HPC Bridge Views

High Performance Concrete — Academia, States, Industry, FHWA — HPC

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In This Issue...

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I-35W St. Anthony Falls Bridge

Jon Chiglo, Minnesota Department of Transportation

The new I-35W bridge across the Mississippi. Photo: FIGG

On Thursday, August 2, 2007—less than 24 hours after the collapse of the I-35W bridge—a group of approximately 30 individuals from the City of Minneapolis, Federal Highway Administration, and the Minnesota Department of Transportation (Mn/DOT) met to discuss how to begin the rebuilding process. The collapse resulted in the death of 13 people and injured 145. It also severely impacted the public trust and confidence in the Department of Transportation's ability to provide a service dependent on safety to the citizens of Minnesota.

Design-Build Decision

The discussion during the meeting primarily evolved around two delivery processes that Mn/DOT has already used successfully: the more traditional design-bid-build process and the design-build process. The pros and cons of each process and their anticipated times of delivery were discussed. Ultimately, the design-build process was selected in large part because of the speed of delivery, risk transfer, and the ability to allow more flexibility and innovation. Immediately after the decision was made to use this method, Mn/DOT established a team with past design-build experience to lead the charge and begin the process of rebuilding the I-35W bridge and to take the first steps in re-establishing public trust and confidence.

The I-35W project ultimately validated the use of design-build as the appropriate delivery process under these circumstances. The Flatiron-Manson Team, using FIGG Engineering as the lead designer, provided a design and construction approach with many innovations including those in structural design, concrete mix design, construction staging, and cold weather protection. This allowed the successful completion of a project that many in the bridge industry and the public doubted could ever be achieved.

The Mn/DOT design-build delivery process does not allow a "pure" design-build approach with complete flexibility. The design and construction criteria encompass an approach that enhances the ability of the contractor and the designer to take advantage of each team's strengths. Mn/DOT has learned through each of their seven previous design-build projects that allowing flexibility in design and construction enables the design-build teams to capitalize on innovative approaches to solving problems. Assigning risk to the party that can best manage that risk is also a key to success but it does not mean assigning all the risk to the design-build team. Mn/DOT accepts the risks in the areas that it can best manage.

Bridge Description

The bridge consists of twin 1223-ft (373-m) long parallel structures that carry northbound and southbound traffic. Each structure consists of two variable depth box girders joined together through their top flanges to provide a 90-ft 4-in. (27.5-m) wide deck. Each box girder is supported on separate columns with pairs of columns sharing the same footing. The footings are supported on drilled shafts that are socketed into bedrock. Span lengths are 330, 504, 242, and 47 ft (101, 154, 74, and 14 m).

As part of this project, Mn/DOT encouraged innovation through establishing performance specifications associated with the concrete mixes. Each element of this project seemed to produce a different challenge to overcome when it came to the concrete. The substructure consisted of 7- and 8-ft (2.1- and 2.4-m) diameter drilled shafts, up to 95-ft (29-m) deep cast with self-consolidating concrete. Each pier footing was 13 ft (4.0 m) deep, 109 ft (33.2 m) long, and 34 ft (10.4 m) wide and contained over 1700 yd^3 (1300 m^3) of concrete. Those footings needed both mass concrete considerations and cold weather protection. The main span of the superstructure was built using the cantilever method with 120 precast segments match cast using the long-line method. The side spans were cast-in-place on falsework. The contract requirements associated with the full depth deck approach ensured long-term performance and durability through permeability and strength parameters.

100-year Service Life

The request for proposals required the contractor to submit a corrosion protection plan to assure a 100-year service life for the structural elements of the bridge. The plan was required to assess the effects of concrete permeability, corrosion thresholds, corrosion rates, impact of cracked concrete, and time to repair. Recommendations on the use of calcium nitrite, silica fume, sealers, membranes, reinforcement coatings, concrete cover, and other corrosion inhibitors were required.

The Outcome

The new I-35W bridge opened on September 18, 2008—only 11 months from notice-to-proceed. The performance of Flatiron-Manson, FIGG team working with Cemstone Concrete Products was exemplary in solving all of the concrete-related challenges during this project through innovation and a depth of experienced personnel second to none. The innovative approaches that were used to achieve this remarkable project will continue to be used to enhance future projects; thereby ensuring that the value of this project will be sustained.

Further Information

A significant amount of information about this project is available at http://projects.dot.state.mn.us/35wbridge/index.html or contact the author at jon.chiglo@dot.state.mn.us. for further information.

(articles continue on next page)

HPC for 100-Year Life Span

Alan R. Phipps, FIGG Bridge Engineers, Inc.

Precast concrete superstructure segment. Photo: Tim Davis, FIGG

The new I-35W bridge across the Mississippi River in Minneapolis features high performance concrete (HPC) for all concrete components of this post-tensioned, box girder structure. The bridge accommodates 10 lanes of traffic and is designed for future traffic demands including rapid bus or light rail transit and a suspended pedestrian bridge.

The Minnesota Department of Transportation's (Mn/DOT's) vision for the bridge included a minimum design service life of 100 years—one third longer than for most bridges. A corrosion protection plan was developed by FIGG to frame the design strategy for achieving this requirement. Some of the key elements of the strategy were:

- Concrete bridge with the superstructure post-tensioned in two directions to provide a residual compressive stress
- High performance concrete containing silica fume and fly ash for low permeability
- Integral concrete wearing surface
- Durable post-tensioning system incorporating polyethylene ducts, prepackaged thixotropic grout, and multiple layer anchorage protection

Structure health monitoring system, including corrosion potential sensors in the deck

All concrete compressive strengths were specified at an age of 28 days. However, for the mass concrete in the footings, abutments, piers, and portions of the superstructure, the special provisions allowed 80% of the specified strengths at 28 days provided 100% of the specified strengths were achieved at 56 days and no superimposed loads were placed on the element until it had reached the specified strength. Four basic types of HPC mixes were developed for the project as part of the overall corrosion protection strategy to meet the unique requirements of individual bridge elements.

Drilled Shafts

A total of 40 shafts, with diameters of 7 and 8 ft (2.1 and 2.4 m) and depths up to 95 ft (29 m), support the main bridge piers. In addition, sixty-nine 4-ft (1.2-m) diameter shafts, up to 27 ft (8.2 m) long are used for support at the north abutment and at the 2nd Street overpass north of the main bridge. To assure monolithic high quality concrete with tremie placement into slurry-filled heavily reinforced shafts, self-consolidating concrete (SCC) was used. This was the first large-scale use of cast-in-place SCC for Mn/DOT. To control temperatures in the large diameter shafts during curing, pozzolans such as fly ash and slag were incorporated as the majority of the cementitious material. This reduced the heat of hydration by approximately 50%.

Substructure

The concrete mixtures for the footings and piers were proportioned for mass concrete and durability through the use of fly ash and slag. This was important since the least concrete dimension was 13 ft (4 m) for the main pier footings and 8 ft (2.4 m) for the main pier columns. Also, because the substructure elements are adjacent to the Mississippi River, they are subject to significant moisture exposure. Mass concrete plans were developed for the footings and piers. The plans included thermal monitoring, concrete mix modifications (cementitious materials, chilled water, and cooled aggregates), placement sequence, lift heights, form insulation, and use of internal cooling pipes. The combination of a high quality monolithic element and low permeable concrete with these mixes will provide a durable substructure. Average strengths for these mixes were 12 to 23% above the two design requirements of 5000 and 5500 psi (34 and 38 MPa) for the footings and 4000 psi (28 MPa) for the piers.

Superstructure

The HPC mix used for the superstructure was based on a mix that had been used extensively by the concrete supplier in the construction of parking structures in Minnesota. The concrete was designed for a 28-day compressive strength of 6500 psi (45 MPa) and included fly ash and silica fume for low permeability. The corrosion protection plan required the superstructure concrete to have a rapid chloride permeability not exceeding 2000 coulombs at 60 days. The use of pozzolans will ensure that the permeability continues to decrease over time. The use of silica fume increases the impedance of the concrete, thereby inhibiting any corrosion that may occur in the future. The mixture was required to have low shrinkage although a maximum value was not specified. This is important in that it reduces the stresses due to shrinkage resulting in fewer cracks in the structure.

Because of the silica fume, the superstructure mix was stiffer and more of a challenge to place and finish properly. Flatiron-Manson overcame this challenge by staging a series of slab test placements off-site with the concrete mix, crews, and equipment that would be placing the concrete. Once the techniques for working with the mix had been successfully refined, concrete placement on the actual bridge superstructure proceeded easily.

Gateway Features

Two gleaming white concrete sculptures, each comprised of three wavy columns, tower 30 ft (9.1 m) high at each end of the bridge in a vertical interpretation of the universal symbol for water. These symbols serve as markers to identify that travelers are crossing the Mississippi River, a fact that was not evident on the previous bridge. The sculptures were precast using an SCC mix that included a self-cleaning, pollution-reducing photocatalytic cement. The surfaces destroy atmospheric pollutants, resulting in cleaner surfaces with little maintenance. The monuments are the first high-profile North American application of this cement. The SCC mix, with a spread of 20 to 24 in. (510 to 610 mm) and a design strength of 6500 psi (45 MPa), resulted in a marble-like, smooth white finish to the concrete surface. With a low water-cementitious materials ratio, air entrainment, and a rapid chloride permeability less than 1500 coulombs at 28 days, the monument will also be a durable feature in the severe environment adjacent to the I-35W roadway.

Conclusion

High performance concrete was a key element in the strategy for producing a high quality structure for the new I-35W bridge with a service life of at least 100 years. The committed efforts of Mn/DOT, FHWA, Flatiron-Manson, Cemstone Concrete Products, and the design team helped ensure that this important bridge was in service more than 3 months ahead of schedule.

Further Information

For further information about the design of this bridge, contact the author at aphipps@figg-bridge.com or 850-224-7400. A commemorative book about the project is available for purchase at www.figgbridge.com. All proceeds from the sale of the book benefit the Admissions Possible and the Architecture, Construction, and Engineering (ACE) mentor programs.

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HPC for 100-Year Life Span

Alan R. Phipps, FIGG Bridge Engineers, Inc.

Casting the bottom flange of the cast-in-place superstructure. Photo: Tim Davis, FIGG

With only a few weeks from collapse of the old bridge to commencement of reconstruction, there was no time to develop the concrete mixes from first principles. Consequently, concrete mixtures that had been used successfully in parking structures and on other projects were utilized. In addition, the conventional Minnesota Department of Transportation (Mn/DOT) mixtures could not be used because they would not provide the required levels of long-term performance.

Although specific limits for rapid chloride permeability and shrinkage were not specified for every element, these properties were measured for some of the mixes. The four elements that required specific mixture proportioning were the drilled shafts, footings, piers, and superstructure. Each element had its own challenges and solutions.

Drilled Shafts

The concrete for the drilled shafts consisted of a ternary blend of fly ash, ground-granulated-blast-furnace slag, and portland cement. The aggregate gradation was selected to allow proper manufacture of self-consolidating concrete with a slump flow of 24 in. (610 mm). The concrete was air-entrained. This was not required for the exposure conditions, as the footing and soil would protect these elements from freezing and thawing, but was included to reduce the volume of cement required per cubic yard of concrete.

In the initial design process, the drilled shaft concrete strength was required to be 4000 psi (28 MPa). This was subsequently revised to 5000 (34 MPa). As strength was not the primary design criterion in the proportioning of this mixture, the required increase in the strength did not cause any need for reproportioning.

Cores removed from drilled shafts at an age of 21 days indicated an in-place strength of over 10,000 psi (69 MPa). The rapid chloride permeability of the concrete was approximately 750 coulombs at 28 days. This is considered to be very low permeability. Low heat-of-hydration concrete benefits significantly by being placed as self-consolidating concrete. The dispersion of the cementitious fraction results in a more efficient use of the hydratable materials; thus reducing the need for excess hydratable material. As a result, the heat-of-hydration is reduced at a fixed cement content, or, as used in this case, the observed compressive strength was increased. The use of self-consolidating concrete was the appropriate decision.

Footings

The footing concrete, requiring a compressive strength of 5000 or 5500 psi (34 or 38 MPa) at 28 days depending on location, was a similar mixture to that used in the drilled shafts, except that it was placed at a conventional slump of 8 in. (200 mm). Shrinkage of these mixes was about 0.04% after 28 days of drying per

ASTM C157. This is considered to be very low shrinkage. Internal cooling was used to control the temperature rise and temperature gradient in the footings.

Piers

The more interesting concrete in the substructure was used in the elegant curved piers. This concrete had several requirements. The piers are 8-ft (2.4 m) square at the waist, expanding to more than 16 x 8 ft (4.9 x 2.4 m) at the top. The entire element was mass concrete. However unlike the footings, cooling pipes could not be placed due to the nature of the formwork. This called for a much more aggressive mixture. Concrete in the piers had approximately 15% of the cementitious material as portland cement, with the remainder being a blend of fly ash and slag. Concrete was placed at a very low water-cementitious materials ratio and a slump of approximately 8 in. (200 mm) due to the high use of a dispersant. Concrete generates approximately 24 BTU/h/ft3 (250 watts/m3) during early hydration, then heat development drops off dramatically. In contrast to many mass concrete elements, these members were required to be held at a minimum temperature of 100 °F (38 °C) for 3 days so that early age strength would be developed to facilitate construction. This resulted in the unusual situation of a mass concrete element with heat being pumped into the system in order to maintain the temperature. The concrete strengths were well in excess of 4000 psi (28 MPa) at 28 days. The concrete had a rapid chloride permeability in the range of 500 coulombs at 90 days.

Superstructure

A similar mixture was used for both precast and cast-in-place elements of the superstructure. Concretes were made at a cementitious materials content of approximately 700 lb/yd3 (415 kg/m3), with 25% fly ash and 4% silica fume. The pozzolan content was less in comparison to the other project mixtures to remove the risk of surface scaling. There were several criteria required for this mixture to gauge its performance. While a low water-cementitious materials ratio and a good air-void system were necessary, they were not sufficient for a durable structure. The concrete mix was designed to have very low rapid chloride permeability. Samples cast during production had permeability values ranging from 90 to 250 coulombs at ages ranging from 28 to 90 days. The diffusion coefficient for chlorides was approximately 4x10-8 ft2/h (1x10-12 m2/second). The average concrete compressive strength at 28 days was approximately 8000 psi (55 MPa) or 23% above the specified strength of 6500 psi (45 MPa).

One of the major design criteria for this mixture was its shrinkage. Concretes were measured in the laboratory to have shrinkage of approximately 0.04% after 56 days of drying, as determined by ASTM C157. In addition, due to the very large post-tensioning stresses, both modulus of elasticity and creep coefficients were determined—a process that the specifications gave 18 months to accomplish! The structure will have been in service nearly 8 months at that time. The whole as-built structure has a very high level of resistance to the environmental loads and the service loads it will encounter during its century or more of service, using state-of-the-art concrete technology.

Further Information

For further information about the concrete mixes, contact the author at kmacdonald@cemstone.com or (651) 686-4224.

Concrete Mixes

Component	Specified Strength, PSI	w/cm Ration	Total, [1] lb/yd^3	Portland Cement ,[2] %	Fly Ash, [4] %	Slag, %	Silica Fume, %
Superstructure	6500	0.35	700	71	25	-	4
Piers	4000	0.45	575	15	16	67	-
Footing	5000 or 5500	0.45	<600	40	18	42	-
Drilled Shafts	5000	0.38	<600	40	18	42	-

1. Total cementitious materials
2. Type I low alkali
3. Meets both Class C and F

The above table lists the specified strength, water-cementitious materials ratio, total cementitious materials content, and percentages of portland cement, fly ash, slag, and silica fume used in the concrete mixes for the superstructure, piers, footings, and drilled shafts.