Design and Evaluation of a Single-Span Bridge Using UHPC

tech transfer summary

Several characteristics make UHPC a desirable construction material, including high strength, low permeability, and low life-cycle costs.

Objectives

- Develop a shear design procedure for ultra high-performance concrete (UHPC) bridge girders.
- Evaluate the structural performance of UHPC girders used in a Wapello County, Iowa, bridge to ensure the design's viability and verify design assumptions.
- Further define the material properties and understand the flexural behavior of UHPC bridge girders.

Problem Statement

UHPC is a relatively new construction material with several important advantages. Due to its low coarse aggregate content and the presence of steel or organic fibers, UHPC has higher compressive and tensile strengths than conventional concrete. The material can thus support greater loads, while UHPC's higher strength also allows for smaller and lighter structural components. The material's high density also makes it practically impermeable to water and chlorides and provides high durability.

Given these advantages, UHPC has the potential to improve bridge components. The first UHPC bridge in the United States was constructed in Wapello County, Iowa, during the fall of 2005. This bridge provides an opportunity, along with laboratory testing, to evaluate the design procedures for UHPC and more thoroughly define material properties and flexural behavior.

Elevation of Wapello County UHPC bridge during construction in 2005

September 2009

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

SPONSORS
Federal Highway Administration
Iowa Highway Research Board (TR-529)
Wapello County, Iowa

CO-PRINCIPAL INVESTIGATORS
Terry J. Wipf
Prof., Civil, Construction, and Environmental Engineering; Dir., Bridge Engineering Center
Iowa State University
515-294-6979, tjwipf@iastate.edu

Brent M. Phares
Assoc. Dir., Bridge Engineering Center
Iowa State University
515-294-5879, bphares@iastate.edu

Sri Sritharan
Assoc. Prof., Civil, Construction, and Environmental Engineering
Iowa State University
515-294-5238, sri@iastate.edu

MORE INFORMATION
www.intrans.iastate.edu

BEC
Iowa State University
2711 S. Loop Drive, Suite 4700
Ames, IA 50010-8664
515-294-8103
www.bec.iastate.edu

The Bridge Engineering Center (BEC) is part of the Institute for Transportation (InTrans) 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.

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Research Description

Research included 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 of the Wapello County UHPC bridge.

Analytical models to understand the flexure and shear behavior of UHPC members were developed using iterative computer-based procedures. A shear design procedure that can be used in the design of UHPC members was developed based on the Modified Compression Field Theory (MCFT). The basic idea of the MCFT is to combine equilibrium, compatibility, and the materials' constitutive properties into an analysis based on average strains and stresses.

Vehicle used for second live load test on Wapello County UHPC bridge

Key Findings

- UHPC's compressive strength depends on curing method; steam curing produced the highest strengths. Compressive strengths measured in this research were between 24 and 25 ksi; an assumed compressive strength of 28 ksi is not conservative.
- Tensile cracking strength depends on curing methods. The approximately -1.1 ksi tensile strength measured in this study agrees with previously published values.
- An analytical model using the strain compatibility approach correlated well with the large-scale flexure test results, and the test results verified that the service level and ultimate level flexural capacities are adequate for the Wapello County bridge.
- The MCFT approach can accurately determine the ultimate shear capacity of UHPC beams. The MCFT model correlated well with the large-scale shear test results up to the point of shear cracking and correlated well with the large-scale flexure-shear test results. The shear test also verified that the service level and ultimate level shear capacities are adequate for the Wapello County bridge.
- The small-scale shear test results were inconclusive due to unexpected slipping of strands rather than shear or flexure failure. This bond failure suggests that the bond strength may be less than that found in previous research.
- The Wapello County bridge was within the service level limit under live load testing and complied with the appropriate criteria. All stresses at midspan were well below the expected live load stresses and UHPC's measured cracking stress (1.1 ksi). No cracks were observed in the UHPC girders or concrete deck.
- The girder neutral axes were generally at or above the theoretical composite neutral axes, confirming composite action between the girders and bridge deck.
- The experimental distribution factors correlated well with design distribution factors. In all cases, the experimental distribution factors were less than the design distribution factors, which suggests a slightly conservative design.

UHPC samples on top of conventional concrete samples

Implementation Benefits

Several characteristics make UHPC a desirable construction material, including high strengths that can support greater loads and allow for smaller and lighter structural components. In addition, UHPC may prove to have lower life-cycle costs than other concretes.

Implementation Readiness

Live load testing conducted on the Wapello County bridge has confirmed the UHPC girder's structural performance. Further research can help more fully define UHPC shear strength characteristics and help apply MCFT to UHPC. Additional investigation is also warranted to study the bond among prestressed strands in UHPC, which were observed to slip during this research.