Bridge Views

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HPC Spans San Francisco Bay

Ken Beede, California Department of Transportation

HPC was used in the Skyway to provide a 150-year service life.

On October 17, 1989, the Loma Prieta earthquake caused the collapse of a 50-ft (15-m) long section of the upper deck of the East Span of the San Francisco-Oakland Bay Bridge. After completing emergency repair of the structure, the California Department of Transportation (Caltrans) undertook the design of a new East Span that would replace the 2.2-mile (3.5-km) long section of the bridge from Yerba Buena Island to the touchdown in Oakland.

Skyway

The new East Span includes the Skyway section—twin parallel 1.3-mile (2.1-km) long precast concrete segmental viaducts, each carrying a five-lane roadway and shoulders. The superstructure includes a total of 452 precast, post-tensioned, segmental units that are constructed with high performance concrete designed to provide a service life of at least 150 years.

The pier tables were cast-in-place and the cantilever segments were precast in Stockton, California and shipped by barge to the site. The inclined webs of the box consisted of lightweight concrete panels that were precast ahead of the main box section. The substructure involved driving large diameter cast-in-steel shell (CISS) piles up to 350 ft (107 m) deep, installing prefabricated steel footing boxes that are filled and encased in concrete, and placing variable height concrete columns, pier tables, and bridge fenders.

HPC Concrete

Prior to the start of construction, various concrete mix designs were

Concrete for Skyway Superstructure				
Materials	**Precast Bridge Segments (per yd³)**	**Precast Bridge Segments (per m³)**	**Pier Table Segments (per yd³)**	**Pier Table Segments (per m³)**
Cement, Type II/V	689 lb	409 kg	600 lb	365 kg
Fly Ash, Type F	229 lb	136 kg	200 lb	119 kg
Fine Aggregate	996 lb	591 kg	1242 lb	737 kg
Coarse Aggregate	1893 lb	1123 kg	1750 lb	1038 kg
Water	258 lb	153 kg	244 lb	145 kg
High-Range Water-Reducing Admixture	29 fl oz	1120 mL	26 fl oz	1106 mL
Concrete Stabilizer	27 fl oz	1040 mL	28 fl oz	1083 mL
Shrinkage-Reducing Admixture	N/A	N/A	64 fl oz	2476 mL
Water-Cementitious Materials Ratio	0.28	0.28	0.40	0.30
Properties				
Slump	8.9 in	225 mm	8.9 in	225 mm
Air Content	1.5%	1.5%	2.0%	2.0%
Unit Weight	150.6 lb/ft³	2412 kb/m³	149.5 lb/ft³	2395 kb/m³
Specified Compressive Strength at 56 days	8000 psi	55 MPa	8000 psi	55 MPa
Typical Compressive Strength at 56 days	10,560 psi	72.8 Mpa	10,850 psi	74.8 MPa

Source: Caltrans Management Information System, November 2007
The above table lists the concrete constituent materials and their proportions for the precast and cast-in-place concrete mixes used in the superstructure segments. Typical measured properties for each concrete mix are provided.

developed and tested to determine compressive strength and modulus of elasticity at various ages. In conjunction with the initial mix evaluation, other tests were performed to determine set times, mix rheology, and thermal properties. The testing activities, material evaluations, and reviews described below were extensive; but the results demonstrated that high performance concrete could be obtained efficiently and on a continual basis, while providing a realistic 150-year service life.

Specific requirements for concrete used in the Skyway design included limits for compressive strength, durability, corrosion, and thermal control for the portions of the concrete designated as mass concrete. The specified properties of the superstructure concrete included compressive strength at ages up to 60 days, creep based on 365 days of loading, modulus of elasticity, and shrinkage. A summary of the specified properties is given at the end of this article.

Concrete Production

Multiple mixes were evaluated for use in the concrete placement of the CISS piles, footing and column structures, pier tables, and precast bridge segments. Special mixes were also evaluated to obtain suitable concrete for the structural lightweight panels and for the in-fill concrete for the box footing interior cells. Unique mixes were also designed for the concrete fenders, footing encasements, and closure placements.

In the preconstruction stage, it was determined that a dedicated on-site batch plant would be required to produce the degree of uniformity required for the critical cast-in-place concrete. Barges from the onshore batch plant in Oakland, California, transported the bulk of the concrete to the bridge site. Each barge was equipped with two 20 cu yd (15 cu m) mixers and a liquid nitrogen cooling system with fully operable admixture dispensers and supply tanks. Each barge operator was a licensed weighmaster, an ACI Grade 1 concrete field testing technician, and qualified mixer operator. A mixer on the concrete pump barge provided additional mixing and mix agitation of the fresh concrete between barge deliveries. The contractor was responsible for all aspects of the concrete production while Caltrans was responsible for the quality assurance testing.

An important requirement for the high performance concrete was the selection of the concrete materials including the cementitious materials, aggregates, and admixtures. The project cements included Type II/V and a modified high early strength cement.

The prime concrete aggregate was a Sechelt aggregate from British Colombia, Canada. This aggregate source is known for its uniformity, thermal transfer properties, and high quality. It has been used to produce concrete for more than 20 years with no known incidence of alkali reactivity or incompatibility with cement.

Both a Class F fly ash and a ground-granulated blast-furnace slag were used to supplement the cement and provide additional corrosion protection and thermal properties. Several concrete admixtures were used to help achieve specific mix requirements including reduced shrinkage, mix stabilization, increase in strength, and reduced bleeding capacity. Several of the concrete admixtures had been prequalified and were approved for use in the project concrete. The shrinkage-reducing admixture used in the superstructure concrete and the viscosity-modifying admixtures used in the self-consolidating concrete of the pile caps were specially approved for the use on this project.

Excerpted Special Provisions for the Lightweight Superstructure Concrete

Modulus of Elasticity

The modulus of elasticity of the portland cement concrete shall be at least 35,600 MPa (5160 ksi) at 28 days when tested in accordance with the requirements in California Test 522. The samples shall be moist-cured for 7 days, followed by air drying at 23°C (73°F) and 50 percent relative humidity until test age. The modulus shall also be reported at 3, 7, 56, and 90 days. Test specimen size shall be the same as used for compressive strengths. Test results shall be based on the average of three test specimens at each age.

Creep

The specific creep coefficient, as determined in accordance with the requirements in ASTM C 512, after 365 days of loading, shall not exceed 75 millionths/MPa (0.52 millionths/psi). Test specimens shall be 152x305 mm (6x12 in.) cylinders and shall be moist cured for 7 days, followed by air drying at 23°C (73°F) and 50 percent relative humidity. Test cylinders shall be loaded at 28 days to a stress of 20 to 40 percent of the 56-day design compressive strength shown on the plans but not less than 20 percent nor greater than 40 percent of the measured strength at 28 days. For submittal of the prequalification data, coefficients after 28, 56, and 90 days of loading shall be submitted and used to predict the coefficient at 365 days based on the procedures of CEB-FIP Model Code for Concrete Structure, by the Comité-Euro-International du Béton. Mix design approval shall be contingent upon the 365-day creep coefficient satisfying the stated requirement.

Shrinkage

The shrinkage strain of portland cement concrete shall not exceed 0.045 percent after 180 days of drying in accordance with the requirements in ASTM C 157. Sample size shall be 100x100x285 mm (4x4x11-1/4 in.). Samples shall be moist-cured for 7 days, followed by air drying at 23°C (73°F) and 50 percent relative humidity. Shrinkage strain shall be calculated as the change in strain from the beginning of drying at 7 days.

Source: Caltrans, Notice to Contractors, Skyway Project, Contract No. 04-012024, Special Provisions; Revised Field Edition, p. 154. Publication Date: April 2002. (U.S. customary units have been inserted by the Editor.)

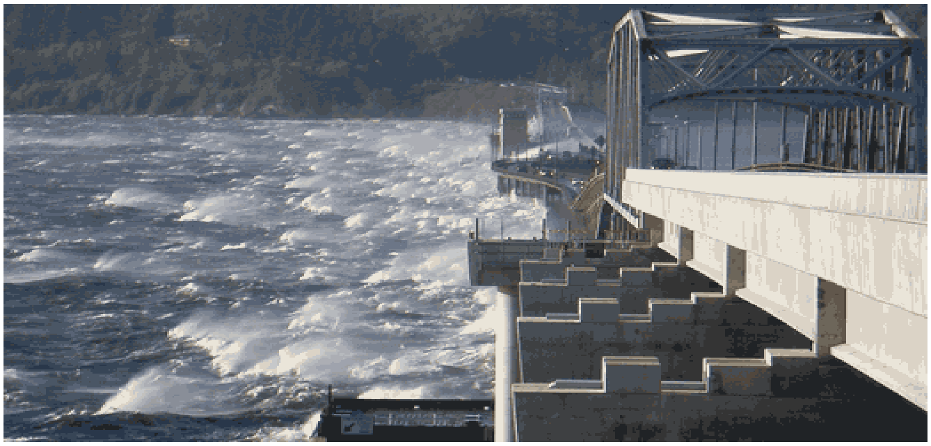
Further Information

For further information, contact the author at ken_a_beede@dot.ca.gov or see ASPIRE, Winter 2007 at www.aspirebridge.org.

Erection of precast concrete segments from a barge.

Hood Canal Bridge West-Half Retrofit and East-Half Replacement

Mark A. Gaines, Washington State Department of Transportation and Michelle L. Tragesser, Parametrix



High performance concrete was specified to resist the harsh salt environment of the Hood Canal.

The Hood Canal Bridge provides an important link between the Olympic and Kitsap Peninsulas in northwestern Washington State. The bridge is the longest floating bridge over saltwater in the world and has a movable 600-ft (183-m) wide draw span that provides access for marine traffic vital to national security. Extensive use of prestressed concrete and high performance materials are required to withstand the large tidal fluctuations, strong winds, and wave action of Hood Canal's harsh marine environment.

The most significant project work item is constructing 14 new floating prestressed concrete pontoons to replace the existing east-half structure. The high performance concrete (HPC) pontoons are being constructed in four separate cycles at a graving dock in Tacoma, Washington. The largest of the cellular box structures is 60 ft (18 m) wide, 18 ft (5.5 m) tall, and 360 ft (110 m) long. They are all heavily reinforced with both conventional reinforcing steel and longitudinal, transverse, and vertical post-tensioning tendons.

Mix Selection

The HPC used for the pontoons was originally developed for the I-90 Lacey V. Murrow (LVM) floating bridge project in the 1990s. This mix design, now used by the contractor, Kiewit-General Joint Venture, is as follows:

The table lists the concrete mix proportions as 625 lb of Type I / II cement, 100 lb of Class F fly ash, 50 lb of silica fume, 1350 lb of fine aggregate, 1680 lb of coarse aggregate, 255 lb of water, and 0 to 80 fl oz of high-range water-reducing admixture for a total water-cementitious materials ratio of 0.33.

The approximately 31,000 cu yd (24,000 cu m) of concrete required for the pontoon construction must adhere to the contract specifications by achieving a minimum 28-day compressive strength of 6500 psi (45 MPa) and a maximum 56-day permeability of 1000 coulombs. To date, these standards have been exceeded. The actual 28-day compressive strengths are approximately 11,000 psi (76 MPa) and the 56-day permeability of this mix is less than 800 coulombs.

Placement

Early in the project, the contractor realized that the LVM concrete placement in the pontoon walls would be challenging because the walls are up to 21 ft (6.4 m) tall, only 10 in. (255 mm) thick, and heavily congested with reinforcing steel and post-tensioning ducts. To improve concrete placement and consolidation, the contractor requested to add more high-range water-reducing admixture and exceed the previously defined maximum 9-in. (230-mm) slump. After conducting a series of qualification tests and constructing a mock-up pontoon wall, the contractor successfully demon-

Materials	Quantities (per yd^3)	Quantities (per m^3)
Cement, Type I/II	625 lb	371 kg
Flay Ash, Class F	100 lb	59 kg
Silma Fume	50	30 kg
Fine Aggregate	1350 lb	801 kg
Course Aggregate	1680 lb	997 kg
Water	255 lb	151 kg
High Range Water-Reducing Admixture	0 to 80 fl oz	0 to 3090 mL
Water-Cementitious Materials Ration	0.33	0.33

strated that this "new" mix could be placed without segregation. Testing and acceptance of this concrete was accomplished using the spread test that is common with self-consolidating concrete. A spread of up to 23 in. (585 mm) with a visual stability index of 0 or 1 per ASTM C 1611 was allowed. To date, approximately 70 percent of the total LVM concrete quantity needed has been placed with virtually no consolidation or segregation issues.

Curing

One of the challenges encountered during pontoon construction was crack formation in the wall concrete. On the first cycle of pontoons, vertical cracks were observed that extended the full height of the wall. The cracks had a spacing of 8 to 10 ft (2.4 to 3.1 m), average widths between 0.006 and 0.030 in. (0.15 and 0.76 mm), and extended through the full thickness of the wall. Washington State Department of Transportation (WSDOT) investigated and found that the likely mechanism for the crack formation was thermal expansion and contraction of the wall concrete in conjunction with restraint provided by the base slab. At the time the wall concrete was placed, the base slab concrete was at an ambient temperature of about 60°F (16°C).

The high cementitious materials content of this concrete resulted in a high heat of hydration and associated thermal expansion. Within 24 hours of placement, the wall concrete reached its peak temperature and also achieved final set. As the wall concrete slowly cooled, thermal contraction was resisted by the base slab, creating tensile stresses in the wall that ultimately led to cracking. After the first cycle of construction, WSDOT allowed the contractor to remove forms and apply curing water after only 12 hours. This lowered peak temperatures in the concrete and reduced thermal expansion and contraction. During subsequent cycles, the number of cracks was reduced by about 10 percent and the cracks that did form were narrower. This improvement decreased the amount of crack repair required.

High performance concrete with a flow of 23 in. (585 mm) and a compressive strength of 11,000 psi (76 MPa) was used to cast the pontoon walls.

Cracks with a width larger than 0.006 in. (15 mm) after post-tensioning was completed were repaired with epoxy injection. Cracks measuring 0.006 in. (15 mm) or less were sealed with a crystalline waterproofing product.

The main lesson learned from the cracking in the first cycle of pontoon construction was the importance of early removal of the wall forms and application of water on the surface to lower the peak concrete temperatures. It was also learned on the first cycle that the longitudinal post-tensioning closed these cracks by 50 to 75 percent.

Quality Product

Lessons learned during each stage of pontoon construction continue to be shared with the project team and applied in order to facilitate constructing a quality product. To date, 12 pontoons have been successfully constructed and are floating in the Puget Sound near Seattle. These pontoons are currently being joined together to form the movable draw span portion of the bridge. Work continues to move forward on schedule to meet the May-June 2009 east-half bridge replacement date.

Further Information

For further information, please contact the authors at gainesm@wsdot.wa.gov or tragesm@consultant.wsdot.wa.gov.

North Avenue Bridge Reconstruction – A Modern High Performance Structure

Alison Smith, URS Corporation

HPC was specified for both strength and durability.

The North Avenue Bridge spanning the Chicago River has been a part of Chicago history for over 100 years. The original structure was one of the oldest bridges in the city—a steel trunnion bascule bridge, built in 1907. The bridge had significant historical value, but was in a state of deterioration and did not meet the needs of the approximately 30,000 vehicles traveling over the bridge each day between two rapidly changing neighborhoods. The design for a new bridge, with a comparable degree of structural distinction and durability was initiated by the Chicago Department of Transportation (CDOT).

The new structure is a $25 million, suspension and cable-stayed hybrid bridge that will have double the traffic capacity. The 10-in. (255-mm) thick deck and 4-ft (1.22-m) deep longitudinal beams are post-tensioned, high performance concrete (HPC). The exposed portion of the gravitational anchor blocks, used to counter-balance the center of the bridge through the suspension cable, is HPC as well. The beams and deck were cast on shoring until the suspension cable and cable stays were installed and stressed.

HPC Mix

The CDOT requires extensive prequalification and rigorous testing of the proposed HPC from each supplier. The mix used was specifically formulated for use on the North Avenue Bridge Reconstruction Project.

The HPC for the project had two quality components: strength and durability. The specification required a 28-day compressive strength between 6000 and 9500 psi (41 and 66 MPa). The average 28-day strength of the concrete was 7400 psi (51 MPa). Test results confirmed that the mix design met the specified properties for resistance to freeze-thaw cycles, salt scaling, shrinkage, chloride ion penetration, and chloride permeability. These characteristics make the mix superior to conventional concrete, in that the concrete is designed to withstand a severe environment and sustain a longer service life.

Curing

To achieve the required strength and reduce shrinkage, the specified curing method involved immediately placing cotton mats over the finished concrete and soaking the mats with a mist, placing soaker hoses, and then polyethylene sheeting for a curing period of 7 days. The concrete temperature was monitored to ensure that it was between 50 and 150°F (10 and 66°C). The concrete was placed in the early morning hours so that ambient air temperatures were not above 80°F (27°C) during the placement. The temperature requirements are very important due to less excess available free water than a standard concrete mix and to prevent plastic shrinkage cracking and drying or thermal shrinkage. Ground-granulated blast-furnace slag (GGBFS) and silica fume were used to help achieve the strength and durability properties.

Concrete Mix Proportions

The following table lists the concrete mix proportions as 605 lb of Type I portland cement, 120 lb of Grade 100 GGBFS, 30 lb silica fume, 971 lb of fine aggregate, 1844 lb of coarse aggregate, and 264 lb of water for a water-cementitious materials ratio of 0.35. Air entraining, retarding, and high-range water-reducing admixtures were used as required.

Materials	Quantities (per yd^3)	Quantities (per m^3)
Portland Cement, Type I	605 lb	359 kg
GGBFS, Grade 100	120 lb	71 kg
Silma Fume	30 lb	18 kg
Fine Aggregate	971 lb	576 kg
Course Aggregate	1844 lb	1094 kg
Water	264 lb	157 kg
Air Entraining	as required	
Retarding Mixture	4 to 15 fl oz	150 to 580 mL
High-Range Water-Reducing Admixture	30 to 60 fl oz	1160 to 2320 mL
Water-Cementitious Materials Ration	0.35	0.35
Water-Cementitious Materials Ration	0.33	0.33

Innovative Construction Methods

Due to river traffic clearance limitations, formwork under the bridge was not feasible, making an off-site construction method more practical. The 109-ft (33.2-m) long center span was, therefore, shored and formed on three barges. The HPC 10-in. (255-mm) thick deck, the 4-ft (1.22-m) deep beams, and the sidewalk were monolithically placed with concrete pumped from the shore. The placement was a challenge because of balancing issues created by the buoyancy of the barges. A detailed placement procedure and constantly surveyed deck elevations ensured a uniform and safe placement. Additional, temporary post-tensioning was added to the beams to provide enough rigidity to lift the center span into place. The 800-ton (7.2-MN) HPC center span was floated up the river, adjusted into position, and jacked up from a temporary structural system consisting of launching trusses sitting on temporary piers. A total of sixteen 100-ton (890-kN) jacks lifted the center span into its final position.

Conclusion

The high performance concrete system is meant to provide a structure that will have a 100-year service life. Long-term, the extended bridge life provides a structure that will be less expensive to maintain and provides Chicago with a unique, signature bridge.

Further Information

For further information, please contact the author at alison_m_smith@urscorp.com.

Editor’s Note

The method of construction of the center span of this bridge is an excellent example of a prefabricated bridge system that uses accelerated construction to minimize the impact on river traffic.