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Fiber Reinforced Concrete and Deck Slab Cracking

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Abstract

Many bridges in the state of India have been identified to have cracking in the concrete deck. Cracking has been identified in the negative and positive moment regions of bridges on both the top and bottom surface and can appear before or shortly after the opening of the structure to live loads. Significant cracks widths and various degrees of cracking exist in different bridge systems including both concrete and steel superstructures. A number of causes have been identified, including thermal movement, plastic shrinkage, and early age settlement, as well as a number of other issues. Polymer fibers are a possible solution to many of the causes of bridge deck cracking: they have been shown to help early age properties like shrinkage and movement, and as a bonus, fibers improve post-cracking behavior. More understanding of the benefits and uses of polymer fibers in concrete is needed. The study researched the properties of four-polymer fiber: two of the fibers were microfibers, and two were microfibers. Each fiber was tested at several dosage rates to identify optimum dosage levels. Early age shrinkage, long-term shrinkage, compressive strength and tensile strength were investigated. The most likely causes of the observed early-age cracking were found to be inadequate curing and curing and failure to properly eliminate the risk of plastic shrinkage cracking. Macro fiber and microfiber were found to have different impacts on concrete behavior, with different optimal dosage rates. Microfiber greatly dried out the concrete mixture, hindering workability. The microfiber substantially reduced plastic shrinkage and improved concrete strength at early age, Macro fibers, while not hindering workability did not provide benefit as great as the microfiber to the concrete strength.

Keywords: *Concrete, Slab Cracking, plastic shrinkage, Macro fibers.*

Introduction

Bridge decks slab have many problems with cracking. Early age cracking is the most common deck distress reported by the State Highway Agencies. These include thermal movement, early age shrinkage, and early age settlement. These causes may all be counteracted by the addition of polymer fiber. Polymer fibers have been shown to be beneficial to the early age properties of concrete as well as to crack mitigation. Research presented here analyzes a number of fiber and dosage rates for their shrinkage properties. Four types of fiber are tested; each one is tested at three to five different dosage rates. The results indicate that long-term strength is not strongly impacted by polymer fiber addition, but early age shrinkage is greatly decreased and early age strength is increased. While the expansive corrosion of steel reinforcement is a major concern in reinforced concrete bridge deck slabs, the noncorrosive fiber-reinforced polymer (FRP) composite bars provide an excellent alternative reinforcement In this paper, the behavior of edge-restrained concrete bridge deck slabs reinforced with glass FRP and carbon FRP bars was investigated. Six full-scale deck slabs 3000 mm long × 2500 mm wide × 200 mm deep were constructed and tested to failure in the laboratory. Three deck slabs were reinforced with glass FRP (GFRP) bars, two deck slabs were reinforced with carbon FRP (CFRP) bars, and the remaining slab was reinforced with steel bars as control. The test parameters were the reinforcement type and ratio in the bottom transverse direction. The deck slabs were supported on two steel girders spaced at 2000 mm center-to-center and were subjected to a monotonic single concentrated load over a contact area of 600 × 250 mm to simulate the footprint of sustained truck wheel load (87.5 kN CL-625 truck) acting on the center of each slab. The experimental results were presented in terms of cracking, deflection, strains in concrete and reinforcement, ultimate capacity, and mode of failure. It was observed that the mode of failure for all deck slabs was punching shear with carrying capacities of more than three times the design factored load specified by the Canadian Highway Bridge Design Code. It was also concluded that the maximum measured crack widths and defections at service load level were below the allowable code limits. In addition, a new empirical model to predict the punching shear capacity of restrained FRP-reinforced bridge deck slabs was introduced and verified against the available models and experimental results of others researchers.

Research

The research that was conducted focused on the shrinkage properties of fiber-reinforced concrete, both long term and at early age. The matrix tested is an extension of that test, with four new fibers and several higher dosage rates. The primary objective of this research was to evaluate the fibers' usefulness in controlling bridge-deck cracking. To study this, tests were selected that focused on the shrinkage behavior of the concrete. The primary tests included unrestrained shrinkage, compression strength, splitting tensile strength, and a new test unrestrained shrinkage from time zero. The only modification to the mixes was the addition of the fiber, and the removal of a corresponding volume of sand to compensate. The fiber dosage rates were set at high levels, compared to those typically used for microfibers. It was hoped that the limits of the fibers' usefulness would be reached and the point at which the improvement of the mix diminished located for each fiber. The matrix used consisted of one, three and five pounds per cubic yard dosage rates, as those levels had given good results in previous research. The eight-pound per cubic yard dosage was removed from the matrix, as the same research indicated that dosage was too high for microfiber mixes, as workability became a major issue, and shrinkage increased over the five-pound dosage rate. For the microfiber mixes, much higher dosage rates were possible without loss of workability, so ten and fifteen pounds per cubic yard dosages were tested as well, to evaluate the limits of the fiber usefulness.

Tests

Each batch of the matrix had the same set of tests run on it. The fresh concrete tests performed were the slump test, air content test, temperature, and unit weight. The tests that were run included compressive strength, tensile strength, unrestrained shrinkage, and unrestrained shrinkage from time zero.

Fresh Concrete Tests

Several environmental conditions were measured at the time of batching, in addition to several fresh concrete tests being run. The air temperature and humidity were tested with a combined thermometer/hygrometer device. The concrete temperature was measured with a probe thermometer. The unit weight and air content of the mixes were measured with a pressurized air pot. The pot was weighed, filled with concrete, and weighed again. Using this data, and the fact that the pot was 0.25 cubic feet in volume, the unit weight was measured. The air content was measured according to ASTM C231. Figure 5.1 shows the air content pot apparatus. The slump test was carried out according to ASTM C143. Figure 5.2 shows the slump cone apparatus in use, before finishing.

Figure 1: Air Content Pressurized Air Pot Apparatus

Figure 2: Slum Test Apparatus

Compression Strength

The compressive strength of the concrete was obtained using the procedures in ASTM C39. Generally, twenty-five cylinders of concrete were cast in 4x8" plastic cylinder molds. These were greased with diesel prior to batching to facilitate the samples' removal. The molds were removed at about one day after batching, and the first samples broken. Three cylinders were broken at each testing time, unless there were not enough samples or one of the samples failed as a result of an obvious defect, in which case the result was thrown out. The cylinders were tested in a Forney compression-testing machine; neoprene caps set in metal plates were used to provide an even loading surface. The load was applied at a rate between 16,000 and 38,000 pounds per minute. These tests were run at 1, 7, 14, and 28 days. Figure 5.3 shows a compression test setup.

Conclusions

Bridge decks have problems with cracking. These problems are caused to a large extent by thermal movement, early-age shrinkage, and early age settlement. All three of these issues may be counteracted by the addition of polymer fibers. Polymer fibers also assist in reducing crack widths after cracking.

Microfibers and microfibers behave differently, and should be treated differently. Microfibers affect workability by drying the mix out; macro fibers by making finishing difficult. Low to moderate dosages of fibers improve early age compression strength significantly, but 28 day compression strengths are not influenced much. The addition of fibers slightly increases 24 hour splitting tensile strengths; 28 day effects are insignificant. Fibers slightly decrease ASTM unrestrained shrinkage results, measured from 24 hours to 28 days. Fibers drastically reduce early age shrinkage, depending on the dosage level; higher is better, up to a certain point that is different for each fiber. Fibers dramatically change failure types; all failures were more ductile.

The optimum dosage rate for Stealth fiber seemed was approximately 3 lb per cubic yard; the benefits were moderate. Grace Microfiber's optimum dosage rate was 3 lb per cubic yard, and the benefits seen were significant. The best dosage rate for Strux 90/40 was about 10 lb per cubic yard, and that dosage showed exceptionally good plastic shrinkage benefits, greater than any other mix in this research. Finally, the HPP fiber had its optimum dosage rate at either 3 or 5 lb per cubic yard, and had the best strength results in this study. The unrestrained shrinkage from time zero test performed excellently. This test allowed good quantitative measurements to be made of plastic shrinkage starting at the batch time. The results correlated well with the ASTM unrestrained shrinkage test. The main objective of this research was to identify the causes of longitudinal early age cracking in concrete deck segments placed adjacent to the newly replaced bridge deck expansion joints and to provide a blueprint of steps necessary to perform this type of investigation.

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