Design and Evaluation of a Single-span Bridge

tech transfer summary

The first UHPC bridge in the United States was successfully constructed in Wapello County, Iowa during the fall of 2005.

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RESEARCH PROJECT TITLE
Design and Evaluation of a Single-span Bridge Using Ultra-High Performance Concrete

SPONSORS
Iowa Highway Research Board (TR-574)
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The Bridge Engineering Center (BEC) is part of the Center for Transportation Research and Education (CTRE) at Iowa State University. The mission of the BEC is to conduct research on bridge technologies to help bridge designers/owners design, build, and maintain long-lasting bridges.

Objective

This research describes an application of a newly developed material called Ultra-High Performance Concrete (UHPC) to a single-span bridge. The two primary objectives of this research were to develop a shear design procedure for possible code adoption and to provide a performance evaluation to ensure the viability of the first UHPC bridge in the United States. Two other secondary objectives included defining material properties and understanding flexural behavior of a UHPC bridge girder.

Background and Problem Statement

In 2003 the Iowa Department of Transportation (Iowa DOT) and Wapello County, Iowa began planning for a bridge replacement project. At that time, the bridge known as FHWA structure #330530 100th Ave. over Little Soap Creek was closed due to durability and strength concerns. This bridge was a steel truss bridge with a timber deck and timber abutments. The need and timing for a bridge replacement presented an opportunity to use a newly developed material called Ultra-High Performance Concrete (UHPC). Ultimately, this became the first UHPC bridge constructed in the United States and construction was partially funded through the Federal Highway Administration's (FHWA) Innovative Bridge Research and Construction (IBRC) program.

Wapello County truss bridge prior to replacement

Research Description

The research consists of several components. The initial work included designing, documenting, and constructing the first UHPC bridge in the United States. Concurrently, research was conducted to perform a performance evaluation to ensure the viability of the UHPC bridge design. To help facilitate the design of the UHPC bridge, a shear design procedure was developed. Two other aspects were investigated further to aid in design: defining of material properties and understanding of flexural behavior. In order to obtain information in these areas, several tests were carried out including material testing, large-scale laboratory flexure testing, large-scale laboratory shear testing, large-scale laboratory flexure-shear testing, small-scale laboratory shear testing, and field testing.

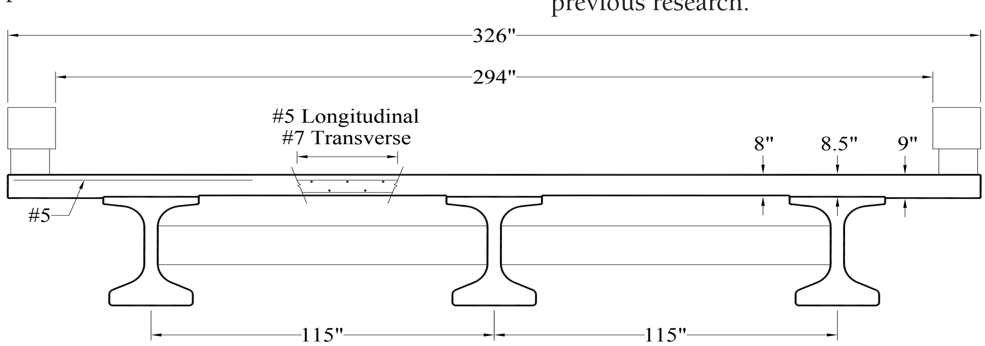
Key Findings

The following conclusions apply to the use of UHPC in general:

- An assumed compressive strength of UHPC of 28 ksi is not conservative. The compressive strength of UHPC is dependent on curing methods in which steam curing was shown to produce the highest strengths. The compressive strength of UHPC tested in this work was found to be between 24 ksi and 25 ksi.
- The tensile cracking strength of UHPC is again dependent on curing methods; however, the tensile strength of approximately -1.1 ksi measured in this work generally agrees with previously published tensile strengths.
- The flexural and shear service strength of UHPC beams can be accurately determined using an uncracked beam analysis based on standard mechanics of materials equations.
- The ultimate flexural capacity of UHPC can be accurately determined using the strain compatibility approach described by ACI [9] and AASHTO [15]. This method assumes that after cracking plane sections remain plane, stress and strain can be related through constitutive properties, and shear stress is constant.
- The MCFT approach can accurately determine the ultimate shear capacity of UHPC beams.

Additional conclusions have been made pertaining to the large-scale and small-scale laboratory testing of UHPC:

- The analytical model using the strain compatibility approach correlated well with the large-scale flexure test results and, furthermore, the test results verified that the service level and ultimate level flexural capacities are adequate for the Wapello County bridge. The calculated service moment capacity of the bridge beam was determined experimentally to be 4,760 ft-kips which is greater than the applied service bridge moment of 4,624 ft-kips. The calculated ultimate moment capacity of the bridge beam was determined analytically to be 7,620 ft-kip which is greater than the applied ultimate bridge moment of 7,350 ft-kip.
- The MCFT model correlated well with the large-scale shear test results up to the point of shear cracking. After shear cracking, the experimental strain data were difficult to interpret due to discontinuities caused by shear cracking. However, the shear test verified that the service level and ultimate level shear capacities are adequate for the Wapello County bridge. The calculated service and ultimate shear capacities of the bridge beam was determined experimentally to be 312 kips and 497 kips, respectively, which are greater than the applied service and ultimate bridge shear of 210 kips and 301 kips, respectively.
- The MCFT model correlated well with the large-scale flexure-shear test results, and using data from the shear test and flexure-shear test, an idealized shear stress-strain relationship could be formulated. The idealized relationship is expressed as being linear until a shear stress of 2.3 ksi is reached, at which point the stress-strain relationship may be assumed to follow a parabolic curve.
- The small-scale shear test results were inconclusive due to unexpected slipping of strands instead of shear or flexure failure. This bond failure suggests that the bond strength may be less than that concluded in previous research.



Cross section of Wapello County UHPC bridge