ADVANCING ULTRA-HIGH PERFORMANCE CONCRETE IN THE BRIDGE SECTOR

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INTRODUCTION

Ultra-high performance concrete (UHPC) has gained a foothold in the U.S. bridge sector through more than 200 deployments across 27 states. Most of these deployments have engaged UHPC as a field-cast grout that offers simplified connection detailing and enhanced performance in projects using prefabricated bridge elements. Interest is growing in broader uses of UHPC to address other challenges in bridge design, construction, maintenance, and rehabilitation. The structural concrete research group at the FHWA Turner-Fairbank Highway Research Center is developing innovative solutions [El Helou and Graybeal 2019] and widely applicable guidance [Graybeal and El Helou 2019]. One current study focuses on key structural performance metrics relevant to the use of UHPC in primary structural elements, including flexure, beam shear, interface shear, and prestressing strand bond. Full-scale pretensioned girder testing is underway. Of interest to the design community, structural design guidance for UHPC is under development. Working with the American Association of State Highway and Transportation Officials' (AASHTO) structural concrete design committee, FHWA researchers are drafting a guide specification that may be adopted by AASHTO upon completion. Additionally, UHPC-based rehabilitation innovations are being developed and refined so that long-term challenges facing the bridge maintenance community have new, compelling solutions.

UHPC-BASED BRIDGE REHABILITATION SOLUTIONS

The inventory of over 600,000 bridges in the United States is aging, and many of these bridges require intrusive maintenance to retain their level of service. Nearly every bridge has a reinforced concrete bridge deck, and these decks are inherently susceptible to degradation associated with structural and environmental stressors. Many bridges also have expansions joints whose resiliency is suspect, thus allowing environmental contaminants to pass through the joint and begin attacking the underlying structure. UHPC offers novel solutions to both issues.

UHPC overlays are a compelling solution because they allow the exceptional durability properties to be engaged in the replacement of the cover concrete on deteriorated bridge decks. UHPC provides an armoring layer that both spans over underlying defects and is resilient against future degradation. Given that UHPC is concrete, this solution can be implemented within the framework of existing construction techniques. The Swiss have been leaders in developing this bridge rehabilitation solution [Brühwiler and Denarié 2013], while in the United States, there have been a handful of deployments, including the one shown in Figure 1. Researchers at FHWA are investigating optimal mix designs and surface preparations for UHPC overlays subjected to high-cycle fatigue loading after being installed on a deteriorated bridge deck [Graybeal and Haber 2017].

Source: FHWA

Figure 1. UHPC overlay construction in Buchanan County, Iowa.

Deteriorated steel beam ends are also of concern to bridge owners across the country, particularly in regions where there is a confluence of older steel beam bridges, failed expansion joints, and heavy use of deicing salt. A novel UHPC-based solution encases the deteriorated end region to provide an alternate load path around locally corroded cross sections. Researchers at the University of Connecticut developed and supported the first deployments of this solution [Zmetra et al. 2017]. Researchers at FHWA, in collaboration with the original researchers, are further investigating and expanding the applicability of this solution.

STRUCTURAL PERFORMANCE OF PRIMARY BRIDGE ELEMENTS

Some of the earliest full-scale tests of UHPC in primary bridge elements were conducted by FHWA [Graybeal 2006]. At the time, UHPC was promising but not practical given the lack of knowledge surrounding performance and construction methods. U.S. bridge owners and designers have recently shown renewed interest in using UHPC for primary structural elements. This shift can in part be attributed to the bridge community’s use of UHPC in connections and thus their comfort level with this class of concrete. It can also be attributed to the growth in the number of available UHPC-class suppliers and the fact that precasters are beginning to develop their own in-house UHPC mix designs.

FHWA has an ongoing research program that is testing a suite of pretensioned UHPC bridge girders. Phase 1 of the effort is underway and consists of flexural and shear testing of lightly optimized I-girders. All girders are based on the PCEF cross section that is common in the mid-Atlantic region, with modifications to web widths, flange widths, and bottom flange heights. The girders have 24 0.7-inch diameter strands in the bottom flange spaced on a 2-inch by 2-inch grid. The web widths range from 3 inches to 7 inches. The girder depths range from 35 inches to 43 inches. The flexural and shear design of the girders includes capacity from the UHPC in tension. The shear design is differentiated from conventional concrete because the UHPC in the web resists the beam shear demand through principal tensile stresses oriented perpendicular to the compression strut. Most of the girders do not include any discrete steel reinforcement in the web.

Shear testing completed to date has demonstrated that the design methodologies being developed for UHPC structural elements are capable of conservatively predicting performance. In each case, the girders reached a capacity in excess of the design capacity, then failed through a diagonal tension localization action occurring in the UHPC in the web (see Figure 2).

Source: FHWA

Figure 2. Shear testing of a UHPC I-Girder.

GUIDE SPECIFICATION FOR STRUCTURAL DESIGN

Demand for UHPC use in primary bridge components (e.g., girders, piles) is growing, but the lack of structural design guidance in the United States is hindering advancement. Designing UHPC components in accordance with existing design specifications, such as the AASHTO Load and Resistance Factor Design (LRFD) Bridge Design Specifications, would usually create inefficient components from both the cost and the structural performance standpoint. Designing members according to nondomestic codes or specifications, such as the French supplement to the Eurocode [AFNOR 2016], is generally not an option. To meet the need for guidance, FHWA is working with the AASHTO committee on structural concrete design to develop a UHPC structural design guide specification [Graybeal and El Helou 2019]. Guide specifications are a common method used by AASHTO to introduce a promising new technology to the broader community.

FHWA, through its structural concrete research group, is crafting this document to address the highest priority needs. Specifically, the draft guide specification provided to AASHTO will propose a framework that defines UHPC, describes key parameters and associated test methods to determine those parameters, and offers guidance on appropriate methodologies for the structural design of primary bridge components. UHPC will be defined as a tension strain hardening fiber reinforced concrete with a very high compressive strength and exceptional durability. A first principles approach will be used, and measured mechanical behaviors (e.g., tensile and compressive responses) will be integrated into structural behaviors (e.g., flexure and shear) to develop conservative capacity predictions. Full-scale structural test results as well as experiences in international jurisdictions with developing UHPC design guidance will help guide the document development. It is anticipated that the draft guide specification will be delivered to AASHTO in 2021.

CONCLUDING REMARKS

The U.S. bridge community is embracing UHPC as a promising new solution. Owners are interested in the opportunities it presents for novel, durable structural components. Designers are interested in using UHPC for longer spans, lighter cross sections, and stronger piles. Maintenance professionals are interested in armoring their structures, particularly structures already deteriorating, with layers of UHPC. As the U.S. bridge community continues to learn about UHPC, it is clear that new solutions addressing long-standing performance, economic, and constructability challenges will continue to be developed.

REFERENCES

Association Française de Normalisation (AFNOR). 2016. "National Addition to Eurocode 2 – Design of concrete structures: Specific rules for Ultra-High Performance Fibre-Reinforced Concrete (UHPFRC)." NF P 18-710.

Brühwiler, E., and E. Denarié. 2013. "Rehabilitation and Strengthening of Concrete Structures Using Ultra-High Performance Fibre Reinforced Concrete." *Structural Engineering International*, 23; 4:450–457.

El Helou, R., and B. Graybeal. 2019. "The UltraGirder: A Design Concept for a 300-foot Single Span Pretensioned Ultra-High Performance Concrete Bridge Girder." *Proceedings of the 2nd International Interactive Symposium on Ultra-High Performance Concrete*. 9 pp.

Graybeal, B. 2006. "Structural Behavior of Ultra-High Performance Concrete Prestressed I-Girders." FHWA Report HRT-06-115. 104 pp.

Graybeal, B., and R. El Helou. 2019. "Development of an AASHTO Guide Specification for Ultra-High Performance Concrete." *Proceedings of the 2nd International Interactive Symposium on Ultra-High Performance Concrete*. 9 pp.

Graybeal, B., and Z. Haber. 2017. "Ultra-High Performance Concrete for Bridge Deck Overlays." FHWA, U.S. Department of Transportation. FHWA-HRT-17-097. 16 pp.

Zmetra, K., K. McMullen, A. Zaghi, K. Wille. 2017. "Experimental Study of UHPC Repair for Corrosion-Damaged Steel Girder Ends." *ASCE Journal of Bridge Engineering*. 22:8.