Development of the AASHTO Guide Specifications for Ultra-High-Performance Concrete

by Dr. Thomas Murphy, Modjeski and Masters, and Dr. Oguzhan Bayrak, University of Texas at Austin

Recent advancements in concrete materials science led to the development of ultra-high-performance concrete (UHPC). In May 2023, to facilitate the use of UHPC-class materials in bridge design, the American Association of State Highway and Transportation Officials (AASHTO) Committee on Bridges and Structures adopted a guide specification addressing the design of structural components made from UHPC. This guide specification is the culmination of the efforts of various organizations and individuals to make this advanced material available for use in bridges. The development of the guide specification was driven by the need for explicit guidance on how to design bridges using this new material, whose failure mechanisms may differ from those of conventional concrete. Use of UHPC, which began primarily in cast-in-place joints between precast concrete deck components, has been expanding into more prominent structural components and connections. Thus, there is a need for design equations that can accurately predict the capacity of components constructed using UHPC in a design framework that is consistent with the *AASHTO LRFD Bridge Design Specifications*.[1] When using UHPC for girder sections that take advantage of the properties of this material—thus resulting in much more slender webs and better-optimized flanges—the practical span lengths for precast concrete components can be extended. Reductions in superstructure weight in UHPC bridges can result in structures that employ a greater fraction of their capacities to support live loads and superimposed loads, leading to greater levels of structural efficiency.

The guide specification was developed based on research performed by the Federal Highway Administration, research and development sponsored by PCI, and other research efforts in the United States and around the world. Without the long-term vision and commitment of these organizations and the dedication of the research teams carrying out the work, the guide specification would not exist.

To be considered a UHPC by the guide specification, the material must have a strain-hardening behavior in tension, a minimum compressive strength of 17.5 ksi, and a minimum effective cracking strength of 0.75 ksi. The fibers used to obtain these mechanical properties must be steel, although other nonsteel fibers can also be included. Generally, UHPCs contain no coarse aggregate; instead, particle packing, admixtures, fibers, and a low water–cementitious materials ratio are used to obtain high compressive and tensile strengths. UHPCs are self-consolidating, but adjustments to the batching process can be required to properly mix the material.

Appearance of ultra-high-performance concrete in its fresh state as it is used for testing (left) and beam production (right). Photos: PCI.

The guide specification provides minimum and typical values for the important mechanical properties of UHPC based on the testing that has been performed to date. Designers are encouraged to open a dialogue with suppliers to ensure that the properties required by the design are practical and achievable. For UHPC used in precast and prestressed concrete components, the guide specification provides additional guidance on the values for mechanical properties that have proven to be practical and economical, in a relative sense, in prior research.

In terms of structural behavior, aside from the dramatic differences in compressive and tensile strengths, the primary distinction between traditional concrete and UHPC is the potential for a failure mode involving the localization of cracking. This mode of failure occurs when the tensile strains reach a critical value and the cracking in the UHPC, which tends to be well distributed before this strain, localizes into a single, large crack. The fibers spanning the crack will then begin to fail, resulting in an increase in tensile stress in any prestressed or nonprestressed reinforcement crossing the crack. Depending on the relative proportions of the cross section, this phenomenon can result in a rapid loss of strength with additional deflection. The phenomenon can occur both in flexure and in shear, and is predominantly a concern when the amount of reinforcement in the section is low, with the UHPC supplying a large proportion of the resistance to tensile stresses arising from either flexure or shear.

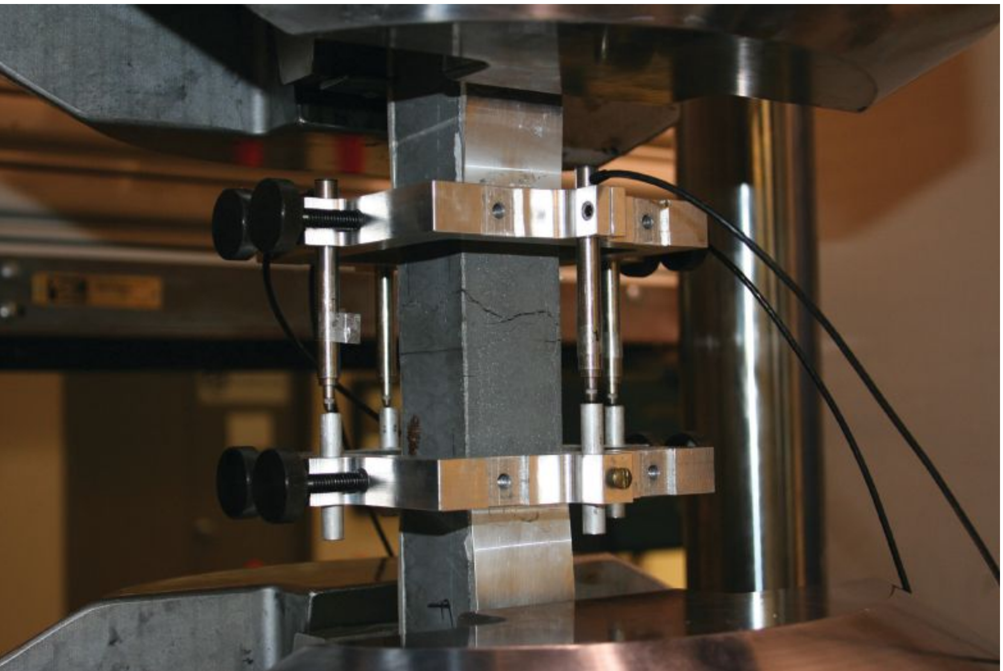
Because it is necessary to mathematically keep track of strains in the design, flexural design is accomplished using a strain-compatibility approach. For shear, the modified compression field theory (MCFT) of design has been adapted for UHPC. Since crack localization may occur before shear reinforcement yields, an iterative approach to determining the key variables in the MCFT equations is needed. However, tables are provided for these variables in an appendix of the guide specification; these tables may be used if the designer desires to avoid iterations and is willing to accept a more conservative result. Unlike typical designs employing conventional concrete, consideration for the tensile strength of UHPC is allowed in structural design. This aspect of structural design necessitated a series of considerations that are not common in designs conducted per the AASHTO LRFD specifications for conventional concrete.

For strength limit states, the resistance factor ϕ varies depending on whether the section is expected to experience crack-localization behavior. This variable is determined through the use of a curvature-ductility ratio, with the resistance factor ranging from a maximum of 0.9 for conventional behavior to 0.75 when crack localization is expected.

In addition to providing methods for calculating capacities for flexure and shear at the strength limit states, the guide specification also addresses service limit states. For flexure, controlling stresses are provided in compression and tension. These are very similar to the stress limits governing the design of conventional concrete components, with the addition of a tensile strain check for nonprestressed components.

The calculation of creep and shrinkage strains, and the resulting prestress losses, are addressed in the guide specification. Shrinkage in UHPC can be larger than that of conventional concrete due to the action of autogenous shrinkage, which is caused by the chemical reactions that occur during curing and is more prevalent in UHPC because UHPC has a higher proportion of cement content. Available data indicate that the amount of creep exhibited by UHPC can vary significantly based on the properties of the individual mixtures and curing techniques, and designers therefore need to allow for variations in the predicted creep deformations. Other topics covered in the guide specification include interface shear capacities, and development and transfer lengths for reinforcement in UHPC.

AASHTO is currently developing a companion material specification to define how the material properties of a UHPC should be established through testing, and how these properties should be verified at the project and component level. It is expected that the material specification will be ready for consideration by the AASHTO Committee on Bridges and Structures at its annual meeting in June 2024.



Direct tension test of an ultra-high-performance concrete prism. Photo: Federal Highway Administration Turner-Fairbank Highway Research Center.

Reference

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

Dr. Thomas Murphy is a senior vice president and the chief technical officer at Modjeski and Masters.

Dr. Oguzhan Bayrak is a chaired professor at the University of Texas at Austin, where he serves as the director of the Concrete Bridge Engineering Institute.