Bridge Views

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HPC IN VERMONT

Jim Wild, Vermont Agency of Transportation

Vermont's awareness of high performance concrete (HPC) began in 1997 at an HPC Bridge Showcase meeting held in New Hampshire. After the meeting, Vermont's Agency of Transportation (VTrans) began plans to incorporate higher performing concrete into its bridges. A bridge that had already been bid was selected for a trial in 1997. The lessons learned were then incorporated into our first specifically bid HPC project that was built in the 1999-2000 construction season.

In about 1998, alkali-silica reactivity (ASR) became a recognized issue in Vermont. To combat the problem and prior to beginning an aggregate screening process, new concrete mixes containing supplementary cementitious materials were developed. For concretes used in superstructure and substructure elements, repairs, and overlays, the cementitious materials were required to include 40 lb/cu yd (24 kg/cu m) of silica fume and either fly ash at 20 percent or ground granulated blast-furnace slag at 25 percent of the total cementitious materials. Alternatively, the total amount of cement and silica fume could be supplied as a preblended product. The silica fume was included to reduce the permeability of the concrete.

In 2002, VTrans began to require HPC as a preventative measure against potential ASR in all bridge projects for the substructure and superstructure elements except the prestressed concrete beams. Measured concrete compressive strengths are generally in the range of 5000 to 6800 psi (34 to 47 MPa) depending on the class and source of the concrete.

VTrans specification requires a pre-placement meeting prior to any deck concrete placement. The goal is to achieve consistent placement and curing procedures for the concrete. This, in turn, helps us recognize problems that may be mix design related. The importance of proper curing is emphasized to the contractor during these meetings. Unfortunately, some contractors still do not follow the stated procedures for curing. The reasons include crews that do not have enough people or experience, not being organized, or curing is not a priority to them. The specification requires fogging equipment. Application of the wet cure must begin within 10 minutes after the screed machine has passed. Wet curing durations remain the same as conventional concretes: 7 days for substructure elements and 10 days for superstructure elements.

In the beginning, contractors were reluctant to deal with HPC because the silica fume concrete was more difficult to finish and required more effort and attention for curing. During the deck pre-placement meetings, VTrans emphasizes to the contractor that a smooth warehouse floor surface is not needed. The surface should be lightly finished and covered with wet burlap as soon as possible. The contractor must also be willing and able to adjust the finishing technique to obtain the desired results because HPC finishing characteristics change rapidly with the environmental conditions. Most of the major contractors are now familiar with HPC and know what they must do.

The price of in-place HPC is approximately \$150 to \$250/cu yd (\$196 to \$327/cu m) greater than conventional concrete. We believe that the increased cost is worth it for the better product.

VTrans is currently updating its prestressed concrete specifications to include a maximum permeability requirement at 56 days and ASR testing of the aggregates. If the aggregates are found reactive, then retesting with the proposed mitigation method is required.

Summary

High performance concrete is still relatively new to VTrans, so long-term data on field performance is not yet available. If HPC performs as well as the laboratory testing indicates, VTrans will have longer lasting bridges with less maintenance for future generations.

THE EVOLUTION OF HPC IN VIRGINIA

Claude S. Napier, Jr., Federal Highway Administration

Virginia has used a systematic approach to improve its existing and new concrete bridge structures. The key to success has been close cooperation between the bridge, materials, and construction engineers and the researchers, managers, and Federal Highway Administration (FHWA) staff using the best available technology to solve problems and to implement new technologies. The operations personnel of the Virginia Department of Transportation (VDOT) have worked closely with the Virginia Transportation Research Council's (VTRC) concrete and bridge research advisory committees and industrial partners.

High performance concrete has been evolving in Virginia over the last fifteen years through extensive laboratory research and field testing with numerous pilot projects to ensure that the performance is acceptable before full-scale implementation. Since 1989, Virginia has made significant changes to its concrete specifications and procedures for high performance concretes including concretes with low permeability, high durability and, when needed, higher early and later-age compressive strengths. The following sections highlight some of the changes that have been made.

Bridge Decks

In 1988, based on recommendations by FHWA, VDOT added requirements for limiting surface evaporation rates for concrete bridge decks. The following year, saw-grooving of concrete bridge decks was specified as a means to improve the quality and durability of the riding surface. And in 1994, a trial special provision requiring 7 days of moist curing for low permeability concrete (LPC) bridge decks was introduced. This is now a standard requirement for all LPC bridge decks.

Prestressed Concrete Girders

Traditionally, VDOT had not used high strength concrete in its precast, prestressed concrete girders. However, in the 1995-1997 construction seasons, five bridges with specified concrete compressive strengths of 7000 to 8000 psi (48 to 55 MPa) were built. In addition, bridges were built in Brookneal and Richlands to demonstrate the applications of HPC. The girders used in the Richlands' bridge had a specified concrete compressive strength of 10,000 psi (69 MPa) at 28 days. In 1999, VDOT changed its practice to allow the use of compressive strengths up to 10,000 psi (69 MPa) in design, but required approval by the State Bridge Engineer for strengths over 8000 psi (55 MPa). In the same time period, VDOT was working with the Mid-Atlantic Prestressed Concrete Economical Fabrication (PCEF) Committee to develop bulb-tee beam sections that are more efficient than the AASHTO I-beams and permit longer span lengths. These new sections were adopted in 1999 to eventually replace the AASHTO sections. In 2003, bids were received on 13 PCEF bulb-tee bridges. VDOT's federally funded bridge costs were reduced to \$81/sq ft (\$870/sq m) from \$89/sq ft (\$960/sq m) in 2002.

Permeability

In 1994, Virginia developed a permeability special provision for HPC. Maximum permeability values of 1500 coulombs were specified for precast, prestressed concrete, 2500 coulombs for the deck concrete, and 3500 coulombs for the substructure concrete because it was felt that the ready mix industry and the prestressed concrete producers could obtain them consistently. This approach bolstered the confidence of the VDOT operations personnel and the contracting industry in using HPC. The specimens are cured for one week at 73°F (23°C) followed by three weeks at 100°F (38°C) and then tested at 28 days. Seven HPC bridge structures were constructed between 1995 and 1997 and five included the permeability special provision. The requirements were adopted for all HPC projects after 1997.

Materials Technology

In 1992, the need for corrosion protection of strands prompted the inclusion of corrosion inhibitors in prestressed concrete. For LPC containing pozzolans or slag, corrosion inhibitors are used at low dosage rates only for concrete in a marine environment. Also in 1992, VDOT addressed the alkali-silica reaction problem by requiring either cement with an alkali content of less than 0.40 percent or the use of pozzolans or slag with cement having an alkali content up to 1 percent.

In 1998-1999, under an Innovative Bridge Research and Construction (IBRC) Program project, monofilament fibers were used on the Route 11 bridge over the Maury River to control or minimize deck cracking over the piers. In 2003, the total length of cracks was about 25 percent of the length of cracks in a control section without fibers and the average crack width was about half.

Lightweight Concrete

In 1998-1999, another IBRC project was used to implement the use of lightweight HPC (LWHPC) in the prestressed concrete girders and reinforced concrete deck of the Route 106 bridge over the Chickahominy River. Subsequently, LWHPC is being used in haunched spliced bulb-tee beams, PCEF bulb tees, and concrete decks of the Route 33 bridge over the Mattaponi River and in haunched spliced bulb-tee beams with span lengths up to 240 ft (73 m) on the Route 33 bridge over the Pamunkey River.

Summary

By October 2002, 19 HPC bridges had been built in Virginia, 42 were under construction, and 90 under design for a total of 151 projects. Beginning in November 2003, HPC has been used on all bridges that use federal funds. It is expected that HPC will be used on all state-funded bridges sometime in 2005.

The HPC program is progressing successfully based on VDOT's partnership with industry and FHWA to ensure that the technologies are functionally and economically acceptable. Higher performance concrete structures are cost-effective and are expected to have higher durability, longer service life, and minimum maintenance requirements.

Readers may visit the VTRC website at www.virginiadot.org/vtrc/main/index_main.htm to see reports on a number of the items mentioned above.

Editor's Note

This article is the fourth in a series that describes how the use of HPC has progressed since it was first introduced into a State's program. Other articles appear in Issue Nos. 30, 35, and 36.

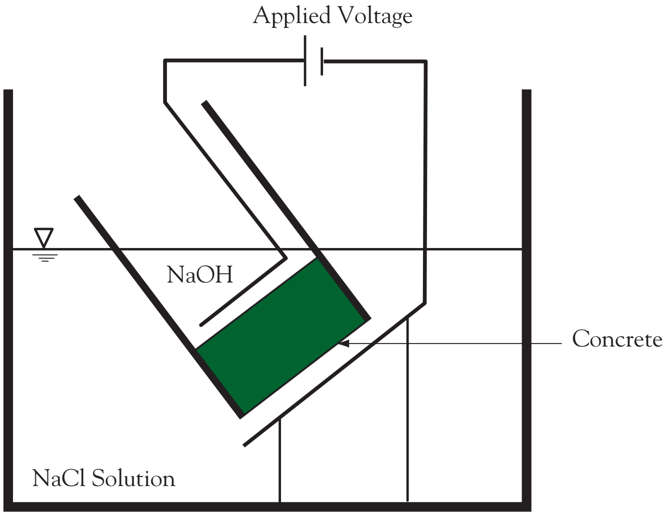
THE RAPID MIGRATION TEST FOR HPC

Kyle Stanish, University of Cape Town, R. Doug Hooton, University of Toronto, and Michael D. A. Thomas, University of New Brunswick

Chloride-induced corrosion is a major cause of deterioration of reinforced concrete structures. The best method of minimizing the problem is by producing high quality concrete that is capable of resisting the ingress of chlorides. To ensure quality concrete, it is necessary to have a measure of the concrete's ability to resist chloride ingress that can be used as a standard test.

The traditional test that has been used for this purpose is AASHTO T 277 (ASTM C 1202), commonly referred to as the Rapid Chloride Permeability Test (RCPT). This test, while providing a rapid indicator of concrete's resistance to fluid penetration, does have a few drawbacks, principally: (i) the current passed is related to all the ions in the pore solution, not just chloride ions; (ii) the high voltage leads to temperature increases during the test, which affects the properties of the concrete; and (iii) a relatively high variability. To overcome some of these drawbacks, the FHWA sponsored an investigation of various alternative test methods.(1) Some of the results of this investigation were reported in *HPC Bridge Views, Issue No. 13*. This investigation recommended the use of a Rapid Migration Test, which has since been adopted as AASHTO provisional Standard TP 64. The Rapid Migration Test was originally proposed by Tang and Nilsson(2) in Sweden, and has been standardized by Nordtest, a Scandinavian organization, as NT Build 492.

The main difference between AASHTO TP 64 and Nordtest NT Build 492 is that NT 492 allows calculation of a non-steady state, chloride diffusion coefficient. This was considered for the AASHTO test, but the theory behind the calculation has been questioned.(3)



Schematic of the Rapid Migration Test.

For the Rapid Migration Test, a 50-mm (2-in.) long, 100-mm (4-in.) diameter concrete sample must be obtained. It is then saturated using the vacuum saturation procedure of the RCPT. Next, the sample is clamped inside a silicone rubber tube between two solutions: 10 percent sodium chloride on one side and 0.3 molar sodium hydroxide on the other. A typical test setup is illustrated in the figure, although other options are possible including using AASHTO T 277 cells.

Initially, a 60 volt potential is applied across the sample and the current measured. Based upon the initial current, the voltage is adjusted to bring it to a range suitable for that quality of concrete. The voltage is then applied for 18 hours. The applied voltage drives the chloride ions into the previously uncontaminated concrete. Upon removal, the concrete sample is split in half along its length. The broken faces are then sprayed with 0.1 molar silver nitrate solution—a colorimetric indicator. The silver nitrate reacts with any stable chloride ions that are present to form a white layer, while the uncontaminated area turns brown. The average depth of chloride penetration is obtained by taking measurements at 10 mm (0.4 in.) intervals across the diameter. The average value is then divided by the product of the applied voltage in volts and time in hours to rate the sample.

The results from this test have been shown to be unaffected by different cementitious materials and the presence of conductive admixtures. The specimen does not experience a temperature rise during the test. The test also has a lower variability than the RCPT.(3, 4) An approximate correlation between the results of the Rapid Migration Test and the RCPT is shown in the table. It is believed that the Rapid Migration Test has significant advantages and its use will lead to improved evaluation of concrete quality in a chloride environment.

Comparison of Test Results

Rapid Migration, mm/V-hr	RCPT, coulombs
0.034	3000
0.024	2000
0.012	800

References

1. Hooton, R. D., Thomas, M. D. A., and Stanish, K., Prediction of Chloride Penetration in Concrete, Publication No. FHWA-RD-00-142, Department of Transportation, Federal Highway Administration, McLean, VA, 2001, 419 pp.
2 Tang, L. and Nilsson, L. "Rapid Determination of the Chloride Diffusivity in Concrete by Applying an Electrical Field," ACI Materials Journal, Vol. 89, No. 1, January-February 1992, pp. 49-53.
3. Stanish, K., Hooton, R. D., and Thomas, M. D. A., "A Novel Method for Describing the Chloride Ion Transport Due to an Electrical Gradient in Concrete – Part I: Theoretical Description, and Part II: Experimental Evidence," Cement and Concrete Research, Vol. 43, pp. 43-57, 2004.
4. Tang, L. and Sorensen, H. E., "Evaluation of the Rapid Test Methods for Chloride Diffusion Coefficient of Concrete, Nordtest Project No. 1388-98," SP Report 1998:42, Swedish National Testing and Research Institute, Boras, Sweden, 1998.

Editor's Note

This article is the second in a series that describes tests for use with HPC. The first article appeared in Issue No. 36.

Question

What is the maximum modulus of elasticity that can be achieved with lightweight HPC?

Answer

The modulus of elasticity (MOE) of lightweight high performance concrete (HPC) is affected by numerous variables including concrete compressive strength; concrete density; lightweight aggregate (LWA) type, size, and content; fine aggregate properties; air content; concrete age; and method of curing. To consider each factor in calculating MOE is difficult and impractical. Therefore, a simplified equation is used.

Current Method

The AASHTO Standard and LRFD Specifications provide the following equation for the calculation of MOE, E_c, for concrete densities, w_c, from 90 to 155 lb/cu ft (1.44 to 2.48 Mg/cu m):

$$E_c = 33w_c^{1.5}\sqrt{f'_c} \qquad \text{(Equ. 1)}$$

Using the equation, a designer might believe that MOE values of over 4000 ksi (27.6 GPa) are possible for lightweight HPC having a density of 120 lb/cu ft (1.92 Mg/cu m) and a strength of 10,000 psi (69 MPa).

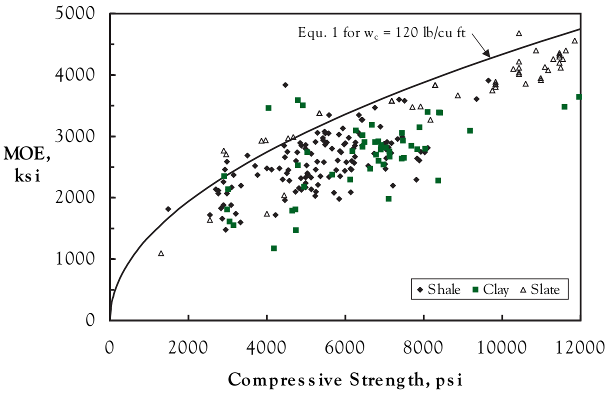
Experimental Results

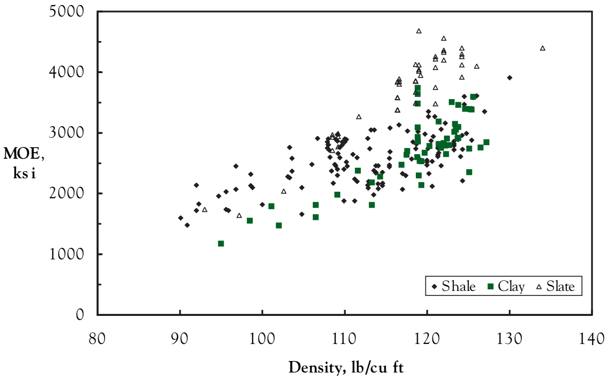
The figures provide a sampling of experimental MOE results for shale, clay, and slate aggregates and indicate that MOE values for lightweight HPC seldom reach the levels suggested by the equation.

The figures show a large variation in MOE for a given strength or density. The figures also show that it is not always possible to identify a particular type of LWA as being superior to another one for MOE values across the spectrum of strengths and densities depicted. This suggests that the use of a generally applicable equation to predict MOE based only on strength and density is not very precise.

The Maximum MOE

The best answer to the original question does not involve an equation. The only guaranteed method is to conduct an experimental study based on the same concrete mixture proportions and constituent materials planned for the project. The study will produce a range of MOE values from which the designer may choose. Local lightweight aggregate suppliers will be able to provide starting points. However, subtle changes in regionally available fine aggregate, as well as the other factors mentioned above, can affect the MOE.





Answer contributed by Karl F. Meyer, United States Military Academy, West Point, NY. He may be contacted at karl.meyer@usma.edu.

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