of silica fume, lightweight aggregate, different cements, slag cement, fly ash, corrosion inhibitors, and chemical admixtures were discussed in previous issues of HPC Bridge Views.

SPECIFICATION CHANGES FOR HPC—CLASSES OF CONCRETE AND CEMENTITIOUS MATERIALS

The AASHTO Standard Specifications for Highway Bridges – Division II, AASHTO LRFD Bridge Design Specifications, and the AASHTO LRFD Bridge Construction Specifications include a table that defines classes of concrete for use in highway structures. The table, which is similar in all three documents, has prescriptive requirements for minimum cement content, maximum water-cement ratio, air content range, size of coarse aggregate, and specified compressive strength. For many high performance concrete (HPC) applications, performance based specifications are more applicable.

The transition to performance based specifications can be facilitated by the introduction of two new classes of concrete as shown in the table. Class P(HPC) is intended for use in prestressed concrete members with a specified concrete compressive strength greater than 6000 psi (41 MPa). Class A(HPC) is intended for use in cast-in-place construction where performance criteria in addition to concrete compressive strength are specified.

For both classes of concrete, a minimum cement content is not included since this should be selected by the producer based on the specified performance criteria. A maximum water-cementitious materials ratio has been retained to be consistent with the existing water-cement ratios for Class P and Class A concretes. For Class P(HPC) concrete, a maximum size of coarse aggregate is specified since it is difficult to achieve the higher concrete compressive strengths with aggregates larger than 3/4 in. (19 mm). For Class A(HPC) concrete, the maximum aggregate size should be selected by the producer based on the specified performance criteria.

The introduction of these two classes of concrete allows provisions to be developed that are only applicable to the HPC concretes while retaining many of the existing provisions for conventional concrete. For Class P(HPC), a total cementitious materials content of up to 1000 lb/cu yd (593 kg/cu m) needs to be allowed instead of the existing limit of 800 lb/cu yd (475 kg/cu m). The higher cementitious materials content is needed to achieve the higher strength concretes. For both Class P(HPC) and Class A(HPC), the use of fly ash pozzolans, calcined natural pozzolans, ground granulated blast-furnace slag, and silica fume as mineral admixtures needs to be allowed since these are essential ingredients for HPC.

Class of Concrete	Min. Cement Content	Max. Water-Cement Ratio	Air Content Range	Size of Coarse Aggregate Per AASHTO M 43 (ASTM D 448)		Specified Compressive Strength
	lb/yd^3		%	Square Openings	Size Number	psi
P(HPC)	—	0.40[a]	As specified in contract documents	″3/4 in.	67	> 6000 as specified in contract documents
A(HPC)	—[b]	0.45[a]	As specified in contract documents	—[b]	—[b]	4000

[a] *Ratio of water to total cementitious materials.*

[b] *Minimum cementitious materials content and coarse aggregate size to be selected to meet other performance criteria specified in the contract.*

Editor's Note

This article is the first in a series that addresses specification changes that are needed to facilitate the implementation of HPC. The proposed revisions are based on work performed as part of FHWA Project No. DTFH61-00-C-00009.

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