Development of Non-Proprietary UHPC Mix: Application to Deck Panel Joints

Quarterly Progress Report
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Submitted by:
PI- Mohamed Moustafa
Graduate Student- Mohamed Abokifa

Department of Civil and Environmental Engineering
University of Nevada, Reno

ACCELERATED BRIDGE CONSTRUCTION
UNIVERSITY TRANSPORTATION CENTER

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1. PROJECT ABSTRACT

One of the most common application of Accelerated Bridge Construction (ABC) nowadays is the use of precast deck panels and fill the joints in the field using advanced materials such as Ultra-high performance concrete (UHPC). This application has been used around the country in several ABC projects in Iowa, New York, etc. A lot of research has been done on optimizing the field joint reinforcement details such as shortest lap length and shear key shape and dimensions. However, most of the applications used proprietary UHPC mixes, which can sometimes constrain the DOTs bidding process due to lack of several UHPC vendors. Accordingly, research on the non-proprietary UHPC is growing and many state DOTs are interested in developing their own mixes using local materials. UHPC is cementitious composite material with mechanical and durability properties far exceeding those of conventional concrete, which makes it an ideal material for bridge deck joints. It combines a high percentage of steel fibers with an optimized gradation of granular constituents, resulting in a compressive strength more than 22 ksi, a high post-cracking tensile strength, and exceptional durability. In this collaborative effort among all five institutions in the ABC-UTC consortium, comprehensive research on non-proprietary UHPC mix design and extension to common ABC applications is sought. The coordination efforts are led by the University of Oklahoma as explained in the next section. The objective of this part of the project which will be conducted by the University of Nevada, Reno is to finalize the selection of best feasible non-proprietary UHPC mix and demonstrate its validity for the use for precast deck panel transverse and longitudinal joints. The goal is to optimize and provide confidence in the new materials for this type of joints rather than optimizing the joint detail itself given that a lot of previous work has already investigated best details for deck panel joints.

2. RESEARCH PLAN

2.1. STATEMENT OF PROBLEM

Prefabricating bridge elements and systems (PBES) offers major time savings, cost savings, safety advantages, and convenience for travelers. According to the FHWA, the use of PBES is also solving many constructability challenges while revolutionizing bridge construction in the US. In the past decade, innovative PBES connections have been evolved and many of these connections used Ultra-High performance concrete (UHPC). UHPC has superior mechanical properties and durability. However, some of the limitations associated with UHPC wide spread use include: the very expensive price tag and most of the robust mixes are currently proprietary. Several DOTs see the proprietary nature of UHPC leads sometimes to sole-sourcing and in turn, bidding issues. Accordingly, research on the non-proprietary UHPC is growing and many state DOTs are interested in developing their own mixes using local materials. The goal of this project is to finalize the selection of the best feasible non-proprietary UHPC mix and demonstrate its validity for use as a closure pour material into precast deck panel transverse and longitudinal field joints.

2.2. RESEARCH APPROACH AND OBJECTIVES

Our approach for this proposed study is mainly an experimental approach with the main activity is large-scale structural tests at UNR laboratories. The specific research objective of this study is to collaborate with OU and ISU on acquiring local materials for non-proprietary UHPC mix design and optimization, and conduct full-scale testing of deck panel joints to study the response of the finalized mix design as used in actual structural ABC applications.

This study will coordinate the efforts of researchers at the five ABC-UTC partner institutions to investigate bond strength, shear strength, and full-scale structural performance of non-proprietary UHPC developed by the partner institutions. Two mix designs developed by the partner institutions (one at OU and one at ISU) will be shared with the other partner institutions for comparative testing with the proprietary UHPC Ductal® used as the baseline. Fiber content and fiber type will be considered as primary variables for a given mix design. Figure 1 shows the overall organization of the project. The primary objective is to determine whether a mix design developed with local materials can achieve the necessary bond strength and durability for use in bridge component connections, thereby providing an additional option for DOTs. Sharing of information between the partner institutions will allow for consideration of repeatability of the proposed mix designs and the combined efforts of the partner institutions will lead to more significant results than could be obtained by any of the institutions working individually. Understanding the effect of fiber type and content on bond, shear, and overall structural performance will identify the optimum fiber content required for a non-proprietary material to achieve the properties required for a given application. For example, minimum joint width for precast panel connections may be set by constructability concerns, so a sufficiently short development length may be greater than the shortest development length that could be obtained using UHPC.

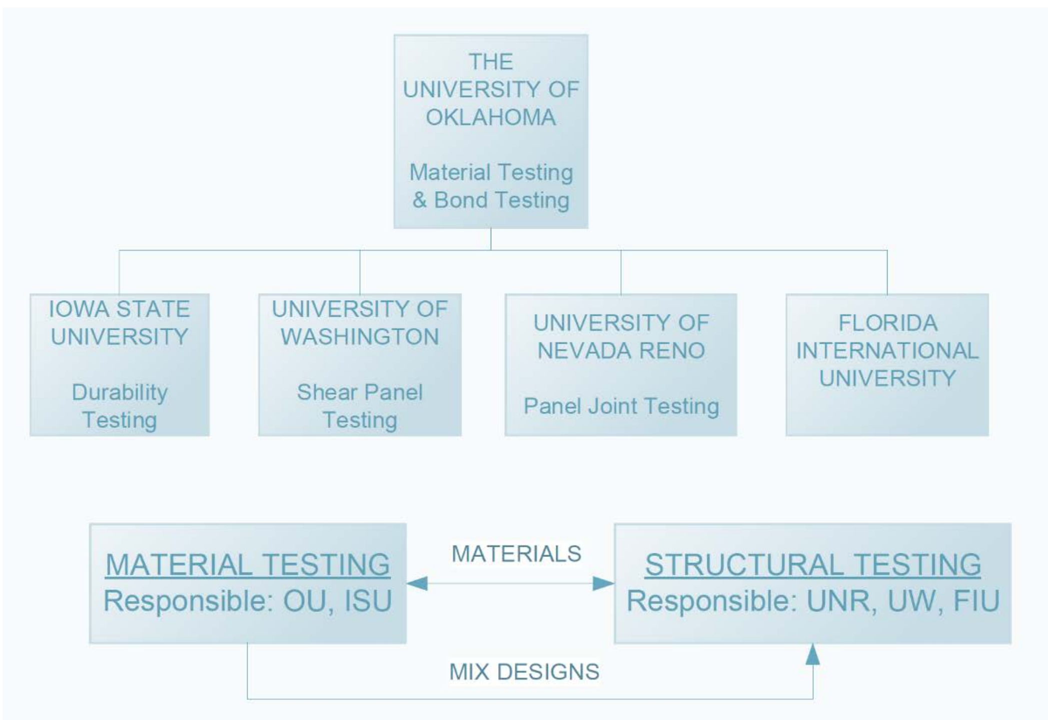


Fig. 1 – Overall organization of project and information sharing

Researchers from OU and ISU will provide UHPC mix designs developed at those institutions to the team members at UNR, UW, and FIU for use in structural testing. OU and ISU will also have the exact cementitious materials and admixtures used for each mixture shipped to UNR, UW, and FIU so that each institution can exactly recreate the mix designs. OU and ISU will provide enough aggregate (sand) for a sufficient quantity of material for one of the proposed structural tests. For the other tests, researchers at UNR, UW, and FIU will use their own local aggregates. Researchers at UNR, UW, and FIU will provide local cementitious materials and admixtures to researchers at OU and ISU, such that they can obtain sufficient quantities of material to investigate the effects of locally available cementitious materials and admixtures on non-proprietary mix designs. Researchers at OU and ISU will consider concrete compressive strength and modulus of rupture for comparison of the effects of local cementitious materials on mix design performance. They will also conduct at least one set of bond tests (OU) and durability tests (ISU) considering local cementitious variations provided by the other partner universities. In all cases, researchers will obtain the same ½ in. steel fibers produced by Bekaert for use as the base fiber case. Institutions sharing the exact materials will allow all institutions to begin their work at the same time, without needing to wait for additional mix design development.

The focus of this project is to apply non-proprietary UHPC mixes with optimized characteristics to deck panel field joints as shown in Figure 2 to demonstrate the validity of such materials.

Fig. 2 – Field connections/joints for precast deck slabs (photo credit: Georgia DOT)

2.2.1. Summary of Project Activities

An experimental approach will be used and several research activities will be executed to accomplish the objectives of this study. A summary of the proposed research tasks is as follows:

- Task 1 – Updated literature search on precast deck panel connections
- Task 2 – Development of experimental program and specimens design
- Task 3 – Experimental testing of deck slabs joints
- Task 4 – Summarize the results in a final report

2.2.2. Detailed Work Plan

A detailed description of the proposed research tasks is presented in this section.

Task 1 – Update the literature review on precast deck panel joints:

A fresh update for the literature review of previous work on deck panel joints was conducted. The goal of this task is to summarize the most common and feasible design details of deck panel joints. In other words, a summary of recommended deck reinforcement overlap, lap splice length, shear key shape and dimensions, and overall joint dimensions will be provided.

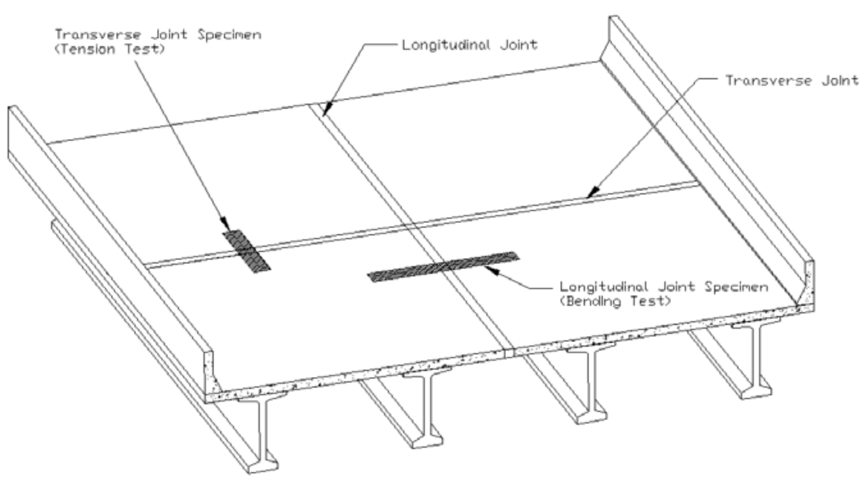
Our scope in this part of the study is to review and report the previous experimental and numerical studies in the precast bridge deck field joints. Through the last decade, many researches started working on using the "UHPC" in the precast deck panels field joints like the work done by Ben Graybeal (2010). While all the research before this period was directed into investigating the behavior of the PBES connections with using different materials such as advanced grouts, high performance concrete (HPC) and HPC with fiber reinforcement. A current experimental study was conducted at UNR Laboratories on using polymer concrete as a closure pour material into precast deck field joints. This study investigated the structural performance of the transverse and longitudinal filed joints under static vertical loading.

AASHTO conducted three research programs which focused specifically on advancing the state-of-the-art with regard to non-post-tensioned deck-level connections details between prefabricated concrete components.

The first research project "Full-Depth Precast Concrete Bridge Deck Panel Systems" and frequently referred to as NCHRP 12-65. A primary focus of this project was to develop an economical, non-post-tensioned transverse connection detail capable of developing the yield strength of straight lengths of mild steel.

The second project "Design and Construction Guidelines for Long-Span Decked Precast, Prestressed Concrete Girder Bridges" and frequently referred to as NCHRP 12-69. This research demonstrated that redesign of the traditional connection systems used in the longitudinal connections between decked girders could allow for a simpler connection.

The third project "Cast-in-Place Concrete Connections for Precast Deck Systems" and frequently referred to as NCHRP 10-71. This project focused on both transverse and longitudinal connections between precast concrete components as shown in Figure 3.



B.1.1: Orientation of joints and corresponding test specimens

Fig. 3 – Transverse and longitudinal field connections/joints for precast deck slabs.

Task 2 – Development of experimental program and specimens design

The objective of this task is to finalize the number and type of specimens to consider for validating and demonstrating the different non-proprietary mixes, which was developed in collaboration with other ABC-UTC partner universities as part of this project. This project is also building on another ongoing ABC-UTC project led by PI Moustafa at UNR which focuses on using polymer concrete for deck panel joints as another alternative to UHPC. Thus, similar joint types and specimen design were implemented in this project for comparison purposes. Two types of connections and tests were proposed which are: (1) longitudinal connections of deck bulb tee girders that will be tested for flexure; (2) deck panels' transverse connections that will be tested for flexure. Figures 4 through 7 show the details of reinforcement of the test specimens. Four specimens were constructed to conduct three transverse and one longitudinal joint test. The details of the tested specimens are reported in Table 1. The design of the specimens was performed according to the AASHTO LRFD Bridge Design Specification (AASHTO, 2018). The positive and negative design moments were determined based on the AASHTO Equivalent strip method. The moment values provided in this method takes into account the largest values that could be experienced by the deck slabs with respect to different loading conditions. The bridge example that was used to analyze the reinforced concrete deck slab for the transverse specimens in this study has a cross-section consisted of five steel girders spaced at 12 ft on center and a deck slab of 8 in thickness. The instrumentation plan of the test specimens was also finalized, and the reinforcement strain gage locations were also reported in Figures 4 through 7.

Table 1. Test specimens details

Specimen	Joint width	Lap length	Lap detail	field joint type	Closure material	Concrete dimensions
SP1	6.0 in	5.0 in	straight	Transverse	Non-Proprietary UHPC	9' x 8' x 8"
SP2	6.0 in	4.5 in	U-bar	Transverse	Non-Proprietary UHPC	9' x 8' x 8"
SP3	8.0 in	7.0 in	straight	Transverse	Non-Proprietary UHPC	9' x 8' x 8"
SP4	6.0 in	5.0 in	straight	Longitudinal	Non-Proprietary UHPC	8' x 7' x 6"

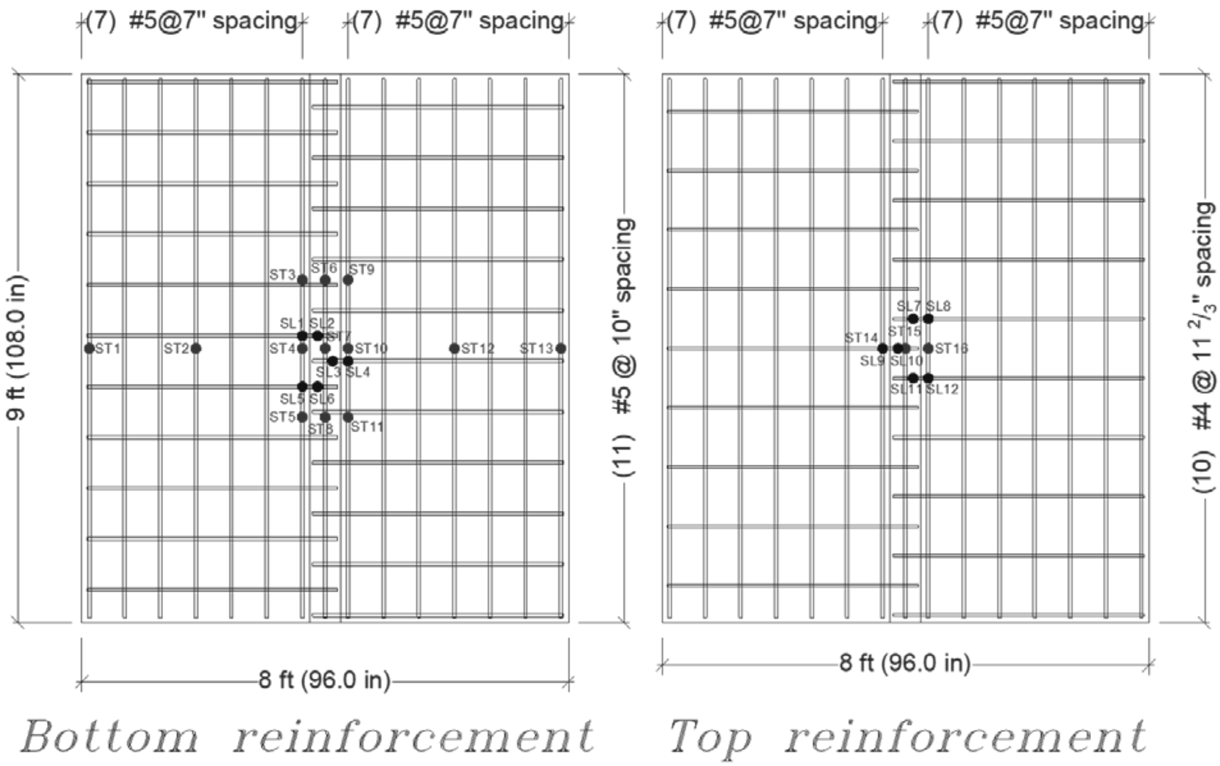


Fig. 4 – Structural details and instrumentation plan for the first transverse specimen (SP-1).

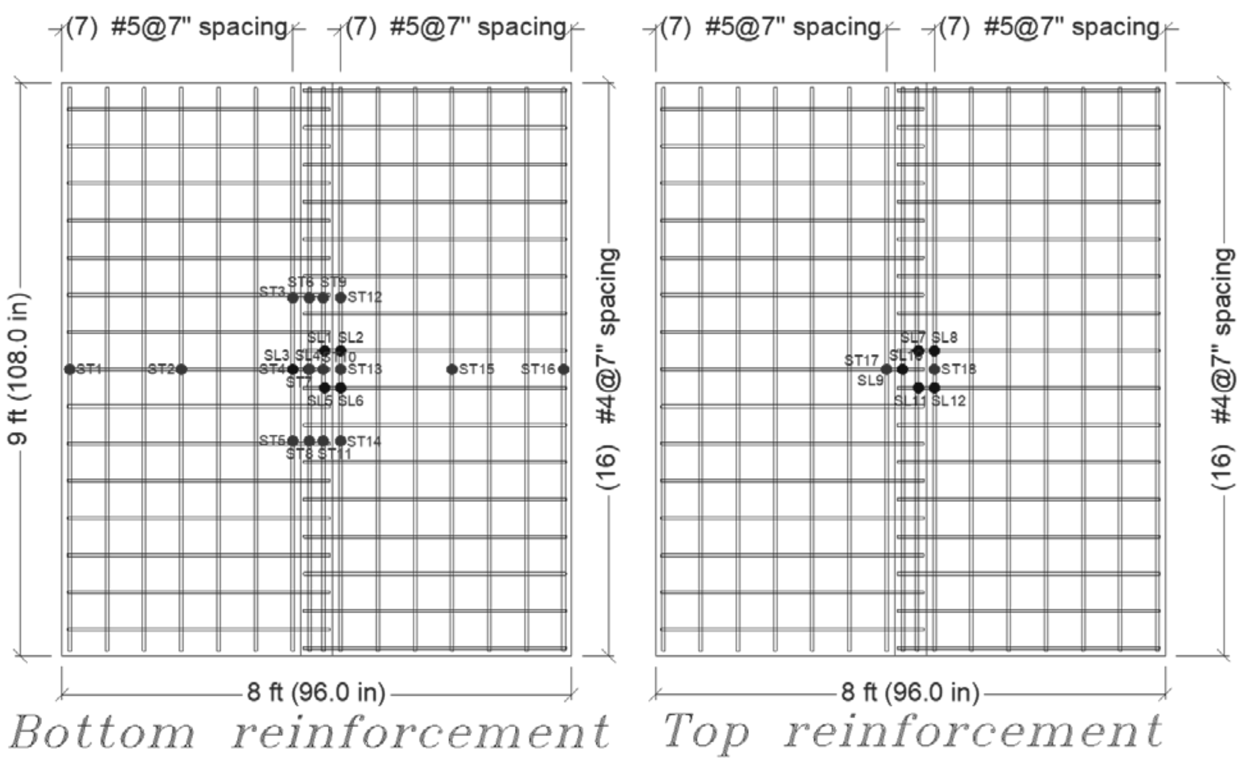


Fig. 5 – Structural details and instrumentation plan for the second transverse specimen (SP-2).

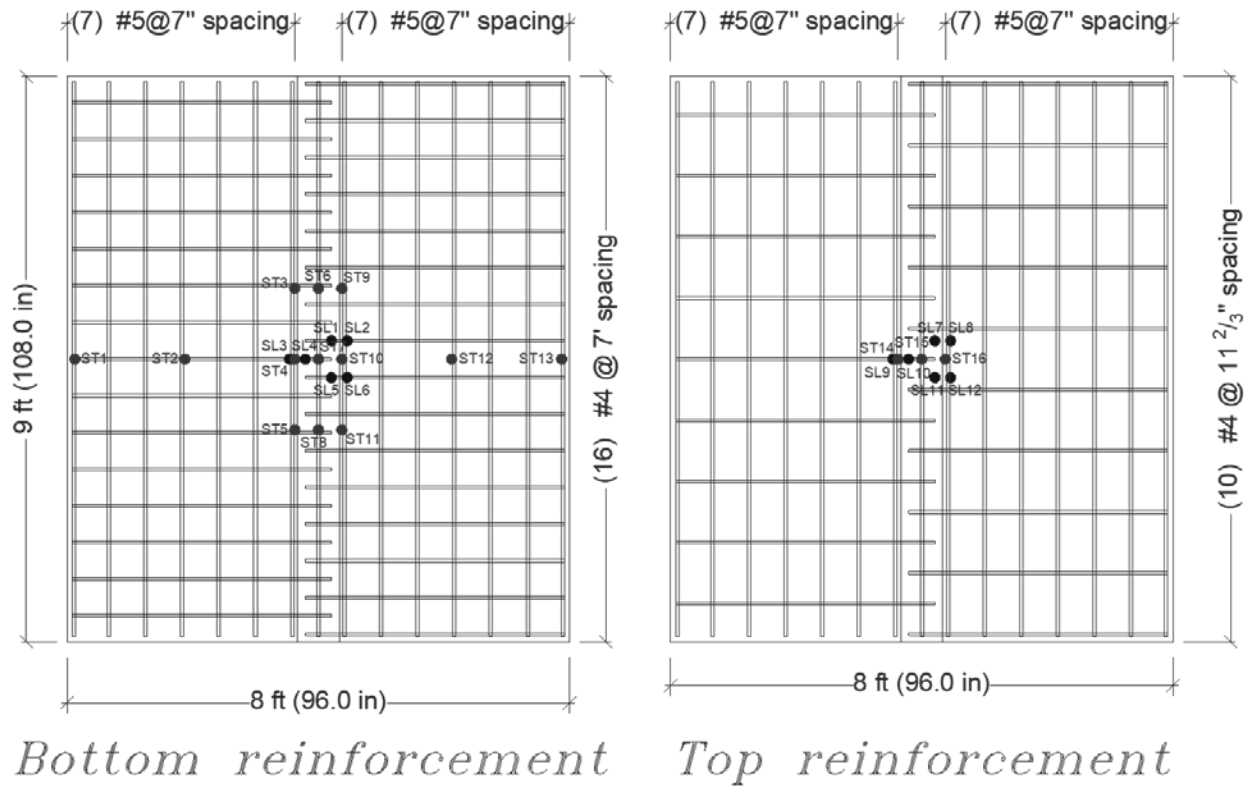


Fig. 6 – Structural details and instrumentation plan for the third transverse specimen (SP-3).

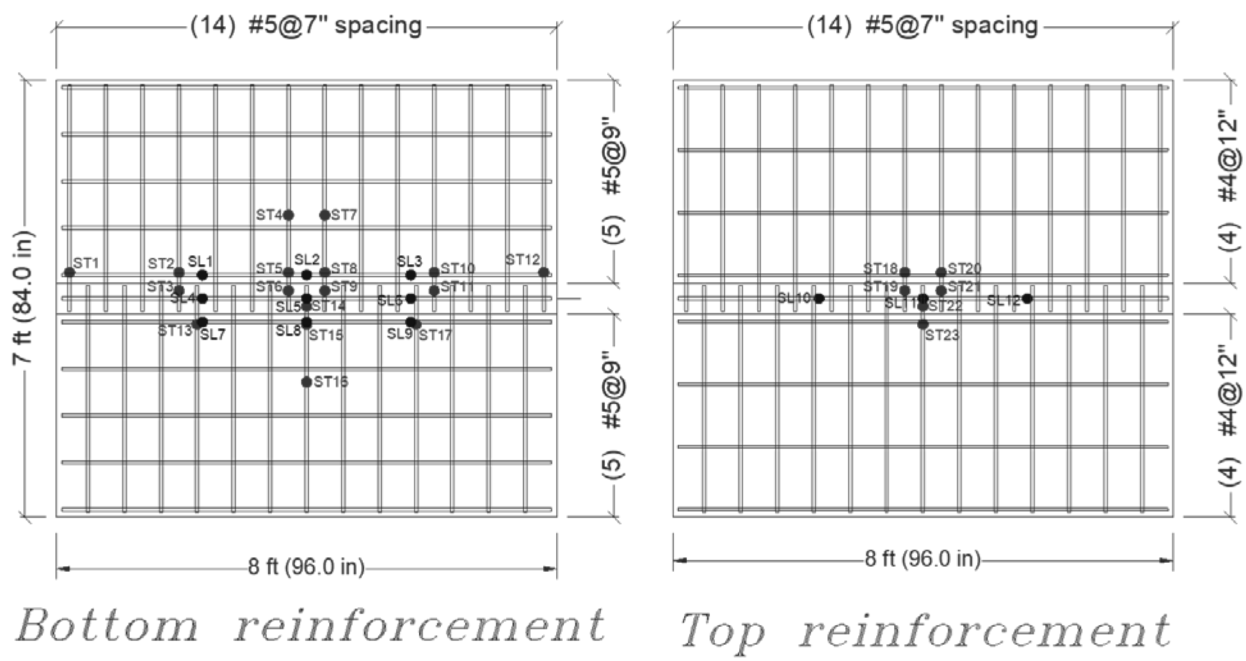


Fig. 7 – Structural details and instrumentation plan for the longitudinal specimen (SP-4).

This task also includes the collaboration with the OU University to finalize the non-proprietary UHPC mix. The baseline mix design was already set-up as shown in Table 2 and we are coordinating with the OU university to send our local materials and requested the OU mix materials needed in our large-scale experimental testing. Once we have these materials, we will start conducting the proposed material tests on the developed mixes in UNR Laboratories. The Material property tests recommended by FHWA to be conducted on the "ABC-UTC Non-Proprietary UHPC Mix" using materials from other states are shown in Table 3.

Table 2. Baseline non-proprietary UHPC mix design

Material	Quantity	Specific Gravity	Supplier
Type I Cement, lb/yd^3	1179.6	3.15	Ash Grove Chanute, Kansas
Slag, lb/yd^3	589.8	2.97	Holcim, South Chicago
Silica Fume, lb/yd^3	196.6	2.22	Norchem Ohio
w/cm	0.2	NA	NA
Fine Masonry Sand, lb/yd^3	1966	2.63	Metro Materials Norman, OK
Steel Fibers, lb/yd^3	255.2	7.85	Bekaert (Dramix® OL 13/0.2)
Steel Fibers, %	2.0		
Superplasticizer, oz./cwt	15.77	1.07	BASF (Glenium 7920)

Table 3. Material property tests recommended by FHWA

Property	Test Method	Specimen Size	Testing Ages	#Specimens Per Test
Flowability	ASTM C1437	Per ASTM	At casting	1
Compressive Strength	ASTM C39	3x6 in. cylinder	3 and 28 days	3
Flexural Strength	ASTM C78/ASTM C1609	3x3x11 in. rectangular prism	28 days	3

Task 4 – Conduct experimental testing of precast deck slabs with new joint connection

Extensive precast deck panels with field and UHPC joints have been tested (e.g. Perry and Royce 2010, Graybeal 2010, Hartwell 2011). Testing procedures from our previous experimental work done at UNR Laboratories will be adopted to conduct large-scale testing on deck panels connected using the non-proprietary UHPC mixes. Four full-scale tests will be conducted in this task. Monotonic loading until failure will be considered to determine the capacity and mode of failure of the joints. All test specimens were properly instrumented to measure strain in the slab reinforcement inside the panels and in the joint location, and measure the displacement and curvature of the slab. Data from the tests will be processed and interpreted to investigate whether the new sought non-proprietary UHPC mixes valid for this type of connection, and if so, provide confidence on the large-scale applications of the new materials. The proposed test-setup for the transverse and longitudinal specimens included in this study are shown in Figures 8 and 9, respectively.

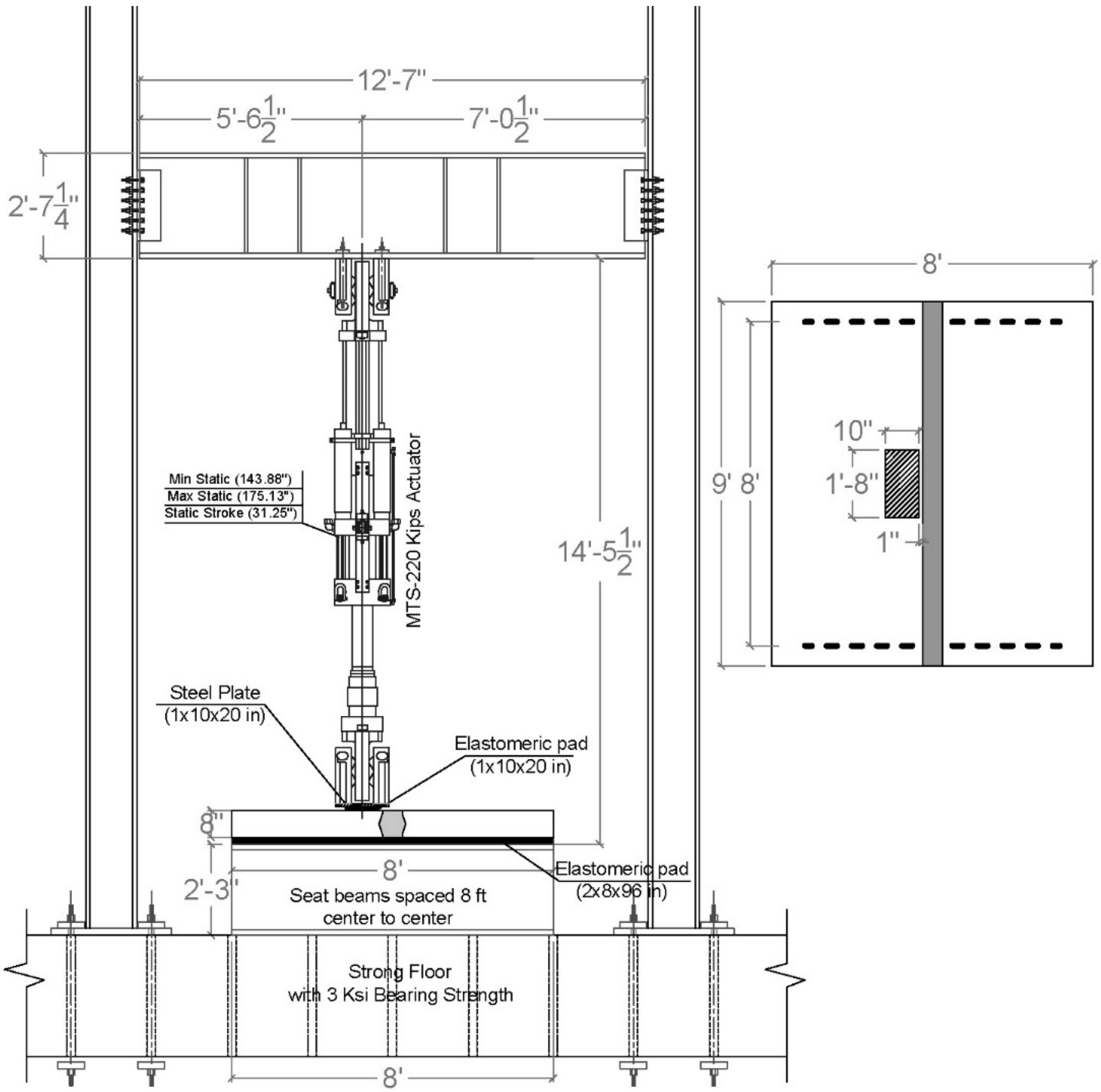


Fig. 8 – Test setup for transverse specimens.

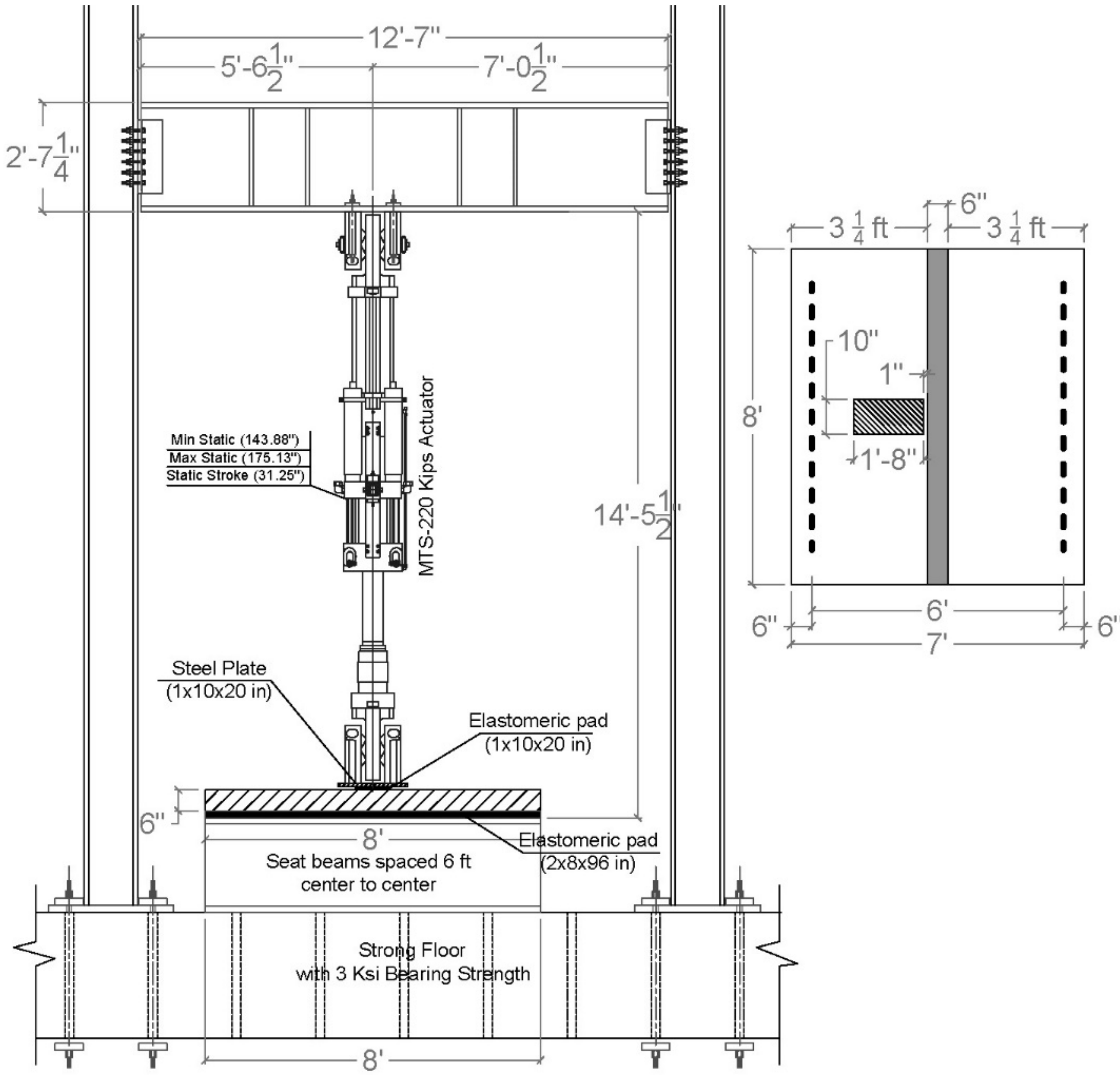


Fig. 9 – Test setup for longitudinal specimens.

The construction and assembly of all the deck panels for the test specimens have been completed at UNR as shown in Figures 10-13. The figures show also the sequence of construction. Recently, we have finished the construction of the precast parts of the test specimens and they are now ready for pouring the Non-proprietary UHPC closure pour inside the joints.

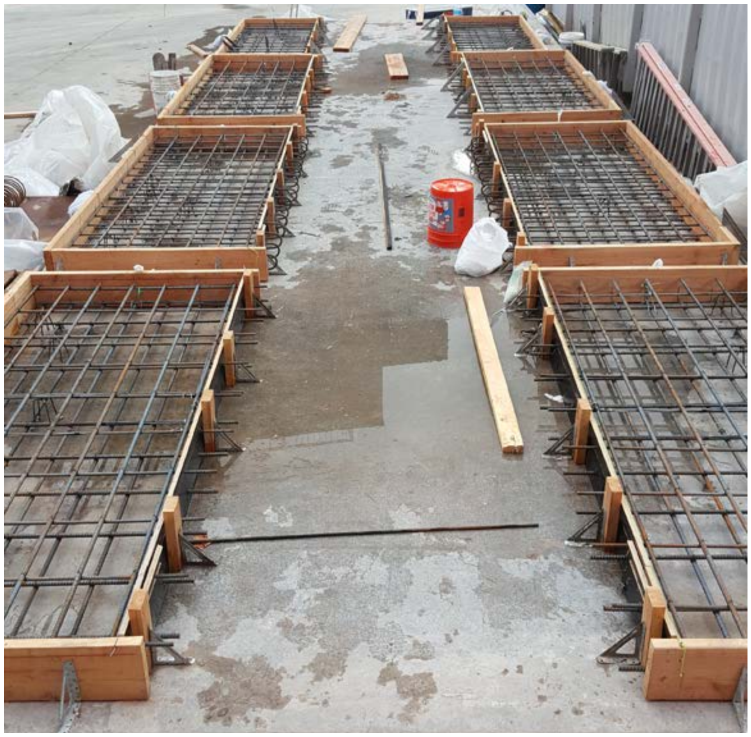


Fig. 10 – Formwork and reinforcement for construction of deck panels and specimens

Fig. 11 – Deck panels' construction, reinforcement, and cast concrete

Fig. 12 – Close-up views of the constructed deck panels and shear keys for the field joints.

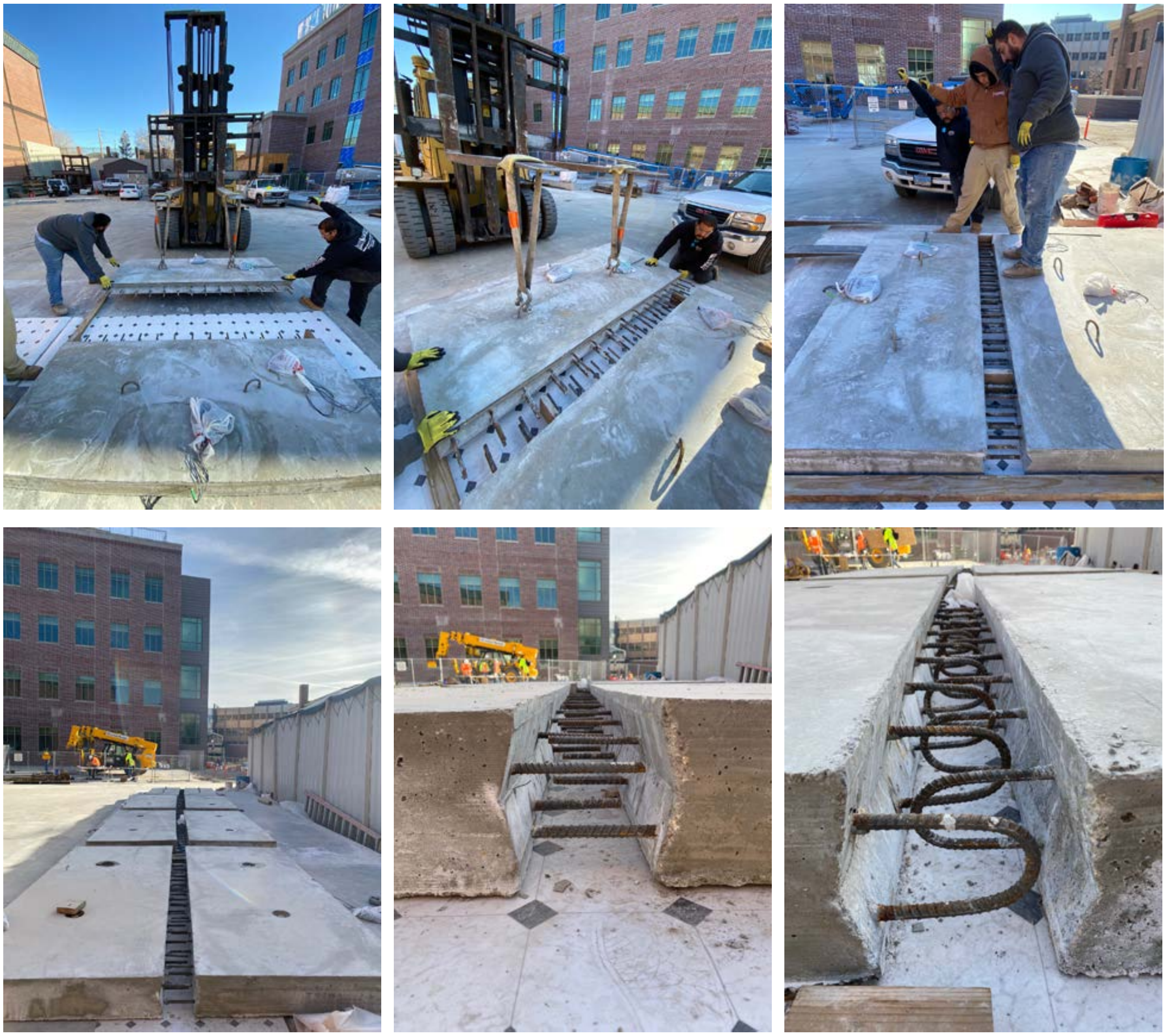


Fig. 13 – Alignment and assembly of the test specimens at UNR.

Task 5 – Summarize the investigation and the results in a draft final report

A final report describing the details of different tasks will be prepared and submitted to the ABC-UTC steering committee for review and comments. Upon addressing the review comments, the report will be finalized and made widely available for dissemination.

2.3. ANTICIPATED RESEARCH RESULTS AND DELIVERABLES

2.3.1. TENTATIVE ABC-UTC GUIDELINE

This part of the project at UNR will complement the work at the four other partner institutions towards developing an ABC-UTC guideline for designing and using non-proprietary UHPC mixes for deck panel joints.

2.3.2. A FIVE-MINUTE VIDEO SUMMARIZING THE PROJECT

Another format to disseminate the results from this project and contribute to workforce development and outreach is to develop a video and presentation slides to summarize the project. A webinar format can be sued to publish and make available such videos or presentations.

2.3.3. FINAL REPORT AND PUBLICATIONS

As mentioned before, a comprehensive report will be developed to summarize all the experimental results. Data sets could also be produced and published using existing or new cyber infrastructure or data platforms if a unified one will be eventually used for ABC-UTC related projects. Publications in peer-reviewed journals and conference presentations will also be considered for delivering project results.

3. TIME REQUIREMENTS (GANT CHART)

To allow for the completion of all the project tasks, the study will be conducted over a period of 12 months (4 quarters) following the schedule in Table 4.

Table 4 – Gant schedule of major project tasks

Task	2019				2020	
	Q1	Q2	Q3	Q4	Q5	Q6
1. Literature Search						
2. Specimens design/construction						
3. Deck panels joint tests						
4. Final report and dissemination						

	Completed or work in progress		Remaining

Percent work completed: 50%

Remaining work: 50%