FHWA

Pairing Prefabricated Bridge Elements with UHPC Connections

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Owners across the United States and Canada are recognizing the value pairing ultra-high-performance concrete (UHPC) connections technology and prefabricated bridge elements to build robust structures. Structural connections must perform at least as well as the connected elements, but traditional field-cast connections have at times proved to be difficult to fabricate, difficult to install, expensive, and susceptible to underperformance. The exceptional mechanical and durability properties of UHPC open doors to field-cast connections that simplify construction while simultaneously delivering a structure anticipated to meet long service life demands.

Advances in concrete technology, including fiber reinforcement, superplasticizers, particle packing, and supplementary cementitious materials, began to be packaged together into a new generation of cementitious composite materials in the 1970s and 1980s. Commercialization in the 1990s brought to market a new class of materials referred to as UHPC. Available today primarily from major construction materials suppliers, but also likely available soon as a locally sourced product, UHPC is gaining widespread attention in American and Canadian markets as a field-cast grout. Market conditions and owner expectations in other parts of the world are creating alternative focal points, such as using prefabricated UHPC components for curtain walls and façades, pedestrian bridges, urban furniture, and even security applications.

Deployment of UHPC Connections

Deployments of UHPC connections have shown significant growth in recent years, with more than 130 bridges already in service. The first bridges to engage this concept were constructed in Ontario starting in 2005, and in New York State starting in 2009 (Fig. 1 and see *ASPIRE*™ Fall 2009). Dozens of new deployments are happening each year, with experienced owners moving to institutionalize the technology and new owners encouraging first installations. As shown in Fig. 2, the early adopters have continued to press forward with use of this technology as the broader community comes on board.

The robustness of the UHPC connections has resulted in a few high profile deployments wherein owner-defined requirements stipulated that the overall finished structure needed to have an exceptionally long service life. Two ongoing examples include the redecking of the 3.5-mile-long Pulaski Skyway in Newark, N.J., and the construction of the Nipigon River Bridge by the Ontario Ministry of Transportation on the Trans-Canada Highway. Two upcoming examples are the rehabilitation of the Franklin Avenue Bridge over the Mississippi River in Minneapolis, Minn., and the Major Deegan Expressway in New York City.

FHWA Every Day Counts Support

The Federal Highway Administration's (FHWA's) Every Day Counts (EDC) program, now in its sixth year, is geared toward advancing effective, proven, market-ready technologies into widespread use. FHWA's Turner-Fairbank Highway Research Center began investigating the use of UHPC in 2001, leading to the eventual development and delivery of optimal solutions that are in use today. Given the level of market adoption in 2014, it was decided to include UHPC connections as one of the 11 technologies whose deployment is being supported via EDC in 2015 and 2016.

Figure 1. Ultra-high-performance concrete connections were used in the bridge over the Canandaigua Outlet in New York. Photo: Federal Highway Administration.

The EDC program provides stakeholders with the assistance they need to successfully demonstrate, integrate, and institutionalize a technology into their toolbox of solutions. For UHPC connections, the deployment support team is delivering workshops across the country, is facilitating site visits to ongoing projects, is supplying expert technical assistance, and is delivering the support content (for example, design and construction guidance) needed by the adopting entity. Admittedly, the strong interest in UHPC connections technology has stretched the capacity of the deployment team, but the team is looking forward to continuing to meet stakeholder needs throughout 2016 and beyond.

Fundamental Principles

The fundamental mechanical principle undergirding the performance of UHPC connections is the fact that increasing the tensile resistance of concrete will allow it to better engage the connectors originating from a prefabricated concrete element. The tensile splitting and pullout behaviors that commonly limit the capacity of field-cast cementitious connections are mitigated

Figure 2. Locations of ultra-high-performance concrete connections currently in-service across the United States and Canada. Figure: Federal Highway Administration, created using Google Maps.

through the combination of the high load of fiber reinforcement and the cementitious matrix of the UHPC. In effect, UHPC acts as liquid confinement around reinforcement and other connecting elements in order to allow for simple, small connections that exceed the capacity of the adjacent prefabricated components. UHPC affords a pre- and post-cracking sustained tensile strength greater than 720 psi (5 MPa), as shown in the tensile responses for a set of example UHPCs in Fig. 3.

Common Connections

The most common connection is a reinforcing bar lap splice arrangement. Used today to connect prefabricated concrete bridge deck panels, the top flanges of decked girders, the backwalls of prefabricated integral abutment elements, and even pier columns to caps, these connections have proved to be cost effective to fabricate and easy to assemble in the field. The research-based design guidance indicates that uncoated and epoxy-coated reinforcement can be developed beyond the bar yield strength when the embedment length is only eight times the bar diameter. This results in non-contact lap spliced connections for No. 5 bars that might only be 6 in. wide and will not require post-tensioning, headed bars, hooked bars, lacer bars, or any other specialized anchorages.

UHPC also affords exceptional interface bond to precast concrete, increasing the likelihood that a leak-free structure can be placed into service. The enhanced bond is attributed to the fineness of the UHPC matrix combined with the increased tensile strength; however, the bond strength will only be increased if the surface of the precast concrete element is appropriately prepared. Most commonly, this preparation includes the creation of micro- and macrotexture through the use of a paste retarder to create an exposed aggregate surface along with prewetting to reduce the desiccation of the field-cast UHPC adjacent to the interface.

Field-cast UHPC can also be used for shear connections between bridge decks and supporting girders, for headers at expansion joints, for link slabs over piers in multi-span structures, and for seismic retrofits of substandard lap splices in conventional reinforced concrete substructures. Emerging uses of field-cast UHPC include its use as a structural overlay for rehabilitating bridge decks and as a field-cast retrofit to increase the capacity of deteriorated steel beam end regions.

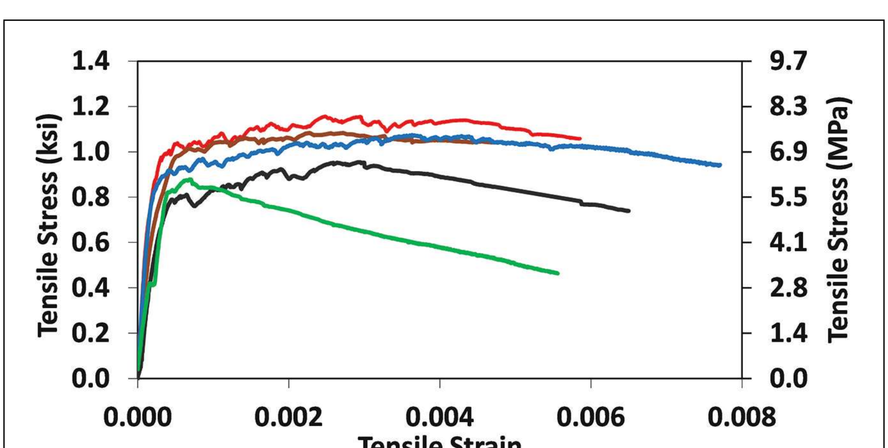

Figure 3. Tensile stress-strain response of five different ultra-high-performance concretes. Figure: Federal Highway Administration.

Conclusion

UHPC is rapidly being adopted as a field-cast material that addresses long-standing bridge construction needs and that outperforms conventional solutions. Fourteen states and four Canadian provinces have already begun using this technology, and use is expected to continue to grow over the coming years as it becomes a common state-of-the-practice solution. The bridge community is yet again demonstrating that proven solutions addressing critical need will be vetted and implemented in ways that deliver enhanced performance for future generations of the traveling public.

EDITOR'S NOTE

Please see the announcement in the last issue of ASPIRE *for The First International Interactive Symposium on UHPC being held on July 18-20, 2016. See www.uhpc2016.com for another avenue to learn more about the application of this material.*

For More Information

FHWA's UHPC research and innovation efforts are led by the author at the Turner-Fairbank Highway Research Center. Further information on UHPC technology can be obtained by accessing the FHWA UHPC webpage (https://www.fhwa.dot.gov/research/resources/uhpc/) or by contacting the author at benjamin.graybeal@dot.gov.