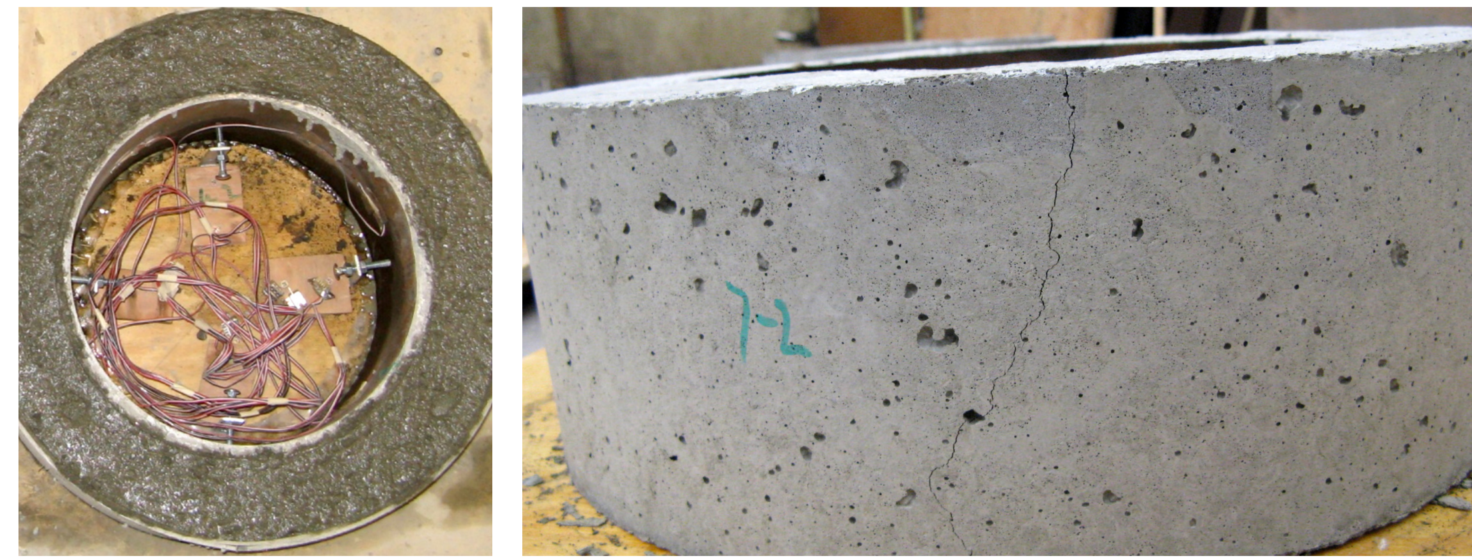
Research Note

Mitigation Strategies for Early-Age Shrinkage Cracking in Bridge Decks

April 2010

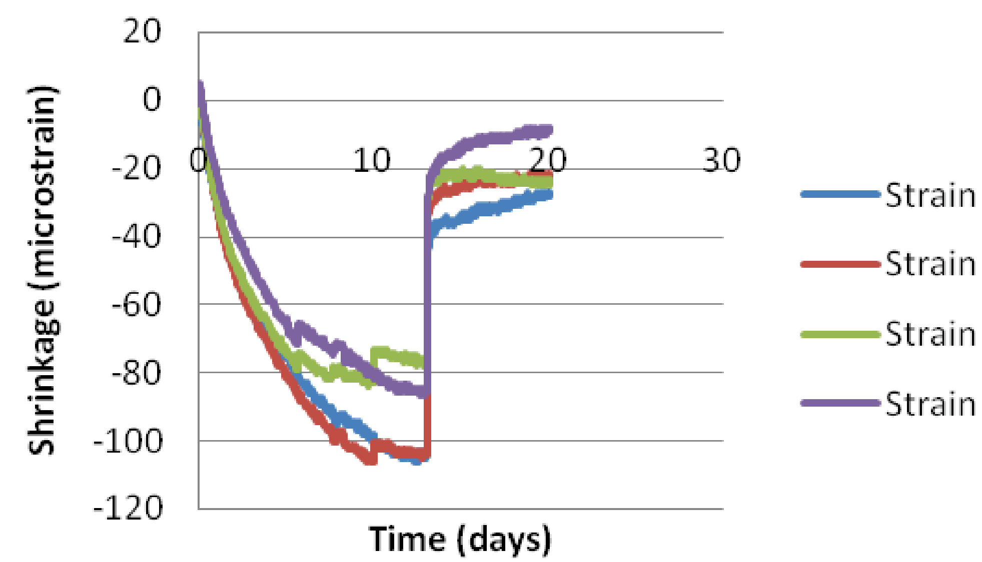
Washington State Department of Transportation



AASHTO ring test for restrained shrinkage measurement.

Background

Early-age shrinkage cracking of concrete bridge decks is a common problem in the U.S. When the induced tensile stress is larger than the tensile strength of the concrete, cracking occurs. According to a survey conducted by Krauss and Rogalla (1996), more than 100,000 bridges in the U.S. have experienced early-age transverse cracking.



Occurrence of shrinkage cracking in AASHTO ring.

Summary and Results

Based on the experimental evaluation of different mix designs conducted in this study, the following conclusions were obtained: (1) The use of SRA significantly reduces the free and restrained shrinkages of all concrete mixes using aggregates from Washington State; (2) The replacement of cement by fly ash decreases the early-age strength of concrete, and concrete containing fly ash cracks earlier than the corresponding concrete without fly ash; (3) Paste volume plays an important role in the free shrinkage of concrete, and concrete mixes with a smaller paste volume have lower tendency for shrinkage cracking; (4) Concrete cracking resistance is the combined effects of both its flexural (tensile) strength and its free shrinkage properties, and a concrete mix with an acceptable tensile strength and low free shrinkage strain is anticipated to have relatively good cracking resistance; (5) ADVA 190 high-range water-reducing admixture has a considerable effect on adjusting the workability of concrete; (6) When several chemicals are used in one concrete mix, it is difficult to achieve the desired fresh concrete properties, such as air content; and (7) Both the size of coarse aggregates and the source of coarse aggregates play a very important role in the property of concrete: the larger coarse aggregates reduce both the free shrinkage and restrained shrinkage properties and also minimize the paste content.

Recommendations

Based on the comprehensive experimental program conducted in this study, the following recommendations were suggested for improved concrete design to mitigate the shrinkage cracking in concrete: (1) SRA is recommended to be used in concrete mix to mitigate early-age shrinkage cracking in concrete bridge decks; (2) Adding fly ash or including more fly ash in the partial replacement of cement is not recommended due to its low early-age strength; (3) Concrete designs with less paste volume are recommended to be used to increase the cracking resistance; (4) Using as large a size of coarse aggregate as practical is recommended in construction; and (5) When several cementitious materials and chemical admixtures are used in the same concrete mix, trial batches should be evaluated before field applications.

Implementation

The outcome of this study identified optimum concrete mix designs as appropriate mitigation strategies to reduce or eliminate early-age shrinkage cracking and thus help minimize shrinkage-associated cracking in concrete bridge decks, potentially leading to longer service life.

WSDOT will utilize the results of this study in the future to eliminate early age bridge deck shrinkage cracking.

Report Title and WA-RD Number

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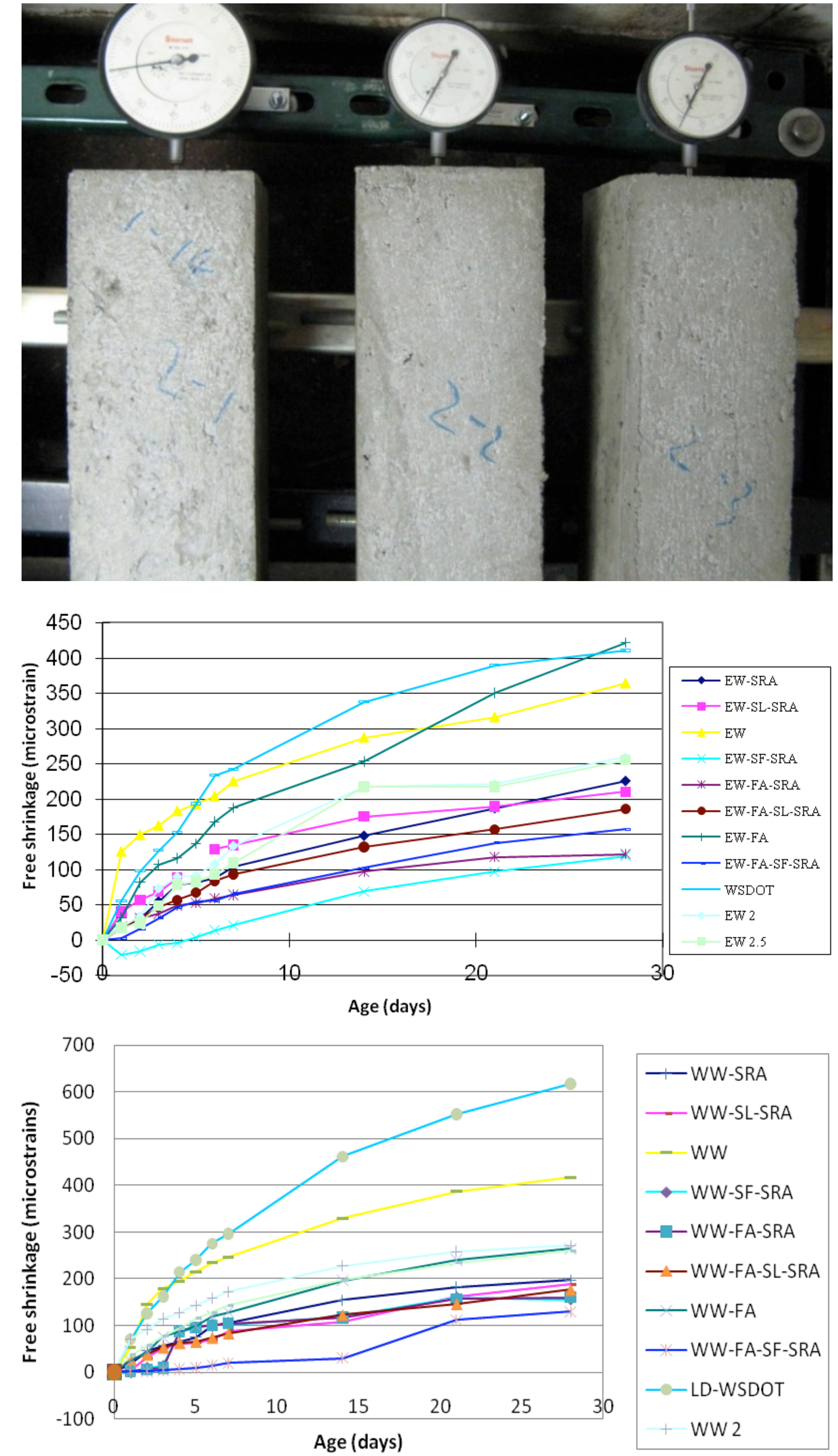
The Problem

The presence of early-age cracking in concrete bridge decks increases the effects of freeze-thaw damage, spalling due to sulfate and chloride penetration, and corrosion of steel reinforcement, thus resulting in premature deterioration and structural deficiency of the bridges. A recent investigation by the Washington State Department of Transportation (WSDOT) found transverse, full-depth cracks (Figure A) in the decks of all inspected bridges that developed as a result of early-age concrete shrinkage (occurring within 48 hours after the deck concrete is poured). These cracks in the bridge decks provide an avenue for water, de-icing chemicals, sulfates, and other corrosive agents to penetrate into the concrete and substantially diminish the decks' service life. Concrete deck repair is expensive and can result in significant traffic delays. Accordingly, there is an urgent need to reduce the extent of this cracking and thereby prevent the premature deterioration. Although the concrete materials, concrete mix designs, design specifications and construction technologies have changed a lot over the years, shrinkage cracking still remains a significant problem and is prevalent in construction.

Figure A

Transverse, Full-depth Cracks on a Prestressed Girder Bridge developed within 48-hours of pouring.



Free shrinkage measurement.

Research Approach

The goal of this research is to find mitigation strategies for early-age shrinkage cracking in concrete bridge decks. A comprehensive literature search was first conducted. Based on the literature, the main causes of shrinkage cracking and mitigation strategies were identified. With recommendations from WSDOT and the previous studies, the evaluation of concrete mix designs was considered as a key mitigation strategy to minimize or eliminate early-age shrinkage cracking in concrete bridge decks and 20 concrete mixes were accordingly designed. Two current WSDOT concrete mixes were also included as benchmarks for comparisons with other newly developed concrete mix designs. Different sources (i.e., eastern Washington (EW) and western Washington (WW)) and aggregate sizes (i.e., 1.5 in., 2 in. and 2.5 in.) were considered, and the effects of paste content, cementitious materials (cement, fly ash, silica fume, slag), and shrinkage reducing admixture (SRA) were experimentally evaluated. A series of concrete fresh, mechanical, and shrinkage property tests were performed for all the 22 groups of concrete mixes, from which optimum concrete mix designs minimizing or eliminating the shrinkage cracking were obtained.