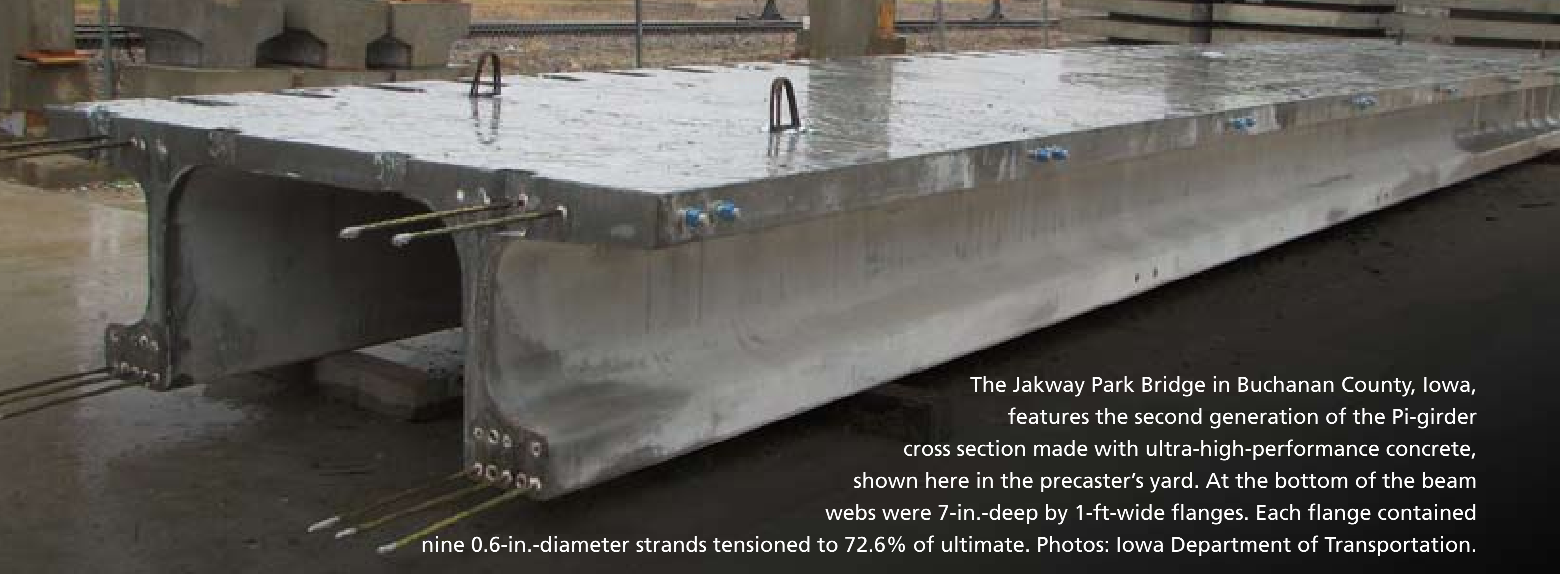
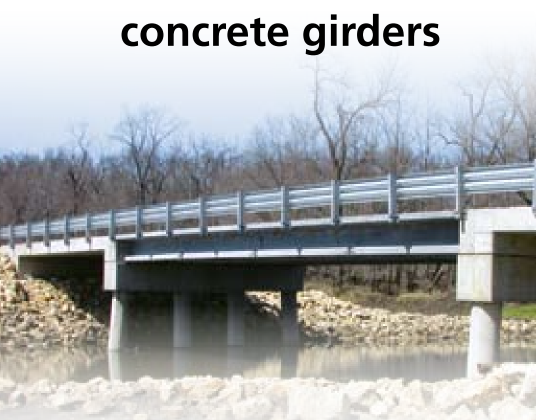


The Jakway Park Bridge in Buchanan County, Iowa, features the second generation of the Pi-girder cross section made with ultra-high-performance concrete, shown here in the precaster's yard. At the bottom of the beam webs were 7-in.-deep by 1-ft-wide flanges. Each flange contained nine 0.6-in.-diameter strands tensioned to 72.6% of ultimate. Photos: Iowa Department of Transportation.

FHWA, Iowa Optimize Pi Girder

by Brian Keierleber, Buchanan County, Dean Bierwagen, Iowa Department of Transportation, Terry Wipf, Iowa State University, and Ahmad Abu-Hawash, Iowa Department of Transportation

Buchanan County constructs a bridge using ultra-high-performance concrete girders



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.

Officials in Buchanan County were granted funding through the TEA-21 Innovative Bridge Research and Construction Program (IBRC), managed by the Federal Highway Administration, to construct a highway bridge using an optimized Pi-girder section with UHPC. The design, using the second generation of the Pi-girder section, provides the first application of the Pi section for a highway bridge in the United States. The girders are pretensioned longitudinally and tied together transversely with mild reinforcing steel and steel diaphragms.

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

profile

JAKWAY PARK BRIDGE / BUCHANAN COUNTY, IOWA

ENGINEER: Iowa Department of Transportation, Ames, Iowa

CONSULTING ENGINEERS: Buchanan County Department of Engineering, Independence, Iowa; IIW Engineers & Surveyors P.C., Dubuque, Iowa; and Iowa State University Bridge Engineering Center, Ames, Iowa

AWARDS: *Co-winner of PCI's 2009 Design Award for Best Bridge Project (up to 75 ft span); 2009 Iowa Quality Initiative Structures Research Merit Award from the Associated General Contractors of Iowa and the Iowa Department of Transportation* prestressed bulb-tee beam tested by the Bridge Engineering Center at Iowa State University. Three 110-ft-long prestressed concrete bulb-tee beams were then used in a single-span, integral-abutment bridge-replacement project near Ottumwa, Iowa. (For more information on this project, see the Summer 2007 issue of *ASPIRE*.™)

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.

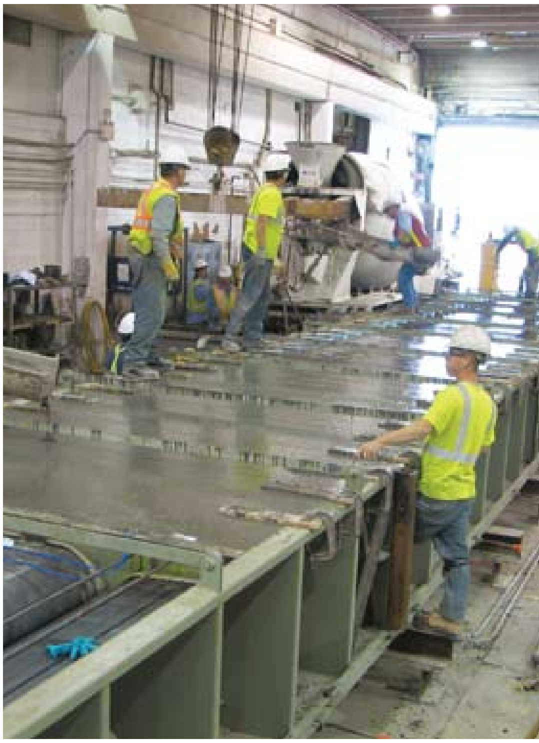
As a starting direction, the design team used the initial optimized (first generation) Pi shape, which was developed by the TFHRC and the Massachusetts Institute of Technology. It was created to optimize the UHPC mix by minimizing the cross section and taking advantage of the material properties for 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 reinforcement or 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.



The precaster cast two 25-ft-long beams for testing purposes by the FHWA, followed by three 51-ft-long production beams.

Ready-mix concrete trucks were used to provide the mixing required to achieve 21,500 psi compressive strength.

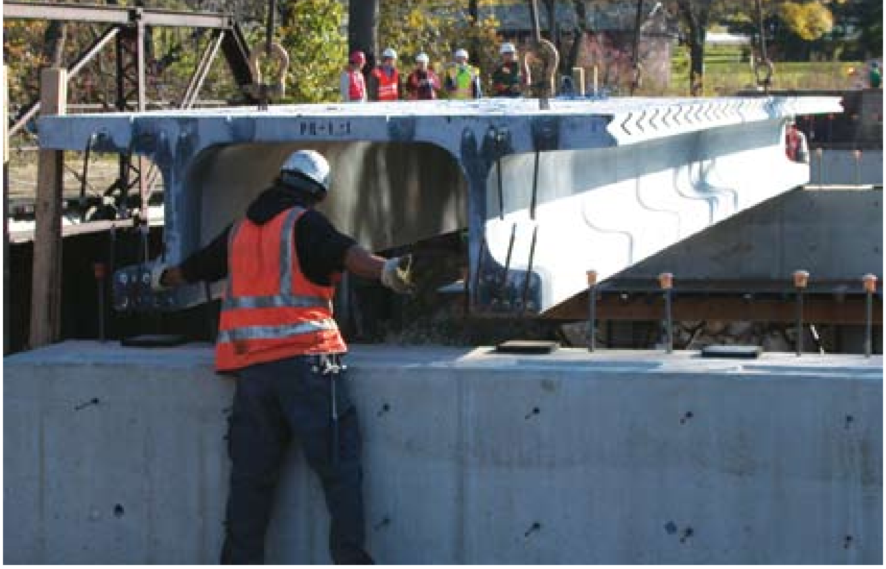
THREE-SPAN CONCRETE BRIDGE WITH A CENTER SPAN CONSISTING OF THREE ULTRA-HIGH-PERFORMANCE CONCRETE, PI-SHAPED GIRDERS / BUCHANAN COUNTY, OWNER

PRIME CONTRACTOR: Taylor Construction Inc., New Vienna, Iowa

UHPC PRECASTER: LaFarge North America, Winnipeg, Manitoba, Canada, a PCI-certified producer

BRIDGE DESCRIPTION: 115-ft 4-in.-long by 24-ft 9-in.-wide, three-span concrete bridge with a 51-ft 4-in.-long center span using Pi girders

BRIDGE CONSTRUCTION COST: $600,000



The 50-ft simple-span Pi girders are supported on plain neoprene bearing pads.

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 to reduce setup and casting costs for all of the beams. In addition, the revised section would be available for use on future projects by other state agencies.

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 yd^3 of UHPC per unit.

Ready-Mixed Concrete Trucks Used

Typically, high-speed pan mixers are used because of the large amount of time and energy needed to thoroughly mix the concrete. In this case, ready-mixed concrete trucks were used for mixing the required 21,500 psi design compressive strength. As the material's performance is affected by the alignment of the steel fibers, a horizontal bucket almost as wide as the form was fabricated to place the material so it would flow freely along the form and properly align the fibers.

The beams were cured in two stages. The first stage involved curing at ambient temperatures, although steam curing up to 115 °F could be used in a similar manner to curing precast, prestressed concrete beams. The Pi girders were covered with plastic and kept at ambient temperatures until match-cured cylinders indicated a compressive strength of 5100 psi had been achieved. Then the forms were opened but left in place to allow for shrinkage of the section. Curing at ambient temperatures continued until the compressive strength of match-cured cylinders reached 14,500 psi. The forms then were removed and the strands were detensioned.

The second curing stage began with thermal treatment applied to the UHPC beams with moisture present. The goal was to achieve a temperature of about 190 °F along with relative humidity of at least 95% for at least 48 hours. Thermal treatments have been shown to enhance not only the members' strength but their durability as well. The beams were wrapped with insulating tarps, and steam was injected underneath the girders. The temperature was increased gradually over a period of approximately 6 hours. Once the second curing period was completed, the curing temperature was decreased gradually over a period of approximately 6 hours.

The beams were fabricated in September 2008, while the contractor began mobilization, grading, and substructure work. The beams were erected in mid-October, and the concrete for the end spans was placed a few weeks later. The project was completed in November, requiring 52 days from start to finish.

Waffle Slab Project

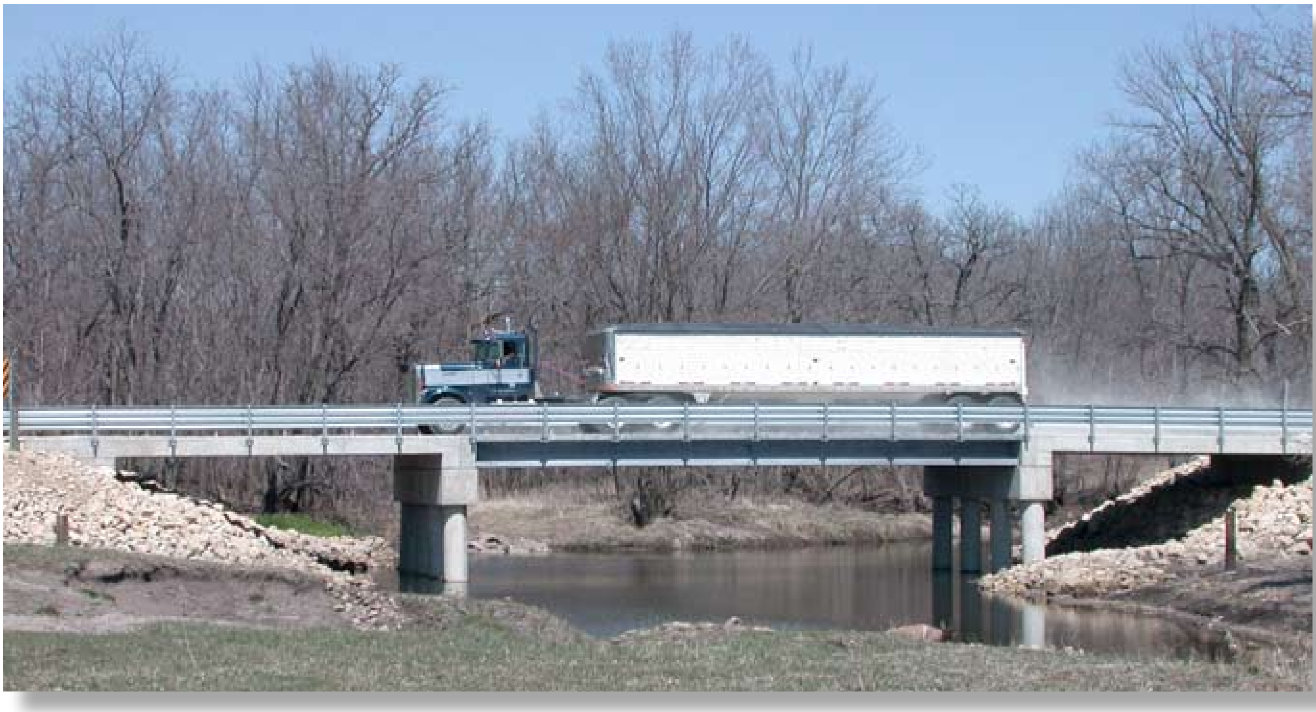
Work with UHPC continues, with a third bridge project now under development with Coreslab Structures (Omaha) in Bellevue, Neb., for use in Wapello County, Iowa. This project will use the UHPC mix in a precast concrete deck on a single-span, prestressed concrete beam bridge. To optimize the material, 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.

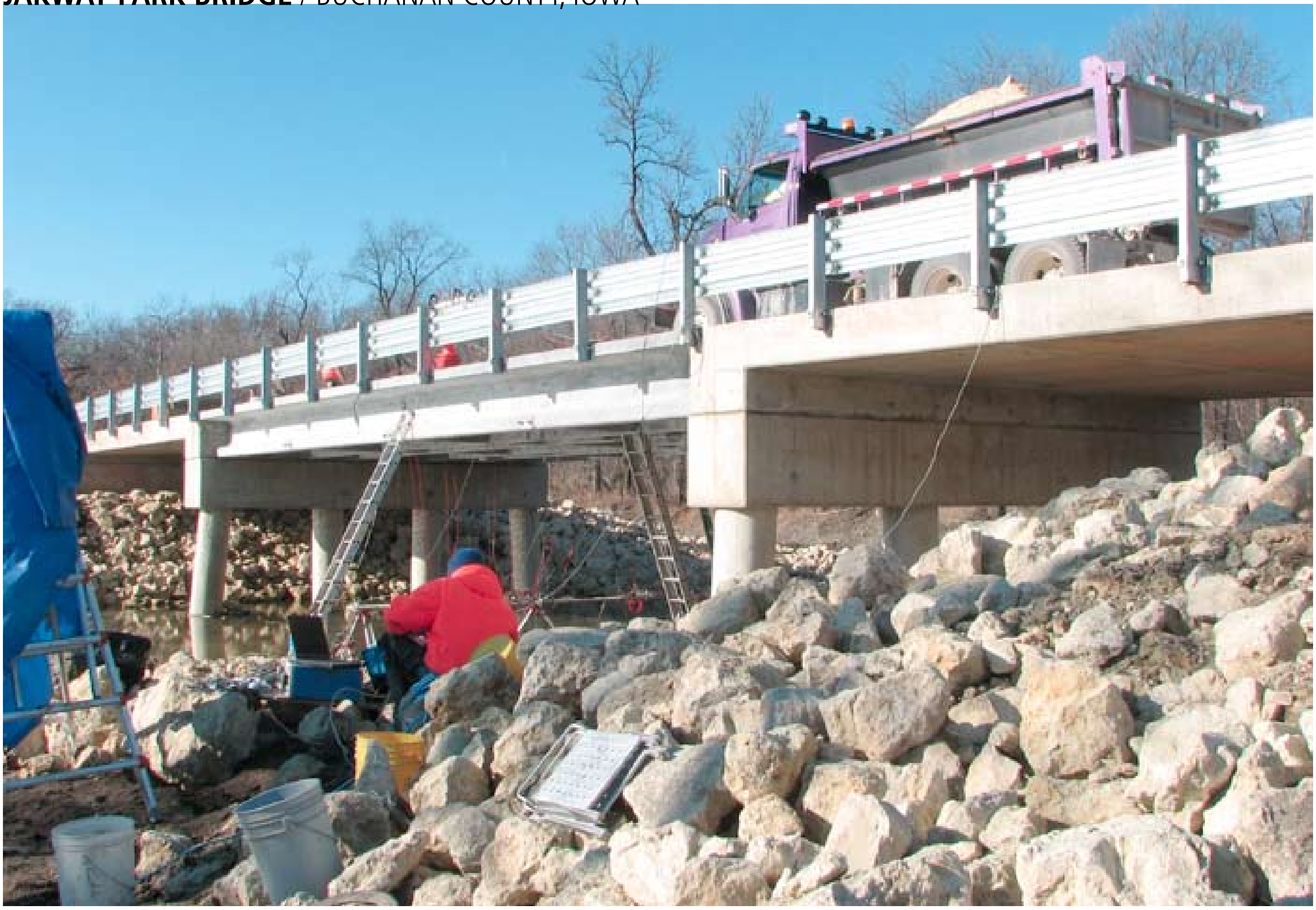
By using UHPC in bulb-tee beams, the optimized pi girder, and a waffle-shaped deck panel, the project team will expand the knowledge base and facilitate the wider use of advanced cementitious materials to solve specific transportation challenges.

Brian Keierleber, is 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.

For more information on this or other projects, visit www.aspirebridge.org.

Three Pi girders were used to construct the bridge's center span.





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:

Modulus of elasticity at release	5800 ksi
Modulus of elasticity final	7800 ksi
Design compressive strength at release	14,500 psi
Design compressive strength final	21,500 psi
Tensile strength	1200 psi
Allowable compressive stress at release (0.6x12,500) psi	7500 psi
Allowable compressive stress at service (0.6x21,500) psi	12,900 psi
Allowable tensile stress at service (0.7x1200) psi	840 psi

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):

1. Gowripalan, N. and Gilbert, R. I., *Design Guidelines for Reactive Powder Concrete, Prestressed Concrete Beams,* University of New South Wales, 2000.
2. Graybeal, B. A., *Structural Behavior of Ultra High-Performance Concrete Prestressed I-Girders,* Federal Highway Administration, Publication No. FHWA-HRT-06-115, 2006, 104 pp.
3. Graybeal, B. A., *Material Property Characterization of Ultra High-Performance Concrete,* Federal Highway Administration Publication No. FHWA-HRT-06-103, 2006, 186 pp.
4. Ulm, F. J., Research and design recommendations, 2004.