HPC Bridge Views

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INSIDE THIS ISSUE…

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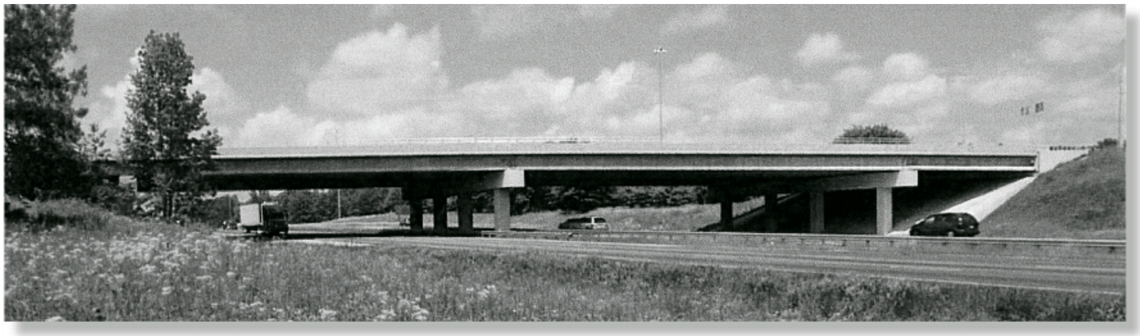
HPC IN GEORGIA

Paul V. Liles, Jr., Georgia Department of Transportation



High-strength concrete was used in the beams to minimize superstructure depth.

While attending a national conference on high performance concrete (HPC) in Houston, Texas, in 1996, the Georgia Department of Transportation (GDOT) determined that this new material would have significant applications in Georgia to provide longer spans for prestressed concrete beams for highway bridges. An added benefit would be the use of more efficient beam spacings and the possible use of shallower beams for a given span length.

With this in mind, a research program was initiated at the Georgia Institute of Technology in 1997. This research project studied HPC mix designs using Georgia's granite and granite gneiss crushed stone aggregates and determined that HPC mix designs could be developed using local aggregates. Strengths in the 10,000 to 14,000 psi (70 to 100 MPa) range were easily obtained. In addition, these mixes could be produced without difficulty by local precasting plants. Representative samples of prestressed concrete beams were built and tested. Results showed that the current AASHTO specifications conservatively predicted the transfer and development lengths of 0.6-in. (15.2-mm) diameter prestressing strands.

At this point, design was started on Georgia's first HPC bridge project — the Jonesboro Road bridge over I-75 located in Henry County, south of Atlanta. The bridge has a span arrangement of 53, 127, 127, and 45 ft (16.25, 38.75, 38.75, and 13.75 m) and is 90 ft (27.4 m) wide carrying five lanes of traffic with bike lanes and shoulders. AASHTO Type IV girders are used for the 127-ft (38.75-m) long spans and AASHTO Type II girders for the shorter spans. Beam spacing is 7.60 ft (2.31 m). The specified concrete strength was 10,000 psi (70 MPa) at 56 days. Maximum specified chloride permeability for the beams was 3000 coulombs at 56 days. The deck concrete was specified to have a compressive strength of 7000 psi (50 MPa) at 56 days and a maximum chloride permeability of 2000 coulombs at 56 days. To show the feasibility of placing a concrete deck using 7000 psi (50 MPa) concrete, a demonstration test slab was required to be placed under field conditions adjacent to the bridge.

The bridge was constructed in two stages to handle traffic during construction. In the first stage deck placement, the maximum chloride permeability of 2000 coulombs was exceeded. For the second stage deck placement, Class F fly ash and more silica fume were included in the concrete. Otherwise, the project was very successful and all the HPC goals set out in the program were met.

HPC was critical to the design of the project. The use of 127-ft (38.75-m) long AASHTO Type IV beams minimized the overall depth of the superstructure and avoided the problem of raising the grade with the subsequent need for expensive land purchases. With construction of this bridge, designs of precast, prestressed girders using HPC compressive strengths up to 10,000 psi (70 MPa) were approved by GDOT. The future is bright for the use of HPC in Georgia. We should continue to see increases in concrete strengths with further optimization in the future.

HIGH PERFORMANCE CONCRETE BRIDGE DECKS IN MINNESOTA

Paul Kivisto, Minnesota Department of Transportation

Bridges in Minnesota experience harsh conditions with wide temperature extremes, fairly long snow and ice seasons, and many applications of deicing chemicals. The standard bridge deck protection system of the Minnesota Department of Transportation (Mn/DOT) includes epoxy-coated reinforcement, a 7-in. (175-mm) thick conventional concrete structural slab, and a 2-in. (50-mm) thick low-slump concrete overlay. This system has worked extremely well since the mid 1970s and is specified on most bridges. High performance concrete (HPC) bridge decks offer potential benefits to the state including decreased construction time, lower permeability, and cost savings of 5 percent or more compared to decks with low-slump overlays.

HPC Specifications

Mn/DOT's HPC specifications include a minimum cementitious materials content of 611 lb/cu yd (363 kg/cu m) and the use of 75 percent Type I cement with 20 percent Class C or F fly ash and 5 percent silica fume to reduce permeability. The specified compressive strength is 4300 psi (29.6 MPa) at 28 days. The specifications also require a water-cementitious materials ratio no greater than 0.40, 4-in. (100-mm) slump, and well graded aggregates. The curing specifications require concrete placement when surface evaporation rates are less than 0.1 lb/sq ft/hr (0.5 kg/sq m/hr), prewetted burlap or cotton mats placed within 15 minutes of finishing, and wet curing for seven days. The specifications do not include any values for permeability since adherence to the specifications is expected to produce a concrete mix with a chloride permeability less than 1500 coulombs at 56 days.

Experiences

Fifteen HPC bridge decks have been placed in Minnesota since 1997. Most of the deck placements have gone well, but we have experienced a few problems. On two different decks placed in 1999, significant spalling occurred due to silica fume balls that had accumulated in the concrete. The balling was not evident during the deck placement but manifested itself after one winter. In both cases, the concrete contained silica fume slurry that was added to the mix from an external tank at the concrete plant. We are unsure if the balling occurred because of improper mixing in the slurry tank, the ready-mixed concrete facility, or the concrete truck itself.

The specifications now require that the concrete trucks comply with ASTM C 94 and limit the truck capacity to 75 percent of its rated capacity. The contractor is also required to wet sieve concrete samples on site to detect the presence of any silica fume balls. The specifications still allow the concrete supplier to use either silica fume slurry or a dry densified powder, but in most recent deck placements the concrete supplier has used dry densified powder. Since the specifications were revised, we have not experienced any additional balling problems.

On the two decks that experienced silica fume balling, the deck contractor was allowed to core out the spalled areas and patch with concrete. In both cases, additional spalling occurred after the second winter, and we felt that the patching would not provide adequate long-term protection for the deck. The contractor was required to mill off the top 2 in. (50 mm) of one HPC deck, and replace it with a 2-in. (50-mm) thick low-slump concrete overlay. That deck is performing adequately at this time. The second deck has been patched a second time, and we continue to monitor the patches.

Another problem that we have encountered is cracking in the deck surface due to improper curing practices. The first instance happened in 1999 when the curing specification only required the contractor to fog the deck to keep it wet prior to placing wet burlap. During the deck pour, the wind speed increased, and the manual fogging operation was not able to keep up with the rate of evaporation. Several areas of map cracking were evident in the deck after completion of the curing. In an effort to reduce shrinkage cracking due to improper curing, the specifications were revised to require placement of wet burlap within 15 minutes of finishing. The burlap must be maintained in a wet condition for seven days after placement of the deck.

A second instance of deck cracking occurred in 2002, when the contractor did not have his work bridges set up behind the paving machine for immediate application of the wet burlap. The contractor tried to fog the deck from the ends and sides of the bridge. As the wind increased, the manual fogging was not able to keep up with the surface evaporation. Transverse cracks at 5 ft (1.52 m) intervals have occurred throughout the deck. We plan to flood the deck surface with methacrylate to seal the hairline cracks. The specifications were not modified after this placement, but we will continue to discuss these problems during deck pre-placement meetings.

For the most part, contractors are taking a favorable view of HPC bridge decks in Minnesota. Contractors have requested a change to HPC decks on a few bridges to reduce construction time by two weeks or more compared to conventional concrete decks with an overlay. With only 15 HPC decks in service, contractors are still learning how to best place and cure the concrete. One contractor has placed the last three HPC decks at night. This has vastly reduced the potential for plastic shrinkage cracks.

Future Plans

Mn/DOT has been pleased with HPC bridge decks and continues to look at ways to improve the product and specifications. We are investigating the use of a concrete mix with up to 30 percent Class F fly ash and no silica fume. This will provide reduced permeability as well as easier curing. HPC decks provide options to our standard low slump concrete overlays by reducing construction time and providing a high quality deck with low permeability.

Further Information

For further information, contact the author at paul.kivisto@dot.state.mn.us or 651-747-2130.

THE VIRGINIA DARE BRIDGE, NC

Thomas E. Tallman and Thomas M. Harris, Wilbur Smith Associates

Concrete mix proportions were selected to provide a target service life of 100 years. Photo: Wilbur Smith Associates

The Virginia Dare Bridge, the longest bridge in North Carolina, is located on US 64/264 over the Croatan Sound at Manteo. The bridge connects the mainland to Roanoke Island at the midpoint of the Outer Banks and is on a hurricane evacuation route. With a target service life of 100 years, the most significant design challenges of the bridge project included the highly corrosive coastal environment, high level navigable clearances, vessel impact forces, coastal storm surge and scour characteristics, and environmentally sensitive high quality wetlands.

Early in the design process, a study of bridge types was performed in order to determine economical alternates for the bridge. The bridge was segmented into regions based on soil type, vessel impact loads, and bridge profile. For the superstructure, six different structural member types were analyzed with multiple variations in span lengths, girder spacings, and material strengths. The substructure analysis included three different structural frame systems and two foundation types. A precast segmental superstructure and a conventional precast, prestressed concrete girder superstructure were offered as alternates for bid. The bid was awarded to the conventional alternate.

The main three-span unit across the navigation channel has span lengths of 137.75, 229.6, and 137.75 ft (42.0, 70.0, and 42.0 m) and provides clearances of 65 ft (19.8 m) vertically and 180 ft (54.9 m) horizontally. The superstructure utilizes precast, prestressed concrete modified bulb-tee girders. Girder section depths are 6.5 ft (1.98 m) in the positive moment regions transitioning to 11.0 ft (3.35 m) in the negative moment regions. The girder lines consist of five segments post-tensioned in three phases during construction of the superstructure. Girder sections were initially supported by temporary towers and strongbacks and then post-tensioned to form a continuous unit.

The substructure units are designed to withstand the vessel impact loads while providing flexibility to redistribute the impact loads through the superstructure. The mid- to high-level units use hammerhead piers supported by two columns on table-top footings and 30-in. (760-mm) square precast, prestressed concrete piles. The pile embedment depth in the soil is 100 ft (30.5 m), pile lengths approach 120 ft (36.6 m), and estimated scour depths approach 75 ft (22.9 m).

High Performance Concrete

The Croatan Sound has variable chloride content in the water ranging up to 13,000 ppm. As a result, high performance concrete (HPC) was utilized throughout the approximately 190,000 cu yd (145,000 cu m) of concrete in the structure. The different types of structural elements were evaluated independently with the goal of achieving a service life of 100 years before any member would need repair as a result of corrosion. Different dosages of calcium nitrite, chloride concentrations, and concrete permeabilities were considered using Fick's Second Law of Diffusion. The most cost-effective scheme for each element was selected. Constructibility issues were also examined prior to final selection of corrosion inhibiting measures.

In the superstructure elements, calcium nitrite at a dosage of 2.0 gal/cu yd (9.9 L/cu m) was used in order to elevate the corrosion threshold of all members. For the substructure elements, the amount of calcium nitrite was increased to 3.0 gal/cu yd (14.9 L/cu m). Five percent silica fume was also used in the substructure elements in order to achieve low permeability at an early age. Class F fly ash at 20 percent of the total cementitious materials was utilized to reduce the permeability in both the superstructure and substructure with 30 percent fly ash being used for the pile caps in order to reduce the heat of hydration in these mass concrete elements. The specified maximum water-cementitious materials ratios were 0.40 for the precast, prestressed concrete and 0.43 for the cast-in-place concrete. The specified minimum cementitious materials content varied from 560 to 640 lb/cu yd (332 to 380 kg/cu m).

Epoxy-coated reinforcement was used in both the superstructure and substructure. The typical concrete cover was 3 in. (75 mm) with an increase to 4 in. (100 mm) for the main reinforcing steel in the substructure elements. As an additional corrosion protection measure, the precast, prestressed concrete members were designed for zero tensile stress under service loads. Specified concrete compressive strengths at 28 days were 4500 psi (31 MPa) for the bridge deck, railings, and the cast-in-place substructure; 8000 psi (55 MPa) for the precast, prestressed concrete girders; and 6000 psi (41 MPa) for the precast, prestressed concrete piles.

The Virginia Dare Bridge is an aesthetically pleasing crossing of the Croatan Sound, implementing design features respectful of the environment while providing safe, efficient travel for vehicle and marine traffic for the next 100 years. It was opened to traffic in August 2002.

Further Information

For additional information on research on HPC by the North Carolina Department of Transportation, visit www.ncdot.org/planning/development/research/research_str.html.

Acknowledgement

The authors thank Rodger D. Rochelle, of the North Carolina Department of Transportation for his contribution to this article.

SPECIFICATION CHANGES FOR HPC—COMPRESSIVE STRENGTH

The current AASHTO Standard Specification for Concrete Made by Volumetric Batching and Continuous Mixing (M 241) contains a table that lists the overdesign criteria for concrete compressive strengths. The table was developed before today's high-strength concretes existed. The ACI Building Code Requirements for Structural Concrete (ACI 318-02) and commentary (ACI 318R-02) has recently revised its equivalent requirements to limit the previous values to concrete compressive strengths less than or equal to 5000 psi (34 MPa). For compressive strengths greater than 5000 psi (34 MPa), the new ACI requirements, when stated in the AASHTO style, are as follows:

No. of Tests	Required Average Compressive Strength
< 15	$1.10\,f'_c + 700$ in psi units $1.10\,f'_c + 5.0$ in MPa units
≥ 15	Use the larger of $M(f'_c + 1.34s)$ $M(0.90f'_c + 2.33s)$

where:

f'_c = specified compressive strength

s = standard deviation

M = modification factor depending on number of tests as follows:

No. of Tests	15	20	25	≥ 30
M	1.16	1.08	1.03	1.00

These requirements are based on a probability of 1 in 100 that the average strength of three consecutive tests will not fall below the specified strength and no individual test result will be less than $0.90\,f'_c$. Because of the above changes, the AASHTO acceptance criteria for concretes with compressive strengths greater than 5000 psi (34 MPa) also needs to be revised to state that no individual strength test shall be more than $0.10\,f'_c$ below the specified strength.

AASHTO Specification M 241, as well as the AASHTO LRFD Construction Specifications, currently define a strength test as the average strength of two cylinders. For concrete compressive strengths greater than 5000 psi (34 MPa), a strength test should be based on the average of three cylinders to improve the reliability. Also, when 4x8-in. (100x200-mm) cylinders are used, the strength should be based on three cylinders because of the higher variability with the smaller cylinders.

The AASHTO Standard Method of Test for Making and Curing Concrete Test Specimens in the Field (T 23) should be revised to be consistent with recent revisions in the equivalent ASTM Method (C 31). For HPC with a specified strength of 6000 psi (40 MPa) or greater, the initial on-site curing temperature should be between 68 and 78°F (20 and 26°C) compared to the current range of 60 to 80°F (16 to 27°C).

Editor's Note

This article is the fourth 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.

HPC BRIDGE CALENDAR

October 19-22, 2003
Third International Symposium on High Performance Concrete, Orlando, FL. Jointly sponsored by FHWA and PCI. Contact Paul Johal, Precast/Prestressed Concrete Institute at 312-786-0300, info@pci.org or www.pci.org

May 17-18, 2004
2004 Concrete Bridge Conference on High Performance Concrete Bridges and Rapid Bridge Construction, Charlotte, NC. Jointly sponsored by FHWA and NCBC. Short abstracts are due by August 15, 2003. See www.nationalconcretebridge.org for more information.

June 20-24, 2005
Seventh International Symposium on Utilization of High Strength/High Performance Concrete, Washington, DC. Organized by ACI. Contact Phyllis Erebor, American Concrete Institute at 248-848-3784 or phyllis.erebor@concrete.org.

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Reproduction and distribution of this newsletter is encouraged provided that FHWA and NCBC are acknowledged. Your opinions and contributions are welcome. Please contact the Editor, Henry G. Russell, at 847-998-9137; (fax) 847-998-0292; e-mail: hgr-inc@att.net.

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