Use of Ultra-High-Performance Concrete for Bridge Deck Overlays

tech transfer summary

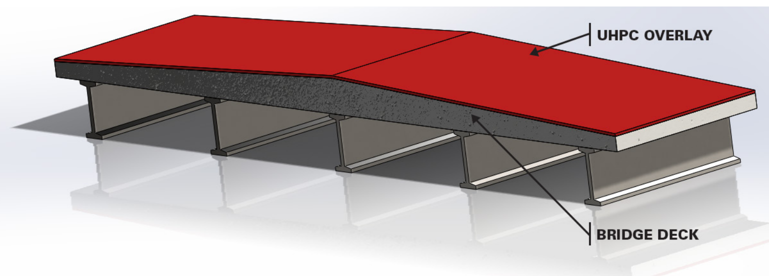
Applying thin ultra-high-performance concrete overlays over normal concrete bridge decks can improve bridge deck durability by increasing the cracking resistance and providing protection against moisture penetration and chloride ingress.

Problem Statement and Background

The most common bridge deterioration begins with cracking in the deck followed by water and chloride infiltration into the concrete core and corrosion damage to the reinforcement of the deck. Further damage to bridge deck occurs due to freeze-thaw cycles, exposure to deicing salts, and dynamic loads from vehicular traffic and plow trucks. Cracking on bridge decks is common, and bridge deck deterioration is a leading cause of structurally obsolete or deficient inspection ratings.

One innovative and conceptually simple solution developed at Iowa State University to combat this problem involves overlaying a thin layer of highly durable ultra-high-performance concrete (UHPC) integrally at the top of the normal concrete (NC) deck.

Thin UHPC overlay over normal concrete bridge deck



Project Objectives

- Evaluate a new UHPC mix design that will allow bridge deck overlays to be completed with appropriate crowning
- Demonstrate the applicability of the new UHPC mix by performing a deck overlay on an existing bridge
- Evaluate the performance of the UHPC overlay
- Evaluate the benefits of using UHPC overlays through experimental testing
- Conduct workshops on new UHPC overlay technology

Project Methodology

Research tasks in this project included evaluation of a UHPC overlay mix provided by a supplier, field implementation and performance evaluation of a UHPC overlay on a county bridge, and laboratory testing of three deck slab specimens.

Given the potential for this technology to help combat bridge deck deterioration, two workshops were conducted as part of the field implementation/demonstration to educate state and county engineers, consultants, and contractors on the characteristics and benefits of UHPC, past UHPC applications, and the use of the UHPC as an overlay material.

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RESEARCH PROJECT TITLE
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SPONSORS
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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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Evaluation of UHPC Overlay Mix

Two 8 ft x 8 ft x 7.75 in. concrete slabs were designed and constructed with reinforcement details similar to those of bridge decks to support dead and live loads. One slab had an exposed aggregate surface (Slab A) and the other had a broom-finished surface (Slab B) with a surface roughness of about 1/8 in. (3 mm). A 1.5 in. thick UHPC overlay was then placed on top of both slabs.

Slabs overlaid with UHPC

The slabs were positioned at a 6% slope to ensure that the UHPC overlay can be placed on sloping surfaces. For this purpose, a new UHPC mix was developed by the material supplier, LafargeHolcim.

Field Implementation of UHPC Overlay

Mud Creek Bridge in Buchanan County, Iowa, was selected to be the first UHPC overlaid bridge in North America. For the demonstration project, both lanes of the bridge were overlaid with UHPC in two stages.

A UHPC overlay thickness of 1.5 in. was chosen for the entire bridge deck. Welded wire reinforcement (wire mesh) was placed in one lane at the pier locations to evaluate the usefulness of such reinforcement in the negative moment region and the ease with which such reinforcement could be used within the overlay. Once the UHPC hardened, the surface was ground and grooved to give an appropriate roughness for vehicular traffic.

Mud Creek Bridge: (a) deck before the overlay was placed, (b) UHPC overlay placed in one lane, (c) girding of the surface, (d) completed deck

After the overlay was placed, both destructive and nondestructive tests were carried out to assess performance over the course of a year. Pull-off tests were carried out according to ASTM C1583 by Federal Highway Administration researchers, both at locations suspected to have experienced delamination and at locations where no delamination had been detected.

Infrared thermal image scanning was also performed to assess the delamination potential of the UHPC overlay.

Infrared thermal imaging results for the entire Mud Creek Bridge deck

Laboratory Testing of Slab Specimens with and without UHPC Overlays

Three slab specimens representing regular concrete bridge decks in Iowa were constructed. The size of each slab specimen was 2 ft by 8 ft, and the thickness of the normal concrete slab was 9 in. Two of these slab specimens were brought to the field and overlaid with 1.5 in. thick UHPC, which made the slab thickness 10.5 in. Both slabs included wire mesh reinforcement in the overlay. A UHPC overlay was not applied to the remaining specimen.

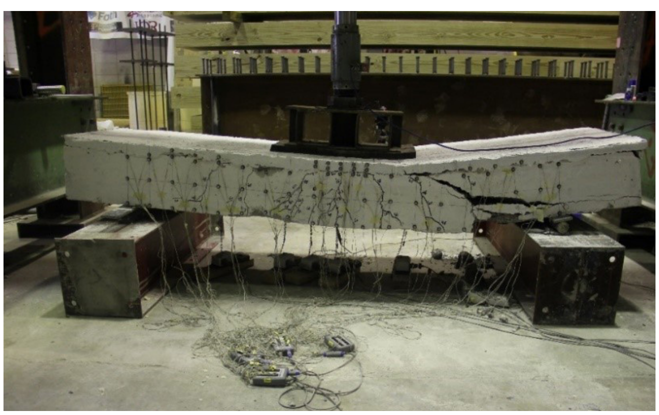
Concrete slab specimen with wire mesh being overlaid with UHPC

The actual concrete strength of the slabs was 6.6 ksi, the rebar yield strength was 75 ksi with an ultimate strength of 100 ksi, and the specified UHPC compressive strength was 18 ksi with a tensile strength of 1.3 ksi. The specimens were simply supported with a span of 6 ft and were subjected to quasi-static load using a loading frame to simulate wheel loading.

During testing, the overlay was left on the top surface in one of the specimens to represent a positive moment case, and the other specimen was tested in an upside down position with the overlay on the bottom to represent a negative moment case.

Key Findings

- The UHPC overlay technology developed in a previous phase of research was successfully demonstrated to be a viable technology on Mud Creek Bridge in Buchanan County, Iowa.
- The results of the pull-off tests at the potentially delaminated areas on the Mud Creek Bridge deck showed that areas of delamination existed within the NC deck and not at the UHPC-NC interface.
- For the laboratory tests, the specimen without UHPC overlay failed in shear where a large shear crack formed approximately 1 ft away from a support toward the midspan, as expected. A similar shear failure mode was found for the specimen with UHPC overlay on top, but this failure occurred at a higher load. The shear cracks did not penetrate into the UHPC layer but turned horizontally and began to separate the UHPC overlay from the NC.



Specimen with overlay on top at failure

- For the specimen with UHPC overlay on the bottom, a rather brittle failure mode was observed where a single flexural crack developed primarily in the UHPC layer at the midspan and propagated towards the top before the specimen finally experienced flexural tension failure, with little bit of the concrete at the top being crushed. This failure mode is typical of cases in which tension reinforcement is insufficient.
- The laboratory specimen with the UHPC overlay on top, simulating a positive moment region, showed an increase in stiffness and strength compared to the specimen with NC only. The strength increase is largely due to the increase in depth rather than the addition of UHPC, but the ductility of the unit increased partly because the UHPC can carry large compressive stress.
- The specimen with the overlay on the bottom, simulating a negative moment region, also showed an increase in strength, most of which was also due to the increase in depth. The wire mesh in the negative moment did not contribute significantly because its total area was fairly small and was insufficient to distribute flexural cracks. A higher amount of reinforcement within the overlay could increase the structural performance of the deck significantly. However, it could negatively impact the bond between the NC and UHPC. A negative aspect of increasing the depth of the slab is that it increases the self-weight of the bridge deck.

Implementation Readiness and Benefits

The new UHPC mix developed by LafargeHolcim was found to be suitable for use in bridge deck overlay projects and was found to be appropriate for crowning and for placement on sloping deck surfaces. No concerns have been identified for the top surface nor the interface bond between the old concrete deck and the UHPC overlay, suggesting that the surface preparation adopted for Mud Creek Bridge was satisfactory.

Due to its high tensile strength and low permeability, a UHPC overlay can improve the performance of a bridge deck by providing resistance against moisture penetration and chloride ingress. With the developed overlay technology, UHPC can be applied as a thin layer on top of a concrete deck with a roughened surface, making it an attractive solution for bridge rehabilitation and new bridge construction.

Recommendations for Further Research

- The selected demonstration bridge was a county bridge with a relatively low volume of traffic. With the experience gained from this project, this technology can be applied to larger bridges with higher traffic volumes. For such projects, automating the placement of the UHPC may lead to cost benefits.
- The use of reinforcement within the overlay layer can be further explored. The amount of reinforcement used in this project was insufficient to determine its benefits.
- The UHPC overlay requires continuous monitoring to understand the buildup of strains and its long-term performance.