# HPC Bridge Views

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## HPC for Route 36 Highlands Bridge, NJ

*Chester Kolota, Federal Highway Administration*

Route 36 Highlands Bridge, New Jersey.

The Route 36 Highlands Bridge in Monmouth County, NJ, replaces the existing bridge, a 1240-ft (378-m) long, low-level, double-leaf bascule bridge that connects the boroughs of Highlands and Sea Bright. The bridge is part of an emergency evacuation route from the seashore towns to the mainland. The new mid-level fixed bridge over the Shrewsbury River consists of twin 65-ft (20-m) high segmental box girder structures that are approximately 1611 ft (491 m) long with a maximum span of 232 ft (71 m). The new bridge will eliminate many existing substandard features of the old bridge and remove the vehicular and marine traffic conflicts that existed with the movable bridge. Construction is scheduled to be completed by spring 2011.

Components of the Highlands Bridge were precast at three different plants: square piles at Precast Systems in Allentown, NJ; cylindrical piles at Bayshore Concrete Products in Cape Charles, VA; and segmental box girders and the pier columns at Unistress Inc. in Pittsfield, MA. Different concrete compressive strengths were specified for different components.

### Performance Requirements

The use of high performance concrete (HPC) was critical for this project due to the bridge being located in a salt water environment as well as exposed to roadway deicing salts. In order to mitigate these environmental risks, the New Jersey Department of Transportation specified the following performance requirements for development of the HPC mix design:

| Property | Age, days | Test Procedure(1) | Requirement |
|---|---|---|---|
| Compressive Strength P-2 | 56 | T 22 | ≥ 7000 psi (≥ 48 MPa) |
| Compressive Strength P-4 | 56 | T 22 | ≥ 8000 psi (≥ 55 MPa) |
| Compressive Strength P-5 | 56 | T 22 | ≥ 9000 psi (≥ 62 MPa) |
| Modulus of Elasticity | 28 | C469 | ≥ 6000 ksi (≥ 41 GPa) |
| Creep(2) | 180 | C512 | ≤ 0.31 millionths/psi (≤ 50 millionths/MPa) |
| Shrinkage(3) | 28 | C157 | ≤ 600 millionths |
| Chloride Permeability | 56 | T 277 | ≤ 1000 coulombs |
| Abrasion Resistance | 28 | C944 | ≤ 0.04 in. (≤ 1.0 mm) |

1. Test procedures beginning with a C are ASTM designations. Test procedures beginning with a T are AASHTO designations.
2. Test specimens loaded at 28 days and under load for 180 days.
3. After 32 weeks of drying following 4 weeks of wet curing.

Acceptance requirements for the production HPC consisted of the following:

- Air entrainment = 5.5 ± 2.0%
- Slump = 6 ± 2 in. (125 ± 50 mm)
- Chloride permeability at 56 days ≤ 2000 coulombs
- 56-day concrete compressive strength ≥ 6400, 7400, and 8400 psi (44, 51, and 60 MPa) for Class P-2, P-4, and P-5, respectively.

### Concrete Mix Proportions

A Class P-5 concrete with the following mix proportions was used for the pier segments and the segmental box girders:

### Concrete Mix Proportions

| Material | Quantities (per yd³) | Quantities (per m³) |
|---|---|---|
| Cement, Type I | 736 lb | 437 kg |
| Fly Ash, Class F | 130 lb | 77 kg |
| Fine Aggregate | 1321 lb | 784 kg |
| Coarse Aggregate | 1600 lb | 949 kg |
| Water | 263 lb | 156 kg |
| High-Range Water-Reducing Admixture | 43 fl oz | 1.66 L |
| Air-Entraining Mixture | 4.5 fl oz | 175 mL |
| Water-Cementitious Materials Ratio | 0.30 | 0.30 |

### Segmental Match Casting using HPC

Production time for the precast pieces was critical when using HPC due to the low water-cementitious materials ratio combined with the high cementitious materials content. A Type F high-range water-reducing (HRWR) admixture was used in large quantities to improve workability. However, once the HRWR admixture began to dissipate, workability became more difficult for the finishers. The potential for the concrete setting before it could be finished was mitigated by the use of a roller screed that enabled the segment to be finished very quickly. Both the pier and the box girder segments used a single-sided match-cast system. Low pressure steam was used to cure the segments, but because they were match cast, each segment was steam cured twice. Following a pre-steaming period of 4 hours, the segments were steam cured for approximately 8 to 10 hours, which achieved the 2500 psi (17 MPa) strength required to remove formwork. The segment was then allowed to cool and moved to the match-casting bed, where it was positioned against the formwork for the next segment. After placing concrete for the next match-cast segment, the initial segment was steamed again for 8 to 10 hours until the new segment achieved the stripping strength.

A mix with fly ash can slow down strength development and production. However, the mixes used almost always made the required strength for post tensioning within 3 days, which allowed the contractor to transversely post-tension the segment and grout it quickly to keep ahead of schedule. Final 28- and 56-day concrete compressive strengths averaged between 8500 and 10,000 psi (59 and 69 MPa), well above the required strengths.

### Further Information

Further information about the Route 36 Bridge is available in ASPIRE, Summer 2010 and from the New Jersey Department of Transportation at http://www.state.nj.us/transportation/commuter/roads/route36highlands.

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10,000 psi (69 MPa) concrete was used in the beams.

## High Strength Concrete for the Hoosick River Crossing

*Ben Cota, J.P. Carrara & Sons, Inc.*

The new four-span Hoosick River Crossing carries Route 7 across the Hoosick River in the town of Hoosick, Rensselaer County, in the northeast corner of New York State. The new bridge replaced an existing steel bridge that was originally built in 1932 and rehabilitated in 1976.

The new bridge consists of two end spans with a length of 115 ft (35.1 m) and two interior spans of 137 ft (41.8 m). The cross section utilizes five beam lines of New England bulb tees (NEBT 2000) with a depth of 78.7 in. (2000 mm) at a spacing of 9.0 ft (2.7 m) and a 9½-in. (240-mm) thick cast-in-place concrete deck.

### Precast, Prestressed Concrete Beams

The longer precast, prestressed concrete beams contain a total of fifty-two 0.6-in. (15.2-mm) diameter strands including 10 draped strands and 6 top strands. The total prestressing force was 2.3 million lb (10 MN). The shorter beams contain a total of fifty 0.6-in. (15.2-mm) diameter strands and required a prestressing force of 2.2 million lb (9.8 MN). Bursting reinforcement at the ends of the beams consists of pairs of No. 6 stirrups at 2¾ in. (70 mm) centers. Shear reinforcement consists of pairs of No. 4 stirrups at a spacing varying from 4 in. (100 mm) at the ends of the beams to 24 in. (610 mm) at midspan. The longer and shorter beams weighed 73 and 62 tons (66 and 56 Mg), respectively.

### High Strength Concrete

The specified concrete compressive strengths for the precast, prestressed bulb-tee beams were 7100 psi (49.0 MPa) at prestress transfer and 10,000 psi (69.0 MPa) at 56 days. An air content of 5 to 9% was specified. The concrete was placed at an 8 to 10 in. (200 to 250 mm) slump. The following concrete mix proportions were used:

| Material | Quantities (per yd$^3$) | Quantities (per m$^3$) |
|---|---|---|
| Cement, Type III | 750 lb | 445 kg |
| Silica Fume | 50 lb | 30 kg |
| Fine Aggregate(1) | 1000 lb | 593 kg |
| Coarse Aggregate(2) | 1850 lb | 1100 kg |
| Water | 216 lb | 128 kg |
| High-Range Water-Reducing Admixture | 64 fl oz | 2.47 L |
| Set Retarder | 32 fl oz | 1.23 L |
| Air-Entraining Mixture | 9 fl oz | 350 mL |
| Corrosion Inhibitor | 5 gal. | 24.76 L |
| Water-Cementitious Materials Ratio | 0.27 | 0.27 |

1. Fineness modulus of 2.78
2. ¾ in. (19 mm) maximum aggregate size

Prior to approval of the concrete mix proportions, the New York State Department of Transportation required the mix design to satisfy the state requirements for freeze-thaw durability, scaling resistance, modulus of elasticity, shrinkage, creep, and chloride penetration. In addition, the concrete was required to contain a minimum of 5% silica fume measured as a percentage of the total cementitious materials. The goal is to achieve a bridge with a 75-year service life. The concrete mix was qualified for use on this specific project.

**Beam Production**

Concrete for each longer beam was produced in four batches of 9.25 $yd^3$ (7.1 $m^3$) each for a total of 37 $yd^3$ (28.3 $m^3$). For the shorter beams, six batches of 10.8 $yd^3$ (8.3 $m^3$) each were used to produce two beams. Ambient temperatures during production ranged from 65 to 85°F (18 to 29°C) and concrete temperatures at time of placement ranged from 75 to 86°F (24 to 30°C), which were less than the specified maximum temperature of 90°F (32°C). The water content of the first batch for each placement was measured using AASHTO T 318, Water Content of Freshly Mixed Concrete Using Microwave Oven Drying. Slump and air content were measured for each batch. Cylinders representing each batch were cast and cured with the beams until the specified strength was achieved.

Although the concrete had a measured slump of 8½ to 10¼ in. (215 to 260 mm), both internal and external vibration were used to ensure adequate concrete consolidation in the areas of congested reinforcement. Measured air contents ranged from 5 to 8½% with an overall average of 6.3%. The average measured compressive strengths at transfer and 28 days were 7580 and 11,270 psi (52.3 and 77.7 MPa), respectively.

**Lessons Learned**

Two lessons were learned about the concrete mix design:

- The low sand content made it difficult to achieve the air content at the high slump
- Mechanical consolidation with both internal and external vibrators was tedious. Self-consolidating concrete will be used in the future

**Further Information**

For more information about this project, contact the author at bcota@jpcarrara.com or 802-388-6363.

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Beams for the Hoosick River Bridge.

# Field-Cast UHPC Connections for Modular Bridge Deck Elements

*Ben Graybeal, Federal Highway Administration*


Placement of UHPC into the longitudinal connection between deck bulb-tee girders. (Photo courtesy of New York State DOT.)

The use of modular bridge deck components has the potential to produce very high quality and extremely durable concrete bridge decks. Advanced cementitious composite materials, whose mechanical and durability properties far exceed those of conventional concretes, present an opportunity to significantly enhance the performance of field-cast connections thus facilitating the wider use of modular bridge deck systems. Ultra-high performance concrete (UHPC) represents a class of such advanced cementitious composite materials. Of particular interest, UHPCs can exhibit both exceptional bond when cast against hardened concrete and can significantly shorten the development length of embedded steel reinforcement. These properties allow for a redesign of the modular component connection, facilitating simplified construction and enhanced long-term system performance.

## Field-Cast UHPC Connection Details

The concept of using the advanced properties of UHPC to significantly modify the design of connections between precast concrete components is not new. Research and deployments in this area date back to at least 1995 in Denmark and Sweden.[1] More recently, the concept of using the properties of UHPC to redesign the connections between modular bridge components has been recognized in North America. As of late 2010, field-cast UHPC connections between prefabricated bridge components have been implemented in nine bridges in Ontario, Canada, and two bridges in the United States. These bridges use a range of details to connect a variety of different precast concrete modular bridge components, including adjacent box beams, full-depth precast deck panels, and deck bulb-tee girders. The connection designs used to date have tended to mimic non-contact lap splice connections with a female-female shear key profile.

The photograph shows the casting of UHPC into the longitudinal connection between the top flanges of deck bulb-tee girders on the Route 31 Bridge over the Canandaigua Outlet in New York State. This bridge was opened to traffic in 2009.

The two fundamental differences between the field-cast UHPC connection concept and conventional modular component connection concepts are simplicity and performance. This connection concept allows for small, simple connections without requiring the use of post-tensioning or the use of large volumes of field-cast concrete.

## Ultra-High Performance Concrete

Advances in the science of concrete materials led to the development of the next generation of cementitious materials, namely UHPC. As a class, these concretes tend to have high cementitious materials contents, very low water-cementitious materials ratios, compressive strengths above 22,000 psi (150 MPa), and sustained tensile strength resulting from internal fiber reinforcement.[2] Tensile behavior of UHPC stands in contrast to that of conventional concrete. The discrete steel fiber reinforcement included in UHPC components allows the concrete to maintain tensile capacity beyond cracking of the cementitious matrix. The inelastic straining of the component is resisted by the fiber reinforcement that bridges the tight, closely-spaced cracks. The mechanical behavior exhibited by UHPC allows for the full development of discrete embedded reinforcing bars in exceptionally short distances; thus facilitating the redesign of closure placements and other field-cast connections between modular components.

### Physical Testing Program

The Federal Highway Administration (FHWA) through its Structural Concrete Research Program recently completed an experimental study focused on the performance of field-cast UHPC deck-level connections between precast modular bridge components. This study was part of Transportation Pooled Fund Project 5(217), which is being completed in partnership with New York State Department of Transportation (DOT) and Iowa DOT. A summary of the study and results can be found in FHWA-HRT-11-022.(3) The full study results are in NTIS-PB2011-101995[4] available at www.ntis.gov.

Bridge deck components simulating both longitudinal and transverse connections were fabricated and tested under both cyclic and static wheel patch loadings. The loading program was designed to allow for the assessment of three critical behaviors. First, cyclic loading below the cracking load allowed for the assessment of the cracking performance of the field-cast UHPC and the bonding performance of the UHPC to the precast concrete interface. Second, cyclic loading generating stresses above the static cracking stress of the specimen allowed for the assessment of the cracking performance of the system, including whether there was any uncontrolled, progressive cracking or any interface debonding. Finally, the loading program allowed for the assessment of the static overload performance of the system.

### Test Results

The results of this test program, in combination with the experience gained through deployments of field-cast UHPC-filled connections, have demonstrated the viability of this connection system for precast modular bridge deck components. The structural behavior of the UHPC-filled connections tested in the FHWA research program fulfilled the requirements for deck behavior. The study also demonstrated that the non-contact lap spliced reinforcement in the transverse and longitudinal UHPC-filled connections was not susceptible to debonding from the UHPC under cyclic and static loadings. The most severe cyclic test concluded with the metal fatigue failure of a series of straight, uncoated No. 5 (16M) steel reinforcing bars, which were lapped over a 5.9 in. (150 mm) length in a non-contact lap splice configuration. No evidence of the reinforcing bars debonding from the field-cast UHPC was observed.

### Future Implementation

The concept of using field-cast UHPC to facilitate the use of prefabricated modular bridge components is gaining interest around the United States and Canada. The Ontario Ministry of Transportation and the New York State DOT are continuing to use this technology as appropriate projects arise. Iowa DOT is also working toward a first application. Other states are also considering the benefits of this technology as they move toward increased usage of modular components and other accelerated bridge construction technologies.

### Further Information

For further information, readers are encouraged to contact the author at 202-493-3122 or benjamin.graybeal@dot.gov.

### References

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2. Graybeal, B., Material Property Characterization of Ultra-High Performance Concrete, Report No. FHWA-HRT-06-103, Federal Highway Administration, August 2006, 186 pp.

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