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COOPER RIVER BRIDGE—A HIGH PERFORMANCE CONTRACT

Charles Dwyer, South Carolina Department of Transportation

The Cooper River Bridge Project involves the replacement of two existing river crossings between Charleston and Mount Pleasant on the coast of South Carolina. The new crossing has an overall length of approximately 3 miles (4.8 km) and includes two interchanges, two high level approach structures, and a cable-stayed bridge with a main span of 1546 ft (471 m) — the longest in North America.

The $531 million design-build contract is the largest and most complex project ever completed by the South Carolina Department of Transportation (SCDOT). Construction costs for this project alone are comparable to the average annual statewide construction budget for SCDOT.

SCDOT classified the bridge as a critical structure because it crosses a busy shipping channel and provides a link to the city of Charleston, which has the only hospital in the area with a trauma center. The critical bridge classification meant that the bridge needed to meet the highest standards and be designed to withstand hurricanes, earthquakes, and ship collisions.

Project Criteria

Because this bridge is unlike any other bridge on SCDOT's highway system, we did not rely solely on our established standards, specifications, and design criteria. Project-specific criteria were developed for many components ranging from the design of the stay cables to the development of the corrosion control plan.

As with all aspects of SCDOT's design-build contracts, primary control of the design was given to the contractor. This included concrete mix designs as the contract provided that mix proportions in the standard specifications were for guidance only.

To ensure that the bridge would meet the needs of the state, SCDOT included criteria for a corrosion control plan. Firstly, the criteria set the service life of the bridge at 100 years. Secondly, this plan was one of the few stop points written into the contract. The contractor needed SCDOT's approval of the corrosion control plan before proceeding.

The corrosion control plan outlined how the bridge will meet its 100-year service life and documented the process of material selection. The contractor was free to select epoxy-coated reinforcement or high-performance concrete provided that the service life could be met with reasonable life-cycle costs. The selection of low permeability concrete by the contractor led SCDOT and the contractor to agree on a plan for testing and acceptance of concrete under this criterion.

Construction Quality Control

The contract emphasized the requirement for contractor quality control (CQC), which included both construction inspection and materials testing. SCDOT still performed its own materials testing at twenty percent of the standard frequencies, or one for every five CQC tests. These test results were the acceptance tests and were used for quality assurance of the CQC results.

The concrete was tested for permeability as part of the mix design process. The potential for variations in the permeability test results meant that we did not have the confidence to require it as an acceptance test. Instead, the low permeability concretes were tested before and periodically during their production. If any mix had failed an interim test, the mix design would have been adjusted and retested. Fortunately, all interim permeability tests met the criterion.

Project Status

The new bridge opened to traffic on July 16, 2005, more than one year ahead of the required completion date in the contract. Demolition of the two old truss bridges is now underway.

Editor's Note

This edition of *HPC Bridge Views* focuses on one design-build project from the perspectives of the owner, designer, general contractor, and concrete supplier. A previous article on this project appeared in Issue No. 29.

DESIGN CHALLENGES

Michael J. Abrahams, Parsons Brinckerhoff Quade & Douglas, Inc.

The design of the bridge was challenging because of the need for a cost-competitive design, a ductile and relatively lightweight structure to satisfy the relatively high seismic demands, a structure strong enough to withstand ship collision and high wind forces, and a 100-year service life. For example, the towers of the cable-stayed bridge were designed with enough reinforcement to withstand hurricane-generated wind loads. Yet, the reinforcing steel in the towers was limited so that ductile hinges could form at the tower bases without requiring excessive amounts of reinforcing steel or generating excessive forces on the drilled shafts.

The 100-year service life was an important challenge. As this was a design-build project, it was necessary to develop the most economical plan that would be responsive to the project criteria. There were many options available, including the use of solid stainless steel reinforcement, but cost considerations in a competitive design-build environment did not favor this approach.

In addition, there was the need to demonstrate that the design would meet a 100-year service life. There was no code to follow, nor was there much literature on the subject. Available analytical models for service life were overly simplistic. There was little guidance available on how to quantify environmental effects at a particular site. For example, literature on airborne chlorides was limited to data on balconies. Thus, the design team was tasked with developing an appropriate analytical model and the appropriate environmental conditions to be used at the bridge site e.g. water salinity, annual amounts of chlorides applied to the deck, level of airborne chlorides, etc. Considerable judgment was needed. Particularly helpful in developing these data were measurements of chloride levels that had been collected by SCDOT on the adjacent 1929 Grace Memorial and 1956 Pearman Bridges.

The approach adopted was to utilize uncoated reinforcing steel, and to specify the required permeability, which, in combination with the assumed rate of chloride application and concrete cover specified in the design criteria would provide the 100-year service life.* In the splash zone, two alternatives were developed. One utilized concrete with a maximum permeability of 500 coulombs and a minimum concrete cover over the reinforcement of 4 in. (100 mm). The second used concrete with a maximum permeability value of 1400 coulombs and minimum a cover of 6 in. (150 mm).

The contractor then solicited quotes from local concrete suppliers for concrete that would meet the typical material and strength requirements as well as the project-specific permeability values. Two local suppliers used different approaches. One supplier used slag cement while the other supplier used Class F fly ash to achieve the required permeability.

In developing this approach, it was recognized that fly ash concrete does not achieve its full permeability for approximately one year and that conducting permeability tests at 28 days would not result in an economical mix with fly ash. Thus, the specification allowed the use of the accelerated curing method used by the Virginia DOT.

There were no design limitations due to the use of low permeability concrete. However, the more economical mix was the one using fly ash. This may not be the case in other locations where local material prices may dictate a different approach. A concrete sealer was applied to the elements in the splash zone to improve the concrete's durability for the first year.

The use of performance-based specifications for determining concrete mix proportions is a departure from traditional bridge construction projects in the United States, where the tendency has been for each state highway department to prescribe the mix to be used for each portion of the structure. A performance-based approach may be a more objective and cost-effective way of developing long-lasting economical structures. If this approach is to be used, there is a need for both better analytical models that have been peer reviewed as well as site-specific environmental criteria. It is suggested that the latter may be developed by agencies on a regional or statewide basis, just as seismic and wind criteria have been developed based on local site conditions.

**See HPC Bridge Views, Issue No. 29.*

CONSTRUCTION CHALLENGES

Wade Watson, Tidewater Skanska

Palmetto Bridge Constructors, a joint venture of Tidewater Skanska and Flatiron Constructors, Inc., was awarded the $531 million contract for the construction of the Cooper River Bridge in July 2001. Construction began in earnest in January 2002.

The project is located near the mouth of the harbor, close to the Atlantic Ocean, and crosses the shipping channel to the port of Charleston — the fourth busiest container port in the country. This location produces an extremely corrosive environment and tidal currents that are often severe with an average tide range of 6 ft (1.8 m). This clearly presented challenges for construction of the spans over water.

Marine transportation of concrete was accomplished with a system of custom-made 125 cu yd (96 cu m) hoppers mounted on barges. Two "traveling hopper" barges received concrete shore-side and then moved to the placement location assisted by tugboats. A third "holding hopper" and a 180-ft (55-m) pump truck were mounted on a barge stationed at the placement location. Once in position, the contents of the traveling hoppers were transferred, via a high-speed conveyor, into the holding hopper. The pump was fed directly from a small conveyor at the bottom of the holding hopper.

Not only did the project's design dictate concrete performance requirements, construction means and methods, as well as placement limitations, added additional performance needs. Virtually each element of the structure, depending on its access (i.e., marine, trestle, or land), had its own particular placement requirements.

Marine drilled shafts required a tremie mix with high slump and small aggregate

HPC was used in many components of the Cooper River Bridge (Photo courtesy of SCDOT/Rob Thompson)

size. Additionally, this concrete had to remain plastic during the entire transport and placement cycle, often requiring 18 hours or more. This was accomplished with admixtures such as hydration stabilizers and water reducers.

Footings for the main span towers required a continuous placement of approximately 5000 cu yd (3800 cu m) each. The mix needed an initial long life for transportation and then had to begin to set to reduce form pressures on the 20-ft (6-m) high formwork.

The diamond-shaped main span towers rose to a height of about 575 ft (175 m) and required a 7000 psi (48 MPa) compressive strength concrete with long plastic life for marine transportation. However, once the placement was completed, the schedule demanded a strength of 2500 psi (17 MPa) in 12 hours, so the next construction cycle could begin.

Bridge decks were typically pumped from the previously placed decks. This required pumping long distances over newly placed sections as well as a staggered placement sequence. The placements of 700 to 1000 cu yd (535 to 760 cu m) for the 160-ft (49-m) wide deck required a pumpable mix that maintained plastic performance during the entire 6 to 8 hour placement time. Even a normally “routine” placement such as slip forming the barrier walls necessitated a zero slump mix, 200 ft (61 m) over the river.

Specified concrete compressive strengths on the project ranged from 3000 to 8000 psi (21 to 55 MPa). Due to the congestion of the reinforcement associated with seismic design, a high slump small aggregate size mix was often used.

The heat of hydration was also a major concern due to the specifications for mass concrete, which stated a maximum concrete temperature at placement of 80°F (27°C), a maximum concrete temperature of 160°F (71°C) during curing, and a 35°F (19°C) maximum differential temperature between the core and outside surface. Where placements were smaller, mix designs were optimized to reduce the heat of hydration using the lowest possible concrete temperature at placement. Exterior insulation was used on the formwork to control temperature gradients. Still, most placements required a closed-loop internal cooling system.

The South Carolina Department of Transportation (SCDOT) standard specifications had to be modified and supplemented to address the new mix designs. This included not only extensive, but also intimate involvement with design. Overstrength concrete can be as much of a problem as under-strength in seismic design. The design-build approach, and a partnering owner, allowed us to use the best technology available to create concrete mixes that would meet the design and placement requirements.

All concrete was purchased as ready-mixed concrete from a local supplier, who set up a facility dedicated to the project. The concrete was procured on a performance-based specification that met design and construction requirements. This took a close working relationship between the supplier, the contractor, the designer, the SCDOT, admixture suppliers, and inspection personnel.

CONCRETE SUPPLIER'S CHALLENGES

David Hand, Wando Concrete, LLC

Mix design, batching, transporting, and testing of the concrete for the Cooper River Bridge project posed some challenges from a producer’s standpoint. The first challenge was to develop cost-effective mixes that met the required specifications and could be modified to meet the non-specified challenges. As concrete supplier, our team had a real place at the partnering table with the contractor, designer, and the South Carolina Department of Transportation. The real story in the success of this project was everyone’s commitment to construct the very best bridge possible and the design-build process allowed us the flexibility to achieve that goal.

The project required the production of over 320,000 cu yd (245,000 cu m) of concrete involving high strength concrete, high early strength concrete, low permeability concrete, extended set times, extended transportation times, and control of initial concrete temperatures.

Slump life and initial set were critical in the construction of the drilled shafts. A 6- to 9-in. (105- to 225-mm) slump and initial set durations in excess of 11 hours were accomplished with the use of hydration stabilizing admixtures. In effect, the hydration process was stopped for various durations with the use of these chemicals. This method was preferred over using retarders, which can become unstable at higher dosage rates. This also worked well for the bridge deck concrete, which was placed transversely, because differential displacement from loading the deck beams would cause cracking in deck mixes with normal setting times. The potential for surface drying and plastic shrinkage cracking due to extended set times of about 4 hours for the deck concrete was a significant potential problem. Specific combinations of admixtures were used to provide the desired set time while achieving the workability, paste, and bleeding characteristics consistent with normal bridge deck concrete.

Permeability requirements led to the use of cementitious materials containing

400 lb/cu yd (237 kg/cu m) of cement and 300 lb/cu yd (178 kg/cu m) of fly ash for the substructures. Cost and material supply issues precluded the use of slag or silica fume. Temperature control and finishability were added benefits of the high amount of fly ash.

Strength requirements were met using a high cementitious materials content and a low water-cementitious materials ratios. Design strengths of 7000 and 8000 psi (48 and 55 MPa) were often accompanied by additional requirements. For example, portions of the cable-stayed bridge deck infill concrete with a specified 28-day compressive strength of 8000 psi (55 MPa) needed to remain at a 7- to 9-in. (175- to 225-mm) slump for 4 hours but achieve 3000 psi (21 MPa) compressive strength at 18 hours. In addition, the maximum aggregate size was limited to 1/2 in. (13 mm) to ensure passage through the closely spaced reinforcement.

All testing was initially performed in the laboratory followed by full-scale batches of 10 cu yd (6 cu m) or larger to ensure success in the field. Several full-scale dry runs were made on critical placements to ensure the concrete behaved as expected.

Concrete temperatures were important to allow for year-round production as well as for mass concrete placement. Several methods were involved in lowering concrete temperatures. Cement was readily available from a local mill, but due to the high demand during this period, the temperature of the cement as delivered was relatively hot. With the help of the supplier, cement was imported from Greece, which allowed a 14-day cooling period during shipment. Because the water-cementitious materials ratios were low and the cementitious materials content high, the use of ice was discounted because rates of 100 percent ice would be necessary. In addition, there were concerns about achieving full hydration and proper mixing when all the batch water was added as ice. Our solution was to immerse and chill the coarse aggregate in very large pits filled with near-freezing water. This, accompanied by chilled water and, at times, a small amount of ice allowed us to produce extremely cool concrete while maintaining a homogeneous product.

Concrete Mix Proportions[1]

Property	Drilled Shafts	Sub-Structures	Towers	Piers	Infill
Specified Strength, psi	4000	5000	7000	7000	8000
Mix Proportions, lb/yd^3					
Portland Cement	588	400	830	600	800
Fly Ash, Class F[2]	176	300	199	250	199
Coarse Aggregate	1805	2000	1800	1600	1780
Fine Aggregate	1030	1015	854	1010	806
Water	333	265	352	323	328
w/cm ratio	0.44	0.38	0.34	0.38	0.33

[1]*Chemical admixtures not listed*
[2]*Carbon burn out fly ash*

HPC PUBLICATIONS

HPC Bridge Views, Issue Nos. 1-38 in one bound volume, SP 397, available from the Portland Cement Association.

Seventh International Symposium on Utilization of High-Strength/High-Performance Concrete, SP 228, hard copy or CD available from the American Concrete Institute while supplies last.

Guide Specification for High Performance Concrete for Bridges, EB 233, from the Portland Cement Association.

High-Performance Concrete Structural Designers' Guide available from the Federal Highway Administration.

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