

PREFABRICATED BARRIER SYSTEM UTILIZING UHPC CONNECTIONS

Quarterly Progress Report

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**ACCELERATED BRIDGE CONSTRUCTION
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Submitted to:

ABC-UTC

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Miami, FL

1. Introduction

Barriers are one of the essential components in bridges to ensure safety for vehicles and redirect errant vehicles passing the bridge. Several attempts were made to develop prefabricated barriers connected to the bridge deck using post-tensioned threaded rods and stainless-steel bars. However, those connections are associated with higher cost and durability issues. A new prefabricated barrier system utilizing UHPC connection to deck overhangs is proposed herein. A single-slope prefabricated barrier with grooves will be connected to the deck overhang with dowels extended vertically from its end. The grooves in addition to the 1 in. leveling pad will be filled using UHPC to connect the prefabricated barrier to the bridge deck overhang. The use of UHPC allows for shorter development length of overhang extended dowels resulting in easy erection and simplification in reinforcement details of the barrier itself. Under this project, component and large-scale testing will be conducted along with extensive finite element models to ensure that the proposed prefabricated barrier system with UHPC connections meets TL-4 requirements.

2. Problem Statement

One durability issue regarding cast-in-place (CIP) barriers is the early-age cracking due to temperature gradients and curing conditions which can subject them to excessive risk of corrosion, leading to costly repair projects. To avoid this undesired phenomenon, a new detail is being developed using Ultra-High Performance Concrete (UHPC) to connect the prefabricated barriers to deck overhangs which can significantly reduce on-site construction time and enhances work zone safety.

3. Objectives and Research Approach

The main objectives of this project are:

- a) Development of new connections utilizing UHPC to connect prefabricated barriers to bridge deck considering geometry and fit-up issues.
- b) Conducting detailed finite element modeling on the proposed barrier system and connections.
- c) Conducting a proof of concept experimental work on component tests for the proposed prefabricated barriers with UHPC connections.
- d) Conducting a proof of concept experimental work on a large test for the proposed prefabricated barriers with UHPC connections.
- e) Assessment of the performance of the prefabricated barriers with UHPC connections compared to the most common barrier systems.
- f) Developing detailed finite element models for the proposed prefabricated barriers with UHPC connections for a better understanding of system performance, therefore, extending the study to analyze other specimens which will not be possibly tested.

4. Description of Research Project Tasks

Descriptions of tasks carried out to date are as follows.

Task 1– Development of new connections using UHPC for Prefabricated Barrier Systems

In this task, a single-slope prefabricated barrier with grooves was considered to be connected to the deck overhang with dowels extended vertically from its end. The vertical bars in the barrier will be spliced to the existing dowels in the deck using UHPC in the grooves which provide a continuous connection along the length of the barrier.

Progress: This task is completed, and the connections are designed and analyzed as shown in Figure 1. The researchers adopted a single slope barrier that passed crash testing at the Midwest Roadside Safety Facility at the University of Nebraska Lincoln (UNL) using cast-in-place. The barrier will be a prefabricated unit and will be connected to the bridge overhang using a UHPC connection by splicing the vertical reinforcement in the barrier with dowel reinforcement extended from the bridge overhang forming a U-shape connection as shown in Figure 1.

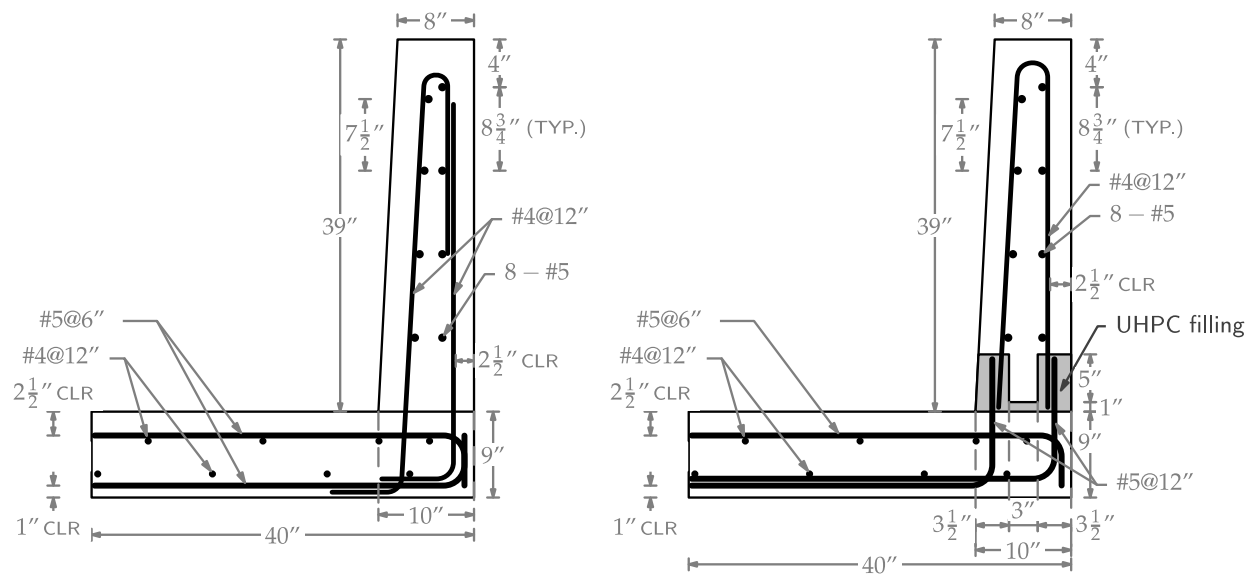


Figure 1 The CIP and Proposed connection between the prefabricated barrier and deck overhang utilizing UHPC.

Task 2– Finite Element Analysis of the Proposed Prefabricated Barrier System

Progress: This task is completed, and the design of test specimens is finalized.

In this task, a series of nonlinear finite element (NLFE) analyses were performed to evaluate the performance of the proposed connection. The CIP and prefabricated barrier system which were placed at the edge of a 60-in long bridge overhang were modeled in ATENA software and the results are presented hereinafter. The critical length of the yield line failure pattern, L_c , for the CIP barrier, was calculated as 13.2 ft. using the yield line approach recommended by AASHTO. The length of the barrier should be longer than L_c to ensure that the yield line failure mechanism would develop. For this study, it was found that a longitudinal length of 20 ft. is suitable to effectively simulate the estimated yield line failure pattern which is almost equal to the length of the deck resisting transverse load ($L_c + 2H$). This task focuses on investigating the structural performance of the proposed prefabricated barrier systems subjected to transverse static loading according to Test Level Four (TL-4) based on AASHTO MASH.

A half model is adopted due to symmetrical load conditions and boundary conditions, as shown in Figure 2. Displacement-controlled load is applied at nodes in the middle of the loading plate. The effect of the loading height was also investigated.

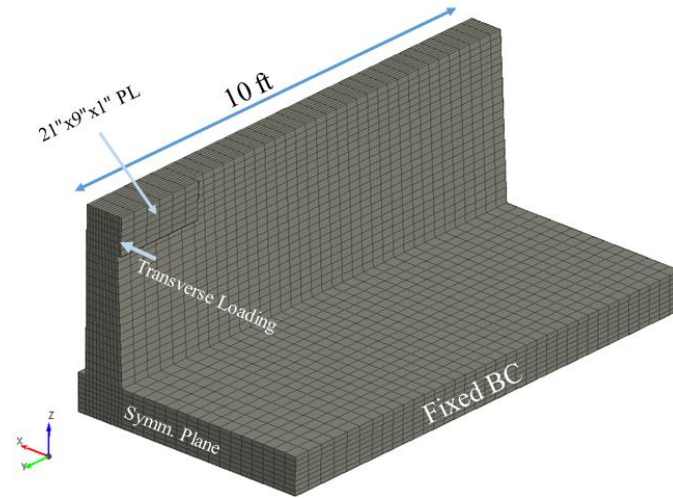


Figure 2 FE model representing static test for the CIP and prefabricated barrier.

After reaching the cracking moment of the deck, $M_{cr} = 1374$ kip-in, the stiffness of the system reduces significantly, and the damage started to occur in the barrier. This remains until the barrier reaches the ultimate capacity along with the development of a yield line failure pattern. The lateral load-deflection curves of the CIP barrier under different loading heights are shown in Figure 3. The nominal capacity of the barrier was calculated as 56 kip using the yield line method which is higher than the 50 kips obtained from the Finite Element Modeling.

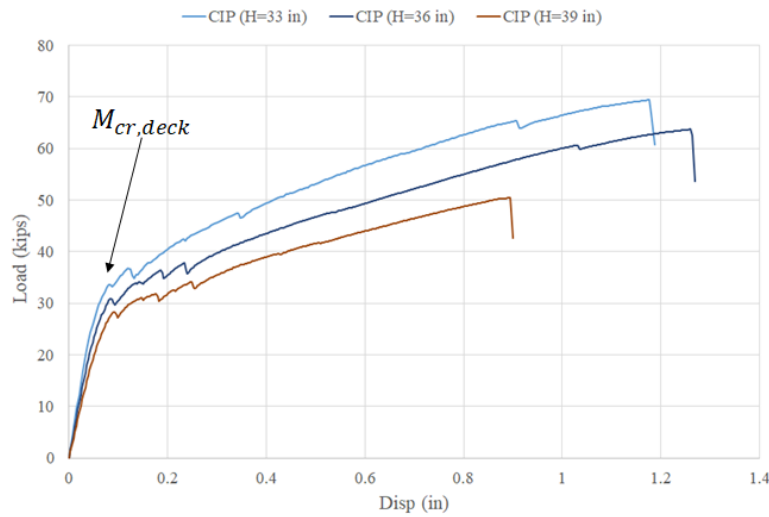


Figure 3 Load-Deflection Curves for the CIP barrier system under different loading heights.

Figure 4 shows the comparison between the load-deflection curves of the CIP and prefabricated barrier systems under loading at the height of 33 in.

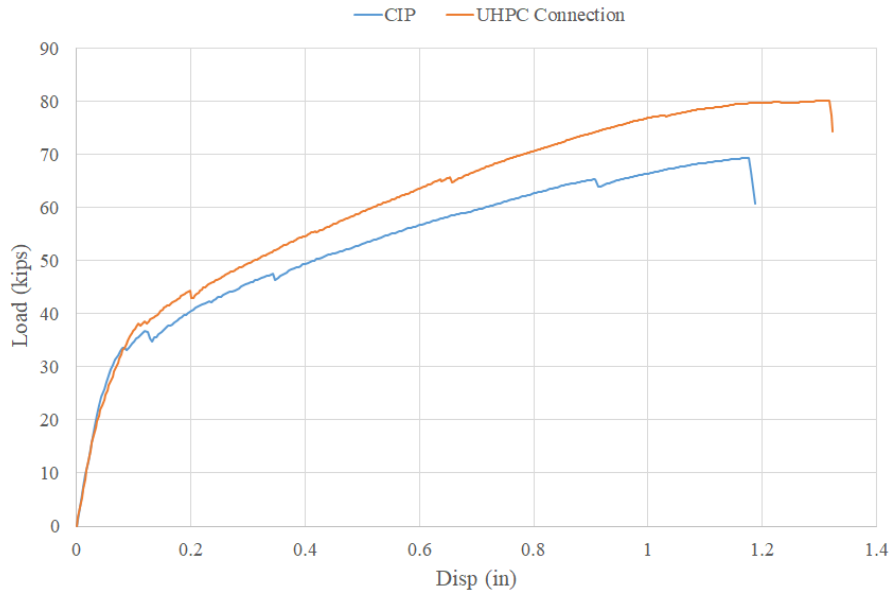


Figure 4 Comparison between the Load-Deflection Curves for the CIP and prefabricated barrier systems ($H_e = 33$ in).

The higher capacity of the prefabricated barrier system with respect to the CIP barrier can be attributed to shifting the yield line in the barrier about 6 in. upward, leading to smaller L_c in the prefabricated barrier (Figure 5).

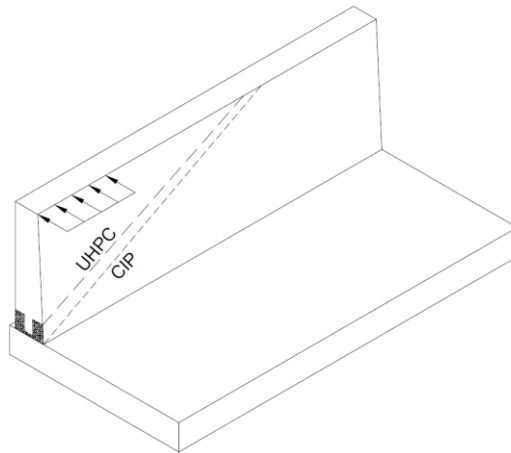


Figure 5 Development of the yield line failure pattern in CIP and UHPC-based connections.

The results of the FE show that the UHPC connection will perform in a more desirable pattern with less damage in the deck if compared to the CIP barrier while the barrier exhibits a desirable yield line failure pattern.

Task 3– Component Level Experimental Work

Progress: This task is completed.

In this task, experimental work was conducted on component-level specimens to verify the outcome of Task 2. Two 3 ft long specimens representing CIP and prefabricated barrier were tested in a cantilever test setup, as shown in Figure 6.

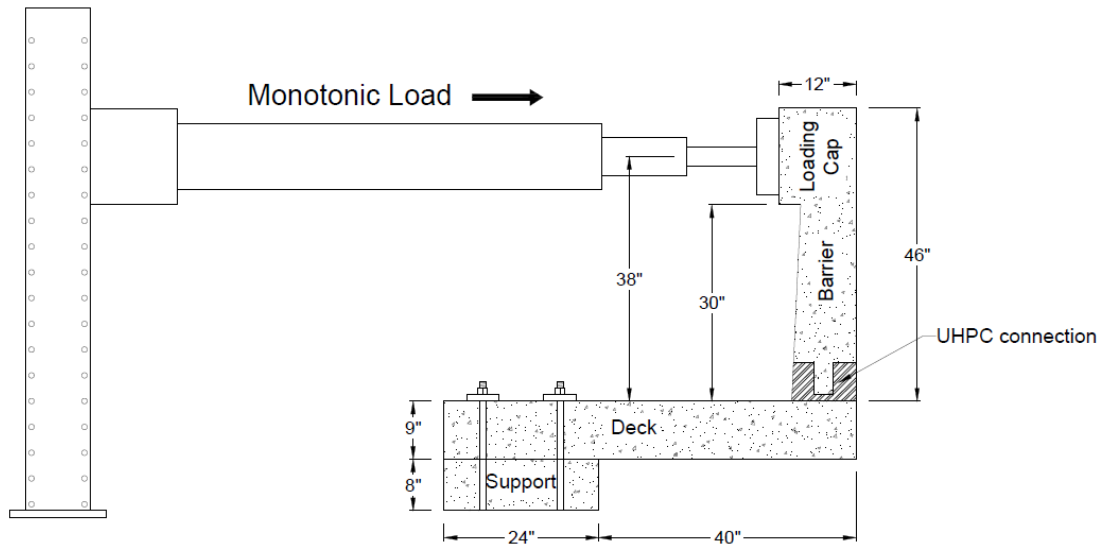


Figure 6- Test setup for the component level experimental work.

The formworks for the specimens were built and reinforcement cages were placed inside. It was chosen to cast the prefabricated barrier from the side for ease of construction. The CIP barrier and deck overhang were cast together to avoid cold joint between them. Figure 7 shows the construction of the formworks. The specimens were instrumented using strain gauges in critical locations.



(a)



(b)

Figure 7- Construction of test specimens for a) CIP barrier and b) Prefabricated deck and barrier.

During this reporting period, the CIP barrier specimen, and prefabricated barrier specimen were cast as shown in Figure 8. The prefabricated barrier was connected to the prefabricated bridge deck overhang as shown in Figure 8.

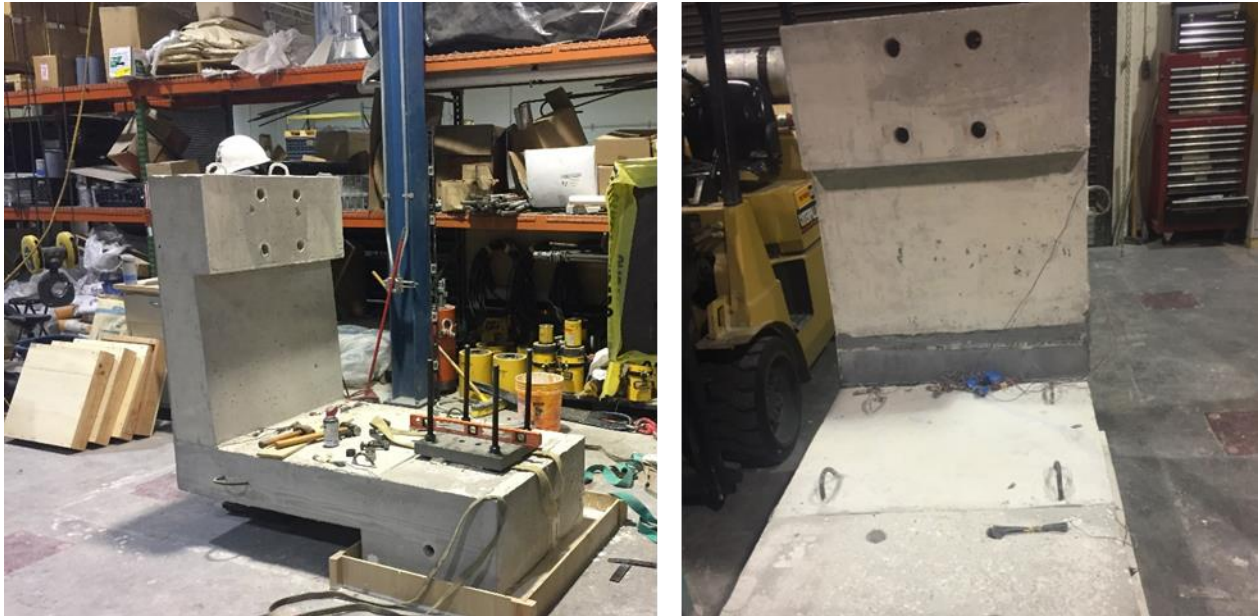


Figure 8- Constructed specimens, cast-in-place barrier (left) and prefabricated barrier with UHPC connection (right).

The experimental testing was conducted to compare the behavior of the UHPC connection under transverse loading (Figure 9). Displacement controlled monotonic load was applied to the barrier at a height of 38” until failure. Figure 10 shows the load-deflection curves for the cast-in-place and prefabricated barrier with a UHPC connection.



Figure 9- Load test setup for a) cast-in-place barrier and b) prefabricated barrier with UHPC connection.

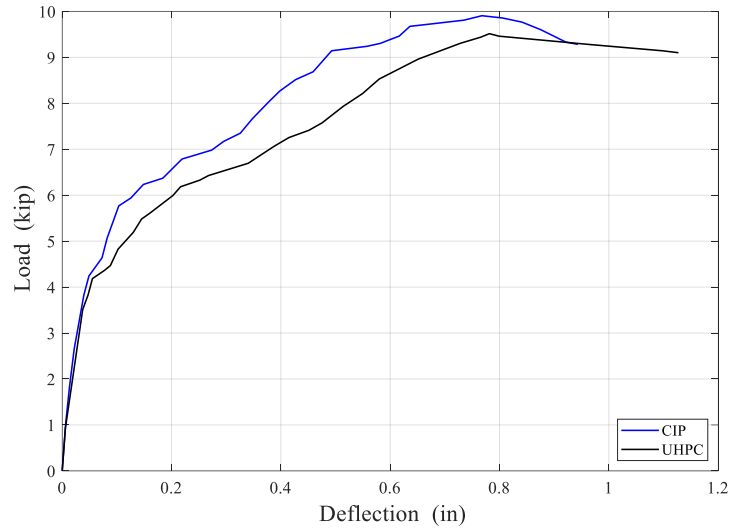


Figure 10- Load-Deflection curves for cast-in-place and prefabricated barrier with UHPC connection.

Based on the finding from this task, this task was extended, and modifications have been made to the connection. Three strip specimens of 1 ft long were built to investigate the constructability of the new connection. Figure 11 shows the details of the modified UHPC connection and constructed 1 ft strip specimens.

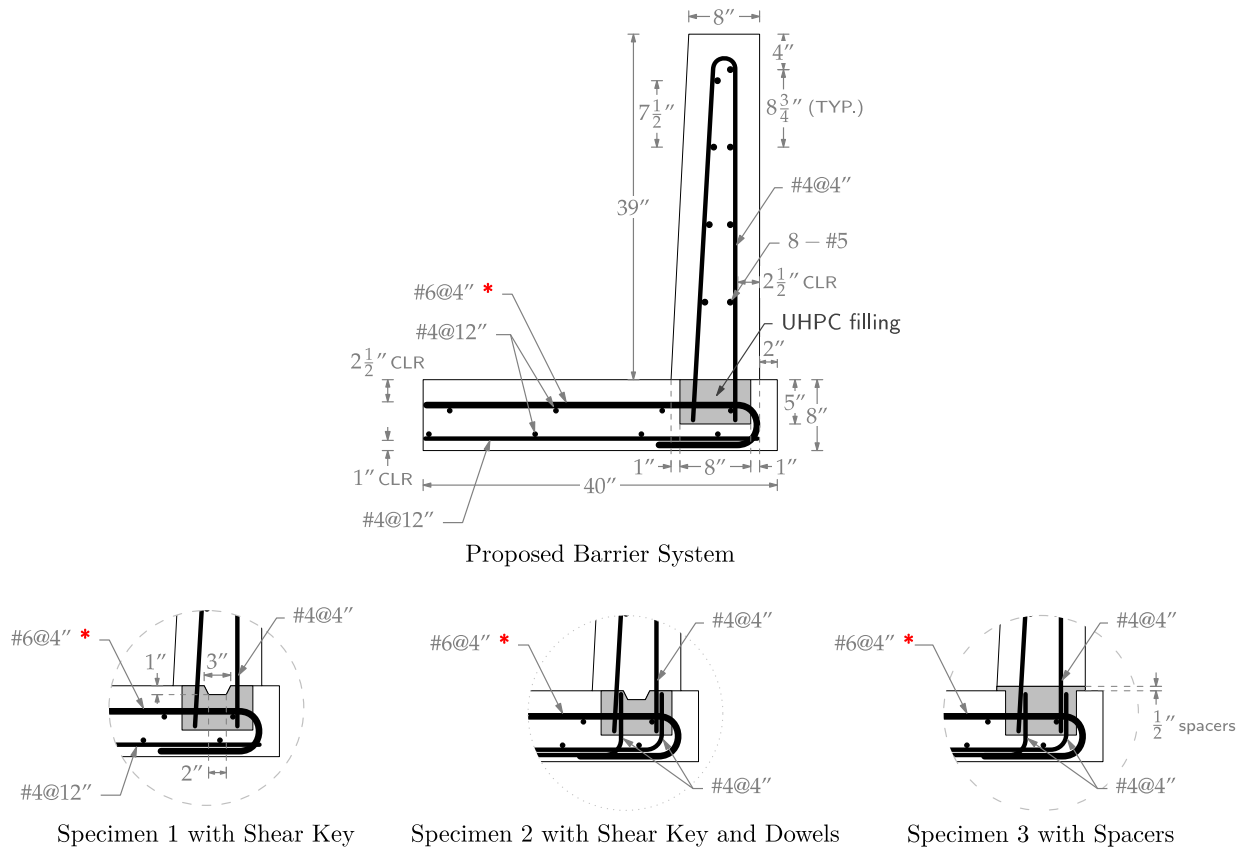


Figure 11- Proposed UHPC connection and details of the constructed 1 ft strip specimens.

The 1 ft long strip specimens were constructed as shown in Figure 12. The construction sequence consisted of pouring UHPC into the cavity and placing the prefabricated barrier on the deck overhang.



Figure 12- Construction of Specimen 2 with shear key and dowels.

The component level testing was performed on the constructed specimens to investigate the one-way flexural behavior of the barrier system subjected to transverse loading at a height of 30". Figure 13 shows the load-deflection curves for the strip barrier specimens with UHPC connection.

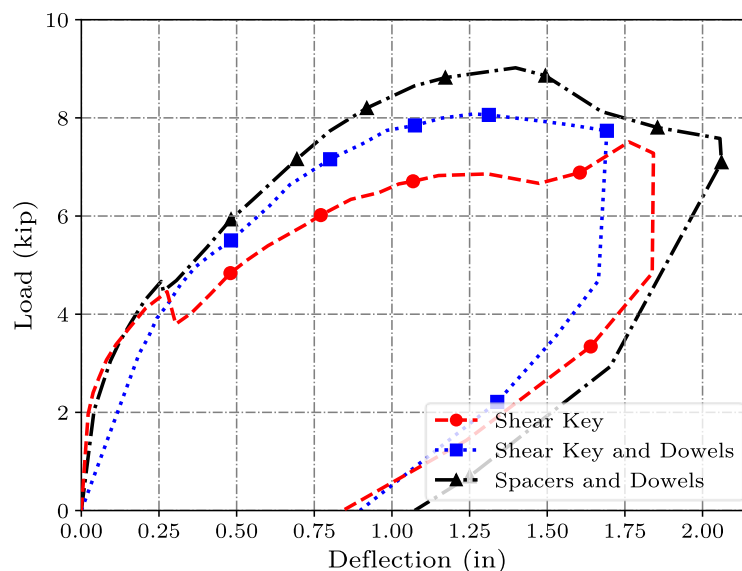


Figure 13- Load-Deflection curves for the strip barrier specimens with UHPC connection

Task 4– Large Scale Experimental Work

In this task, a full-scale specimen of the proposed prefabricated barrier system will be conducted to verify the outcome of tasks 2 and 3.

Progress: This task is completed.

In this task, experimental testing is being conducted on full-scale specimens to verify the structural behavior of the developed system based on MASH requirements. Two specimens of 5 ft. and 15 ft. long utilizing UHPC connection were chosen to be tested. The 5 ft long specimen loaded over its

whole length is designed to study the one-way flexural behavior of the barrier and deck system. The 15 ft long specimen loaded at its free end is designed to represent the most critical case regarding the capacity of the system. Details of the reinforcements in the full-scale specimens are shown in Figure 14.

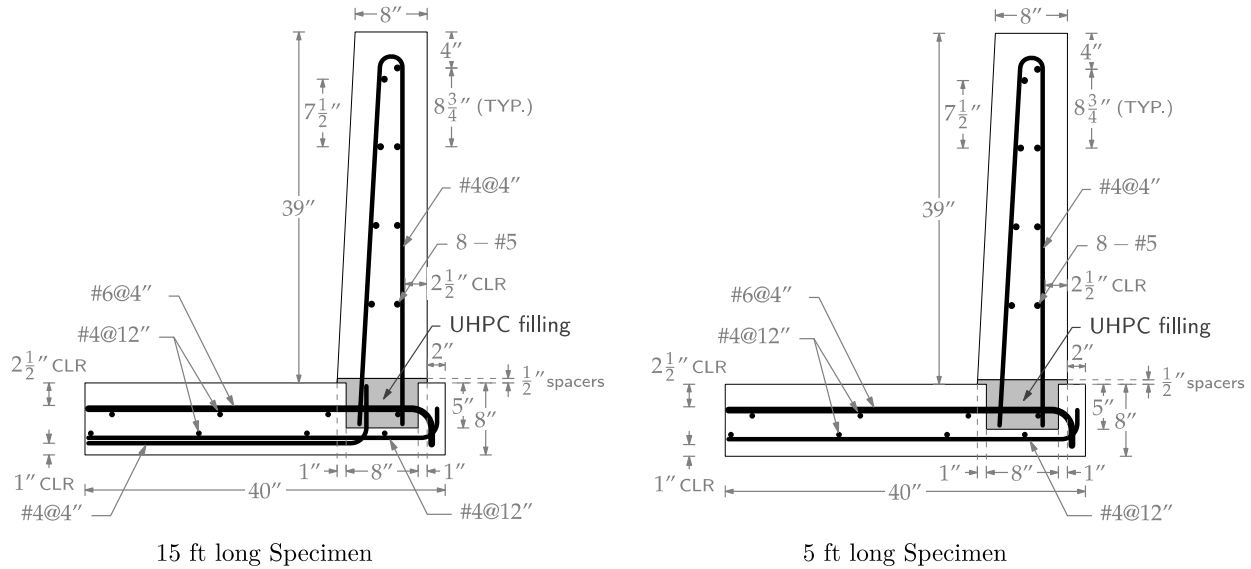


Figure 14- Details of the reinforcements in the full-scale prefabricated barrier specimens.

During this reporting period, both specimens were cast as shown in Figure 15. The prefabricated barriers were connected to the prefabricated bridge deck overhang and the experimental testing was performed on the 5 ft. long specimen. The load-deflection curve for the full-scale 5 ft. long prefabricated barrier specimen with UHPC connection is shown in Figure 16.

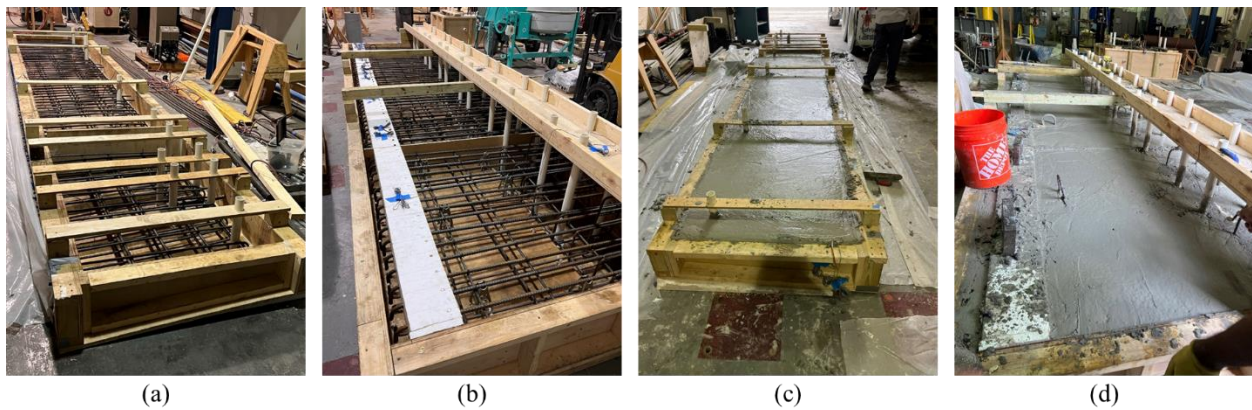


Figure 15- Details of the specimens: (a) reinforcement of prefabricated barriers, (b) reinforcement of the deck overhangs, (c) prefabricated barriers after casting, and (d) bridge deck overhangs after casting.

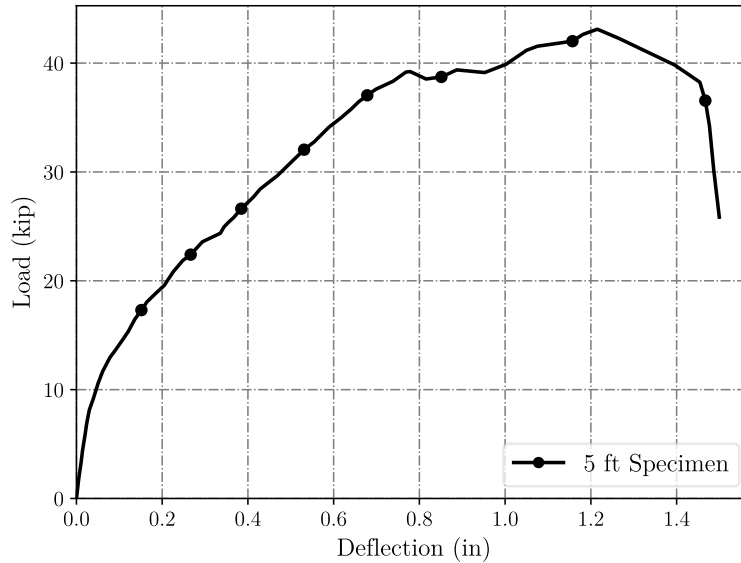


Figure 16- Load-Deflection curve for the full-scale 5 ft. long barrier specimen with UHPC connection.

The connection for the full-scale 15 ft. long prefabricated barrier specimen was constructed as shown in Figure 17. Formworks of 30 in. high were placed at both ends of the specimen to provide an extra pressure head for the UHPC to ensure complete filling of the connection region along the length of the specimen.



Figure 17- Construction of the full-scale 15 ft. long barrier specimen with UHPC connection.

The test setup for the full-scale 15 ft. long prefabricated barrier specimen is shown in Figure 18. The specimen is instrumented using load cells, potentiometers, LVDTs, and strain gauges in critical locations. The full-scale 15 ft. long prefabricated barrier specimen has been tested, and the results will be presented in the next quarterly report.



Figure 18- Test setup for the full-scale 15 ft long barrier specimen with UHPC connection.

Task 5– Assessment of the Performance of the Proposed Prefabricated Barrier System

In this task, a full performance assessment of the proposed prefabricated barrier system will be conducted in addition to a comparison between the proposed prefabricated barrier system with the most common prefabricated barrier system.

Progress: This task is in progress.

Task 6 – Final Report

In this Task, a full assessment of the findings from Task 1 throughout Task 5 will be conducted and a report will be published including design recommendations for the proposed prefabricated barrier system with UHPC connections.

Progress: This task is in progress.



5. Expected Deliverables

The final report, journal articles, design guidelines, and five-minute video presentation will be the expected deliverables.

6. Schedule

Item	% Completed
Percentage of Completion of this project to Date	Almo

Research Task	2021				2022				2023			
	Jan - Mar	Apr - Jun	Jul - Sep	Oct - Dec	Jan - Mar	Apr - Jun	Jul - Sep	Oct - Dec	Jan - Mar	Apr - Jun	Jul - Sep	Oct - Dec
Task 1– Development of new connections using UHPC for Prefabricated Barrier Systems												
Task 2– Finite Element Analysis of the Proposed Prefabricated Barrier System												
Task 3– Component Level Experimental Work												
Task 4– Large Scale Experimental Work												
Task 5– Assessment of the Performance of the Proposed Prefabricated Barrier System												
Task 6– Final Report												

 Proposed
 Completed

7. Reference

- American Association of State Highway and Transportation Officials. (2017). *AASHTO LRFD bridge design specifications*.