EXPLORATION OF ULTRA-HIGH PERFORMANCE CONCRETE (UHPC) APPLICATIONS FOR MONTANA BRIDGES

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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, and this current project 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. This research 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.

OBJECTIVES

- Material Level Evaluation: Test bond strengths to regular concrete and other material level properties of two non-proprietary UHPC mixes and one proprietary UHPC mix.
- Summarize existing UHPC bridge deck overlay projects and specifications from other states to assist MDT in developing their own specification (not included on poster).
- Structural Testing: Construct and perform flexural testing of five different slabs to compare the effects of overlay thickness, substrate concrete strength, and negative vs. positive moment behavior.

RESEARCH METHODS

MATERIAL LEVEL EVALUATION


Slant Shear


Direct Tension


Flexure

- Compare non-proprietary Montana UHPC (MT-UHPC), a non-proprietary thixotropic version of MT-UHPC with the addition of a viscosity modifying admixture (MT-UHPC-T), and a proprietary thixotropic Ductal mix (Ductal-T).
- Perform compressive (ASTM C1856 and ASTM C39), flexural (ASTM C1609), tension bond strength (ASTM C1583), and shear bond strength (ASTM C882) testing on all UHPC materials.

STRUCTURAL TESTING

Five slabs were constructed and tested in 3-Point Bending:

1. Control: 6.25" thick, regular-strength concrete (~4 ksi)
2. Overlay-Positive Regular 1 (O-PR1): target overlay thickness of 1.5", tested in positive moment, regular substrate concrete
3. Overlay-Positive Regular 2 (O-PR2): target overlay thickness greater than 1.5", tested in positive moment, regular substrate concrete
4. Overlay-Positive Weak (O-PW): target overlay thickness of 1.5", tested in positive moment, weak substrate concrete (~2 ksi)
5. Overlay-Negative Regular (O-NR): target overlay thickness of 1.5", tested in negative moment, regular substrate concrete


Test Setup

MATERIAL LEVEL EVALUATION RESULTS

MATERIAL PROPERTIES

	Flow (in)		Compressive Strength, f'c (ksi)			Ultimate Tensile Strength (ksi)		
UHPC Type	Static	Dynamic	7-Day	14-Day	28-Day	Measured	Predicted	Meas/Pred
MT-UHPC	10.25	-	14.3	15.1	17	3.37	0.978	3.45
MT-UHPC-T	4	5.5	11.6	-	15.4	2.8	0.931	3.01
Ductal-T	4	6.5	15.1	17.3	17.4	3.43	0.989	3.47

- MT-UHPC and Ductal-T reached 28-day strengths of around 17 ksi.
- MT-UHPC-T only reached a 28-day strength of 15.4 ksi.
- Measured tensile strengths were about three times the predicted values.

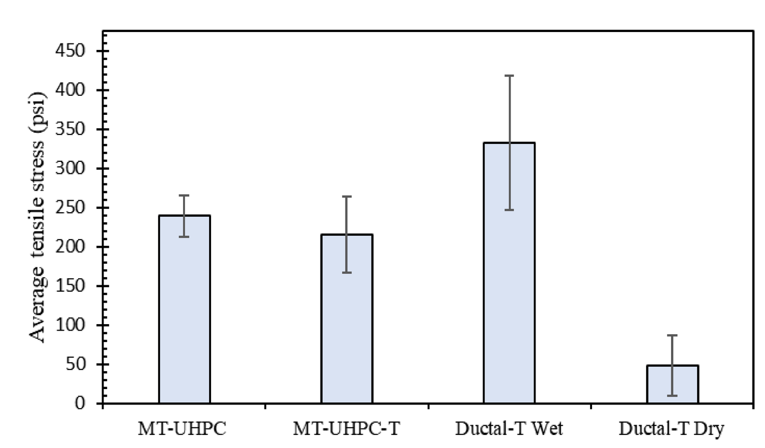
SLANT SHEAR

Sample Number	Minimum Bond Shear Strength (ksi)		
	MT-UHPC	MT-UHPC-T	Ductal-T
1	2.94	3.15	3.13*
2	2.77	3.33	3.26
3	2.75	3.31	3.3
4	2.82	3.37	3.16
Average	2.82	3.29	3.24
CoV	3.02%	2.94%	2.23%

*Bond Failure

- All UHPC mixes exceeded the ACI recommendations for concrete repair.
- Only one specimen failed at the bond, therefore the results shown are **minimum** bond strengths.

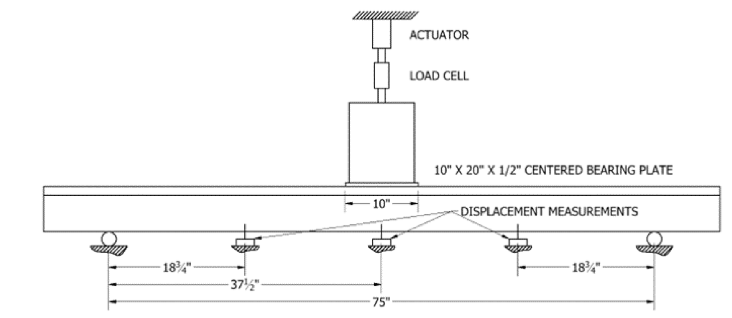
DIRECT TENSION



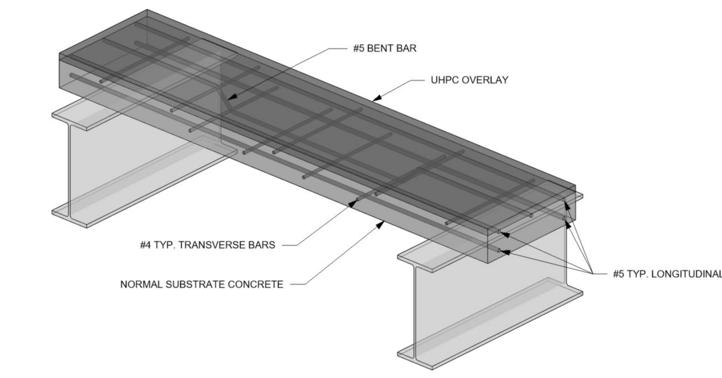

Direct Tension Specimen

- All UHPC mixes exceeded the ACI recommendations for concrete repair.
- Results demonstrate the importance of wetting the substrate concrete prior to casting.

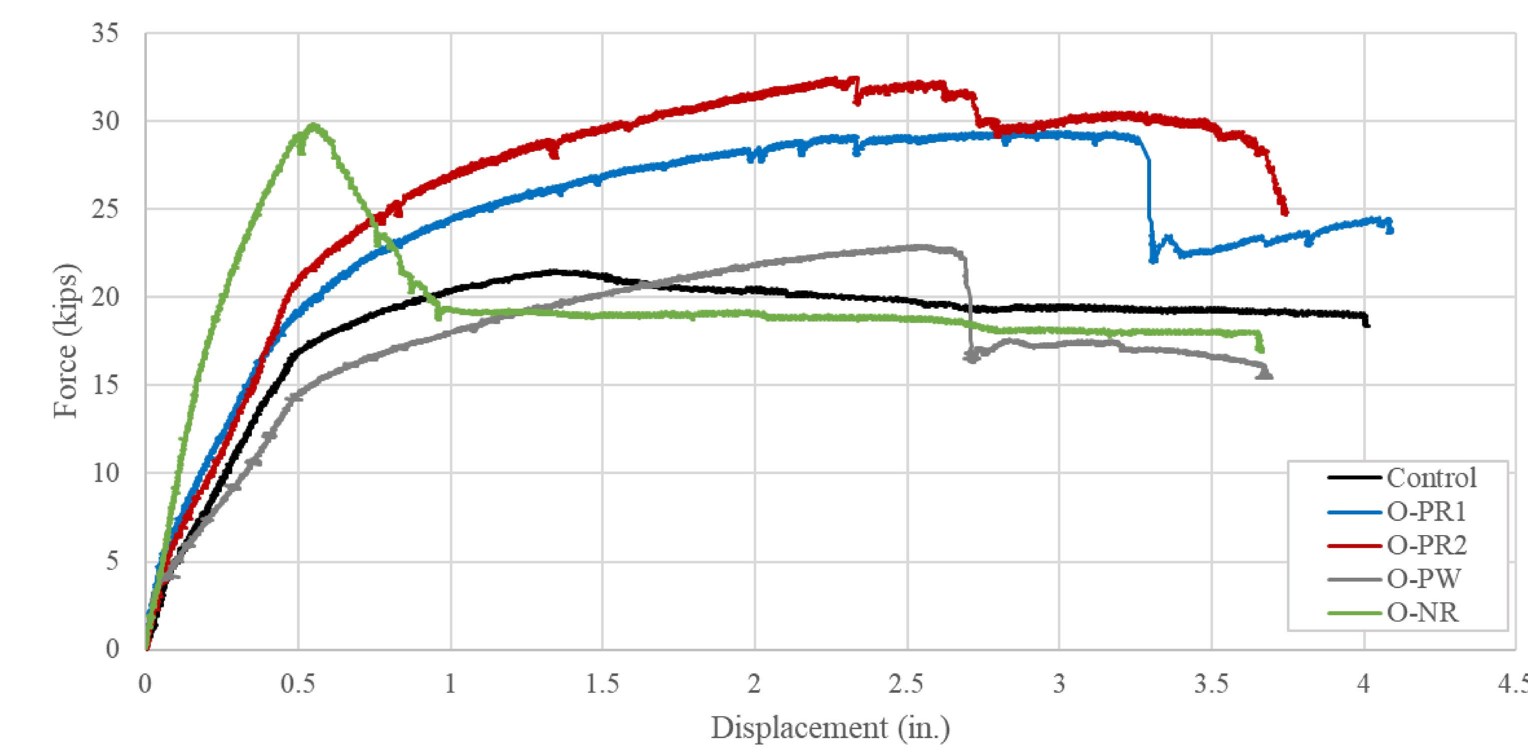
STRUCTURAL TESTING RESULTS



Schematic of Test Setup



Test Slab Schematic Isometric View



ACI/FHWA PREDICTED CAPACITIES

Slab	Failure Mechanism	Measured Values			Moment Calculations		Shear Calculations	
		Measured P (kips)	Measured Moment (k-ft)	Measured Vc (kips)	Predicted Mn (k-ft)	Meas/Pred	Predicted Vc (kips)	Meas/Pred
Control	Concrete crushing	21.5	31.4	10.8	25.6	1.22	11.1	0.97
O-PR1	Shear in substrate	29.4	42.9	14.7	33.9	1.26	11.4	1.29
O-PR2	Shear in substrate	32.5	47.4	16.3	35.7	1.33	11.6	1.40
O-PW	Shear in substrate	22.9	33.4	11.5	28.4	1.18	10.2	1.12
O-NR	Cracking/ Concrete Crushing	29.8	43.5	14.9	45.4	0.96	10.9	1.37

PHOTOGRAPHS


O-PR1 Shear crack widening/spreading


O-PR2 Shear crack extending through the overlay


O-NR Midspan after failure, showing crushed concrete

STRUCTURAL TESTING CONCLUSIONS

- The inclusion of a UHPC overlay significantly improved the stiffness and ultimate capacity of the positive moment slab specimens. The O-PR1 and O-PR2 specimens exhibited 37% and 51% higher strengths, respectively, compared to the control specimen.
- The observed failure mechanisms of the positive moment slab specimens varied depending on the presence of a UHPC overlay and other influencing factors. The Control slab failed due to concrete crushing in the compression zone at midspan. In contrast, the three positive moment slabs with UHPC overlays ultimately failed due to shear in the substrate concrete. This difference in 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, where it failed due to shear, well after the longitudinal steel had yielded and there were significant deflections.
- The specimen subjected to negative moment loading did not form significant flexural cracks until a load of nearly 30 kips, 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 and ultimately failed due to concrete crushing at the midspan.
- The Control and O-PW slabs performed similarly despite the large difference in substrate concrete strengths (4.1 ksi Control vs. 2.7 ksi O-PW) and differences in overall depths; indicating that a bridge deck constructed with lower-strength concrete retrofitted with a thin UHPC overlay can exhibit comparable performance to a deck built with higher-strength conventional concrete.
- Regarding the efficacy of capacity calculations, the ACI calculations were in line with the test results for the positive moment specimens and were conservative, with Meas/Pred ratios ranging between 1.12-1.40. For the negative moment specimen, the FHWA predicted capacity closely matched the observed capacity, with a Meas/Pred ratio of 0.96, when accounting for the tensile capacity of the UHPC.