HPC Bridge Views

Sponsored by
U.S. Department of Transportation
Federal Highway Administration
Co-Sponsored by NCBC

**Issue 60**
**Mar/Apr 2010**

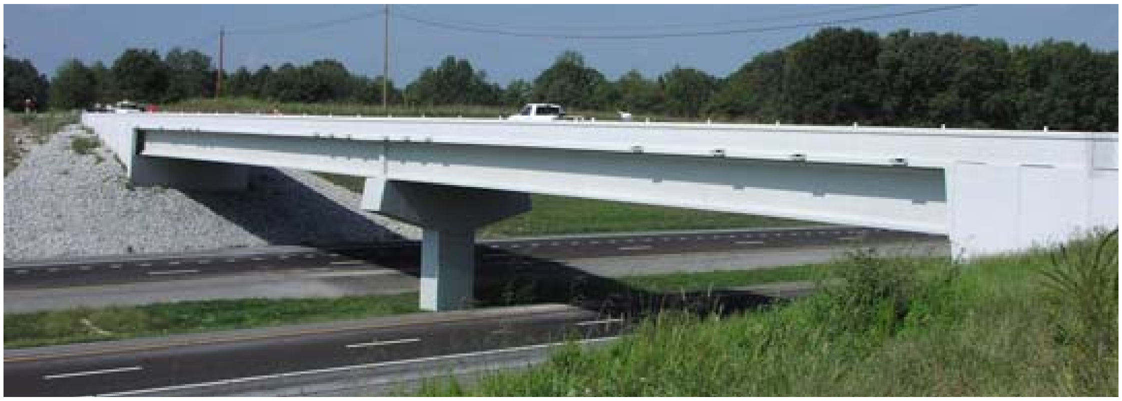
***Contents:***

***HPC Bridge Views*** is published jointly by the Federal Highway Administration and the National Concrete Bridge Council.

**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 847.998.9137
847.998.0292 fax
email:
Hhenry@hgrconcrete.comH

This material is based upon work supported by the Federal Highway Administration under Cooperative Agreement No. "DTFH61-07-H-00041".



**HPC was used in the superstructure of the Hickman Road Bridge, TN**

# High Performance Concrete Bridge Decks Revisited

*David W. Mokarem and Mohammad S. Khan, Professional Service Industries, Inc.*

In 1993, the Federal Highway Administration (FHWA) initiated a national program to implement the use of high performance concrete (HPC) in bridges. The program included the construction of one or more demonstration bridges in each of the FHWA regions and dissemination of the technology and results at showcase workshops. Nineteen bridges in 14 States were constructed. In addition to the joint state-FHWA HPC initiative, other states have independently implemented the use of HPC in various bridge elements.

The bridges are located in different climatic regions of the United States and use different types of superstructures. The bridges demonstrate practical applications of high performance concretes. Construction of these bridges also provided opportunities to learn more about the placement and actual behavior of HPC in bridges. Consequently, many of the bridges were instrumented to monitor their short- and long-term performance. In addition, concrete material properties were measured for most of the bridges.

Following completion of the HPC bridges, information about the 19 bridges was compiled into a single source.(1,2) The structural systems used in the 19 HPC bridges consisted of three types. Fourteen of the bridges consisted of precast, prestressed concrete beams with a full depth, cast-in-place concrete deck. Three of the bridges consisted of precast, prestressed concrete beams supporting precast, prestressed concrete deck panels with a partial depth, composite cast-in-place concrete deck. Two bridges consisted of adjacent precast, prestressed concrete box beams one with and one without a cast-in-place concrete deck.

## Bridge Inspection

After the bridges had been in service for generally 5 to 10 years, they were inspected to assess and evaluate their in-service condition relative to the compiled data. These inspections included a visual survey and a detailed crack survey to document the number, length, and width of the transverse, diagonal, and longitudinal cracks on each deck. The crack densities were calculated from these surveys.

An in-depth analysis was performed on the concrete material properties for all the decks.(3) Analyses were made to compare the calculated crack densities to water-cementitious materials ratios (w/cm) and total cementitious materials content. These analyses were performed to determine the ranges and combinations of w/cm and cementitious materials contents that resulted in the least amount of cracking.

## Conclusions

The following conclusions were drawn from the observations and analyses performed in this investigation:

- The average crack density for all concrete bridge decks ranged from 0.003 to 0.74 $ft/ft^2$ (0.01 to 2.43 $m/m^2$) with an overall average of 0.12 $ft/ft^2$ (0.41 $m/m^2$).
- The average crack density for 14 bridges with full-depth cast-in-place concrete decks ranged from 0.003 to 0.17 $ft/ft^2$ (0.01 to 0.54 $m/m^2$) with an overall average of 0.074 $ft/ft^2$ (0.24 $m/m^2$).
- A w/cm between 0.35 and 0.40 resulted in an average crack density of 0.069 $ft/ft^2$ (0.23 $m/m^2$).
- Cementitious materials contents between 600 and 700 $lb/yd^3$ (356 and 415 $kg/m^3$) resulted in an average crack density of 0.053 $ft/ft^2$ (0.17 $m/m^2$).
- The measured compressive strengths for the cast-in-place decks ranged from 4000 to 8000 psi (28 to 55 MPa) at 28 days. There did not appear to be a correlation between 28-day compressive strength and crack density, although higher compressive strengths are generally expected to result in more cracking.(4)
- The measured permeability values ranged from 320 to 5600 coulombs and were generally less than the specified values. All values except one bridge were in the very low to moderate ranges defined by AASHTO T 277.
- There were no indications of alkali-silica reaction (ASR), sulfate attack, or other deleterious reactions.
- No significant spalling or delamination was observed on the bridge decks; however, some spalling was observed along the edges of some of the cracks.
- Observations from the Texas bridges indicated that bridge geometry influences the amount of concrete cracking, particularly when the bridge geometry results in torsional stresses from skewed supports.
- When the structural system of the bridge included skewed supports, diagonal cracks developed near the supports.

- When the structural system of the bridge included continuity over the supports, negative moment transverse cracks developed.
- Observations from the bridge in Ohio showed that longitudinal reflective cracks occurred in the asphalt topping above the edges of the adjacent boxes.

## Summary

From the data obtained from this study, a high performance concrete mixture with a w/cm between 0.35 and 0.40, cementitious materials content between 600 and 700 lb/yd$^3$ (356 and 415 kg/m$^3$), and appropriate construction practices, is expected to result in lower crack density. The associated rapid chloride permeability is expected to be in the low to moderate range for these mixtures. This average w/cm and cementitious materials content is reasonable and readily producible. These data show that if these types of concrete mixtures are produced, placed, and cured properly, they can aid in reducing the incidence of cracking in bridge decks.

The observations and analysis of collected data from the study indicated that the HPC in both decks and girders performed well. The measured properties of the HPC used in the bridges showed that the concrete met design specifications. In addition, field surveys on the individual bridge decks indicated that the material was performing well with no indication of deterioration due to material properties. The study demonstrated that HPC can be designed and fabricated in a cost effective and efficient manner to produce durable concrete bridges.

## References

1. Russell, H. G., Miller, R. A., Ozyildirim, H. C., and Tadros, M. K., "Compilation and Evaluation of Results from High-Performance Concrete Bridge Projects, Volume I: Final Report," FHWA, U.S. Department of Transportation, Report No. FHWA-HRT-05-056, October 2006, 178 pp.

2. Russell, H. G., Miller, R. A., Ozyildirim, H. C., and Tadros, M. K., "Compilation and Evaluation of Results from High-Performance Concrete Bridge Projects, Volume II: Appendixes," FHWA, U.S. Department of Transportation, Report No. FHWA-HRT-05-057, October 2006, 303 pp.

3. Mokarem, D., Russell, H., and Khan, M., “High Performance Concrete Bridge Deck Investigation,” FHWA, U.S. Department of Transportation, Report No. FHWA-HRT-10-28, November 2009, 733 pp. Available as PB 2009-115497 at www.ntis.gov.

4. Browning, J. and Darwin, D., "Specifications to Reduce Bridge Deck Cracking," HPC Bridge Views, May/June 2009.

# High Strength Concrete for the Girders of Colorado's SH58 Ramp A Flyover

*Gregg A. Reese, Summit Engineering Group, Inc. and Jim Fabinski, EnCon Colorado*

**High strength, flowable concrete was used in the curved and straight girders.**

The $31 million State Highway 58 (SH58) Ramp A Bridge in Golden, CO, features a state-of-the-art design using curved, precast concrete bridge girders to overcome the serious challenges that arise when creating complex highway interchange projects. This latest project is the fifth of six projects to date to use this technique in Colorado. This project demonstrates the benefits of this approach in constructing cost-effective, complex, long-span structures in high-profile locations, where aesthetics and urban geometrics are significant design considerations.

The ramp, which connects eastbound I-70 traffic to westbound SH58, was value-engineered by the general contractor, Ames Construction, Inc., to use curved girders. The 10-span bridge crosses Clear Creek, a bike path, three traffic openings, east and westbound I-70, and eastbound SH58.

The roadway consists of a 38-ft wide deck designed for three traffic lanes, but currently accommodates one traffic lane and two wide shoulders. Its alignment consists of a spiral curve with a minimum radius of 809 ft (247 m), which transitions to a tangent section at the bridge’s end.

The superstructure consists of two lines of 86-in. (2.18-m) deep modified Colorado Department of Transportation U84 girders spliced near the quarter points of the typical span. The bridge begins in a spiral curve in Unit 1, which continues through Unit 2 and transitions in Unit 3 to a straight section. The first and last pairs of girders in the spiral curve were cast at varying radii to form the beginning and end of the spiral curve. The remaining girders in the central curve were cast with an 809-ft (247-m) radius for both girder lines. The straight girders in Unit 3 were precast in a conventional girder bed. The superstructure contained 30 curved and 8 straight precast concrete girders. Girders varied in length from 93 ft 2 in. to 119 ft 7 in. (28.4 to 36.5 m) and weighed from 220 to 265 kips (978 to 1179 kN).

The girders were designed for handling and erection loads with varying levels of prestressing in the bottom slab. Curved girders used post-tensioning tendons. Straight girders were designed with conventional pretensioning.

## High Strength Concrete

The girder concrete was specified to have a compressive strength of 6500 psi (45 MPa) for initial post-tensioning or pretensioning and a 28-day strength of 8500 psi (59 MPa). Measured strengths ranged from 7500 to 10,000 psi (52 to 69 MPa) at 16 hours using match-cured cylinders and from 11,000 to 13,000 psi (76 to 90 MPa) at 28 days. The concrete mix proportions are given in the following table.

| **Materials**(1) | **Quantities (per yd$^3$)** | **Quantities (per m$^3$)** |
|---|---|---|
| Cement, Type III | 800 lb | 475 kg |
| Fine Aggregate | 1302 lb | 772 kg |
| Coarse Aggregate(2) | 1585 lb | 940 kg |
| Water | 272 lb | 161 kg |
| High-Range Water-Reducing Admixture | 96 fl oz | 3.71 L |
| Viscosity Modifier | 32 fl oz | 1.23 L |
| Water-Cementitious Materials Ratio | 0.34 | 0.34 |

1. Set retarders and accelerators were used as weather conditions required.
2. 3/8 in. (9.5 mm) maximum size pea gravel.

## Girder Production

The formwork for the curved girders used 10-ft (3.05-m) long chorded sections. Each 7 ½-in. (190-mm) thick web contains four 3-in. (75-mm) diameter post-tensioning ducts. The 8-in. (200-mm) thick bottom flange has significant nonprestressed reinforcement. All reinforcement was delivered straight and bent to the curve as it was tied in place. Welded wire reinforcement in 8-ft (2.4-m) wide sheets was used for the stirrups and bent to shape in one piece. All reinforcement embedded inside the girders was uncoated, whereas reinforcement protruding from the tops of the beams was epoxy coated.

The concrete was cast monolithically in the U-shaped forms. A flowable mix was designed that allowed the concrete to be placed first on one side such that it flowed across the bottom and approximately halfway up the other side. The second side was then topped off. Although the concrete had a spread of over 20 in. (510 mm), external vibration was required to help the concrete flow past the many obstacles in the girders. Special patented plastic duct chairs were developed to prevent hydraulic pressure from misplacing the post-tensioning ducts.

The use of a flowable concrete mix was essential to produce the girders. There were no signs of aggregate segregation although the concrete did require continuous monitoring. In addition to slump flow, quality control tests included air content, concrete temperature, and unit weight of the concrete. The beams were steam cured.

The success of this project and similar ones in Colorado has shown that curved, precast concrete girders are a viable option for long-span interchange construction.

### Further Information

For further information about this bridge, see ASPIRE™ Spring 2010.

### Reference

Abu-Hawash, A., Khalil, H., Schwarz, P., Phares, B., and McDonald, N., "Accelerated Construction and Innovations, The 24th Street Bridge," Proceedings, The National Bridge Conference, Bridges for Life, October 4-7, 2008, Orlando, FL, Precast/Prestressed Concrete Institute, Chicago, IL, Compact Disc, 2008.

## FHWA Research Program on Lightweight High Performance Concrete

*Gary S. Greene, Jr. and Benjamin Graybeal, Federal Highway Administration*

**Reinforced concrete beams are being tested to evaluate lap splice lengths.**

The Federal Highway Administration (FHWA) is currently conducting a study on lightweight (specified-density) high performance concrete (LWHPC) at the Turner-Fairbank Highway Research Center (TFHRC). This study includes a comprehensive experimental program to investigate the performance of lightweight concrete (LWC) with a mixture of a lightweight and normal weight coarse aggregates, commonly known as specified-density concrete. The target densities range from 125 to135 lb/ft$^3$ (2000 to 2160 kg/m$^3$). The research program is investigating the performance of LWHPC members in terms of their shear strength, short- and long-term prestress losses, transfer and development lengths of prestressing strands, and the bond strength of nonprestressed reinforcement. The intended goal of the study is to identify any necessary changes to the AASHTO LRFD Bridge Design Specifications pertaining to the use of specified-density LWHPC.

Under contract to FHWA, Russell summarized the articles in the AASHTO LRFD Specifications that currently address or should address LWC, synthesized the existing LWC research, and outlined the need for additional research.(1) The FHWA then developed a research program focusing on specified-density LWHPC to address many of these needs.

As part of this research program, 27 full-scale bridge girders and 40 beams with lap splices were fabricated by Standard Concrete Products, a company specializing in precast and prestressed concrete construction, in Mobile, AL. The girders and lap splice beams used three different lightweight aggregates (Haydite, Stalite, and Utelite), from sources geographically distributed across the United States. The Expanded Shale, Clay, and Slate Institute assisted FHWA in identifying existing specified-density concrete mix designs that could be used for the structural components tested in the research program. To date, all 40 splice beams and 9 of 27 bridge girders have been tested. A summary of the research program status is provided below.

## Lap Splice Strength of NonPrestressed Reinforcement in LWHPC

Forty reinforced LWHPC splice beams with depths of 18 in. (460 mm) and widths of 6, 9, 12, and 18 in. (150, 230, 305, and 460 mm) were fabricated and tested to evaluate the bond strength of nonprestressed reinforcement in LWHPC. Each beam had three bottom-cast, uncoated, bars lap spliced at the same location. Eighteen of the beams also had transverse reinforcement as stirrups evenly spaced over the splice length.

These tests are significant because of the paucity of bond strength test data for this type of concrete. Key test parameters include the lightweight aggregate, bar size, splice length, and the presence of transverse reinforcement. The measured 28-day cylinder compressive strengths of the concretes in the beams ranged from 5700 to 10,600 psi (39.3 to 73.1 MPa) with densities ranging from 126 to 138 $\text{lb/ft}^3$ (2018 to 2210 $\text{kg/m}^3$). Applicability of the current AASHTO LRFD and ACI 318 equations for development length of deformed bars in tension to LWHPC was determined from the test results. First, the maximum reinforcement stress in the test specimens was computed from the maximum applied moment based on equilibrium and strain compatibility. This stress was then compared with the stress calculated using the AASHTO LRFD and ACI 318 equations for development lengths.

Both the AASHTO LRFD Specifications and the ACI 318 Building Code specify modification factors for use with LWC. Alternatively, the lightweight modification factor can be calculated using the splitting tensile strength when specified.

The tension development length equation of ACI 318-08 code gave conservative estimates of average bar stress at failure for all 40 splice beam tests i.e. the experimental bar stresses were greater than calculated.

For design purposes, the AASHTO LRFD Specifications multiply the basic tension development length of an individual bar by 1.7 for lap splices where 100% of the bars are spliced and the area of reinforcement provided is less than twice the area required as provided in the test specimens. Incorporating this factor resulted in conservative predictions for all 40 tests.

## Development Length of Prestressing Strands in LWHPC Bridge Girders

Twelve AASHTO Type II girders were fabricated with varying aggregate types, prestressing force, strand size, and amount of shear reinforcement. The girders were made with specified-density concrete that had a blend of lightweight and normal weight coarse aggregate and normal weight sand. The average measured 28-day compressive strengths for the three girder mixes ranged between 7400 and 10,500 psi (51.0 and 72.4 MPa). Normal weight concrete decks were cast on the girders after they were delivered to TFHRC. A photograph of a strand development length test setup is shown below.

Development length tests have been completed on 9 of the 12 girders. Preliminary results indicate that the AASHTO LRFD Specifications provide a conservative estimate of the development length for 0.5- and 0.6-in. (12.7- and 15.2-mm) diameter strands in the specified-density LWHPC mixes investigated in this study.

## Shear Performance of LWHPC Bridge Girders

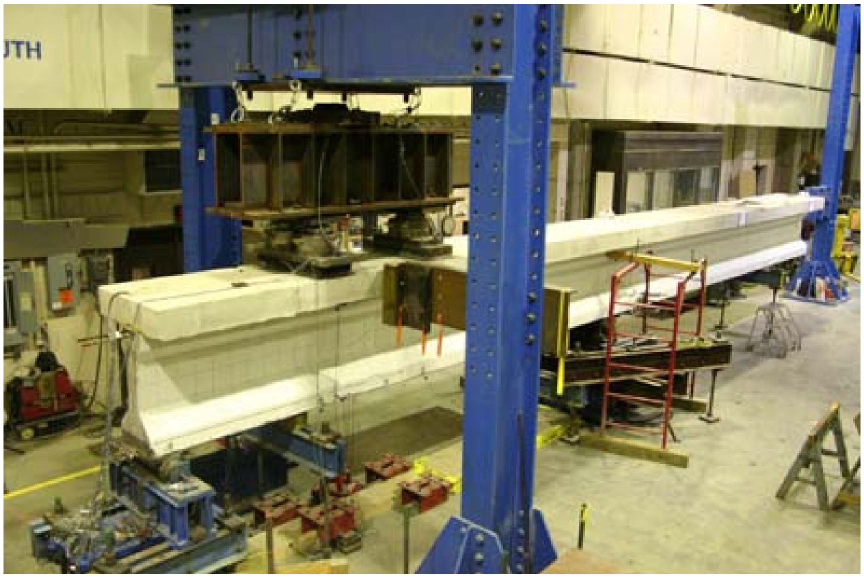
An additional nine AASHTO Type II and six BT-54 girders were fabricated alongside the twelve girders discussed above. These girders will be tested to evaluate the shear performance of LWHPC bridge girders. Parameters including quantity of shear reinforcement, prestressing force, strand size, and type of lightweight aggregate will be evaluated. The physical testing will be completed by the end of 2010.

## Prestress Losses

Long-term prestress losses are being monitored in the 15 prestressed concrete girders to be used for the shear tests. Internal concrete strains at multiple locations and long-term deflections are being measured.

## References

Russell, H. G., “Synthesis of Research and Provisions Regarding the Use of Lightweight Concrete in Highway Bridges,” FHWA U.S. Department of Transportation, Report No. FHWA-HRT-07-053, 114 pp. Available as PB2007-110768 at www.ntis.gov.



**Strand development length test of LWHPC beam.**

## Editor's Note

The research described in this article complements the research currently being performed in NCHRP Project 18-15, High Performance/High Strength Lightweight Concrete for Bridge Girders and Decks.

# ASTM Test Method for Static Segregation Resistance of Self-Consolidating Concrete

*Henry G. Russell, Henry G. Russell, Inc.*

**Apparatus used in ASTM C1712.**
**Photos: BASF**

Self-consolidating concrete (SCC) must have the ability to flow under its own weight, to pass between reinforcing bars or other obstacles without segregation, and not segregate during or after casting. Three ASTM standard test methods were described in HPC Bridge Views Issue No.

50. In 2009, ASTM International published C1712, Standard Test Method for Rapid Assessment of Static Segregation Resistance of Self-Consolidating Concrete Using Penetration Test. The test method is useful during mixture development and prior to concrete placement in the field. The test does not measure static segregation resistance directly, but provides an assessment of whether static segregation is likely to occur in normal weight concrete.

The test apparatus and protocol were developed based on tests with SCC mixtures containing saturated surface dry coarse aggregates ranging in relative density from 2.67 to 2.79 and in nominal size from 3/8 to 1 in. (9.5 to 25 mm).

The test method uses the penetration apparatus and an inverted slump cone shown in the photographs. After filling the slump cone, the hollow cylinder is aligned in the center of the cone and lowered onto the concrete surface. After 30 seconds, the penetration depth, *Pd*, is measured. Less penetration means a higher degree of static segregation resistance. A non-mandatory appendix provides the following correlation:

| **Penetration Depth in.** | **Penetration Depth mm** | **Degree of Static Segregation Resistance** |
|---|---|---|
| $Pd \leq 0.4$ | $Pd \leq 10$ | Resistant |
| $0.4 < Pd < 1.0$ | $10 < Pd < 25$ | Moderately resistant |
| $Pd \geq 1.0$ | $Pd \geq 25$ | Not resistant |