ULTRA-HIGH-PERFORMANCE CONCRETE

A Bridge of the Future–A Solution Today

by Dr. Benjamin A. Graybeal with M. Myint Lwin,
Federal Highway Administration

Ultra-high-performance concrete (UHPC) refers to a class of exceptionally durable and strong cementitious composites, usually containing fiber reinforcement and exhibiting self-consolidating properties. UHPC has been used in Europe and Asia in building vehicular bridges, pedestrian bridges, and other types of structures. In the United States, the Iowa, Virginia, and New York Departments of Transportation have used UHPC in building highway bridges. More applications of UHPC are expected in the years ahead.

The ongoing deterioration of highway bridges is an issue across the nation. This deterioration in combination with congestion related issues has created a situation where bridge owners need to repair, replace, and construct durable bridges. Those needs are greater than ever. Given the ever increasing demands on our bridge structures and resources, it is clear that conventional construction techniques of the 20th century are not in themselves sufficient to meet 21st century needs. There is a strong demand for new solutions to existing problems, whether the solutions emanate from materials or structural configurations or construction techniques. The advanced properties of UHPC open many new avenues toward these solutions.

The Federal Highway Administration's (FHWA) Bridge of the Future initiative seeks to develop new solutions to our existing highway bridge deterioration and congestion problems. The initiative has the following performance goals for highway bridges:

- 100-year service life with little or no maintenance
- Significantly reduced construction time
- Easily widened or adapted to new traffic demands
- Significantly reduced life-cycle-cost
- Significantly improved resistance to typical and extreme natural and man-made hazards including blast, flood, earthquake, fire, wind, fracture, corrosion, overload, and collision
- Integrated substructure and superstructure design and construction
- Reduction of vertical and lateral clearance problems

FHWA's UHPC efforts are a core component of the Bridge of the Future initiative. The efforts focus on engaging UHPC's exceptional durability and mechanical properties to create optimal structural systems capable of meeting current and future demands.

What is UHPC?

UHPC is a general classification that encompasses a range of advanced cementitious composite materials. Just as with conventional concretes, UHPC contains cement, aggregates, and water. Like many high-performance concretes, UHPC also contains supplementary cementitious materials and chemical admixtures to enhance specific presetting and post-setting behaviors. Unlike most concretes, UHPC generally contains no coarse aggregates, instead it includes a few percent by volume of short, discrete fibers.

Worldwide, UHPC-type materials are available from multiple suppliers. In the United States, one multinational firm has led the way in supplying UHPC for infrastructure-scale projects. Other entities are currently working to develop and deploy competing products in this market.

The performance attributes exhibited by these concretes may be up to an order of magnitude better than those exhibited by conventional and high-performance concretes. UHPC is sometimes thought of as 'extremely strong concrete'; however, a compressive strength seven or more times that of conventional concrete is only part of the story. UHPC exhibits sufficient sustained tensile capacity to allow for the reimagining of concrete structural design. Moreover, the durability properties of UHPC are so exceptional that they cannot be quantified with many standard concrete test methods. The table on page 47 presents some attributes of a widely available UHPC as independently measured by FHWA.

Applications

There are many potential applications for UHPC in the highway infrastructure; however, as is always the case with new technology, only some implementations will prove to be economically viable. The range of concepts being considered runs the gamut from conventional ideas such as bridge redecking systems and optimized prestressed girders,[1] to connection details such as field-cast spliced joints between precast modular elements,[2] to novel concepts such as energy dissipating seismic elements and cladding shells for bridge barriers.

Since its initiation in 2001, FHWA's UHPC program has been focused on developing practical UHPC applications that address pressing needs.

Ultra-high-performance concrete was used in the Cat Point Creek Bridge in Warsaw, Va. Photos: Ben Graybeal, FHWA

The UHPC Pi Girder is a 33-in.-deep and 100-in.-wide decked bridge girder designed to span up to 87 ft and allows for rapid construction of an extremely durable superstructure.
Drawing: Ben Graybeal, FHWA.

This UHPC has been mixed in and is being discharged from a ready-mixed concrete truck.
Photo: Ben Graybeal, FHWA.

UHPC was used to connect these deck bulb tees in the Route 31 Bridge over Canandaigua Outlet in the Village of Lyons, N.Y. Tests showed that the No. 6 epoxy-coated reinforcement was fully developed with a 6-in. lap in the joint.[2] Photo: New York State Department of Transportation.

Initial efforts demonstrated that one-for-one replacement of conventional concrete with UHPC in standard prestressed concrete girder shapes was feasible and would produce results consistent with basic engineering mechanics principles. This work also demonstrated that the tensile capacity of UHPC is sufficient to reduce and even eliminate the secondary mild steel reinforcement in a girder, thus opening the door to reduced cover demands and lighter, optimized sections.

Subsequent efforts have focused on developing optimal solutions which engage the advanced mechanical and durability properties of the UHPC to create economically desirable components. One project of note has developed a deck bulb-double-tee girder that can span up to 87 ft using an 8-ft 4-in.-wide component that has structural depth of only 33 in. This 932-lb/ft girder is transportable, stable, and does not require any structural overlay.[3] A second project has developed a bridge redecking system, which uses the strengths of UHPC to reduce deck weight and simplify connection details. A third project has developed practical QA/QC methods for assessing UHPC properties in plant and field environments.

Conclusion

In coming years, the demand to rehabilitate, construct, or reconstruct highway bridges will only grow stronger. Construction techniques and structural materials implemented in the middle of the twentieth century have left us with structures nearing the end of their service lives at a time when highway mobility is increasingly important and budgets for maintenance and repair are strained. Advanced structural materials open doors to new structural systems and construction techniques. UHPC is the culmination of decades of research in concrete materials science. This class of concretes has already been demonstrated to allow for structural forms heretofore considered impossible with conventional concrete. Further development of optimal solutions is underway and existing knowledge has facilitated initial deployments of UHPC technology in bridges around the nation. Additional details on UHPC deployments and opportunities will be covered in the Summer issue of *ASPIRE*.™

UHPC Physical Properties

Property	Plant-Cast*	Field-Cast*
Compressive Strength	28 ksi	18.3 ksi
Modulus of Elasticity	7600 ksi	6200 ksi
Sustained Tensile Strength	~1.5 ksi	~0.9 ksi
Creep Coefficient	0.3	0.8
Scaling (ASTM C672)	None	None
Chloride Penetrability (AASHTO T 277)	20 coulombs	360 coulombs
Freeze/Thaw Resistance (AASHTO T 161)	RDM > 95%	RDM > 100%

** Field-cast UHPC is cured through conventional means while plant-cast refers to UHPC that has had its properties enhanced through early-age steam treatment.*

References

1. "A Whole New Cast," *ASPIRE,*™ Summer 2007, pp. 26-29.
2. "UHPC Joint Provides New Solution," *ASPIRE*, Fall 2009, pp. 28-30.
3. "FHWA, Iowa Optimize Pi Girder," *ASPIRE*, Winter 2010, pp. 24-26.

EDITOR'S NOTE

More information on research and deployment of UHPC technology can be obtained by contacting Dr. Graybeal at bgraybeal@dot.gov or 202-493-3122.