ULTRA HIGH PERFORMANCE CONCRETE HIGHWAY BRIDGE

Dean Bierwagen, PE, Methods Engineer, Office of Bridges and Structures, Iowa Department of Transportation
Ahmad Abu-Hawash, PE, Chief Structural Engineer, Office of Bridges and Structures, Iowa Department of Transportation

ABSTRACT

Wapello County and the Iowa Department of Transportation were granted funding through the TEA-21 Innovative Bridge Construction Program, (IBRC) for a project using ultra high performance concrete (UHPC). Plans using UHPC in the prestressed concrete beams for a bridge replacement project in Wapello County, Iowa are being prepared. The beams will be pretensioned using 0.6 inch diameter strands and without mild reinforcing steel, except to provide composite action with the cast-in-place deck. The research will include the testing to verify shear and flexural capacities of a 70 ft long test beam. If testing efforts are successful, the UHPC design will be incorporated in the 110 ft single span bridge replacement project. Discussion of the design efforts and current progress of this research project are the focus of this report.

Keywords: Ultra High Performance Concrete, Steel Fibers, Ductal Concrete, LaFarge North America, Bulb-Tee, and Reactive Powder Concrete

INTRODUCTION

Developed in France during the 1990's, ultra high performance concrete (UHPC) has seen limited use in North America. UHPC consists of sand, cement, and silica fume in a dense, low water-cement ratio (0.15). Compressive strengths of 18,000 psi to 30,000 psi, along with low permeability can be achieved depending on the curing process. To improve ductility, steel or fiberglass fibers (approximately 2% by volume) are added, replacing the use of mild reinforcing steel. For this project the patented mix (Ductal) developed by LaFarge North America will be used.

Research is currently being conducted at Ohio University, Michigan Technological University, Iowa State University, and Virginia Polytechnic Institute and State University to help better understand UHPC properties. Testing is on going at the Turner-Fairbanks Laboratory near Washington DC on a prototype prestressed pretensioned section (pi section). In addition, an IBRC project by the Virginia Department of Transportation using UHPC in prestressed beams for a highway bridge is underway.

PROJECT BACKGROUND

In 2003, Wapello County and the Iowa Department of Transportation were granted funding through the TEA-21 Innovative Bridge Construction Program, (IBRC) for a project utilizing ultra high performance concrete (UHPC). UHPC will be used in pretensioned prestressed concrete beams in a bridge replacement project in southern Wapello County, Iowa (see Figure 1).

The beams will be pretensioned using 0.6-inch diameter low relaxation strands. No mild reinforcing steel except to provide composite action between the beam and cast-in-place deck will be used. To verify shear and flexural capacity of the beam, 10-inch and 12-inch shear beams, and a 70 ft long test beam will be cast. Testing will be by Iowa State University (ISU) and the Center for Transportation Research and Education (CTRE) in Ames, Iowa. If capacities can be verified by testing, the bulb tee section will then be used in the 110 ft single span bridge replacement project.

BRIDGE DESCRIPTION

The replacement bridge for Wapello County will be a 110 foot simple span bridge with a three beam cross section. The abutments will be integral and the 8 inch cast-in-place deck will use a high performance concrete. Beam spacing will be 9 foot 7 inches with 4 foot 0 inch overhangs. See Figure 2 for additional details.

Figure 1. Existing Bridge

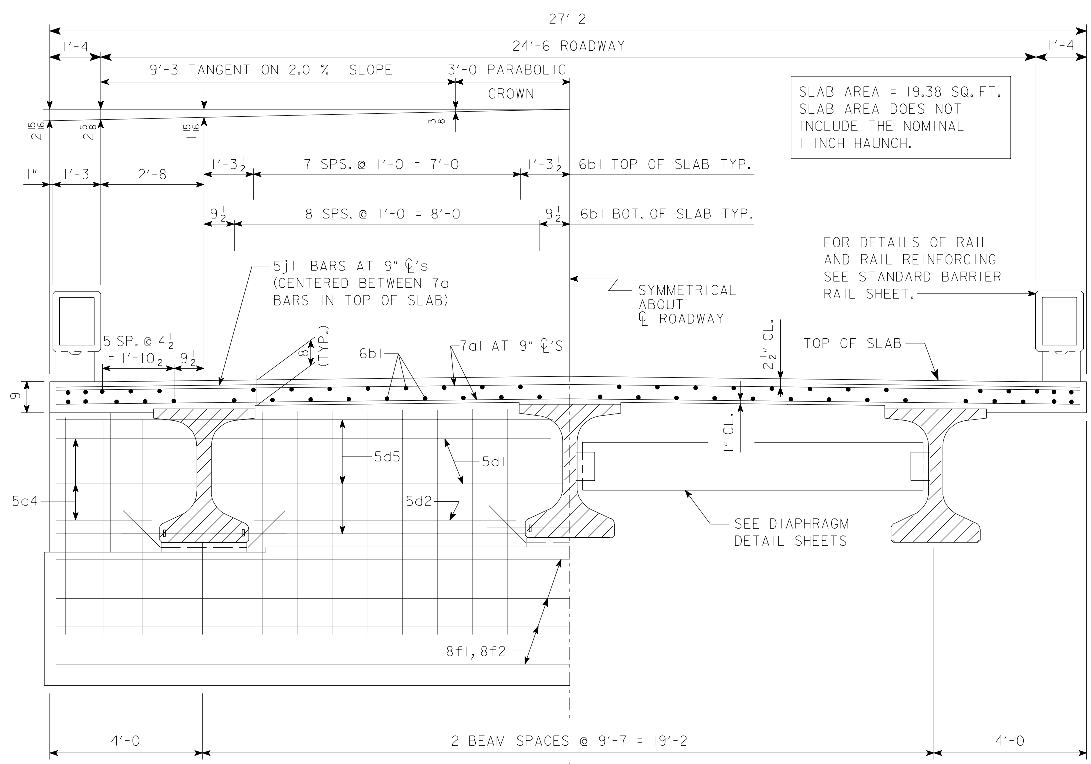

Figure 2. Bridge Cross Section

STAGES OF PROJECT

Because of the uniqueness of UHPC and the special requirements for mixing, casting and curing, this project was organized into stages as listed below to gain experience and confidence for all parties involved in the project.

1. Ultra-High Performance Concrete Design Seminar (completed 8-12-03).
2. Test batch at Iowa Department of Transportation Materials Laboratory in Ames (completed 12-11-03).
3. Review of precasting plants (completed 12-11-03).
4. Additional test batch at Materials Laboratory in Ames (completed 1-26-04).
5. Test batch at precasting plants (completed 04-12-04).
6. Casting of shear beam specimens.
7. Casting of 70-foot test beam.
8. Testing of shear and 70-foot test beams.
9. Casting of three 110-foot production beams.
10. Construction of replacement structure.

ULTRA-HIGH PERFORMANCE CONCRETE DESIGN SEMINAR

On August 12, 2003, the Iowa Department of Transportation and CTRE organized a seminar on ultra-high performance concrete to provide information to people that would be involved in the project. The seminar was sponsored by the Federal Highway Administration (FHWA) and attended by the FHWA, State, industry and academia. Speakers and topics were the following:

1. Joey Hartmann, P.E., Turner-Fairbanks Highway, Research Center, FHWA, McLean, Virginia (Research Program)
2. Eugene Chuang, Ph.D., P.E., Garg Consulting Services, Inc, formerly from MIT, (Design Issues and Section Optimization)
3. Ben Graybeal, PSI, Inc.
   (Material Testing)
4. Chris Hill, Prestress Services of Kentucky, Lexington, Kentucky
   (Design Issues and Precasting)
5. Vic Perry, P.Eng., LaFarge North America, Calgary, Alberta, Canada
   (Material Overview and Precasting Issues)
6. Brent Phares, Ph.D., ISU/CTRE, Ames, Iowa
   (Overview of IBRC Project)

TEST BATCH MATERIALS LABORATORY IN AMES

On December 11th, 2003, a test mix was produced at the Iowa DOT Materials Laboratory in Ames, Iowa. Personnel from the precasting industry, Iowa DOT, ISU and CTRE attended. LaFarge provided the test mix and Gavin Geist from LaFarge demonstrated the mixing procedure (See Table 1 for mix proportions). For the demonstration, a 1958 Lancaster mixer with a two cubic foot capacity was used to produce a one cubic foot batch (See Figure 3 and 4). Three inch by six inch test cylinders were cast along with four inch by four inch by eighteen inch beams (See Figure 5). Specimens were cast on a vibrating table using a small plastic tremie tube. Curing of the specimens took place in sealed metal containers placed in ovens at 140 degrees F for 72 hours.

Table 1. Test Mix Proportions

Description	Quantity
Ductal Mix	137 lbs
Water	8.03 lbs
3000NS (Super Plasticzer)	850 g
Steel Fibers	9.7 lbs

Figure 3. Mixing of UHPC

Figure 4. Addition of steel fibers

After the demonstration and casting, an open discussion took place to address questions and potential problems that could develop using the UHPC in a production mix.

In addition, Mr. Geist inspected two precasting plants in the area that expressed an interest in casting the beams for the project. This inspection was part of a certification process that required test batches be performed on site.

Figure 5. Casting of 3 inch x 6 inch test cylinders

Results of the test cylinder compressive strengths are shown in Table 2 (See Figure 6). Results of the flexure test of the 4-inch by 4-inch by 18-inch beam showed initial cracking at 2,529 psi and an ultimate capacity of 2,933 psi (See Figures 7 and 8).

Table 2. Compressive Strengths of 12-11-03 mix

Cylinder	Compressive Strength (psi)
1	15,896
2	16,123
3	20,004
4	15,943

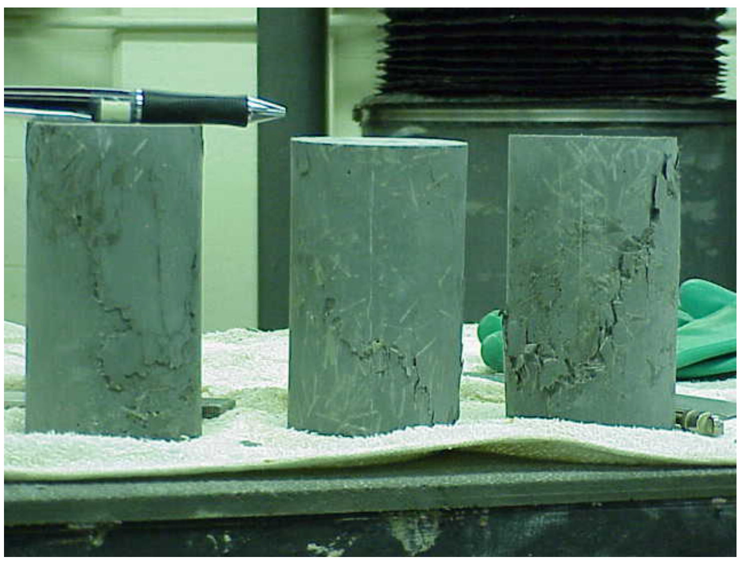

Figure 6. Broken 3 inch x 6 inch test cylinders

Figure 7. 4 inch x 4 inch x 18 inch flexure beam

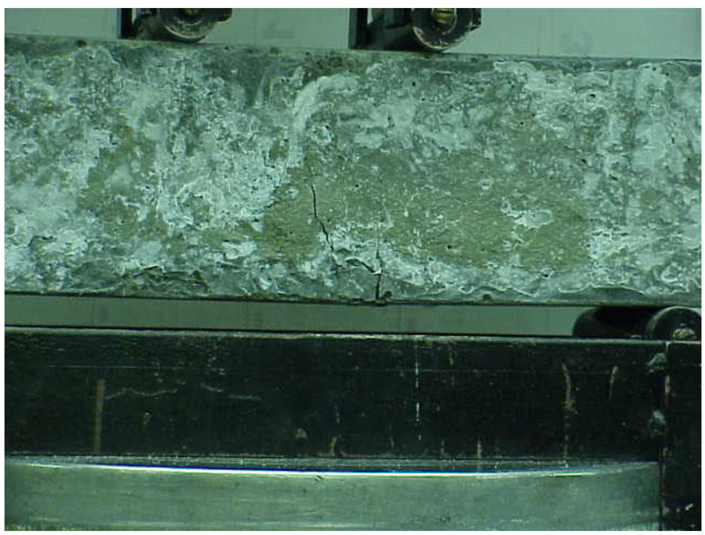

Figure 8. Failed 4 inch x 4 inch x 18 inch test beam

Lower than expected compressive strengths were found (predicted 30,000 psi) when the cylinders were tested, and the following reasons may have contributed to the reduced strengths:

1. Steam curing was started 24 hours after casting and before initial set had taken place. Without accelerators, initial set can take up to 40 hours.

2. There was difficulty in achieving plane ends of test cylinders for uniform compressive loading. The ends of the cylinders were trimmed with a concrete saw to provide square ends.
3. Visual inspection of a cylinder that was cut lengthwise showed higher than expected air voids.

Because of these problems, and to gain more experience working with the mix, the IDOT Materials Lab produced a second test batch on January 26th, 2004. Three by six inch test cylinders, two-inch cubes and four inch by four inch flexure beams were cast. Casting of the two-inch cubes provided a test specimen with plane sides that did not require end preparation. Specimens were cured in sealed steel containers in ovens at 195 degrees F with 95% humidity (See Table 3 and Table 5) and in water (See Table 4).

Table 3 (95% Humidity)

2 inch cubes	Compressive Strength (psi)
1	29,930
2	27,540
3	30,610

Table 4 (Water Cured)

2 inch cubes	Compressive Strength (psi)
1	31,210
2	30,750
3	27,640

Table 5 (95% Humidity Cured)

3 inch x 6 inch cylinders	Compressive Strength (psi)
1	23,820
2	24,570
3	22,510

Compressive strengths of the cylinders improved, but were still lower than expected for the cylinders. Difficulty in achieving plane surfaces for uniform compression loading was believed to be the main cause of the lower strength values.

The flexure beam was cured at 195 degrees F with 95% humidity and also tested at a lower than expected strength (1320 psi at failure). The beam was cast using two small tremie tubes on each end of the beam form to save time. This casting method caused a plane (cold joint) to develop at the centerline of the beam where the fibers did not cross, which reduced its flexural strength.

TEST BATCH AT PRECASTING PLANTS

A test batch was performed at Iowa Prestressed Concrete (IPC), Inc. of Iowa Falls, Iowa on April 13th, 2004. The results of the 3-inch by 6-inch cylinders, tested by LaFarge North America for IPC are shown in Table 6 and Table 7.

Table 6. Sample Set 1

3 inch x 6 inch cylinders	Compressive Strength (psi)
1-A (tested as delivered)	29,239
1-B (tested as delivered)	28,037
1-C (lab cured)	32,111
1-D (lab cured)	32,343

Table 7. Sample Set 2

3 inch x 6 inch cylinders	Compressive Strength (psi)
2-A (tested as delivered)	25,062
2-B (tested as delivered)	24,685
1-C (lab cured)	31,691
1-C (lab cured)	31,052

Concerns expressed by IPC are listed below:

1. Batching time

   Longer time to batch the mix (possibly 15 to 30 minutes per batch) and additional cleaning time for mixers because of the steel fibers and fine aggregate.

2. Equipment

   UHPC could damage mixers due to the high mixing energy required.

3. Placement

   Proper placement in forms and the requirement to produce the complete form amount before placement could be started.

4. Shrinkage of mix and modification of forms

   Because of the large amount of cement in the mix, shrinkage values were estimated to be twice the amount normally expected from standard mixes. Special modifications must be made to the forms to compensate for the additional shrinkage. Larger shrinkage will require properly timed release of the strands and removal of forms.

5. Curing Time

   Long curing time (40 hours set time) and the lost production time in the casting beds

7. Testing

   Precasters are not equipped to do the special testing required for the UHPC mix. Precasters do not have available the equipment to prepare the three inch by six inch test cylinders or do compressive testing of two inch cubes. Plans were made to complete the test at ISU.

SHEAR BEAM TESTING

Shear capacity testing of the mix was included as part of the research. CTRE and ISU will be conducting the tests on a series of smaller beam shapes (10-inch deep by 54-inch long and 12-inch deep by 64-inch long) with web widths from 1 ½ to 2-inches. See Figure 9.

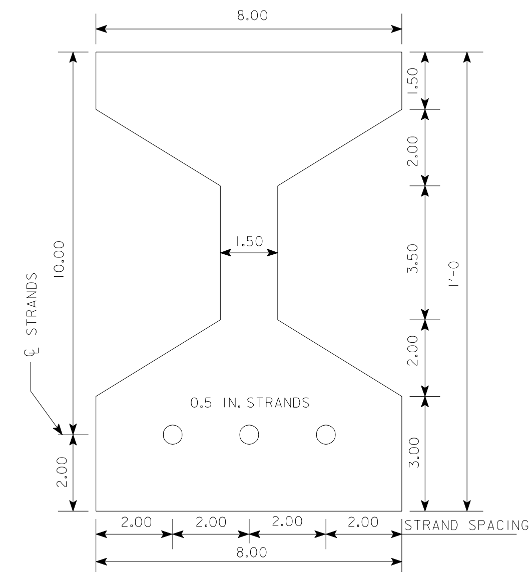

Figure 9. 12 inch shear beam cross section

BEAM DESIGN

CTRE and the Iowa Department of Transportation, Office of Bridges and Structures jointly designed the final beam section for the bridge, a modified Iowa 45-inch bulb tee. To save material in the beam section, the web width and flange thicknesses were reduced (See Figure 10 and Figure 11). Dr. Ulm of MIT reviewed the revised cross section design.

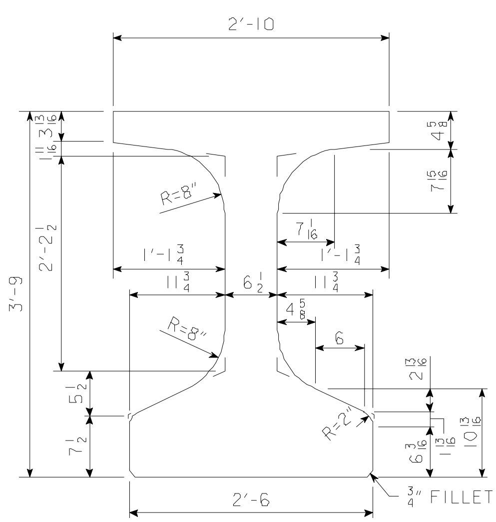

Figure 10. Iowa 45-inch Bulb Tee Section

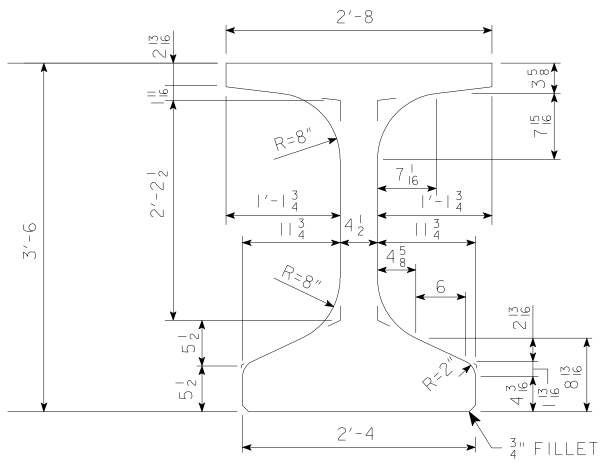

Figure 11. Modified Section for UHPC

The section design was based on the following design information:

1. Modulus of elasticity 8,000 psi
2. Release Compressive Strength 12,000 psi
3. Final Design Compressive Strength 24,000 psi
4. Allowable tension under service stress 1,000 psi
5. LRFD HL-93 loading
6. Grillage analysis for distribution factors
7. Ultimate strength based on Dr Ulm's model developed at MIT.

The design of the beam was a challenge for the staff involved. Design issues discussed are listed below:

1. Lack of approve specifications

   France has developed recommendations for the design with UHPC, but currently there are no guidelines available in the United States. A review of the service and ultimate strength checks that were recommended by the French design guide and the research model developed by Dr. Ulm were used as a guide for design.

2. Composite connection between beam and cast-in-place deck

   The test beam will be cast with three options for developing the composite connection between the beam and deck (See Figure 12). These options were necessary due to the requirement that the top of the beam be covered with plastic immediately after placement of the concrete and the plastic be in direct contact with the concrete.

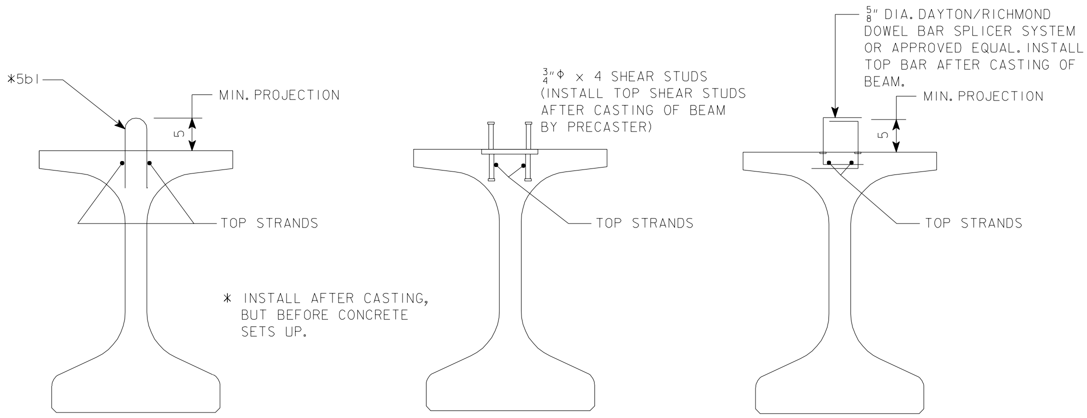

Figure 12. Composite connections

3. Strand anchorage and transfer of prestressing force

   Research completed at Ohio University, "Bond Performance Between Ultra-High Performance Concrete and Prestressing Strands" showed improved bond strength using UHPC. Because of the improved bond strength there was concern for reduced transfer lengths and higher concentration of release strengths at the beam ends. To reduce these forces debonding of the strands as well as draping of the strands were provided in the details.

4. Losses

   Because of the uniqueness of the mix, examples for loss calculations were limited and measurement of the losses in the test beam will be done.

5. Release and Final Compressive Strengths (percent difference)

   The large difference between the release (12,000 psi) and final compressive strengths (24,000 psi) of the mix proved difficult to use in the design of the prestressed beam. Release stresses controlled the number of strands that could be used in the design and limited the designer from taking full advantage of the final compressive strengths. A post-tensioning design would allow for more economical section design and should be considered in any future project.

6. Camber and Growth

   Release cambers could be calculated but factors to use for growth due to creep were not available. Estimates were made in design and field measurements will be taken to verify the estimates.

CURRENT STATUS

As of August 22, 2004 Wapello County will be receiving proposals from the precasters to produce the smaller shear beams and the 70-foot test beam. If testing of the 70-foot beam is successful, then the bridge replacement contract will be let in the fall.

CONCLUSION

This IBRC project has allowed the Wapello County, Iowa Department of Transportation, CTRE and Iowa State University, as well as local precasters the opportunity to gain valuable experience designing, testing, mixing, and casting ultra high performance concrete. Additional research in the future will need to address current design and production concerns, and develop more efficient beam designs to maximize UHPC unique structural properties.