# RAPID CONSTRUCTION OF AN ULTRA-HIGH PERFORMANCE CONCRETE BRIDGE

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ABSTRACT

The Federal Highway Administration recently constructed a prestressed concrete highway bridge that was optimized for a combination of structural, durability, and constructability aspects. The bridge, constructed at the Turner-Fairbank Highway Research Center as part of the Ultra-High Performance Concrete (UHPC) research program, has an innovative design driven by the enhanced material properties exhibited by UHPC. The 16-foot wide, 70-foot long bridge is composed of two 8-foot wide, 33-inch deep bulbed-double-tee prestressed concrete girders. The thin sections, which are devoid of mild reinforcing steel, create a relatively lightweight girder/deck combination that can easily be placed on abutments, attached to similar girders, and grouted. This paper discusses some unique design aspects of this bridge as well as its rapid construction.

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## INTRODUCTION

The ability to rapidly construct highway bridges has become increasingly important in recent years. This need has been driven by the increasingly congested nature of our nation's highways. One effort to alleviate construction congestion has been undertaken by the Federal Highway Administration in their Ultra-High Performance Concrete (UHPC) research program. This research program, which is focused on how UHPCs can best be used in highway bridges, has resulted in the construction of a prestressed concrete bridge that is well suited to rapid construction.

## BACKGROUND

The Federal Highway Administration's ongoing UHPC research program is focused on determining the best uses for this type of concrete in highway bridges. This research has included an extensive material characterization study as well as full scale structural testing of bridge girders (Graybeal and Hartmann, 2003; Graybeal 2003; Graybeal, Hartmann, and Perry, 2004). The material characterization study included testing for mechanical behaviors, durability, and long-term stability of the concrete. The full scale structural testing completed to date included flexural and shear testing of AASHTO Type II girders.

Although the worldwide UHPC market includes a number of competitors, there is currently only one UHPC commercially available in the U.S. This concrete, marketed by Lafarge, Inc. under the name Ductal®, consists of an optimized gradation of powders. This premixed powder includes fine sand, cement, ground quartz, and silica fume. This powder is mixed with water in a ratio of less than 0.20 to create a flowable concrete. A high-range water-reducing admixture aids in achieving the correct rheology. Undeformed steel fibers (0.5 in. long and 0.008 in. diameter) are added at two percent by volume to complete the mix.

This UHPC exhibits an impressive set of material properties. In terms of strength, the steam treated compressive strength is 28 ksi and the steam treated tensile strength is at least 1.5 ksi. The concrete also exhibits significant post-cracking tensile toughness. Durability test results are also quite impressive with virtually no scaling occurring after 150 cycles and very little freeze-thaw damage occurring after 700 cycles. A rapid chloride penetrability of less than 20 Coulombs passing through a steam treated specimen has also been observed. In terms of dimensional stability, this concrete exhibits significant shrinkage during setting and initial strength gain; however, after steam treatment the concrete matrix is stabilized and no further shrinkage occurs. The creep coefficient for this concrete is also very low at 0.3 for a steam treated condition.

The UHPC bridge girder structural testing completed to date has focused on the flexural and shear behavior of prestressed UHPC girders that contain no mild steel reinforcement. A flexural test of an 80 foot long AASHTO Type II girder demonstrated that this UHPC could carry significant tensile stresses up through girder failure. Three shear tests on similar girders demonstrated that the unreinforced, six inch thick web on this girder could carry between 400 and 500 kips of shear force prior to failing.

## BRIDGE DESIGN

The results from the material characterization study and the structural testing indicate that the use of UHPC in conventionally shaped highway bridge girders is not efficient. Traditional prestressed I-girder shapes were designed for normal strength concretes that required an internal mild steel reinforcing cage to carry secondary tensile forces (i.e., shear, temperature, shrinkage). UHPC is very different in that its tensile capacity and toughness allow for the elimination of mild steel reinforcement, thus eliminating many of the cover requirements and allowing for thinner sections. Additionally, the enhanced durability of UHPC combined with the elimination of the need for mild steel reinforcement in the bridge deck allows for a much thinner bridge deck.

The aforementioned topics led the FHWA to work with researchers at the Massachusetts Institute of Technology to develop an optimized highway bridge girder design for UHPC (Soh 2003; Park, Chuang, and Ulm, 2003). This work resulted in the girder cross-section shown in Figure 1. This bulbed-double-tee prestressed girder is optimized for 70 to 100 foot spans. The prestressing arrangement shown in the figure is for a 70 foot span. This girder has a 3 inch thick deck, a 33 inch overall depth, and is 8 feet wide. This bridge superstructure unit contains no mild steel, so all tensile forces are carried by the concrete matrix and the steel fiber reinforcement.

The optimized bridge girder was designed in accordance with the AASHTO LRFD Bridge Design Specifications (2002). The design loadings included the HL-93 load configuration and an anticipated 25 $lb/ft^2$ wearing surface. The girder is designed for no cracking at the service limit state (i.e., Service III) and for Strength I at its ultimate capacity. The formal design of the girder was completed through the use of 3-D finite element modeling.

## RAPID CONSTRUCTION ASPECTS

The design of this superstructure element includes numerous aspects that are relevant to the rapid construction of highway bridges. The most important aspect is that this superstructure unit is a manageable size, shape, and weight.

This 70 foot long, 8 foot wide optimized girder only weighs 23 tons, thus allowing for easy transport to the bridge site. This girder is also easy to erect due to its light weight and inherent stability. The stable design of this girder allows for placement of any number of girders across the bridge width without the need for temporary bracing.

Another aspect in the design that allows for rapid construction is the connection mechanism between parallel girders. Figure 2(a) shows bolt holes that are cast into the thickened portion of the deck while 2(b) shows a bolt passing through the connection. This positive connection occurs every 3 feet along the length of the bridge. The bolted connection is easily completed from the underside of the deck as shown in Figure 3.

A third aspect of the rapid constructability of this bridge design is the longitudinal shear key that runs the length of the bridge between any two girders. The bottom of this female-female key only needs to be filled with a backer rod before grout may be placed. Depending on the grout and grout placement machinery used, this shear key could be placed quite quickly.

## UHPC BRIDGE CONSTRUCTION

An optimized UHPC bridge of the design discussed above has been constructed at the FHWA's Turner-Fairbank Highway Research Center. This 16 foot wide bridge was constructed using the rapid construction techniques previously discussed. The erection of the two superstructure units was completed in less than one hour through the use of two sixty ton cranes. Figure 4 shows the erection of the second girder. The bolted connections were subsequently completed. Bolting the single longitudinal joint between the two girders was completed within two man-hours and could easily be completed quite quickly by a multi-person crew. The grouting of the longitudinal shear key was then completed in approximately three hours. After setting of the grout, the bridge was structurally complete. Figure 5 shows the completed bridge. The final tasks prior to opening the bridge to traffic would include installing the railings, applying the wearing surface, and painting the traffic markings.

## SUMMARY

The FHWA's UHPC research program has recently constructed a prestressed concrete highway bridge that is optimized for the advanced structural and durability aspects of this concrete. This bridge included a number of features geared toward rapid constructability. These include the decked superstructure girders and the bolted shear key connection between girders. The bridge was constructed in a short timeframe to demonstrate how this next generation of concrete partnered with rapid construction techniques could easily allow a bridge replacement to occur over a weekend.

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This paper is intended as an academic discussion, not as engineering advice, and no reliance upon this paper is permitted. Independent advice by the professional of record as to the application of the concepts and opinions contained herein to any specific project should be sought.

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CONVERSION TABLE

| U.S. Customary | | SI Equivalent |
|---|---|---|
| 1 foot | = | 0.3048 m |
| 1 inch | = | 25.4 mm |
| 1 kip | = | 4.448 kN |
| 1 ksi | = | 6.895 MPa |
| 1 $lb/ft^2$ | = | 47.88 $N/m^2$ |
| 1 ton | = | 8.896 kN |

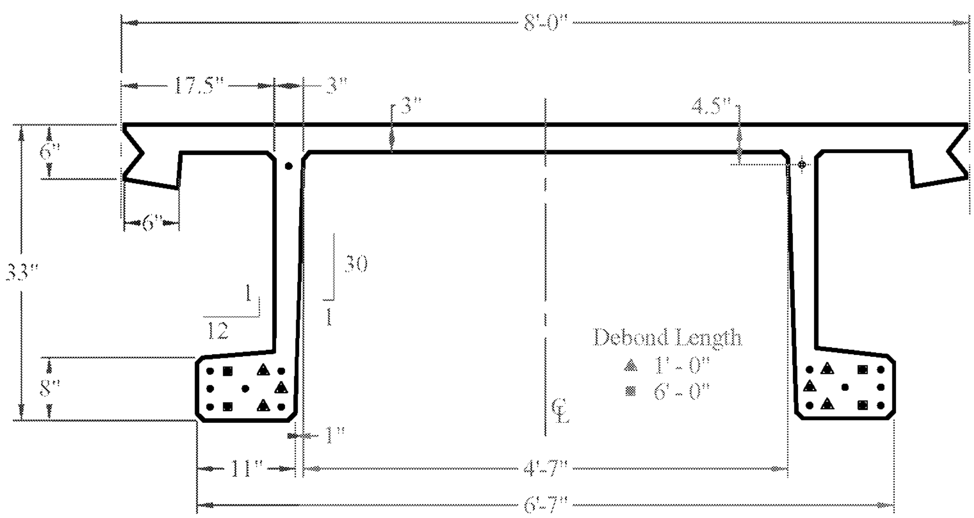


Figure 1. Optimized UHPC Girder/Deck Combination for a 70 Foot Span.

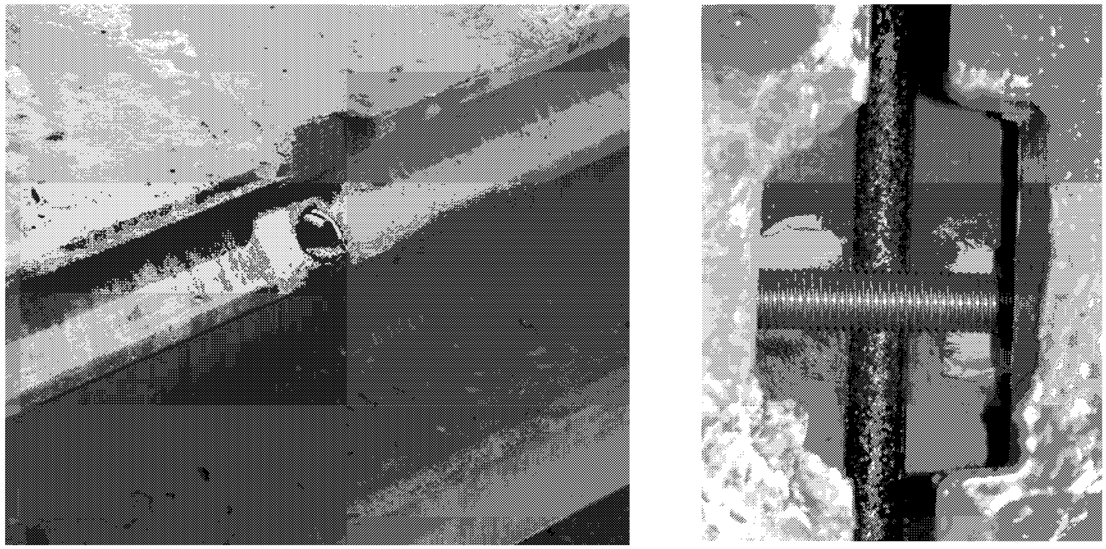

Figure 2. (a) Bolt Hole Cast into Shear Key. (b) Bolt Passing through Shear Key Prior to Grouting.

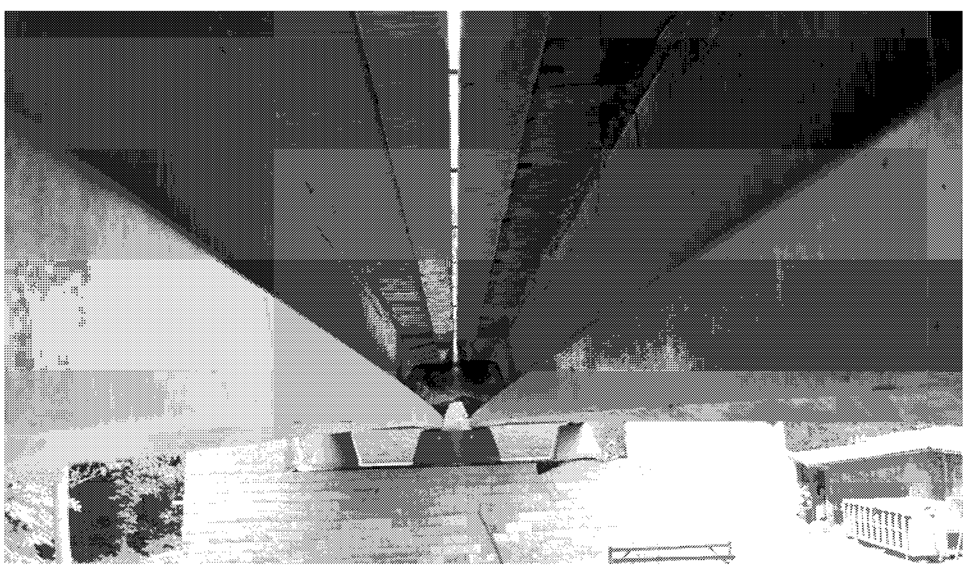

Figure 3. Bolt Placement after Girder Erection.


Figure 4. Girder Placement.

Figure 5. Completed Bridge.