The UHPC component was used in the center span. The new Jakway Park Bridge in Buchanan County, Iowa, offers great potential for expanding the use of ultra-high-performance concrete (UHPC) in bridge girders and specifically in the new Pi (as in the Greek letter π) girder. By understanding the process used to create the second generation of this girder and leveraging its full capabilities, designers can take better advantage of the properties of this unique material and help reduce costs in future projects.

The Jakway Park Bridge in Buchanan County, Iowa, offers great potential for expanding the use of ultra-high-performance concrete (UHPC) in bridge girders and specifically in the new Pi (as in the Greek letter π) girder. By understanding the process used to create the second generation of this girder and leveraging its full capabilities, designers can take better advantage of the properties of this unique material and help reduce costs in future projects.

Developed in France during the 1990s, UHPC has seen limited use in North America. UHPC consists of fine sand, cement and silica fume, and quartz flour in a dense, low water-cementitious materials ratio (0.15) mix. Compressive cylinder strengths of 18,000 psi to 30,000 psi can be achieved, depending on the mixing and curing regimen. The material has extremely low permeability and high durability. To improve ductility, steel or fiberglass fibers (approximately 2% by volume) are added, replacing mild reinforcing steel. For this project, the patented mix Ductal®, developed by Lafarge North America, was used with steel fibers.

Iowa was first introduced to UHPC with a bridge project in Wapello County, which was completed in 2006. Wapello County was also granted funding through IBRC for that project. The UHPC mix was used in four Iowa bulb-tee beams that were modified to better utilize the mix. Beam performance was verified by flexure and shear tests on a 71-ft-long...
The precaster cast two 25-ft-long beams for testing purposes by the FHWA, followed by three 51-ft-long production beams.

Five Beams Produced
Buchanan County and Iowa Department of Transportation (DOT) were given the opportunity to build on that UHPC experience with this project. The same UHPC mix was used to fabricate five optimized Pi girders: two 25-ft-long girders reserved for testing at the Federal Highway Administration’s (FHWA) Turner-Fairbank Highway Research Center (TFHRC) in McLean, Va., and three 51-ft-long girders used for the bridge construction.

The replacement bridge, 115 ft 4 in. long by 24 ft 9 in. wide, is located on a county road in a northeast section of Buchanan County over the east branch of Buffalo Creek. The UHPC component is the center span, 51 ft 2 in. from center-to-center of the pier caps. The 50-ft-long simple-span Pi sections are supported on plain neoprene bearing pads. The beam ends are encased in cast-in-place diaphragms with 3500 psi compressive strength concrete. End spans consist of traditionally reinforced cast-in-place concrete slabs with integral abutments supported on steel HP10x42 piles. The pier caps are supported on steel piles encased in concrete.

As a starting direction, the design team used the initial optimized (first generation) Pi shape, which was developed by the TFHRC and the Massachusetts Institute of Technology. It was created to optimize the UHPC mix by minimizing the cross section and taking advantage of the material properties for the bridge deck. Testing of the section by TFHRC 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 improvements to the initial Pi-girder section would need to be made.

Testing Leads to Improvements
Load testing at TFHRC showed that the 3-in.-thick 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 33% impact included. Improvements to the section were investigated by the Iowa DOT and Iowa State University and included finite element analysis of the different modifications. Improvements to the first-generation Pi section were initially investigated, with the intention of reusing or modifying the existing forms.

Several design options were considered for strengthening the deck. These included increasing the deck thickness with or without reinforcement, adding ribs under the deck with or without mild post-tensioning, and thickening the deck with or without reinforcement. After review, it was decided to use a uniform 4-in.-thick deck with transverse post-tensioning. This kept the changes as simple as possible and attempted to keep the cost of modifying the beam forms within budget limits.

The connection detail that was used in the initial test consisted of a grouted keyway with horizontal tie bolts provided at 3-ft spacing. To improve load distribution and help stiffen the section, two adjustments were made. Steel diaphragms were added at the quarter-span points across the bottom flange, and grouted, pockets containing No. 8 reinforcing tie bars were provided at 18-in. spacing.

Ready-mix concrete trucks were used to provide the mixing required to achieve 21,500 psi compressive strength.
Due to the high costs of upgrading and modifying the forms, the sole fabricator interested in casting the modified Pi sections delivered a bid that was too high for the budget. FHWA officials at TFHRC suggested that further revisions be made to the first-generation section and new forms be created for a second-generation Pi girder. The FHWA agreed to fund the forms and purchase two test beams for evaluation. The three production beams would be purchased at the same time as the slab section.

This approach was taken, leading to four key revisions being made to the first-generation section:

1. Two types of fillets, 5 in. and 8 in. deep, were added at the web-to-deck connection to improve concrete flow during placement and to stiffen the slab section.

2. The interior deck thickness between the webs was increased to 4 1/8 in. to reduce service load stresses.

3. The web spacing was reduced by 4 in. to provide a more balanced spacing of the webs for the three-beam cross section and to reduce service load stresses.

4. The post-tensioning was removed from the deck. Due to the lack of test data on the revised section, No. 5 reinforcing bars at 1-ft centers were included in the deck.

Two 25-ft-long test beams were cast first, followed by three 51-ft-long production beams. The three bridge beams were 8 ft 4 in. wide and 2 ft 9 in. deep with two tapered webs about 3 in. thick spaced at 4 ft 5 in. Deck thickness was a constant 4 1/8 in. between the webs and a tapered thickness outside the webs from 6 7/8 in. to 5 1/4 in. at the edge of the slab. Flanges at the bottom of the beam webs were 7 in. deep by 1 ft wide. Each flange contained nine 0.6-in.-diameter strands tensioned to 72.6% of ultimate. Total concrete quantity was 11.3 yd³ of UHPC per unit.

**Waffle Slab Project**

Waffles were cast in a precast concrete deck on a single-span, prestressed concrete beam bridge. To optimize the material, the deck panels will be cast with a waffle shape. Component casting is scheduled to begin in the winter of 2009-2010, with construction to take place in the summer of 2010.

By using UHPC in bulb-tee beams, the optimized pi girder, and a waffle-shaped deck panel, the project team will expand the knowledge base and facilitate the wider use of advanced cementitious materials to solve specific transportation challenges.

*Brian Keierleber, county engineer for Buchanan County, Independence, Iowa; Dean Bierwagen, and Ahmad Abu-Hawash, are with the Office of Bridges & Structures of the Iowa DOT in Ames, Iowa; and Terry Wipf, is director of the Bridge Engineering Center at Iowa State University in Ames, Iowa.*

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Three Pi girders were used to construct the bridge’s center span.
New Design Relies on Past
The team took advantage of the design work for the Wapello County project, along with testing by the Bridge Engineering Center at Iowa State University 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):


UHPC Properties and Design Stresses
Material properties and design stresses for 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:

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
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<tr>
<td>Modulus of elasticity at release</td>
<td>5800 psi</td>
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<tr>
<td>Modulus of elasticity final</td>
<td>7800 psi</td>
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<tr>
<td>Design compressive strength at release</td>
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<tr>
<td>Design compressive strength final</td>
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<td>Tensile strength</td>
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<td>Allowable compressive stress at release</td>
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<td>Allowable compressive stress at service</td>
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<tr>
<td>Allowable tensile stress at service</td>
<td>840 psi</td>
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