First U.S. Bridge with a 100% UHPC Superstructure: A Small Bridge with Big Implications

Bricker Road Bridge over Quackenbush Drain, St. Clair County, Mich.

by Dr. Sherif El-Tawil, HiPer Fiber LLC, and William Hazelton, St. Clair County Road Commission

The Bricker Road Bridge over the Quackenbush Drain in St. Clair County, Mich., is the first U.S. bridge with a 100% ultra-high-performance concrete (UHPC) superstructure. The bridge is a demonstration project constructed under the auspices of the National Cooperative Highway Research Program (NCHRP) project "High Bond Steel Fibers for Ultra High-Performance Concrete (UHPC)"[1] in conjunction with the St. Clair County Road Commission—the bridge owner and research partner. The bridge was built to replace a deteriorated reinforced concrete slab bridge.

The entire superstructure was made of open-recipe UHPC, with the new steel fibers developed under the NCHRP project. The term "open-recipe" UHPC signifies that the UHPC mixture design is nonproprietary and available for all to use and experiment with.[2]

Although small, with a span of only 23.7 ft, this bridge represents a big step forward in UHPC technology. To the knowledge of the authors, it is the first bridge in the United States to have its entire deck panel made of open-recipe UHPC mixed in a traditional ready-mixed concrete truck.

The cost-saving aspects of this project are notable. First, although the materials for UHPC cost more than regular concrete, the materials used for the open-recipe UHPC mixture cost much less than proprietary UHPC mixtures. Additionally, compared with normalweight concrete, UHPC greatly reduces the weight of components, and as a result, the foundation, transportation, and handling costs on this project were substantially lowered.

Although the upfront cost savings are an advantage, the true benefit of UHPC is its extreme durability, which stems from its dense microstructure and its imperviousness to water and the ingress of chloride ions. With an estimated service life of 200 years (based on freeze-thaw and chloride-penetration data from Alkaysi et al.[3]), the bridge will provide great long-term savings. The bridge can also be considered a highly sustainable structure because the maintenance and

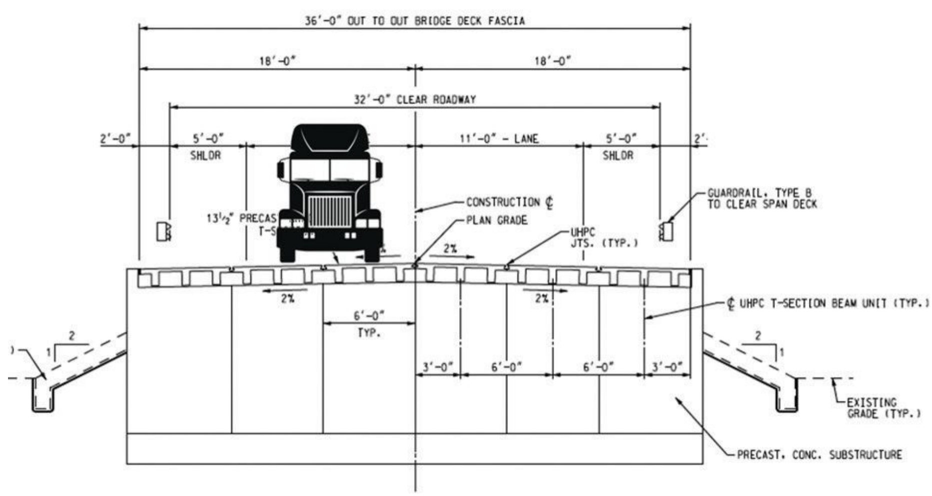

Figure 1. Bridge cross section. All Photos and Figures: HiPer Fiber LLC/St. Clair County Road Commission.

profile

BRICKER ROAD BRIDGE OVER QUACKENBUSH DRAIN / ST. CLAIR COUNTY, MICHIGAN

BRIDGE DESIGN ENGINEERS: Michael Clark, St. Clair County Road Commission, and Todd Stelma, TEG Engineering, Wyoming, Mich.

PRIME CONTRACTOR: St. Clair County Road Commission, St. Clair, Mich.

CONCRETE SUPPLIER: St. Clair County Road Commission, St. Clair, Mich.

PRECASTER: ADL Systems, Portland, Mich.

OTHER MATERIAL SUPPLIERS: Abutments: Redi-Rock, Howell, Mich.

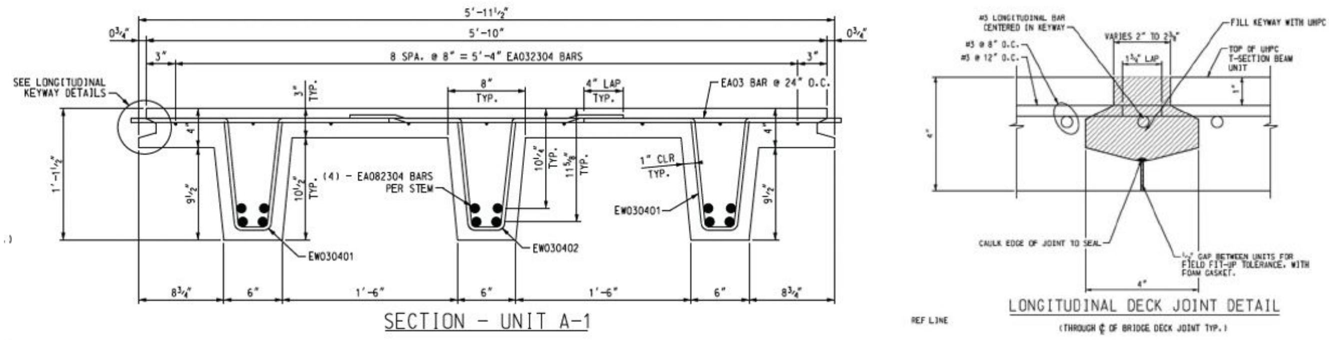

Figure 2. Three-ribbed deck panel details of the superstructure.

replacement cycles have been greatly extended.

Bridge Details

The replacement bridge comprises six ribbed panels, each 6 ft wide for a total width of 36 ft (**Fig. 1**). Each panel has a 3-in.-thick deck with 10.5-in.-deep ribs (**Fig. 2**). New forms were purchased for this project, and they have been used three times since for similar bridges. The panels were installed by county crews using a backhoe; they were light enough that a crane was unnecessary. After the panels were installed, the closure pours were filled with UHPC that was mixed in a planetary (mortar) mixer on site, and an overlay was installed. As compared to the traditional solid-slab deck bridge that was being replaced, the weight of the new structure is reduced by approximately two-thirds.

Analysis and Design

The design of the bridge was conducted according to the American Association of State Highway and Transportation Officials' *AASHTO LRFD Bridge Design Specifications*[4] as well as the draft specifications proposed by the Federal Highway Administration (FHWA) that will be included in the forthcoming *Guide Specifications for Structural Design with Ultra-High-Performance Concrete*[5] (see the AASHTO LRFD article in the Fall 2023 issue of *ASPIRE*®). The UHPC compressive design strength was 21.7 ksi. Figure 2 shows the reinforcing bar arrangement. The no. 8 reinforcing bars were necessary to ensure sufficient flexural strength. However, no stirrups were required for shear reinforcement because the shear computations showed adequate shear strength compared with the demand. The stirrups shown in Fig. 2 are widely spaced and were used to facilitate longitudinal bar placement.

Bridge Construction

Figure 3 shows the construction process. The UHPC for each panel was mixed at the precaster's facility in a typical commercial ready-mixed concrete truck. Given the rather high temperatures observed during mixing, 40% of the water was replaced with ice to help cool the mixture. Experience has shown that UHPC will start setting prematurely in temperatures above 80°F. The spread of the concrete was monitored and tracked with the onboard flow meter in the truck. Previously mixed and placed material was used as a guide as to when the material was ready for placement. The flow meter on the truck had a reading of 1100 psi (the amount of pressure needed to turn the mixer drum), which equated to approximately 8.5-in. spread. Placement was not started until a reading of 1100 psi was observed.

After casting, the panels were covered with wet burlap and polyethylene plastic sheeting and left in their forms for 24 hours. After removal from the forms, the ribbed panels were wet cured while covered with burlap and polyethylene plastic sheeting for an additional six days.

Table 1 shows the results of laboratory testing of the field-cast 2-in. cubes arranged by deck panel casting date. Samples were not collected from the first mixture due to an omission. Compression testing was done by a third party. Table 1 also shows the progression of strength gain with time. Initial strength gain was rapid, with the compressive strength reaching 15.1 ksi in three days. The rate then slowed substantially, and the average strength across all UHPC mixtures eventually reached 23.9 ksi, with the lowest strength being 23.4 ksi. The measured values are all above the 21.7-ksi design strength.

Tensile tests were also conducted. The results showed that the actual tensile strengths were greater than the design values. Testing also showed that the samples exceeded the strain-hardening capacity by a large margin. For example, the forthcoming AASHTO guide specification requires a minimum strain-hardening capacity of 0.0025, whereas the capacity was 0.0045 in the test.

ST. CLAIR COUNTY ROAD COMMISSION, ST. CLAIR, MICHIGAN, OWNER

BRIDGE DESCRIPTION: First U.S. bridge with a 100% ultra-high-performance concrete (UHPC) superstructure, 36-ft wide, 23.7-ft-span precast open-recipe (nonproprietary) UHPC ribbed panels

STRUCTURAL COMPONENTS: Precast UHPC, 5-ft 11.5-in.-wide ribbed deck panels with three 10.5-in.-deep webs, 3-in.-thick deck, open recipe cast-in-place UHPC closure pours between the panels

BRIDGE CONSTRUCTION COST: $379,000

AWARD: First place, short-span bridge category, Third International Interactive Symposium on Ultra High Performance Concrete (3IISUHPC): "A Small Bridge with Big Implications"

Figure 3. Fabrication of ultra-high-performance concrete (UHPC) ribbed panels.

Table 1. Progression of ultra-high-performance concrete compressive strength (2-in. cubes)

Pour date	Strength, ksi							
	Curing time, days							
	3	4	5	7	10	11	14	28
12-Jul	15.1			20.2				25.0
14-Jul			16.7	20.6				23.4
15-Jul		17.6			20.7			23.5
18-Jul						19.1	20.2	24.1
19-Jul					18.9		22.4	23.7
Average	**15.1**	**17.6**	**16.7**	**20.4**	**19.8**	**19.1**	**21.3**	**23.9**

Project Cost

As noted, this bridge project achieved substantial cost savings. The abutment and foundation did not require piles, which helped lower construction costs. The Michigan Department of Transportation 2022 Scoping Estimate Worksheet, which is based on recent experience with similar bridge projects, projected a cost of $560,000. The actual cost for St. Clair County was $379,000. This amount included road work, new abutments, UHPC panels, county labor, and equipment rental. The short-term savings were therefore $181,000 (32.3%).

Conclusion

The bridge opened to the public in September 2022. Although the materials for open-recipe UHPC cost more than regular concrete, this project demonstrated that there are important bridge construction applications where lighter-weight UHPC can compete with traditional concrete in terms of overall costs. 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.

For additional project information and photos, as well as access to a recorded webinar on the project visit https://abc-utc.fiu.edu/mc-events/first-u-s-bridge-with-100-uhpc-superstructure-michigans-bricker-road-bridgeover-quackenbush-drain/?mc_id=863.

Acknowledgment

This work was funded by the St. Clair County Road Commission and the National Academies of Sciences, Engineering, and Medicine through project NCHRP IDEA 235. The funding and assistance are gratefully acknowledged. The opinions stated in this article are those of the authors and do not necessarily represent the position or opinions of the agencies mentioned herein.

References

1. El-Tawil, S. 2022. *High Bond Steel Fibers for Ultra High-Performance Concrete (UHPC)*. National Cooperative Highway Research Program Innovations Deserving Exploratory Analysis (NCHRP IDEA) Project 235. Washington, DC: Transportation Research Board. https://onlinepubs.trb.org/onlinepubs/IDEA/FinalReports/Highway/NCHRP235.pdf.

2. El-Tawil, S., Y-S. Tai, J. A. Belcher, and D. Rogers. 2020. "Open-Recipe Ultra-High-Performance Concrete (UHPC)." *Concrete International* 42 (6): 33–38.

3. Alkaysi, M., S. El-Tawil, Z. Liu, and W. Hansen. 2016. "Effects of Silica Powder and Cement Type on Long Term Durability of Ultra High Performance Concrete (UHPC)." *Cement and Concrete Composites* 66: 47–56. https://doi.org/10.1016/j.cemconcomp.2015.11.005.

4. American Association of State Highway and Transportation Officials (AASHTO). 2020. *AASHTO LRFD Bridge Design Specifications*. 9th ed. Washington, DC: AASHTO.

5. AASHTO. Forthcoming. *Guide Specifications for Structural Design with Ultra-High-Performance Concrete*. Washington, DC: AASHTO.

Dr. Sherif El-Tawil is the CEO and cofounder of HiPer Fiber LLC in Taylor, Mich. William Hazelton is the managing director of the St. Clair County Road Commission in St. Clair, Mich.

OPEN-RECIPE ULTRA-HIGH-PERFORMANCE CONCRETE

The open-recipe ultra-high-performance concrete (UHPC) used on this project was as follows:

<u>Mixture proportions for a cubic yard of UHPC:</u>

Cement (portland Type I): 653 lb

Slag cement (GGBS 100): 653 lb

Silica fume (Elkem 965): 327 lb (if using Elkem 900W, reduce the HRWRA)

Water: 264 lb = 31.6 gallons

High-range water-reducing admixture (HRWRA) (3% using Sika ViscoCrete-2100): 39.2 lb (550 oz)

Steel fibers (2% by volume; Type X from HiPer Fiber): 265 lb

Fine sand (SHORT MOUNTAIN glass sand): 395 lb

Coarse sand (SHORT MOUNTAIN Silica Sands 3070): 1580 lb

Defoaming agent (such as AIR OUT from Euclid or Sika PerFin-305): 4 lb

<u>The mixing and testing protocols are as follows:</u>

Dry mix for 10 minutes. Add water and HRWRA over 2 minutes. Wait for turnover (fluidity), which usually occurs within 15 minutes. Mix another 10 minutes after turnover. Add fibers gradually over 2 minutes. Mix for 10 minutes; then perform a spread test before casting. You need 7 to 12 in. of spread. Steam cure for 48 hours. Perform compressive strength tests according to ASTM C109 with 2-in. cubes. The target strength is 21.5 ksi.

EDITOR'S NOTE

In 2006, a 113-ft-long, 24.5-ft-wide bridge was constructed in Wapello County, Iowa, using ultra-high-performance concrete bulb-tee girders. However, the cast-in-place deck was constructed using conventional concrete. See the Summer 2006 issue of Ascent *magazine for an article on this project (https://www.pci.org/PCI_Docs/Publications/Ascent%20Magazine/2006/Summer/Iowa%20Bridge%20Gives%20Glimpse%20Into%20The%20Future.pdf).*