Bridge Views

DELAWARE'S HPC BRIDGES

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The Delaware Department of Transportation (DelDOT) first discussed the use of high performance concrete (HPC) with the Federal Highway Administration early in 1996. Based on these discussions, DelDOT initiated trial projects with HPC specifications. Although these were formal HPC specifications, DelDOT had been utilizing ground granulated blast-furnace slag (GGBFS) and other pozzolans in concrete since the late 1980s to take advantage of the improved workability, protection against alkali-silica reactivity, and lower permeability.

The first contract incorporating the HPC specifications was for ramp widening at U.S. 202 to I-95 southbound in Wilmington. This structure was bid and constructed in late 1996. To date, DelDOT has constructed five projects with the HPC specifications and two more projects are in the design phase. Constructed bridges include three bridges in Frederica, one bridge in Little Creek, and one bridge in New Castle County. Bridges being designed include one in Milton and Churchman's Road bridge over I-95 in Wilmington.

The benefits that our designers look for when specifying HPC include increased durability, lower concrete permeability, and higher compressive strengths. The latter allows for longer spans, thereby reducing substructure costs.

Specifications that were created for the HPC concrete are shown in the table. For concrete Classes A and D (cast-in-place), most producers have chosen to meet the specifications by using a 7 percent addition of silica fume to the specified minimum cementitious materials content of 705 lb/cu yd (418 kg/cu m). For concrete Classes B, B/Slipform, and Precast, producers and suppliers have used GGBFS at 50 percent of the specified minimum cementitious materials content of 564 lb/cu yd (335 kg/cu m) to meet the specifications.

The DelDOT specifications require the producer to cast trial batches of the proposed mixtures at least 28 days prior to incorporation into the project. Chloride permeability and compressive strength tests are then made on field-cast cylinders.

There have been a few problems associated with the HPC. The most serious problem was on one bridge in Frederica. The contractor was unfamiliar with HPC and had difficulty with finishing and curing the concrete bridge deck. The first attempt at placing the deck surface resulted in numerous random cracks with widths up to 1/8 in. (3 mm). This required removal of approximately 1-1/2 in. (38 mm) of the top surface of the original deck and subsequent replacement. The cause of cracking was determined to be the contractor's inability to start curing the silica fume concrete soon enough. The contractor treated the HPC in the same way as conventional concrete. The lesson learned in this experience was that when placing deck concrete containing silica fume, the contractor must "underfinish and overcure" the concrete.

Aside from this major problem, the other problems associated with HPC have been relatively minor. The success of a project depends upon proper design, proportioning, mixing, placing, consolidation, and curing of the concrete. DelDOT realizes that one of the keys for successful implementation of HPC is education of the concrete supplier and placement contractor. Consequently, pre-pour meetings are mandatory for construction personnel, materials personnel, contractors, and concrete suppliers.

Property	Concrete Class[1]			
	A and D	B	B/Slipform	Precast
Compressive Strength, psi	4500	3000	3500	6000
Permeability,[2] Coulombs	2500	3500	3500	1500

[1]Classes A and D are structural concrete. Class B is foundation concrete. Class B/Slipform is roadway paving concrete. Precast is used for precast and prestressed concrete components.

[2]Maximum chloride permeability at 28 days following 7 days curing at 73°F (23°C) and 21 days at 100°F (38°C).

Further Information

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Pretensioning, post-tensioning, and high-strength concrete were used to achieve a record length. (Photo courtesy of Con-Force.)

THE BOW RIVER BRIDGE – A PRECAST RECORD

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Currently under construction near Calgary, Canada, the 774-ft (236-m) long twin structures of the Bow River Bridge use high performance concrete for their precast, prestressed concrete girders. Each structure consists of two 174-ft (53-m) and two 213-ft (65-m) long spans. The precast concrete alternative provided a cost savings of about 10 percent (CAN $9.6 million versus CAN$10.5 million) compared to the steel plate girder option.

This bridge marks the first time a one-piece 211-ft (64.25-m) long girder weighing 268,000 lb (122 Mg) has spanned the entire distance between permanent pier supports without recourse to segmental I-girders, intermediate splice joints, and temporary falsework towers. Another source of economy is the relatively wide girder spacing of 11.65 ft (3.55 m). This spacing resulted in fewer girder lines despite the relatively long spans and the uncommonly heavy design live load mandated in Alberta. The heavy equipment hauling demands of the oil refinery industry result in a maximum live load moment that is 1.5 to 2 times that produced by AASHTO HS20 loading.

An NU 2800 girder with a depth of 9.2 ft (2.8 m) and a standard web width of 6.9 in. (175 mm) was used for the 213-ft (65-m) long span. The thin web is one of the primary reasons for the minimized girder weight and the increased span efficiency. Previously, the Alberta bulb-tee girder was limited to 138-ft (42-m) lengths. The largest NU 2800 bridge girder to be used prior to this project was part of the Oldman River Bridge in Alberta. It had a length of 188.6 ft (57.5 m) and weighed 240,000 lb (109 Mg).

The Bow River Bridge girders were pretensioned to resist forces caused by lifting, shipping, and erection. After erection, the girders were post-tensioned with four tendons of twelve 0.6-in. (15.2-mm) diameter strands each in 3-in. (76-mm) diameter ducts. One tendon was stressed prior to placing the deck making the girders continuous for deck weight. The remaining tendons were post-tensioned after the deck was cast. This established continuity of the composite section over the intermediate supports for superimposed dead loads and live loads.

Advantages of I-Girder Post-Tensioning

The NU I-girder, developed at the University of Nebraska, is most suitable for installations where girders from adjacent spans are post-tensioned for continuity. This eliminates the need for staggered deck placement to control deck cracking. Post-tensioning of the entire bridge length significantly increases girder capacity and produces precompression in the deck in the negative moment regions. The latter effect eliminates transverse cracking in the deck. The balanced combination of pretensioning and post-tensioning allowed a relatively low concrete compressive strength of 5100 psi (35 MPa) to be specified for release of the prestressing strands, while requiring a compressive strength of 9500 psi (65 MPa) at 28 days.

Girder Handling

The girders were carefully evaluated for stability during lifting off the precasting bed, shipping, and erection until composite action with the deck was achieved. Special lifting devices were designed and used in conjunction with a top-flange bracing truss to mitigate the potential of the top flange buckling at time of lifting off the bed. The bracing truss and special trailer truck saddles were used during shipping. The stability analysis summarized in Chapter 8 of the PCI Bridge Design Manual proved valuable for this analysis. Delivery of the girders proceeded without significant problems.

Erection crews reported that the NU girder exhibited better stability during placing compared to other girder cross sections because of the wider bottom flange. Erection was temporarily halted when wind gusts reached 19 mph (30 km/hour). Immediately after each girder was placed and before the cranes were released, each girder was braced diagonally to the previously installed girders; stability of the first girder in each span was provided with diagonal braces to the tops of the pier supports.

Keys to Economy

A key to the competitiveness of the recent Alberta girder bridges was that the precaster serves as both the erection and post-tensioning subcontractor. The success of this project may prompt other contractors to consider undertaking the operations of erection and post-tensioning.

The use of end-to-end post-tensioning without intermediate anchorages was important in the overall economy of the system. The NU girders were most economical because the simple post-tensioning scheme allowed their use without custom changes to the relatively expensive girder formwork.

Editor's Note

See the following table for a comparison of the length of the Bow River Bridge girders with other applications:

Bridge	Beam Length, ft	Beam Type
Bow River, AB	211	NU 2800
Oldman River, AB	189	NU 2800
Tom Music, WA	168	Deck BT-65
SR 840, TN	156	BT-72
San Angelo, TX	153	IV

BENEFITS OF CHEMICAL ADMIXTURES IN HPC

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Chemical admixtures have been incorporated into concrete mix proportions for many years in order to attain performance properties. Most high performance concrete (HPC) mixes contain at least one type of chemical admixture. In girder construction, high compressive strength is the property frequently required. For concrete compressive strengths above 5000 psi (34 MPa), chemical admixtures are usually necessary to achieve a cost-effective mix. In bridge decks, low chloride permeability is required. Chemical admixtures are used to facilitate placing and finishing. AASHTO M 194 (ASTM C 494) classifies the most commonly used chemical admixtures as Types A through G, based on the admixture's effect on lowering water demand or influencing setting time.

Water-Reducing Admixtures

Water-reducing admixtures can be used to increase slump while maintaining a constant water-cementitious materials ratio (w/cm), or maintaining slump while lowering the w/cm. In general, increasing the amount of water in a concrete mix while maintaining a constant cementitious materials content results in an increase in slump of the fresh concrete and a decrease in compressive strength in the hardened concrete. Water-reducing admixtures can be used to produce concrete with higher slump without the usual strength reduction associated with an increase in water content.

Water-reducing admixtures are distinguished by the reduction in the amount of water necessary to make workable concrete. Today, most high-strength concrete requires a high range water-reducer (HRWR). Classified as Type F in AASHTO M 194, HRWRs typically reduce water demand by 12 to 30 percent. HRWRs can be added to concrete with low-to-normal slump to produce a high-slump, flowing concrete. They also can be added to concrete with low slump and very low w/cm to produce high-strength concrete. In addition to increasing compressive strength, HRWRs can increase concrete's durability by decreasing permeability.

Conventional water-reducing admixtures, classified as Type A in AASHTO M 194 typically reduce water demand by 5 to 10 percent. Conventional water reducers differ chemically from HRWRs and can cost about half as much or even less. They are often used in combination with HRWRs to reduce overall cost and enhance performance. Varying the dosages of different admixtures allows fine-tuning of slump, slump retention, and setting time. In projects where closely spaced or congested reinforcement makes concrete placement difficult, HRWRs can help concrete to flow around these obstructions without segregation.*

Retarding Admixtures

Retarding admixtures, classified as Type B in AASHTO M 194, are admixtures that decrease the rate at which concrete sets. High temperatures can result in early stiffening and rapid slump loss. When concrete sets too rapidly, placing and finishing can be very difficult. Retarding admixtures are often used when concrete is to be placed in hot weather, or when concrete is placed under difficult circumstances, or conveyed over unusually long distances. Retarding admixtures that also comply with the water-reduction requirements of AASHTO M 194 are classified as Type D, while high range water-reducing admixtures that comply with the set retarding requirements of AASHTO M 194 are classified as Type G.

Accelerating Admixtures

Accelerating admixtures, classified as Type C in AASHTO M 194, are admixtures that increase the rate at which concrete sets. Accelerating admixtures are often used during cold-weather placement, or in other cases where high early strength or faster setting time is desirable. Although calcium chloride is historically the most effective accelerating admixture, it must not be used in reinforced or prestressed concrete, concrete with embedded aluminum, concrete subject to alkali-aggregate reaction, concrete exposed to sulfates, or in mass concrete applications. Accelerating

See HPC Bridge Views, Issue No. 18, November/December 2001 for an article on self-consolidating concrete.

admixtures that also comply with the water-reduction requirements of AASHTO M 194 are classified as Type E.

Air-Entraining Admixtures

Although not considered chemical admixtures by definition, air-entraining admixtures can be very important in an HPC mix. Air-entraining admixtures, covered in AASHTO M 154 (ASTM C 260) introduce stable microscopic air bubbles into the concrete mix. Air entrainment can significantly improve the freeze-thaw durability of concrete subjected to saturated conditions and deicers and is essential in bridge decks exposed to freeze-thaw conditions. Air-entraining admixtures generally reduce water demand slightly and increase workability. Because the introduction of entrained air can reduce compressive strength, it should be used very cautiously in high-strength concrete.

Testing

The availability of chemical admixtures allows dramatic improvements in concrete performance. However, extra care and attention are required during the specification process and mix proportioning. Various combinations and dosages of chemical admixtures result in numerous ways to achieve a particular set of properties in a cost-effective manner. It's important to understand not only the effect of each component in the concrete mix, but also how all the components interact. For these reasons, mix verification testing is very important and essential for HPC.

Further Information

For further information, contact the author at 847-972-3158 or mcaldarone@ctlgroup.com

Question

What is service life and how is it predicted?

Answer

The AASHTO LRFD Bridge Design Specifications defines service life as the period of time that the bridge is expected to be in operation. The design life is defined as the period of time on which the statistical derivation of transient loads is based. Though the subject specifications prescribe transient loads based on a design life of 75 years, they are silent on the extent of the expected service life.

A bridge's ability to fulfill its intended function can be compromised due to degradation. Major causes of degradation are high transient loads and severe environmental conditions. Proper structural design addresses the effects of transient loads through adequate member proportioning and design details.

Environmental conditions that cause degradation include carbonation, sulfate attack, alkali-silica reaction, freeze-thaw cycles, and ingress of chlorides and other harmful chemicals. Adverse environmental conditions, if not properly addressed, typically cause chemicals to invade the concrete's pore structure and initiate physical and/or chemical reactions causing expansive by-products. The most damaging consequence of these reactions is depassivation and eventual corrosion of reinforcing steel causing cracking and spalling of concrete. The end of the service life of the structure occurs when the accumulated damage in the bridge materials exceeds the tolerance limit. However, the service life is typically extended by performing periodic repairs to restore the serviceability of the structure.

Chlorides from deicing salts and salt water penetrate concrete by several transport mechanisms: ionic diffusion, capillary sorption, permeation, dispersion, and wick action. During the last several years, computer models have been developed to predict the service life of concrete bridges exposed to chlorides. Several service life prediction models assume diffusion to be the most dominant mode of transport for chloride ions. The time taken by chlorides to reach reinforcing steel and accumulate to a level exceeding the corrosion threshold is known as Time to Initiation of Corrosion (TIC). Typically, TIC is computed by modeling chloride ingress according to Fick's Second Law of Diffusion. TIC depends on many factors; major among them are diffusivity of concrete, concrete cover, temperature, and the degree of exposure. The Propagation Time—from initiation of corrosion to intolerable accumulation of damage—also depends on many factors including environmental conditions and corrosion protection strategies.

The following is a list of some of the service life prediction models now available:

Life-365: Computer software developed by M. D. A. Thomas and E. C. Bentz, University of Toronto for W. R. Grace, Master Builders Technologies, and Silica Fume Association. Addresses time-dependent diffusion of chlorides. Predicts service life and life-cycle costs for various protection strategies.

CIKS: Computer-Integrated Knowledge System developed by D. Bentz, NIST. Predicts chloride ion diffusivity coefficients and TIC.

Duramodel: Developed by W. R. Grace. With the help of effective diffusion coefficients, the model accounts for mechanisms other than pure diffusion.

ConFlux – A Multimechanistic Chloride Transport Model: Developed by A. Boddy, E. C. Bentz, M. D. A. Thomas, and R. D. Hooton, University of Toronto. PC-based program accounts for diffusion, permeability, chloride binding, and wicking.

ClinConc: Developed by L. Tang, Chalmers University of Technology, Goteborg, Sweden. Chloride penetration model is based on mass balance and genuine flux equations. Promising for predicting chloride profiles in submerged parts of structures.

HETEK Model: AEC Laboratory, Denmark. Applicable to marine structures and salt water splash zones. Ten-step spreadsheet calculation for service life.

Further reading: Frohnsdorf, G., "Modeling Service Life and Life-Cycle Cost of Steel-Reinforced Concrete," NIST/ACI/ASTM Workshop, Gaithersburg, MD, November 9-10, 1998.

Answer contributed by Shri Bhidé of the Portland Cement Association. He may be contacted at sbhide@portcement.org or 847-972-9100 for further information.

NEW WEB SITE

As announced in HPC Bridge Views, Issue No. 19, a new FHWA Community of Practice web site has been established at:
http://knowledge.fhwa.dot.gov/cops/hpcx.nsf/home