HPC Bridge Views

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HPC FOR DECKS IN NEVADA

Sohila Bemanian, Nevada Department of Transportation

As a result of the state's fast growth rate, the Nevada Department of Transportation (NDOT) is faced with the largest work program in its history. NDOT will spend $1 billion in the next several years constructing and reconstructing major freeways and urban arterial systems. These projects include major bridges such as the Galena Bridge in northern Nevada, which will be the second longest concrete arch structure in the United States.

Implementation

In 1999, NDOT created a High Performance Concrete (HPC) Task Force consisting of personnel from the Materials, Bridge, and Construction Divisions; the Federal Highway Administration; and an experienced consultant, who provides many concrete mix designs for NDOT. The mission of the HPC Task Force was to develop HPC specifications utilizing local aggregates.

Based on a research study conducted by the University of Nevada-Reno, none of the local aggregates resulted in concrete that met all the HPC requirements suggested by FHWA. Therefore, the HPC Task Force selected permeability and modulus of elasticity as requirements for the northern part of the state and only permeability for the southern part of the state. Modulus of elasticity was included because field values were much lower than values assumed in design. Several mix designs were made to determine how HPC properties could best be achieved utilizing local aggregates. In addition to permeability and modulus of elasticity for the northern part of the state, creep and shrinkage properties were identified as important parameters in the concrete mix design for the Galena Bridge. Preliminary mix designs using these parameters were developed prior to project bidding.

A 10-day wet curing period was added to the specifications and became a mandatory requirement for all bridge decks in order to reduce plastic shrinkage cracking and to make bridge deck curing practices more consistent throughout the state. Continuous fogging is required prior to placement of the burlap. The second addition to the specifications was a maximum rapid chloride permeability requirement of 2000 coulombs at 56 days. Several meetings were organized with contractors to discuss the importance of wet curing and constructing crack free bridge decks. During mandatory pre-bid meetings and pre-placement conferences, the HPC requirements were discussed again.

Life Expectancy

The main objective of HPC is to increase the life of a structure. In a greater sense, the objective is to reduce the life-cycle cost. Any increase in the cost of the material and workmanship used to create the structure is expected to be regained by less maintenance and longer times between rehabilitation and replacement. At this time, we expect a 35 to 50 percent increase in life expectancy of the structures.

Cost

Implementation of the HPC can increase the cost of a concrete bridge deck by 30 percent. The cost of HPC for materials and placement is approximately $415/cu yd ($543/cu m). This is an increase of $100/cu yd ($131/cu m) over traditional concrete costs. The Galena Bridge structure is anticipated to cost about $600/cu yd ($785/cu m) because of additional requirements and very complex falsework. However, this cost increase is insignificant compared to the overall cost of the project and the potential for less frequent rehabilitation in the future. In addition, as contractors become familiar with the process of producing quality HPC, the cost is expected to become more competitive.

Galena Bridge Deck Concrete Specifications – Class EA, Modified (Major, Special)

Minimum Compressive Strength(1)	Minimum Modulus of Elasticity(1)	Maximum Permeability(2)	Maximum Shrinkage(3)	Maximum Specific Creep,(3) Microstrain
4500 psi	3480 ksi	2000 C	0.07%	0.50/psi

(1)At 28 days. (2)At 56 days. (2)After 56 days of drying or loading.

LESSONS LEARNED IN NEW HAMPSHIRE

Mark D. Whittemore and Peter E. Stamnas, New Hampshire Department of Transportation

Ten years ago, New Hampshire (NH) would have been considered an unlikely candidate to become involved in high performance concrete (HPC). NH's subsequent success in the development and refinement of HPC and performance based specifications evolved through a series of three bridges. NH's philosophy was to start simple and work towards more complex projects.

Route 104, Bristol

The first HPC bridge* was a straightforward 65-ft (19.8-m) single span structure. The concrete mix design for the bridge deck was provided in a prescriptive specification. A test placement was required. This gave the contractor and producer the opportunity to refine the mix and placement techniques. The required average concrete strength of 9400 psi (65 MPa) at 28 days for the girders was not as high as other states were targeting, but was still substantially more than NH's typical design value of 5000 psi (35 MPa) at that time. The following lessons were learned on this bridge:

- The decision to start simple proved to be a wise one. Specifying higher concrete strengths would have accentuated the problems experienced in girder production. More testing and trial batching and stricter quality control were necessary.
- The post-bid meeting should be mandatory. Development of the HPC mix for the girders was time consuming; time to develop and test mixes must be considered in the project schedule. Cooperative involvement of all parties became a focus on future HPC projects.
- The air requirement of 5 to 8 percent was a significant reason that the higher girder concrete strengths were difficult to obtain. The percentage of air entrainment for the girders was adjusted down to a target value of 5 percent.
- Match curing for girder concrete was required and found to be very useful.
- The wider girder spacings of 12 ft 6 in. (3.81 m) resulted in the need for special formwork at an estimated increased cost of 75 percent over typical formwork.
- The emphasis placed on the importance of deck curing was very successful in achieving positive results. Eight years later, there are still no visible deck cracks.
- The biodegradable bags used for silica fume did not fully disintegrate in the mixing process. Blended cement with silica fume is the preferred method to include silica fume in the mix.
- Specify only what is needed. Research indicated that target values of 1000 coulombs for permeability could be increased to 1500 coulombs at 56 days.

Route 3A, Bristol

The second bridge* was a 60-ft (18.3-m) long simple span structure completed in 1999. The superstructure consists of precast concrete deck panels with a cast-in-place concrete deck overlay and New England bulb-tee (NEBT) HPC girders. Several new lessons were learned:

- The girder test section and the test deck placement helped placement during production proceed smoothly.
- The revised permeability limits and less stringent air requirements facilitated achieving the required girder strength.
- The match-curing system was very successful.
- The use of the deck panels was a much quicker and less expensive means of forming the deck.

The performance of Route 3A Bridge has been excellent. The only observed deck cracking consists of four short cracks.

Rollinsford Bridge

The third HPC project was a 110-ft (33.5-m) simple span bridge using NEBT girders. This was NH's first project with alkali-silica reactivity (ASR) language in the specification. The addition of slag or Class F fly ash to control ASR introduced several noticeable changes in the mix characteristics.

Current Practice

NH has moved exclusively to a quality control/quality assurance (QC/QA) performance based specification for concrete bridge decks. The specification provides incentives for achieving consistency in results within given target ranges for concrete cover, air content, water-cementitious materials ratio, and permeability. A disincentive is provided for strength.

This specification has undergone numerous changes, most significantly in the permeability limits. With significant pay incentives for permeability, contractors pursued a high content of cementitious materials in the mixes. This practice resulted in substantial positive pay adjustments to the contractors but also much more deck cracking. The correlation between deck cracking and the high cementitious materials concrete convinced the NH Department of Transportation to increase the permeability target from 1500 to 2500 coulombs. The revised permeability specifications and more stringent curing specifications have led to a dramatic decrease in the number of concrete decks exhibiting cracking. The importance of proper curing cannot be overstated. Curing blankets (cotton mats or burlap) need to be on the deck and wet within a maximum of 30 minutes after concrete placement, and are required for a minimum of 7 days.

NH's specifications continue to require girder test sections. Also, match curing of cylinders is now required for all prestressed concrete members. This benefits fabricators who are subsequently able to turn over their casting beds quickly. It provides the owner with the best non-destructive estimate of the actual concrete strength within the girder. Cylinder molds and controllers are expensive: ask only for the number of match-cured cylinders that you need.

The overall HPC philosophy has been incorporated into NH's Standard Specifications and everyday practice. All of NH's concrete decks have been QC/QA since 1999 and use of this performance specification will continue at least into the foreseeable future. Similarly, all concrete girders have used HPC since 2001. The successful construction and excellent performance of these structures have convinced NH of the benefits of HPC.

Editor's Note

This article is the third 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 and 35.

**See HPC Bridge Views, Issue Nos. 4 and 17.*

HPC TESTS — ALKALI-SILICA REACTION

William G. Hime, Wiss, Janney, Elstner Associates, Inc

Alkali-silica reaction (ASR) was discovered by Stanton* in 1940. Since then, and certainly even now, it has been mischaracterized, misdiagnosed, and probably mistested. At the same time, ways to mitigate its effect have been developed.

Contrary to much of the literature, ASR is not a reaction of sodium or potassium (or other alkali metal ions) with a form of silica. Rather, it is the reaction of the hydroxides of those ions (ammonium ion is the exception) with, almost always, microcrystalline silicon dioxide. Only the hydroxides of these ions are soluble enough to produce the pH levels of 13, or more, that are needed to cause the reaction. The silicate that is produced occupies more space than the silica did, causing "map" cracking in the concrete.

The reaction stops when either the hydroxyl ion is sufficiently depleted (by reaction or carbonation to drop the pH below 13), or when the reactive silica particles have been consumed. Completion of the reaction occurs in hours, weeks, or years, depending upon the thickness of the concrete.

It is obvious that the higher the cement content, the more the alkalies in the concrete. It is less obvious that the higher the alkali metal content, the higher the hydroxyl ion content. But when water is added to portland cement, the alkali metal compounds largely produce alkali metal hydroxides. This is usually not true with mineral admixtures or aggregates. The alkali metals in them do not produce hydroxides.

Test Methods

To some extent, there is an easy method of analysis for reactive silica in aggregate: petrographic microscopy. However, even an excellent petrographer may not be able to predict whether or not some forms of silica will be deleteriously reactive, or if they are of sufficient quantity and reactivity to be of concern. Therefore, several tests have been developed to permit better predictions. Unfortunately, these tests may not correctly predict the duration or extent of the deleterious reaction. Certainly, the first step should be the use of ASTM C 295: Petrographic Examination of Aggregates for Concrete. Such a test, by an experienced petrographer, can provide definitive "yes" or "no" answers in most cases, but a "maybe" in others.

ASTM C 289: Potential Alkali-Silica Reactivity of Aggregates (Chemical Method) involves the chemical determination of the potential reactivity of an aggregate with alkalies in portland cement concrete. The test partially duplicates the chemical reaction of the microcrystalline silica in the aggregate, but also counts some silicates that completed their reaction a long time ago as reactive silica. It fails to detect slowly reactive aggregates, doesn't measure expansive forces (or the lack of them), and may produce unreliable results with some carbonate aggregates. Many false positives or negatives have led to decreased usage of this test. Its value is in providing results in two days.

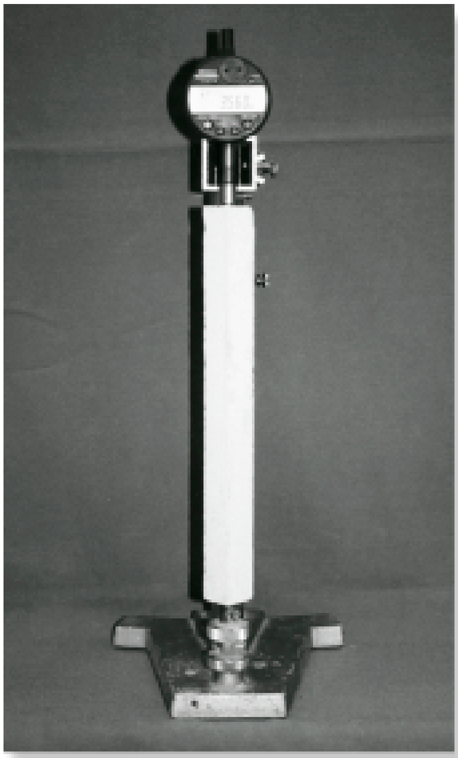
ASTM C 227: Potential Alkali Reactivity of Cement-Aggregate Combinations (Mortar-Bar Method) involves measuring the change in length of mortar bars at an elevated temperature. Disadvantages of the test are that it takes at least 14 days and as long as one year to perform, and usually does not provide information on slowly reactive aggregates. The test is advantageous in that it can mimic actual performance of the cement-aggregate combination, can provide specimens for petrographic examination, and is performed at 100°F (38°C), which may double or triple the rate of reaction of concrete compared to that in normal outdoor exposure.

ASTM C 1260: Potential Alkali Reactivity of Aggregates (Mortar-Bar Method) also uses a mortar bar. The test primarily differs from ASTM C 227 in that it greatly accelerates any ASR reaction by immersing two-day old mortar bars in a sodium hydroxide solution at 176°F (80°C) for 14 days. Thus it may provide the same information in 16 days provided by C 227 after six months or a year. It is a current method of choice of many laboratories; those laboratories generally state that the test is conservative. However, a footnote in the ASTM test procedure warns that some reactive aggregates may go undetected. Furthermore, some false positives have been reported.

ASTM C 1293: Concrete Aggregates by Determination of Length Change of Concrete Due to Alkali-Silica Reaction involves the length change of concrete or mortar prisms made with 3/4 in. (19 mm) maximum size aggregate and with cement. Alkali content is increased by the addition of sodium hydroxide. Since the test involves the preparation of concrete, it may use the suspect fine or coarse aggregate with known unreactive counterparts. Because it measures expansion occurring during exposure at a temperature of only 100°F (38°C), it takes about five times longer than C 1260 to provide the data.

ASTM C 33: Standard Specification for Concrete Aggregates includes an Appendix X1 entitled "Methods for Evaluating Potential for Deleterious Expansion Due to Alkali Reactivity of an Aggregate." It provides a useful discussion of alternative methods.

Finally, optical petrography provides a reliable test to identify ASR in an actual concrete structure but only when performed by an experienced concrete petrographer using the procedures of ASTM C 856: Petrographic Examination of Hardened Concrete.



Measuring the length change of a mortar bar per ASTM C 227 and C 1260.

Stanton, T. E., "Expansion of Concrete Through Reaction Between Cement and Aggregate," Proc. ASCE, Vol. 66, No. 10, Dec. 1940, pp. 1781-1811.

PERFORMANCE BASED DURABILITY SPECIFICATIONS

Véronique Baroghel-Bouny, Laboratoire Central des Ponts et Chaussées (Research Laboratory of Bridges and Roads Administration), France

Nowadays, worldwide efforts are being made to develop durability design approaches in order to ensure a longer life for reinforced concrete (RC) structures at the lowest cost. With the increasing use of complex concrete mixtures incorporating hydraulic and pozzolanic materials, a performance based approach seems particularly relevant for durability issues.

Such an approach(1) has been developed in France within the framework of an AFGC* Working Group. It is based on key material properties called durability indicators (DI), on the specification of appropriate performance based criteria, and on the use of predictive models. The purpose of this approach is to design concrete mixtures capable of protecting RC structures against a given degradation, such as reinforcement corrosion or alkali-silica reactivity (ASR), for a target lifetime in given environmental conditions.

Durability Indicators

The DIs include universal indicators, such as water porosity and chloride diffusion coefficient, which are relevant to many degradation processes, as well as indicators specific to a degradation process such as ASR or freeze-thaw damage. Each DI has a test method that is well defined and produces consistent results. Each DI is classified into five levels of potential durability ranging from very low to very high depending on the laboratory test results. With this classification system, various concrete mixes can be ranked, selected to meet specified criteria, or optimized to satisfy several criteria. When several DIs are used, the durability of a concrete mix can be based on an overall weighted rating.

Performance Based Criteria

Performance criteria for the DIs have been developed for different target service lives and several exposure conditions. These criteria have been based on experimental data obtained on a broad range of concretes and verified using several analytical or numerical models. As the target service life increases and the environment becomes more aggressive, more DIs are specified and the criteria are more stringent. In practice, the suggested criteria can be adapted for specific project conditions depending on local environment, concrete cover, or economics. The criteria are also likely to evolve as further experience is obtained.

Service Life Prediction

With the purpose of predicting the service life of RC structures, several predictive models have been selected for each degradation process.(1) These models, in which the DIs are introduced as input data, have different levels of sophistication and thus address different issues. The most sophisticated models are based on well-identified physical and chemical mechanisms including moisture transport and take into account the microstructural changes induced by the degradation process. But simple engineering models are also proposed. This multi-level modeling approach can be applied at the design stage and during the monitoring of existing structures.

Concluding Remarks

This new approach offers greater freedom to engineers and designers. It takes advantage of all the technical and economical benefits of new concepts of mix design and high-technology materials such as high performance concretes, for which an extended service life can be expected for the structures. This has been confirmed by field performance data already available. Moreover, this approach is being used as a basis for revisions of current French and European documents for test procedures, cement and concrete standards, and design codes.

Further Information

For more information, the author may be contacted at Veronique.Baroghel-Bouny@lcpc.fr.

Reference

1. Baroghel-Bouny, V., et al., "Concrete Design for Structures with Predefined Service Life - Durability Control with Respect to Reinforcement Corrosion and Alkali-Silica Reaction. State-of-the-Art and Guide for the Implementation of a Performance-Type and Predictive Approach Based upon Durability Indicators," (in French), Documents Scientifiques et Techniques de l'Association Française de Génie Civil, AFGC, Paris, July 2004, 252 p.

**French Association of Civil Engineering (http://www.afgc.asso.fr).*

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For further information on High Performance Concrete, contact:

FHWA Headquarters: Jerry L. Potter, 202-366-4596; (fax) 202-366-3077; e-mail: jerry.potter@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: Shri Bhidé, PCA, 847-972-9100; (fax) 847-972-9101; e-mail: sbhide@cement.org;
website: www.nationalconcretebridge.org

Editorial Committee:

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