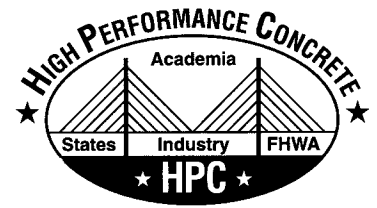




Bridge Views



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Issue No. 40

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120-YEAR BRIDGE SERVICE LIFE, IS IT POSSIBLE?

Tarif M. Jaber, Jaber Engineering Consulting, Inc. and Frank J. Nelson, Oregon Department of Transportation

Imagine designing bridges with an expected service life of 100 to 120 years. That is what the Oregon Department of Transportation (ORDOT) is considering as it looks towards the future. Those who plan, design, and build bridges and highways think of 40, 50, or maybe 75 years for the expected service life of structures. But why not consider longer time frames?

Investing in the Future

ORDOT is undertaking a bold investment in their future highway infrastructure. Using a time horizon of 100 plus years, a design must pass two tests – it must be economically justifiable and technically feasible. Building a bridge for 40 years and then coming back and building a second bridge for another 40 years, and a third bridge for 40 years, involves the cost of building that bridge three times, interruption in service, public safety, and the maintenance costs. Therefore, it makes good engineering and financial sense to build the bridge one time for a life of 120 years, by investing the money up front.

Durability

The key technical challenges to extending the life of bridges are corrosion resistance, freeze-thaw durability, and surface abrasion. Most of Oregon's highways have two-lane bridges, and the climate requires extensive use of ice melting chemicals. In addition, ORDOT highways receive significant studded tire traffic during the snow season.

Silica fume concrete was found to have the best resistance to abrasion. It also offers reduced concrete permeability and improved corrosion protection for reinforcement. ORDOT believes, based on the number of bridges that they have built and the comfort level that the contractors have working with silica fume concrete, that there is no real additional cost in adding silica fume to the concrete. In fact, all ORDOT bridge deck concretes have silica

fume at 3 to 4 percent of the total cementitious materials. For bridges near the ocean, silica fume is used in the concrete of all bridge components.

Corrosion Protection

ORDOT decided to look at an engineered approach for corrosion protection and to face the corrosion problem head-on. Two alternative approaches are used:

- Completely mitigate the corrosion issue by using non-corrosive steel reinforcement and a very low permeability concrete
- Use regular uncoated reinforcing steel and introduce a cathodic protection system when corrosion starts

For complete mitigation of corrosion, ORDOT uses silica fume concrete to reduce chloride penetration and solid stainless steel reinforcement to prevent corrosion. Corrosion takes place at the steel. With one mat of stainless steel at the top and one at the bottom of the deck, the stainless steel reinforcement will not corrode, even if the concrete becomes contaminated with chlorides. For bridges near the ocean, stainless steel is used in both the deck and the concrete girders. For bridges further inland, stainless steel is used only in the decks.

The cost of using stainless steel reinforcement in bridges ranges from 10 to 15 percent of the total cost of the bridge depending on whether the steel is used in the girders as well as the deck. But that cost yields a major jump from a 40-year service life of the bridge all the way to 120 years and beyond because stainless steel is never going to corrode, regardless of how much chloride is in the concrete.

ORDOT's priority is return on investment, public safety, and reduced maintenance. It realizes the need to invest more money up front to get a longer service life. The combination of silica fume and stainless steel reinforcing bars gives tremendous long-term economic advantage.

GALVESTON BAY BRIDGES

Kevin Pruski, Texas Department of Transportation

In June 2003, the Texas Department of Transportation (TxDOT) awarded a contract to replace two parallel structures connecting Galveston Island with the Texas mainland. The northbound bridge built in 1938 and the southbound bridge built in 1959 are being replaced because of deterioration from chloride-induced corrosion.

The new bridges include precast, prestressed concrete beams in the approach spans and a cast-in-place concrete segmental box girder with a main span of 350 ft (107 m). The designers used generous structural proportioning, increased concrete cover to the reinforcement, and high performance concrete (HPC) as primary tools to achieve the goal of a 100-year service life for the new causeway. TxDOT specified the use of supplementary cementitious materials (SCM) to create durable concrete for the project. TxDOT also specified lowering the water-cementitious materials ratio (w/cm) for the concrete and the use of a calcium nitrite corrosion inhibitor for the precast, prestressed concrete beams.

Structural Considerations

The durability of concrete structures can be enhanced considerably by reducing the probability of significant crack development. With this in mind, the designers of the structural components appropriately sacrificed efficiency by using a low design stress in the reinforcing steel to achieve reduced crack widths. A maximum working stress limit of 22 ksi (152 MPa) was used for design purposes.

The thickness of concrete cover protecting the reinforcing steel was specifically addressed. For the members near the splash zone, the concrete cover was 4 in. (100 mm), double what is typically used. Practical issues with formwork also had an impact on cover. The standard configuration of strands in the precast, prestressed concrete beams was modified to obtain a minimum cover of 2.75 in. (70 mm) to the steel.

Concrete Requirements

TxDOT used prescriptive concrete mix requirements to provide specific characteristics and properties consider-

ing the environment, locations in the structure, and design of the structural element. Class F fly ash up to 30 percent of the cementitious materials was the primary SCM required in the concrete. Class F fly ash was chosen because of its availability and to improve resistance to sulfate attack and alkali-silica reactivity, to lower the concrete permeability, and to lower the heat of hydration.

For the columns, pier caps, and segmental superstructure, a requirement to include either silica fume or an ultra-fine Class F fly ash up to 7 percent of the cementitious materials was added. The contractor chose to use the ultra-fine fly ash.

The concrete for the precast, prestressed concrete beams was required to include either Class C or Class F fly ash in the mix. Class C fly ash was allowed because the concern for sulfate attack on the elevated beams was not a factor. In addition, using Class C fly ash typically does not have the same negative impact on strength gain as occurs with a Class F fly ash. A calcium nitrite corrosion inhibitor at a rate of 3 gal/cu yd (15 L/cu m) was required in the precast, prestressed concrete beams.

To get this project completed rapidly, TxDOT added a \$20,000 per day incentive for early completion or penalty for late finish. Concerns were expressed that requiring the use of Class F fly ash at prescribed rates could delay progress of the work to allow time for strength gain if very tight controls were not used at the batch plant. Consequently, contractors would increase bid prices to account for this uncertainty. Therefore, TxDOT provided a performance-based option to address concrete permeability. The contractor chose the prescriptive requirements.

Construction Provisions

Many of the bridge elements are designated as mass concrete. This designation puts a maximum placement temperature of 75°F (24°C) on fresh concrete and a maximum temperature differential of 35°F (19°C) on in-place concrete. Additionally, TxDOT placed a general note in the plans requiring the contractor to keep all forms in place for 4 days before removal. This is believed to reduce

the risk of thermal shock and subsequent cracking that can occur when the forms are removed while the concrete is at a high temperature. The contractor is required to submit a heat generation and dissipation plan.

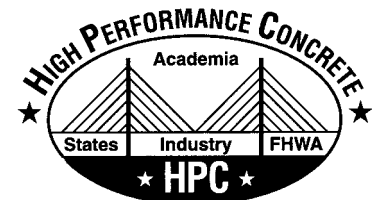
Observations

Execution of the durability plan has brought about new challenges that are being addressed as they arise. The first large footing placement revealed that the mass concrete provisions were not being met. A compromise was reached on how to handle the situation, which resulted in the concrete mix design being changed. The allowable amount of Class F fly ash was increased to 40 percent of the cementitious materials, the maximum temperature differential within the member was increased to 50°F (28°C), and the maximum temperature in the concrete limited to 160°F (71°C).

The contractor chose to develop the mix designs using a low w/cm ratio. It was thought that the slow strength gain, resulting from the requirement to use SCM, would be reversed by using a low w/cm. A low w/cm is good for low permeability but there is concern that autogenous shrinkage may cause cracking. Some cracking has occurred, which prompted the requirement that all noticed cracks be sealed by epoxy injection. Perhaps the incentive to finish early negatively affected the plan to get the most durable structure.

Lessons Learned

The main lessons learned from this project are that a high performance concrete structure requires continuous attention throughout the project and the project team should be prepared to make adjustments as the need arises.



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HPC TESTS — SULFATE RESISTANCE

Rachel Detwiler, Braun Intertec

Three factors are important for the sulfate resistance of concrete — the severity of exposure, selection of cementitious materials, and concrete permeability.

Exposure

The severity of exposure needs to be determined based on the concentration of sulfate in the water or soil. Exposure conditions are defined as negligible, moderate, severe, or very severe as shown in the table. If there is any doubt as to whether sulfate attack could occur in a given situation, the concrete materials should be selected for the next more severe exposure.

Test Methods

In the last few years, there has been some debate regarding the determination of the concentration of sulfate in soil⁽¹⁾ due to the lack of a standard test method. The United States Bureau of Reclamation (USBR) originated the requirements for concrete exposed to sulfates based on its own test method.⁽²⁾ ASTM C 1580, “Standard Test Method for Water-Soluble Sulfate in Soil,” is similar to the USBR test method. Both methods prescribe a quantity of water to extract the sulfate from the soil sample. The concentration of the sulfate in solution is used to determine the quantity of sulfate in the original sample. If a different test method is used, the limits on sulfate content should be adjusted to maintain the same degree of conservatism.

Once the exposure is characterized, the cementitious materials to mitigate sulfate attack may be selected. One approach is to specify Type II cement for moderate exposure and Type V cement for severe and very severe exposures. The requirement for sulfate resistance may be met either by the optional chemical requirement or by the

optional physical requirement, as specified by the purchaser. The chemical requirement limits the calculated tricalcium aluminate (C₃A) content of the cement since it is the hydration product of the C₃A that is most vulnerable to chemical attack. The optional physical requirement limits the maximum expansion as measured using ASTM C 452 to 0.040 percent at 14 days for Type V cement. In ASTM C 452, “Standard Test Method for Potential Expansion of Portland-Cement Mortars Exposed to Sulfate,” mortar bars made with the cement and additional gypsum are stored in water at 73°F (23°C) and the expansion measured between ages of 1 and 14 days.

Another approach to mitigate sulfate attack is to use a blended cement or combination of cementitious materials such as portland cement and fly ash or slag. Appropriate combinations of these materials can be more effective than the use of Type II or Type V cements. ASTM C 1157 for blended cements limits the expansion at 6 months to a maximum of 0.10 percent for moderate sulfate resistance (MS) or 0.05 percent for high sulfate resistance (HS). A one-year limit of 0.10 percent applies for high sulfate resistance if the 6-month expansion exceeds 0.05 percent. The applicable test method is ASTM C 1012, “Standard Test Method for Length Change of Hydraulic-Cement Mortars Exposed to a Sulfate Solution,” which can be used for portland cements, blended cements, or combinations of cementitious materials. In this test, mortar bars are stored in a sulfate solution at 23°C (73°F). Typically, 50 g/L sodium sulfate solution is used but other concentrations and/or other sulfates may be used to simulate field conditions. The length changes of the bars are measured periodically.

Concrete Permeability

The use of sulfate-resistant cementitious materials is necessary but not sufficient to make sulfate-resistant concrete. The concrete must also have low permeability. Low permeability does not automatically follow from low w/cm or high strength. Good concreting practices, particularly proper curing, are essential. At least 7 days wet curing at moderate temperatures should be specified and enforced. Longer curing times are necessary at lower temperatures.

Summary

When concrete will be exposed to sulfates, the exposure must be characterized using the USBR test or ASTM C 1580. The appropriate requirements for cementitious materials and concrete quality can then be determined from the table. The cementitious materials must meet the requirements of ASTM C 150 for sulfate resistance with portland cement or ASTM C 1157 for combinations of cementitious materials. In addition, the w/cm must be limited and careful attention must be paid to good concreting practices, particularly curing.

References

1. Rebel, B., Detwiler, R. J., Gebler, S. H., and Hooton, R. D., “The Right Sulfate Test Makes a Difference,” Concrete International, Vol. 27, No. 2, February 2005, pp. 49-52.
2. Method of Test for Determining the Quantity of Soluble Sulfate in Solid (Soil or Rock) and Water Samples, United States Department of the Interior, Bureau of Reclamation, 1973.
3. Adapted from Kosmatka, S. H., Kerkhoff, B., and Panarese, W. C., Design and Control of Concrete Mixtures, EB001, 14th Edition, Portland Cement Association, Skokie, IL, 2002, p. 28.

Requirements for Concrete Exposed to Sulfates⁽³⁾

Sulfate Exposure	Water-soluble Sulfate in Soil, % by Mass	Sulfate in Water, ppm	Cement Type*	Maximum w/cm by Mass
Negligible	Less than 0.10	Less than 150	No special type required	—
Moderate (Includes Seawater)	0.10 to 0.20	150 to 1500	II, MS, IP(MS), S(MS), P(MS), I(PM)(MS), I(SM)(MS)	0.50
Severe	0.20 to 2.00	1500 to 10,000	V, HS	0.45
Very severe	Over 2.00	Over 10,000	V, HS	0.40

*Pozzolans or slags that have been determined by test or service record to improve sulfate resistance may also be used.

Editor's Note

This article is the fourth in a series that describes tests for use with HPC. Previous articles appeared in Issue Nos. 36, 37, and 39.

Question

What is the status on the use of self-consolidating concrete in bridges?

Answer

Self-consolidating concrete (SCC) is a highly workable concrete that flows easily into the formwork and around congested reinforcement without segregation. SCC has been used extensively for bridges in Japan and Europe. Interest in its use in the United States has increased rapidly in recent years because SCC results in better consolidation, less bug holes, less manpower, less noise, less time for placement, and less maintenance cost of equipment.

A 2003/2004 survey by FHWA indicated that 36 percent of the states responding had made changes in the last 10 years to accommodate the use of SCC and 17 percent included it in their current specifications. A recent survey by North Carolina State University indicated that 55 percent of the states responding had used SCC in precast and/or prestressed concrete products but only within the last four years. Several states responded that they have ongoing research projects into its use. An article about its use for a bridge in Maine appeared in *HPC Bridge Views*, Issue No. 33.

In August 2004, the National Cooperative Highway Research Program Project 18-12 was initiated to develop guidelines for the use of self-consolidating concrete in precast, prestressed concrete bridge elements and to recommend relevant changes to the AASHTO LRFD bridge design and construction specifications. These guidelines are expected to provide highway agencies with the information necessary for considering concrete mixtures that are expected to expedite construction and yield economic benefits. Concurrently, other research is ongoing at several universities to support state implementation.

As owners become more confident in the use of SCC and producers and contractors become more knowledgeable about the material, its use is expected to increase. *HPC Bridge Views* is interested in learning about SCC applications in specific bridges.

More Information

PCI National Bridge Conference, October 16-19, 2005 session on SCC.

SCC 2005, Second North American Conference on the Design and Use of Self-Consolidating Concrete, October 30-November 2, 2005.

Interim Guidelines for the Use of Self-Consolidating Concrete in PCI Member Plants, TR-6-03, Precast/Prestressed Concrete Institute.

HPC BRIDGE CALENDAR

October 16-19, 2005

PCI National Bridge Conference — Bridges for Life,™ Innovative Solutions: Imagineering with Concrete Bridges, Palm Springs, CA. See www.pci.org for more information.

October 30-November 2, 2005

Second North American Conference on the Design and Use of Self-Consolidating Concrete and the Fourth International RILEM Symposium on Self-Compacting Concrete, Chicago, IL. Organized by the Center for Advanced Cement-Based Materials at Northwestern University. Visit www.scc2005.info for more information.

May 7-9, 2006

HPC: Build Fast, Build to Last, 2006 Concrete Bridge Conference, Reno NV. Sponsored by FHWA, NCBC, NVDOT, and ACI. Organized by the Portland Cement Association. Visit www.nationalconcretebridge.org/cbc for more information.

ERRATA

HPC Bridge Views No. 38, Page 3, Table on Concrete Mix Proportions: The correct values of water reducer and HRWR are 98.7 fl oz (3818 mL) and 49.4 fl oz (1911 mL), respectively.

HPC Bridge Views is published jointly by the Federal Highway Administration and the National Concrete Bridge Council. Previous issues can be viewed and downloaded at http://www.cement.org/bridges/br_newsletter.asp.

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Reproduction and distribution of this newsletter is encouraged provided that FHWA and NCBC are acknowledged. Your opinions and contributions are welcome. Please contact the Editor, Henry G. Russell, at 847-998-9137; (fax) 847-998-0292; e-mail: hgr-inc@att.net.

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