DESIGN OF BUCHANAN COUNTY, IOWA, BRIDGE, USING ULTRA HIGH-PERFORMANCE CONCRETE AND PI BEAM CROSS SECTION

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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). When completed, the Buchanan County project will be the first application of the PI section for a highway bridge in the United States. The girders will be pretensioned longitudinally and tied together transversely with mild reinforcing steel and steel diaphragms. The bridge will use the second generation of the Pi girder section.

The Office of Bridges and Structures at the Iowa Department of Transportation and the Bridge Engineering Center at Iowa State University have completed the bridge design. The basis for the design was conventional and finite element analysis, which was validated by prior laboratory testing of the first generation Pi girder section at the FHWA's Turner-Fairbank Highway Research Center in McLean, Virginia near Washington, DC. The paper will cover the design and analysis effort by the Iowa DOT, Office of Bridges and Structures and the Bridge Engineering Center at Iowa State University. In addition, the current status of the project will be covered.

Keywords: Ultra-High Performance Concrete, Ductal Concrete, Optimized Cross-Section, Pi Girder, Prestressed Girder, Steel Fiber, Finite Element Modeling, Analytical Models

INTRODUCTION

Developed in France during the 1990s, ultra high-performance concrete (UHPC) has seen limited use in North America. UHPC consists of fine 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 mixing and 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 continuing also at the FHWA's Turner-Fairbank Highway Research Center in McLean, Virginia near Washington, DC. In addition, a bridge project by the Virginia Department of Transportation using the mix in the prestressed beams was recently completed.

PROJECT BACKGROUND

Iowa was first introduced to UHPC with a bridge project in Wapello County, which was completed in 2006 (Wipf et al, 2008). See Figures 1, 2, 3 and 4. 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 four Iowa bulb tee beams that were modified for the mix. Beam strength was verified by flexure and shear tests on a 71 ft. prestressed bulb tee beam tested by the Bridge Engineering Center at Iowa State University (Degen, 2006). Three 110 ft. long prestressed concrete bulb tee beams were then used in a single span integral abutment bridge replacement project south of Ottumwa, Iowa. See Figure 3 for bridge cross section details.

Figure 1. Casting of 110 ft. UHPC beam used on Wapello County Bridge

Figure 2. UHPC beams prior to shipping to bridge site in Wapello County

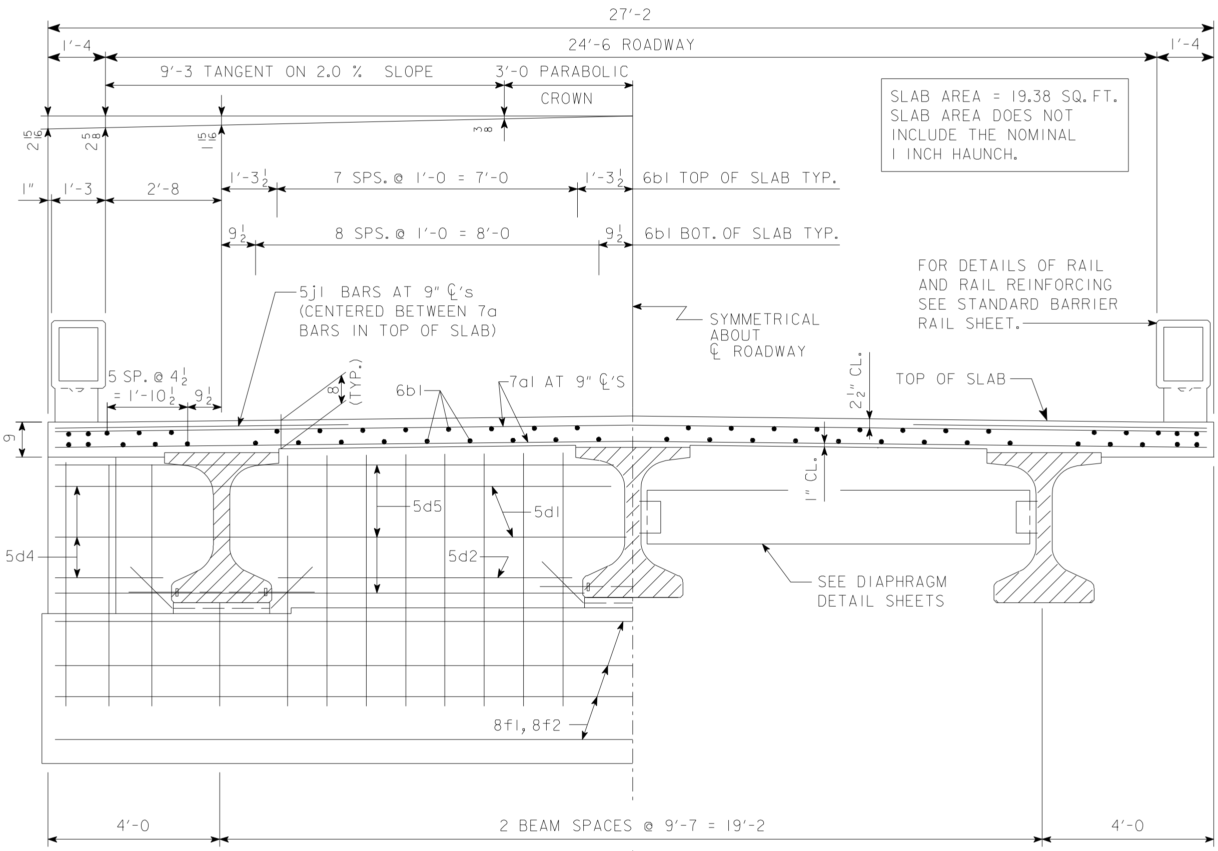

Figure 3. Cross section of Wapello County Bridge

Figure 4. Completed Wapello County Bridge

Buchanan County and the Iowa DOT were given the opportunity to build upon the experience with UHPC in the second UHPC project that was granted funding in 2005 through the TEA-21 IBRC. The same UHPC mix will be used in five optimized PI beams; two 25 foot beams for testing at the FHWA Turner-Fairbank facility and three 51 foot beams for the Buchanan County bridge project.

BRIDGE DESCRIPTION

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 5, 6 and 7). The bridge will be 24 ft 9 in. wide by 115 ft. 4 in. long. The center span, the UHPC segment of the bridge, will be 51 ft. 2 in. from center to center of the pier caps. The 50 ft. 0 in. simple span PI section will be supported on plain neoprene bearing seats (see Figure 8 for cross section details). The beam ends will be encased in cast-in-place concrete diaphragms with 3,500 psi compressive strength. End spans will be cast-in-place traditional reinforced concrete slabs with integral abutments supported on steel HP10x42 piles and the pier caps will be supported on steel HP10x42 piles encased in concrete as shown in Figure 9.

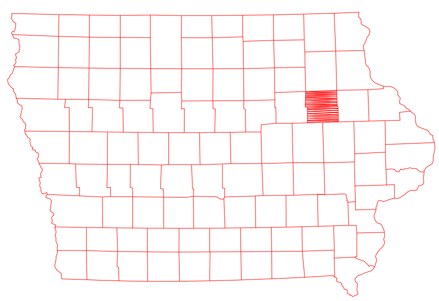

Figure 5. Location of Buchanan County in Iowa

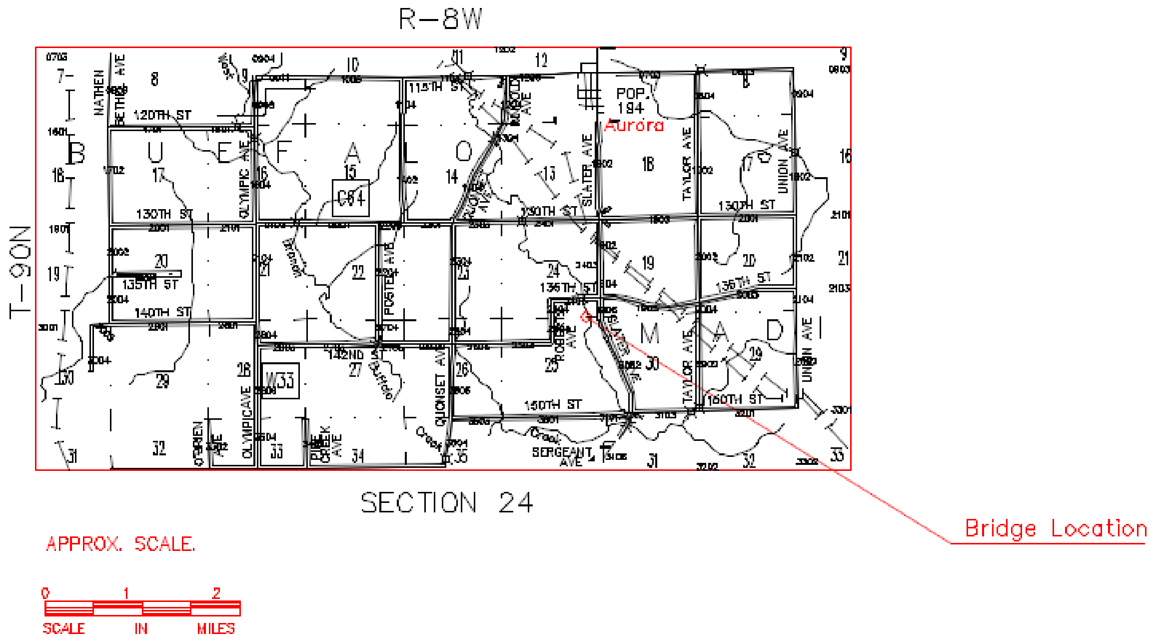

Figure 6. Bridge location in Buchanan County

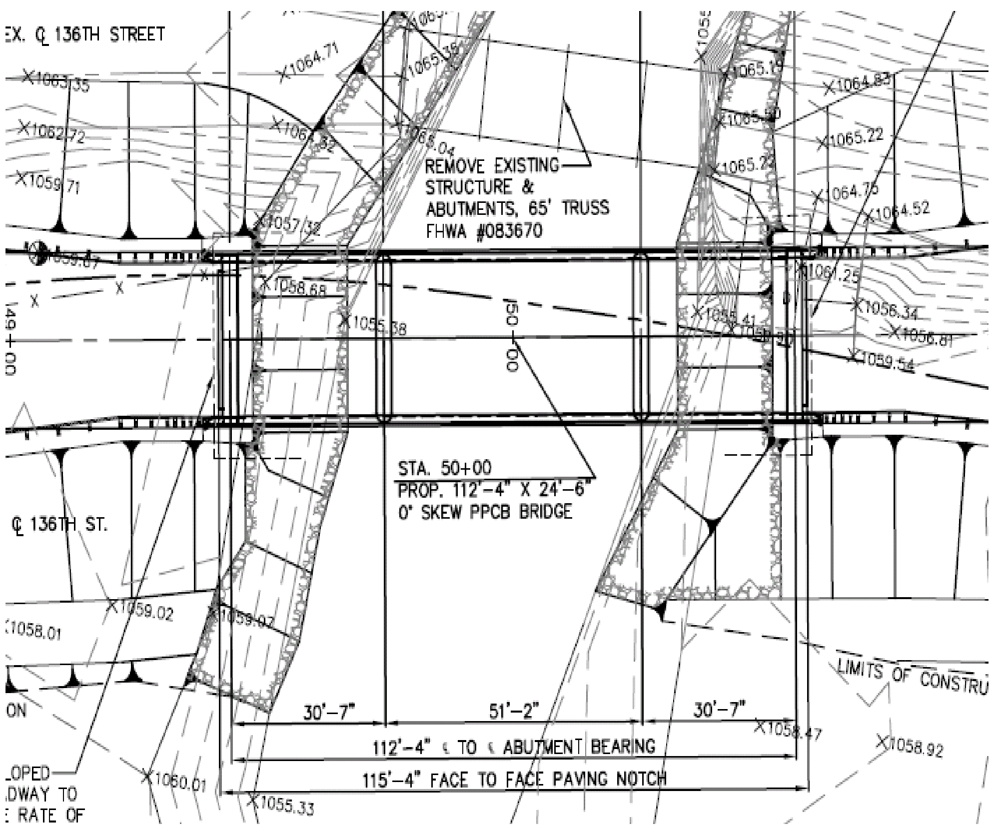

Figure 7. Situation plan of Buchanan County Pi Girder Bridge

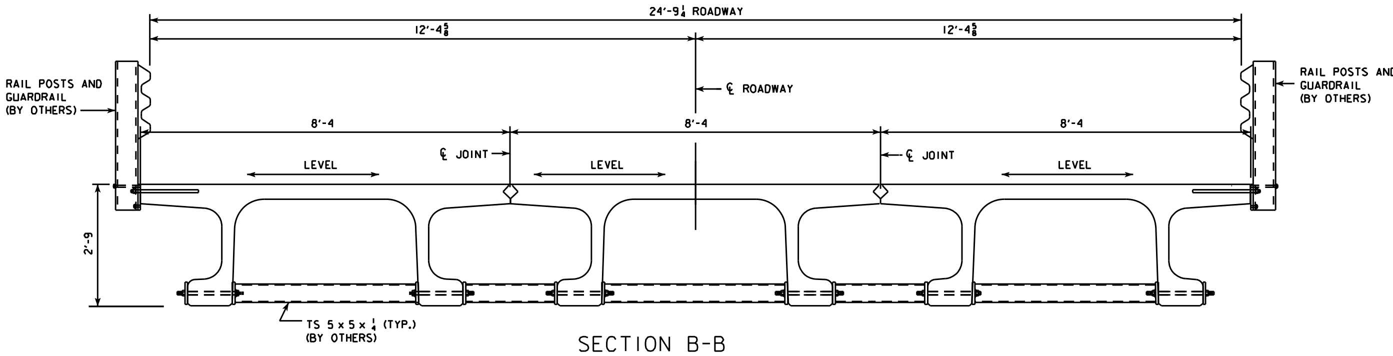

Figure 8. Proposed bridge cross section of Buchanan County Bridge

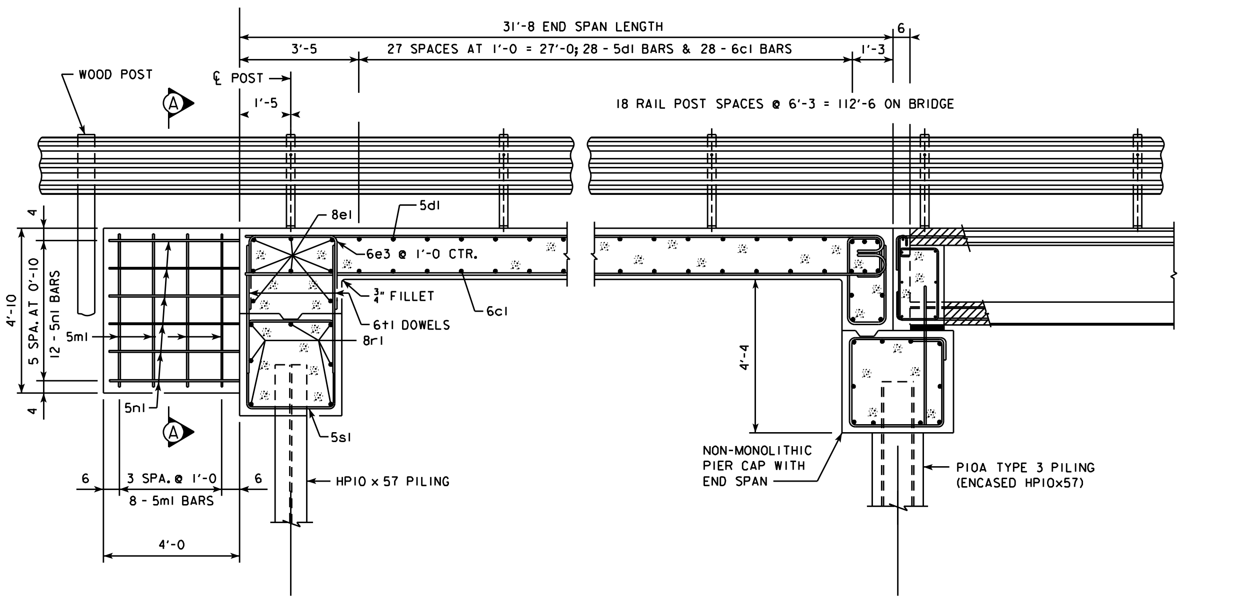

Figure 9. End span details of Buchanan County Bridge

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 FHWA and Lafarge. Values are shown below; note the final values are after heat curing:

Modulus of elasticity at release	5,800	ksi
Modulus of elasticity final	7,800	ksi
Design compressive strength at release	12,500	psi
Design compressive strength final	21,500	psi
Tensile strength	1,200	psi
Allowable compressive release stresses 0.6 (12,500 psi)	7,500	psi
Allowable compressive stress at service 0.6 (21,500 psi)	12,900	psi
Allowable tensile stress at service 0.7 (1200 psi)	840	psi

DESIGN GUIDELINES

For the design, the team again took advantage of the design work that was done for the bridge project in Wapello County, along with the testing by the Bridge Engineering Center and Turner-Fairbank Highway Research Center. Research reports and guide specifications listed below were also used, as well as discussions with Ben Graybeal (FHWA) and Vic Perry (Lafarge):

1. Research and design recommendations from Dr. Ulm of MIT (Ulm 2004)
2. Design Guidelines for Reactive Powder Concrete, 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 used the initial optimized (first generation) PI shape, Figure 10, developed by the FHWA's Turner-Fairbank Highway Research Center and MIT as a starting section. The section was developed to optimize the UHPC mix by minimizing the cross section and take advantage of the properties in the bridge deck. Testing of the section by Turner-Fairbank had revealed overstresses in the transverse capacity of the deck and a low transverse live load distribution between adjacent Pi sections. These two issues were the biggest design challenges for the project and suggested that a second generation Pi girder section would need to be developed.

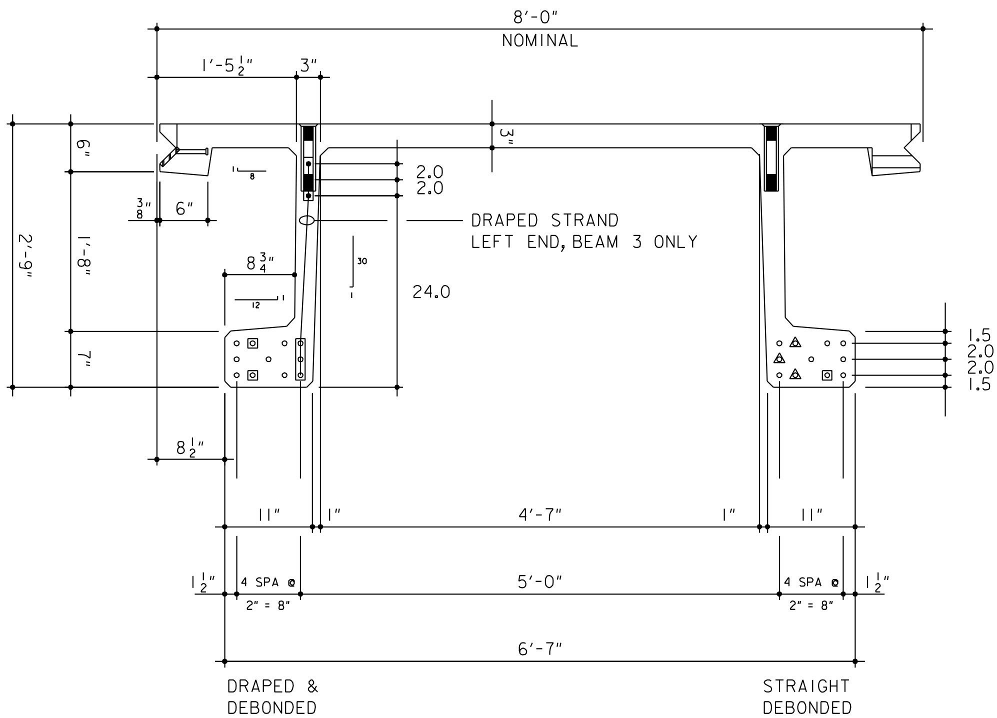

Figure 10. Initial (first generation) PI section

TRANSVERSE STRENGTH OF DECK

Load testing at Turner-Fairbank Laboratory (see Figure 11) had shown that the three inch deck under service load did not have the strength to meet the design specifications for a 12.5 kip tandem or single 16 kip wheel load with the 33% impact included. Improvements to the section were investigated by the Iowa DOT and Iowa State University and included finite element analysis (FEA) of the different modifications (see Figure 12).
Improvements of the first generation Pi section were initially investigated, with the intention of reusing or modifying the existing forms. Increasing the deck thickness and use of a ribbed sections with mild reinforcing or post-tensioning were considered. After reviewing all options, a decision was made to use a constant four inch deck with transverse post tensioning. The decision was based on keeping the changes as simple as possible and the cost of modifying the beam forms within the budget limits.

Figure 11. Transverse deck test of first generation Pi girder at Turner Fairbank Laboratory
(Photo courtesy of FHWA)

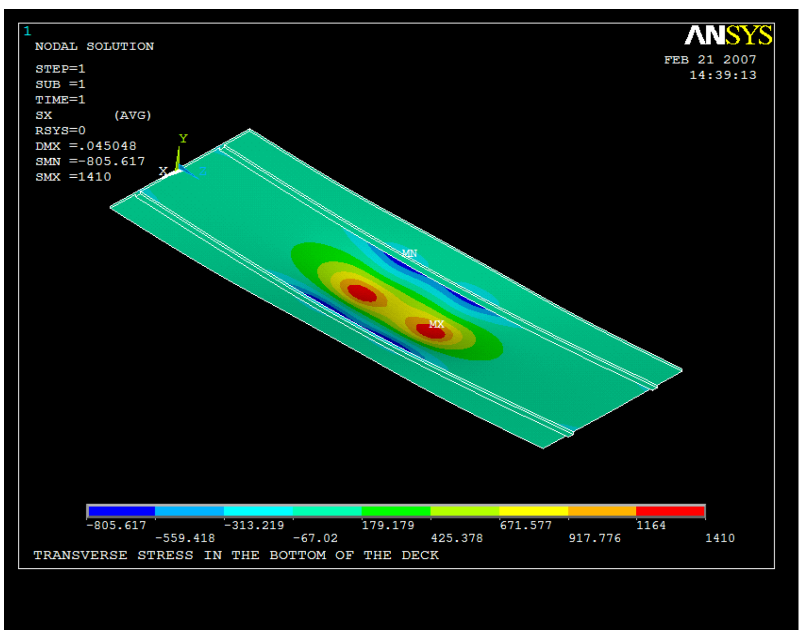

Figure 12. Finite element analysis of second generation Pi girder to be used in Buchanan County Bridge
(Photo courtesy of Iowa State University)

LIVE LOAD DISTRIBUTION

Testing by FHWA had revealed poor distribution between the first generation Pi beam sections. The connection detail that was used in the test consisted of a grouted keyway with horizontal tie bolts provided at three foot spacing. To improve load distribution and help stiffen the section:

1. Steel diaphragms were added at the ¼ span points across the bottom flange as shown in Figure 7.
2. Grouted reinforced pockets with No. 8 reinforcing tie bars were provided at 18 inch spacing (see Figure 13).

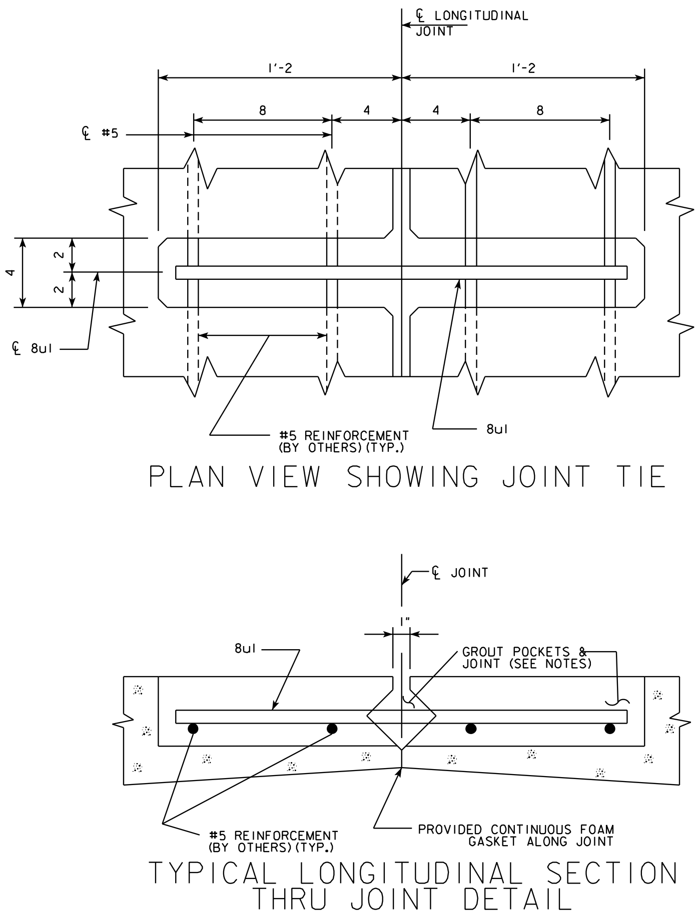

Figure 13. Slab Connection between adjacent Pi girders tested at Turner Fairbank Laboratory

FINAL SECTION

Due to the high costs for upgrading and modifying the forms, bids from the sole source fabricator for the revised second generation Pi section were too high. A suggestion was then made by Ben Graybeal of FHWA to further revise the first generation section and use new forms. FHWA would purchase new forms and two test beams for evaluation. The three production bridge beams would be purchased at the same time helping reduce the setup and casting cost of all beams. In addition, the revised section would be available for use on future projects by other state agencies. This suggestion was adopted and the following additional revisions were made to the first generation section (see Figure 14):

1. Five inch and eight inch fillets were added at the web to deck connection to improve concrete mix flow during casting and stiffen the slab section.
2. The interior deck thickness between the webs was increased to 4 1/8 inches to meet service stresses.
3. The web spacing was reduced by four inches to provide a more balanced spacing of the webs for the three beam cross section and reduce service stresses.
4. The post-tensioning was removed from the deck, however, due to the lack of test data on the revised section, mild reinforcing steel was included in the deck (# 5 reinforcing steel at 1’-0 spacing).

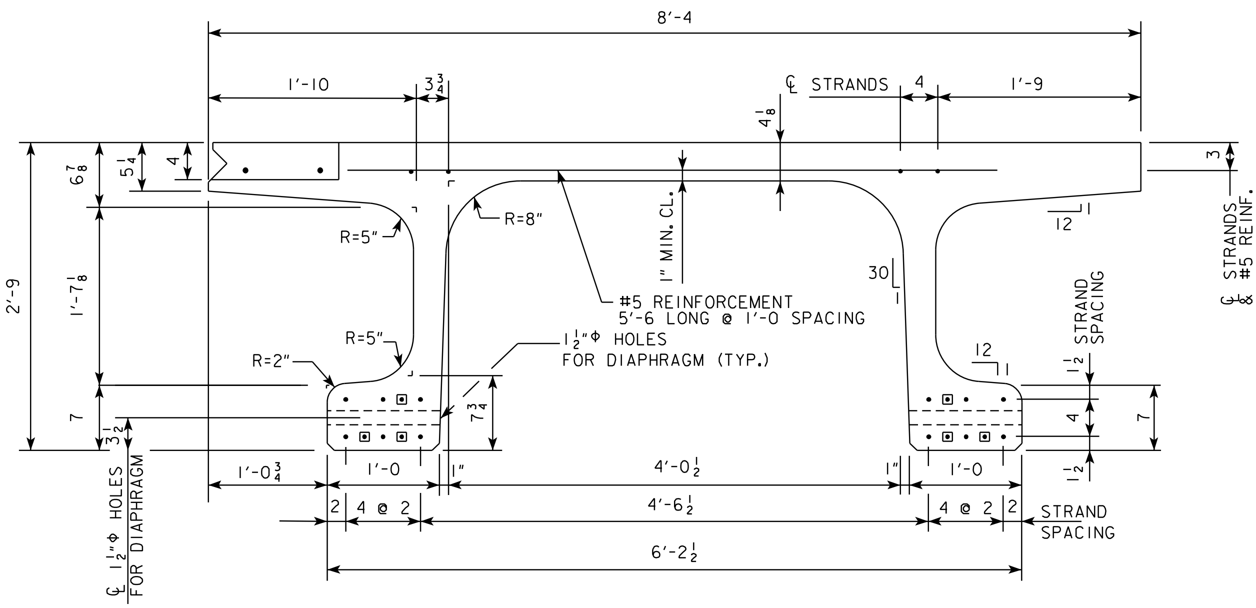

Figure 14. Modified (second generation) PI section

CONSTRUCTION SCHEDULE

Design plans for the beams were finalized in the spring of 2008 and a contract was signed with Lafarge of North America to have the second generation Pi sections cast at their plant in Winnipeg, Manitoba, Canada. Two 25’-0 test beams will be cast first and then the three 51’-0 production bridge beams. The tentative casting schedule at this time is August and September 2008 with delivery in October, 2008. The bridge construction letting was June 2008 with construction to take place in the fall of 2008.

CONCLUSION

This brief report covered the work to date for the bridge project in Buchanan County, Iowa that will use the second generation of the optimized UHPC PI section. Based on the results of testing of the first generation Pi section by the FHWA used to validate finite element models during the design phase of the Buchanan County Bridge, changes were made to that Pi section. Along with other design considerations, the result was the development of a second generation Pi section. Evaluation of that PI section to be used in the Buchanan County Bridge will take place during construction, and a load test will be conducted once the bridge is complete. By using a modified optimized section, the project team hopes to take better advantage of the properties of this unique material and help reduce the cost of using it in future projects.

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- Bridge Engineering Center at Iowa State University
  - Fouad Fanous and Isaac Couture (Graduate Student)
- Lafarge North America - Vic Perry

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