

Ultra-High-Performance Concrete Connections

A robust solution for prefabricated bridge element system construction

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The use of prefabricated components in the construction of highway infrastructure provides many advantages. However, it also frequently necessitates the use of field-deployed connection details. These details must facilitate component installation while simultaneously providing a robust structural system that meets or exceeds the performance that can be obtained through conventional construction processes. Demand for the use of prefabricated components is growing, as is the need for connection systems that provide enhanced performance.

Advances in the science of concrete materials have led to the development of a new class of cementitious composites. Ultra-high-performance concrete (UHPC) exhibits mechanical and durability properties that make it an ideal candidate for use in developing new solutions to pressing concerns about highway infrastructure deterioration, repair, and replacement.^{1,2} Connections between prefabricated bridge components have proven to be a promising application for field-cast UHPC.³ These connections can be simpler to construct and can provide more robust long-term performance than conventional connection designs.

UHPC is a cementitious composite material composed of an optimized gradation of granular constituents, a water-to-cementitious materials ratio less than 0.25, and a high percentage of discontinuous fiber reinforcement. The mechanical properties of UHPC include compressive strength greater than 21.7 ksi and sustained post-cracking tensile strength greater than 0.72 ksi. UHPC has a discontinuous pore structure that reduces liquid ingress, significantly enhancing durability compared to conventional concrete.

Availability of UHPC

UHPC is composed of a variety of constituents that are combined to create the composite. UHPC may be locally produced according to project specifications or may be obtained from a product supplier.⁴ Because UHPC, like conventional concrete, is defined in terms of the properties of the composite material, it must be recognized that multiple formulations may produce similar composite systems.



Placing operation for the field-cast, ultra-high-performance concrete. All photos: Federal Highway Administration.

Cementitious Composite

The cementitious composite portion of a UHPC is frequently composed of portland cement, silica fume, fine aggregates, chemical admixtures, and water. UHPC formulations may also include small coarse aggregates and supplementary cementitious materials. The sophistication of the UHPC cementitious composite as compared to conventional concrete has led to the development of preblended UHPCs. This production and distribution model is similar to that commonly used for many of the proprietary grouts and patching materials frequently deployed in the construction of the public infrastructure.

Steel Fiber Reinforcement

The exceptional mechanical properties of UHPC can be largely attributed to the fiber reinforcement contained in the concrete. These properties cannot be achieved without inclusion

Connection detail on underside of precast concrete deck panel.





Bridge deck after grinding, grooving, and opening to traffic.

of specific fibers that afford appropriate fiber efficiency, a topic influenced by fiber type, geometry, volume fraction, dispersion, and orientation. The most common steel fiber deployed in UHPC applications is a 0.008-in.-diameter by 0.5-in.-long straight fiber with a specified minimum tensile strength of 290 ksi. Buy America provisions of federal law apply to the use of steel fibers in federally funded transportation projects. Domestic production of this type of fiber is now available.

UHPC Connection Concepts

The mechanical properties of UHPC allow for the redesign of connection details between prefabricated concrete bridge elements. UHPC displays high compressive and tensile strength along with internal micro-reinforcement that helps distribute stresses, limit crack widths, and provide passive confinement to embedded discrete reinforcements. Through these mechanisms, UHPC can develop embedded reinforcements in far shorter distances than can conventional concrete.

The simplest and most common connection concept involves the lap splicing of reinforcing bars. In UHPC, the tension development length of reinforcement is a fraction of the length observed in conventional concrete. For example, ongoing and recently completed research at the Federal Highway Administration (FHWA) indicates that an embedment of eight times the bar diameter can allow for the development of the yield strength of ASTM A615 Grade 60 reinforcing bars in many common connection configurations.^{5,6} Thus, adjacent precast concrete elements can be connected to each other through the use of protruding straight lengths of reinforcement in comparatively

narrow connections. This type of UHPC connection detail is most commonly deployed to connect adjacent elements such as prefabricated concrete bridge deck panels.

Connections where interface shear dominates the response can also be redesigned through the engagement of UHPC. This connection location commonly occurs between bridge girders and prefabricated bridge decks, wherein the composite action of the superstructure system must be ensured through the use of appropriate connection details. With UHPC, the connection detail can be revised so that the interlacing of discrete reinforcements is reduced and the reliance on the field-cast grout performance is increased.⁷ Adjacent components can be fabricated such that discrete connectors are exposed on each side of the connection and the UHPC provides the tensile and mechanical performance to stitch the components together. The UHPC can flow into tight spaces and thus a continuous hidden connection detail without any pockets can be deployed.

Conclusion

Dozens of highway bridge projects that engage field-cast UHPC connections between prefabricated concrete elements have been completed in the United States over the past few years. States having deployed UHPC connections to date include New York, Iowa, Oregon, Montana, and Pennsylvania. Additional projects are underway during the 2014 construction season, with the largest being the redecking of the Pulaski Skyway in Newark, N.J.

Design and construction guidance for UHPC connections is being developed concurrent with these innovative applications. FHWA anticipates publishing a guideline late in 2014.

Field-cast UHPC connections provide new opportunities to create robust structural systems composed of prefabricated components. Research has demonstrated the performance of these connection concepts in the laboratory. Deployments are now demonstrating the constructability, field performance, and robustness of these systems in bridge inventories across the country.

References

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EDITOR'S NOTE

For additional information on UHPC technology, please visit FHWA's UHPC web page at <https://www.fhwa.dot.gov/research/resources/uhpc/>.