Bridge Views

HIGH PERFORMANCE CONCRETE
Academia · States · Industry · FHWA · HPC

www.fhwa.dot.gov/bridge/hpc

Issue No. 18 November/December 2001

INSIDE THIS ISSUE…

Maryland SHA's First HPC Structure

Self-Consolidating Concrete—A New Class of HPC

Benefits of Different Cements in HPC

Letters to the Editor

Web Sites

NCHRP Project

HPC Bridge Calendar

SPONSORED BY

U.S. Department of Transportation
Federal Highway Administration

CO-SPONSORED BY
NATIONAL CONCRETE BRIDGE COUNCIL

PORTLAND CEMENT ASSOCIATION

PRECAST PRESTRESSED CONCRETE INSTITUTE

NATIONAL READY MIXED CONCRETE ASSOCIATION

AMERICAN SEGMENTAL BRIDGE INSTITUTE

EXPANDED SHALE CLAY AND SLATE INSTITUTE

CONCRETE REINFORCING STEEL INSTITUTE

Concrete Corrosion Inhibitors Association

POST-TENSIONING INSTITUTE

WIRE REINFORCEMENT INSTITUTE

SILICA FUME ASSOCIATION

MARYLAND SHA'S FIRST HPC STRUCTURE

Paul Finnerty, MDSHA, Vicki Stewart, MDSHA, and Rodney Meyers, Master Builders , Inc.

In September 1996, Mr. Samuel Miller Jr., Deputy Chief Engineer of the Maryland State Highway's Office of Materials and Technology authorized the formation of a high performance concrete (HPC) committee. The committee membership represented the State Highway's Bridge and Materials Offices, the Federal Highway Administration, and members of the Maryland Ready Mixed Concrete Association. The committee's objective was to develop a specification for high performance portland cement concrete to achieve a 75-year service life in Maryland State Highway Administration (MDSHA) bridge decks.

Implementation

The specification was implemented last year with an HPC bridge deck on MD Route 64 over the CSX railroad in Washington County. The superstructure has a span length of 100 ft (30.5 m) and consists of six precast, prestressed concrete AASHTO Type IV girders spaced at 7 ft 8 in. (2.34 m) centers supporting an 8-in. (203-mm) thick cast-in-place concrete deck. The specified concrete compressive strength of the girders was 7000 psi (48 MPa) at 28 days.

Deck Concrete Specifications

The deck concrete mix design used the following criteria:

- Maximum cement content of 550 lb/cu yd (326 kg/cu m) to reduce early age thermal stresses
- Maximum water-cementitious materials ratio of 0.45
- A 28-day specified compressive strength of 4200 psi (29 MPa), compared to the standard strength of 4500 psi (31 MPa), to provide ductile behavior and to reduce cracking
- Air content of 6.5 ± 1.5% to provide freeze-thaw resistance
- Pozzolans at 35 percent of the total cementitious materials to reduce chloride permeability and mitigate against alkali-silica reactivity
- Average charge passed per AASHTO 277 of 2000 coulombs or less with no individual value greater than 2500 coulombs
- Corrosion inhibitor at 2 gal/cu yd (10 L/cu m) to inhibit corrosion of the reinforcing steel
- Polypropylene fibers to provide resistance to plastic shrinkage cracking
- Maximum 28-day drying shrinkage of 400 microstrain to reduce drying shrinkage cracking

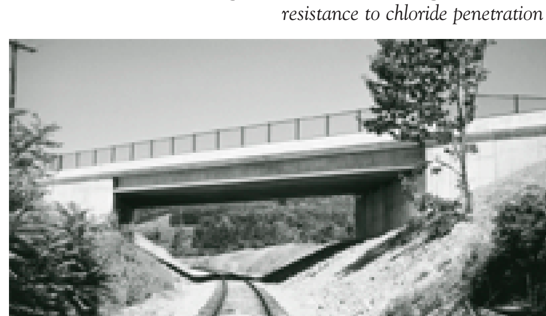
Life Expectancy

The use of HPC is expected to increase the time until corrosion initiation to 50 years calculated using Fick's second law of diffusion. The proper use of epoxy-coated reinforcement should inhibit corrosion for another 25 years. Consequently, the first significant repair for the HPC bridge deck is not expected for at least 75 years.

Cost

Implementation of the specified quality control standards increased the in-place cost of the bridge deck concrete by approximately $50/cu yd ($65/cu m) for this particular project compared to a cost of $75/cu yd ($98/cu m) for conventional concrete. The normal range of cost increase is $40 to $80/cu yd ($52 to $105/cu m) and is largely dependent on the risk associated with higher quality standards and competitive market forces. Currently, the time to rehabilitate a bridge deck is less than 40 years. Therefore, the added cost of HPC is a sound investment for the anticipated service life of 75 years.

HPC was used in the bridge deck to reduce cracking and increase resistance to chloride penetration



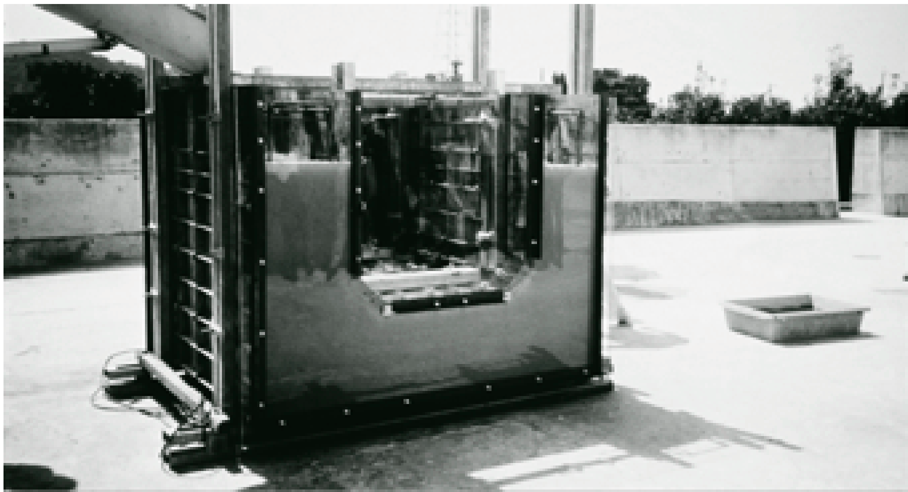


Fig. 1 Casting SCC in a mock-up of a beam-column element

SELF-CONSOLIDATING CONCRETE—A NEW CLASS OF HPC

Kamal H. Khayat, University of Sherbrooke, Quebec, Canada

Self-consolidating concrete (SCC) is a new class of high performance concrete based primarily on the properties of the concrete during placement. When properly proportioned and controlled, SCC can flow significant distances and consolidate to normal density without the application of compactive effort, as illustrated in Fig. 1. The concrete maintains sufficient resistance to segregation to remain homogeneous during and after placement.

The use of SCC can accelerate the filling of formwork, especially when casting densely reinforced elements and sections with restricted access. It reduces labor demand and noise on construction sites and in precasting yards. SCC can result in high-quality, smooth surfaces that are free of honeycombing and signs of bleeding.

This "vibration-free" concrete was initially used in the casting of large civil engineering structures. Subsequently, SCC has been used for a variety of applications, including building construction, short-span bridges, concrete repairs, and precast, prestressed concrete members. Some properties of the hardened SCC relative to those of conventional concrete are described in References 1 and 2.

Quality Control

From a rheological point of view, SCC exhibits a low yield value, which ensures that the concrete will flow, and has a moderate viscosity, so the concrete remains homogeneous during placement. Consequently, different test methods are needed with SCC. A number of field-oriented test methods have been proposed for quality control of SCC. The ease of flow is often determined by measuring the slump flow as shown in Fig. 2. Special tests are employed to evaluate the resistance to segregation during placement, ability of the concrete to flow through restricted spaces, resistance to bleeding, settlement, and segregation.[3,4]

Mixture Proportioning

Material selection and mixture proportioning should be aimed at reducing interparticle friction among the solid particles. SCC typically incorporates fly ash, blast-furnace slag, or limestone filler to enhance both deformability and stability of the fresh concrete. Deformability is the ability of the concrete to undergo a change in shape under its own weight, even in the vicinity of obstacles that interfere with its flow. Proper stability can be obtained by reducing the water-cementitious materials ratio, increasing the concentration of solids finer than 80 μm, and/or incorporating a viscosity-modifying admixture. The use of a high-range water-reducing admixture can disperse cement grains and reduce interparticle friction. This allows a reduction in water content while maintaining the required levels of flowability and viscosity.

Fig. 2 Measuring slump flow consistency

Conclusion

In recent years, the interest in SCC has spread widely. With further training of personnel, more experience gained with the design and proportioning of SCC using readily available materials, specification changes, and the use of proven quality control tests, this new class of HPC has great potential for use in bridges.

Selected References

1. Khayat, K. H., Paultre, P., and Tremblay, S., "Structural Performance and In-Place Properties of Self-Consolidating Concrete Used for Casting Highly Reinforced Columns," ACI Materials Journal, Vol. 98, No. 5, September-October 2001, pp. 371-378.
2. Khayat, K. H., Manai, K., and Trudel, A., "In Situ Mechanical Properties of Wall Elements Cast Using Self-Consolidating Concrete," ACI Materials Journal, Vol. 94, No. 6, November-December 1997, pp. 491-500.
3. Khayat, K. H., "Workability, Testing, and Performance of Self-Consolidating Concrete," ACI Materials Journal, Vol. 96, No. 3, May-June 1999, pp. 346-353.
4. Okamura, H., "Self-Compacting High-Performance Concrete," Concrete International, Vol. 19, No. 7, July 1997, pp. 50-54.
5. Japan Society of Civil Engineers Proc., International Workshop on Self-Compacting Concrete, Kochi, Ed. Ozawa, K., Ouchi, M., JSCE Concrete Engineering Series 30, August 1998, 400 pp.

BENEFITS OF DIFFERENT CEMENTS IN HPC

Paul D. Tennis, Portland Cement Association

Although all materials play a role in high performance concrete (HPC) mixtures, cement is the essential component. The characteristics of HPC may include low permeability, high strength, low temperature rise, high durability, and combinations of these or other properties. Cement is the material largely responsible for these critical properties. It is important to note that most cements perform well in HPC applications. However, some cements have been developed with particular characteristics that lend themselves to use in HPC. Table 1 provides a list of the cement types described in the AASHTO and ASTM specifications classified according to their intended applications.

General Purpose Cements

General purpose cements are used where no special properties of the other cement types are necessary. HPC can be made with these "general purpose" cements if the concrete mixture is carefully chosen to provide the specified concrete properties. For example, high strength concrete can be made with Type I cement if low water to cement ratios and high cement contents are used. One benefit of using these cements is that they are usually locally available, whereas, some specialized cements may not be.

Low Heat Cements

All cements generate heat from the chemical reaction between cement and water. In massive concrete placements, this can be a concern. The rate that cements generate heat and the corresponding temperature rise in concrete can be controlled somewhat by the cement fineness, chemistry, and choice of supplementary cementitious materials (SCMs). Cement Types IV, P(LH), and LH have low heat of hydration requirements. However, these cements are rarely produced because there is not a large demand for them.

Cement types developed to provide moderate heat generation are more readily available. For Type II cements and cements under AASHTO M 240 (ASTM C 595), a moderate heat (MH) option must be requested. Under ASTM C 1157, Type MH can be specified. SCMs can be used in the concrete mixture to reduce the temperature rise in HPC concretes; but the rate of strength development may be slower.

High Early Strength Cements

Cement Types III and HE are used when high early strength is required. Later age strengths may be lower than with other cements, but the tradeoff is worthwhile in some applications. These cements are often used in fast-track and repair applications where concrete strengths of about 4000 psi (28 MPa) are needed in just a few hours.

Sulfate-Resistant Cements

If concrete is placed in an environment where exposure to sulfate is a concern, a water-cementitious materials (w/cm) ratio of about 0.40 is essential to minimize permeability. If w/cm ratios up to 0.50 must be used, cements with moderate or high sulfate resistance are available. Type II, C 1157 Type MS, and M 240 (C 595) cements with (MS) suffix are moderately sulfate resistant. Types V and HS are highly sulfate resistant. These designations are applied based on expansion in standardized tests. Sulfate resistant cements will not control sulfate attack in concretes with high w/cm ratios.

ASR-Resistant Cements

When aggregates that are susceptible to alkali-silica reaction (ASR) must be used in the concrete, cements resistant to ASR may help durability. All three cement specifications have optional requirements for ASR resistance. AASHTO M 85 (ASTM C 150) has a low alkali option. AASHTO M 240 (ASTM C 595) and ASTM C 1157 use expansion in a mortar bar test to predict performance. Testing to confirm that the job material combinations are sufficient to control deleterious expansions should also be performed as a check, if sufficient history on the use of specific mixtures is not available.

Conclusions

Although HPC may be obtained with the proper use of SCMs, chemical admixtures, w/cm ratios, and aggregate gradations, non-general purpose cements may enhance performance. Laboratory or field testing should always be performed to confirm that the chosen concrete mixture meets project requirements.

Further Information

More information on cements for HPC can be found in the following publication: Portland, Blended and Other Hydraulic Cements, IS004, Portland Cement Association, Skokie, Illinois, 2001.

Editor's Note

This article is the third in a series that addresses the benefits of specific materials used in HPC. The benefits of silica fume and lightweight aggregate were discussed in previous issues of HPC Bridge Views.

Table 1. Applications for Commonly Used Cements (Adapted from PCA IS004)

Cement Specification	General Purpose	Moderate Heat of Hydration	High Early Strength	Low Heat of Hydration	Moderate Sulfate Resistance	High Sulfate Resistance	Resistance to Alkali-Silica Reactivity(1)
AASHTO M 85 (ASTM C 150)	I	II (moderate heat option)	III	IV	II	V	Low alkali option
AASHTO M 240 (ASTM C 595)	IS IP I(PM) I(SM) P	IS(MH) IP(MH) I(PM)(MH) I(SM)(MH)	—	P(LH)	IS(MS) IP(MS) P(MS) I(PM)(MS) I(SM)(MS)	—	Low reactivity option
ASTM C 1157(2)	GU	MH	HE	LH	MS	HS	Option R

(1) The option for low reactivity with aggregates can be applied to any cement type in the columns to the left. (2) ASTM C 1157 is a specification giving performance requirements.

LETTERS TO THE EDITOR

The following letter was received from Pierre-Claude Aitcin of the University of Sherbrooke, Quebec, Canada, concerning Issue No. 15 of HPC Bridge Views.

This issue of Bridge Views pleased me very much. Actual problems related to the implementation of HPC by the construction industry are well addressed. For too long, too many agencies have applied conventional concrete technology to HPC. This has been a serious mistake. In spite of the fact that HPC is still a concrete made with the same ingredients as a conventional concrete, the compactness of the matrix in the fresh and harden state makes HPC a different material. HPC mixes are very sensitive to the compatibility and robustness of the cement/superplasticizer combination. Non air-entrained HPC is sticky. HPC can experience slump loss. It can be difficult to entrain an air bubble system with a low spacing factor in HPC. Pumping affects the spacing factor. HPC does not bleed as much as conventional concrete and is more susceptible to plastic shrinkage. When HPC is not water cured before hydration begins, HPC develops a very rapid and significant autogenous shrinkage at a time when the concrete has not developed any tensile strength.

The use of HPC necessitates the implementation of precise placing and curing specifications. This can be done successfully. The City of Montreal is paying contractors specifically to cure concrete. The contractors are now zealous because they see concrete curing as an easy source of profit. The cost premium for the implementation of a particular water-curing program has been calculated to be between 0.1 and 0.5 percent for an HPC bridge. This is much less than the 0 to 20 percent premium cited by Hannah Schell in her article. The Department of Transportation of Quebec has found that an HPC bridge costs 8 percent less than its counterpart in conventional concrete.

The kind of technological information contained in HPC Bridge Views will help the U.S. Departments of Transportation and the construction industry take advantage of the full benefits of HPC. In Quebec, we are now using air entrained HPC with a 0.35 water-cementitious materials ratio to build our infrastructure. This concrete is made using a blended silica fume cement or a ternary cement that includes 5 percent silica fume and about 20 percent fly ash or slag.

WEB SITES

The FHWA HPC web site address has been changed to www. fhwa.dot.gov/bridge/hpc. The National Concrete Bridge Council (NCBC) web site is at www. nationalconcrete bridge.org.

NCHRP PROJECT

The National Cooperative Highway Research Program has announced the award of Project No. 12-56, entitled "Application of the LRFD Bridge Design Specifications to High-Strength Structural Concrete: Shear Provisions," to the University of Illinois. The Principal Investigator is Dr. Neil Hawkins. For further information about the project, go to www4.nas.edu/trb/crp.nsf/all+projects/nchrp+12-56 or www.ce.uiuc.edu/nchrp

HPC BRIDGE CALENDAR

June 16–20, 2002
Sixth International Symposium on Utilization of High Strength/High Performance Concrete, Leipzig, Germany. Web site at www.HPC2002.de

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

CORRECTION

In Issue No. 17 of HPC Bridge Views, it was stated that the HPC bridge compilation was available for viewing and downloading at the NCBC web site. Due to technical difficulties, it is only available for downloading.

HPC Bridge Views is published jointly by the Federal Highway Administration and the National Concrete Bridge Council. Previous issues can be viewed and downloaded at http://www.portcement.org/br/newsletters.asp.

For a free subscription to this newsletter, change of address, or copies of previous issues, contact NCBC at 5420 Old Orchard Road, Skokie, IL 60077-1083; 847-966-6200; (fax) 847-966-9781; email: ncbc@portcement.org.

For further 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 Subcommittees on -
Bridges and Structures: William N. Nickas, 850-414-4260; (fax) 850-488-6352; e-mail: william.nickas@dot.state.fl.us
Materials: John B. Volker, 608-246-7930; (fax) 608-246-4669; e-mail: john.volker@dot.state.wi.us
Construction: Gene R. Wortham, 208-334-8426; (fax) 208-334-4440; e-mail: gwortham@itd.state.id.us

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