HPC Bridge Views

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HPC AND INNOVATIVE DESIGN ENSURE LONG-TERM DURABILITY

Alexander K. Bardow, Massachusetts Highway Department

Experience has shown that bridges with continuous beams and rigid frame abutments exhibit better long-term durability than bridges with leakage-prone roadway joints. Thus, when the existing Great Road Bridge (State Route 119) over the Boston & Maine Railroad in Littleton, MA, required replacement, every attempt was made to eliminate these joints.

Building a cast-in-place structure was not feasible since the falsework would reduce the existing railroad clearances. The Massachusetts Highway Department (MassHighway) decided to use "emulation design" to replicate cast-in-place concrete construction with precast, prestressed concrete beams and precast concrete abutment panels.

A three-span structure, comprised of two 46 ft (14 m) end spans and a 54 ft (16 m) central span, proved to be the most economical. The piers were designed as conventional, cast-in-place concrete elements. However, using the emulation design technique, the pier components could have been precast concrete and connected in the field using reinforcing bar couplers — an option that MassHighway may consider for future projects.

The superstructure consists of adjacent, 21-in. (530-mm) deep prestressed concrete deck beams. The beams are rigidly connected to the precast abutment panels using reinforcing bar couplers. This eliminates the deck joint and provides an efficient means of transferring longitudinal loads to the approach embankment fill.

At the piers, the beams are made continuous for live load by using grouted sleeves to connect the reinforcing bars that project horizontally from the tops of adjacent beams. The continuity closure pour of high performance concrete (HPC) is reinforced and extends into a closed-cell, foam-lined key in the top of the pier cap. This detail provides longitudinal and transverse restraint for seismic forces but allows beam rotation under load.

HPC was used to enhance durability of the cast-in-place superstructure components.

High Performance Concrete

To enhance durability, a high performance silica fume modified concrete was required for all cast-in-place superstructure components, including the continuity closure pour, sidewalk slab, and barriers. The concrete was specified to have a maximum water-cement ratio of 0.40, a minimum compressive strength of 5000 psi (35 MPa), and a maximum permeability of 1000 coulombs at 90 days. The HPC contained 635 lb/cu yd (377 kg/cu m) of cement and 50 lb/cu yd (30 kg/cu m) of silica fume. A high-range water-reducer conforming to ASTM C 494 Type F or G was specified to help achieve the specified maximum slump of 6 in. (15 mm) and to improve workability. Finally, the specifications called for a fog mist during the placement and finishing operations to prevent surface drying followed by a seven-day minimum wet burlap cure. No problems were reported during either the placement and curing operations or in the final product.

The Confederation Bridge used HPC for both durability and strength.

HPC FOR DURABILITY OF THE CONFEDERATION BRIDGE

Laszlo Dunaszegi, Stantec Consulting Ltd., Calgary

The Confederation Bridge is an 8.1-mile (13-km) long bridge across the Northumberland Strait between Prince Edward Island and New Brunswick, Canada. Opened in 1997, the bridge consists of gravity-based piers and a single-cell box-girder superstructure. It was constructed under a design-build-operate-transfer contract in which the developer operates the bridge for 35 years and then transfers the bridge to the federal government.

Long-Term Durability

The aggressive environment of the Northumberland Strait includes significant amounts of annual ice that are constantly moving, high winds that result in splash and spray zones on the piers, and frequent cycles of freezing and thawing.

After extensive review and consideration of the various factors affecting corrosion, it was concluded that the most effective way to protect the structure against corrosion was to utilize high performance concrete in combination with increased concrete cover to the reinforcement. No epoxy-coated reinforcement or corrosion inhibiting admixtures are used due to a perceived high cost-to-benefit potential. The HPC specified on this project possesses a low chloride ion permeability and a high electrical resistivity.

Diffusivity tests conducted on concrete specimens made in the field using the actual mixture and using field placement techniques yielded diffusion coefficients as low as 4.8 x 10^{-13} m^2/s at a maturity of six months. This value is 10 to 30 times lower than the diffusion coefficients of conventional concretes.

The electrical resistance of the HPC was measured in the 470 to 530 ohm-m range, based on wet specimens with a six-month maturity. This compares to a 50 ohm-m range for conventional concretes.

Since the attainment of long-term durability depends on the quality of the concrete protecting the reinforcement, curing of the surface concrete is important. Moist curing was not always practical due to the size of the components and construction in winter. Therefore, combinations of water curing, membrane curing, and in-form curing for five days were used.

Service Life Estimate

As part of a more general evaluation of the corrosion protection system, a series of theoretical chloride ion profiles were generated using the test results and Fick's Second Law of Diffusion. These calculations provided an order of magnitude estimate of the increase in chloride concentration with time. For the case of concrete located in the splash or tidal zones, the generally accepted chloride ion threshold level of 0.4 percent of the cement content, or 2.7 lb/cu yd (1.6 kg/m^3), is not expected to be exceeded until an approximate age of 60 years with 3 in. (75 mm) of concrete cover to the reinforcement. Also, since research results indicate that the diffusion coefficient of HPC continues to decrease with time, it is anticipated that the time required to actually depassivate the reinforcement will be longer than the 60 years projected.

Attainment of the theoretical corrosion threshold, however, does not mean that significant corrosion will occur immediately. The rate of corrosion in the reinforcement depends on a number of factors including temperature, oxygen availability, and concrete resistivity. The high concrete resistivity in itself will result in a rate of corrosion that is potentially less than 10 percent of the corrosion rate for conventional concretes. This could extend the duration from depassivation to initial spalling from three years, which is typically assumed for conventional concretes, to over 30 years.

Taking all these factors into account, it is felt that the specified HPC, in conjunction with the inspection and maintenance program, should efficiently protect the embedded reinforcement from corrosion during the 100-year design life.

Further Information

More detailed information about this bridge is given in a series of articles in the *Canadian Journal of Civil Engineering*, December 1997.

Design Requirements		Mix Proportions	
91-day Strength	8700 psi	Cement*	725 lb/yd^3
Min. Cementing Materials	758 lb/yd^3	Fly Ash	76 lb/yd^3
Max. w/c	0.34	Sand	1188 lb/yd^3
Cement Type*	10 SF	Stone	1736 lb/yd^3
Fly Ash	10% max.	Water	244 lb/yd^3
Permeability	<1000 coulombs	Water Reducer	47 fl oz/yd^3
Air Content	5-8%	Superplasticizer	83 fl oz/yd^3
Slump	7 ±1.5 in.	Air Entrainment	as required

* *Includes 7.5 percent silica fume*

HOW TO ACHIEVE A HIGHER MODULUS OF ELASTICITY

John J. Myers, The University of Missouri-Rolla

The modulus of elasticity of concrete is an important mechanical property since it affects the camber of prestressed concrete beams at release of prestressing strands and deflections under superimposed dead and live loads. The modulus is closely related to the properties of the cement paste, stiffness of the selected aggregates, and the method of determining the modulus. The standard test method is ASTM C 469 — Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression.

One approach to increase the modulus of elasticity of concrete for a given mix design is to increase the coarse aggregate content of the mix. In doing so, the concrete producer might be required to adjust other mix constituents to satisfy placement and workability requirements. Figure 1 illustrates the effect of three different coarse aggregate contents on the modulus of elasticity for the same concrete constituent materials.

For ASTM standard-cured specimens, the modulus at 56 days was enhanced by approximately 3.5 percent for every 2 percent increase in the coarse aggregate content. The gain in modulus occurred more gradually at early ages with higher coarse aggregate contents for a given cementitious material content. Increasing the coarse aggregate content beyond 40 percent by weight increased the modulus but did not increase the compressive strength. The modulus appeared to be independent of aggregate size although a smaller-size aggregate for the same aggregate content resulted in a small increase in compressive strength.

For concrete subjected to high heat of hydration, as was the case with the high strength beams investigated in Texas[1], over 90 percent of the 56-day modulus was achieved within 24 hours after casting. This may be attributed to the high early-strength development and the improved paste matrix and bond characteristics. When compared to ASTM standard-cured specimens, the high strength precast concrete had a lower later-age modulus due to the reduced later-age compressive strength development and increased microcracking [1,2].

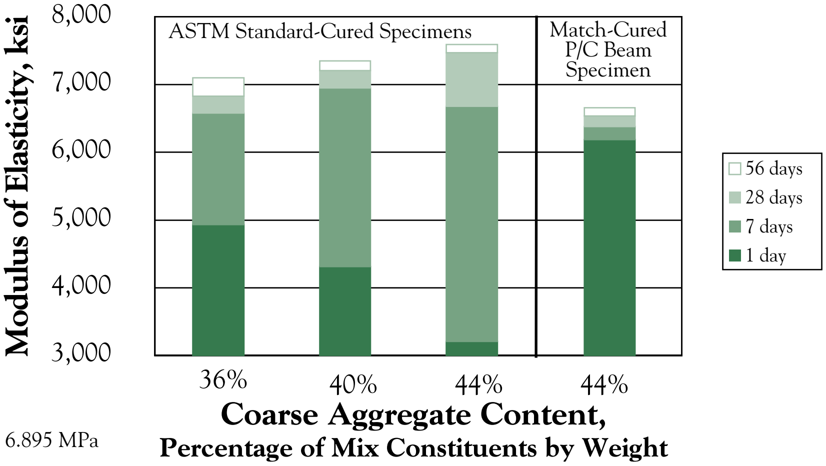

Fig. 1. Effect of Coarse Aggregate Content

A second approach to enhance the modulus of elasticity for given mix proportions is to use a hard, dense aggregate which is compatible with the paste matrix characteristics. Figure 2 illustrates the modulus of elasticity for comparable mix designs with various types of aggregates. While stiffer, denser aggregates improve the modulus of the concrete, they can act as stress risers resulting in stress concentrations at the transition zone and subsequent microcracking at the bond interfaces. This reduces the compressive strength of the concrete. Thus, the compatibility of materials in producing high strength concrete is important for development of mechanical properties. To develop optimum strength and modulus of elasticity, it is desirable to match the stiffness characteristics of the aggregates and paste matrix. Crushed or angular aggregates are preferable because of their enhanced aggregate-matrix bond characteristics. The net result is a more homogeneous material with optimal performance characteristics, and is also cost effective.

This article describes the results obtained in Texas. Optimized mix designs should always be determined from trial batches using locally available materials.

References

[1] *Myers, J. J. and Carrasquillo, R. L., "Production and Quality Control of High Performance Concrete in Texas Bridge Structures," Center for Transportation Research, The University of Texas at Austin, Preliminary Research Report 580/589-1, to be published.*

[2] *Myers, J. J. and Carrasquillo, R. L., "Effect of Curing Temperature on Compressive Strength Development," HPC Bridge Views, Issue No. 2, March/April 1999.*

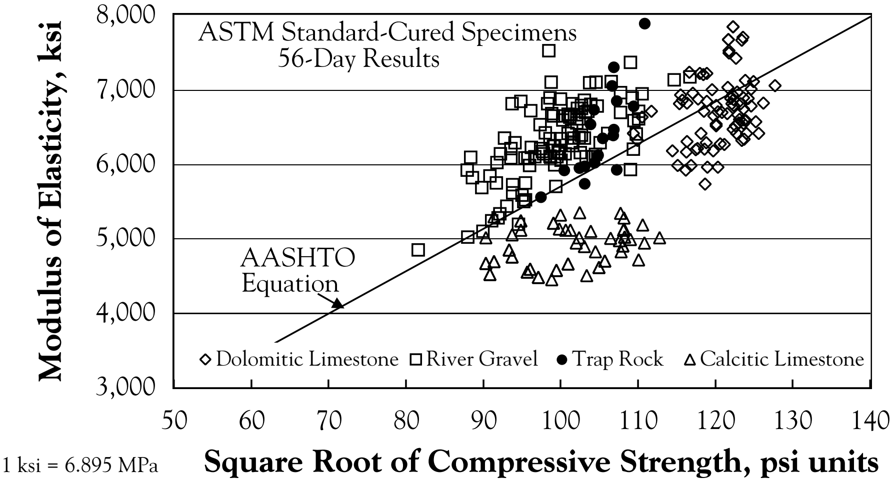

Fig. 2. Effect of Coarse Aggregate Type

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:

With HPC, should I specify compressive strength at 56 days rather than the traditional age of 28 days?

Answer:

The use of a 56-day age for the measurement of concrete compressive strength was introduced into the building industry many years ago. The primary application was cast-in-place columns for high-rise buildings. For structural purposes, columns only receive their full design load after the building is finished and occupied. Since it takes many months to build a high-rise building, the concrete design strength is not needed until an age much later than 28 days. An age of 56 days is selected for most projects with an age of 90 days being used occasionally. From an economic viewpoint, this means that the same concrete mix can be used for a higher design strength because of the strength gain that occurs between 28 and 56 days. This is particularly important when a mineral admixture such as fly ash is used.

For precast, prestressed concrete bridge components such as beams and piles, the Engineer generally specifies both a minimum strength at release of the prestressing strands and a design strength. For conventional strength concretes, mix proportions are then selected to achieve the release strength while the specified design strength at 28 days is easily exceeded. With high strength concrete, the design strength is higher and the release strength is correspondingly higher. To achieve the higher strength, it is necessary to increase the cementitious material content. As a result, the heat of hydration is higher. The resulting higher curing temperature facilitates development of the release strength but makes it more difficult to achieve the design strength because of the slower strength gain at later ages. The use of a specified design strength at 56 days, therefore, makes it easier to achieve the design strength. Many concrete specifications for high strength, high performance concrete for prestressed bridge beams are now using 56 days.

For cast-in-place high performance concrete, as used in bridge decks or substructures, durability criteria rather than strength often control the selection of concrete mix proportions. When high compressive strengths are not needed or specified for cast-in-place concrete, the strength can usually be achieved at 28 days even with the use of mineral admixtures. Consequently, there is no need to change from the traditional age of 28 days.

NCHRP PROJECT

The National Cooperative Highway Research Program has announced the award of Project No. 18-07, entitled Prestress Losses in Pretensioned High-Strength Concrete Bridge Girders, to the University of Nebraska-Lincoln. The Principal Investigator is Dr. Maher K. Tadros. For further information about the project contact, Amir N. Hanna at TRB, 202-334-1892 or ahanna@nas.edu, or go to http://www4.nas.edu/trb/crp.nsf/ and click on NCHRP Projects, Area 18 Concrete Materials, and 18-07.

HPC BRIDGE CALENDAR

September 24-27, 2000
Second International Symposium on High Performance Concrete, Orlando, FL. Jointly sponsored by PCI, FHWA, and *fib*. *Contact Paul Johal, Precast/Prestressed Concrete Institute at 312-786-0300 or info@pci.org.*

PREVIOUS ISSUES

HPC Bridge Views
Previous issues are available at http://www.portcement.org/newslet1.htm.

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Contact: Editor, *HPC Bridge Views*, 5420 Old Orchard Road, Skokie, IL 60077-1083, e-mail: ncbc@portcement.org, or Henry G. Russell, Editor, 847-998-9137; (fax) 847-998-0292; e-mail: hgr-inc@worldnet.att.net

For futher information on High Performance Concrete, contact:

FHWA Headquarters: Terry D. Halkyard, 202-366-6765; (fax) 202-366-3077; e-mail: terry.halkyard@fhwa.dot.gov

AASHTO Lead States Team: James A. Moore, NHDOT, 603-271-2731; (fax) 603-271-2759; e-mail: n18jam@dot.state.nh.us

NCBC: Basile G. Rabbat, PCA, 847-966-6200; (fax) 847-966-9781; e-mail: basile_rabbat@portcement.org