Laboratory and Field Evaluation of an Alternative UHPC Mix and Associated UHPC Bridge

tech transfer summary

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RESEARCH PROJECT TITLE
Laboratory and Field Evaluation of an Alternative UHPC Mix and Associated UHPC Bridge

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The Bridge Engineering Center (BEC) is part of the Institute for Transportation (InTrans) at Iowa State University. The mission of the BEC is to conduct research on bridge technologies to help bridge designers/owners design, build, and maintain long-lasting bridges.

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This project evaluated the properties and performance of an alternative UHPC mix called K-UHPC that was used for accelerated bridge construction of the Hawkeye Bridge in Buchanan County, Iowa.

Objective

The objective of this project was to evaluate an alternative ultra-high performance concrete (UHPC) mix that used locally sourced cement, sand, and ready-mix trucks and a bridge constructed using the mix for its cross-section pi-girders in Buchanan County, Iowa.

Background

UHPC is a relatively new class of concrete that has material and durability properties superior to normal concrete. These unique properties make it appropriate for use in accelerated bridge construction (ABC) for highway bridges.

The unique properties of UHPC offer several advantages, which can be summarized as follows:

- Because of the increase in compressive and tensile strengths, smaller sections can be used to design flexural beams that support large loads. Using smaller sections leads to reduced dead weight of the structure. In addition, the depth of the girders and shear reinforcement can be reduced.
- Due to the compactness of the material, it is impermeable to water and aggressive chemicals, making it a highly durable material. High durability can lead to longer service life of the structure and lower maintenance cost over the structure's lifecycle.

Field applications of UHPC for highway bridges in the US started in 2006. After understanding the effective properties of UHPC, the Iowa Department of Transportation (DOT) used it in the rehabilitation and construction of several bridges in Iowa: the Wapello County UHPC bridge, the Jakway Park Bridge in Buchanan County, a waffle deck panel system bridge in Wapello County, and the Mars Hill Bridge south of Ottumwa.

Formwork for pouring and casting the K-UHPC cross-section pi-girders in the Buchanan County Secondary Roads yard

For this project, UHPC called K-UHPC, which was developed by the Korea Institute of Civil Engineering and Building Technology (KICT), was used for construction of the Hawkeye Bridge in Buchanan County. As part of this project and in collaboration with the Iowa DOT and the Buchanan County Secondary Roads Department, KICT helped construct the bridge as a replacement to an old timber bridge. This was the first application of K-UHPC in the US.

The bridge that was constructed is 52 ft long and 32.5 ft wide, with a 30 ft roadway. The pi-girder design for the cross section of the bridge has proven to be both economical and efficient, and six girders were separately cast near the bridge site in the Buchanan County Secondary Roads yard and later assembled in the field.

Problem Statement

Although UHPC displays superior properties and offers several advantages, there are challenges in using the material for construction purposes, summarized as follows:

- Application of UHPC comes with high initial cost due to the use of steel fibers and admixtures that are relatively expensive.
- Steam curing is required to attain design strength. Equipment to maintain the high steam temperature in the field can be expensive and often challenging.
- Conventional concrete mixers cannot typically be used, and mixing time is lengthy compared to that with conventional concrete.
- Local availability of materials such as steel fibers, superplasticizer, and other admixtures can be challenging.
- Given that it is a developing material, there are no established testing standards to quantify the material properties or established design guides to follow for designing structures.
- Specialized technical knowledge is required to use this material.

Research Methodology and Scope

The scope of this project was to assess selected properties of K-UHPC independently, under two different scenarios. The first was based on samples collected in the field at the Hawkeye Bridge site, where K-UHPC was mixed in regular concrete mixers using locally available materials. Second, a set of samples was prepared in the laboratory using the same materials.

The research focus was on the evaluation of strength behavior (compressive strength), long-term stability properties (creep and shrinkage strains), bonding with reinforcement, and durability properties (freeze-thaw resistance and chloride ion penetration/surface resistivity). These properties were estimated using samples prepared in the two different environments (field-cast and laboratory-cast). The evaluated properties from the two different environments were compared to each other, and also compared to the properties reported in the literature for K-UHPC and other UHPCs.

Live load tests were also conducted on the bridge shortly after completion of construction in November 2015, with follow-up load tests conducted two years later, in August of 2017. These live load tests were conducted to evaluate the structural behavior of the bridge.

Pouring the K-UHPC mix into the formwork

Instrumentation of the precast girders for live load testing two years post-construction

Live load testing in 2017

Key Findings

- Overall, the test results from the samples collected from the field proved development of adequate compressive strength in K-UHPC. The compressive strength of samples collected at different stages reached average values of 18 and 20 ksi after 28 and 60 days, respectively, which can be considered adequate, particularly by considering the use of local materials (cement and fine aggregate) in the mixes.
- The samples collected from the field showed promising durability performance in terms of resistance against chloride penetration and freeze-thaw cycles. The penetration of chloride ions measured by the surface resistivity test and durability loss in the frost resistance test were negligible.
- The compressive strength results of the samples cast in the laboratory were almost similar to those obtained from the field samples. The consistent data points proved the replicability of the reported results (in both laboratory and field conditions).
- The shrinkage of K-UHPC cast in the laboratory was in the range of 1,200 to 1,500 microstrain, which was slightly higher than the total shrinkage reported in the literature. The creep coefficient was 0.35, which was in the typical range reported in the literature.
- The K-UHPC showed proper bonding to both steel and glass fiber reinforced polymer (GFRP) reinforcement.
- From the load tests, for all of the load paths and both years tested, none of the displacement transducers recorded any measurable relative displacement between adjacent girders.

Implementation Readiness and Benefits

The following conclusions made through this research project can be further applied to the use of K-UHPC for bridge construction in Iowa:

- The results indicated that K-UHPC can develop adequate strength with the use of local cement and fine aggregates and conventional ready-mix trucks.
- The load test results indicated satisfactory structural performance of the Hawkeye Bridge at the time of construction and after two years.
- The K-UHPC showed proper and even superior bonding to both steel and GFRP reinforcement compared to normal strength concrete.
- The samples collected from the field also showed promising durability performance in terms of resistance against chloride penetration and freeze-thaw cycles.