DEVELOPMENT OF NON-PROPRIETARY UHPC MIX – EVALUATION OF THE SHEAR STRENGTH OF UHPC

Quarterly Progress Report
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1. Background and Introduction

Ultra-high performance concrete (UHPC) is a relatively recent advancement in cementitious composite materials with mechanical and durability properties far exceeding those of conventional concrete, which makes it an ideal material for bridge deck joints and other connections. While considerable information has been developed about many characteristics of UHPC, information about shear behavior is sparse. The study proposed here will investigate experimentally the behavior of UHPC mixes subject to a variety of stress states, focusing on shear.

The testing will be conducted in a special purpose panel testing machine that is capable of applying loads to a 2-D panel in any combination of shear, tension and compression. The variables to be investigated include the mix design, the fiber content and the stress states. The expected outcome is the data on which to base a constitutive model for shear behavior in UHPC in general, and in particular the non-proprietary UHPC materials being developed by the partner universities.

2. Problem Statement

The high bond and tension strengths exhibited by UHPC make it an ideal material for making connections between precast concrete elements. Such elements are widely used in ABC, and examples are provided by pre-cast deck panels and deck-bulb tees. While these members could theoretically be connected using conventional concrete in a relatively wide joint that can accommodate the necessary bar development lengths, those joints require formwork and curing time, and thus jeopardize the economy and time savings associated with Precast Bridge Elements and Systems (PBES). The use of UHPC allows the joint to be much narrower, thereby reducing the formwork demands to very low levels, and the material gains sufficient strength to accelerate the bridge opening to traffic.

Information is available on the compression, tensile and bond strengths of UHPC, although much of it has been focused on the proprietary material Ductal. However, such joints are also subjected to shear stresses, and much less is known about shear response. The purpose of the work proposed here is to fill that knowledge gap. The results will be valuable not only for optimizing the design of joints, but also for future projects when whole girders are constructed from UHPC. Such girders will have thin webs in order to minimize the amount of UHPC needed, in which case an understanding of the response to combinations of shear and direct stresses is essential.

The work will be conducted in collaboration with FIU and partner universities Iowa State, Oklahoma and Nevada Reno. Those institutions will conduct studies on non-proprietary UHPC mixes, and the fundamental properties thereof (ISU and OU), and on the performance of UHPC joints between structural panels (UNR). The shear tests will be conducted at UW.

3. Objectives and Research Approach

Summary of Project Activities

The activities will include:

- A literature review to determine details of other test programs investigating multi-axial states of stress in UHPC. The researchers know of only two other institutions with the test equipment capable of doing such work.
- Preparatory companion material tests on the materials to be used in the shear panel tests.

- Tests under biaxial stress states on panels made from UHPC materials, with different mixes and fiber contents.
- Analysis of the test data and preparation of results for presentation.
- Participation in the UHPC workshop proposed by OU to share results.

Detailed Work Plan

The following is a description of tasks carried out to date.

Task 1 – **Literature review.** A literature review to determine details of other test programs investigating multi-axial states of stress in UHPC. The researchers know of only two other institutions with the test equipment capable of doing such work, but they will nonetheless conduct a world-wide search. UHPC is being intensely studied in particular countries such as Malaysia.

<u>This task has been completed.</u>

Task 2 – **Preparatory companion material tests**. These will include compression, tension and bond tests. The tension tests will be conducted on dog-bone specimens. The team has conducted such tests on UHPC in the past, but they have plans for new arrangements for gripping the specimen in order to minimize any eccentricity in the load path. These tests will act as fore-runners of the companion materials tests that are planned (see Task 3) to accompany each shear panel test.

Because the shear, tension and bond properties of the UHPC materials are the most important for use in bridge joints, the materials test will focus primarily on tension and bond. The purpose of those tests is to act as quality control test for the materials being used in the (more expensive and difficult) shear panel tests. The preparatory tests are intended to optimize the test specimens and procedures before those are used with the shear test panels.

<u>This task has been completed.</u> Some photos of the material tests performed are provided in Figure 1.

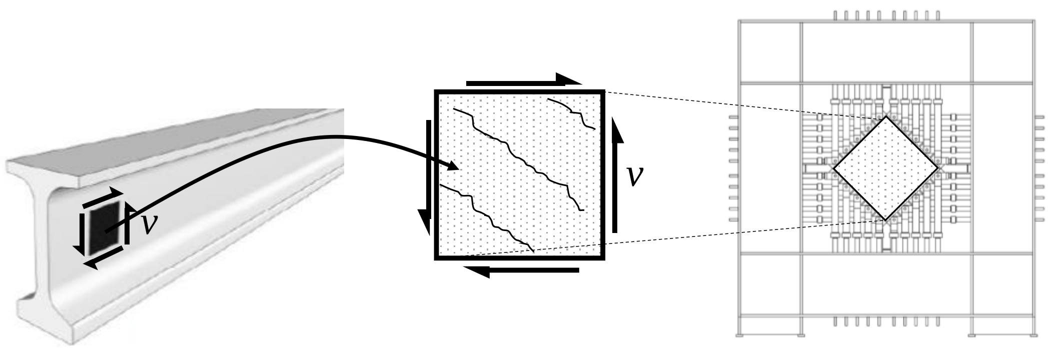
Figure 1. Material tests

Task 3 – **Conduct biaxial in-plane tests on UHPC panels (see Figure 2), with different fiber contents.** Tests will include (see also Table 1):

- One trial panel to verify that the planned methods for connecting the test panel to the loading system will prove effective with UHPC. (The UHPC is expected to have higher shear strength than that of conventional concrete and may require connections that are different and more robust).

- Three panels, made from local material, reinforced with the reference fiber content 2% under pure shear loading conditions.
- Two panels to investigate the effects of other fiber contents (0% and 1%).
- One panel made from materials provided by OSU, reinforced with the reference fiber content 2% under pure shear loading conditions.

It should be noted that it is not possible to conduct tests on all combinations of all parameters. Thus we propose to focus the tests on a single UHPC mix, which will be selected from the array of materials tested by the partner universities. This choice is made because the shear response is expected to be dominated by the fibers, in which case details of the cementitious components of the mix are expected to have a smaller influence on the response than the stress state and the fiber content. The partner universities are anyway proposing to focus their efforts on comparisons of different mixes. This demonstrates one of the many the benefits of collaboration – the ability to explore the greatest range of properties by avoiding unnecessary duplication.



(a) UHPC Bridge Girder (b) UHPC Panel in biaxial stress conditions (c) UW Panel Element Tester

Figure 2. UHPC element testing

<u>This task has been completed.</u>
A photograph of one of the panel specimen tested in provided in Figure 3 and key results are summarized in Table 1.

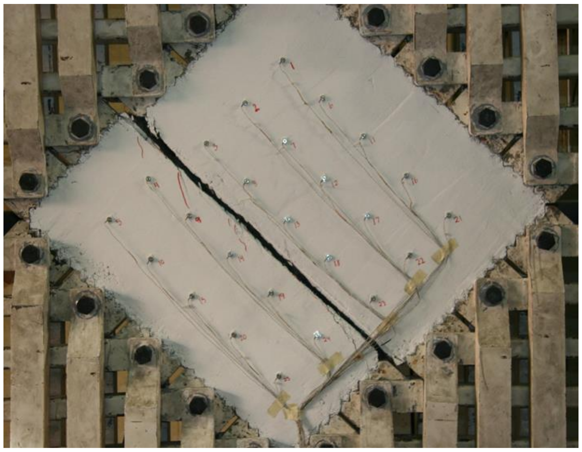


Figure 3. Panel 1 after failure

Table 1. Specimen properties and failure loads

Specimen	Fiber Content (%)	Loading	Compressive Strength (MPa)	Shear Strength (MPa)
UW2*	2	Pure Shear	166.91	8.77
UW2C**	2	Pure Shear	123.69	7.33
UW2A	2	Pure Shear	108.91	8.89
UW2B	2	Pure Shear	138.89	9.75
UW1	1	Pure Shear	132.63	7.38
OU2	2	Pure Shear	133.38	9.29
UW2D	2	Pure Shear	134.13	9.91

*Pilot test 1: excessive amount of admixture in the mix
**Pilot test 2: concrete consolidation problems

Task 4 – **Data analysis**. The data will be analyzed and prepared in presentation form. The results will be communicated to the partner universities on an ongoing basis, so that they can, if necessary, adjust their own programs of study. A rudimentary constitutive model will be developed for shear stress-strain response of UHPC under biaxial loading. It should be noted that more extensive testing than is possible within this program will be necessary to optimize such a model.

This task is approximately is complete.

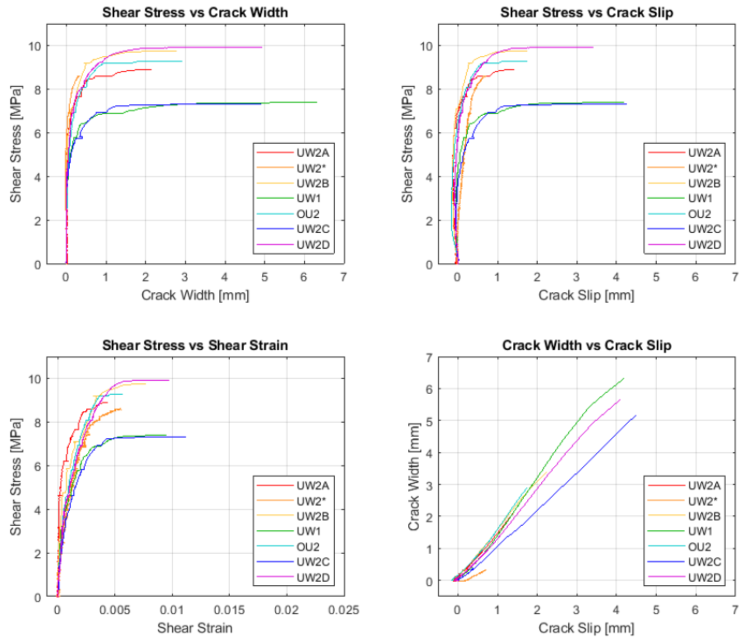


Figure 4. Key experimental results

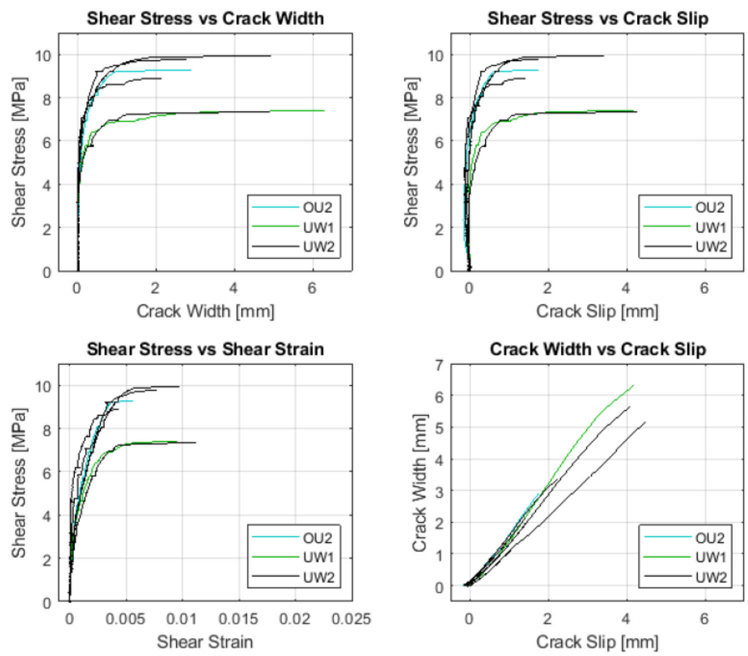


Figure 5. Key experimental results as a function of fiber content

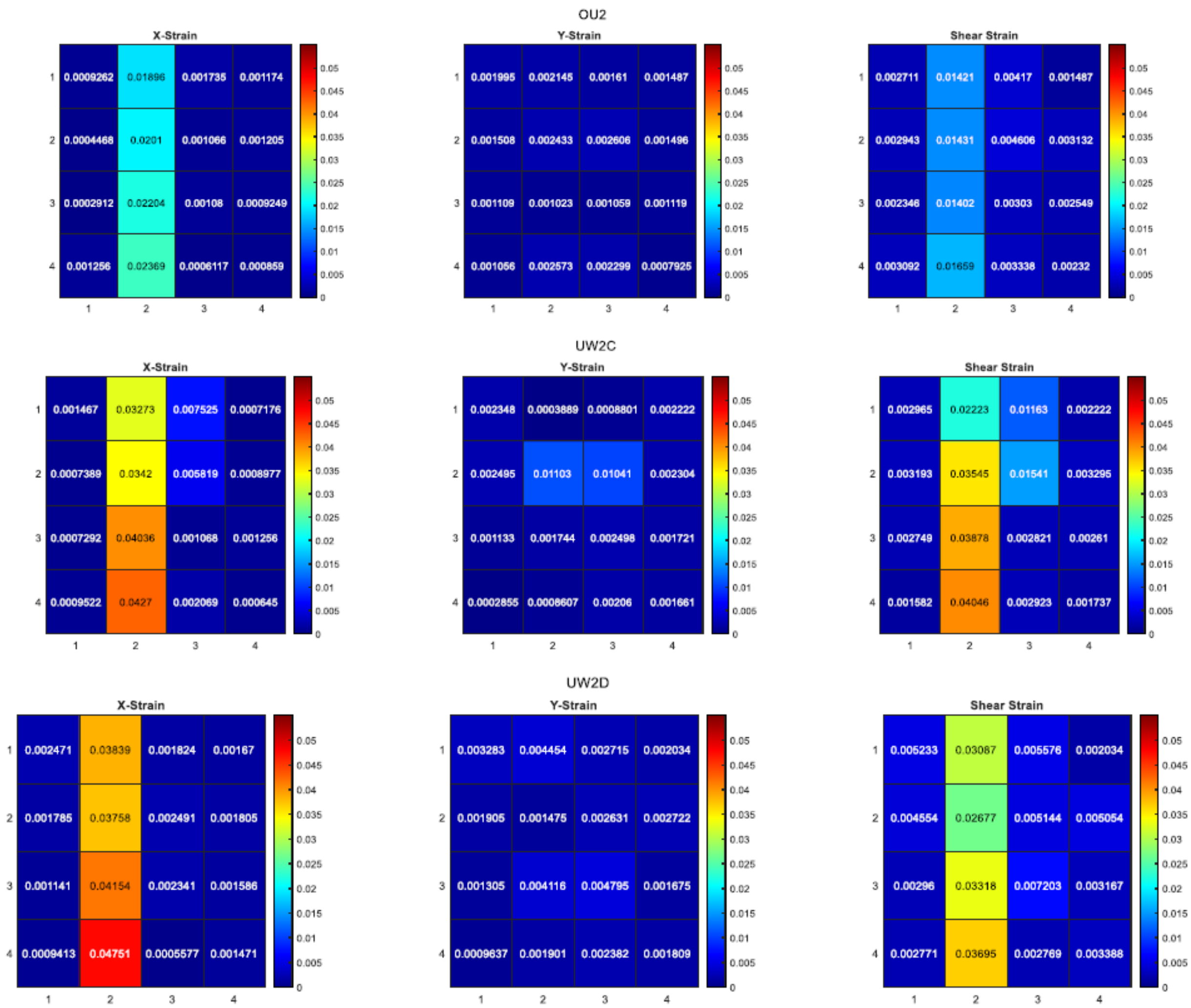


Figure 6. Pre-failure strain field overview for one of the specimen tested

Task 5 – **Participation in the UHPC workshop to be hosted by OU**. The goal is to present the results and integrate them with the results obtained by the partner universities.

<u>No work has yet been performed on this task.</u>

Task 6 – **Preparation of the Final Report**. Although the testing program is aimed at developing fundamental stress-strain data, the report will be prepared with end applications in mind. These include response to vertical shear stresses in the joint caused by wheel loads on deck panels or horizontal shear stresses caused by seismic action, as well as the future possibility of gravity shear stresses in a thin-walled UHPC girder.

<u>This task is approximately 85% complete.</u>

4. Expected Results and Specific Deliverables

The expected products resulting from this research will include:

(1) Databases that includes all the relevant information on material shear behavior of UHPC girders and other structural elements (including geometry, loading, reinforcement, material properties, mix design, test setup, instrumentation readings when available, test results including global response and photographs).
(2) New experimental results for UHPC that will include compressive, tensile and shear strengths.
(3) A new rational shear behavior model. In addition to a simple design model to predict the shear strength of UHPC elements, the model will be capable of describing the mechanical behavior of UHPC elements subjected to multiaxial loads (e.g. shear and axial tension), properly accounting for the various resisting mechanisms. Its close correlation with the physical behavior will allow it to predict behavior more reliably, and designers to achieve safer, more economical solutions.

5. Schedule

Progress of tasks in this project is shown in the table below.

Item	**% Completed**
Percentage of Completion of this project to Date	98%

Research Task	June-Sep.	Oct-Dec.	Jan. - Mar	Apr-Jun
1. Literature Review	Completed Task			
2. UHPC-Material Tests	Completed Task			
3. UHPC Panel Testing	Completed Task			
4. Experimental Data Analysis	Completed Task			
5. Technology Transfer Workshop				
6. Assemble Reports				