Design of Buchanan County, Iowa, Bridge Using Ultra High Performance Concrete and PI Girders

ABSTRACT

Buchanan County, Iowa, was granted funding through the TEA-21 Innovative Bridge Construction Program (IBRC), managed by the Federal Highway Administration (FHWA), to construct a highway bridge using an optimized PI girder section with ultra high performance concrete (UHPC). UHPC is a relatively new structural material that is marketed by Lafarge, Inc. under the name Ductal. The PI girder section was developed to optimize the amount of material used in a girder, since currently the cost is relatively expensive. The Buchanan County project will be the first time the PI section has been used for a highway bridge in the United States. The girders will be pretensioned longitudinally and the deck will be post-tensioned transversely.

The Office of Bridges and Structures at the Iowa Department of Transportation and the Bridge Engineering Center at Iowa State University are currently working on the bridge design, which is a challenge since currently there is no design specification available in the United States for UHPC. The basis for the design will be conventional and finite element analysis, which is validated by prior laboratory testing at the FHWA’s Turner-Fairbank Laboratory in Washington, DC. In addition, the paper will cover the design and analysis effort by the Office of Bridges and Structures at the Iowa Department of Transportation and the Bridge Engineering Center at Iowa State University.

Keywords: Ductal concrete—LaFarge North America—ultra high performance concrete—steel fibers—PI section
INTRODUCTION

Developed in France during the 1990s, 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) mix. Compressive strengths of 18,000 psi to 30,000 psi can be achieved, depending on the curing process. The material has a low permeability and high durability. 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 was used.

Research has been conducted at Ohio University (Lubbers 2003), Michigan Technological University, Iowa State University, and Virginia Polytechnic Institute and State University to help better understand UHPC properties. Testing is ongoing at the FHWA’s Turner-Fairbank Laboratory near Washington, DC, on the optimized prestressed bridge girder cross 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

Iowa was first introduced to UHPC with a bridge project in Wapello County, completed 2006. See Figures 1, 2, and 3. Wapello County and the Iowa Department of Transportation (Iowa DOT) were granted funding through the TEA-21 Innovative Bridge Construction Program (IBRC). The UHPC mix was used in three 110 ft. long prestressed concrete bulb tees for a bridge replacement project south of Ottumwa, Iowa.

Figure 1. Casting of 110 ft. UHPC beam
As a continuation of this work, Buchanan County and the Iowa DOT were granted funding in 2005 through the TEA-21 IBRC for an additional project using UHPC. The UHPC mix will be used in three 51 ft. optimized PI sections developed by the FHWA’s Turner-Fairbank Laboratory and the Massachusetts Institute of Technology (MIT).
The replacement bridge project is located on a county road (136th Street) over the east branch of Buffalo Creek in northeast, Buchanan County, Iowa. See Figures 4 and 5. The bridge will be 24 ft. 3 in. wide by 112 ft. 4 in. long. The center span will be 51 ft. 2 in. from center to center of the pier caps, and plain neoprene bearing seats will be provided for the 50 ft. 0 in. simple span PI section. See Figure 7 for cross section details. The beam ends will be encased in normal strength cast-in-place concrete diaphragms at the bridge site. End spans will be cast-in-place reinforced concrete slabs with integral abutments and pier caps. See Figure 8.

Figure 4. Location of Buchanan County

Figure 5. Bridge location
Figure 6. Situation plan

Figure 7. Proposed bridge cross section
DESIGN

Materials Properties and Design Stresses

Material properties and design stresses of the Ductal mix were based on experience with the Wapello County project, FHWA testing, and recommendations by LaFarge. Values are shown below:

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modulus of elasticity at release</td>
<td>5,800 psi</td>
</tr>
<tr>
<td>Modulus of elasticity final</td>
<td>8,000 psi</td>
</tr>
<tr>
<td>Design compressive strength at release</td>
<td>14,500 psi</td>
</tr>
<tr>
<td>Design compressive strength final</td>
<td>24,000 psi</td>
</tr>
<tr>
<td>Tensile strength</td>
<td>1,200 psi</td>
</tr>
<tr>
<td>Allowable compressive release stresses</td>
<td>8,700 psi</td>
</tr>
<tr>
<td>Allowable compressive stress at service</td>
<td>14,400 psi</td>
</tr>
<tr>
<td>Allowable tensile stress at service</td>
<td>840 psi</td>
</tr>
</tbody>
</table>

Design Guidelines

For the design, the team took advantage of the design work that was done for the bridge project in Wapello County, along with the testing that was performed by Turner-Fairbank Laboratory on UHPC concrete and the PI section. In addition, research reports and guide specifications listed below were used, as well as discussions with Ben Graybeal and Vic Perry:

1. Research and design recommendations from Dr. Ulm of MIT (Ulm 2004)
2. Design Guidelines for RPC Prestressed Concrete Beams, University of New South Wales (Gowripalan and Gilbert 2000)
3. Structural Behavior of Ultra High Performance Concrete Prestressed I-Girders, Publication No. FHWA-HRT-06-115 (Graybeal 2006a)
4. Material Property Characterization of Ultra High Performance Concrete, Publication No. FHWA-HRT-06-103 (Graybeal 2006b)
Beam Design

The design started with the PI section (see Figure 9) that was developed by the FHWA’s Turner-Fairbank Laboratory and MIT. During testing of the section at Turner-Fairbank, some problems were found with the initial shape. These problems were addressed during the design process, and changes to the section are planned. The areas that were addressed during the design process were as follows:

1. Transverse strength of deck
2. Live load distribution between beams
3. Fiber distribution in web areas

![Figure 9. Initial PI section](image)

Transverse Strength of Deck

A large amount of the design time was spent on improving the transverse strength of the deck system. Based on testing at Turner-Fairbank (see Figures 10 and 11) the 3 in. deck did not meet the requirements for a service loading of 16 kip wheel load with 33% impact.

To strengthen the deck, a number of options were studied using a maximum tensile stress for a service design of 0.84 ksi. To complicate the process, options considered would need to use or modify the existing forms.
Design options that were considered for strengthening the deck were as follows:

1. Adding ribs under the deck with or without mild reinforcing or post-tensioning
2. Adding structural steel diaphragm after casting
3. Thickening the deck with or without reinforcing
These design options were analyzed in the Office of Bridges and Structures at the Iowa DOT and verified by Iowa State University using finite element analysis (FEA). See Figure 12. After all options were considered, a decision was made to use a constant 4 in. deck with transverse post-tensioning. This decision was based on keeping the changes as simple as possible and limiting the cost of modifying the beam forms to keep the research budget within allowable limits. A final FEA analysis of the bridge is ongoing and has not been completed at this time.

A decision has not yet been made on the type of post-tensioning to use. The team is considering 5/8 in. high strength rods or 0.6 in. diameter strands at approximately 18 in. spacing in a grouted plastic post-tensioning duct. Additional discussion is still ongoing whether to post-tension each individual section in the precast plant to eliminate field post-tensioning or to post-tension the entire section at the site. Advantages and disadvantages are being discussed for both methods.

Live Load Distribution between Beams

Testing revealed poor distribution between the beam sections, possibly due to the flexibility of the beams, the connection between the beam sections, and the lack of diaphragms. To improve distribution, steel diaphragms were added to the bottom of the section. See Figure 7 for details. In addition, there has been discussion for providing continuous post-tensioning across the joints between the sections in the deck. At the writing of this report, no final decision had been made.

Fiber Distribution in Web Area

During the testing of the original section, it was found that testing wires were disrupting the proper flow of fibers through the web and may have caused planes of weakness in the web sections where the shear
failures took place. To resolve this problem, the webs were thickened by 1/2 in. to improve the flow of the steel fiber in case testing wires are cast in the web.

**Final Cross Section**

Based on the work completed to date, the final PI cross section is shown in Figure 13. Additional changes may be made as final details are completed.

![Figure 13. Modified PI section](image)

**CONSTRUCTION SCHEDULE**

Details are currently being finalized for the beams, with plans to let the casting of the beam for contract this fall. If bids are reasonable, casting will be in late fall or winter. Letting of the bridge project will take place after the beams are successively cast, with construction to begin spring 2008.

**CONCLUSION**

This brief report covered the design work that has been completed to date using the UHPC PI section for a bridge project in Buchanan County, Iowa. The design work to date is adapting the optimized test section that was developed by the FHWA and MIT into an actual bridge project. Based on the results of testing by the FHWA, changes were made to the optimized PI section. Evaluation of the final modified PI section bridge will take place during construction, and a load test will be conducted once the bridge is complete. If successful, the next step will be the use of this revised section on a primary highway with higher traffic and loading. By using the optimized section, the people involved in this project hope to take better advantage of the properties of this unique material and help reduce the cost of using it in future projects.
REFERENCES


Perry, V., personal communication, 2006 and 2007.