

MATERIALS

BY KEVIN MACDONALD, P.E., PH.D., AND ALAN PHIPPS, P.E., S.E.
CONTRIBUTING AUTHORS

SELF-

*The benefits of using
self-consolidated concrete stand
clear at I-35W bridge site*

EXPLANATORY



After the tragic collapse of the original bridge on Aug. 1, 2007, the Minnesota Department of Transportation (Mn/DOT) set a fast-tracked schedule for construction of a new I-35W Bridge in Minneapolis.



The Flatiron-Manson Joint Venture with Figg Bridge Engineers, the selected design-build team, faced completing the project in less than 15 months from the construction notice to proceed on Oct. 8, 2007. The new bridge features two concrete post-tensioned box girder structures, each approximately 1,223 ft in length with 504-ft precast segmental spans over the Mississippi River. Initially, each of the 90-ft 4-in.-wide dual box girder structures will accommodate five lanes of traffic, with design accommodations for future mass transit use.

Foundations utilizing predominantly drilled shafts were preferred in the urban site for many reasons: efficient load transfer with site subsurface conditions, scour resistance, minimal construction noise and good production speed. Most importantly, drilled shafts provided compact high-capacity foundations that could be located to avoid interference with existing utilities, a rail line, several tunnels and the previous bridge foundations. A total of 40 shafts, 7 and 8 ft in diameter and up to 95 ft deep, support the main bridge piers. In addition, 69 4-ft-diam. shafts, up to 27 ft long, are used for support at the north abutment and at the 2nd Street overpass farther north of the main bridge.

Given the subsurface conditions that included artesian water flows near the river, installation of the shafts was by the drilled slurry method with permanent steel casing and tremie concrete placement. With the fast-track project schedule, it was essential that the materials and methods used result in monolithic high-quality concrete for these shafts on which the entire bridge is supported. To achieve this, the design-build team proposed the use of self-consolidating, high-performance, high-pozzolan concrete in the drilled shafts. This was the first large-scale use of cast-in-place self-consolidating concrete (SCC) for Mn/DOT, but a routine application for Cemstone Products Co., the concrete supplier for the project.

Experienced mix

Concrete mixes used in the I-35W structure were mixes with which Cemstone had a great deal of experience. The drilled-shaft mixture, in a non-SCC form, had been incorporated into other concretes in the past decade, all with good performance. For this project, SCC was needed with certain performance properties in both the plastic and hardened states. An air content of 6-8% and a slump flow of 23 to 27 in. with a stability index of 1 or less defined the plastic properties. Cemstone used a blend of a $\frac{3}{4}$ -in., 100% crushed bedrock and a $\frac{3}{8}$ -in.-nominal-size river gravel, combined with a natural sand, to give an appropriate gradation.

In addition, a polycarboxylate-based superplasticizer and a water-binding, viscosity-modifying admixture were used to transition the concrete from a Bingham plastic, with the consistency of ketchup, which can be piled up, into a Newtonian fluid, like water, which flows under very small stresses.

In its cured state, volume stability (shrinkage), rapid chloride permeability and compressive strength were the important performance characteristics of the concrete. However, the required design strength of 5,000



Cemstone constructed a pair of mock-ups, similar to the ones shown here, to demonstrate the performance of SCC. The 5-ft-diam. tubes confirmed that the key performance components of strength, self-consolidation and resistance to chloride penetration were achieved.

psi did not govern the proportioning of the mixture. Laboratory 28-day strengths were well in excess of 7,000 psi, with an average design strength using the requirements of ACI 318 of 7,000 psi.

Because of the large shaft diameters, controlling the core temperature and differential temperatures within the concrete was important to prevent cracking or the formation of undesirable minerals as the concrete hydrated. To control the temperatures, slower-hydrating materials, pozzolans such as fly ash and slag, were incorporated as the majority of the cementitious material, with cement being significantly less than 50%. The heat of hydration, which is the amount of heat liberated as the cement transitions to the glue that binds concrete together, was reduced approximately 50% in this method. Low-heat-of-hydration concrete benefits significantly from being placed as SCC. The dispersion of the cementitious fraction results in a more efficient use of the hydratable materials, reducing the need for excess hydratable material and thereby reducing the heat of hydration at a fixed cement content or, as used in

this case, increasing the compressive strength.

Strong impersonation

To demonstrate the performance of the SCC, a pair of mock-ups was constructed at Cemstone's Minneapolis plant. The mock-ups consisted of 5-ft-diam. tubes, with a reinforcing cage of four No. 20 bars spaced at 8-in. centers (similar to the proposed shafts) approximately 2 ft from one side.

The trial placement consisted of pumping SCC with a cement content of approximately 40% (the remainder being pozzolan) and a total cementitious content well below 600 lb on the 3-ft side behind the reinforcing steel. After curing, cores were removed at three heights, as well as on the inflow and outflow sides of the steel cage, and examined under the microscope to verify texture and measure as-cast properties. The results confirmed that the key performance components of strength, self-consolidation and resistance to chloride ion penetration were achieved. Five weeks after the notice to proceed, the SCC mix was successfully placed in the 93-ft-deep

test shaft that was then used for Osterberg load cell tests.

Just restrict water

One of the challenges in the production of SCC is in control of the material at the plant. While the liberal addition of water to the mix would produce concrete that flows long distances and nearly self-levels, strength and volume stability would be compromised. Testing fluidity of the concrete visually or with a slump cone will not detect moisture condition problems, therefore strict batching controls must be maintained on aggregate moisture, admixture dosage and truck condition. Cemstone's practice is to completely discharge any wash water or other material that may be in the truck just prior to loading at the batch plant. This practice ensures that no extraneous water is added to the concrete. Moisture determinations were made on coarse and fine aggregate at a minimum of every 100 yd of production, frequently more often, to ensure accurate accounting for the amount of water being added along with the aggregate materials.

A Cemstone engineering techni-

cian was present at the plant during all concrete production for the I-35W Bridge to ensure correct admixture doses and performance of the concrete in the plant prior to shipping the load for incorporation into the structure.

Another challenge was the cold Minnesota weather in winter and early spring. Snow and ice on stockpiled material at the plant had to be minimized and any remaining moisture accounted for in the batching process to produce concrete as required on the 24/7 project schedule.

SCC was incorporated in all of the main bridge pier 7- and 8-ft-diam. shafts by mid-January 2008, and in the 4-ft-diam. shafts at the north abutment and Second Street Bridge by the following month.

Shafts were monitored for temperature and found to fall well within the described temperature profiles modeled by Cemstone's engineering department. Cross-hole sonic logging was used to confirm the quality of the in-place drilled shafts.

10,000 strong

Testing has shown the performance of the SCC mix used in the drilled shafts to exceed expectations. Cores removed from the shafts at an age of 20 days showed in-situ strengths of over 10,000 psi (versus the design requirement of 5,000 psi), providing an extra level of performance. Durability modeling performed by Cemstone for the drilled-shaft mix predicted a time to corrosion using Fickian Diffusion models of 118 years (versus a bridge design life of 100 years). In addition, laboratory permeability was determined using the AASHTO method to validate the assumed diffusion coefficients. The rapid chloride permeability of the shaft concrete at an age of 28 days was determined to be approximately 750 coulombs passed, which is considered very low permeability. Determinations made at 56 days were in the range of 300 ku, an extremely low result. Shrinkage of these mixes was determined to be in the range of 400 microstrain measured using ASTM C 157. This is

considered to be very low shrinkage at 28 days.

The use of SCC in America is less than a decade old. The decision by the design-build team, Mn/DOT and Cemstone to adopt this material for the drilled-shaft foundations on the I-35W Bridge provided construction speed and quality critical to the success of the project. At press time, it is expected that I-35 traffic will be restored by mid-September to early October 2008, as much as three months ahead of schedule and 11 months after the notice to proceed. **P&E**

MacDonald is Cemstone's vice president of engineering services and is responsible for the technical aspects of concrete, product development and technology transfer. Phipps is the senior vice president and director of operations for Figg Bridge Engineers, Tallahassee, Fla.

LearnMore!
For more information related to this article, go to: www.roadbridges.com/lm.cfm/rb090813

NEW METRO CRACKSEALER

- Environmentally "Green" – Controls Fumes
- New Hose Carrier – Reduces Operator Fatigue
- Non Contact Sealant Loading – Protects Workers
- Worry-Free Control System - Auto or Manual
- More Convenience, Performance And Safety Features



**THE ROAD IS LONG.
SO MAKE IT LAST.**

WWW.CIMLINE.COM 2601 NIAGARA LANE PLYMOUTH, MN 55447 800-328-3874 866-557-1971 FAX

Circle 760