MONTANA
Department of Transportation
Research

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Project Summary Report
FHWA/MT-24-002/10000-844

# EXPLORATION OF UHPC APPLICATIONS FOR MONTANA BRIDGES

https://www.mdt.mt.gov/research/projects/uhpc.aspx

## Introduction

Ultra-high performance concrete (UHPC) has mechanical and durability properties that far exceed those of conventional concrete. A series of research studies on UHPC have been conducted at Montana State University, including an implementation project employing UHPC for precast member connections on two bridges spanning Trail Creek on Highway 43, west of Wisdom, MT. The project summarized here aimed to build on the successes of this previous research and explore additional applications for UHPC on Montana bridges. Bridge deterioration, including decks and other structural members, is a significant issue across Montana. UHPC overlays and patching/repair methods may offer a viable alternative to complete bridge or member replacement. The research discussed herein mainly focused on using UHPC as a bridge deck overlay material, and included the necessary testing to ensure its successful implementation in this new application. Overall, this research was a critical step toward capitalizing on the benefits of using UHPC in new applications, ultimately increasing the lifespan of Montana's existing concrete infrastructure.

*Figure 1: Example direct tension specimen prior to testing.*

The research for this project focused on three main objectives:

1. Determine the material-level properties of several UHPC mixes, including the bond strength between the UHPC and conventional concrete.

2. Summarize existing UHPC bridge deck overlay projects and several UHPC overlay material specifications from other states to assist MDT in developing their own specification for future UHPC overlay implementation projects.

3. Evaluate the structural performance of slabs repaired with UHPC overlays. This was completed by constructing and testing five slabs with varying overlay thickness, substrate concrete strength, and negative vs. positive moment behavior.

## What We Did

The objectives of this research were achieved through the following tasks:

*Figure 2: UHPC overlay slab test set-up.*

- The project began with a comprehensive literature review of UHPC applications for bridge repair, focusing primarily on thin-bonded overlays and bridge member repairs. Following the literature review, the decision was made to primarily focus on the use of UHPC as a bridge deck overlay material.
- Material testing was conducted to determine the repair potential of three different UHPC mixes. Specifically, the mixes that were evaluated were the MT-UHPC, the MT-UHPC with a viscosity modifying admixture for thixotropy (MT-UHPC-T), and a proprietary thixotropic Ductal mix (Ductal-T). This evaluation focused on the effects of surface preparations on the subsequent bond strengths between the UHPC and conventional substrate concrete. The properties evaluated for each mix were workability, compressive strength, tensile strength, direct-tension bond strength (Figure 1), and slant-shear bond strength.
- A thorough literature review was conducted to investigate UHPC overlay projects completed by other states, and learn from their newly developed material specifications and evaluate any implementation issues and construction considerations. A recent FHWA report on UHPC-based preservation and repair methods served as the primary source for this work. Recommendations from this report were compared to those from UHPC-related material specifications/provisions from four other state DOTs.
- Five UHPC overlay composite deck slab specimens were designed, constructed and tested (Figure 2). The effects of varying overlay depth, substrate concrete strengths, and positive vs. negative bending behaviors were then evaluated. The measured slab capacities were then compared to ACI and FHWA predicted capacities to evaluate the efficacy of these methods.

## What We Found

Based on this investigation, the following conclusions were made:

*Conclusions from the material level evaluation.*

- The UHPC mixes tested in this research exhibited adequate compressive and tensile strengths, consistent with previous research on UHPC.
- The thixotropic mixes investigated in this research had appropriate flows for the desired overlay application, where a low-slump mix is required for placement on graded/crowned bridges.
- The direct-tension bond tests for all three concretes and nearly all surface preparation methods met the minimum strength specified by ACI for concrete repairs.
- The minimum bond strengths obtained from the slant-shear tests for all concretes met the ACI specified shear bond strength for concrete repairs, despite a conservative surface preparation method with grooves parallel to the loading direction.

*Conclusions from the structural testing.*

- The inclusion of a UHPC overlay significantly improved the stiffness and ultimate capacity of the positive moment slab specimens. Further, it was determined that an increase in overlay depth resulted in an increase in ultimate capacity (Figure 3).

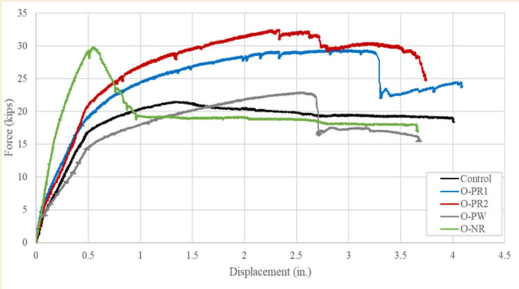


*Figure 3: Comparison of all test slabs (force-displacement graphs).*

- The observed failure of the UHPC overlay slab specimens tested in positive moment was due to shear in the substrate concrete (Figure 4). This failure mechanism can be attributed to the increased ultimate strain of UHPC, which delayed the onset of concrete crushing in the overlay specimens. This delay in crushing forced the failure mechanism into the substrate concrete, which failed due to shear well after the longitudinal steel had yielded and significant deflections had occurred.
- The UHPC overlay slab specimen subjected to negative moment loading did not form significant flexural cracks until a much higher load compared to the other slabs, owing to the high tensile capacity of the UHPC overlay. After this crack formed, there was a significant drop in capacity, and the specimen behaved similarly to the control specimen, ultimately failing due to concrete crushing at the midspan.
- The slab test results indicate that a bridge deck constructed with lower-strength concrete retrofitted with a thin UHPC overlay can exhibit comparable performance to a deck built completely with higher-strength conventional concrete.
- ACI calculations were consistent with the test results for the positive moment specimens and were conservative. For the negative moment specimen, the FHWA predicted capacity that accounts for the tensile capacity of the UHPC closely matched the observed capacity.


*Figure 4: Shear failures of the positive moment UHPC overlay slab specimens.*

## What The Researchers Recommend

Overall, UHPC overlays have shown promise as an option for retrofitting existing bridge decks, significantly improving the performance of concrete slabs by enhancing strength and durability. Not only were the test results from this project encouraging, but the success that other states have had using UHPC for overlays is very promising for its potential implementation in Montana. However, the specific benefits should be evaluated on a case-by-case basis, considering factors such as cost, construction constraints, and the project's specific demands. To further capitalize on the findings of this research, a future project could pursue implementation of a UHPC bridge-deck overlay on a bridge in Montana. Additionally, further research could focus on refining and enhancing the thixotropic properties of MT-UHPC and increasing its possible batch sizes to facilitate its use as a bridge deck overlay material.

*More Info:*

The research is documented in Report FHWA/MT-24-002/10000-844


### Principal Investigator:

Kirsten Matteson, kirsten.matteson@montana.edu, 406.994.1566

### MDT Technical Contact:

Lenci Kappes, lkappes@mt.gov, 406.751.2033

### MDT Research Project Manager:

Vaneza Callejas, vcallejas@mt.gov, 406.444.6338


To obtain copies of the final report, contact MDT Research Programs, 2701 Prospect Avenue, PO Box 201001, Helena MT 59620-1001, mdtresearch@mt.gov, 406.444.6338.