BRIDGE ENGINEERING CENTER

Investigation of a Suitable Shear Friction Interface between UHPC and Normal Strength Concrete for Bridge Deck Applications

tech transfer summary

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RESEARCH PROJECT TITLE
Investigation of a Suitable Shear Friction Interface between UHPC and Normal Strength Concrete for Bridge Deck Applications

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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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SPR UHPC-011

The focus of this project was the structural characterization of different shear friction interfaces that may be appropriate for overlaying a thin ultra-high performance concrete layer over a normal-strength concrete slab and identifying the most suitable connection for a strong, durable bond.

Problem Statement

Given that bridge deck deterioration occurs due to the formation of cracks on the top surface, a cost-effective yet highly durable composite bridge deck could be formed by overlaying a thin ultra-high performance concrete (UHPC) layer over a normal-strength concrete (NC) slab. However, a dependable shear friction for the UHPC and NC interface and the factors influencing the connection's behavior needs to be investigated to make this concept a reality for field applications. Mechanically connecting the two layers was not considered a possible option as this would increase the cost of construction

Background

In the coming decade, a large percentage of the bridges in the US will reach their expected service life of 50 years. More than 10% of these bridges are listed as structurally deficient, while more than 13% are rated as functionally obsolete. Bridge decks, in particular, are vulnerable to cracking due to corrosion from freeze-thaw cycles and exposure to deicing salts, and also to degradation due to dynamic loads from vehicle traffic and plow trucks.

The deterioration of bridge decks is a leading reason that bridges receive an obsolete or deficient inspection rating. The exposure of bridge deck reinforcing steel to a combination of high moisture, varying temperatures, and corrosive chlorides from de-icing salts through surface cracks leads to concrete deterioration and serviceability challenges. These problems, in turn, necessitate bridge deck replacement or major repairs.

State Department of Transportation (DOT) and Federal Highway Administration (FHWA) officials are looking for bridge repair methods and new bridge decks that are cost-efficient, cause minimal traffic disruption, have low maintenance demands, and fall within the load-bearing capacity of the existing bridge supports.

Concrete Overlays for Bridge Deck Repair

A promising method for bridge deck repair is concrete overlays. Overlays extend the life of a bridge by adding a layer on top of the existing bridge deck, providing a durable wearing surface that also protects the steel reinforcement inside the deck from water and chemical penetration.

Various materials have been used as bridge deck overlays, but none so far have provided an ideal mix of durability, reasonable cost, and low maintenance demands. As a self-leveling, high-strength concrete material with excellent durability and high tensile strength, UHPC shows promise as an excellent overlay material. While UHPC has been gaining momentum in terms of its use in bridge applications, it's relatively expensive.

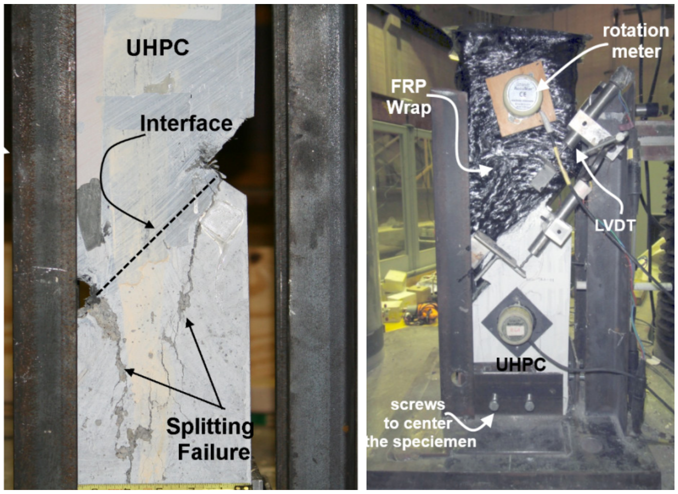
Objective and Scope

The objective of this research was to determine whether placing a thin overlay of UHPC over an NC slab would be a cost-effective way to form a composite bridge deck with a durable surface that remains crack free and resists water and chemical penetration. The research also aimed to determine the interface texture that would most likely contribute to a strong, durable bond between the two types of concrete without needing mechanical connection.

Research Description/Methodology

A total of 60 UHPC-NC slant shear specimens were created in the laboratory to test the impact of several variables on the bond characteristics at the interface: compressive strength of normal concrete, shear interface surface texture, curing condition, and pouring sequence.

- NC samples with strengths of 5, 7, and 10 ksi and different interface textures were prepared through the use of form liners measuring 1.26 mm, 1.59 mm, 3 mm, 5 mm, and 6.5 mm (with 1 mm = 0.0394 in.). The NC was always air cured, but the UHPC was either air cured or steam cured.
- In the pouring sequence, 45 of the samples were wet UHPC poured over NC, while 16 samples were wet NC poured over heat-treated UHPC.
- Each sample was tested according to ASTM C882 with uniaxial compression at the ends of each sample using a universal testing machine. Each sample was tested to failure, which came either due to significant slip at the interface or a splitting in the NC.



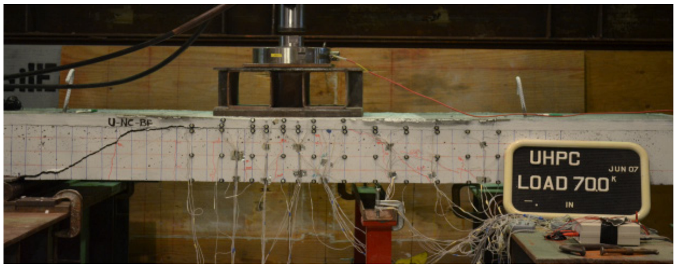
During the first series of slant shear tests on 5 ksi normal-strength concrete (NC) specimens with deeper textures, splitting cracks in the NC caused them to fail prematurely before the interface experienced significant sliding. These cracks initiated at the ends of the interface and propagated into the NC, as shown on the left. In order to prevent such premature failures, samples with deeper textures were retrofitted with fiber-reinforced polymer (FRP) wrap, as shown on the right.

For flexural testing using three-point bending tests, the researchers constructed four composite UHPC-NC bridge deck specimens: three had interface texture depths of 5 mm, 3 mm, and 1.26 mm and one was broom finished.

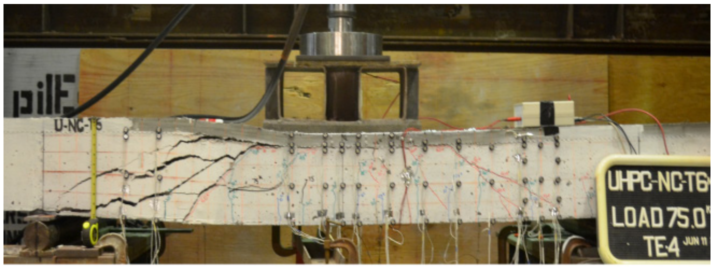
- After 28 days of curing, UHPC overlays were poured onto each of the four dampened, roughened NC surfaces and allowed to air cure. For comparison, researchers also constructed a standard NC-NC overlay specimen.
- The samples were tested following American Association of State Highway and Transportation Officials (AASHTO) load resistance factor design (LRFD) guidelines for bridges using a hydraulic actuator and a 10 in. × 20 in. steel plate in two orientations: perpendicular to the specimen (orientation A) and parallel with the specimen (orientation B).
- Instruments including a 100 kip load cell, string potentiometers, and a three-dimensional (3D) Optotrak system were used to test the specimens.
- Specimens were load tested in the following order:
    1. Loading up to 12.5 kips in load orientation A
    2. Loading and unloading up to 21.3 kips and 48 kips in load orientation B to represent expected service load conditions
    3. Loading up to 60 kips using load orientation A to cause shear cracking in the NC
    4. Loading to failure in load orientation B to estimate the capacity of the system

Key Findings from Slant Shear Testing

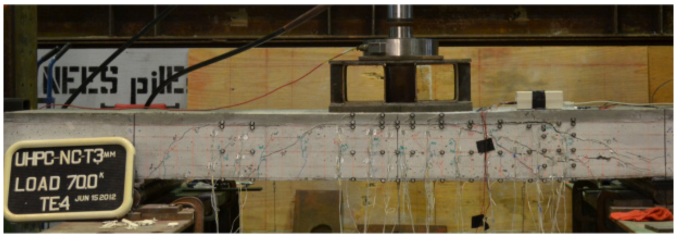
- The bond strength at the interface was highly dependent on interface roughness. The specimens with no surface roughness failed at the interface. The specimens with grooves or shear keys did not fail at the interface; instead, the NC experienced splitting failure. These results indicate that proper surface preparation with sufficient roughness yields greater bond strength in shear/compression than the individual substrate material capacity.
- A minimum roughness of 2 mm was sufficient to develop adequate bond strength at the UHPC and NC interface under combined shear and compression loading. The casting sequence did not have any significant influence on the bond strength at the interface.
- Regardless of concrete strength, the UHPC-NC bond capacity at 28 days surpassed the requirements of the American Concrete Institute (ACI 546.3R-06) for all texture depths greater than 2 mm. However, the average bond strength values for texture depths less than 1.6 mm were below the recommended values for 5 ksi normal strength concrete mix. Therefore, if UHPC is applied to NC with a surface roughness of 1.6 mm or less, the UHPC layer can delaminate.



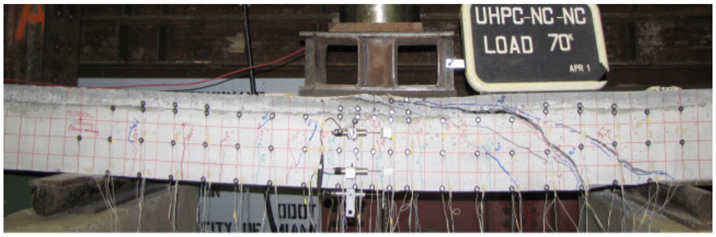
UHPC-NC specimen with hand broom finish texture



UHPC-NC specimen with TR1 (5 mm) texture



UHPC-NC specimen with TR2 (3 mm) texture



NC-NC standard overlay specimen

Cracking in composite specimens at their ultimate failure loads during flexural testing

Key Findings from Flexural Testing

- All specimens ultimately failed with the initiation of shear failure in the NC portion of the composite deck at a load of about 4.5 to 4.9 times the designed service-level wheel load.

- Flexural testing of the composite UHPC-NC deck specimens yielded no interface failures. There was no interfacial slip during testing. The maximum shear stresses at the interface ranged from 150 to 200 psi at the deck shear failure load, which are much lower than the bond strengths observed in the slant shear tests.

Implementation Readiness and Benefits

This project investigated the use of thin UHPC overlays as a bridge deck rehabilitation or construction method. Determining what makes a strong, durable bond between NC and UHPC is an important step in developing UHPC overlays.

- Based on the flexural tests on the composite slabs, it is clear that UHPC can be used as a durable overlay in bridge decks. Given that the investigation focused largely on short-term effects, 3 mm minimum roughness is recommended for the UHPC-NC interface for practical applications.

- The behavior of the UHPC-NC composite section can be accurately calculated using analytical models based on traditional beam bending theory with appropriate material stress-strain characteristics.

- Additional research should be conducted before widespread implementation of UHPC overlays is undertaken.

Future Research Recommendations

The following topics need to be addressed through future research before implementing UHPC-NC composite decks or UHPC overlays in routine field applications:

- Further research on large-scale specimens is needed to understand the effects of thermal variations, differential shrinkage, and creep on the long-term performance of composite decks.

- The integrity of the UHPC bridge deck overlay should be evaluated under high cyclic fatigue loading.

- Further research needs to be conducted on large-scale samples to understand the long-term effects of freeze-thaw cycles and deicing salt on the interface bond behavior.

- In this study, the UHPC overlay and the interface were predominantly in compression, representing the state of stress on a simple span bridge. However, on a continuous span bridge, the stress at locations of maximum negative bending are different. Therefore, experimental and analytical studies involving multi-span bridges should be conducted.

- The effects of cracks in the existing bridge deck on localized stresses and the possibility of crack propagation through the depth of the UHPC overlay should be investigated.