

Cheaper to Build, Faster to Construct: Novel Short and Medium Span UHPC Bridges

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Abstract

This paper discusses the Authors' ongoing efforts to develop and construct novel short to medium span bridges whose entire deck is made of open-recipe (non-proprietary) UHPC mixed in a traditional ready-mix truck. Two examples are provided. The first employs precast UHPC decks made composite with galvanized steel press brake tub girder prefabricated units resulting in a slim and ultra-durable bridge system with an expected maintenance-free life of at least 100 years. The second uses novel triple-stem precast panels that are ultra slim, ultralightweight, and ultradurable. Design and construction details are provided. Using actual construction numbers, it is shown that the upfront cost of building these novel bridges is substantially cheaper than comparable regular concrete alternatives. Given their many advantages, a case is made for much broader deployment of these types of systems.

Keywords: short span, medium span, ultrahigh performance concrete, open recipe, cheap

1. Introduction

Ultrahigh performance concrete (UHPC) is increasingly being used in bridge applications in the US. Most applications so far have used proprietary UHPC. Due to the high cost of proprietary products, UHPC is strategically utilized, usually in small parts of a bridge such as closure pours or for targeted repairs. The authors (Alkaysi and El-Tawil 2016) and others have developed open-

recipe UHPC as a substantially cheaper alternative capable of delivering similar performance to proprietary products. The term open-recipe was coined by El-Tawil et al. (2020) and is intended to differentiate non-proprietary UHPC from proprietary products that are closed or have protected formulas. The formula and mixing method for an open-recipe UHPC are published (known) and conducive to further development by others (in analogy to open development in software engineering)

The State of Michigan has been a hot bed of innovation in the development and application of open-recipe UHPC technology. To the knowledge of the Authors, Michigan has seen many firsts in the use of open-recipe UHPC technology in bridge construction, including the first bridge to use open-recipe UHPC (El-Tawil et al. 2018), the first composite deck bridge to employ open recipe UHPC and the first bridge in which the entire deck is made of open recipe UHPC. The latter two bridges, which have relatively short spans but could also be suitable for medium span bridges, are briefly described in this paper. Currently there are immediate plans to build several other similar bridges in Michigan using the technologies pioneered during design and construction of these prototype bridges.

2. Example 1: UHPC Bridge Deck Composite with Galvanized Steel Press Brake Tub Girder Prefabricated Bridge Units

This new bridge construction project was a single-span, two-lane bridge, consisting of prefabricated bridge units utilizing a bridge deck of Ultra-High-Performance Concrete (UHPC) composite with a galvanized steel press brake tub girder (PBTG). The superstructure was 36 feet (11 m) wide and 35 feet (10.5 m) long. The prefabricated bridge units were placed at a center-to-center distance of 6 feet (2 m). The PBTG was formed by press brake into a trapezoidal box girder section. Angle braces were welded at 6 feet (2 m) increments along the girder and diaphragms were welded at each end. Shear studs were welded to the top flanges of the girder at 12-inch (30 cm) intervals.

The UHPC deck system was designed to act compositely with the galvanized steel PBTGs using the shear studs. The deck system consisted of a slab cast integrally on a stay-in-place galvanized steel form deck spanning in the transverse direction. The galvanized form deck consisted of 22 gauge formed sheet steel, conforming to ASTM A653 with a G235 hot dipped galvanized coating. The overall deck thickness of the deck was 6 inches (15 cm), of which the slab was 3 inches (7.5 cm) and the ribs were 3.0 inches (7.5 cm) deep ribs.

The units were connected across the width of the bridge using a field cast UHPC bridge deck joint connection. In this connection, the transverse reinforcement bars from each unit were tied together with additional longitudinal reinforcement and the gaps between the panels were filled with UHPC. This connection provided continuity and load transfer between the units. UHPC for the units was mixed in a ready-mix concrete truck with no modifications as outlined in El-Tawil et al. (2023) and cast in a concrete plant. UHPC for the closure pours was delivered via truck and cast onsite.

This project demonstrated that new materials and new steel fabrication processes could be combined to produce a cost-effective, prefabricated, bridge with a 100-year maintenance-free service life. The project showed that a UHPC/ PBTG prefabricated bridge unit could be cost-effectively produced and installed at accelerated rate. The MDOT bridge worksheet indicated that the cost for a conventional bridge would be \$788,000. The final cost to Clare County was

\$534,000, which included guardrail, paving, and epoxy overlay. The short-term savings were therefore \$254,000 (32.2%). The slim and light weight system contributed much to the cost savings through lower transportation and handling costs and elimination for the need to camber the system. As a first-time endeavor, there was a steep learning curve associated with construction of this prototype and other opportunities for further cost reduction were identified for future efforts.

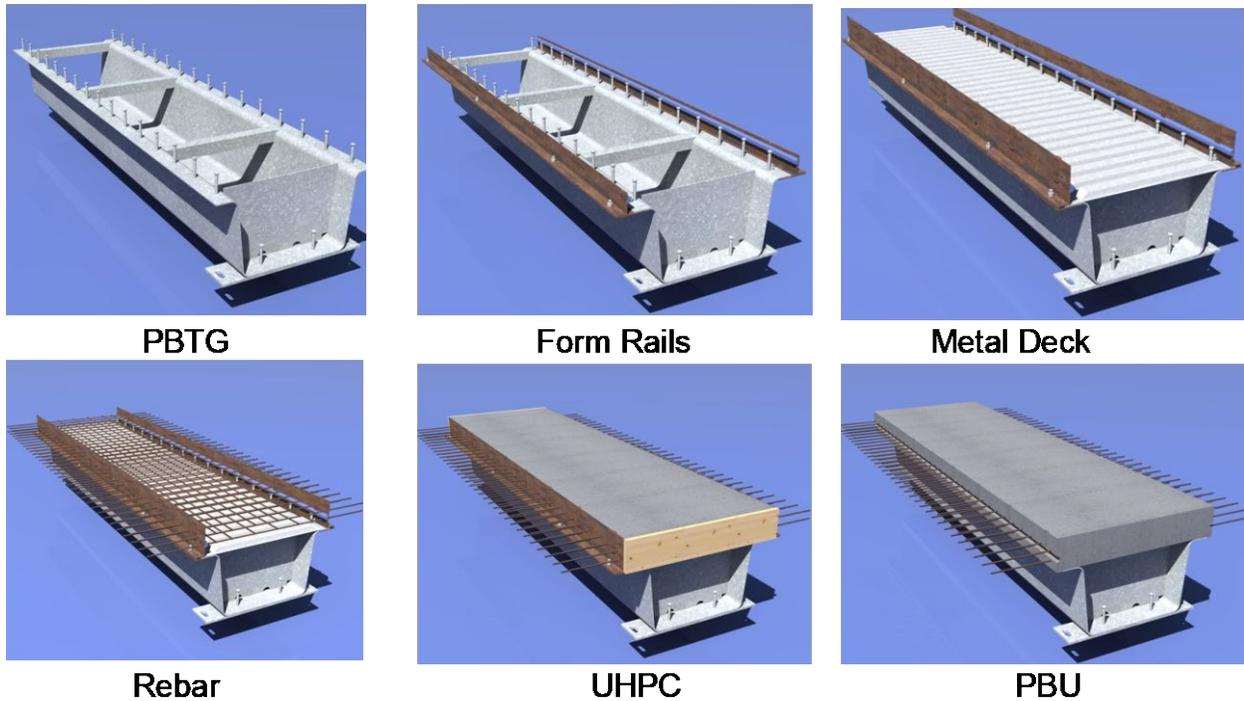


Figure 1: Construction of composite UHPC/ PBTG prefabricated bridge unit



Figure 2: Construction process of the UHPC/PBTG bridge system



Figure 3: Finished UHPC/PBTG bridge system: Mostetler Road over Mostetler Creek Bridge

3. Example 2: Novel, Ultra Slim, Ultra Durable Triple Tee UHPC Deck Panel System

This project was a total bridge replacement. The new UHPC bridge had a 23.7 foot (7.25 m) span by 36.0 foot (11 m) width. The project required construction of new precast block abutments & wingwalls, new road approaches, concrete paving and a new guardrail. The bridge system developed for this project was novel triple tee UHPC deck panel system that employed truck mixed open-recipe UHPC that was precast cured at a local concrete pre-casting plant as outlined in El-Tawil et al. (2023) and El-Tawil (2022).

The bridge, named Bricker Road Bridge over the Quackenbush Drain, is owned by the St. Clair County Road Commission. Figure 4 shows the general plans for the bridge. The entire bridge deck was made of open-recipe UHPC and comprised six ribbed panels, each 6 feet (2 m) wide for a total width of 36 feet (12 m). Each panel had 3” (7.5 cm) deck with 10.5” (26 cm) deep ribs. Once the panels were installed, the closure pours were filled with UHPC that was truck mixed on site. The weight saving over the 16-inch traditional deck was about two thirds. The bridge featured a long span guard rail so as not to attach the rail to the thin decks.

The design of the bridge was conducted according to the AASHTO Bridge Design Specifications (2018) and the draft specifications proposed by FHWA and ACI Committee 239 for incorporation into the AASHTO bridge design specifications. Figure 5 shows the rebars arrangement. The bars were necessary to ensure sufficient flexural strength. However, no stirrups were used for shear reinforcement as the shear computations showed adequate shear strength compared to the demand. The stirrups shown in Figure 5 were used to facilitate bar placement.

The UHPC for each panel was mixed at a precasting plant in a typical commercial ready-mix truck. Slump testing of the mixture was watched and tracked with the onboard flow meter in the ready-mix truck. After casting, the panels were left in their forms for the first 24 hours with wet burlap and visqueen covering them. After the panels were removed from the forms, the planks were wet cured with burlap and visqueen an additional 6 days. Given the rather high temperatures observed during mixing, ice was added to the water to help cool the mixture. Past experience had shown that UHPC will start curing prematurely in temperatures above 80 degrees Fahrenheit. The bridge opened to the public in September 2022 after load testing. Figure 6 is a picture of the new bridge.

As in Example 1, this bridge project also resulted in substantial savings. The MDOT 2022 Scoping Estimate Worksheet projected a cost of \$560,000. The cost to St. Clair County was \$379,000. This included road work, new abutments, UHPC panels, county labor and equipment rental. The short-term savings were therefore \$181,000 (32.3%).

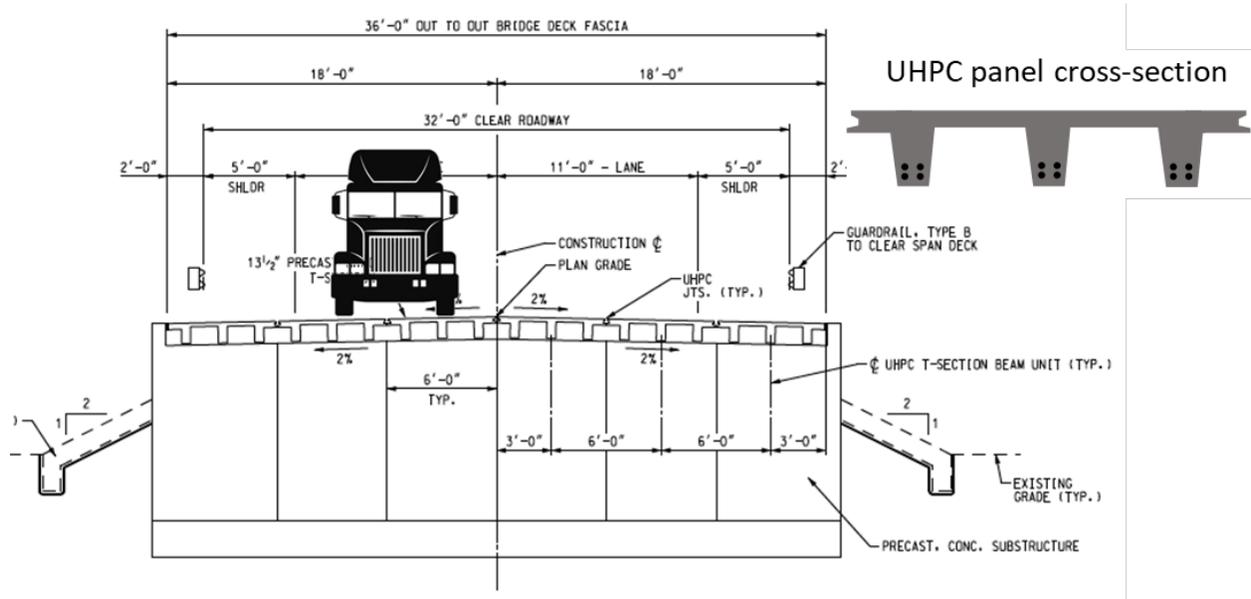


Figure 4: Cross-section of novel UHPC deck bridge

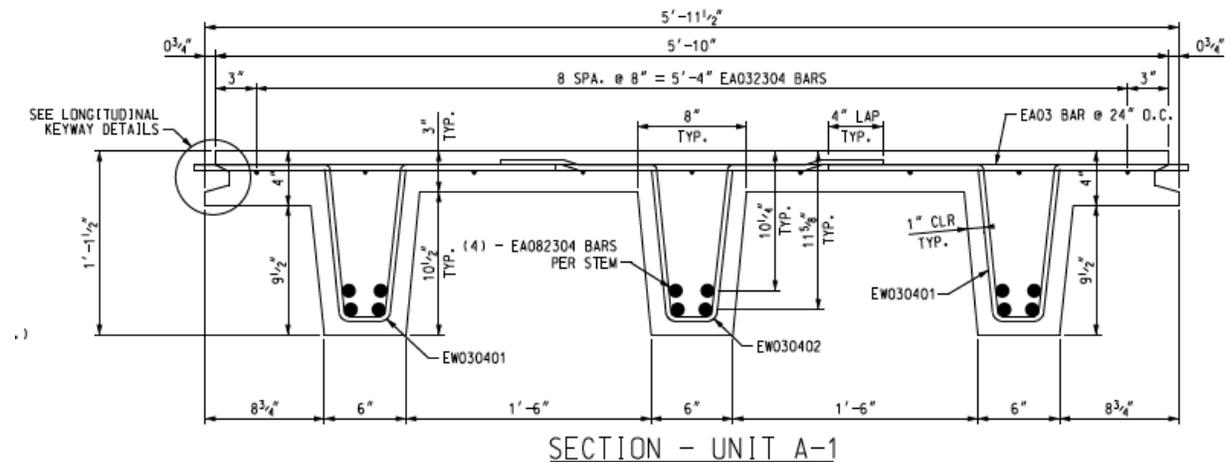


Figure 5: Individual panel cross-section



Figure 6: Finished Bricker Road Bridge over the Quackenbush Drain

4. A Compelling Investment

Although open-recipe UHPC, in terms of material cost, is still more expensive than regular concrete, this paper demonstrated that there are important bridge construction applications where the savings achieved using UHPC make it competitive with regular concrete. As outlined in El-Tawil et al. (2020) and discussed further in this paper, this is due to the weight savings achieved through slimmer sections, which in turn are cheaper to handle and transport and require smaller foundations systems. In Example 1, the use of UHPC removed the need to camber the steel tub girders, which were composite with the lightweight UHPC deck, leading to further cost savings. Ultimately, the cost savings associated with the reduction in maintenance and replacement costs due to the extreme durability of UHPC make a compelling case for new bridge construction using this unique material.

5. Summary and Conclusions

This paper discussed efforts to build two novel bridge systems that are believed to be the first of their kind in the US. A key characteristic of both bridges is that their decks were made entirely of open-recipe (non-proprietary) UHPC mixed in a traditional ready-mix truck. The first employed precast UHPC decks that were made composite with galvanized steel press brake tub girder prefabricated units resulting in a slim and ultra-durable bridge system with an expected maintenance-free life of at least 100 years. The second used novel triple-stem precast panels that were ultra slim, ultralightweight, and ultradurable. Design and construction details of both systems

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were provided and it was shown that the upfront cost of building these novel bridges is substantially cheaper than comparable regular concrete alternatives (on the order of 32%). Others have demonstrated this as well. For example, engineers in Malaysia and Australia have reported cost savings of 17% in their costs for a bridge application (Voo et al. 2015). Given its many advantages, it is clear that UHPC technology can be successfully used to extend the life of the national bridge inventory and reduce overall maintenance requirements. This technology has the potential to reduce future demands for bridge superstructure replacement and repair, lessening the impacts and delays to the ever-growing user demands on our transportation infrastructure.

6. Acknowledgements (Optional)

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