Evaluation and Testing of a Lightweight Fine Aggregate Concrete Bridge Deck in Buchanan County, Iowa

tech transfer summary

Using lightweight fine aggregates to produce internally curing concrete mixtures for bridge decks has the potential to increase strength, lower permeability, and extend concrete service life.

Background

Using saturated lightweight fine aggregate (LWFA) in concrete mixtures can replenish water that is depleted during cement hydration without influencing the water-to-cement (w/c) ratio. This process, known as internal curing (IC), can contribute to a more sustainable infrastructure by reducing shrinkage, increasing strength, lowering permeability, and providing other benefits.

As a result, the service life of concrete structures can be increased and the required cement content may be reduced. These benefits are most useful in bridge decks that are exposed to aggressive environments and are at a high risk of cracking.

Goal

It is reported that inclusion of about 20 to 30% LWFA will not only improve strength development and potential durability, but, more importantly, will significantly reduce shrinking, thus reducing cracking risk. The aim of this work was to investigate the feasibility of such an approach in a bridge deck.

Project Objectives

The objectives of this work were as follows:

- Evaluate the performance of LWFA concrete through laboratory and field testing
- Evaluate the structural performance of a concrete bridge deck made using LWFA through live load tests of the finished structure at the time of construction and after one year and two years of service
- Conduct a lifecycle cost and service life prediction

Live load testing on the completed bridge

National Concrete Pavement Technology Center

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RESEARCH PROJECT TITLE
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Laboratory Testing

For the laboratory tests, samples of all concrete ingredients used in the field were taken to the Portland Cement Concrete (PCC) Pavement and Materials Research Laboratory at Iowa State University and to the contractor for trial batch testing.

Six mixtures were prepared in the laboratory: three control mixtures, two mixtures with 20% by mass of the fine aggregate replaced with LWFA, and one mixture with 30% LWFA replacement. Both the control and test mixtures complied with the normal specifications used by Buchanan County, Iowa Engineer/Secondary Roads, where the bridge deck was constructed for field testing.

A pair of mixtures (one control and one with 20% LWFA replacement) were prepared before construction in 2012 using the proportions planned for use on site. The same mixtures were also prepared and tested by the contractor. Several months later, a second pair of mixtures were prepared using the same proportions to verify the findings. A third test set was prepared that included one control mixture and one with 30% LWFA replacement.

Laboratory tests included slump, unit weight, temperature, and air content of fresh concrete; semi-adiabatic calorimetry, compressive strength, splitting tensile strength, and static modulus of elasticity; surface resistivity; rapid chloride permeability at 28 days; University of Cape Town Air Permeability Method; and restrained shrinkage.

Field Testing

The field test site was the bridge on 220th Street over Pine Creek in Buchanan County. The bridge was a 176 ft long and 30 ft wide three-span bridge, with the eastern half built using a conventional concrete mixture and the western half built using internal curing concrete.

LWFA concrete placement on the bridge deck

Strain gauges attached to the underside of the bridge

The deck was 8 in. thick with a nominal 2.5 in. cover to the top layer of reinforcement and a nominal 1 in. cover to the bottom layer of reinforcement. Six wireless corrosion sensors were installed 0.5, 1.0, and 1.5 in. below the concrete surface in both the control and test sections.

Concrete was placed and sampled on June 28, 2013. All concrete came from a fixed batch plant and was delivered in ready-mix trucks. Fresh concrete tests were conducted by Buchanan County Engineering/Secondary Roads staff, and hardened samples were transported to the PCC Pavement and Materials Research Laboratory for further testing. The same suite of tests was conducted on all materials.

After the bridge was constructed, three sets of live load tests were conducted:

- Immediately after construction and just before opening to traffic (August 2013)
- A year after the initial load test (August 2014)
- A little more than two years after the initial load test (November 2015)

For all load tests, the bridge girders and deck were instrumented with strain transducers and static load tests were conducted using a fully loaded tandem-axle dump truck of known weight. Testing focused on the east and west end spans and evaluated three main structural characteristics:

- Strain magnitudes in the deck
- Transverse load distribution
- Composite action

For each set of tests, six load cases were evaluated. Load Cases 1 and 6 placed the load truck 2 ft from the guardrail. For Load Cases 3 and 5, the truck's interior axle line was located 2 ft from the longitudinal centerline of the bridge, which placed the trucks 4 ft apart from each other when the cases were superimposed and allowed a two-lane loading case to be evaluated. Load Case 4 centered the truck on the centerline of the bridge, which allowed the symmetry in transverse load distribution and general bridge behavior to be evaluated. For Load Case 2, the axle closest to the guardrail was centered between Girder Lines 1 and 2, which maximized the deck strain between those two girders.

Lifecycle Analysis

The lifecycle cost and service life prediction was performed using the Life-365 Service Life Prediction Model software.

Key Findings

- The unit weight and stiffness values of the LWFA laboratory mixtures were slightly lower than those of the control, as expected.
- The use of LWFA in the laboratory mixtures had little effect on the elapsed time to reach peak temperature.
- Neither the 20% or 30% LWFA laboratory mixtures dramatically affected the concrete's mechanical properties, but the LWFA dosage improved the permeability.
- Based on the average stress rate values, all three laboratory mixtures (one control and two with 20% or 30% LWFA replacement) were classified as having a "low" potential for cracking.
- Surface resistivity readings on the bridge deck indicated that the IC section had a marked benefit over the control section.
- The corrosion sensors indicated no evidence of corrosion.
- The results of the live load tests indicate that the west and east spans exhibited similar levels of transverse load distribution for any given year and little change in structural performance throughout the project; the deck is adequately stiff, with no noticeable difference between the performance of the west and east spans under load; and the bridge exhibits adequate composite section behavior for both the west and east spans.
- Little difference could be detected in the structural performance of the test and control sections after two years.
- Based on the lifecycle cost and service life prediction analysis, the service life for the IC section is predicted to be about 20 years longer than that of the control section. The initial cumulative present value is higher for the IC section, but it will be lower after about the year 2060.

Implementation Benefits and Readiness

Internally curing concrete mixes made using LWFA have the potential to reduce shrinkage, increase strength, lower permeability, extend the service life of concrete structures, and decrease required cement content. These benefits are most useful in bridge decks that are exposed to aggressive environments and are at a high risk of cracking.

This research found no significant differences between the structural behavior of the LWFA half of the bridge deck and the conventional concrete half of the bridge deck.

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