FEASIBILITY OF NON-PROPRIETARY ULTRA-HIGH PERFORMANCE CONCRETE (UHPC) FOR USE IN HIGHWAY BRIDGES IN MONTANA: PHASE II FIELD APPLICATION

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1 Problem Statement

Ultra-high performance concrete (UHPC) has mechanical and durability properties that far exceed those of conventional concrete. However, using UHPC in conventional concrete applications has been cost prohibitive, with commercially available/proprietary mixes costing approximately 30 times more than conventional concrete. Previous research conducted at Montana State University (MSU) resulted in non-proprietary UHPC mixes made with materials readily available in Montana. These mixes are significantly less expensive than commercially available UHPC mixes, thus opening the door for their use in construction projects in the state. The MDT Bridge Bureau is interested in using UHPC in field-cast joints between precast concrete deck panels. The use of UHPC in this application will reduce development lengths, and subsequently reduce the requisite spacing between the decks and improve the overall performance of the bridge. The research proposed herein will build on the non-proprietary UHPC research already completed at MSU, and focus on ensuring the successful application of this material in these field-cast joints. Specifically, this research will investigate several items related to the field batching of these mixes, and the potential variability in performance related to differences in constituent materials. Further, rebar bond strength and the subsequent effect this has on development length will be investigated.

2 Background

UHPC became commercially available in the U.S. in 2000, and since then has been actively promoted by the Federal Highway Administration [1-6]. UHPC has been used in the U.S. for various applications, including: field-cast connections of prefabricated bridge components, precast/prestressed girders, precast piles, and thin-bonded overlays for bridge decks. UHPC is generally understood to be a concrete with compressive strength at least 20 ksi, post-cracking tensile strength at least 0.72 ksi, and a discontinuous pore structure that improves durability by limiting permeability. These properties are achieved with: (1) low water-to-cement ratios, (2) aggregate gradations optimized for high particle packing density, (3) high quality aggregates and cements, (4) supplemental cementitious materials, (5) high particle dispersion during mixing, and (6) the incorporation of fiber reinforcement. Although the initial cost of UHPC far exceeds conventional concrete mixes, the use of UHPC has been shown to reduce the life-cycle costs [7], as the increased durability of UHPC results in a longer service life and decreased maintenance costs. Further, the use of UHPC results in smaller/lighter structural elements (e.g., prestressed beams).

The overall objective of the Phase I research [8] was to develop and characterize economical non-proprietary UHPC mixes made with materials readily available in Montana. This objective was achieved by first identifying and obtaining suitable/economical materials to be used in UHPC. Specifically, the materials identified and used in this research were simply Type I/II portland cement (from Trident, MT), class F fly ash (from North Dakota), fine masonry sand (from Billings, MT), silica fume, and high range water reducer. UHPC mixes were then developed/characterized/optimized using a statistical experimental design procedure (response surface methodology). The mixes developed as part of this research obtained compressive strengths of approximately 20 ksi with flows of 9-11 inches, and cost less than $1000 per cubic yard with steel fibers (proprietary mixes cost in the range of $2500-$3500). The mechanical properties and durability of these mixes were evaluated through a suite of mechanical and durability tests, which demonstrated the exceptional performance of this material.

It should be noted that in the Phase I research, the concrete trial batches produced were 0.2 to 1.5 cubic feet in size, and were mixed using equipment available in the MSU concrete lab (i.e., a Hobart industrial cake mixer, and a mortar mixer). This research and previous research on UHPC has shown that batch size, mixing equipment, mixing method, and mixing energy can have a significant effect on the performance of the resulting UHPC mix. Therefore, further research should be conducted on the proposed UHPC mixes using the equipment that will be used in the field (most likely a high-shear mixer), under various mixing conditions (e.g., various temperatures, various aggregate moisture contents), and in larger batch sizes.

Previous research on UHPC field cast joints has shown that UHPC can reduce development lengths of the reinforcing in the inter-element connection zone, and thus reduce spacing between decks [9]. However, this research was conducted using only proprietary UHPC concrete mixes. Further research should be conducted on field-cast joints using the newly developed non-proprietary mixes to ensure that these mixes behave as expected in this application (e.g., increased bond strength, decreased deck spacing).

3 Objective

The objective of the proposed project is to further characterize the non-proprietary UHPC mixes developed in the Phase I research, and ensure its successful application in field-cast joints. This objective will be achieved by (1) investigating the potential variability in concrete performance related to differences in constituent materials, (2) investigating issues related to the field batching/mixing of the these UHPC mixes, and (3) testing rebar bond strength and studying how this will affect requisite development lengths.

4 Business Case

Aging infrastructure and limited budgets require robust and proven bridge construction, rehabilitation and replacement strategies that are cost-effective and efficient. Further, accelerated bridge construction techniques are needed to accommodate short construction seasons and to reduce traffic disruptions. UHPC is an ideal material to address these needs; however, despite the many advantages of UHPC concrete mixes, delivery of UHPC from limited commercial suppliers is expensive – estimated at $2500-$3500 per cubic yard for a fiber-reinforced mix. The non-proprietary fiber-reinforced UHPC mixes developed in the Phase I research are significantly less expensive than these proprietary mixes, costing less than $1000 per cubic yard. However, before these mixes can be used in field applications in the state, further research must be conducted to ensure their performance in the desired application. If these mixes are viable for this application, Montana could take advantage of the cost savings of the non-proprietary mixes and ultimately improve the performance and durability of our bridges.

5 Research Plan

The research proposed herein will build on the recently completed research at MSU, and investigate the use of the newly developed UHPC mixes in field-cast joints. Specifically, the proposed project will investigate potential field application issues (e.g., sensitivity to material variations, set-time adjustment, field batching/mixing), and will investigate rebar bond strength and the effect that this has on requisite development lengths.

Task 0 – Project Management

The Principal Investigator for this project will manage the project in terms of contractual compliance, budget and schedule, administrative tasks, and communications with the Technical Panel. Dr. Michael Berry of the Civil Engineering Department at Montana State University will serve as the Principal Investigator. He will be the primary contact and assume the majority of the project management responsibilities. Management will generally be achieved through regular communication between the Principal Investigator, the MDT project manager and Technical Panel, and research team members.

Task 1 – Literature Review

As this research moves ahead, it is essential to be aware and take advantage of any work completed to date by other investigators/organizations. A comprehensive literature will be conducted to evaluate the state-of-the-practice and recent advances in UHPC, and in particular this review will focus on the use of

UHPC in field cast joints. Additionally, material properties and specifications documented by other researchers and state agencies will be investigated. This information will be helpful in guiding the future directions of this research and in the establishment of MDT material specifications.

Task 2 – Material Sensitivity

The overall objective of the Phase I research was to develop and characterize economical non-proprietary UHPC mixes made with materials readily available in Montana. This objective was achieved by first identifying and obtaining suitable/economical materials to be used in UHPC. Specifically, the materials identified and used in this research were simply Type I/II portland cement (from Trident, MT), class F fly ash (from North Dakota), fine masonry sand (from Billings, MT), silica fume, a high range water reducer, and steel fibers. While these materials worked well in the UHPC mixes developed in this effort, the effect of varying these materials was not systematically investigated. This task of the proposed research will investigate and quantify the effects that variations in the materials (e.g., fly ash source, water reducer, steel fiber source, type and source of sand) and material properties (e.g., aggregate moisture content and gradation) may have on the performance of the UHPC. As part of this task, key properties of the constituent materials and their effects on concrete performance will be well documented. This information will be critical in establishing appropriate material specifications. A statistical experimental design procedure, Response Surface Methodology (RSM), may be used in this task to help characterize the effects of these material variations. This methodology was recently and successfully used by the research team in the Phase I effort [8] and to develop concrete containing reclaimed asphalt pavement [10-12], and may be a useful tool for the research proposed herein.

Task 3 – Field Batching/Mixing

In the Phase I research, the concrete trial batches that were produced were 0.2 to 1.5 cubic feet in size, and were mixed using equipment available in the MSU concrete lab (i.e., a Hobart industrial cake mixer, and a mortar mixer). This research and previous research on UHPC has shown that batch size, mixing equipment, mixing method, and mixing energy can have a significant effect on the performance of the resulting UHPC mix. Therefore, the proposed research will identify mixing equipment that will have the potential to be used in the field (most likely a high-shear pan mixer), and will investigate the use of this equipment under various mixing conditions (e.g., batch sizes, various temperatures, and aggregate moisture contents). This task will also involve a limited field demonstration project. It should be noted, that in this and the previous task, moisture content correction methods will be investigated, and set-times for the select UHPC mixes will be characterized.

Task 4 – Bond/Development Length Characterization

Previous research on UHPC field-cast joints has shown that UHPC can reduce development lengths of the reinforcing in the inter-element connection zone, and thus reduce the spacing and congestion between decks. However, this research was conducted using only proprietary UHPC concrete mixes. In this task, the bond behavior of deformed reinforcing steel in the newly developed non-proprietary UHPC will be characterized, and its effect on bar development lengths will be investigated to confirm its performance in the proposed application. Specifically, the bond behavior will be investigated by conducting direct tension pullout tests similar to those described in [13, 14] and shown in Figure 1. In these tests, the effect of embedment length, concrete cover, bar spacing, bar size, and yield strength may be investigated.

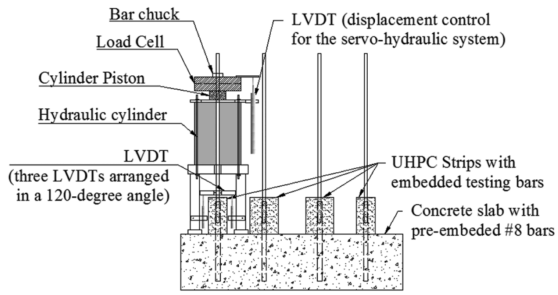

Figure 1: Bond Test Setup [14]

Task 5 – Analysis of Results and Reporting

The results from this work will be thoroughly analyzed in this task. This analysis will include a cost benefit analysis on the use of UHPC in bridges in the state of Montana, and in particular, their use in field joints between precast members.

A comprehensive final report that includes all data, analyses, and recommendations will be written in conformance with MDT's standard research report format to thoroughly document the findings of this project. The report will be concise and include all pertinent information to aid state DOTs in adopting and specifying an efficient, effective, and reliable mix design for UHPC concrete mixes, and will include pertinent information required to establish appropriate material specifications. A draft report will be sent to MDT to be distributed to the Technical Panel for review and comment. The results of the project will also be disseminated, as appropriate, to the professional community through presentations at various conferences and/or through journal papers. A four-page "Project Summary Report" will be written and submitted to MDT near the end of the project to summarize the background, methodology, results and recommendations of this research. This summary report will be edited, published and distributed by MDT to be distributed to the Technical Panel for review and comment.

Three task reports will be written to summarize work associated with the following major activities.

- Task Report 1—Literature review
- Task Report 2—Material Sensitivity
- Task Report 3—Field Batching/Mixing

Quarterly progress reports will be submitted to provide updates on the administrative aspects of the project, such as progress regarding the deliverables, schedule and budget. It should also be noted that the literature review will be updated during the preparation of the final report to include any work that may have been completed after the completion of Task 1.

6 MDT Involvement

In keeping with standard requirements, MDT will also review and comment on task reports, quarterly progress reports, the final report, and the project summary report.

7 Products

The products to be delivered during this project include the following items.

- Kick-off meeting and subsequent notes.
- 7 quarterly progress reports.
- 3-task reports (Tasks 1-3).

- Draft final report and executive summary describing the research methodology, findings, conclusions, and recommendations, followed by a final report addressing comments and suggestions from the Technical Panel.
- Final presentation.
- Draft project summary report.
- Implementation report, meeting, and material specification.
- Performance measures report.
- Project Poster.

8 Implementation

If the proposed research demonstrates the viability of these non-proprietary UHPC mixes in field-cast joints, the first implementation of this research may be in the form of a demonstration/pilot project in which the newly developed mix is used in a bridge project within the state. Upon completion of a successful pilot project, MDT will have a new concrete available for use in bridge construction. The mixture proportions, batching procedures, and material properties will be documented in the final report for the project. This information will be used as appropriate to assist in developing standard specifications for the material and its constituents, and/or to identify additional work that must be done to move this material forward for such standard use.

9 Schedule

The estimated project schedule is depicted in Table 2. The total proposed duration of the project is 24 months, with an estimated start date of March 1, 2018, and an estimated completion date of February 28, 2020. A draft final report will be sent to the Technical Panel two months prior to the end date to provide sufficient time for review and revision.

Table 1: Project Schedule

Task/Milestone	Quarter (after start of work)							
	1	2	3	4	5	6	7	8
Task 0: Project Management	X	X	X	X	X	X	X	X
Task 1: Literature Review	X	X	X	X	X	X	X	X
Task 2: Material Sensitivity		X	X	X				
Task 3: Field Batching/Mixing				X	X	X		
Task 4: Bond/Development Length Characterization					X	X	X	
Task 5: Analysis of Results and Reporting							X	X

10 Budget

This proposal is requesting $145,668 in funding from MDT, as shown in the itemized budget presented in Table 2. A breakdown of expendable supplies and materials is provided in Table 3. The pay rates and benefit rates of the investigators is provided in Table 4. Projected expenditures by task are shown in Table 5. Projected expenditures by state and federal fiscal years are shown in Table 6.

Table 2: Project Budget by Item

Item	Total
Salaries	$64,902
Benefits	$11,232
In-State Travel	$400
Expendable Supplies and Materials	$10,000
Equipment - High-Shear Pan Mixer	$20,000
Participant Support	$10,000
Total Direct Costs	$116,534
Overhead - 25%	$29,134
Total Project Cost	**$145,668**

Table 3: Breakdown of Expendable Supplies and Materials

Item	Budget
Portland Cement/Silica Fume/Fly Ash	$2,000
Admixtures	$2,000
Fine/Coarse Aggregates	$1,000
Steel Fibers	$3,000
Cylinder Molds	$1,000
Misc Supplies	$1,000
Total	**$10,000**

Table 4: Pay Rate and Benefits

Name of Principal, Professional, Employee, or Support Classification	Hourly Rate	Benefit Rate
Michael Berry	$55.50	30%
Graduate Student	$15.14	10%
Undergraduate Student	$11.00	10%
Business Mgr.	$41.77	33%
Admin Staff	$26.00	33%

Table 5: Project Budget by Task

Task	Budget
0 - Project Management	$6,389
1 - Literature Review	$15,918
2 - Material Sensitivity	$29,743
3 - Field Batching/Mixing	$54,743
4 - Bond/Development Length Characterizatino	$23,916
5 - Final Report and Desimination of Results	$14,957
Total	**$145,668**

Table 6: Project Budget by Fiscal Year

Item	State Fiscal Year			Federal Fiscal Year		
	2018	2019	2020	2018	2019	2020
Salaries	$10,817	$32,451	$21,634	$18,930	$32,451	$13,521
Benefits	$1,872	$5,616	$3,744	$3,276	$5,616	$2,340
In-State Travel	$67	$200	$133	$117	$200	$83
Expendable Supplies and Materials	$1,667	$5,000	$3,333	$2,917	$5,000	$2,083
Equipment	$10,000	$10,000	$0	$10,000	$10,000	$0
Participant Support	$1,667	$5,000	$3,333	$2,917	$5,000	$2,083
Total Direct Costs	$26,089	$58,267	$32,178	$38,156	$58,267	$20,111
Overhead	$4,856	$14,567	$9,711	$8,497	$14,567	$6,069
Total Project Cost	**$30,945**	**$72,834**	**$41,889**	**$46,653**	**$72,834**	**$26,181**

11 Staffing

Dr. Michael Berry will be the Principal Investigator and will be the primary manager and sole point of contact with the MDT project manager. The Principal Investigator will be responsible for ensuring that the objectives of the study are accomplished, executing the project tasks, and preparing the written reports. A graduate and undergraduate student will be employed to primarily conduct the various laboratory tests associated with this project.

The research team is well qualified, experienced and available to conduct this research, and, to the best of its ability, will deliver a quality finished-product in a timely and efficient manner. The level of effort proposed for principal and professional members of the research team will not be changed without prior consent of the Technical Panel. The following subsections describe some of the qualifications and experience of project personnel in addition to each person’s role in this study.

11.1 Dr. Michael Berry -- Principal Investigator

Dr. Berry is an Assistant Professor in the Civil Engineering Department at MSU and has a research background in reinforced concrete structures and the behavior of these structures subjected to earthquake excitations. More recently his work has focused on alternative materials and their use in transportation applications and structural elements. He currently serves on several ACI committees including: Committee 341A - Earthquake-Resistant Bridge Columns, Committee 555 - Recycled Materials in Concrete, and Committee 306 - Cold Weather Concrete.

11.2 Graduate and Undergraduate Students

This research effort will be supported by qualified graduate and undergraduate research assistants, who will work part-time on this project throughout its duration. The students will assist with collecting and reviewing specifications, conducting laboratory tests, organizing and analyzing the data, and helping to synthesize information into the final report.

11.3 Research Team Hours and Availability

It is anticipated that the proposed work associated with this research project will take 3,432 person hours. The number of hours committed to the project by each member of the research team during this time period is shown in Table **7**. Key personnel assigned to accomplish the work associated with this project are generally available throughout the duration of this project. In the event that the level of effort proposed for the principal investigator requires significant modification, written consent will be sought from the Technical Panel to justify and approve this change.

Table 7: Summary of Person Hours by Task

Name of Principal, Professional, Employee, or Support Classification	Task						
	0	1	2	3	4	5	Total
Michael Berry	60	16	100	100	100	40	416
Graduate Student	0	400	400	400	400	400	2000
Undergraduate Student	0	200	200	200	200	200	1000
Business Mgr.	8	0	0	0	0	0	8
Admin Staff	4	0	0	0	4	0	8
Total	72	616	700	700	704	640	3432

12 Facilities

A majority of the required equipment is already available in the Civil Engineering Department at MSU and at WTI. However, a high-shear pan mixer will be purchased for this project. MDT will acquire this piece of equipment at the completion of the project.

13 References

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