HPC Bridge Views

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Self-Consolidating Concrete for Caissons in the Stalnaker Run Bridge

Q & A

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HPC Bridge Views—Then and Now

Susan N. Lane, Portland Cement Association and Henry G. Russell, Henry G. Russell, Inc.

Louetta Road Overpass, Houston, TX, Issue No. 1.

Route 22 over Kentucky River, KY, Issue No. 67.

HPC Bridge Views was first published in 1999 as a four- or six- page bimonthly hard copy newsletter and was the first product of an agreement between the Federal Highway Administration (FHWA) and the National Concrete Bridge Council (NCBC). It complemented the FHWA's program to put high performance concrete (HPC) products, developed and evaluated under the Strategic Highway Research Program (SHRP), into the hands of highway agencies and companies.

The initial articles reported on projects that were part of the FHWA national HPC bridge implementation program. Other articles reported on the activities of the AASHTO Lead States Team for HPC implementation. As more states began to use HPC, the scope of the articles increased to cover aspects of HPC that were important for a proper understanding of its application and successful implementation. HPC Bridge Views, therefore, became a valuable tool to disseminate information about the usage of concrete and to introduce new ideas and new technology to the bridge industry. Recent issues have contained articles about FHWA's ongoing programs on lightweight concrete and ultra-high performance concrete (UHPC).

The readership of HPC Bridge Views covers all disciplines of bridge design and construction including owners, designers, contractors, material suppliers, and academics. Consequently, each issue presents a range of topics to interest a broad audience. Authors have also had the same range of backgrounds. As such, HPC Bridge Views provides a cross link between the various disciplines.

With the growth of the internet and subsequent electronic dissemination, the newsletter now has both national and international distribution. In fact, electronic readership has grown 68% since January 2009. Its distribution list includes the following:

- United States federal agencies including the Air Force; Army (and Army Corps of Engineers); Coast Guard; Defense Logistics Agency; Departments of Agriculture, Commerce, Energy, Interior, and Transportation; FHWA; Federal Energy Regulatory Commission; Navy; and the Nuclear Regulatory Commission
- 47 state departments of transportation plus the District of Columbia and Puerto Rico
- City governments in Alexandria (VA), Austin, Chicago, Cincinnati, Honolulu, Los Angeles, New York City, Oklahoma City, Philadelphia, Pittsburgh, Portland (OR), San Jose, Seattle, and West Palm Beach
- Major consulting engineering/architecture firms such as AECOM, Atkins (formerly PBS&J), Berger/ABAM, Buckland & Taylor, CH2M Hill, FIGG, Jacobs, Hardesty & Hanover, HDR, HNTB, Kimley-Horn, Michael Baker, Modjeski & Masters, Parsons Brinckerhoff, Parsons Corp., Stantec, T.Y. Lin, and URS
- 85 U.S. colleges and universities
- 54 U.S. contracting companies (general contractors)
- Concrete industry firms and organizations too numerous to count
- International governments including Belgium, Brazil, Canada, Cuba, Ecuador, England, India, Malaysia, Mauritius, New Zealand, Peru, and Russia
- 32 international colleges and universities

As an example of its value and reputation, articles published in HPC Bridge Views have also been published in whole or in part in the American Concrete Institute's Concrete International, Concrete Producer magazine, Concrete Products magazine, Noticreto magazine (Colombia), Precast/ Prestressed Concrete Institute's PCI Journal, and Singapore's Concrete Technology Today magazine. A compilation of the first 38 issues was published in 2005 to coincide with the Seventh International Symposium on the Utilization of High Strength/High Performance Concrete held in Washington, DC. Copies were distributed to all attendees. HPC Bridge Views is also used frequently by the FHWA and member organizations of NCBC as a hand-out at trade shows and technical meetings.

A former State Bridge Engineer and member of the HPC Bridge Views' Editorial Board wrote: "I have always viewed HPC Bridge Views as a newsletter that reaches designers and materials, maintenance, and construction professionals involved in high performance concrete bridge solutions. The newsletter offers high value for a small investment. . . . This cross cutting approach has even drawn pavement and maintenance engineers to look for innovative new technologies . . . These short articles . . . have a broad readership and bridge professionals at all levels of their careers have a set of resources to gain comfort with new solutions. As information gets dated and new technologies mature, this federal- and industry-funded non-biased resource provides a valuable channel to disseminate the information."

As this newsletter moves forward, we are ready to tackle an expanded scope of concrete bridge longevity, preservation, and innovation. Articles on concrete bridge durability, preservation strategies, new efficient beam shapes, accelerated bridge construction, non-destructive evaluation of bridges, designing for multi-hazard events, new types of reinforcement, how to achieve over 100-year service life, and upcoming materials like UHPC will be featured. It will also change its name to become Concrete Bridge Views. This new name and scope will draw from its roots and extend the concepts of safer and longer-lasting concrete bridges nationwide and even worldwide.

Acknowledgement

The publication of HPC Bridge Views would not have been possible without the many authors who contributed over 250 articles about their concrete bridge projects. To them we extend a special "Thank you."

Note from the Editorial Committee

After this issue, Dr. Henry Russell will be stepping down as Editor of HPC Bridge Views. The Editorial Committee, the Federal

Highway Administration, and the National Concrete Bridge Council would like to thank him for his 12 years of service. Under Dr. Russell's guidance, this publication has aided many bridge professionals nationwide and we are grateful for his dedicated and excellent service.

Self-Consolidating Concrete for Caissons in the Stalnaker Run Bridge

Joseph G. Sweet and Roger H. L. Chen, West Virginia University

Abutment 1 (left) used SCC for its three caissons, while Abutment 2 (right) used a traditional caisson mix.

Self-consolidating concrete (SCC) was used in the construction of three caissons for a rural bridge replacement of the Stalnaker Run Bridge in West Virginia. The project was part of an Innovative Bridge Research and Deployment (IBRD) initiative with support from the Federal Highway Administration (FHWA) and the West Virginia Department of Transportation (WVDOT). The Stalnaker Run Bridge is located on Old Route 219 in Elkins, WV. SCC was used to cast elements of both the substructure and the superstructure of the single-span bridge, with traditional vibrated concrete being used to cast identical elements in the same bridge for purposes of comparison. This bridge was the first construction project for WVDOT that included the use of SCC.

Caisson Dimensions

The caissons for the Stalnaker Run Bridge were designed to consist of 3.5-ft (1.1-m) diameter, 6-ft (1.8-m) deep drilled shafts overlying integral 3-ft (0.9-m) diameter, 12-ft (3.7-m) deep rock sockets. Each abutment is supported by three caissons. The caissons all contained twenty No. 11 longitudinal reinforcing bars that were placed in two-bar bundles, giving a clear spacing of approximately 3.5 in. (90 mm).

Special Provisions for SCC Caissons

At the time of the development of the special provisions for this project, some states had recently adopted guidelines for use of SCC in cast-in-place applications,[1,2,3] even some specifically for drilled shafts using SCC.[4] Furthermore, Brown et al. had reported cast and exhumed drilled shafts using SCC in South Carolina.[5] These precedents, as well as previous laboratory experiences at West Virginia University (WVU) with SCC mix design and testing using WV aggregates,[6] were all used to help develop the desirable characteristics for the drilled shaft SCC. Some of the most important fresh and hardened properties specified for the SCC caissons included:

Spread ASTM C1611	J-Ring Value ASTM C1621	T_{50} ASTM C1611	Air Content ASTM C231	f'_c @ 28 days ASTM C39
21 ± 2 in. (533 ± 50 mm)	≤ 1.5 in. (≤ 38 mm)	2 sec ≤ T_{50} ≤ 7 sec	6% ± 1.5%	4500 psi (31 MPa)

SCC Mix Design

The mix design development for the cast-in-place SCC used in this project involved collaboration between the potential concrete suppliers, admixture representatives, and WVU researchers. The development of the mix included a laboratory casting of a trial caisson section that simulated wet casting conditions as discussed in more detail elsewhere. (7) The mix proportions for the final, approved SCC mix included 750 lb/yd3 (445 kg/m3) of total cementitious materials with 15% Class F fly ash, a water-cementitious materials ratio (w/cm) of 0.38, and a fine aggregate to total aggregate ratio of 0.50. The fresh properties for the mix, as provided by the concrete and admixture suppliers, included a 23-in. (584-mm) spread, a J-ring value of zero, and an air content of 5.5%. It is noted that although blending of more than one type of aggregate was permitted by the project specifications, the final mix design used only No. 67 aggregates for the sake of simplicity, but including an aggregate blend could help optimize the performance.

Caisson Construction

The SCC mix was used to construct the three caissons for Abutment 1 of the bridge. The caissons for the other abutment were made using a traditional vibrated WVDOT Class B Modified mix concrete, which included 634 lb/yd3 (376 kg/m3) of total cementitious materials with 11% Class F fly ash, a w/cm of 0.39, and fine aggregate to total aggregate ratio of 0.41. As anticipated, all six caissons were placed into water-filled holes using tremie placement techniques. The fresh properties were measured for all concrete as delivered by each truck to the site. Both sets of caissons were cast successfully, and they eventually became integral parts of their respective bridge abutments.

No noticeable defects were detected within the cages of any of the six caissons by cross-hole sonic logging (CSL) when tested 5 or more days after casting. With its higher fluidity and better passing ability, SCC has the potential to eliminate or reduce the presence of large voids that may form on the outside of the reinforcement cage. However, no verification of this was done in the field.

Hardened Properties

The compressive strengths (ASTM C39), splitting tensile strengths (ASTM C496), modulus of elasticity values (ASTM C469), and rapid chloride permeability test (RCPT) results (ASTM C1202) for the trial caisson and both types of concrete for the bridge caisson castings are summarized in the table below.

All concrete strengths exceeded the 28-day, specified compressive strength of 4500 psi (31 MPa).

Bridge Construction

In addition to the use of SCC for the three drilled shafts, a second SCC mix was used in the construction of two of the five precast, prestressed concrete box beams that were used to construct the superstructure. The other three box beams were constructed using a traditional vibrated concrete mix. Both the

	Trial Caisson*	Field SCC	Field SCC	Class B Modified	Class B Modified	Class B Modified
Property	SCC	Truck 2	Truck 3	Truck 1	Truck 2	Truck 3
Compressive Strength, psi (MPa)	6390 (44.1) @ 38 days	5400 (37.2) @ 29 days	6610 (45.6) @ 29 days	6050 (41.7) @ 28 days	5400 (37.2) @ 28 days	5960 (44.1) @ 28 days
Modulus of Elasticity, ksi (GPa)	4760 (32.8) @ 38 days	4400 (30.3) @ 29 days		4910 (33.8) @ 28 days	4420 (30.5) @ 28 days	4370 (30.1) @ 28 days
Splitting Tensile Strength, psi (MPa)	517 (3.56) @ 38 days	432 (2.98) @ 29 days		566 (3.90) @ 28 days	494 (3.41) @ 28 days	597 (4.12) @ 28 days
Rapid Chloride Permeability, coulombs	1439 @ 140 days	1906 @ 112 days				

*The trial caisson was cast in the laboratory prior to construction.

SCC and the traditional concrete mixes had compressive strengths that exceeded the specified strength of 8000 psi (55 MPa) at 28 days. All the precast box beams were erected on the Stalnaker Run Bridge on October 5, 2009.

Bridge construction continued through October, and the bridge opened to traffic at the beginning of November 2009. After its completion, WVU researchers installed a solar-powered, long-term monitoring system to continuously record in-situ strain measurements from all the prestressed concrete box beams and the caissons. These include measurements from concrete embedment strain gages as well as foil strain gages mounted directly to the prestressing strands and caisson reinforcement.

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Further Information

Further information about this project is provided in Reference 7 or may be obtained by contacting the second author at roger.chen@mail.wvu.edu or 304-293-9925.

Reinforcement cage being lowered into place.

Reinforcement protruding from the tops of the three SCC caissons after completion.

Q & A

Question: What is the latest definition of high performance concrete for bridges?

Answer: Ever since the term "high performance concrete" (HPC) was introduced into bridge industry terminology, numerous definitions have been created and published.

SHRP Definition

The first definition was developed as part of the first Strategic Highway Research Program (SHRP). It defined HPC by the following three requirements:[1]

1. Maximum water-cementitious materials ratio of 0.35
2. Minimum durability factor of 80% as determined by ASTM C666 Method A
3. Minimum compressive strengths of
   a. 3000 psi (21 MPa) within 4 hours after placement,
   b. 5000 psi (34 MPa) within 24 hours, or
   c. 10,000 psi (69 MPa) within 28 days.

FHWA Definition

In 1996, Goodspeed et al. published a proposed definition for HPC that the Federal Highway Administration (FHWA) developed for bridges.[2] The proposed definition consisted of four strength-related performance characteristics (compressive strength, modulus of elasticity, shrinkage, and creep) and four durability-related performance characteristics (freeze-thaw resistance, scaling resistance, abrasion resistance, and chloride penetration). For each characteristic, a standard test method was listed and various performance grades established. Consequently, the selection of performance characteristics and performance grades became a decision to be made by the owner for the intended application. For example, a precast, prestressed concrete bridge beam could be specified to have a high concrete compressive strength and normal chloride permeability whereas a bridge deck could have a low chloride permeability and normal concrete compressive strength. Both concretes would be HPC but with different requirements.

The intent of the FHWA definition was to stimulate the use of higher quality concrete in highway structures. Based on lessons learned from the FHWA implementation of HPC in bridges, Russell and Ozyildirim proposed that alkali-silica reactivity, sulfate resistance, and workability be added to the performance characteristics.[3] The last characteristic became important because of the introduction of self-consolidating concrete.

ACI Definition

Although not intended specifically for bridges, the American Concrete Institute (ACI) defines HPC as concrete meeting special combinations of performance and uniformity requirements that cannot always be achieved routinely using conventional constituents, and normal mixing, placing, and curing practices.[4] ACI has a separate definition for high strength concrete: concrete that has a specified compressive strength for design of 8000 psi (55 MPa) or greater.

One of the misconceptions that has developed over the years is that HPC is always high strength concrete. Whereas high strength concrete is generally considered as HPC, the reverse is not true. High performance concretes exist that are not high strength concretes but many concretes that are developed to be durable HPCs turn out to have a high compressive strength. A reduction in the water-cementitious materials ratio required to produce a low chloride penetration or high abrasion resistance results in a higher compressive strength even though the higher strength may not be desirable or necessary, such as in bridge decks.

Bridge Specifications

The American Association of State Highway and Transportation Officials (AASHTO) LRFD Bridge Construction Specifications includes two classes of HPC. Class P(HPC) is intended for use in prestressed concrete members with a specified concrete compressive strength greater than 6.0 ksi (41 MPa). Class A(HPC) is intended for use in cast-in-place construction with a specified concrete compressive strength less than or equal to 6.0 ksi (41 MPa) and where performance criteria in addition to concrete compressive strength are specified. Maximum water-cementitious material ratios of 0.40 and 0.45 are specified for Class P(HPC) and Class A(HPC) concretes, respectively. The Commentary to the AASHTO LRFD Bridge Design Specifications includes a Class

P(HPC) concrete intended for use when concrete compressive strengths in excess of 4.0 ksi (28 MPa) are required. A maximum water-cement ratio of 0.49 is specified along with a minimum cement content of 564 lb/yd³ (335 kg/m³). The maximum water-cement ratio is reduced to 0.45 for concrete used in or over salt water.

The Answer

The ACI definition is a qualitative definition that has lasted 12 years and has accommodated new concretes such as self-consolidating concrete and ultra-high performance concrete without change. The FHWA definition is quantitative and needs to be updated with time as new products come along and the technology improves. It is, however, more practical and can be used in performance specifications for bridges, while the ACI definition cannot. The AASHTO Specifications provides a combination of performance and prescriptive criteria.

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4. Russell, H. G., "ACI Defines High-Performance Concrete," Concrete International, Vol. 21, No. 2, February 1999, pp. 56-57.

The answer to this question was provided by Henry G. Russell, Editor of HPC Bridge Views.

Fig. 1. Air drying results

Fig. 2. Air drying versus 7 days burlap curing

Fig. 3. Age at cracking, days, for the restrained shrinkage cracking test
(Green is best performance, red is poorest performance,
and yellow is in between)