Making UHPC Practical for Implementation in Precast, Pretensioned Concrete Elements

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Ultra-high-performance concrete (UHPC) is a class of concrete that relies on a highly refined microstructure and fiber reinforcement to achieve superior performance characteristics, including high compressive strength, postcracking tensile strength and ductility, and exceptionally long-term durability in aggressive environments. The constituent materials of UHPC typically include cement; silica fume; sand; a fine-grained supplemental material such as limestone powder, fly ash, ground silica, or slag cement; and a potent high-range water-reducing admixture (HRWRA) that supports production at water-binder ratios of 0.2 or less. In recognition of the great potential of UHPC to improve the performance of concrete structures, particularly in precast concrete bridge and building applications, the Precast/Prestressed Concrete Institute (PCI) has funded a research project, "Implementation of Ultra-High-Performance Concrete in Long-Span Precast Pretensioned Elements for Concrete Buildings and Bridges," to make UHPC implementation practical for North American precasters. This article presents guidance produced to date by this project.

Advantages and Challenges Associated with UHPC

Because of its exceptional tensile performance, which is sufficiently robust to be relied on for design purposes, and its enhanced durability, UHPC has the potential to greatly extend the capabilities of concrete construction. For example, by using optimized designs member weights can be reduced by 50% compared to conventional concrete without reducing capacities. Also, even with severe marine or deicing salt exposures, service lives of 200 years or more can be reasonably anticipated.

Despite this highly desirable performance, applications of UHPC in the United States have been limited, and designers and owners have been reluctant to accept and use this material. The high cost of proprietary UHPC materials, technical challenges associated with production, and a shortage of national design guidelines have all contributed to limited implementation.

Phase I Outcomes of PCI-Funded UHPC Research

The precast concrete industry is particularly well suited to support implementation of UHPC because of the greater materials handling, concrete production, and construction quality control possible within a plant setting. There is also the potential for efficient production of optimized sections that make effective use of the relatively high-cost UHPC material. Therefore, the PCI-funded research project seeks to foster more widespread implementation of UHPC in precast concrete applications through the publication of guidelines for developing and producing cost-effective UHPC mixtures, a guide specification for UHPC materials qualification and acceptance, and structural design guidelines. The overall project and design guideline development are being led by e.construct USA of Omaha, Neb., and the materials aspects of the project are led by Wiss, Janney, Elstner Associates of Northbrook, Ill.

A first goal of this project is to develop methods for implementing cost-effective UHPC mixtures made with locally available materials and existing production facilities at precast concrete plants throughout the United States. A second goal is to develop design methods and novel designs for optimized long-span structural members for bridges and buildings. The first phase of this ongoing PCI project was recently completed, and a Phase I report[1] about the significant progress made toward achieving these goals was published in February 2020. The report includes draft guidelines for production, a draft materials guide specification, and proposed guidelines for design with examples. Each of these parts of the report are discussed in the following sections.

Guidelines for Production

The draft guidelines for production present an overview of UHPC production specific to long-span precast, pretensioned concrete structural elements. Topics include recommendations for raw materials selection; development of UHPC mixture designs; batching, handling, and placement of materials; and methods for evaluating the performance of UHPC materials for mixture qualification and quality assurance.

The draft production guidelines were validated through UHPC production trials in precast plants in the United States and Canada. UHPC mixtures were developed for five precasters using the efficient mix-development approach presented in the guidelines, which is based on proportioning materials to achieve an optimized packing of particles. The mixtures developed for this project were largely based on materials already used in production at each plant, with the exception that the typical concrete sands were replaced with finer "masonry" sands available from the precasters' local concrete aggregate suppliers. Some precasters also chose to incorporate HRWRAs that differed from their current typical products.

The mixture development process included particle-size analysis of the constituent materials, theoretical determination of optimum proportions based on simplified

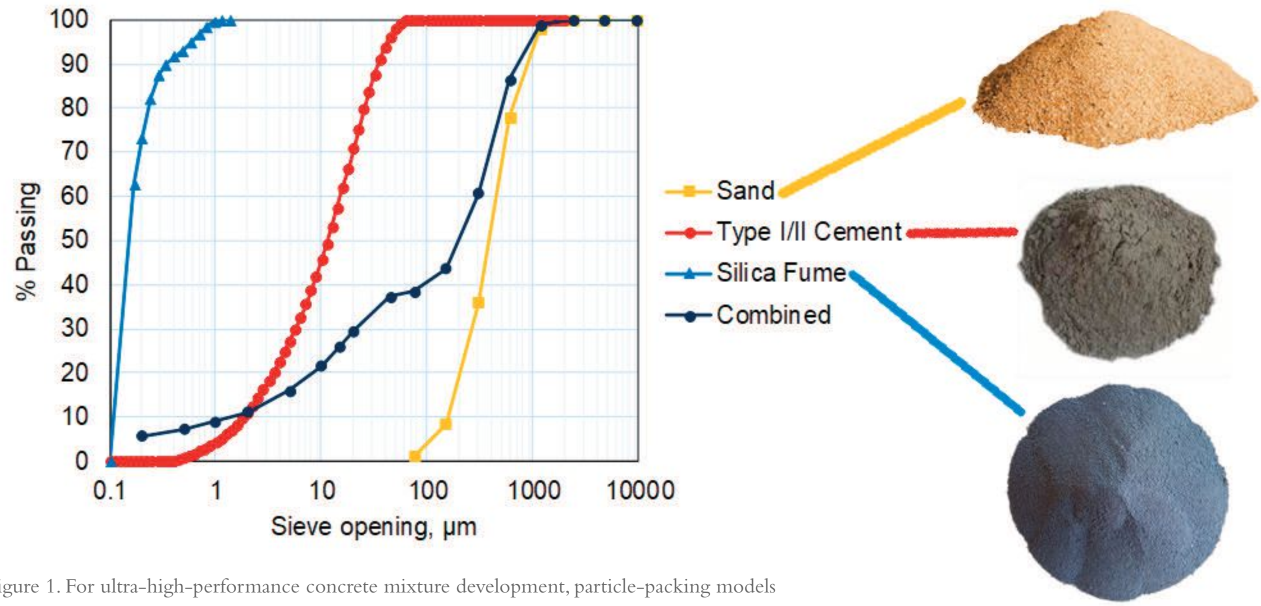

Figure 1. For ultra-high-performance concrete mixture development, particle-packing models considering the particle-size distribution of the constituent materials are used to determine optimized combinations of raw materials. Figure: Wiss, Janney, Elstner Associates Inc.

particle-packing models (**Fig. 1**), small-scale laboratory batches to minimize water content and admixture dosage, and finally, scaled-up testing using full-sized batches (**Fig. 2**) to verify that the UHPC material performance met expectations. **Figure 3** shows a four-point bending test conducted according to ASTM C1609[2] to determine flexural strength, which was employed as the most practical approach for evaluating tensile performance. UHPC has a minimum required tensile strength (see the Concrete Bridge Technology article in the Winter 2020 issue of *ASPIRE*®).

The production and handling guidelines were subsequently validated through production trials at each precast plant. Structural elements of various configurations were produced and used to refine concrete handling, placement, and finishing methods. **Figure 4** shows production at one participating precaster.

Materials Guide Specification

The draft materials guide specification is intended to be used by engineers and owners as a basis for the preparation of materials specifications for building and transportation structures that align with the structural design of precast, pretensioned concrete elements. This draft guide specification addresses the materials and production of structural precast, prestressed UHPC elements and provides requirements for materials qualification (submittals), raw materials, mixture proportioning and documentation, qualification and routine acceptance testing, and production, including storage and handling, mixing, transport and placement, finishing, curing, inspection, and testing.

Proposed Guidelines for Design

The proposed design guidelines provide a rational basis for design parameters such as flexure, vertical shear, interface shear, and punching shear, while considering other factors that will influence member performance, including time-dependent effects, bond, and end-zone bursting.

Figure 2. Mixing ultra-high-performance concrete in an existing horizontal twin-shaft mixer at a precaster's batch plant. From left, addition of water after blending of dry material, achievement of self-consolidating consistency, and addition of brass-coated steel fibers. Photos: Wiss, Janney, Elstner Associates Inc.

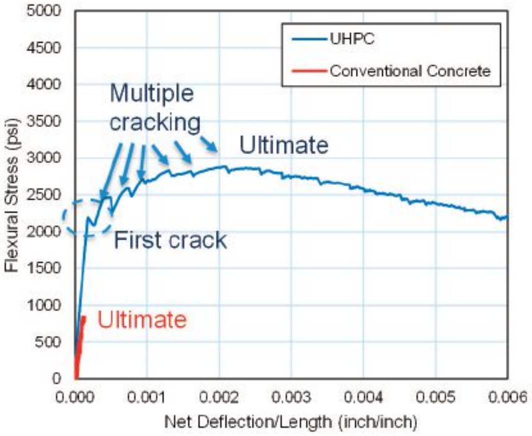

Figure 3. Verification of tensile properties of ultra-high-performance concrete through flexural testing. Photo and Figure: Wiss, Janney, Elstner Associates Inc.

Figure 4. Construction of 60-ft-long voided box beam using an ultra-high-performance concrete mixture developed using the approach outlined in the draft guidelines for production included in the Phase I report of the PCI-funded study. Photo: Wiss, Janney, Elstner Associates Inc.

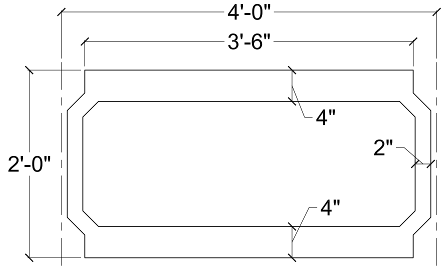

Figure 5. Optimized concrete hollow box beam cross section developed as a part of the PCI-funded study to take advantage of the tensile performance of ultra-high-performance concrete. Figure: e.construct USA LLC.

Chapters 4 through 10 of the Phase I report provide the basis of the design guidelines, which are then demonstrated in design examples. The report also covers product development concepts.

As part of Phase II of the project, several full-scale bridge and building elements have been produced and tested based on the designs developed in Phase I. **Figure 5** shows an example of an optimized box beam cross section intended for bridge construction. The results of the testing to date are promising, as the products have supported loads as much as double the required design loads. Phase II of the PCI project is ongoing and will include additional structural testing of components and full-sized members. This testing program is intended to verify, refine, and confirm the draft design guidelines presented in the Phase I report.

Conclusion

UHPC has the potential to significantly advance the capabilities of precast concrete for bridge and building construction because of the durability and the structurally reliable tensile strength and ductility of the material. It is hoped that the guidance now available for materials development, when combined with the structural design guidelines currently being finalized, will enable practical implementation of UHPC nationwide so that the potential of this material can begin to be realized.

References

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Acknowledgments

The authors would like to recognize and thank the other members of the project team that provided essential assistance in the completion of Phase I and continue to work on the ongoing activities of this project: the University of Nebraska-Lincoln, North Carolina State University, and Ohio State University, as well as the participating precasters: Standard Concrete Products Inc., Tampa, Fla.; Coreslab Structures (Omaha) Inc., Omaha, Neb.; Metromont Corp., Greenville, S.C.; Tindall Corp., Spartanburg, S.C.; Concrete Technology Corporation, Tacoma, Wash.; and FACCA Inc., Windsor, Ontario.

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