Bridge Views

Issue 62 July/August 2010

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HPC for the Angeles Crest Bridge 1

Jose Higareda, California Department of Transportation

Three different high performance concretes were used in the bridge.

The Angeles Crest Bridge 1 is located along scenic Route 2 northwest of the city of Los Angeles within the Angeles National Forest, California. The 208-ft (63.4-m) long single span, precast, prestressed concrete, spliced bulb-tee girder bridge was used to span over an area that was washed out during the spring thaws of 2006 and 2007.

The cross section of the bridge consists of six 96-in. (2.45-m) deep girders spaced at 77 in. (1.96 m) centers and a 7.7-in. (195-mm) thick cast-in-place concrete deck for a total width of about 42 ft (13 m). The girders were shipped to the site in lengths of 56, 92, and 56 ft (17, 28, and 17 m). Two 2-ft (0.7-m) long closures produced a total girder length of 208 ft (63.4 m). The girders were spliced together on the ground in a staging area near the bridge location and then moved onto the abutments. The individual girder segments were pretensioned for transportation and then post-tensioned in two stages. The first post-tensioning stage occurred in the staging area after the closures had achieved the required strengths. The second stage took place after the girders had been moved onto the abutments. Intermediate and end diaphragms were then cast, followed by placement of the concrete deck.

Precast Girder Concrete

The specified concrete compressive strength for the precast bulb-tee girders was 8500 psi (59 MPa) at 56 days. Because the bridge is located at an elevation of 6500 ft (1981 m) above sea level in a freeze-thaw environment, there was an additional requirement for 4.5 to 7.5% air entrainment. Air entrainment can reduce the strength of concrete by as much as 5% for each 1% increase in air content. This meant working with a concrete mix that, without air entrainment, would achieve a strength of about 12,000 psi (83 MPa). The measured compressive strength of the air-entrained concrete was 8750 psi (60.3 MPa) at 28 days. The concrete mix proportions are provided at the end of this article.

Closure Concrete

The concrete strength requirement for the closures was high as well. The design required a compressive strength of 8000 psi (55 MPa) at 56 days with 4.5 to 7.5% air entrainment. The strength requirement was lower at the splice locations because they are located away from the midspan of the girder and have lower flexural stresses. The strength for the splice concrete could have been reduced further if the splices had been moved even further away from midspan. However, the middle segment length of 92 ft (28 m) was already considered a difficult length to ship given the very sharp turns in the highways leading into the Angeles National Forest.

Batching, placing, and curing the splice concrete in the field, away from a controlled environment such as the precasting yard, proved to be challenging. Caltrans worked with the general contractor to establish a special batching process at the jobsite. The contractor used a consultant to develop the mix, prepare mixing procedures, and perform trial batches. The mix was designed to have a water-cementitious materials ratio of 0.32. The volume of concrete required for the splice placements was relatively small. For this concrete only, it was economically feasible to import special, high quality coarse and fine aggregates. Batch-mixer trucks properly equipped for performing volumetric proportioning were used to produce the required concrete on site. The measured compressive strength of the closure concrete was 8080 psi (55.7 MPa) at 7 days. The concrete mix proportions are provided at the end of this article.

Deck Concrete

The 7.7-in. (195-mm) thick, cast-in-place concrete deck had a specified compressive strength of 5000 psi (34 MPa), an air entrainment of 4.5 to 7.5%, and a drying shrinkage not to exceed 0.035% after 7 days of moist curing and 56 days of drying. The mix for this concrete was produced at a batch plant where a hydration stabilizer was added to accommodate a 75 minute haul time. Though a shrinkage-reducing admixture was used, the drying shrinkage requirement proved to be too stringent for use with local aggregates. The mix, however, did meet the Structural Engineers Association of California (SEAOC) specification limit for Class M concrete of 0.036% after 21 days of drying and was accepted. The concrete deck was cast in winter and the contractor placed insulated blankets on the deck and wrapped the deck and girders with polyethylene sheets. Heaters were placed between the girders to keep the deck concrete warm during the initial days of curing. The measured compressive strength of the concrete was 5190 psi (35.8 MPa) at 42 days. The Area Bridge Maintenance Engineer reported during a summer inspection: "You appear to have been successful in mitigating the cracking as the only cracks I could find were some hairline cracks at the westerly end."

Concrete Mix Proportions

Materials	Precast Girders	Girder Closure	Deck
Cement, lb	893	890	652
Metakaolin, lb	-	50	-
Fly Ash, Class F, lb	-	-	115
Fine Aggregate, lb	1292	1145	1099
Coarse Aggregate, lb	1600	1650	1640
Water, lb	200	300	265
High-Range Water Reducing Admixture, fl oz	63	105	18
Water-Reducing Admixture, fl oz	-	36	-
Water-Reducing/Retarding Admixture, fl oz	-	-	15
Shrinkage-Reducing Admixture, fl oz	-	-	123
Hydration Stabilizer, fl oz	-	-	23
Air-Entraining Admixture, fl oz	37	30	8.5
Water-Cementitious Materials Ratio	0.22	0.32	0.35

All quantities are per yd^3.

Further Information

For further information about this bridge, see ASPIRE™ Spring 2010.

The new bridges were constructed entirely of high performance concrete.

HPC for the I-10 Bridges in Louisiana

John Horn, Volkert Construction Services

In August 2005, Hurricane Katrina decimated the Gulf Coast and nearly destroyed the 5.5-mile (8.9-km) long twin-span, I-10 bridges that connect South Mississippi with New Orleans across Lake Pontchartrain. The existing structures were quickly repaired under an emergency project but were not expected to last more than 5 to 10 years. As a result, the Louisiana Department of Transportation and Development (LADOTD) designed a near "Hurricane Proof" replacement structure. It incorporates foundations capable of withstanding tremendous wave impact, heavily reinforced concrete restraining walls that allow expansion and contraction but prevent uplift and lateral shifting, and high performance concrete (HPC) to ensure the longevity of the structure. The parameters for the new structure required a 100-year service life. In order to provide the necessary service life in Lake Pontchartrain's moderately aggressive environment, the designers had to all but eliminate salt intrusion into the concrete. HPC was chosen for its extremely low permeability and long-term durability. In addition, concrete cover to the uncoated reinforcement was specified as 4 in. (100 mm) for the footings; 3 in. (75 mm) for the piles, piers, and pier caps; 1.5 in (40 mm) for the girders; 1 in. (25 mm) for the bottom steel of the deck with galvanized metal deck pans; and 2-3/8 in. (60 mm) for the top steel in the deck.

High Performance Concrete

The HPC mixes specified for this project are considered structural class concrete per the LADOTD Standard Specifications for Roads and Bridges. The contractor was required to use fly ash or ground granulated blast-furnace slag (GGBFS) in the concrete mixes when using Type II portland cement. This required either fly ash at a content of 20 to 30% or GGBFS at a content of 30 to 50% by weight of the total cementitious materials. Only Class F fly ash or Grade 100 or 120 GGBFS slag was allowed. In addition to fly ash or GGBFS, the cementitious materials used for all structural concrete mixes required 5 to 10% silica fume by weight of the total cementitious materials. Table 1 gives the target parameters for the HPC utilized on the project.

Construction

The project budget was established at approximately $800 million with two separate construction contracts executed. One contract for approximately 4-1/2

Table 1. Concrete Mix Parameters

Bridge Component	Compressive Strength at 28 days,[1] psi	Minimum Cementitious Materials, lb/yd^3	Maximum Water-Cementitious Materials Ratio	Slump, in.
Deck	4400	600	0.40	2 to 4 [2]
Girders	8500	700	0.35	2 to 10
Substructure	4400	550	0.40	2 to 4 [2]
Piles	6000	700	0.35	3 to 5[2]

All concrete was required to have a total air content of 5±1% and a maximum permeability of 1000 coulombs at 28 days.

1. Or at 56 days, per the project specification.

miles (7.2 km) of the twin structures was won by Boh Brothers Construction and the other for the 1-mile (1.6-km) sections crossing the channel was won by Traylor, Kiewit, and Massman (TKM), a Joint Venture. Piles were precast by Gulf Coast Pre-Stress and Prestress Services Industries. The girders were cast by Gulf Coast Pre-Stress, Prestress Services Industries, and Boykin Brothers.

The project included 433,500 linear ft (132,100 m) of 36-in. (915-mm) square precast, prestressed concrete piles, 496 concrete pile caps, 32 concrete piers, 29,500 linear ft (9000 m) of AASHTO Type III girders, 317,500 linear ft (96,800 m) of BT-78 girders, and 3,770,000 ft^2 (350,000 m^2) of concrete bridge deck. The pile caps were precast for the BT-78 spans on the low-level portion. All other nonprestressed concrete was cast in place.

Acceptance of concrete both at the precasting plants and at the project site was based on initial slump, initial air content, compressive strength, and permeability at 56 days with compressive strength and permeability being the primary indicators of the quality of the final product. Compressive strength tests were run on every structural concrete placement and at 200 yd^3 (153 m^3) intervals on large placements. Permeability tests were scheduled so that each span would have separate results representing the piles, bent cap, girders, and deck. Table 2 shows the results of the compressive strength and permeability testing performed to date.

Currently, the TKM contract has been completed and the Boh contract is about 85% complete. Compressive strength results have been very consistent throughout the projects resulting in only one concrete penalty to date. Permeability test values have been extremely low and have resulted in no penalties to date. The mixes have performed very well in the field with only minor issues associated with delivery times up to 2 hours. Portions of the project required mixes to be delivered by mixer truck to a barge mounted agitator and barge-mounted pump truck. These issues were overcome by using water-reducing and set-retarding admixtures. Workability has been very good and rapid strength gain has helped move these massive projects along well ahead of schedule. It is expected that all work on the new structures will be completed by the end of 2011. The new twin-span bridges constructed entirely of high performance concrete will stand well into the next century as a symbol of New Orleans recovery from one of the worst natural disasters in history.

Further Information

For more information about this project, contact the author at jhorn@volkert.com or 251-591-3121.

The adoption of this recommended practice is a big step in designing concrete mixtures resistant to ASR. A commentary section will be presented for adoption at the AASHTO Sub-

Table 2. Concrete Test Results

Bridge Component	Average Compressive Strength, psi	Average Permeability, coulombs
Deck	7100	350
Girders	9000-10,000[1]	240
Substructure	6900	230
Piles	8000-9000[1]	260

1. At 14 days

AASHTO Adopts Recommended Practice on Alkali-Silica Reactivity

Gina Ahlstrom, Federal Highway Administration

In August 2008, a task group was formed under the American Association of State Highway and Transportation Officials (AASHTO) Subcommittee on Materials to review current specifications pertaining to alkali-silica reactivity (ASR). The task group was asked to review existing specifications related to ASR and determine if they were appropriate and adequately addressed the subject. The task group found that the AASHTO ASR Lead States Team, which existed from 1995 to 2000, developed a specification for designing ASR-resistant concrete. However, the specification at that time was never adopted. The task group determined that the lack of an existing specification and the increase in the body of knowledge due to research related to designing concrete mixtures resistant to ASR warranted a new specification.

Recommended Practice

The task group reviewed the Federal Highway Administration (FHWA) publication titled "Report on Determining the Reactivity of Concrete Aggregates and Selecting Appropriate Measures for Preventing Deleterious Expansion in New Concrete Construction."[1] Based on the review, the task group determined that the current AASHTO specifications for materials did not fully address the prevention of ASR. The FHWA report outlines the testing required and two approaches to preventing ASR. Both a performance-based and a prescriptive-based approach are presented to allow users to determine the best method for designing a concrete mixture resistant to ASR.

A document titled "Recommended Practice for Determining the Reactivity of Concrete Aggregates and Selecting Appropriate Measures for Preventing Deleterious Expansion in New Concrete Construction" was developed for AASHTO and incorporated the concepts and technical information from the FHWA report. The recommended practice was presented to AASHTO at the August 2009 meeting of the Subcommittee on Materials. Late last year, it was balloted and approved. It will be included in the 2010 publication of AASHTO's "Standard Specifications for Transportation Materials and Methods of Sampling and Testing."

The recommended practice outlines tests to determine the reactivity of aggregates. A process to evaluate performance history, petrographic examination, concrete prism test (ASTM C1293),[2] and accelerated detection test (AASHTO T 303)[3] is presented. Information is also provided on determining the potential for alkali-carbonate reaction (ACR). The sequence of tests is shown in the flow chart at the end of this article. Agencies are encouraged to develop their own testing plan based on the recommended practice, prior experience with ASR, and the acceptable level of risk the agency is willing to accept for ASR in new construction.

Performance-Based Approach

The performance-based approach provides guidelines on test limits for the concrete prism test (ASTM C1293)[2] and the accelerated mortar bar test for evaluating supplementary cementitious materials (SCMs) or blended cements (ASTM C1567).[4] Specifiers should note that ASTM C1567 and AASHTO T 303 have a duration of 16 days, whereas, ASTM C1293 may take up to 2 years. There is, however, general agreement in the research community that ASTM C1293 is more accurate. Guidance is also provided on modifying the detection test (AASHTO T 303)[3] to determine the dosage of lithium nitrate necessary to suppress ASR for a mixture with a specific aggregate. The appendix of the recommended practice includes a worked example for calculating lithium nitrate additions.

Prescriptive-Based Approach

The prescriptive-based approach prevents ASR in new construction by considering the class, size, and exposure condition of the structure, degree of aggregate reactivity, and the level of alkalis from the portland cement. The specifier uses a series of tables to determine the appropriate preventative measures for a concrete mixture. Using the prescriptive approach, ASR prevention can be achieved by limiting the alkali content of the concrete and/or using supplementary cementitious materials or blended cements. A worked example is provided for determining the appropriate preventative measures using the prescriptive approach.

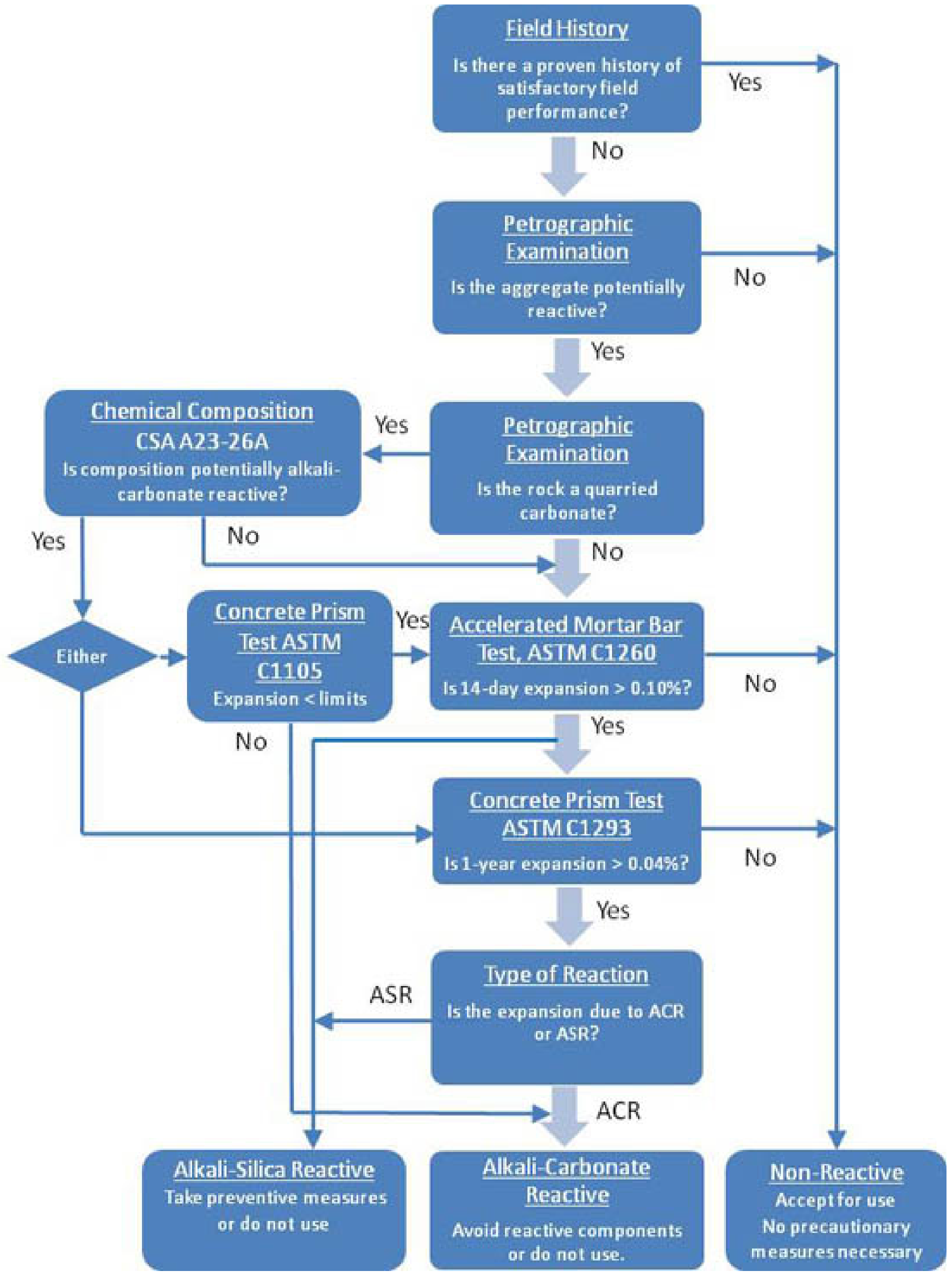
committee of Materials Meeting in August 2010. It is anticipated that the recommended practice will be updated as additional research is completed and new information on test methods and designing concrete free of ASR becomes available.

Further Information

If you would like further information on the recommended practice to prevent ASR in new construction, contact Gina Ahlstrom at gina.ahlstrom@dot.gov.

References

1. Thomas, M. D. A., Fournier, B., and Folliard, K. J., "Report on Determining the Reactivity of Concrete Aggregates and Selecting Appropriate Measures for Preventing Deleterious Expansion in New Concrete Construction," FHWA, U.S. Department of Transportation, Report No. FHWA-HIF-09-001, 2008, 20 pp.
2. Standard Test Method for Determination of Length Change of Concrete Due to Alkali-Silica Reaction, ASTM C1293, ASTM International, West Conshohocken, PA.
3. Standard Method of Test for Accelerated Detection of Potentially Deleterious Expansion of Mortar Bars Due to Alkali-Silica Reaction, AASHTO T 303, American Association of State Highway and Transportation Officials, Washington, DC.
4. Standard Test Method for Determining the Potential Alkali-Silica Reactivity of Combinations of Cementitious Materials and Aggregate (Accelerated Mortar-Bar Method), ASTM C1567, ASTM International, West Conshohocken, PA.



Sequence of laboratory tests for evaluating aggregate reactivity

(articles continue on next page)

Shipping a high strength concrete beam.

Q & A

Question: If the concrete in my precast, prestressed concrete bridge beams has achieved the specified compressive strength before the specified age, is there any reason not to transport and erect them?

Answer: For prestressed concrete bridge beams, the Engineer specifies a minimum concrete strength at time of prestressing force transfer. This is generally assumed to be a percentage of the 28-day strength specified by the owner. The Engineer may also specify a minimum concrete strength or concrete age at time of shipping or erection. For most precast, prestressed concrete beams, the specified strength at time of transfer controls the concrete mix proportions. Concrete strengths at 28 days or later are often in excess of the specified 28-day strength. It is, therefore, not unusual for the specified strength to be achieved before the specified age especially when the specifications require the beams to be at least 90 days old before placing the concrete deck and establishing continuity for live load. If continuity is established before 90 days, different design provisions are applicable.

Unless the project specifications specifically prohibit shipping before a certain age, the following should be considered in making a decision about shipment.

Camber. Camber in prestressed concrete beams begins when the prestressing force is transferred and continues at a decreasing rate until additional load is applied. A beam shipped and erected at an earlier age has less camber than the same beam shipped at a later age. Consequently, if the deck is cast at an earlier age, the depth of haunch above the beams has to be greater to maintain the specified deck thickness and achieve the riding surface profile. This effect is more critical with longer span beams.

Cracking. For design purposes, the flexural tensile strength of concrete is assumed to be proportional to the square root of the concrete compressive strength. In reality, the gain of tensile strength depends on many factors. If the tensile strength gain is relatively slower than the compressive strength gain, the beams are more susceptible to cracking if shipped earlier. Owners may wish to specify that the modulus of rupture of the concrete be measured in accordance with AASHTO T 97 (ASTM C78) with a requirement that the modulus of rupture exceeds either 550 psi (3.8 MPa) or $7.5\sqrt{f'_c}$ psi ($0.62\sqrt{f'_c}$ MPa) for normal weight concrete, where f'_c is the specified concrete compressive strength at 28 days. For sand-lightweight concrete and all-lightweight concrete, the modulus of rupture should exceed $6.4\sqrt{f'_c}$ and $5.6\sqrt{f'_c}$ psi ($0.53\sqrt{f'_c}$ and $0.47\sqrt{f'_c}$ MPA), respectively.

Curing. Some owners have specific curing practices for certain concrete mix designs to ensure adequate hydration of the cementitious materials. The resistance of concrete to chloride penetration does not develop at the same rate as concrete strength. High performance concrete mixes with supplementary cementitious materials may, therefore, require extended wet curing to provide a low permeability concrete prior to installation. An example would be piles intended to be placed in seawater.

Summary. Clearly, the more conservative approach is to wait until the specified age before shipping. Exceptions can, however, be made but need to be addressed on an individual basis as there may be factors other than compressive strength to consider.

Editor

Letter to the Editor

The following letter was received concerning the article titled "Measurement of Air Content in Concrete," which was published in HPC Bridge Views, Issue No. 61, May/June 2010.

Editor

The article describes various methods for measuring the air content of concrete. I think we do a disservice when including the Chace Air Indicator in any discussion of test methods. The very title of the apparatus, "Air Indicator," removes it from the category of test methods. The small sample is a concern. If there is a suspicion that the air content is out of specification, a more accurate method would need to be used prior to acceptance/rejection. I have had experience with concrete being rejected on the basis of results from the Chace Air Indicator and it is very difficult to absorb the financial loss when the concrete may well be within specification.

I would encourage the mandatory use of the gravimetric method in conjunction with the pressure or volumetric methods especially on critical placements. There have been enough instances of false readings in high performance concretes (especially on the high end) that would have been caught by gravimetric testing prior to placement. The mechanics are simple and the results are valuable. And gravity seems to be fairly consistent.

Thomas H. Adams, Executive Director

American Coal Ash Association

Editor's Response

The Chace Air Indicator is an AASHTO standard method of test. Rather than ignore it, we included it but then pointed out its limitations and that it should not be used for determining compliance with the specifications.