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

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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) has focused on the development and evaluation of 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 focus of the proposed project is on taking this material beyond the laboratory, and successfully using it on a bridge project in Montana, specifically for field cast joints. This project is a required step to fully understand and capitalize on the benefits of using UHPC for this application and increase the performance, durability, and efficiency of Montana bridges.

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 steel 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).

Previous research conducted at MSU [8, 9] has included (1) the development of nonproprietary UHPC mixes that are significantly less expensive than commercially available mixes and are made with materials readily available in Montana, (2) an investigation into several items related to the field batching of these mixes, (3) an exploration into the potential variability in performance related to differences in constituent materials, and (4) the investigation of rebar bond strength and the subsequent effect this has on development length. This previous research has been successful and has clearly demonstrated the feasibility of using UHPC in Montana bridge projects. Specifically, this research demonstrated that its use in field cast joints could be particularly useful. In this application, UHPC can reduce congestion and ultimately improve the overall performance of the bridge. However, this research also demonstrated the need for experience with this material to ensure its successful application.

Figure 1: MT UHPC Mixing and Resulting Mix

3 Objective

The focus of the proposed research is on the implementation of this newly developed non-proprietary UHPC on a bridge project in Montana. As of now, two bridges in Montana have already been identified (Trail Creek Bridges on Highway 43 West of Wisdom), and preliminary planning for using UHPC on these bridges has already begun. The scope of this research includes: (1) closing any minor research gaps that may prohibit UHPC use in the desired application, (2) the development of specifications for this material documenting mix proportions and batching/mixing instructions (3) working with the selected contractor to conduct and test several trial batches/pours/mockups to ensure proper mixing/curing/finishing procedures, (4) assisting contractor on bridge projects and preparing specimens on construction day for quality control tests, and (5) monitoring the performance of the deck after completion.

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 and tested in the first two phases of this research are significantly less expensive than these proprietary mixes, costing less than $1000 per cubic yard. That being said, further research on the implementation of these mixes is required to ensure the performance of these mixes in field applications in the state. If this concrete is proven to be viable, Montana could take advantage of the cost savings of the non-proprietary mixes and ultimately improve the performance and durability of their bridges.

5 Research Plan

The research proposed herein will build on the recently completed research at MSU and focus on implementing this newly developed material in a bridge project in Montana. Specifically, this research will include the following tasks.

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 review will be conducted to evaluate the state-of-the-practice for and recent advances in UHPC, and in particular this review will focus on the use of UHPC in actual bridge applications. 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.

Task 2 – Close Minor Research Gaps

This task will focus on closing any minor research gaps in order to ensure the successful use of this material in the proposed field demonstration project. Specifically, this task will investigate the use of a domestically produced steel fiber developed and marketed by HiPer Fiber Solutions. This new fiber is necessary because the steel fibers used in the previous phases of research are no longer produced domestically, and are therefore not permitted on federally funded projects. Further, this research will investigate the short-term strength gain characteristics of this material, which are necessary for scheduling construction activities such as form removal, grinding, and loading. This specific task will include the development of maturity curves for use by the contractors to estimate in-place concrete strengths. Additionally, the bond characteristics of epoxy-coated rebar may also be investigated.

Task 3 – Bridge Construction and Related Activities

As of now, MDT has identified two potential structures for using Montana UHPC in field cast joints: the Trail Creek bridge replacements on Highway 43 West of Wisdom, MT. On these bridges, UHPC is proposed to be used in precast pile cap joints, and shear keys between precast deck elements (as shown in Figure 2).

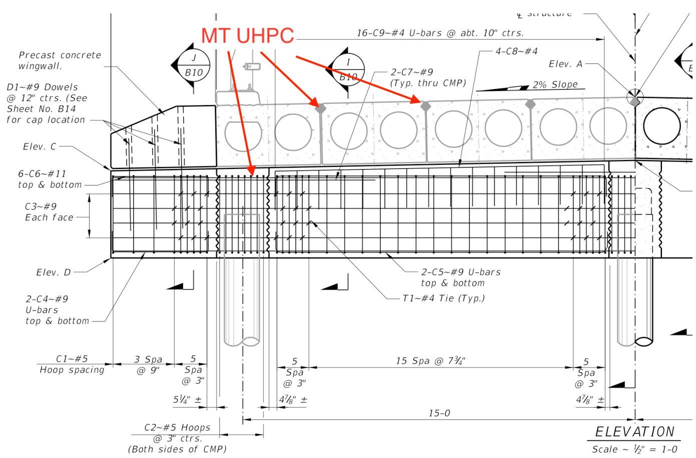

Figure 2: Proposed UHPC Bridge Application

This task will involve: (1) assisting MDT in the development of specifications, mix designs, and mixing procedures to be used on the proposed bridge projects, (2) assisting the contractor during trial batches and possibly modifying mix designs to fine tune mix performance, (3) assisting contractor during specimen mockup construction, and (4) assisting contractor during bridge construction and performing related quality control testing.

Task 4 – Monitoring Bridge Performance

The research team will monitor the performance of the bridge routinely between its completion and the completion of the proposed research project. This monitoring will include continuing to test concrete strengths over this duration, inspecting the bridge and documenting any potential signs of damage (e.g., cracks, debonding, etc). Further, the performance of this bridge will be compared to a similar control bridges made without UHPC. Specifically, the Deep Creek structures on Highway 12 are likely candidates for this comparison.

Task 5 – Analysis of Results and Reporting

The results from this work will be thoroughly analyzed in this task.

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/finalize 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.

In addition to the final report, three intermediate task reports will be written to summarize work associated with the following major activities.

- Task Report 1—Literature review
- Task Report 2—Close of Minor Research Gaps
- Task Report 3—Bridge Construction and Related Activities

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. Further, MDT will be heavily involved in the bridge construction task (Task 3) of the proposed research.

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 and webinar.
- Draft project summary report.
- Implementation report, meeting, and material specifications.
- Performance measures report.
- Project Poster.

8 Implementation

Upon completion of this pilot project, MDT will have a new concrete available for use in bridge construction. This project will demonstrate the feasibility of using this new material in an actual bridge project, and will result in mixture proportions, batching procedures, and material specifications necessary for MDT/contractors to successfully use this material in the future.

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 December 1, 2020, and an estimated completion date of November 30, 2022. 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: Close Research Gaps	X	X	X					
Task 3: Bridge Construction and Related Activities		X	X	X				
Task 4: Monitoring Bridge Performance				X	X	X	X	
Task 5: Analysis of Results and Reporting						X	X	X

10 Budget

This proposal is requesting $102,263 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 fiscal year is shown in Table 6.

Table 2: Project Budget by Item

Item	Total
Salaries	$54,763
Benefits	$9,073
In-State Travel	$2,974
Expendable Supplies and Materials	$5,000
Participant Support	$10,000
Total Direct Costs	$81,810
Overhead - 25%	$20,453
Total Project Cost	**$102,263**

Table 3: Breakdown of Expendable Supplies and Materials

Item	Budget
Portland Cement/Silica Fume/Fly Ash	$1,000
Admixtures	$1,000
Fine/Coarse Aggregates	$500
Steel Fibers	$1,500
Cylinder Molds	$500
Misc Supplies	$500
Total	**$5,000**

Table 4: Pay Rate and Benefits

Table 5: Project Budget by Task

Task	Budget
0 - Project Management	$3,771
1 - Literature Review	$14,145
2 - Close Research Gaps	$24,583
3 - Bridge Construction and Related Activities	$26,043
4 - Monitoring Bridge Performance	$18,030
5 - Analysis of Results and Reporting	$15,691
Total	**$102,263**

Table 6: Project Budget by State Fiscal Year

Item	State Fiscal Year		
	2021	2022	2023
Salaries	$32,858	$10,953	$10,953
Benefits	$5,444	$1,815	$1,815
In-State Travel	$1,784	$595	$595
Expendable Supplies and Materials	$3,000	$1,000	$1,000
Participent Support	$2,500	$5,000	$2,500
Total Direct Costs	$45,586	$19,362	$16,862
Overhead	$11,397	$4,841	$4,216
Total Project Cost	**$56,983**	**$24,203**	**$21,078**

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. Dr. Kirsten Matteson will be the Co-Principal Investigator and will assist Dr. Berry in project management and research related tasks. 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 the project personnel in addition to each person's role in this study.

11.1 Dr. Michael Berry – Principal Investigator

Dr. Berry is an Associate 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 concrete 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 Dr. Kirsten Matteson – Co-Principal Investigator

Dr. Matteson is an Assistant Professor in the Civil Engineering Department at MSU, joining the Department in August of 2018. Her primary research interest involves investigating new materials and their possible structural applications, especially materials with potential for a positive global change. Her research experience includes investigating composite materials for structural elements and numerical modeling. Her modeling background is with both the finite element method and the discrete element method. She has performed extensive FEA simulations on composite materials, including plastic-aluminum composite I-beams and multi-layered ceramic capacitors. She is currently the faculty advisor for the American Society of Civil Engineers student section at MSU.

11.3 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 for the final report.

11.4 Research Team Hours and Availability

It is anticipated that the proposed work associated with this research project will take 2,522 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	20	10	40	80	30	20	200
Kirsten Matteson	10	5	20	40	15	10	100
Graduate Student	0	400	400	400	400	400	2000
Undergraduate Student	0	0	0	0	0	200	200
Business Mgr.	8	0	0	0	0	0	8
Admin Staff	4	2	2	2	2	2	14
Total	42	417	462	522	447	632	2522

12 Facilities

The required equipment is already available in the Civil Engineering Department at MSU and at WTI.

13 References

1. FHWA, *Development of Non-Proprietary Ultra-High Performance Concrete for Use in the Highway Bridge Sector*. 2013, Federal Highway Adminstration, FHWA-HRT-13-100.

2. Goodspeed, C., S. Vanikar, and R. Cook. *High-Performance Concrete (HPC) Defined for Highway Structures*. 2013 [cited 2013; Available from: http://www.fhwa.dot.gov/bridge/hpcdef.htm.

3. Graybeal, B., *Ultra-High Performance Concrete*. 2011, Federal Highway Adminstration, FHWA-HRT-11-038.

4. Graybeal, B., *Construction of Field-Cast Ultra-High Performance Concrete Connections*. 2012, Federal Highway Adminstration, FHWA-HRT-12-038.

5. Graybeal, B., *Material Property Characterization of Ultra-High Performance Concrete*. 2006, Federal Highway Adminstration, FHWA-HRT-06-103.

6. Graybeal, B., *Structural Behavior of Ultra-High Performance Concrete Prestressed I-Girders*. 2006, Federal Highway Adminstration, FHWA–HRT–06–115.

7. Piotrowski, S. and M. Schmidt, *Life Cycle Cost Analysis of a UHPC-Bridge on Example of two Bridge Refurbishment Designs*, in *Proceedings of Hipermat 2012 3rd International Symposium on UHPC and Nanotechnology for High Performance Construction Materials*. 2012. p. 957-964.

8. Berry, M., R. Snidarich, and C. Wood, *Development of Non-Proprietary Ultra-High Performance Concrete*. 2017, Montana Department of Transportation.

9. Scherr, R., *Feasibility of Non-Proprietary Ultra-High Performance Concrete (UHPC) for Use in Highway Bridges in Montana: Phase II Field Application*, in *Civil Engineering*. 2020, Montana State University.