UHPC Based Solutions for Accelerated Bridge Construction

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Abstract

A significant portion of the existing roadway system in the United States was built over 50 years ago and is widely showing signs of increasing deterioration. Construction activities related to bridge replacement and rehabilitation are important contributors to traffic jams and reduced mobility and, most importantly, to safety hazards. Conventional construction practices have proven inadequate to address the magnitude of the problem now facing this nation. Highway system disruptions due to work zones must be considered when evaluating the need for rapid renewal procedures. Accelerated Bridge Construction (ABC) has the potential to reduce both the frequency and duration of work zone disruptions. ABC is a delivery solution method for building and repairing bridges with the capability to reduce the interruption to traffic and increase safety. UHPC provides a new horizon for addressing many actions that are needed to be taken to address the challenges facing the nation with respect to existing bridges. At ABC-UTC, researchers have developed many UHPC based solutions that can retrofit/upgrade existing bridges or be utilized for the construction of new bridges. These solutions include systems where formwork is replaced by a UHPC shell that becomes a permanent part of bridges, connections for connecting prefabricated bridge elements, 3D printing, automation, durability, and fire resistance of bridge elements constructed using UHPC, advanced integral abutment systems, shotcrete and more. This presentation will provide an overview of some of the UHPC based solutions, developed at ABC-UTC.

Keywords: Ultra-high-performance concrete (UHPC); Accelerated bridge construction (ABC); Modular construction; Innovative bridge system; Column retrofit; Accelerated retrofit solution; 3D Printing; additive manufacturing.

1. ABC-UTC Non-Proprietary UHPC Mix

The high cost of commercially available UHPC products has limited their use. Using local materials, ABC-UTC researchers investigated the influence of various variables, such as fiber type, fiber content, and cement type on the final mechanical properties of UHPC and developed a non-proprietary UHPC mix design that offers the necessary mechanical properties for use in bridge construction. A brief summary of this work was provided during In-Depth Web Training conducted by ABC-UTC on September 13, 2022 (link). Complete video and associated materials related to this four-hour webinar can be viewed at the link listed above.

2. Prefabricated UHPC Shells as Stay-In-Place Forms

Generally, conventional formwork and scaffolding serve the purpose of providing a temporary container for supporting the weight of wet concrete in bridge construction. A novel idea was developed to utilize prefabricated UHPC shells as permanent stay-in-place formwork for bridge elements. Using these prefabricated UHPC shells reduces on-site construction time by eliminating traditional formwork and scaffolding. Additionally, it protects the encased reinforcements and normal strength concrete from environmental attacks. Figure 1a shows the construction sequence of using UHPC shells as permanent formwork which is quite similar to conventional construction. ABC-UTC researchers investigated the structural performance of columns and beams constructed with permanent UHPC shells (Figure 1b) (Caluk, Mantawy and Azizinamini). By using this type of construction, the superstructure dimensions and weight can be reduced, and the need for formwork removal would be eliminated.

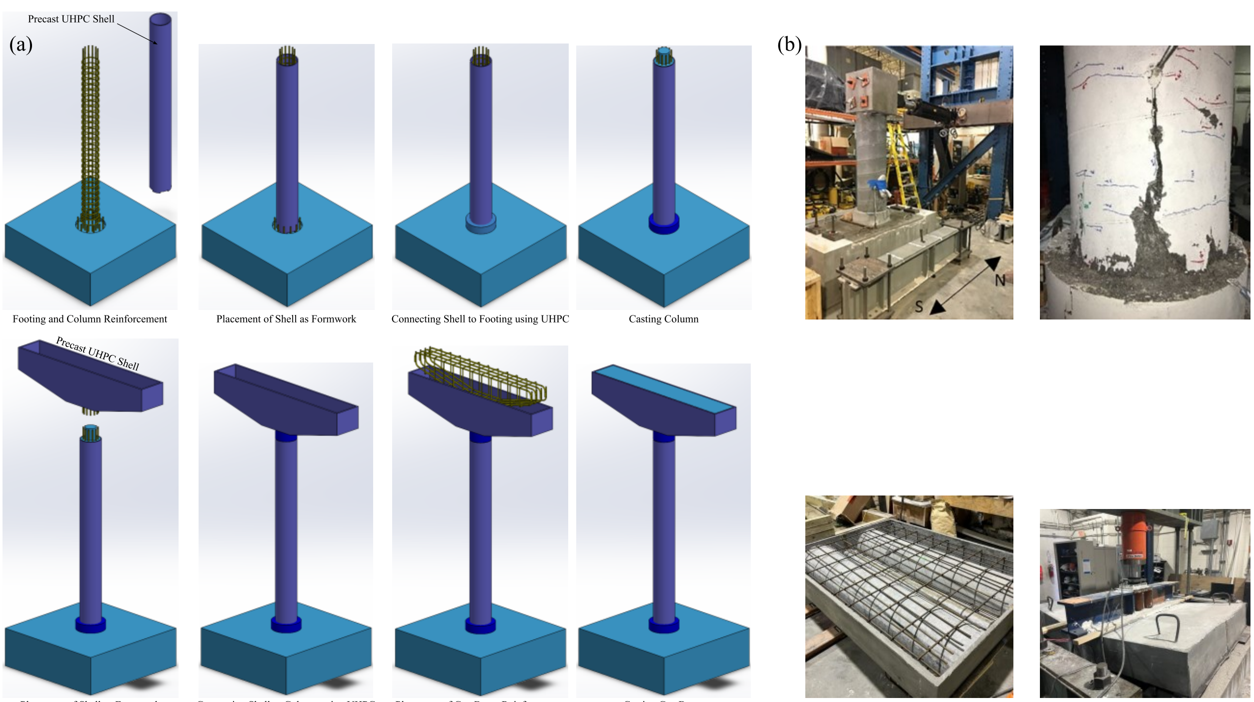

Figure 1. UHPC Shells as Stay-In-Place Forms: (a) Concept and (b) Experimental testing.

3. Retrofitting of Bridge Columns

The harsh environment causes cracking and spalling of concrete, loss of reinforcement, and lack of confinement because of corrosion of transverse reinforcements. This will result in a significant reduction in the structural integrity and load-carrying capacity of such structures. Using UHPC in retrofitted structures can improve their durability and strength. ABC-UTC researchers investigated the feasibility of using UHPC as a repair material for structural members. Typical damages in the beam and column specimens were simulated and repaired with UHPC as shown in Figure 2. The simulated corrosion-induced damages in the specimens included loss of concrete cover, cross-sectional asymmetry, complete loss of transverse reinforcement, and complete loss of several longitudinal reinforcements. Several specimens representing intact column specimens and repaired using UHPC were tested experimentally to investigate the structural behavior of the retrofitted columns. Experimental results showed that the UHPC shell increased the strength without increasing the size of repaired elements (Farzad, Shafieifar and Azizinamini).

(a)

(b)

Figure 2. Using UHPC to retrofit bridge elements: (a) retrofitting column specimen (Farzad, Shafieifar and Azizinamini), (b) retrofitting beam specimen (Valikhani and Azizinamini).

4. UHPC Based Connections

Modular construction is one of the commonly used ABC techniques that involves breaking down the superstructure of a bridge into several pieces, which are constructed off-site, transported to the final bridge site, and then assembled by connecting the modules. The researchers at ABC-UTC have developed several UHPC based connections for bridge construction. By taking advantage of the superior mechanical properties of UHPC, an innovative prefabricated barrier system was developed that is applicable to ABC applications (Khodayari, Mantawy and Azizinamini). Figure 3a shows the construction sequence for the proposed connection. Full-scale experimental testing was conducted to investigate the structural adequacy of the system subjected to static transverse loading at its end. The results of experimental testing showed that the developed connection meets the strength requirement for TL-4-2. The barrier system demonstrated a preferred mode of failure while the deck maintained its integrity and did not experience significant damage in comparison with the CIP barrier systems. A MASH test will be needed before this connection is used in the practice. A separate work is being conducted under NCHRP 22-56 to further develop connection details for prefabricated barrier systems (NCHRP 22-56).

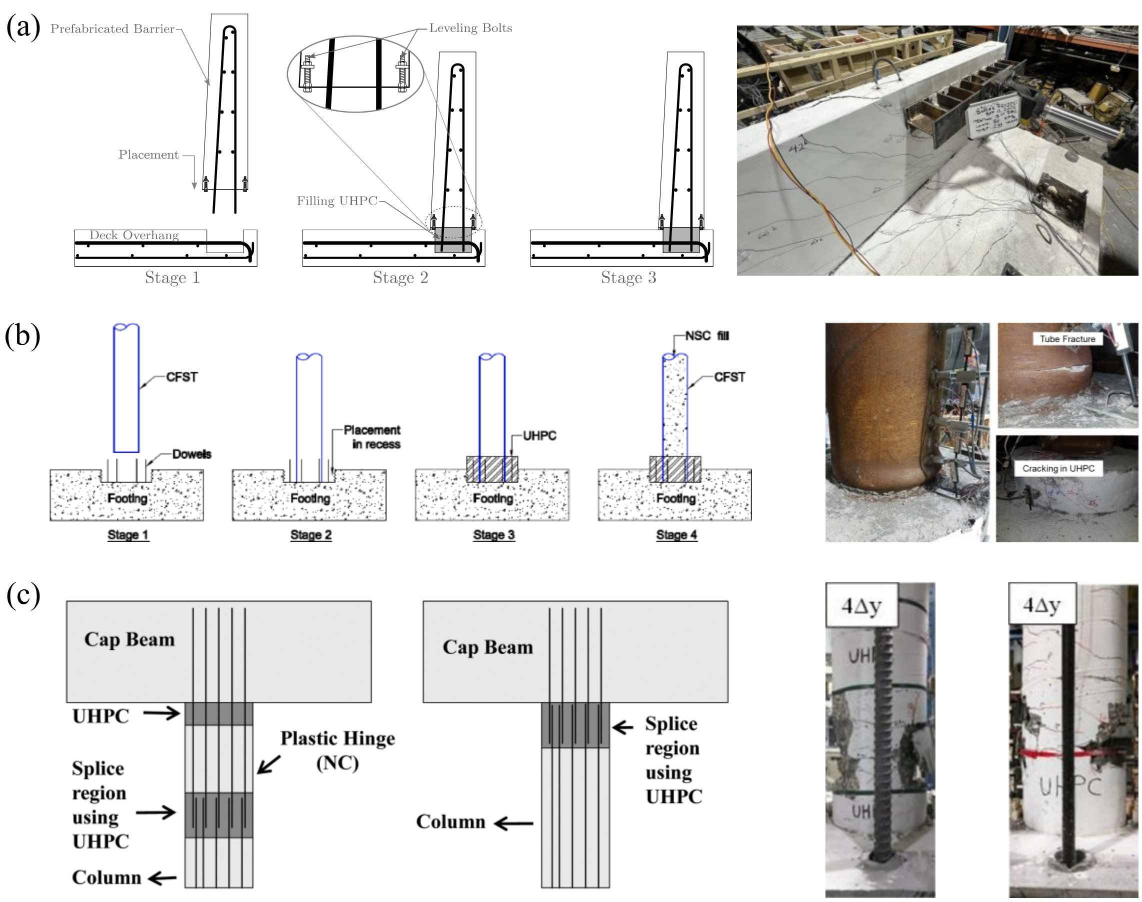

Figure 3. Developed UHPC based connections: (a) Barrier-to-deck connection, (b) concrete filled steel tubes to footing connection, and (c) Column to cap beam connections.

In another study, a new connection detail was developed to connect the concrete filled steel tubes (CFSTs) to the footing using UHPC as shown in Figure 3b (Rehmat, Sadeghnejad and Azizinamini). Steel dowels from the footings are used to transfer force through the CFST embedded in a UHPC layer near the plastic hinge zone of the column. A high level of ductility was observed in the experimental testing of the connection and there were no signs of cracks in the capacity-protected footing. Further, the failure modes were typical of those observed in testing Concrete Filled Columns (Elremaily and Azizinamini).

Separate research was conducted to develop connection details using UHPC for connecting precast cap beams to precast columns in seismic and non-seismic applications (Shafieifar, Farzad and Azizinamini). Figure 3c shows the concept of the developed connections and the failure modes observed in the experimental testing. The results of experimental testing showed that both connections demonstrated adequate levels of displacement ductility. In the connection for seismic applications, a plastic hinge with a certain length was formed at the desired location of the column between two layers of UHPC.

5. 3D-Printing and Automation

Automation in construction is a new trend that is making a paradigm shift in the ways constructed facilities are built. One form of automation in construction is additive manufacturing or commonly known as 3D printing. ABC-UTC researchers have developed a 3D printing system for continuous additive layers of UHPC. An accelerated heat curing method was used to increase the buildability and expedite the printing process for the UHPC layers. In addition, the effect of heat curing on material characteristics was examined to identify the optimal temperature (Javed, Mantawy and Azizinamini). Using this approach, it is possible to automate the process of 3D printing UHPC shells for different shapes as shown in Figure 4a.

Accelerating the construction processes, especially for protective measures or retrofit/upgrade applications is the pneumatic methodology, commonly known as shotcrete. ABC-UTC researchers have investigated UHPC applications with shotcrete techniques for retrofitting deteriorated bridge elements. UHPC mix designs were developed for shotcrete applications on horizontal and vertical surfaces (Figure 4b). A shotcrete robot was designed to automate the process of applying UHPC pneumatically to culverts with a diameter of 3 to 6 feet (0.914 m to 1.83 m) (Afzal and Azizinamini).

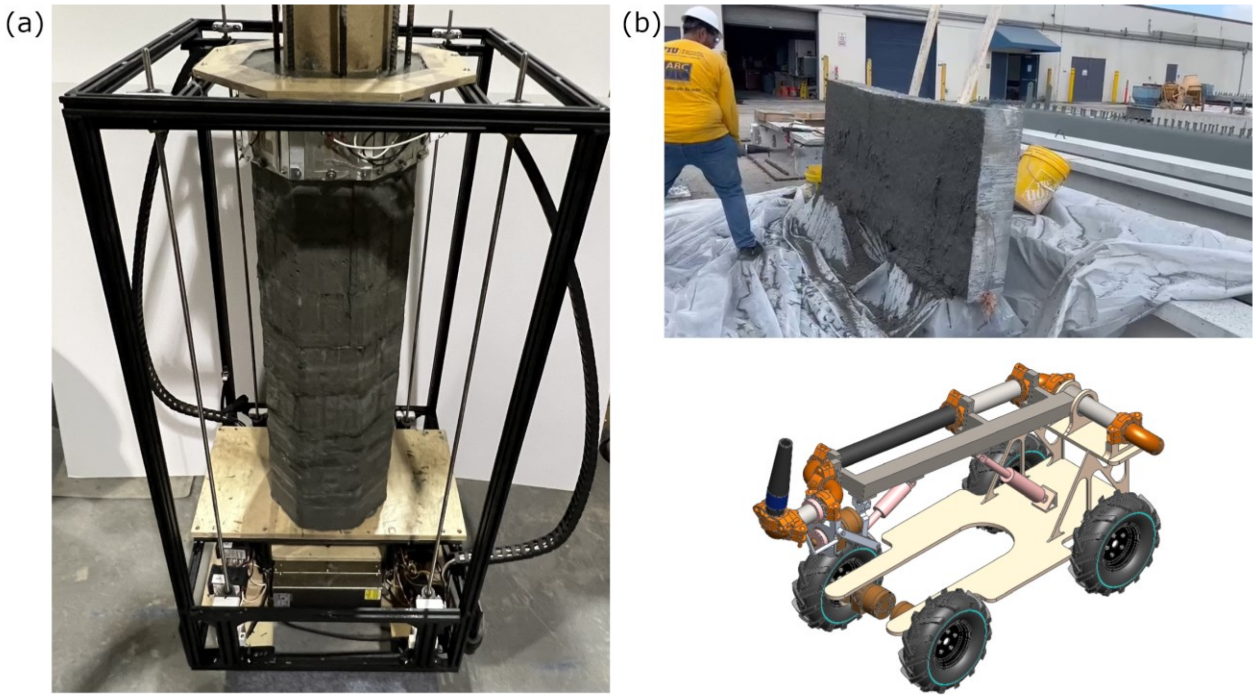

Figure 4. 3D-Printing and Automation: (a) 3D printing of UHPC shells (Javed, Mantawy and Azizinamini) and (b) UHPC application with shotcrete (Afzal and Azizinamini).

6. Summary and Conclusions

A comprehensive study at ABC-UTC is being conducted to develop a series of innovative solutions that can address the challenges facing the constructed facilities. This paper provides a selection of these solutions. For further information and collaboration please contact the principal author at aazizina@fiu.edu.

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