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An experimental study of bridge deck cracking using type K-cement

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HIGHLIGHTS

- Modeled shrinkage strain in concrete bridge decks through laboratory experimentation.
- Varied concrete mix designs to study the shrinkage properties of each one.
- Type K cement can reduce the tensile strain in decks by 40–50 microstrain at early age.
- Both decks cracked, but onset of cracking was delayed by 3 weeks in the type K deck.

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ABSTRACT

This paper experimentally investigates the effects of drying shrinkage on bridge decks, its relation to bridge deck cracking, and possible methods for abating its effects. The experiments were performed through the use of two 7 ft. × 10 ft. experimental concrete bridge bays, each instrumented with strain and temperature gages throughout the deck and girders. The data was collected in a six months' time frame. The first deck was poured with a control concrete mixture used currently in Illinois. The second deck was poured with type K expansive cement concrete, which could battle the effects of shrinkage. For both decks, the results indicated a compressive strain throughout the rebar and along the top surface of the concrete, except for the locations where cracks are found (at these locations the strain slopes upward into tension). The strain in the type K deck, though, was notably less than that in the control deck and the onset of cracking was delayed by three weeks, giving the indication of an improvement over the current mix design.

1. Introduction

Mitigation of cracking in concrete bridge decks remains a challenging problem across the United States, with the dominant pattern of cracking being transverse along the deck as shown in Fig. 1. Though many factors can exacerbate this cracking (such as traffic loads, temperature gradients, and steel deck corrosion), most cracks are initially formed due to shrinkage of concrete. Concrete shrinks anywhere that it is poured, but bridge decks are especially vulnerable to cracking due to their large surface-to-volume ratios, which exposes the concrete to a high water evaporation rate. Even so, there are many ways to counteract the effects of shrinkage, reduce cracking, and increase the life-span and durability of bridges. Due to the overwhelming amount of agreement that restraint shrinkage is the primary cause of cracking, this study focuses on combating that type of shrinkage.

Restraint shrinkage that occurs soon after the deck has been poured is theorized to be one of the primary causes of cracking. In order to verify this, bridges in the state of Illinois were inspected and it was found that regular transverse crack patterns occurred in both positive and negative moment regions in multiple decks. Many of the inspected bridges were designed to not be fully composite in negative moment regions over piers, and yet the same crack pattern was found. Consequently, it is believed that the effects of intermittent structural restraint in combination with long distances without expansion joints caused the concrete shrinkage to create cracking throughout the decks. Significant research has been conducted in the past on assessment of cracking in bridge decks through field investigation (French [3,4]); new approaches to concrete mix designs, particularly using local aggregates and other concrete constituent materials (Streeter [8]; Lawler et al. [5]; Brown et al. [2]), using steel or polymer fibers or other additives (e.g., Whiting et al. [10]; Altoubat and Lange [1]; Subramaniam et al. [9]; Naik et al. [7]); structural design configuration and the potential influence on restraint of the deck (Le et al. [6], French et al. [3,4]); improved curing procedures; and development of laboratory procedures to validate whether specific mixes used in the field are susceptible to premature cracking (Brown et al. [2]).

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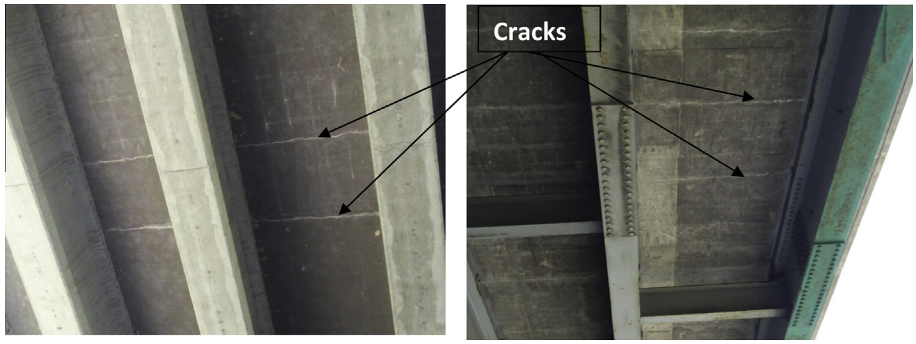

Fig. 1. Transverse cracking in concrete (left) and steel girder bridges (right).

Table 1
Mixture proportions.

	Control mix lbs./ft.^{3}	Type K mix lbs./ft.^{3}
Water	9.90	10.60
Cement (type I)	22.50	16.85
Cement (type K)	N/A	3.33
Fine aggregate	41.80	39.60
Coarse aggregate	67.60	67.80
w/c Ratio	0.44	0.52

Many different studies reported analysis of bridge deck cracking. Their most important finding is that, as discussed earlier, cracking is primarily caused by concrete shrinkage. Although, they also found that minimizing restraint in the bridge, using cast-in-place or newly precast concrete girders rather than steel girders, and pouring the deck when the ambient temperature is neither too cold nor too hot, could all lead to a decrease in cracking. Even though extensive previous research has been done, shrinkage cracking is still not fully understood and an effective way to combat it has not yet been established. Therefore, this study strives to investigate shrinkage cracking through laboratory experimentation using specific concrete mixtures.

Multiple mitigation techniques have shown the ability to extend bridge life, such as shrinkage compensating cements and shrinkage reducing admixtures. There are countless different variations that can be made in a concrete mix design, but the goal of this study is to investigate how shrinkage works in a full-scale bridge deck, as well as possible structural improvements that can reduce it. Therefore, The University of Illinois has been tasked with the materials side of this research. After studying different ways to alleviate shrinkage cracking, the University of Illinois found that a mix design using type K cement was the best choice for further study. The mixture proportions for both the control and type K cement are currently used in Illinois, and listed in (Table 1).

Type-K is hydraulic cement designed for use in shrinkage-compensating concrete, which provides an effective way to minimize the cracking caused by drying shrinkage in portland cement concrete. The expansion associated with the cement hydration produces compressive stresses in the concrete, which consequently reduces the detrimental tensile stresses, lead to shrinkage cracking in the concrete. Type-K cement has the advantage to minimize shrinkage cracks and reduce porosity provides long-term protection against seepage of salts and other corrosive materials from penetrating bridge decks, thus reducing the corrosion of the reinforcing steel and improving the durability of structures.

2. Experimental program

In order to study the effects of shrinkage, an experimental model had to be established. The experiment had to fit within the confines of the lab, yet still provide shrinkage results that could feasibly be found in a full-scale bridge deck. Through investigation of bridge decks in Illinois and based on recommendations from Illinois Department of Transportation (IDOT) engineers, a typical 10 ft. × 7 ft. section of a reinforced concrete bridge bay was settled upon. In order to simulate the continuity of an actual bridge, C-channels were placed around the outside perimeter of the experimental prototype. This created a stiff member for the rebar to attach to, which mimics a concrete deck protruding outwards on all sides of the apparatus. The reinforcement and bay design will be discussed in detail later in Section 2.1.

The experimental program was split up into two separate six month tests. Initially, the experimental model was instrumented with strain and temperature gages and then poured using a control mix design. After this test was completed, a new experimental model was built with the same specifications and also instrumented and then poured using a mix design that included a type K cement mixture. In order to create similar curing conditions, both the control and type K decks were poured in late September.

2.1. Laboratory bay design

There are many factors to be considered when dealing with shrinkage cracking, but the largest contributor is the amount of restraint located in the concrete. Steel girders, shear connectors, rebar, and even parapets all provide attachment points for the concrete and restrain its movement. The restraints cause strains to develop within the deck as the concrete begins to shrink. Therefore, it was imperative that the design of the bridge deck used in these experimental models very closely replicated the "average" design found in the field. Using the recommendations from IDOT engineers and the review of decks in Illinois, a 10 ft. × 7 ft. representative bridge bay with an 8 in. slab thickness was designed and built. The bay is supported by two 10 ft. W12 × 79 steel girders at a 5 ft. spacing. The steel girders are connected to the concrete slab through shear studs spaced at 1 ft. longitudinally along the girder span. The girders are raised off the ground at their ends with 1 ft. long W12 shapes supports. The supports are used to not only to simulate the bay being held in place at the corners, but also to raise the deck off the ground for better study. The girders are also constrained by two C 6.0 × 8.2 steel C-channels in order to prevent girder twisting. Finally, along the perimeter of the concrete bay are four 10 × 15.3 steel C-channels. These C-channels have holes, which give the G60 epoxy coated rebar an attachment points in order to simulate the continuity of a real bridge superstructure. The concrete slab was reinforced using two rebar layers. The top rebar layer is located 1 in. from the top of the concrete surface and is designed as shown in Fig. 2. The bottom layer is located 2 in. from the bottom of the concrete surface and its design is shown in Fig. 2. Caution was taken when

Fig. 2. Deck with rebar and formwork.