Executive Summary, Research Readiness Level Assessment and Technology Transfer

Feasibility Study of Development of Ultra High-Performance Concrete (UHPC) for Highway Bridge Applications in Nebraska

Research Objectives

Evaluated the feasibility of developing an economical non-proprietary UHPC mixes with locally available materials for possible use in different bridge applications in Nebraska. The focus of this study was on UHPC developed for connecting precast superstructure components (e.g. deck panels and decked girders).

Research Benefits

The use of UHPC resulted in significant improvements in the structural capacity and durability of highway bridges. Having concrete with low permeability, high resistance to freeze and thaw cycles, and controlled long-term deformations was ideal for replacing the expensive grout used in precast connections, which resulted in more durable bridges with minimal life-cycle cost.

The study helped to answer concerns (i.e., meeting necessary mechanical properties, construction, and durability requirements) regarding the new developed UHPC mixes and ensure a successful use of the materials in NDOT highway bridge construction.

The developed UHPC mixes are significantly less expensive than the proprietary UHPC mixes, and the demonstration of the development of UHPC with local materials greatly encouraged the use of this material in several applications, such as connections, overlays, repair, and bridge girders.

Background

Ultra-high-performance concrete (UHPC) is a new class of concrete that has superior mechanical, durability, and workability properties that far exceed those of conventional concrete. To achieve these properties, a specific mix design with a very dense internal structure, fiber reinforcement, and low water-to-binder ratio (w/b) is commonly used. The research was to develop a non-proprietary UHPC mix with constituent materials that are readily available in the state of Nebraska for bridge construction applications. In developing this mix, the particle packing model is used, and an experimental study of the impact of various design parameters on the key properties of UHPC is conducted.

Conclusion

Multiple series of UHPC mixtures are investigated with different types and quantities of aggregate, fibers, cement, supplemental cementitious materials (SCMs), high range water reducer (HRWR), w/b, total binder content, and mixers. Mix design with type I/II cement, 8% of silica fume (by mass of binder), and 30% of slag (by mass of binder) is recommended. The developed mix exhibits sufficient flowability and stability to ensure the successful implementation in bridge components and connections.

A comprehensive evaluation of mechanical properties demonstrated that the mix exhibits excellent mechanical properties, including compressive strength, modulus of elasticity, Poisson's ratio, flexural strength, splitting tensile strength, direct shear strength, slant shear strength, and bond strength. The developed mix also exhibits excellent durability properties, including mass loss of less than 1% based on freezing/thawing resistance test, very low chloride ion penetration based on surface resistivity test, and no cracking based on restrained shrinkage test.

The unit cost of the developed mix is approximately $682 per cubic yard, which is approximately one-third of the current commercial products. The batching, handling, placing, and curing of the developed mix was demonstrated in a field-scale panel connection casting, which resulted in a satisfactory performance.

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Interested in finding out more?

Final report is available at: NDOT Research Website

NDOT Recommendations Based Off of Research Project

Having completed the research for Nebraska UHPC mix design, this is the first step in a series of steps to make UHPC available in Nebraska. Not just any Ready-Mix Plant can mix UHPC, it takes special equipment and materials for the mix design. Because of this, contractors will need to practice mixing UHPC. The Department is working with AGC to help the contractor get the experience they will need in order to mix UHPC for specific projects. Once the contractor has experience, then Bridge Division will specify projects using UHPC for precast bridge decks.

Other goals that the Department is working on is using UHPC for precast girders and bridge decks, such as, UHPC Decked I-Beam for Accelerated Bridge Construction research project began in July 2020 and expected completion date of May 2022.

Technology Transfer

Jiong Hu and George Morcous' Transportation Research Board (TRB) papers

- F. Mendonca, J. Hu, G. Morcous, "Fresh and Hardened Behavior of Ultra High-Performance Concrete (UHPC) with Different Mixtures Design Parameters", Proceeding of the Second International Interactive Symposium on UHPC, Albany NY, June 2-5, 2019. https://www.extension.iastate.edu/registration/events/2019UHPCPapers/UHPC_ID96.pdf
- M.A. El-Khier, G. Morcous, J. Hu, "Interface Shear Resistance of Ultra-High Performance Concrete (UHPC)", Proceeding of the Second International Interactive Symposium on UHPC, Albany NY, June 2-5, 2019. https://www.extension.iastate.edu/registration/events/2019UHPCPapers/UHPC_ID13.pdf

Jiong Hu and George Morcous' Conference Presentations

- F. Mendonca, J. Hu, G. Morcous, "Fresh and Hardened Behavior of Ultra High-Performance Concrete (UHPC) with Different Mixtures Design Parameters", Second International Interactive Symposium on UHPC, Albany NY, June 2-5, 2019.
- M.A. El-Khier, G. Morcous, J. Hu, "Interface Shear Resistance of Ultra-High-Performance Concrete (UHPC)", Second International Interactive Symposium on UHPC, Albany NY, June 2-5, 2019.
- Mendonca, F., Hu, J., and Morcous, G. (2019) "Fresh And Hardened Behavior Of UHPC Prepared With Different Mix Design Parameters and Mixers", 2nd International Interactive Symposium on UHPC, Albany, NY, June 2-5.

George Morcous' Conference Presentations

- Morcous, Maguire, M., Tadros, M. K., "High performance materials in concrete bridge construction", Proceedings of the 2019 GeoMEast International Congress and Exhibition, "Recent Research in Sustainable Infrastructure", Springer.

Research Readiness Level (RRL) Assessment

RRL 3

Level 3: Development – Field Level

Research/Technology developed in an operational environment (real-world situation).

This brief summarizes Project SPR-1(18) M072
"Feasibility Study of Development of Ultra-High-Performance Concrete (UHPC) for Highway Bridge Applications in Nebraska"
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