TECHBRIEF

Simultaneous Structural and Environmental Loading of a UHPC Component

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This document is a technical summary of the unpublished Federal Highway Administration (FHWA) report, *Simultaneous Structural and Environmental Loading of an Ultra-High Performance Concrete Component*, available through the National Technical Information Service (NTIS).

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Objective

This TechBrief highlights the results of a study aimed at evaluating the inelastic tensile response of ultra-high performance concrete (UHPC) subjected to simultaneous structural and environmental loading.

Introduction

UHPC is an advanced cementitious composite material that has been developed in recent decades. When compared to more conventional concrete materials, UHPC tends to exhibit superior properties such as exceptional durability, high compressive strength, usable tensile strength, and long-term stability.[1,2]

Practical application of concrete in the highway infrastructure frequently subjects cracked sections to simultaneous mechanical and environmental stressors. This experimental investigation focused on the response of a UHPC beam subjected to concurrent inelastic flexural loading and 15 percent sodium chloride (NaCl) solution application. The results provided insight into the sustained robustness of UHPC structural members loaded beyond their tensile cracking strength.

UHPC

Advances in the science of concrete materials led to the development of new cementitious materials, namely UHPC. As a class, these concretes tend to contain high cementitious materials contents, low water-to-cementitious materials ratios,

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compressive strengths above 21.7 ksi (150 MPa), and sustained tensile strength resulting from internal fiber reinforcement. Table 1 presents a select set of material properties for the type of UHPC investigated in this study.(1)

Table 1. UHPC material properties.

Property	Value
Unit weight	156 lb/ft^3 (2,500 kg/m^3)
Modulus of elasticity	7,600 ksi (52,400 MPa)
Compressive strength	28 ksi (193 MPa)
Post-cracking tensile strength	1.0–1.5 ksi (6.9 to 10.3 MPa)
Chloride ion penetrability (ASTM C1202)(3)	Negligible

The exceptional durability of UHPC has been well documented. Of particular importance, UHPC contains no coarse aggregate, so it does not exhibit the early-age microcracking common to conventional concrete. This aspect, combined with the discontinuous pore structure in the homogeneous cementitious matrix, results in a concrete with extremely low permeability.

The durability and sustained tensile capacity of UHPC present opportunities to reconsider common concepts in reinforced concrete structural design. For example, the tensile capacity of UHPC could eliminate the need for discrete mild steel reinforcement in some structural members, and its durability could reduce the cover required for any remaining reinforcement. These changes can facilitate slender, efficient designs heretofore considered impossible with conventional reinforced concrete.

Durability of Cracked UHPC

Although UHPC's impressive tensile capacity and durability have been assessed separately, prior studies have not investigated the robustness of a cracked UHPC section under simultaneous environmental and mechanical loading. Given the homogeneity and exceptionally low permeability of uncracked UHPC, it is anticipated that discrete structural cracking in UHPC components would necessarily increase the permeability. The ingress of liquids into the UHPC component along crack faces raises the possibility of steel fiber reinforcement degradation and a resulting loss of UHPC tensile capacity.

Tensile behavior of UHPC stands in contrast to that of conventional concrete. The discrete steel fiber reinforcement included in UHPC components allows the concrete to maintain tensile capacity beyond cracking of the cementitious matrix. Studies have shown that tensile capacity can be maintained at or above the tensile cracking strength for as much as 10,000 microstrain.(2,4) The inelastic straining of the component is resisted by the fiber reinforcement, which bridges the tight, closely spaced cracks.

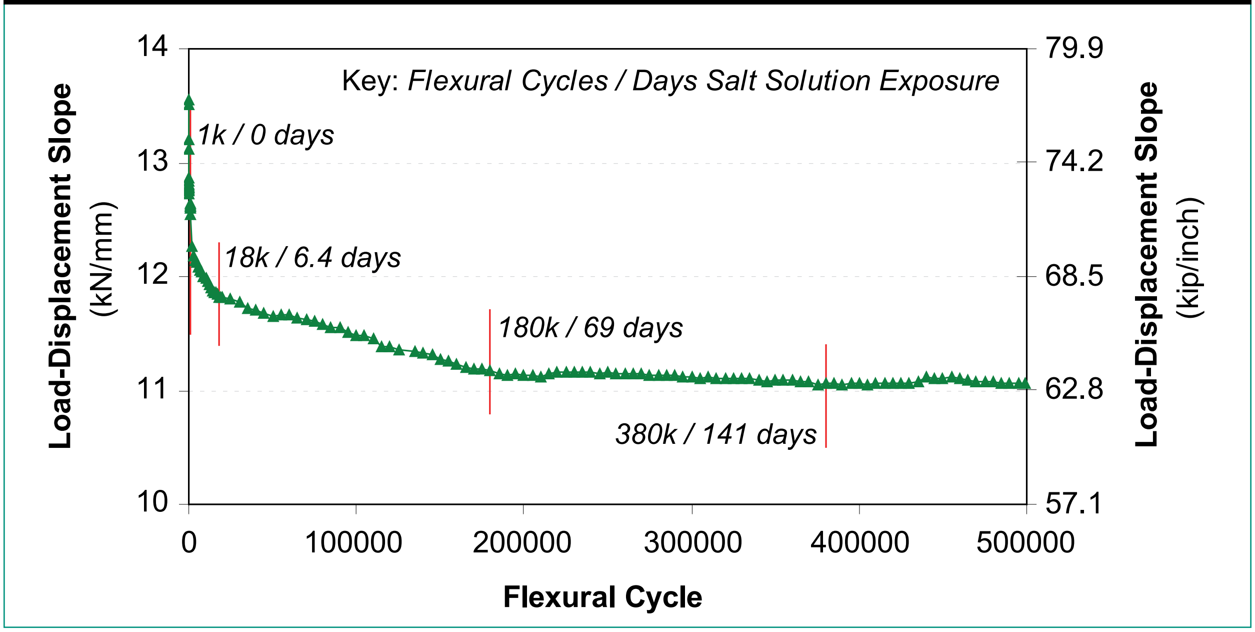
Test Program

To assess the tensile response of UHPC, this research focused on the cyclic loading of a UHPC beam and also included a series of static tests.

One mild steel reinforced, rectangular cross section UHPC beam spanning 16 ft (4.88 m) was fabricated. This beam was subjected to cyclic structural loading in a four-point bending configuration. Figure 1 shows the loading arrangement. The magnitude of load surpassed the elastic limit of the UHPC cementitious matrix, thus causing a series of flexural cracks to occur near midspan.

Figure 1. Test setup for cyclic loading of beam.

Figure 2. Flexural response of UHPC beam under combined loading.



The tensile face of the beam was subjected to continuous wetting via an open-cell sponge containing a 15 percent NaCl solution.

The flexural performance of the beam was monitored for 154 days, during which 500,000 cycles of structural load were applied. The cyclic flexural response results are depicted in figure 2. Afterward, the beam was loaded statically to flexural failure. Finally, a prism was cut from the bottom face of the beam near midspan and loaded in direct tension to failure. Each of these efforts was aimed at assessing the tensile performance of the UHPC after being subjected to structural fatigue loading in the presence of an environment that could potentially degrade the fiber reinforcement. Figure 3 shows the midspan of the beam following the application of all 500,000 cycles of structural load, and figure 4 is a photo of one of the flexural cracks at 800x magnification.

Conclusions

Several conclusions were reached based on the results of this research. The simultaneous application of structural and environmental loading to a UHPC flexural member did not result in any apparent degradation of the member's flexural capacity.

It was concluded that tensile cracking of UHPC is indicative of cementitious matrix properties and

Figure 3. Midspan of beam after 500,000 flexural cycles and 154 days.

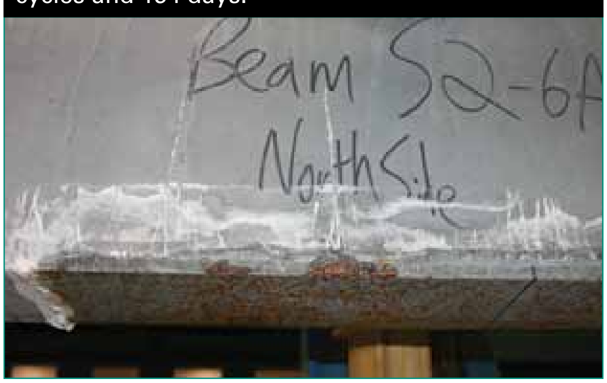


Figure 4. 0.0002-inch (5-μm) wide flexural crack in the beam.

is not necessarily indicative of a plane wherein tensile failure of the section through fiber pullout will eventually occur.

Additionally, the application of the structural and environmental loading was not observed to cause any local degradation of the fiber reinforcement bridging cracked planes. Ingress of NaCl solution along cracked planes was only observed to a depth of 0.12 inches (3 mm) on the side face of the beam and 0.2 inches (5 mm) on the tensile face of the beam. At locations where fiber pullout occurred across preexisting cracked planes, the fiber reinforcement did not show any visible signs of section loss or tensile failure.

Finally, UHPC can exhibit a wide range of ultimate tensile capacities within a small portion of an individual specimen. Cross sections loaded in uniaxial tension along a 7-inch (180-mm) length of an individual prism were observed to fail at 1.88 ksi (12.9 MPa), 2.30 ksi (15.8 MPa) , and 2.63 ksi (18.1 MPa).

References

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Researchers—This study was completed by Ben Graybeal of the FHWA's Turner-Fairbank Highway Research Center. Additional information can be gained by contacting him at 202-493-3122 or in the FHWA Office of Infrastructure Research and Development located at 6300 Georgetown Pike, McLean, VA 22101.

Distribution—The unpublished report (PB2010-110331) covered in this TechBrief is being distributed through the National Technical Information Service, www.ntis.gov.

Availability—The report will be available in July 2010, and it can be obtained from the National Technical Information Service, www.ntis.gov.

Key Words—Ultra-high performance concrete, UHPC, Fiber-reinforced concrete, Bridges, Accelerated construction, Durable infrastructure systems, Permeability, and Tensile response.

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