1. Innovative Full Depth Precast Deck Panel System with Discrete UHPC Joints at 6ft (1.8 m) Spacing

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Abstract:

This paper presents the development and experimental investigation of a new full depth precast concrete deck system that was developed within the NCHRP Project 12-96 as a simplified system for accelerated bridge construction. The system has the following features: shear connectors are located at the transverse joints only that are spaced up to 6 ft (1.8 m) in the longitudinal direction; transverse joints and shear connections are filled with UHPC that enables full composite behavior between the deck and the supporting girders; deck panels can be made solid or ribbed if deck weight reduction is desirable; and unique clustered shear connector assembly is used to resist large interface shear forces.

The paper focuses on the role of using UHPC in achieving the goals of the new system and allowing the extension of the maximum spacing of shear connectors from 4 ft (1.2 m), currently specified by AASHTO LRFD Bridge Design Specifications, to 6 ft (1.8 m). This extension increases the interface shear demand and stress concentration at the joints by 50%, which necessitates the use of a grouting material with superior mechanical and durability properties, like UHPC.

Keywords: Precast Concrete Deck Panels, Accelerated Bridge Construction, Shear Connector, Composite Section, Transverse Joint.

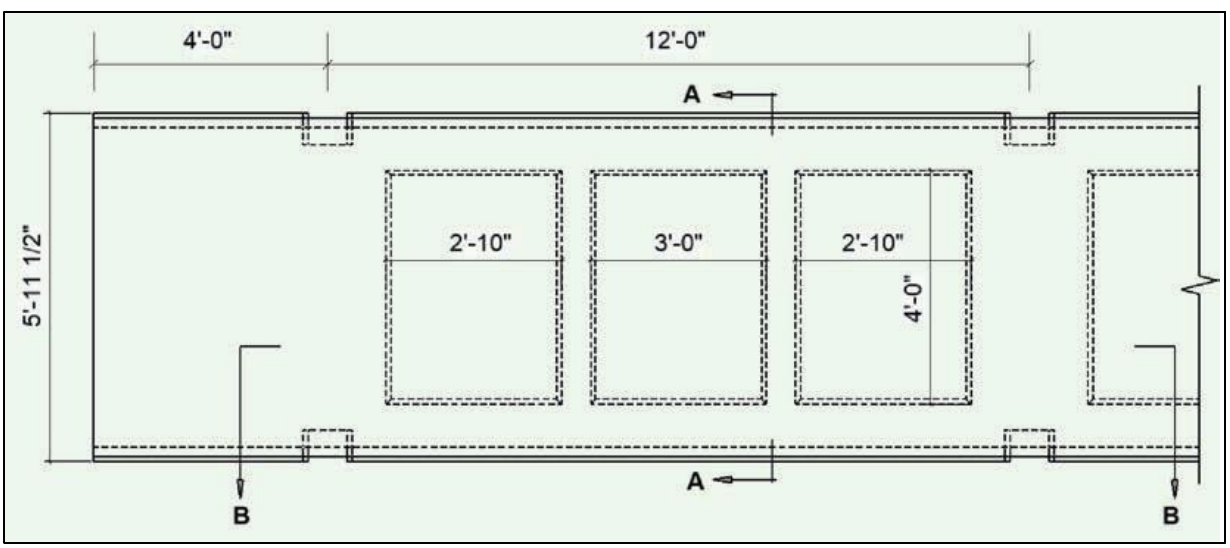
2. Introduction

Full-depth precast concrete deck panels have been widely used in accelerated bridge construction (ABC) in various forms and sizes. As a prefabricated component, a full-depth concrete deck panel system meets the objectives of ABC by expediting construction, enhancing quality and durability, improving public and worker safety, and reducing user cost (PCI, 2011). Typically, deck panels are connected to the supporting girders by shear connectors in formed openings in panels (i.e., shear pockets) to achieve composite action between the deck panels and bridge girders. The current use of shear connectors at small spacing poses several constructability challenges because of the large number of connectors and pockets, including the work associated with the blind grouting/concreting of numerous shear pockets and the longitudinal haunch between deck panels and girders. Specifically, leveling, sealing, forming, grouting, and concreting can be timeconsuming and require access from above and below the deck. These requirements may adversely affect the safety of construction workers and travelling public.

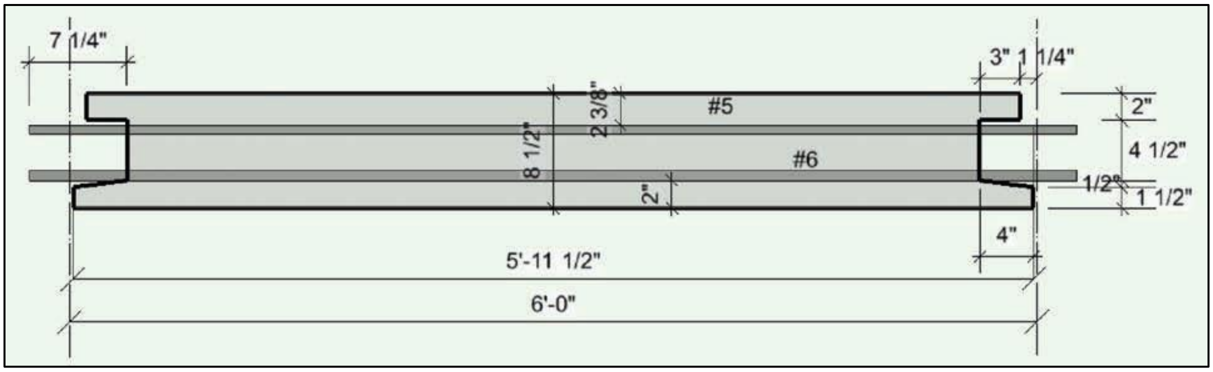
A new simplified precast concrete deck system that overcomes these constructability challenges was developed by reducing the number of shear connectors and eliminating the use of shear pockets and the associated blind grouting (Badie, et al., 2018). The new system utilizes Ultra-High Performance Concrete (UHPC) for grouting the transverse joints and the open discrete connections simultaneously. The following sections present a background on the new system, demonstrate the experimental investigation conducted to evaluate the interface shear resistance of the new UHPC connection, discuss test results, and summarize research conclusions.

3. Background

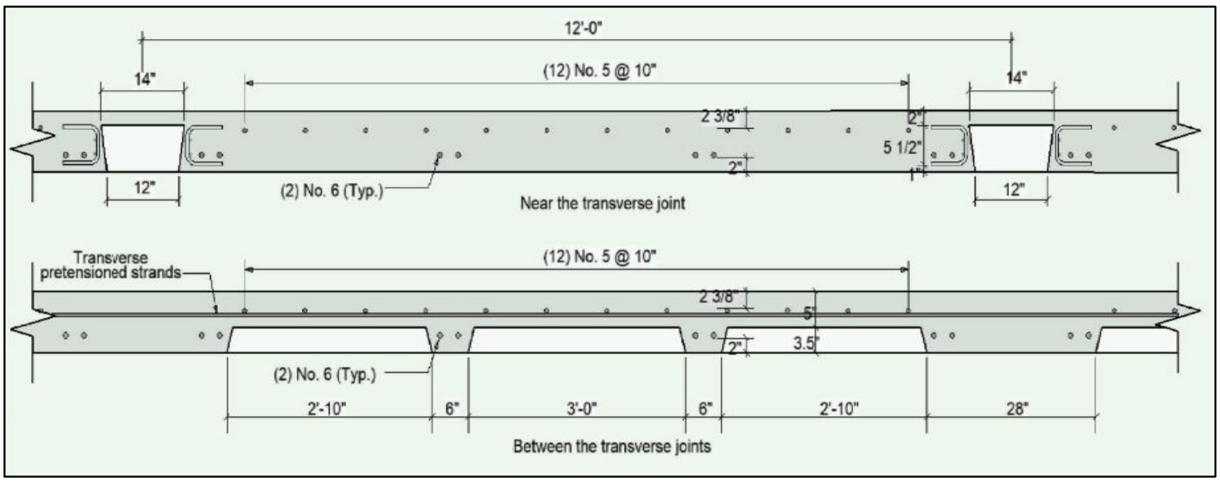
In the newly developed simplified bridge deck system, shear pockets exist only in the transverse joints between deck panels that are made 6-ft (1.8 m) long in the direction of traffic. Only the transverse joints and shear pockets - where the interface shear connectors are located – are required to be grouted in one field cast operation. Such a system is referred to as a system with "discrete joints" between the deck and girders. The haunch between deck and girder top flange may be left unfilled between the shear connectors or completely filled at the same time of grouting the transverse joints. The option of unfilled haunch was used in the experimental investigation as it reduces labor and material cost in addition to being more critical. Figure 1 shows the views of a typical full width, 8.5 in. (21.6 cm) thick precast concrete ribbed panel of the new deck system. The ribbed panel has longitudinal ribs between adjacent girder lines, spaced at 3 ft (0.9 m) or less. In addition, there are longitudinal ribs directly over the girder lines. The precast concrete panel is designed with 6-ksi (41.4 MPa) specified concrete strength and is made 6-ft (1.8 m) long to avoid in-panel shear pockets. At the top, the shear key has a 2.5 in. (6.4 cm) wide gap between panels to fill the transverse joint with grout. Shear key surface is either intentionally roughened by applying a retarder to expose the aggregates or sandblast to enhance the bond between the panel and UHPC. UHPC is used to fill the conventionally reinforced transverse joints as well as shear pockets. The top surface of these joints and pockets shall then be ground when the UHPC compressive strength is between 12 and 14 ksi (82.7 and 96.5 MPa).



a) Plan view of the new precast concrete deck panel



b) Section A-A



c) Section B-B

Figure 1: New Precast Concrete Deck Panel (1 in. = 2.54 cm, 1 ft = 0.3 m).

3. Testing Methods

The objective of the testing program is to evaluate the interface shear resistance of the proposed UHPC connection between the deck and I-girder (concrete and steel). The testing program consists of six push-off specimens: three on concrete girders, and three on steel girders. The precast concrete deck panels used in these specimens were fabricated by Coreslab Structure, Inc. (a PCI certified producer in Plattsmouth, Nebraska). All panels were made using normal weight self-consolidated concrete (SCC) that had a specified stripping strength of 3.5 ksi (24.1 MPa), specified 28-day compressive strength of 6 ksi (41.4 MPa), and measured 28-day compressive strength of 7.9 ksi (54.5 MPa). The surface of transverse joints and shear pockets was prepared by sandblasting at the precast yard to improve its bond with UHPC. Panels were then shipped to the structural laboratories of UNL and GWU for casting the connections on concrete and steel girders, respectively. The UHPC used in the joints and connection was mixed in the laboratory using the commercial mix Ductal JS1000 produced by LafargeHolcim. For each push-off specimen, 2.6 ft3 was made using seven bags of Ductal JS1000. The mixed UHPC had a slump flow of 10 in. (25.4 cm), according to ASTM C1856, at a temperature of 80°F and relative humidity of 50%. A trial mix was tested prior to casting the three connections to evaluate the mechanical properties of the UHPC. The results of testing three cylinders and prisms indicated that UHPC has an average compressive strength of 14.8 ksi (102 MPa) at 4 days and 26.3 ksi (181.3 MPa) at 28 days, 1.6 ksi

(11 MPa) pre-cracking splitting strength, 2.67 ksi (18.4 MPa) post-cracking splitting, and 2.6 ksi (17.9 MPa) flexural strength.

3.1. Testing UHPC Connection on Concrete Girders

Three identical full-scale push-off specimens were tested and the results compared with those predicted using the current AASHTO LRFD bridge design specifications. Table 1 shows the configuration of the three push-off specimens tested to evaluate the constructability and structural performance of the revised connection.

Table 1. Push-off Specimens on Concrete Girders.

Specimen ID	Girder Type	Connector Type and Size	Deck Panels
C1	Concrete Block	2 – 1.5″ A193 B7 Threaded Rods held by a steel collar (Figure 2)	Two 4' x 2'-11.75" x 8.5" Precast Concrete Ribbed Panels
C2	Concrete Tee Section		
C3	Concrete Tee Section		

*1 in. = 2.54 cm, 1 ft = 0.3 m

Figures 2 shows the dimensions of the concrete push-off specimens. It should be noted that the girder of the first specimen was made of a concrete block that was lightly reinforced, which resulted in a premature failure of the concrete block before reaching the connection design load. Therefore, the second and third specimens were made as tee girders using foam blockouts, as shown in Figure 2, with reinforcement comparable to those of top flange and web of bridge I-girders. The push-off concrete girders were cast at UNL laboratory using a ready-mixed SCC with an average slump flow of 22 in. (55.6 cm) and 28-day compressive strength of 6.8, 8.3 and 8.3 ksi (46.9, 57.2 and 57.2 MPa) for the first, second and third specimens respectively. In all specimens, a discrete haunch, 20"x14"x3" (50.8 cm x35.6 cm x7.6 cm), was formed around each connector using sealed wood forms to prevent leakage of the UHPC.

The 1.5" (3.8 cm) diameter threaded rods used as shear connectors were made of Grade B7 A193 with yield strength of 105 ksi (723.9 MPa) and ultimate strength of 125 ksi (861.8 MPa). All other steel components (collars, washer plates, and nuts) were made of Grade 50 A572 steel with E70 electrode welding. Figure 3 shows the setup used for push-off testing of the three specimens at UNL laboratory. The hydraulic jack and load cell were aligned to apply a horizontal force at the center of the concrete deck panels, while the concrete girder was restrained horizontally using a horizontal steel frame. To avoid specimen rotation due to eccentricity of the applied force, hold-down straps were used to anchor the specimen to the floor. All specimens were instrumented to measure the relative displacement between the concrete deck panels and the supporting girders at the connection location using linear variable differential transformers (LVDTs) in both horizontal and vertical directions. Two LVDTs was installed on each side. Electric resistance strain gauges were also installed diagonally at the center of the steel collar and threaded rods to monitor the strain during testing.

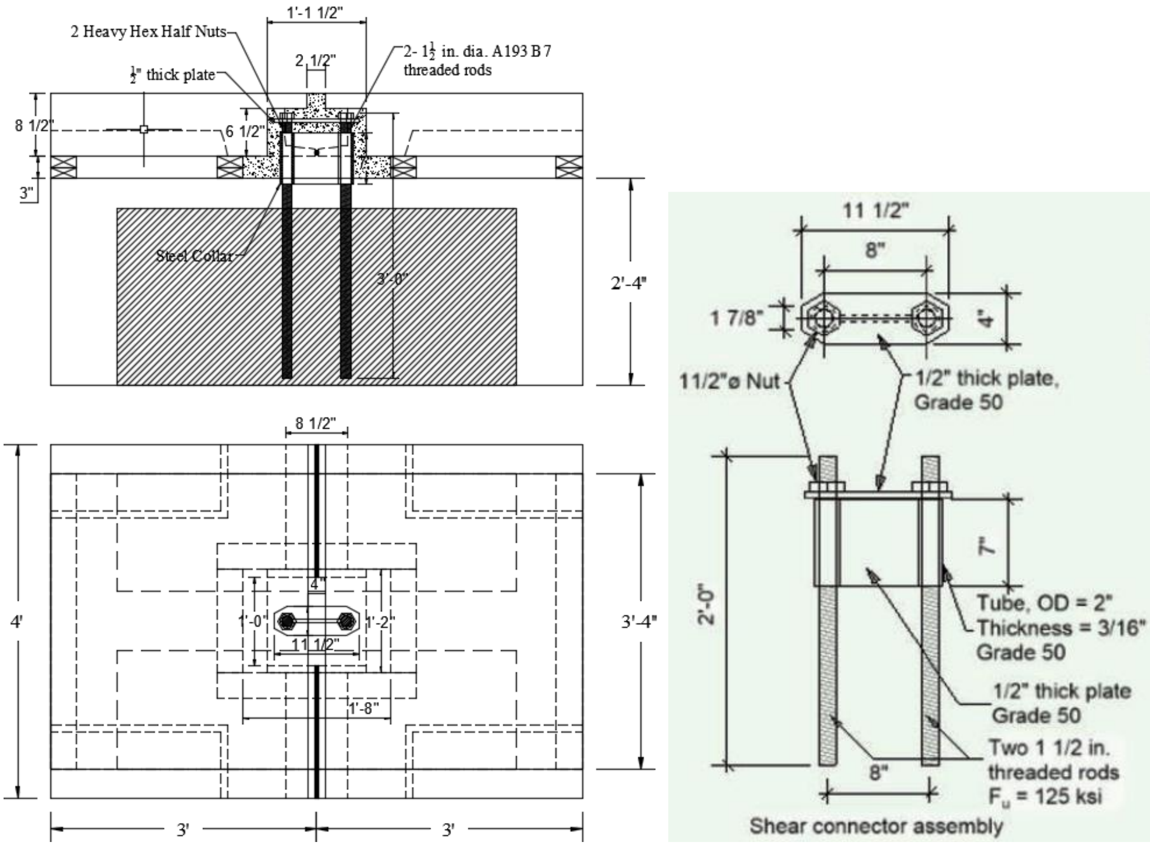


Figure 2: Push-off Test Specimen of UHPC Connection on Concrete Girder and The Connector Assembly (1in. = 2.54cm, 1ft = 0.3m).

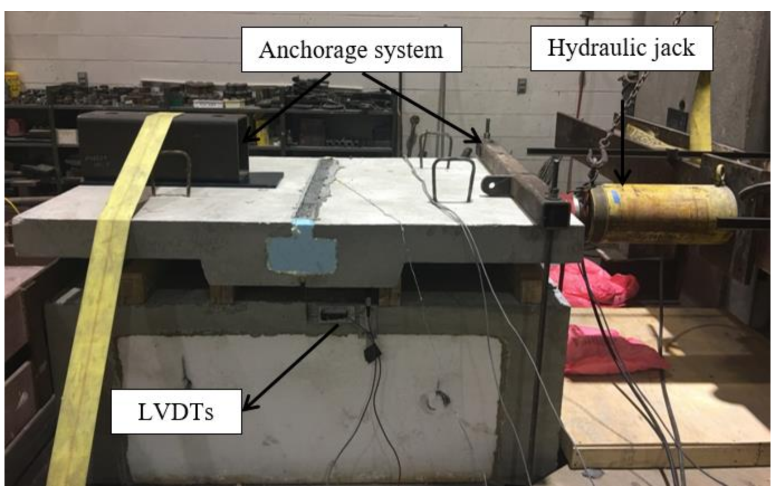


Figure 3: Push-off Test Setup for Concrete Girder Specimens

3.2. Testing UHPC Connection on Steel Girders

Figure 4 shows the details of the push-off specimens of the UHPC connection on steel girders. Nine 1" (2.54 cm) diameter steel studs were installed in three rows (three studs per row). Spacing between the studs was 5" (12.7 cm) in the longitudinal direction and 4" (10.2 cm) in the transverse direction, which satisfied the AASHTO LRFD Bridge Design Specifications' minimum spacing requirement of four times the stud diameter. The push-off specimens were built and tested at the structural testing facility at GWU. The studs were welded by a certified welder using a Nelson stud gun. Properties of the studs were as follows: ASTM C1015 steel, ultimate strength = 71.84 ksi (495.3 MPa), and yield strength = 54.10 ksi (373 MPa). Figure 5 shows the setup of the push-off testing of the three specimens on steel girder. The hydraulic jack and load cell were aligned to apply a horizontal force at the center of the concrete deck panels, while the steel girder was restrained against horizontal movement using a horizontal steel frame. To avoid specimen rotation caused by eccentricity between the hydraulic jack and the horizontal frame, vertical steel frames were built around both ends of the precast deck. A ½” (1.3 cm) thick steel bearing plate was installed in front of the load cell to distribute the load uniformly across the width of the panel. The push-off specimens were tied back to the wall using two 1¼” (0.64 cm) diameter, 120 ksi (827.4 MPa) yield strength bars. The 1¼” (0.64 cm) diameter bars were the maximum size bars that could be fed through the sleeves provided in the strong wall. The capacity of the setup was controlled by the 295 kips (1312.2 kN) yield strength of the bars, which was 7% higher than the predicted shear capacity of the connection. Strain gauges were installed on five studs and on the vertical Dywidag bars holding the panel close to the applied load to monitor the tension force generated in these bars. Two LVDTs were installed—one LVDT at each side of the specimen—to measure the relative horizontal displacement between the panels and the top surface of the steel girder.

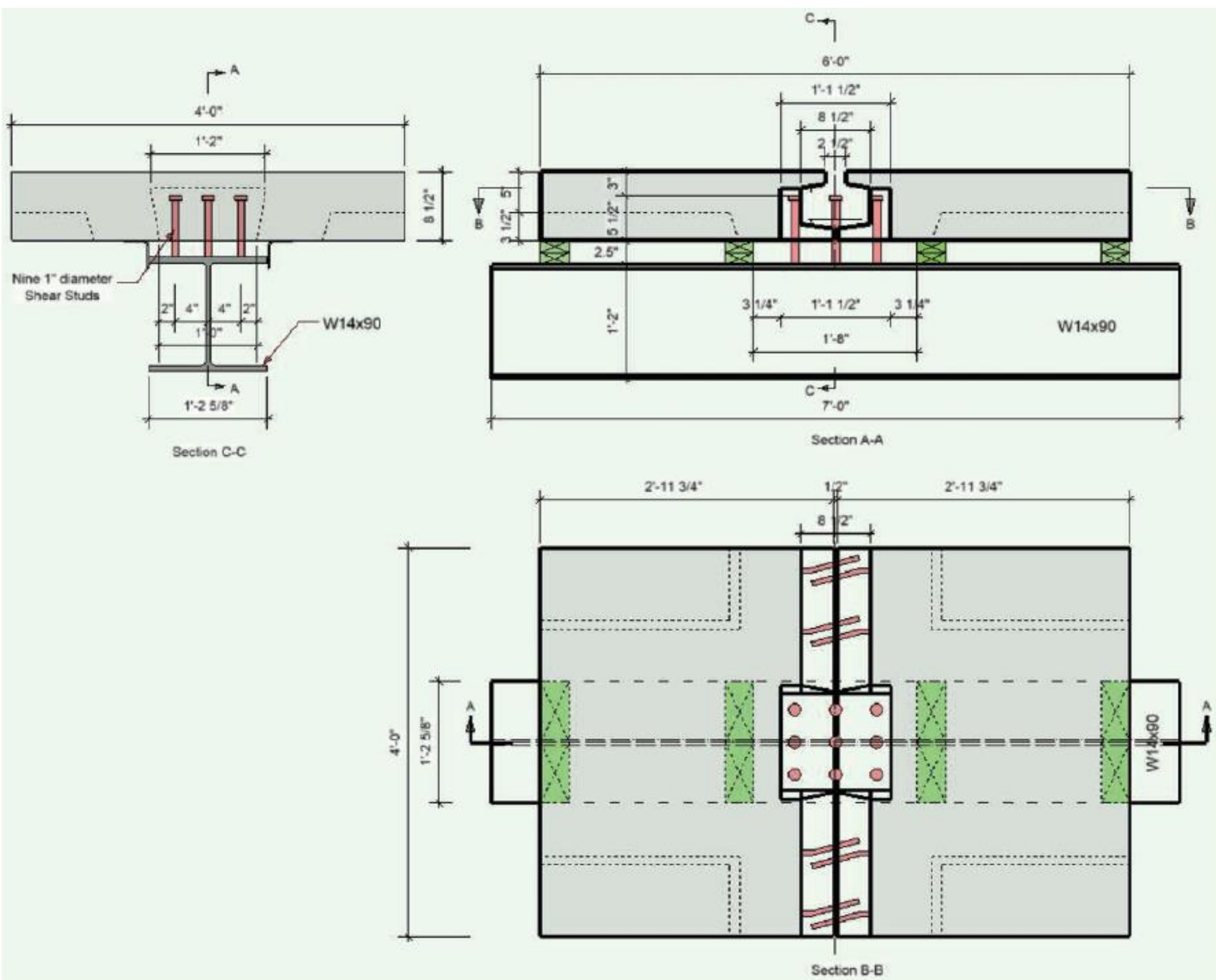


Figure 4: Push-off Test Specimen of UHPC Connection on Steel Girder (1in. = 2.54cm, 1ft = 0.3m).

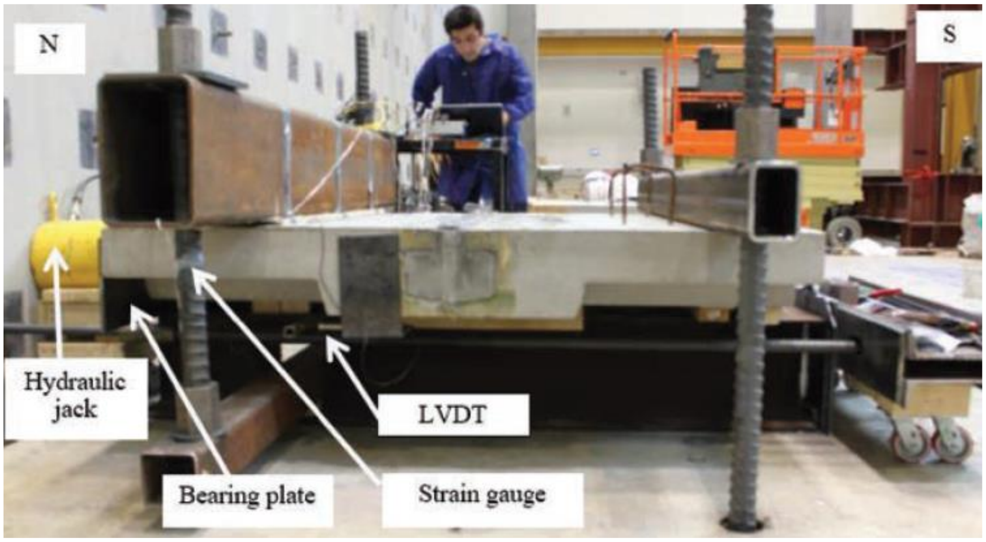


Figure 5: Push-off Test Setup for Steel Girder Specimens.

4. Results

Table 2 presents the summary of test results of push-off specimens on concrete girders. Results of testing the second and third specimens were consistent as they had a tee-shaped girder section that was reinforced similar to conventional bridge girder sections. The average capacity of these two specimens was 327 kips (1455 kN), which is significantly higher than the predicted capacity of 236 (1050 kN) using the shear friction provisions of AASHTO LRFD bridge design specifications article 5.8.4. (AASHTO, 2017)

Table 2. Summary of push-off test results on concrete girders.

Specimen ID	UHPC Compressive Strength, ksi (MPa)	Push-off Failure Load, kip (kN)	Mode of Failure
C1	15.7 (108.2)	232 (1032)	Flexural failure of under-reinforced concrete block
C2	13.5 (93.1)	312 (1388)	Cracking of precast concrete deck at the loading side
C3	15.1 (104.1)	342 (1521)	Cracking of precast concrete deck at the loading side
Average	**14.8 (102)**	**295.3 (1314)**	

Finite Element Analysis (FEA) was conducted using ABAQUS 6.13-3 to model the behavior of the developed UHPC deck-to-girder connection. Push-off test results were used to calibrate the FE model. Figure 6 shows the load-displacement plots of the three push-off specimens as well as the one obtained from FEA. The figure indicates the accuracy of the model in representing the behavior of the tested specimen. The developed model was then used to predict the stresses in the different components of the connection. FEA results indicated that the highest stresses occur at the steel collar attached to the threaded rod located on the loading side, and the highest concrete stresses are the bearing stresses at the UHPC surrounding the steel collar. It also showed high compressive stresses at the concrete girder top flange around the shear connectors, which necessitates providing adequate transverse reinforcement to confine the top flange concrete at the connector locations.

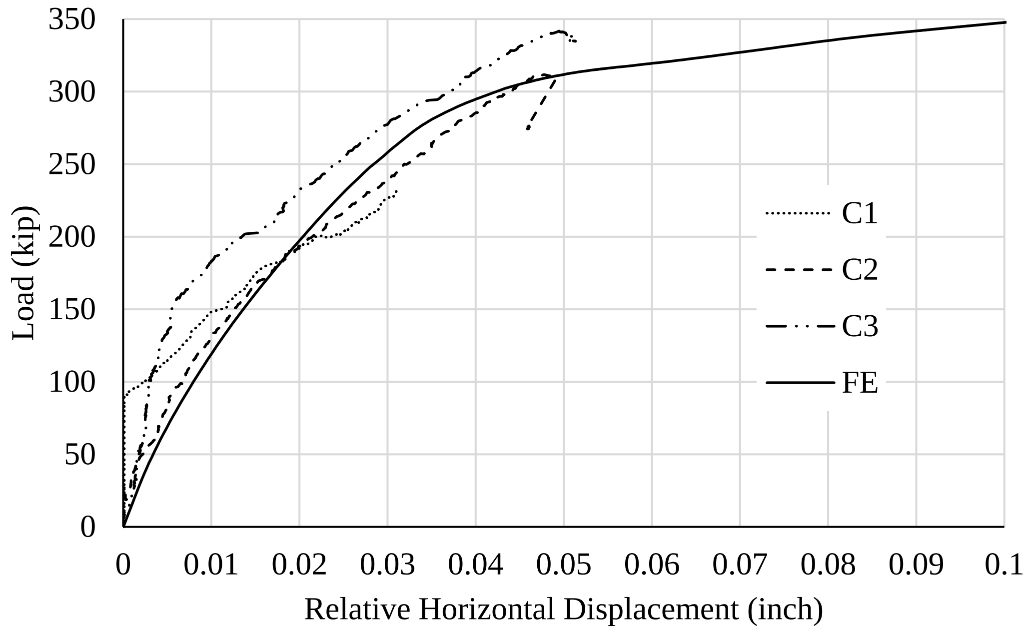


Figure 6. Load-displacement relationships of the three push-off specimens and FE model

(1 in. = 2.54 cm; 1 kip = 4.45 kN)

Table 3 presents the summary of test results of the push-off specimens on steel girders. The first specimen failed by bearing stresses on the precast panel set in front of the hydraulic jack, while the second test was stopped when the maximum capacity of the set up was reached. The third specimen suffered from horizontal rotation when the top flange of the steel beam at the far end of the specimen, where the reaction beam was located, started to bend. The average capacity obtained from the tests was 279.5 kips (1243 kN), which is higher than the predicted capacity of 276.5 kips (1243 kN) according to article 5.8.4 of AASHTO LRFD bridge design specifications (AASHTO, 2017). In addition, no cracks or signs of distress were observed at the UHPC connection, which indicates that the capacity of the connection could be much higher, which needs to be evaluated by testing a full-scale composite girder. Figure 7 shows the load-displacement plots of the three push-off specimens as well as the one obtained from FEA conducted using ABAQUS 6.13-3.

Table 3. Summary of push-off test results on steel girders.

Specimen ID	UHPC Compressive Strength, ksi (MPa)	Push-off Failure Load, kip (kN)	Mode of Failure
S1	14.3 (98.6)	265 (1179)	Bearing failure of the precast panel
S2	13.8 (95.1)	295 (1312)	Maximum capacity of the set up
S3	14.2 (97.9)	278 (1237)	Horizontal rotation of the specimen
Average	**14.1 (97.2)**	**279.5 (1243)**	

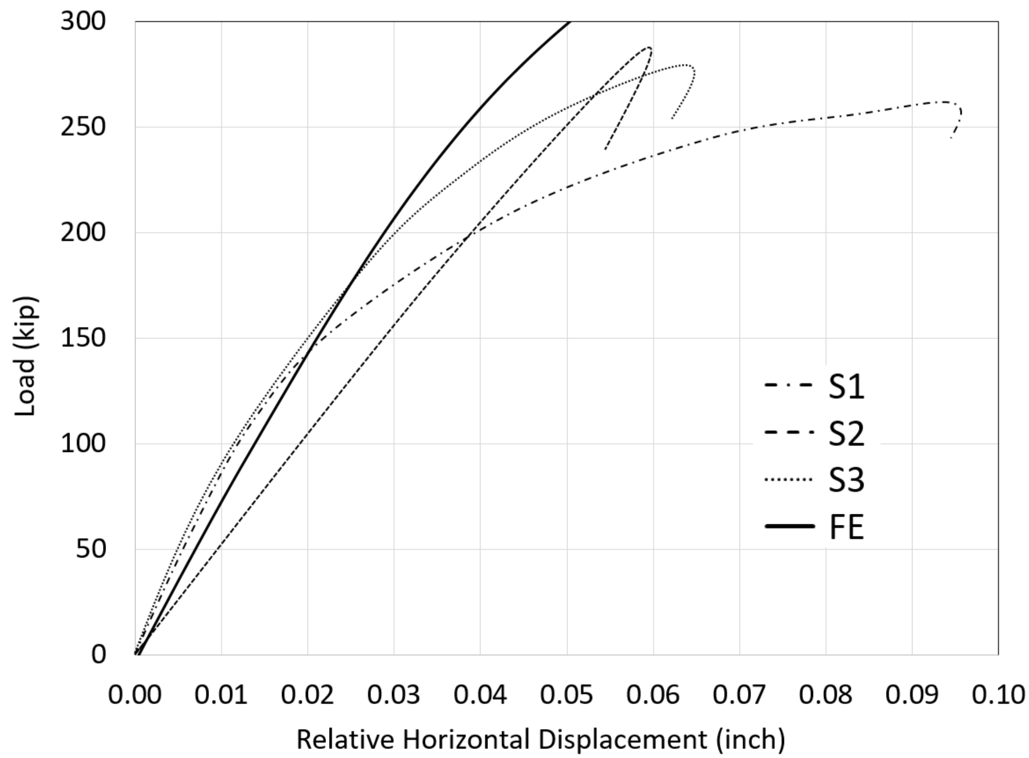


Figure 7. Load-displacement relationships of the three push-off specimens on steel girders

(1 in. = 2.54 cm; 1 kip = 4.45 kN)

5. Conclusions

A full-depth precast concrete deck panel system was developed using an innovative deck-to-girder connection spaced up to 6 ft in the longitudinal direction. The new connection utilizes UHPC to grout the transverse joints and shear pockets at the same time to achieve the structural capacity, durability, and speed of construction requirements of ABC. Based on the experimental investigation presented in this paper on the new UHPC connection for concrete and steel girders, the following conclusions can be made:

- The interface shear resistance of the new connection can be conservatively predicted using the current AASHTO LRFD bridge design specifications shear friction provisions (article 5.8.4).
- Push-off testing of six specimens (3 on concrete girders and 3 on steel girders) indicated that the either the girder or deck panel fails before the UHPC connection even cracks.
- The developed FE models can accurately represent the load-displacement behavior of the new connection during push-off testing. These models can be used to predict the stresses in the different steel and concrete components of the connection.

6. References

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