HPC Bridge Views

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HPC BRIDGES IN CANADA

Rico Fung, Cement Association of Canada

In Canada, the extreme weather conditions and liberal use of deicing chemicals have led to severe deterioration of many concrete structures. In the search to improve durability and extend service life, Concrete Canada was established in 1990 to conduct a coordinated and focused high performance concrete (HPC) program. The technology transfer component of the program included many seminars, workshops, and technology transfer days across Canada as well as demonstration projects to implement HPC on construction sites. As a result, many HPC structures were built in Canada.

The first Canadian HPC bridge was a 56-ft (17-m) long single-span bridge at St. Eustache, Quebec built in 1992. The structure consists of adjacent pretensioned channel girders made with 10,000 psi (70 MPa) compressive strength concrete. The deck was cast with 4300 psi (30 MPa) compressive strength concrete.

In other provinces, HPC applications have been evolving with local expertise and experience. The pre-eminent example of precast HPC is the 8-mile (13-km) long Confederation Bridge connecting Prince Edward Island to Nova Scotia.* Designed for a service life of 100 years in a severe salt exposure and freeze-thaw marine environment, corrosion protection of the reinforcement in the superstructure is provided solely by the HPC.

For short and medium span bridges, precast, prestressed HPC bridge girders have shown significant technical and economic benefits. On the Highway 407 project in Ontario, two prototype bridges were constructed of HPC in 1997. For one of the bridges, precast, pretensioned girders were cast with 8700 psi (60 MPa) compressive strength HPC. The concrete strength at transfer was 7000 psi (48 MPa) and special prestressing strands with a cross-sectional area of 0.167 sq in. (108 sq mm) were used. By these means, the number of girders required in each span was reduced from 4 to 3, realizing a savings of about $19,000 (CAN$30,000). Since then, over 60 bridges with HPC have been constructed in Ontario.

The specifications for cast-in-place and precast HPC tend to include the following common elements:

Cement: ternary Type 10E-SF

Silica fume content: 6.0 to 9.5 percent

Cement content: 590 to 760 lb/cu yd (350 to 450 kg/cu m)

Supplementary cementitious materials (slag or fly ash): 0 to 25 percent

Water-cementitious materials ratio: 0.32 to 0.37

28-day compressive strength: 5800 to 10,900 psi (40 to 75 MPa), with 7250 psi (50 MPa) in most cases

Plastic air content: 5 to 8 percent

Rapid chloride permeability (ASTM C 1202): less than 1000 coulombs at 28 days

Based on experiences in Canada over the last 10 years, several observations can be made. The rapid chloride permeability (RCP) test has proven to be a reliable index of durability. Stable in-situ, air-void systems can routinely be achieved if suitable air-entrainment admixtures are chosen, and the mixes are designed to allow for significant testing variations.

Pre-construction and pre-concreting meetings are essential for the successful implementation of HPC. All those responsible for the supply, installation, and supervision of concreting should participate. Adequate lead-time should be allowed for trial mixes or trial placements.

Fog misting is a must immediately after finishing to prevent premature cracking. This must be followed by 7 days of wet curing.

More Information

Bickley, J. A. and Mitchell, D., "A State-of-the-Art Review of High Performance Concrete Structures Built in Canada: 1990-2000," Cement Association of Canada, May 2001, 114 pp. available at www.cement.ca.

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*See *HPC Bridge Views*, Issue No. 5, September/October 1999.

OHIO HPC BRIDGE DECKS WITH WARRANTY

Harold Schultz, Ohio Department of Transportation

As a result of premature failure of some asphalt concrete on a major interstate highway around Columbus, OH, the state legislature required the Ohio Department of Transportation (ODOT) to produce warranty specifications for various items of work. In October 1999, a specification was produced requiring contractors to warrant new bridge decks constructed with high performance concrete (HPC).

Warranty Items

The specification requires contractors to only warrant their workmanship and not the design of the superstructure or the design of the concrete mix. The contractor is required to warrant against alligator or map cracking for a period of one year and against scaling and spalling for seven years. In addition to the requirements of the warranty specification, the contractor is still required to mix and place the concrete as required in our normal specification for HPC. It is still necessary to inspect the placement of the concrete.

Alligator or map cracks are caused when the contractor fails to properly cure the concrete. Due to the small amount of free water in high performance concrete, timely and adequate water curing is very important. While we require wet burlap to be placed immediately after the surface of the concrete has received a broom finish, there are times when the burlap is not placed immediately, the burlap is not wet when it is placed, or the burlap is allowed to dry out before the concrete has cured for the required curing period.

In our experience, scaling has occurred because the contractor added water to the surface of the deck to aid in finishing, or allowed the uncured concrete to freeze during cold weather. Spalling has occurred because the concrete was not properly mixed and the cementitious materials formed into balls. Allowing these balls to be placed in the work in lieu of rejecting the load of concrete can result in spalling.

Review Process

The deck is evaluated three times by a review team. The first evaluation is at one year for alligator and map cracking. At two years, the deck is evaluated for scaling and spalling. The final review takes place one month before the end of the warranty period when the deck is again evaluated for scaling and spalling.

Remedial Actions

If any of the above mentioned defects becomes evident during the warranty period, the contractor is required to make repairs at no cost to the state. The type of repair depends on the severity of the problem.

If alligator or map cracks are found on 20 percent or less of the entire deck area within the warranty period of one year, the contractor is required to seal these cracks with high molecular-weight methacrylate resin. If the area is greater than 20 percent, the contractor is required to remove the top 1 in. (25 mm) from the entire surface of the deck by hydro demolition. This concrete must then be replaced with either a 1-in. (25-mm) thick inlay of latex modified concrete or silica fume modified concrete.

If deck scaling occurs on 20 percent or less of the entire deck area and the depth is greater than 1/8 in. (3 mm) but not greater than 1/4 in. (6 mm), the defective areas are to be ground out. Transverse grooves are then re-established by saw cutting into the surface of the deck and the area is sealed with an approved concrete sealer. If the deck scaling is greater than 1/4 in. (6 mm) deep, the scaled area must be removed to a depth of 1 in. (25 mm). The concrete is then replaced with a 1-in. (25-mm) thick inlay of either latex modified concrete or silica fume modified concrete. The edges of the inlay are to be sealed with high molecular-weight methacrylate resin.

If the total area of scaling of the deck exceeds 20 percent of the entire deck surface, the entire top surface must be removed to a depth of 1 in. (25 mm) by the use of hydro demolition. The top surface is then to receive a 1-in. (25-mm) thick inlay of either latex modified concrete or silica fume modified concrete. Similar repairs are required for spalling.

Appeal Process

If the contractor disagrees with the findings of the review team, the contractor may appeal in writing to the district construction engineer. Within 45 days of receiving the contractor's appeal, the district construction engineer will inform the contractor of the determination. If the contractor does not agree with the determination of the district construction engineer, the contractor may appeal to the central office.

Maintenance Bond

The contractor is required to provide ODOT with a maintenance bond for the bridge deck for a period of seven years. The amount of the bond is 50 percent of the total price bid for the HPC.

Experience

ODOT began providing warranty projects in January 2000. To date, there have been 65 projects bid. There have been 16 decks that have received the one year review. Six of these decks required corrective work for alligator or map cracking.

During the development of these specifications, there was a concern about the impact on the bid price to perform this work. Prior to the development of the warranty specification, the average unit price awarded for HPC was $514/cu yd ($672/cu m) in 1998 and $521/cu yd ($681/cu m) in 1999. During 2000, the first year after the warranty specification was developed, the average unit price awarded for high performance concrete with warranty was $553/cu yd ($723/cu m). In the following year, the average price awarded for HPC with warranty dropped to $514/cu yd ($672/cu m).

More Information

Details of the specification are available at www.dot.state.oh.us and select warranty program info from the ODOT option menu or contact the author at 614-644-6628.

BENEFITS OF TERNARY MIXTURES

Paul D. Tennis, Portland Cement Association

The majority of concrete placed in the USA now contains at least one supplementary cementitious material (SCM) such as fly ash, ground granulated blast-furnace slag (GGBFS), or silica fume.(1) Most concrete producers and specifiers are comfortable using these materials. These concrete mixtures could be called binary mixtures, indicating that they contain portland cement and one SCM. Ternary mixtures are simply those mixtures that contain two SCMs in addition to portland cement.

Constituent Materials

There are several options for producing ternary mixtures. Two SCMs can be added with portland cement to the mixture at the batch plant. Alternatively, an SCM can be added with a blended cement. For example, a Type IP cement can be mixed with GGBFS. A third option is for two SCMs to be mixed with portland cement to make a ternary blended cement, which could be classified based on its properties under ASTM C 1157. This final option is relatively common in Canada. For example, a Canadian Type 10E-F/SF cement is one with equivalent (E) performance to a Type 10 cement, with fly ash (F) as the dominant SCM in quantity and silica fume (SF) as the secondary SCM.

Ternary concrete mixtures often produce concretes that may be classified as high performance. This use is increasing as concrete producers become adept at optimizing locally available concreting materials and specifiers become comfortable with the use of ternary concrete mixtures.

When to Consider Ternary Mixtures

The benefits of using SCMs in binary concrete mixtures are now generally well-accepted. Many SCMs result in increased later-age strengths and lower permeabilities. Consequently, the use of SCMs improves durability, increases resistance to sulfate attack, and reduces alkali-silica reactivity.

Ternary concrete mixtures can provide the same benefits as binary concrete mixtures, and, if properly optimized, may offer additional advantages. Many SCMs decrease the early strength gain of the concrete because they react slower than portland cement. One method for overcoming this slower strength gain is to add a second, more rapidly reacting SCM, such as silica fume. Thus, the potential long-term durability and strength improvements may be obtained with minimal impact on early age strength. This may present an attractive option for specifiers looking to decrease the time before bridge decks can be opened to traffic. However, special care may be needed to prevent early age cracking.

The use of two different SCMs may have synergistic effects as different mechanisms—chemical or physical—may be responsible for the behavior of concrete incorporating SCMs. For example, part of the benefit of combining silica fume and some fly ashes is due to the physical effects of size and shape of the particles allowing more efficient packing, leading to denser or easier-to-finish concrete. Some Class C fly ashes and some GGBFSs have chemistries that make them more reactive, and thus impart additional early strength to the concrete.

Case Study

A high profile example of the use of multiple SCM concrete mixtures is the $200 million reconstruction of Wacker Drive in Chicago.* This bi-level roadway has an ambitious 75 to 100-year design life, and contains not two, but three SCMs: GGBFS, fly ash, and silica fume (a quaternary mixture). In this project, the focus was on maximizing durability for the columns and superstructure since adequate strength was readily achievable. By keeping the total cementitious materials content to 684 lb/cu yd (405 kg/cu m) and the water-cementitious materials ratio to about 0.37, the mix was easier to place and finish than one with a high cement content and low water-cement ratio. The specific proportions of the SCMs were chosen to minimize permeability to chloride ions.

Trial Mixtures

As with all concrete mixtures, ternary concrete mixtures should be tested with the actual brands of concrete components in the proportions that will be used in the field. With a range of possible proportions for each material, ternary mixtures may provide an opportunity for the optimization of several properties.

Specifications

Bridge specifications often limit the maximum amount of SCMs for concrete. For example, fly ash and pozzolans less than 25 percent, GGBFS less than 50 percent, silica fume less than 10 percent, and all SCMs less than 50 percent by mass of total cementitious materials. These limits are subject to debate, as concretes made with higher dosages of particular materials have proved durable in some concrete mixtures in certain environments. Conversely, combinations of certain materials at dosages under these limits have been found to aggravate scaling or may be ineffective. It is, therefore, advisable to confirm behavior by field experience or laboratory testing.

Reference

1. Survey of Mineral Admixtures and Blended Cements in Ready Mixed Concrete, Portland Cement Association, Skokie, Illinois, October 2000, 16 pp.

Editor's Note

This article is the ninth 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, chemical admixtures, and air-entrainment were discussed in previous issues of HPC Bridge Views.

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**See HPC Bridge Views, Issue No. 19, January/February 2002.*

SPECIFICATION CHANGES FOR HPC— ACCELERATED CURING

The AASHTO Standard Specifications for Highway Bridges – Division II and the AASHTO LRFD Bridge Construction Specifications include provisions related to accelerated curing of concrete through the use of elevated temperatures. This article contains a review of some of the provisions and presents proposed changes that are more appropriate for use with high performance concrete.

Curing Temperatures

The current specifications state that the initial application of steam or heat shall be from 2 to 4 hours after final concrete placement to allow initial set of the concrete to take place. If retarders are used, the waiting period is increased to 4 to 6 hours. Since today's concretes contain a wider variety of constituent materials than in the past, the waiting period of 2 to 4 hours or 4 to 6 hours may not be appropriate. The actual measurement of time of set using AASHTO T 197 (ASTM C 403) entitled "Time of Setting of Concrete Mixtures by Penetration Resistance" for the specific concrete is a more precise approach and should be used for all concretes.

The current specifications have requirements for the rate of temperature rise, maximum temperature, and rate of temperature decrease. These temperatures are defined in terms of the temperature of the curing enclosure. Since high strength concretes generate significantly more heat than conventional strength concretes, it is important that concrete temperatures be monitored rather than enclosure temperatures.

Finally, the specifications do not require immediate transfer of the prestressing force if the ambient temperature is maintained above 60°F (16°C). For precast, prestressed concrete members, the transfer of the stressing force to the concrete should be accomplished immediately after accelerated curing to minimize the likelihood of vertical cracking in the members from thermal contraction. Cracking is more likely in deep members particularly when high strength concrete is used.

Cylinder Curing

When a precast concrete member is steam or radiant-heat cured, the compressive strength test cylinders are required to be cured under conditions similar to the member. Traditionally, this has been interpreted to mean that cylinders placed under the same covers as the member are acceptable. However, for high strength concrete, the heat generated within the member can result in higher temperatures in the member than in the cylinders.* This is particularly true when steam or radiant-heat curing is not used. Since the concrete strength at any point in time is related to the maturity of the concrete, different temperatures result in different compressive strengths. Consequently, match curing is essential for high strength concretes if realistic values for strength are to be measured.

For specified concrete compressive strengths greater than 6000 psi (41 MPa), test cylinders should be match cured in chambers in which the temperature of the chamber is correlated with the temperature in the member prior to release of the prestressing strands.* Temperature sensors for the match curing system should be placed at the most critical locations for release of the prestressing force and for design. After release of the prestressing strands, cylinders should be stored in a similar temperature and humidity environment as the member.

Test Age

For a discussion of the benefits of specifying compressive strengths at 56 days, see HPC Bridge Views, Issue No. 5, September/October 1999.

Editor's Note

This article is the second 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.

See HPC Bridge Views, Issue No. 2, March/April 1999.

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