Bridge Views

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PREFABRICATED BRIDGES FOR RAPID CONSTRUCTION

Mary Lou Ralls, Texas Department of Transportation and Benjamin Tang, Federal Highway Administration

Transportation agencies today face significant challenges to restore highway capacity while enhancing safety through construction work zones. About one-third of our Nation's bridges are in need of repair or replacement. During the summer road work season, 20 percent of the National Highway System is typically under construction. This translates into 6,400 highway work zones with a corresponding loss of 6,200 lane-miles (10,000 lane-km) in capacity. On a road construction project with a high volume of traffic, the cost of traffic control can be 30 to 50 percent of the construction cost. These costs can be reduced and work zone safety enhanced through the use of accelerated construction methods.

Limited available funding and significant construction needs have resulted in initial cost controlling bridge design and construction. In addition to managing costs, owners are now responding to the need to "get in, get out, and stay out" as the advancing age of our highway infrastructure necessitates increased reconstruction. Prefabricated bridge elements and systems, in combination with HPC and accelerated construction requirements in the contracts, help meet the need for rapid bridge construction.

For example, the Virginia Department of Transportation recently replaced the superstructure of its I-95 James River Bridge without closing a single lane to rush hour traffic. Prefabricated superstructure segments with low permeability lightweight concrete decks and accelerated construction requirements were used to accomplish this feat. With 110,000 vehicles per day, the James River Bridge was reconstructed Monday through Thursday nights only from 7 p.m. to 6 a.m., with disincentives that could reach $250,000 a day for failure to open all lanes to traffic. Throughout the nighttime construction, half the structure remained open to carry traffic. The superstructure replacement was completed with partial closures on 167 nights. Conventional construction methods would have required total closure for three years.

As bridge owners strive to meet the challenges of reconstructing the nation's aging highway structures while accommodating traffic, the American Association of State Highway and Transportation Officials (AASHTO) and the Federal Highway Administration (FHWA) have teamed together to implement prefabrication nationwide.

AASHTO, through its Technology Implementation Group (TIG) panel, has been working to implement prefabrication since 2001. The panel's mission is to extend the use of prefabricated elements and systems in bridge design and construction by increasing awareness of and confidence in innovative prefabrication, and by further development and refinement of this technology. The panel has sponsored sessions and workshops; authored articles and papers; facilitated research; and published a brochure, an interactive CD-ROM, and a website featuring projects that used various types of innovative prefabrication.

The AASHTO TIG panel is now mainstreaming its activities prior to being disbanded in 2005. Together with the FHWA, AASHTO will continue its development and refinement of prefabricated systems through its Highway Subcommittee on Bridges and Structures. Working with AASHTO, the FHWA will provide the leadership role in technology transfer of innovative prefabrication. Ongoing AASHTO/FHWA activities include:

- Transfer of the AASHTO TIG prefabricated bridges web site content to the FHWA Accelerated Bridge Construction Technologies web site with a link for future access.
- Presentations on the findings from this spring's international scanning tour.
- Publication of a second brochure this summer.
- A national workshop to be held September 8-10, 2004, in New Brunswick, New Jersey.

The FHWA has been an active partner with AASHTO in the prefabricated bridges initiative from its beginning. The FHWA has sponsored and co-sponsored workshops and presented many proj-

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ect case studies on the use of both HPC and prefabricated bridge systems. Together with the industry partners, the FHWA has developed a new paradigm for constructing bridges over a relatively short time such as overnight project delivery.

In addition to the prefabrication initiative, the FHWA is undertaking a two-pronged process to help states deploy accelerated construction technology. The process involves deploying a team of highly experienced technical experts in numerous disciplines who work with the state owners to scope the project from conception through construction. The process aims at collapsing the timeframes in various tasks before traffic flow is interrupted. The second part of the process is to focus on the bridge construction activity in the critical path. By using prefabricated bridge elements and systems to quickly erect structures, work can be completed in a shorter timeframe. The FHWA is compiling case studies that used different elements and systems and will share the gained knowledge with the community through various workshops in the near future.

High performance concrete (HPC) facilitates the use of prefabrication in design, construction, and long-term performance.* HPC offers the following advantages that are useful in prefabricated bridge elements and systems:

- High early strength concrete facilitates form removal and, therefore, can speed production ("get in").
- High strength concrete can be used in design to reduce the number of required beams or their size and, therefore, reduce hauling and lifting weights ("get out").
- Supplementary cementitious materials improve durability for a longer service life of prefabricated systems ("stay out").

The combination of prefabrication, HPC, and accelerated construction requirements in contracts helps the FHWA and AASHTO meet today's bridge construction challenges.

Web Sites

For further information, see the following web sites:

AASHTO:
www.aashtotig.org/focus_technologies/prefab_elements/
FHWA:
www.fhwa.dot.gov/bridge/prefab/index.htm

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* *See HPC Bridge Views Issue No. 21 May/June 2002.*

MAXIMUM EFFECTIVE CONCRETE STRENGTHS IN PRETENSIONED BEAMS

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

The use of high strength concrete in precast, prestressed concrete beams allows for a higher precompression to be applied to the beams. Consequently, the tensile stress in the bottom flange calculated from the applied bending moment can be higher without exceeding the tensile stress limit. Since the tensile stress limit in the bottom flange at service load usually controls the design for long-span beams, higher compressive strength concrete allows the use of longer span lengths, wider beam spacings, shallower sections, or a combination of these benefits. Articles in previous editions of *HPC Bridge Views* have illustrated many actual applications, yet few have had specified concrete compressive strengths above 10,000 psi (69 MPa).

For high strength concrete to be used efficiently, it needs to be precompressed to the maximum value allowed by the design specifications. Therefore, as the specified concrete compressive strength increases, the prestressing force also needs to increase. The amount of force depends on the diameter, spacing, and strength of the strand and shape of the bottom flange of the beam. Once the bottom flange is full of strands, additional strands can only be placed in the web, which is less efficient because the strands are closer to the neutral axis.

In a parametric study using concrete compressive strengths from 6,000 to 12,000 psi (41 to 83 MPa), Zia et al.(1) reported that the strength level at which the use of higher strength concrete was not beneficial varied between 8,000 and 12,000 psi (55 and 83 MPa) depending on the beam cross section and the prestressing force.

Russell(2) examined the effect of concrete strengths from 6,000 to 14,000 psi (41 to 97 MPa) on maximum span length for various girder spacings. In most combinations, maximum span lengths increased as concrete compressive strengths increased, although the rate of increase declined. In some combinations, a plateau was reached at concrete compressive strengths of 8,000 to 12,000 psi (55 to 83 MPa) depending on strand diameter, beam cross section, and girder spacing.

A similar study by Kahn and Saber(3) concluded that the maximum effective girder compressive strength with 0.5-in. (12.7-mm) modified strand (area = 0.167 sq. in. or 108 sq. mm) varied from 8,000 to 11,000 psi (55 to 76 MPa), depending on beam spacing and cross section. For 0.6-in. (15.2-mm) diameter strand, the effective strengths ranged from 10,000 to 13,000 psi (69 to 90 MPa).

Based on a cost-efficiency index, Russell et al.(4) concluded that the maximum useful concrete strength was in the range of 9,000 to 10,000 psi (62 to 69 MPa) with 0.5-in. (12.7-mm) diameter strands. With 0.6-in. (15.2-mm) diameter strands, the maximum useful strength increased to about 12,000 psi (83 MPa) for bulb-tee beams. With a U-beam having a bottom flange with three rows of strands, strengths up to 14,000 psi (97 MPa) were beneficial.

In summary, the maximum effective concrete strengths for readily available pretensioned beam shapes range from 8,000 to 11,000 psi ((55 to 76 MPa) with 0.5-in. (12.7-mm) diameter strands and 10,000 to 14,000 psi (69 to 97 MPa) with 0.6-in. (15.2-mm) diameter strands.

References

1. Zia, P., Schemmel, J. J., and Tallman, T. E., "Structural Applications of High-Strength Concrete," North Carolina Center for Transportation Engineering Studies, Report No. FHWA/NC/89-006, Raleigh, NC, 1989, 330 pp.
2. Russell, B. W., "Impact of High Strength Concrete on the Design and Construction of Pretensioned Girder Bridges," PCI Journal, Vol. 39, No. 4, July/August 1994, pp. 76-89.
3. Kahn, L. F. and Saber, A., "Analysis and Structural Benefits of High Performance Concrete for Pretensioned Bridge Girders," PCI Journal, Vol. 45, No. 4, July/August 2000, pp. 100-107.
4. Russell, H. G., Volz, J. S., and Bruce, R. N., "Optimized Sections for High-Strength Concrete Bridge Girders," FHWA, U. S. Department of Transportation, Report No. FHWA-RD-95-180, 1997, 156 pp.

SELF-CONSOLIDATING CONCRETE IN MAINE

Joseph L. Hartmann, Federal Highway Administration and Denis Dubois, Maine Department of Transportation

Over the last decade, the Maine Department of Transportation (MDOT) has been an aggressive pursuer of emerging and advanced concrete technologies. MDOT has incorporated the use of pozzolans and admixtures into mix designs in an effort to utilize the elevated durability characteristics of high-performance concrete (HPC) in their bridge inventory. In late 2002, MDOT and a local precast concrete producer discovered a mutual interest in using self-consolidating concrete (SCC) on a bridge project.

SCC is engineered to flow readily into place without segregation of the constituent materials; thereby, alleviating the difficulty of placing concrete in complex formwork or around congested patterns of reinforcing steel and prestressing strands. The result of using SCC can be a significant reduction in the vibration and finishing demands.

After reviewing their inventory of products typically used for bridge construction, MDOT decided to use SCC in the fabrication of some precast, prestressed concrete adjacent box beams. Normally, the beams are constructed in stages; cast the bottom slab first, install the void material and remaining reinforcing steel, and cast the remaining concrete. The delay between casting the bottom slab and the remaining concrete has a potential to cause cold joints in the beams. The complexity of the beam shape, amount of reinforcing steel, top strand layout, and required inserts can make this technique impractical. Therefore, the producer elected to place the voids and tie all reinforcing steel prior to casting the concrete. With this technique, concrete must flow under the void and consolidate around the prestressing strands and reinforcement in the bottom flange of the box with the aid of internal vibrators. Since the vibrators can only access the bottom flange through the thin web section on the sides of the void, there is a possibility of entrapping air voids. Ensuring proper placement of the bottom flange concrete is difficult and time consuming. For this reason, box beams were a perfect application for SCC.

MDOT chose the Ogunquit Beach Bridge project to showcase the use of SCC. This project consisted of a two-stage replacement and widening of an existing steel beam superstructure bridge. The replacement structure is comprised of thirty-three 32-in. (813-mm) deep by 48-in. (1219-mm) wide precast, prestressed concrete adjacent box beams. The bridge has three-spans of approximately 70, 72, and 70 ft (21.3, 21.9, and 21.3 m), 11 beam lines, and a 28-degree skew. At the time this project was identified for implementation of SCC, production was already underway on the box beams for use in the first stage of construction. Therefore, only the second stage beams were cast with SCC.

The concrete requirements for this project were a compressive strength of 6000 psi, (41 MPa) at 28 days, maximum water-cementitious materials ratio of 0.40, and an air content of 5.5 to 7.5 percent. The SCC needed to meet the same requirements. Other details of the SCC mix, such as slump spread limits, visual consistency, and maximum mortar halo around the spread were agreed upon prior to production. The SCC used for the casting of the girders had a spread of 18 to 24 in. (460 to 610 mm) and an approximate unit weight of 143 lb/cu ft (2290 kg/cu m).

As with the introduction of all new technologies, there was an associated learning curve with the use of SCC. The involvement of the admixture supplier during the girder production significantly minimized the number of lessons learned resulting in the successful fabrication of 14 out of 15 box beams without defects.

After one beam was removed from the casting bed, a light sandblast revealed a line across the end of the beam, similar to a cold joint. Further investigation discovered a lack of bond across the line for the full width of the beam for a depth of 4 to 10 in. (100 to 250 mm). Many of the other beams had similar lines but not as pronounced as the one beam. Twelve cores taken from eight other beams revealed no lack of bond across the line. The extent of the problem was determined to be isolated to a single beam.

Further research in the use of SCC revealed that it is common to have lines that appear at the interface between successive lifts or layers of concrete placed into the forms. The lines and lack of cohesion, also called "folds" are a problematic characteristic of SCC. It is the result of the thixotropic behavior of SCC and is generally the result of improper placement techniques, material or formwork temperature differences, or time between consecutive casts. To avoid "folds," it is important to proceed with the casting of SCC as continuously as possible. The single beam was determined to be repairable and a sealant was applied on the exposed face of the beam to prevent water and chloride intrusion.

The Ogunquit Beach Bridge is now open to traffic and is considered another successful implementation of advancing technology by the state.

Concrete Mix Proportions

Material	Quantities	
	per yd^3	per m^3
Portland Cement[(1)]	689 lb	409 kg
Fly Ash, Class F	122 lb	72 kg
Fine Aggregate	1316 lb	781 kg
Coarse Aggregate	1420 lb	842 kg
Total Water	308 lb	183 kg
Corrosion Inhibitor	5.0 gal	24.8 L
Set Retarder	54 fl oz	2.09 L
HRWR	74 fl oz	2.86 L
Viscosity Modifier	23 fl oz	0.89 L
Air Entrainment	13 fl oz	0.50 L
w/cm ratio	0.38	

(1)Type 30

Further Information

For further information, contact the second author at denis.dubois@maine.gov or 207-624-3406.

Question

Does the use of high strength concrete reduce prestress losses in pretensioned bridge beams?

Answer

Experimental evidence shows that higher strength concrete has a higher modulus of elasticity and a lower creep coefficient than conventional strength concrete. The ultimate shrinkage of high strength concrete is lower than that of conventional strength concrete, even though early age shrinkage may be equal or even higher. It would, therefore, appear that high strength concrete would have lower prestress losses from elastic shortening, shrinkage, and creep. However, this is not always the case. Higher strength concrete allows more prestressing force and thus increased member capacity. Consequently, the total losses may be lower or higher depending on the level of prestress and other factors.

Consider an NU 2000 I-beam with a depth of 78.7 in. (2000 mm), containing fifty-six 0.5-in. diameter strands, on a simple span of 127 ft (38.7 m), and with concrete strengths of 3.5 ksi (24 MPa) at prestress transfer and 5.0 ksi (35 MPa) at service. Using the Detailed Method of NCHRP 18-07,(1) the calculated total prestress loss is 43.3 ksi (299 MPa), or 21.6 percent of the initial prestressing force (Case 1). The same beam with concrete strengths of 7.0 ksi (48 MPa) at transfer and 11.0 ksi (76 MPa) at service has a calculated loss of 27.2 ksi (188 MPa) or 13.6 percent (Case 2). However, the increased concrete strength offers an opportunity for the member to span 147 ft (44.8 m) using fifty-six 0.6-in. (15.2-mm) diameter strands. This change results in a calculated loss of 34.1 ksi (235 MPa) or 17.0 percent of the initial prestressing force (Case 3). The contribution of each of the components to the total loss is given in the table.

Impact of Concrete Strengths and Prestress Levels on Prestress Loss Components(1)

Property	Case 1	Case 2	Case 3
Span, ft.	127	127	147
f'_{ci}, ksi	3.5	7.0	7.0
f'_{c}, ksi	5.0	11.0	11.0
Prestressing strands	56 – 0.5	56 – 0.5	56 – 0.6
Elastic loss, ksi	23.1	16.5	23.0
Shrinkage loss, ksi	9.6	6.2	5.8
Creep loss, ksi	8.2	2.1	2.9
Relaxation loss, ksi	2.4	2.4	2.4
Total loss, ksi	43.3	27.2	34.1
Percent loss	21.6	13.6	17.0

The loss calculations for these examples were performed in accordance with the Detailed Method of NCHRP 18-07, which is being considered for incorporation into the AASHTO LRFD Bridge Design Specifications. If the Refined Estimates Method of the 2003 edition of the LRFD Specifications is used, the corresponding total losses for the three examples are 55.6 ksi (383 MPa) or 27.7 percent, 49.6 ksi (342 MPa) or 24.7 percent, and 67.5 ksi (465 MPa) or 33.6 percent. The lower values estimated with the NCHRP method reflect a more precise prediction of the time-dependent properties of high strength concrete and a more precise method of calculating losses.

Reference

1. Tadros, M. K., Al-Omaishi, N., Seguirant, S. J., and Gallt, J. G., "Prestress Losses in Pretensioned High-Strength Concrete Bridge Girders," NCHRP Report 496, Transportation Research Board, Washington, DC, 2003, 63 pp.

Answer contributed by Maher K. Tadros of the University of Nebraska-Lincoln. He may be contacted at mtadros@mail.unomaha.edu or 402-554-4842.

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