HPC Bridge Views

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HPC for the Rigolets Pass Bridge

Ray Mumphrey and Kian Yap, Louisiana Department of Transportation & Development

HPC was used in the girders of two spans of the Rigolets Pass Bridge.

The Rigolets Pass Bridge, with a total length of 5489 ft (1673 m), is part of U.S. 90 between eastern New Orleans and the Gulf Coast towns of Mississippi. The bridge crosses one of two waterways that connect Lake Ponchartrain, LA, with the Gulf of Mexico. The majority of the bridge superstructure consists of two-span continuous units that utilize BT-78 girders over a span length of 131.2 ft (40 m). The main channel crossing consists of a three-span continuous prestressed concrete spliced girder unit with a center span of 254.1 ft (77.5 m). The BT-78 girders used concrete with a specified compressive strength of 7500 psi (52 MPa) with the exception of one two-span continuous unit that used high performance concrete (HPC) with a specified compressive strength of 10,000 psi (69 MPa) at 56 days. The specified compressive strength of the deck concrete was 3400 psi (23 MPa).

HPC with a specified strength of 10,000 psi (69 MPa) was first used in Louisiana in 1999 on the Charenton Canal Bridge, a 365-ft (111.3-m) long structure that featured five lines of AASHTO Type III girders.* At the time of the final design of the Rigolets Pass Bridge project, the HPC specification was not part of the Louisiana Department of Transportation & Development standard specifications. Special provisions were created to supplement the standard specifications.

Special Provisions

The materials specification for the HPC girder concrete was a performance-based specification with the following requirements:

- Silica fume limited to a maximum of 10% by weight of the total cementitious materials (cement, fly ash, and silica fume).
- Fly ash (Class C or Class F) allowed to be used in combination with Type I, II, or III portland cement up to a maximum of 35% by weight of the total cementitious materials.
- An average minimum compressive strength of 10,000 psi (69 MPa) at 56 days.
- A maximum slump of 10 in. (255 mm).
- A maximum permeability (total charge passed) of 2000 coulombs at 56 days in accordance with AASHTO T 277.

In addition, the concrete was required to have a minimum compressive strength of 6670 psi (46 MPa) at strand release and the fabricator had to ensure that concrete did not segregate with the selected concrete mix design and slump. Fly ash was not used in the final approved concrete mix. About 10% by weight of silica fume was used.

The specifications required that the test cylinders for the HPC precast, prestressed concrete girders be match-cured under the same conditions as the corresponding members that they represented. Three cylinders were tested by the contractor at no later than 56 days after casting to determine if the required strength was achieved. Steam curing was done under an enclosure to minimize moisture and heat losses. The initial application of heat began after the concrete had reached its initial set as determined by ASTM C403. During application of steam, the concrete temperature increased at a rate not exceeding 40°F (22°C) per hour until the desired concrete temperature was achieved. The concrete temperature could not exceed 160°F (71°C). Test cylinder results showed that the HPC mix used for these girders achieved a compressive strength of 7500 psi (52 MPa) within a day and exceeded the 10,000 psi (69 MPa) requirement at an age of 28 days.

The fabricator was required to detension the strands before the internal concrete temperature had decreased to 20°F (11°C) less than its maximum temperature to avoid vertical cracking prior to release of the strands. The fabricator was permitted to add heat to maintain the internal concrete temperature within 20°F (11°C) of the maximum temperature. Two recording thermometers showing time-temperature relationships in the concrete were furnished for each 200 ft (61 m) of bed. One thermometer was located at the center of gravity of the top flange and one within 1 in. (25 mm) of the center of gravity of the bottom flange of the girder.

Permeability (total charge passed) of the HPC girder concrete was determined in accordance with AASHTO T 277 and limited to a maximum of 2000 coulombs at 56 days. The permeability samples were cut from 4x8 in. (100x200 mm) cylinders and tested at the Louisiana Transportation Research Center. The HPC test specimens were cured in a similar manner as the girders until the test age of 56 days. Measured permeabilities were less than 200 coulombs at 56 days.

Since the construction of Rigolets Pass Bridge, the HPC specification has been updated. The new 5.5-mile (8.9-km) I-10 Twin Span Bridges crossing Lake Pontchartrain, which are located 5 miles (8.0 km) west of the Rigolets Pass Bridge, utilize HPC for almost the entire bridge structures.

Further Information

For further information about the Rigolets Pass Bridge, please contact the second author at kian.yap@la.gov.

*See HPC Bridge Views, Issue No. 8, March/April 2000.

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Rigolets Pass Bridge—HPC Material Property Studies

John J. Roller, CTLGroup and Robert N. Bruce, Tulane University

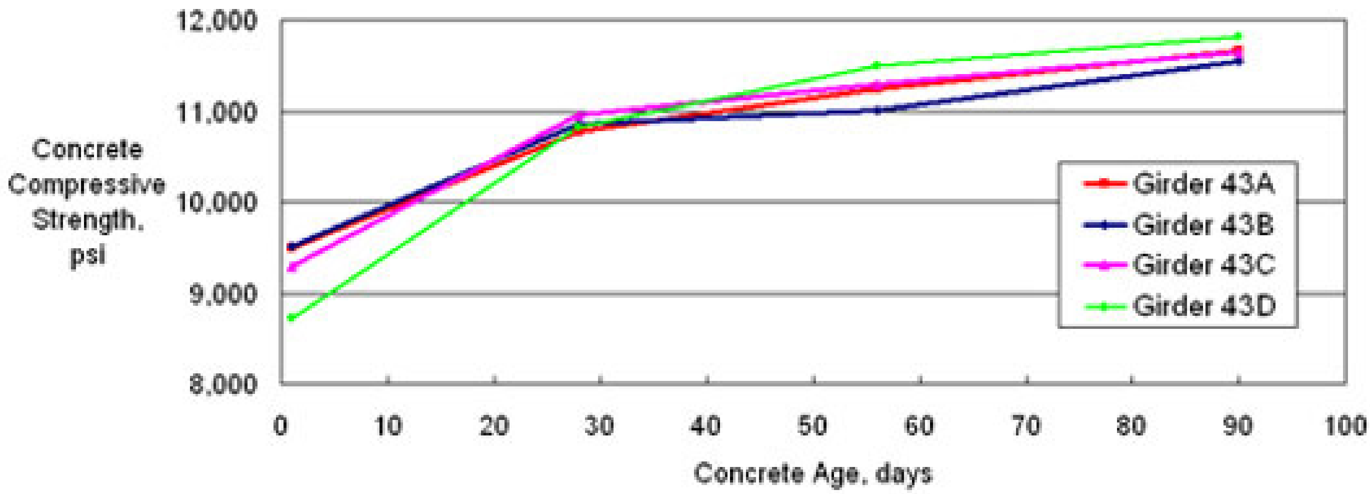


Fig. 1. Average concrete compressive strength versus age.

In conjunction with construction of the Rigolets Pass Bridge, the state initiated a research program with the objective of monitoring the structural behavior of one of the two high performance concrete (HPC) bridge spans (Span 43). Material property studies for four of the HPC girders incorporated in Span 43 (Girders 43A, 43B, 43C, and 43D) were included in the program. The same girders were instrumented with strain gages to measure long-term deformations and with reference points to monitor long-term deflections.

The HPC girders were fabricated by Gulf Coast Pre-Stress (GCP) located in Pass Christian, MS. Material property tests were performed on specimens representing concrete placed in the midspan region of the HPC girders. Concrete cylinders used for compressive strength and modulus of elasticity tests were "match-cured" to match the temperature in the lower flange of each corresponding girder from the time of initial placement until strand release. Other "field-cured" specimens were covered with plastic and stored adjacent to the casting bed. All the match- and field-cured specimens were stripped from the molds just prior to release of the prestressing strands.

Compressive Strength

Concrete compressive strength tests were performed in accordance with ASTM C39 at strand release and at ages of 7, 28, and 90 days. Average measured concrete compressive strength values for the four HPC girders of Span 43 are shown in Fig. 1. Three cylinders for each girder were tested at each test age. As indicated by the data presented in Fig. 1, the concrete used in the four HPC girders exhibited very similar compressive strength values at all test ages.

Concrete modulus of elasticity tests were performed in accordance with ASTM C469 at the same ages as the concrete compressive strengths. Concrete modulus of elasticity versus compressive strength data for the four HPC girders of Span 43 are presented in Fig. 2 for all test ages. The line shown in Fig. 2 represents the relationship between concrete compressive strength and modulus of elasticity given by the $E_c = 33{,}000 K_1 w_c^{1.5} \sqrt{f'_c}$ expression from Article 5.4.2.4 of the AASHTO LRFD Bridge Design Specifications, where K1 is taken as 1.0 and wc is taken as 0.145 kip/ft^3 (2323 kg/m^3). As indicated by the data presented in Fig. 2, the AASHTO LRFD relationship between compressive strength and modulus of elasticity appears to be reasonably consistent with the measured data for the strength levels investigated.

Creep and Shrinkage

Tests to determine creep and shrinkage properties for the girder concrete were performed in

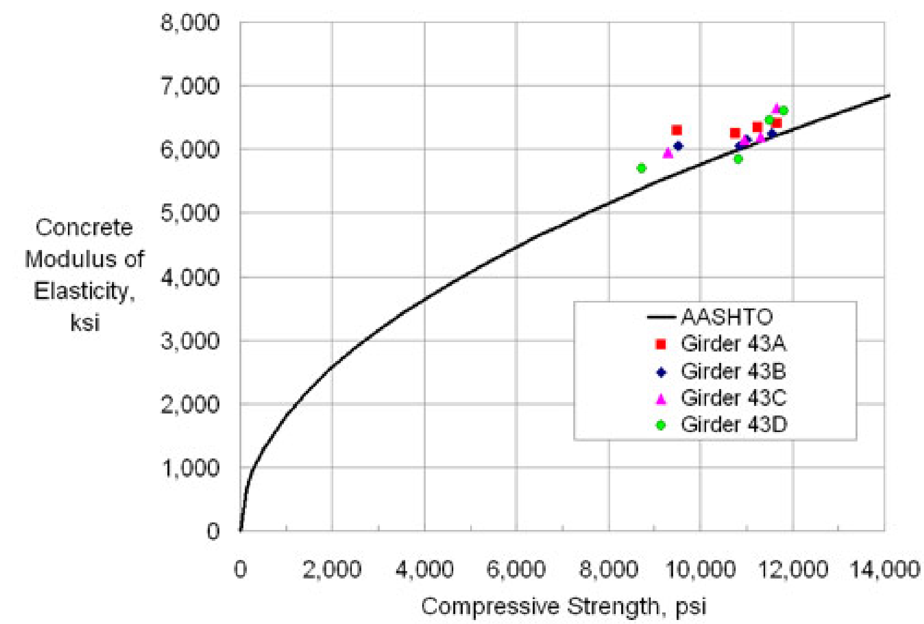


Fig. 2. Concrete modulus of elasticity versus compressive strength.

accordance with ASTM C512 on field-cured 6x12-in. (152x305-mm) cylinders representing concrete placed in the midspan region of one HPC girder (Girder 43D). Creep and shrinkage tests starting at ages of 3 and 100 days were performed under ambient conditions of 73ºF (23ºC) and 50% relative humidity. For both test ages, the target applied load used for creep testing corresponded to 40% of the measured concrete compressive strength at that age. The target applied stresses were 3300 psi (23 MPa) for the 3-day tests and 4880 psi (34 MPa) for the 100-day tests. Measured creep coefficient, defined as the ratio of creep strain to initial strain, and shrinkage data for tests starting at concrete ages of 3 and 100 days are shown in Figs. 3 and 4, respectively.

Corresponding calculated values for tests starting at 3 days determined using provisions from the AASHTO LRFD Bridge Design Specifications are included in Figs. 3 and 4. According to Article 5.4.2.3 of the AASHTO LRFD Bridge Design Specifications, when mix-specific data are not available, estimates of creep and shrinkage may be made using the provisions of Articles 5.4.2.3.2 and 5.4.2.3.3, respectively. Article 5.4.2.3.2 includes an equation for calculating creep coefficient for various ages after initial loading. Article 5.4.2.3.3 includes an equation for calculating shrinkage at various concrete ages.

Based on the data shown in Figs. 3 and 4, it is apparent that the AASHTO LRFD Bridge Design Specifications provisions for estimating creep and shrinkage (when mix-specific data are not available) did not correlate well with the measured data. The final measured creep coefficient value for the 3-day age of loading was approximately twice as great as the corresponding calculated AASHTO LRFD value. The final measured shrinkage value for the tests starting at 3 days was approximately 75% of the corresponding calculated AASHTO LRFD value. Consequently, for the HPC placed in the midspan region of Girder 43D, the provisions of Articles 5.4.2.3.2 and 5.4.2.3.3 of the AASHTO LRFD Bridge Design Specifications underestimated creep coefficient and overestimated shrinkage. As stated in the Commentary to Article 5.4.2.3.1:

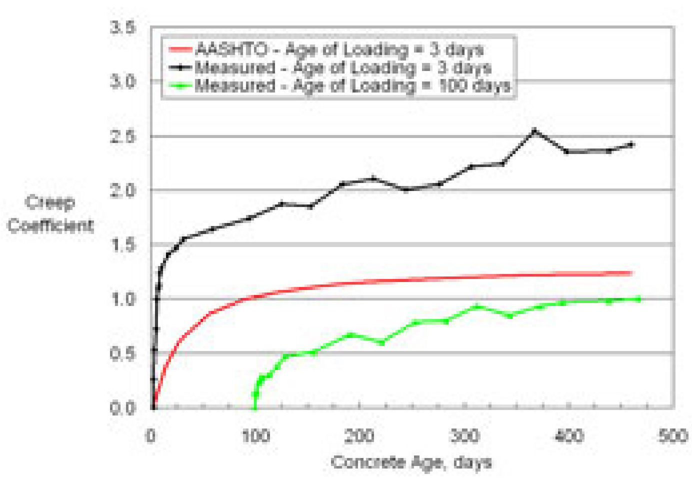


Fig. 3. Creep coefficient versus concrete age.

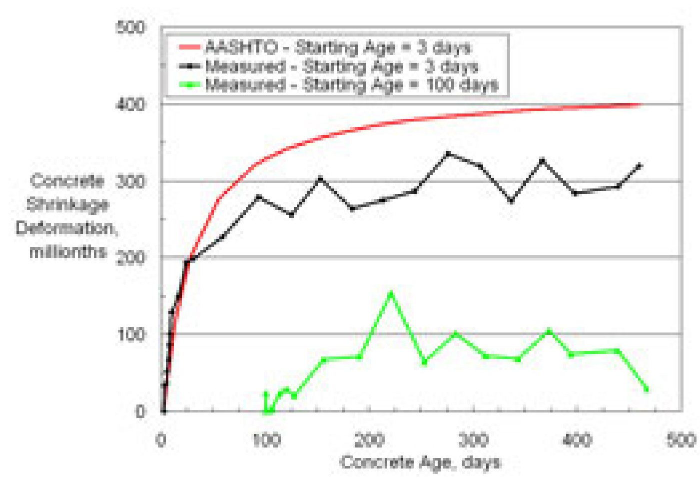


Fig. 4. Shrinkage versus concrete age.

"Without specific physical tests or prior experience with the materials, the use of empirical methods referenced in these Specifications cannot be expected to yield results with errors less than ±50 percent."

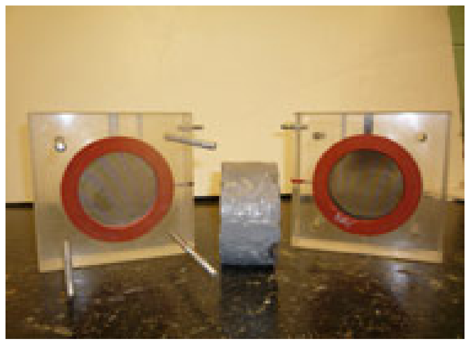
Further Information

Further details from this research program are available in the project report (FHWA/LA/08-437), which can be obtained through the Louisiana Transportation Research Center (LTRC). Work on this project was performed jointly by Tulane University Department of Civil and Environmental Engineering, CTLGroup, and Henry G. Russell, Inc. under the sponsorship of the LTRC and in cooperation with the Louisiana Department of Transportation &

Concrete Permeability Testing – Part 1

D. Stephen Lane, Virginia Transportation Research Council

AASHTO T 259



AASHTO T 277

AASHTO TP 64

For concrete bridges, chloride-induced corrosion of reinforcement has long been the major durability problem and tests developed have attempted to measure, directly or indirectly, the penetrability of chloride ions into concrete. Such tests include the salt ponding methods of AASHTO T 259 and ASTM C1543 and the electrical methods of AASHTO T 277, AASHTO TP 64, and ASTM C1202 for rapid assessment of concrete's resistance to chloride ion penetration. Of these, the electrical resistance tests of AASHTO T 277 and ASTM C1202 have gained the widest use and are often found in specifications for concrete materials when chloride-induced corrosion is a concern. With the advent of service-life prediction models, an emphasis has been placed on methods that measure the more fundamental properties of concrete such as chloride diffusion (ASTM C1556) and water sorptivity (ASTM C1585). This article will describe and discuss the ponding and electrical tests. A future article will focus on the diffusion and sorptivity tests.

Salt Ponding Tests

AASHTO T 259 and ASTM C1543 were designed to simulate the mechanism by which chloride ions penetrate into concrete bridge decks. The test specimens consist of a concrete slab with a minimum thickness and a minimum surface area. A dike is constructed around the top perimeter to hold the ponding solution. The slabs are typically moist cured for a length of time followed by a period of drying at 50% relative humidity before ponding with a 3% sodium chloride solution. AASHTO T 259 calls for 14 days moist curing followed by 28 days of drying, while ASTM C1543 specifies moist curing either until a specified strength is reached or 14 days, followed by 14 days of drying. Prior to ponding, the sides of ASTM C1543 slabs are sealed to prevent evaporation from those surfaces and impose directional control of the chloride penetration. The ponded slabs are stored to allow air circulation around the slabs in a room at 50% relative humidity. A cover is placed over the solution pond to prevent evaporation of water from the solution. AASHTO T 259 calls for a ponding period of 90 days. For low-permeability concretes, this is typically found to be too short for significant penetration of chloride ions into the concrete, and ponding is often extended for longer periods. For this reason, ASTM C1543 allows the user to select the ponding period based on the materials under test, recommending initial sampling at 90 days with subsequent sampling at 6 and 12 months, and 12-month intervals thereafter.

Slabs are sampled by coring or drilling with hollow-stemmed bits to obtain samples for chloride analysis at approximately 0.5-in. (13-mm) incremental depths. The samples are analyzed for total acid-soluble chloride using either AASHTO T 260 or ASTM C1152. Sampling at 0.5-in. (13-mm) depth increments provides a rather gross indication of chloride penetration into the concrete. If a more detailed profile is desired, the slab should be cored and the core carefully milled to obtain samples at increments of 0.04 to 0.08 in. (1 to 2 mm).

Electrical Tests

Because of the length of time needed to directly measure the chloride penetration into concrete with ponding tests, Whiting developed what has come to be known as the rapid chloride permeability test (RCPT).(1) This test is standardized as AASHTO T 277 (ASTM C1202). The electrical charge in coulombs passed through a water-saturated concrete specimen over a 6-hour period is measured. The 4-in. (100-mm) diameter, 2-in. (50-mm) thick specimens are placed between two cells, one containing a sodium hydroxide solution, the other a sodium chloride solution. Each cell contains an electrode and an electrical potential of 60V DC is imposed across the electrodes. The method simulates diffusion flow accelerated by the driving force of the electrical potential as opposed to a concentration gradient and it correlates fairly well with concentration-induced chloride diffusion.(2) This has led to its use as a specification tool for controlling concrete quality by a number of agencies. An example of performance limits based on the RCPT is given in the table.

AASHTO TP 64, the rapid migration test (RMT), operates under the same principle as the RCPT, but is designed to actually drive chloride ions into the concrete specimen so their depth of penetration can be measured. Test specimens have the same dimensions as used for the RCPT. The test apparatus is fairly simple. The concrete specimen is sealed in a neoprene sleeve and placed on plastic strips resting on the electrode immersed in sodium chloride solution in a tub. The second electrode is placed in the sleeve with the sodium hydroxide solution. The potential across the specimen is set based on its conductivity and then maintained for the 18-hour period. Alternatively, the RCPT apparatus can be used. Major differences between the RMT and the RCPT are that a higher (10% versus 3%) concentration sodium chloride solution is used in the RMT; the voltage across the electrodes is adjusted to one of three levels based on the conductivity of the specimen and decreases with increasing conductivity; and the test duration is 18 hours rather than 6 hours. Following the test, the specimen is split and silver nitrate solution is sprayed on the surface to determine the depth of chloride penetration. The test results are also reported to correlate well with long-term ponding tests.(3)

Virginia DOT Criteria for Low-Permeability Concretes using AASHTO T 277

Concrete Class	Maximum Valut at 28 days, coulombs
Prestressed and other special designs (e.g., low-permeability overlays)	1500
Posts & rails	2500
Paving	3500

References

1. Whiting, D., "Rapid Determination of the Chloride Permeability of Concrete," FHWA RD-81-119, Federal Highway Administration, Washington, DC, 1981, 173 pp.
2. McGrath, P. F. and Hooton, R. D., "Re-evaluation of the AASHTO T259 90-Day Ponding Test," Cement and Concrete Research, Vol. 29, 1999, pp. 239-248.
3. Hooton, R. D., Thomas, M. D. A., and Stanish, K., "Prediction of Chloride Penetration in Concrete," FHWA-RD-00-142, Federal Highway Administration, Washington, DC, 2001, 412 pp.

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Ultra-high performance concrete was used in beams of the Jakway Park Bridge.

Q & A

Question: Issue No. 57 of HPC Bridge Views included an article about ultra-high performance concrete (UHPC) in Iowa. How were the beams cured for the Jakway Park Bridge in Buchanan County?

Answer: The pi-girders in the Jakway Park Bridge were made with a particular type of ultra-high performance concrete (UHPC) known as Ductal®. This is also sometimes known as reactive powder concrete. The beams were cured in two stages.

The first stage involved curing at ambient temperatures, although steam curing up to 115ºF (46ºC) would be allowed in a similar manner to curing precast, prestressed concrete beams. The pi-girders were covered with insulating tarps and kept at ambient temperature until match-cured cylinders indicated a compressive strength of 5100 psi (35 MPa). Then the forms were released but left in place. Curing at ambient temperatures continued until the compressive strength of match-cured cylinders attained 14,500 psi (100 MPa). At that point, the forms were removed and the strands were detensioned.

The second stage of curing then began with thermal treatment applied to the UHPC beams with moisture present. The goal was to have a thermal treatment of approximately 190ºF (88ºC) applied along with relative humidity of at least 95% for at least 48 hours. Thermal treatments have been shown to enhance not only the strength of the member but the durability as well. The beams were wrapped with insulating tarps and steam was released underneath the girders. The temperature was increased gradually over a period of approximately six hours. Once the second curing period was completed, the curing temperature was decreased gradually over a period of approximately six hours.

Measured compressive strengths for one set of beams were 5400 psi (37 MPa) at 28 hours, 14,900 psi (103 MPa) at 50 hours, and 32,400 psi (223 MPa) after the second stage curing. For more information on the curing and material properties of this type of UHPC, see the Federal Highway Administration Report "Material Property Characterization of Ultra-High Performance Concrete," Report No. FHWA-HRT-06-103 and Michigan Technological University's Report for Michigan DOT "Ultra-High Performance Concrete for Michigan Bridges, Material Performance-Phase 1," Report No. MDOT RC-1525.

The answer to this question was originally published in the May 2009 issue of Bridges – an E-newsletter published by the Portland Cement Association.