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NEW JERSEY'S MOVE TO HPC

Harry A. Capers, Jr., New Jersey Department of Transportation and Hani Nassif, Rutgers University

High performance concrete (HPC) is now required for use in bridge decks on the state highway system in New Jersey. The use of HPC in prestressed concrete girders is at the discretion of the designer. Specific guidance for HPC is provided in the most recent edition of the Department of Transportation's (DOT) bridge design manual. To support HPC deployment, the Department initiated a research project through Rutgers University to develop several baseline concrete mixtures suitable for the transportation infrastructure in New Jersey.

The research involved (1) review of existing information, (2) development of mix proportions using local aggregates, (3) evaluation of trial mixtures prepared in the laboratory and at a ready-mixed concrete plant, (4) evaluation of concrete material properties, (5) investigation of the effects of different curing methods on early age and long-term performance, and (6) preparation of specifications for use in the project special provisions.

Mix proportions for concretes with compressive strengths from 6,000 to 12,000 psi (41 to 83 MPa) were developed. Mineral admixtures consisted of silica fume, Class F fly ash, and ground granulated blast-furnace slag. Chemical admixtures such as high-range water reducers (HRWR) and air-entraining agents were included. The performance of selected HPC mixtures was evaluated by measuring various properties including compressive strength, modulus of elasticity, early age (autogenous) and drying shrinkage, creep, rapid chloride permeability, surface scaling, and freeze-thaw resistance.

Conclusions of this research were as follows:

1. Mixtures that contained at least 5 percent silica fume produced concrete with good mechanical and durability properties. Using more than 10 percent silica fume did not produce significant improvement over the use of 5 to 10 percent.
2. Fly ash increased the workability of the concrete, reduced the required amount of HRWR, and reduced the early age compressive strength of the concrete. The optimum range for fly ash was between 10 and 15 percent of the total cementitious materials in the presence of 5 percent silica fume. For concrete decks, where the compressive strength is not as important as durability, adding more fly ash reduced the permeability of the concrete. However, adding more than 30 percent fly ash did not result in any significant reduction in permeability.

The DOT now requires that the HPC mix designs for bridge decks be tested to verify a maximum scaling resistance rating of 3, a minimum freeze-thaw durability after 300 cycles of 80 percent, a maximum chloride permeability at 56 days of 1000 coulombs, and a minimum compressive strength at 56 days of 5400 psi (37 MPa). If the chloride permeability and compressive strength are achieved at 28 days, the performance is considered acceptable.

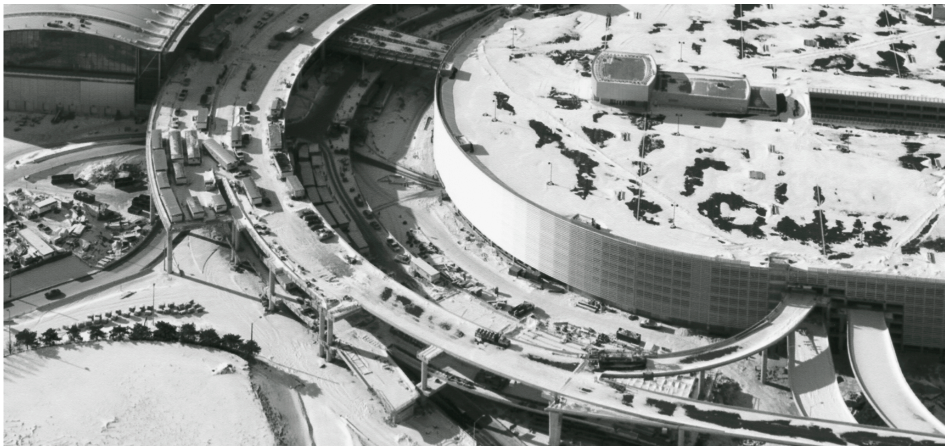
The specifications require that the concrete be placed 6 to 8 ft (1.8 to 2.4 m) ahead of the finishing machine. Wet burlap for curing of the deck slab must be placed within ten minutes after the concrete is struck off. If it is anticipated that the 10-minute limitation will not be met, the concrete placement operation must be stopped and a cold joint formed. Wet curing is required for 7 days followed by an additional 7 days with a liquid membrane curing compound.

Acceptance of production concrete for the deck is based on a maximum chloride permeability of 2000 coulombs at 56 days and a minimum compressive strength of 4400 psi (30 MPa) at 56 days. Whenever one or more individual test results for chloride permeability exceeds 2000 coulombs at 56 days, the contractor is required to remove the defective concrete or submit a plan for corrective action.

For a copy of the Department's bridge design manual go to www.state.nj.us/transportation/cpm/ and click on Design Manual – Bridges & Structures and scroll down to BDC02MB-02. For questions, contact the first author at harry.capers@dot.state.nj.us or 609-530-2557.

LARGE-SCALE USE OF HPC FOR BRIDGES AT TORONTO AIRPORT

Ken Bontius, Hatch Mott MacDonald Ltd.



Preblended silica fume cement and slag cement were used to obtain a 50-year service life.

As part of the redevelopment of Toronto's International Airport, Canada, a multi-level road system providing access to three levels of a new terminal building was required. The elevated road structure was arranged as a double-deck bridge with the upper decks partially staggered from the lower deck and forming part of the roof system for the terminal space below. Over 40,000 cu yd (30,000 cu m) of high performance concrete (HPC) was specified for these cast-in-place post-tensioned concrete bridges to address the owner's request for a 50-year maintenance-free service life.

The selection of HPC and development of the specifications were based upon the designer's successful experience with large-scale precast HPC projects and trial programs of the Ontario Ministry of Transportation. On this fast track project with such a large concrete volume cast in only 10 individual placements, a thorough application of all the lessons learned from HPC projects was required.

The contractor was responsible for the concrete mix design within the following parameters:

- Use of pre-blended silica fume and portland cement with 8 to 10 percent silica fume
- Up to 25 percent of the cementitious materials could be fly ash, slag cement, or a combination thereof
- Minimum compressive strength of 7250 psi (50 MPa) at 28 days
- Maximum rapid chloride permeability of 1000 coulombs at 56 days
- Minimum in-place total air content of 3 percent and average spacing factor per lot of no more than 0.01 in. (0.25 mm) and no individual test result greater than 0.012 in. (0.30 mm)
- Use of a high-range water reducer with a maximum concrete slump of 9 in. (230 mm) prior to placing
- Concrete delivery temperature between 50 and 77°F (10 and 25°C)

The specifications required continuous fog misting of the exposed concrete surface until covered with wet burlap, which had to be placed within 12 ft (3.7 m) of the deck finishing operation. The burlap was required to be covered with a vapor barrier and kept continuously wet with soaker hoses for 7 days. The contractor was also responsible for developing a plan to monitor and control the temperature gain and differential temperatures of the concrete within specified limits. A field trial batch (truck load) was required to demonstrate that the mix design satisfied both the fresh and hardened concrete parameters. Finally, the contractor was required to place a trial slab, utilizing the same mix design, placing and finishing equipment, and crew that would be employed on the project, to demonstrate the ability to carry out the placing and curing requirements. Pre-placement meetings were held before each placement to review previous results and reinforce the requirements for a successful placement.

The contractor's initial mix design was based on the use of pre-blended silica fume cement only, and was also used for the construction of the pier columns. While the concrete met all the performance requirements, the temperature differential and gain approached the maximum allowable values. Due to concerns with temperature effects for the solid 40-in. (1-m) thick concrete decks, a revised mix design utilizing a 25 percent replacement of the pre-blended cement with slag cement was developed to reduce the thermal effects. For comparative purposes, the revised mix was used in the remaining pier columns, and demonstrated a marked improvement in thermal properties.

An independent materials testing agency carried out quality control monitoring and testing. Concrete from the first five trucks from each plant was tested for slump, air, and temperature with the frequency changing to every fifth truck from each plant once control was established. Representative concrete cores were sampled from the bridge deck and tested for in-place air void parameters and rapid chloride permeability. Results of every test of the plastic and hardened concrete met the specifications. Most importantly, all rapid chloride permeability results were acceptable with an average value of only 430 coulombs.

Inspection of the concrete surface after the curing period and thereafter has not revealed any visible shrinkage cracking. The finished condition of the deck surface in the first deck placement was noted to be somewhat rough in some areas as the finishing pan tended to stick to the paste. With subsequent placements, attempts to improve this situation using a weighted pan or stainless steel pan were not as successful as simply removing this part of the finishing process. The roller finish without the pan has provided the preferred surface for future application of a waterproofing membrane.

This case study presents excellent evidence that, by following known requirements, HPC can be used in large-scale cast-in-place bridge deck construction with consistently successful results.

Further Information

For further information, contact the author at ken.bontius@hatchmott.com or 905-403-3940.

GREAT BEND BRIDGE OVER THE SUSQUEHANNA RIVER

Thomas Drda, Federal Highway Administration and Bryan Spangler, Pennsylvania Department of Transportation

The Pennsylvania Department of Transportation (PENNDOT) has been involved with high performance concrete (HPC) for several years. A performance based specification has been developed and several bridge decks have been constructed. Contractors, material suppliers, producers, and Penn State University have all been active participants in the development of a performance based specification. This approach developed strong support in our contracting community. The Great Bend Bridge on Route 11 over the Susquehanna River is one example of a successful application.

The Great Bend Bridge is a 537-ft (164-m) long, prestressed concrete I-beam bridge with two spans of 129.3 ft (39.3 m) and two of 139.4 ft (42.5 m). Each span consists of five AASHTO Type V beams spaced at 11.2 ft (3.40 m) with an 8-1/4 in. (210-mm) thick HPC deck. The superstructure was made continuous for live load by the placement of continuity diaphragms at the supports. The typical bridge width is 53 ft (16.2 m) with two travel lanes, two shoulders, and a raised sidewalk.

HPC Features

PENNDOT's objective in implementing HPC is to develop a durable concrete deck that has low permeability, good durability, minimal cracking, and adequate strength. On this project, there were specified requirements for compressive strength, chloride permeability, and shrinkage. Freeze-thaw resistance and abrasion resistance were measured for information only. The 28-day compressive strength was limited to a minimum of 4000 psi (28 MPa) and maximum of 6200 psi (43 MPa). The ratio of 28-day to 7-day compressive strength was required to be greater than 1.33 to help reduce early age cracking by having a more controlled strength gain. The maximum value of chloride permeability was specified to be 1600 coulombs at 28 days.

Construction – Lessons Learned

The prime contractor placed the concrete deck in two separate placements during August 2002. The specifications required that the evaporation rate, as determined using the American Concrete Institute's evaporation chart for hot weather concreting, not exceed 0.10 lb/ft^2/hr (0.49 kg/m^2/hr). The first placement commenced at 3:20 a.m. and ended at 4:00 p.m. Weather conditions were cool and humid at the beginning of the placement to hot, dry, and windy at the completion when the evaporation rate was estimated to be 0.24 lb/ft^2/hr (1.17 kg/m^2/hr). Even under these adverse conditions, the placement went well with the exception of some finishing problems late in the day. Because of the high evaporation rate, the contractor applied an intermediate curing compound, which became a finishing aid even though a finishing aid was prohibited by the specification. The use of the intermediate curing compound in this fashion may lead to scaling problems on the deck in the future. Fogging or wind screens, as allowed by the specifications, should have been used to reduce the evaporation rate.

Fortunately, the only apparent detrimental effects were twelve small areas where the concrete did not finish properly after the finishing machine sat at these locations because of construction delays. These areas were scarified and patched with latex concrete. In the second placement, these problems did not occur because of the smaller placement size and more favorable weather conditions.

Some minor sand balling of the mix was detected during the first placement but was immediately dealt with by reducing the charging rate of the concrete mixers. Cell phone communication between the job site and the concrete plant kept this from being a problem. All sand balls in the delivered concrete were removed at the pump hopper. The deck received a 7-day wet cure followed by the application of a curing compound. Transverse saw grooving was not allowed to begin until three days after the placement of the curing compound.

Results

Follow-up inspections have detected only a few hairline cracks in the deck. The Department anticipates a 75- to 100-year service life for this structure because of the low permeability, other factors contributing to enhanced durability, and prior testing of concrete mixtures at Penn State. Based on our experiences with the Great Bend Bridge, the specifications have been revised towards eliminating the problems that occurred.

Benefits

The use of HPC on bridge decks holds the promise of lower total life-cycle costs by providing bridge decks that are more durable with longer life expectancy. The success of this project is the result of a partnership and cooperation between PENNDOT, the Association of Pennsylvania Contractors, academia, and the FHWA in the development and implementation of an HPC specification.

Further Information

For further information, contact the second author at brspangler@state.pa.us or 717-783-5347.

Concrete Mix Proportions

Material	Quantities	
	per yd^3	per m^3
Portland Cement(1)	500 lb	297 kg
Fly Ash, Class F	135 lb	80 kg
Silica Fume	40 lb	24 kg
Fine Aggregate	1111 lb	659 kg
Coarse Aggregate	1723 lb	1022 kg
Water	270 lb	160 kg
Water Reducer(2)	7 oz	270 mL
Set Retarder(2)	34 oz	1315 mL
Air Entrainment(2)	5.5 oz	213 mL
w/cm ratio	0.40	

(1) Type I/II
(2) Quantities were modified as required during production

Concrete Properties

Property	Specified	Measured
Compressive Strength		
at 7 days, psi	—	3550
at 28 days, psi	4000 to 6200	5520
Ratio	> 1.33	1.55
Chloride Permeability, coulombs	≤ 1600	1330
Entrained Air, %	6 ± 1.5	5.3

Question

How can vertical pre-release cracks in prestressed concrete beams be avoided?

Answer

Vertical cracks have been observed in prestressed concrete beams before the prestressing strands are released. Their occurrence appears to be more frequent in deep, long-span members. These pre-release cracks, usually two to four in number, are generally located within the middle third of the beam length. They run transversely across the top flange of the beam, extend downward through the beam web, and may extend into the bottom flange of the beam. As soon as the strands are released, the cracks are closed by the prestressing force and become virtually invisible.

Research[1,2] conducted in North Carolina determined that the vertical pre-release cracks are caused by the restraining effect of the prestressing strands when the newly cast beams begin to cool and shorten before the strands are released. After the beams have been heat cured overnight, the temperature of the prestressed concrete beams is generally much higher than the ambient temperature. This temperature differential causes the beams to contract while the prestressing strands are still anchored to the ends of the casting bed. In addition, the lower ambient temperature causes the exposed strands to contract.

These thermal contractions are restrained by the anchored prestressing strands before they are released. The restraining force exerts a tensile force on the beams, causing pre-release vertical cracks when the tensile stress in the beams exceeds the concrete tensile strength, which is relatively low since the concrete is usually less than one day old.

The tensile stress induced in the concrete by the restrained thermal contraction increases with longer spans, larger sizes of the beams, greater temperature differential, and reduced length of exposed strands. The occurrence of the cracks can be minimized by two approaches. The first is to release the strands immediately following the curing period as required by the PCI Manual for Quality Control.[3] The second approach is to increase the exposed strand length between adjacent beams and between the end beams and the anchorages. For a temperature drop of 60°F (33°C), the exposed tendon length should be about 28 percent of the beam length.[2] The first approach is preferable since the second approach reduces the efficiency of production. It is also beneficial to protect the exposed strands from low ambient temperatures until the strands are released.

Since the problem of beams with pre-release vertical cracks occurs from time to time, outright rejection of the beams with such cracks is not a practical approach. North Carolina Department of Transportation has developed a set of acceptance criteria for beams with pre-release vertical cracks and the criteria can be found in Reference 1.

References

1. Zia, P. and Caner, A., "Cracking in Long-Span Prestressed Concrete AASHTO Girders During Production," Symposium Proceedings, PCI/FHWA/FIB International Symposium on High Performance Concrete, Orlando, Florida, Precast/Prestressed Concrete Institute, Chicago, IL, 2000, pp. 459-469.
2. Zia, P. and Caner, A., "Cracking in Large-Sized Long-Span Prestressed Concrete AASHTO Girders," Report No. FHWA/NC/94-003, NCDOT, Raleigh, NC, 1994, 98 pp.
3. Manual for Quality Control for Plants and Production of Structural Precast Concrete Products, MNL-116-99, Precast/Prestressed Concrete Institute, Chicago, IL, 1999.

Answer contributed by Paul Zia of North Carolina State University. He may be contacted at zia@eos.ncsu.edu.

HPC BRIDGE CALENDAR

September 13-15, 2004
International Symposium on Ultra High Performance Concrete, Kassel, Germany. Organized by the University of Kassel. See www.uni-kassel.de/uhpc2004 for more information.

June 20-24, 2005
Seventh International Symposium on Utilization of High Strength/High Performance Concrete, Washington, DC. Organized by ACI. Abstracts due by February 1, 2004. Contact Thomas H. Adams, American Concrete Institute at 248-848-3742 or thomas.adams@concrete.org.

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2004 Concrete Bridge Conference
May 17-18, 2004
The Westin Hotel, Charlotte, North Carolina

CBC ’04 - Conference Program Overview

Sunday, May 16, 2004

12:00 pm–5:00 pm	Registration
6:00 pm–7:30 pm	Reception

Monday, May 17, 2004

8:30 am–5:20 pm	Plenary Session Technical Sessions
6:00 pm–9:30 pm	Reception & Dinner

Tuesday, May 18, 2004

8:30 am–5:20 pm	Technical Sessions

The conference is being cosponsored by the Federal Highway Administration, the National Concrete Bridge Council, and the American Concrete Institute. The Concrete Bridge Conference (CBC) has quickly become the premier national venue for the exchange of ideas and information on all aspects of concrete bridge design and construction. The first CBC held last year in Nashville, Tennessee was a great success. The conference was attended by over 300 bridge engineers including 100 DOT and highway agency officials.

This year’s CBC will be even bigger and better. 90 papers in 18 technical sessions will feature state-of-the-art topics fresh from design boards, research laboratories and construction sites, presented by experts from all facets of the concrete industry. A Proceedings will be published following the Conference and will be provided to all attendees. The 18 Technical Program Sessions include:

- Plenary Session
- Bridge Aesthetics
- Corrosion Resistant Reinforcement
- Innovative Technologies
- Bridge Decks
- Rapid Bridge Construction I
- Rapid Bridge Construction II
- Bridge Rehab. Retrofit, Repair & Replacement
- Case Studies—Girder Bridges
- Segmental Concrete Bridges
- Cast-In-Place PT Bridges
- R&D-Structural Testing
- Design & Analysis I
- Design & Analysis II
- Service Life and Life-Cycle Cost of Concrete Bridges
- Concrete QA/QC & Mix Design
- Research & Development
- Performance Specifications

The 2004 Concrete Bridge Conference is being held in conjunction with the 2004 Post-Tensioning Institute (PTI) Technical Conference and Exhibition. Your registration will enable you to attend both conferences. Up to 600 attendees are expected.

The CBC will highlight exhibits showcasing the latest industry products and services. This premier conference provides a unique opportunity to interact with experts from around the country.

The conference will provide ample time for networking with colleagues and making new acquaintances. Social events include receptions, breakfasts, luncheons, coffees, and guest activities.

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The conference is cosponsored by the Federal Highway Administration, the American Concrete Institute, and the National Concrete Bridge Council—*(*NCBC is comprised of the American Segmental Bridge Institute—Concrete Corrosion Inhibitors Association—Concrete Reinforcing Steel Institute— Expanded Shale Clay and Slate Institute—National Ready Mixed Concrete Association—Portland Cement Association—Post-Tensioning Institute—Precast/Prestressed Concrete Institute—Silica Fume Association—Slag Cement Association—Wire Reinforcement Institute)*

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