UHPC is a Game-Changing Material for Bridge Producers

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Editor's Note
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Five members of the TechnoQuest team with Dr. Voo (in white shirt) on the UTC Perak Footbridge. Not pictured: Maher Tadros. Photo: Precast/Prestressed Concrete Institute.

Last year, ultra-high-performance concrete (UHPC) generated considerable buzz in the concrete bridge industry. In March, during the Precast/Prestressed Concrete Institute's (PCI's) Convention and National Bridge Conference in Nashville, Tenn., Dr. Yen Lei Voo gave a presentation on the remarkable uses of nonproprietary UHPC solutions by his company, DURA® Technology, to the PCI Committee on Bridges, which includes bridge design engineers, owners, and producers. Then in July, the First Interactive International Symposium on Ultra High Performance Concrete was held in Des Moines, Iowa. At that symposium there were site visits, presentations, and interactive panel sessions moderated by experts. The Summer 2016 issue of *ASPIRE*™ included an article titled "Taking Ultra-High-Performance Concrete to New Heights."[1] In September, fib task group 6.5 held a meeting in Malaysia and PCI conducted a TechnoQuest to visit DURA's facility located in Ipoh, Malaysia, at the same time. As shown in the photograph above, the PCI group included (from left to right) Dr. John Lawler (WJE), Mason Lampton (Standard Concrete Products), J.P. Binard (formerly with Bayshore Concrete Products), our host Dr. Voo, Jim Fabinski (ENCON Colorado), and William Nickas (PCI's managing director of transportation systems). Dr. Maher Tadros (e.construct USA LLC) also attended but was not in the photograph. Finally, in November Dr. Voo gave a presentation on his material and accomplishments during the opening session of the American Segmental Bridge Institute (ASBI) Convention in Long Beach, Calif.

The PCI TechnoQuest group was inspired by Dr. Voo's presentation to embark on this journey to Malaysia because to date, UHPC has not been considered a viable, consistent option for precast concrete components in the United States. DURA, however, is producing large components fabricated from UHPC that are incorporated into a variety of bridges throughout Malaysia. These bridges include the longest UHPC single span in the world, as well as the longest composite bridge fabricated with UHPC in the world, which is currently under construction. The company utilizes a facility solely focused on UHPC that directly competes with conventional structural solutions.

The Game-Changing Material

UHPC is not a new material. Projects and publications throughout the world have highlighted this material and its various applications in bridges, buildings, and other sectors for about 20 years.[2] With nonproprietary versions of this class of material becoming more commonplace,

Batu 6 segmental box-girder bridge with 100 m (328 ft) span. Photo: DURA Technology.

Post-tensioned U-beam segments produced by DURA Technology. Photo: Precast/Prestressed Concrete Institute.

there is a great opportunity to advance the industry by adding this material to our repertoire.[3] A new market share may be viable when UHPC components are applied as an overall bridge solution.

A standard prestressed concrete bridge girder merely cast with UHPC instead of high-performance concrete is not cost effective. However, a modified section utilizing 40% to 50% less material with less reinforcement and extending the span of the structure with the same depth as an equivalent steel section becomes an attractive alternative.

With less material, superstructure weights are less, thereby reducing foundation costs. Onsite crane and lifting requirements become similar to those for steel beams. Perhaps other UHPC elements can be combined to reduce the overall structure weight further, resulting in more efficient use of the material. Automating precast, prestressed concrete manufacturing to new levels with less, or perhaps no, manual labor may be possible.

Several challenges and limitations pertaining to precast, prestressed concrete components are diminished or eliminated by implementing UHPC.

Clear Cover and Crack Control

UHPC minimum clear cover can be as little as ¾ in. Steel fibers within the matrix of the UHPC take the place of conventional crack-control reinforcement.

Camber, Creep, and Shrinkage

UHPC components, after a secondary stage of curing at 194°F for 48 hours, implemented within 14 days after detensioning or demolding, exhibit a really low creep and shrinkage rate that may be considered zero for computations.[1] Therefore, the camber measured in a fabricator's yard will remain constant, which leads to a predictability or a tolerance similar to that of steel products. Post-tensioned systems will incur significantly fewer losses due to the essentially nonexistent creep and shrinkage of prefabricated UHPC components.

Development and Bond

The bond capability of UHPC is chemical. Therefore, at ultimate strength the fibers pull out rather than fracture, leading to stress relief in lieu of damage. Development of strand and nonprestressed reinforcement as well as lap-splice lengths are also greatly reduced when compared to conventional concrete.[4]

End Regions

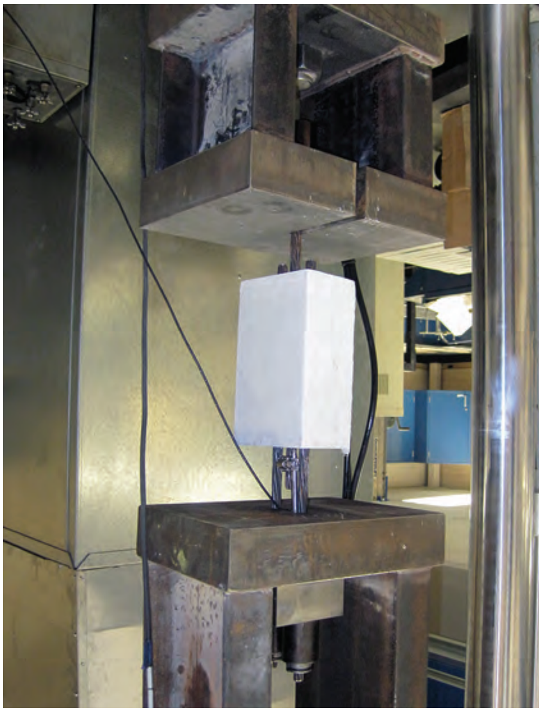
UHPC simplifies end regions of beams by greatly reducing or eliminating shear reinforcement, splitting reinforcement, and confinement reinforcement,[5] and also provides a shorter development length for longitudinal reinforcement.

Detailing and Reinforcement Placement

UHPC may not require nonprestressed reinforcement apart from potential connections, if applicable, such as for a composite deck, closures for continuity, and the like. Therefore, labor is greatly reduced in the plant. This, along with detailing alterations such as potentially closer spacing of strands and clear cover no longer governed by confinement reinforcement, allows greater eccentricity of the prestressing force relative to the centroid, thereby leading to more efficient use of the material, as illustrated by the comparison of details on the following page.

Compression-Controlled Release Strength and Temporary Tensile Stress Control

A UHPC element is likely to have a reduced cross section because of the significantly greater strength and toughness of the material. Passive reinforcement is not required, so concrete cover is less of a limiting factor, also allowing a smaller cross section. Hence, utilizing the higher early and long-term compressive and tensile strengths allows UHPC elements to be designed without debonding or draping of strands, thus resulting in more efficient production.



Lap-splice test of untensioned strands in ultra-high-performance concrete. Photo: Federal Highway Administration.

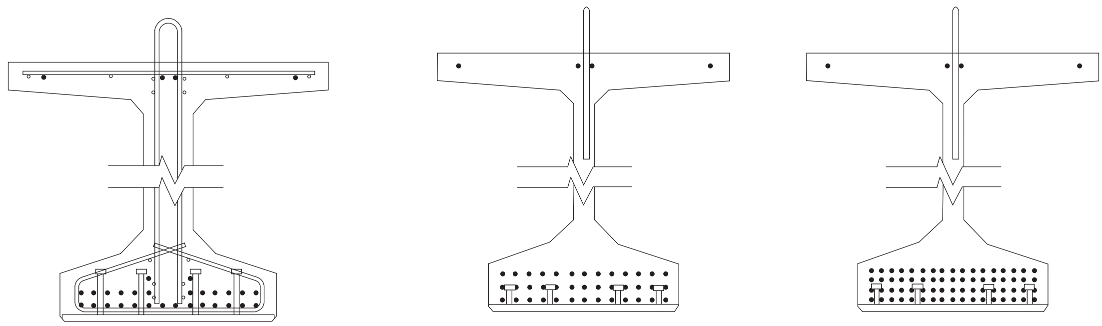
Implementing UHPC

There are essentially no adverse effects to the general contractor if UHPC is selected as the material for a component instead of another material. Fabrication activities, however, require greater attention in casting, material selection and handling, cleaning of forms and surfaces, form geometry, and curing. One unique aspect of DURA's approach to casting is that its molds are sized to accommodate a single batch from its mixer.[1] This approach ensures consistency and uniformity of the mixture within an element and entirely removes the risk of a cold joint or anomaly during a multiple-batch casting. The components are match-cast and all products cast in this manner are connected via thin shear keys that have been validated through testing.[6] The segments are then post-tensioned together in the field to achieve the span length.

The material is expensive. One clever idea observed at DURA is how it utilizes its surplus concrete in making small ¾-in.-thick, stay-in-place forms for cast-in-place concrete deck placement. Top corners of beams are notched to provide a simple seat for these panels so they can be set easily by the contractor and not affect the overall deck thickness.

Conclusions

Opportunities to redefine an industry or define new markets do not arrive every



Typical bulb tee
Max. 1st 3 rows = 40 strand
2 in. spacing

UHPC bulb tee w/ 3.5 in. web
Max. 1st 3 rows = 39 strand
2 in. spacing

UHPC bulb tee w/ 3.5 in. web
Max. 1st 4 rows = 68 strand
1.5 in. spacing

Comparison of details for standard bulb tee and ultra-high-performance concrete alternatives. Drawing: Precast Systems Engineering.

DURA Technology's stay-in-place precast concrete deck form panel. Photo: Precast/Prestressed Concrete Institute.

day. Refinement of prestressed, precast concrete has occurred incrementally over the past decades. However, UHPC is a complete game-changing material, capable of spawning a new renaissance for the industry while meeting infrastructure demands now and in the future.

Therefore, when looking into the future and how UHPC will benefit bridges, producers should not merely replace today's concrete with UHPC. When this industry was developed, research and testing in universities was not as common as it is today. There was a boldness in the founders of the industry along with an incredible vison to understand the potential of this new type of business. Precast, prestressed concrete bridge solutions are well positioned to embrace this technology and advance these and other possibilities to the next level.

References

1. Tadros, M. K. and Y. L. Voo. 2016. "Taking Ultra-High-Performance Concrete to New Heights." *ASPIRE* 10(3): 36-38.
2. Russell, H. G., and B. A. Graybeal. 2013. *Ultra-High Performance Concrete: A State-of-Art Report for the Bridge Community*. FHWA-HRT-13-060. McLean, VA: FHWA (Federal Highway Administration).
3. Graybeal, B. 2013. *Development of Non-proprietary Ultra-High Performance Concrete for Use in the Highway Bridge Sector*. FHWA-HRT-13-100. McLean, VA: FHWA.
4. Graybeal, B. 2014. *Splice Length of Prestressing Strand in Field-Cast Ultra-High Performance Concrete Connections*. FHWA-HRT-14-041. McLean, VA: FHWA.
5. Voo, Y. L., W. K. Poon, and S. Foster. 2010. "Shear Strength of Steel Fiber-Reinforced Ultrahigh-Performance Concrete Beams without Stirrups." *Journal of Structural Engineering* 136 (11): 1393–1400.
6. Voo, Y. L., W. K. Poon, C. C. Voo, and S. Foster. "Ultrahigh-Performance Concrete Segmental Bridge Technology: Toward Sustainable Bridge Construction." *Journal of Bridge Engineering* 20 (8): BS50114001-1– BS50114001-12.

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EDITOR'S NOTE

To participate in this exciting new opportunity, please contact the author at binard.jp@gmail.com or attend the next meeting of the UHPC Subcommittee to the PCI Committee on Bridges.