INDOT Research

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INVESTIGATION OF BRIDGE DECK CRACKING IN VARIOUS BRIDGE SUPERSTRUCTURE SYSTEMS

Introduction

Many bridges in the state of Indiana 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 surfaces and can appear before or shortly after the opening of the structure to live loads. Significant crack widths and various degrees of cracking exist in different bridge systems including both concrete and steel superstructures. This research project was divided into five phases to determine the factors affecting transverse and longitudinal bridge deck cracking, as well as, to develop design recommendations that minimize or prevent these types of bridge deck cracking. The research focused on the design and construction of new bridge decks. For bridge decks being rehabilitated with overlays, overlay cracking can also be of concern. Therefore, for completeness, an overview of this type of cracking is also provided.

The first phase was a field evaluation to investigate the scope of the problem. Using the information gathered from the first phase, the second phase instrumented a typical bridge structure to provide an understanding of the behavior of transverse cracks in a concrete bridge deck. With the findings from the previous two phases, the third phase conducted a laboratory investigation to study the effects of shrinkage and restraint of a concrete deck and to determine the contribution of stay-in-place steel forms to the formation of transverse cracking. The fourth phase evaluated the effect of formwork type on restrained shrinkage. The two primary form types considered were wood forming and stay-in-place metal deck pans. In the final phase, the effect of reinforcing bar spacings and epoxy thickness on crack width and spacings were evaluated.

Findings

Based on the research investigation, transverse deck cracking is caused by restrained shrinkage of the concrete deck. Restraint is primarily provided by composite attachment to the girders. Longitudinal deck cracking is caused by a combination of factors including restrained shrinkage and the use of an angle to support stay-in-place formwork with a leg turned into the deck. The angle leg included in the deck forms a crack initiation location. Since reduction of restraint is not possible due to the economic advantages of composite construction, recommendations are presented to minimize deck cracking.

The following recommendations are provided to minimize bridge deck cracking in new construction.

1. The requirement in the *INDOT Standard Specifications* (1999) for a minimum of 96 hours of wet curing of the concrete deck is insufficient. A minimum 7 day wet curing process is recommended to reduce drying shrinkage cracking by reducing overall shrinkage strains.
2. Drying shrinkage of the concrete mix should be minimized. Measures that reduce the shrinkage tendency of the mix should be encouraged. This can be

achieved through mix design and materials selection. As an example, proper aggregate selection and gradation can produce lower shrinkage mixes.

3. Concrete compressive strength should be minimized. Strengths higher than specified by design are not required and can exacerbate deck cracking. Higher concrete strengths affect cracking in several ways. Higher compressive strengths resulting from additional cement can produce higher shrinkage concretes. Furthermore, higher compressive strength concretes have a higher tensile strength that can increase the likelihood of reinforcement yielding as well as a higher modulus of elasticity that provides additional internal restraint. Current INDOT class C concrete requires 659 lbs/yd^3 of cement which is regularly producing strengths in excess of 6,000 psi. This cement requirement can be reduced for bridge decks as only 4000 psi is required by design.
4. Current code requirements for shrinkage and temperature reinforcement do not place sufficient limits on bar spacings to control early-age bridge deck cracking. To produce maximum crack widths in the range of 16 mils, a maximum bar spacing of 6 in. is necessary when using current cover requirements and currently accepted epoxy thicknesses (6 to 12 mils). It should be noted that during this study, INDOT increased the required thickness to the range of 8 to 13 mils which falls approximately in the range investigated here. If epoxy coating thicknesses are increased beyond these values in the future, smaller bar spacings would be required to achieve similar crack widths.
5. Additional reinforcement above current practice is required to control the crack widths in concrete decks. The total amount of reinforcing steel recommended is:

$$A_s = \frac{6\sqrt{f_c'}}{f_y} A_g$$

where:
A_g = gross area of section, in.^{2}
A_s = area of reinforcement in cross-section, in.^{2}
f_c' = specified compressive strength of concrete, psi.
f_y = specified yield strength of reinforcement, psi.

The purpose of this reinforcement is to prevent yielding of the reinforcement that can result in uncontrolled crack growth. For 4,000 psi concrete and 60,000 psi reinforcement, this requirements results in 0.63% steel in the deck cross-section.
6. Alternatives to stay-in-place (SIP) forms should be considered. From the experimental investigation, SIP forms produce curling that can exacerbate cracking on the top surface of the deck, provide for a crack initiation location due to the pan shape, as well as prevent visual inspection of the bottom deck surface. Removable formwork with a flat surface eliminates these problems.
7. Support of formwork through the use of an angle leg turned into the deck should be discontinued. The leg of the angle included in the deck causes a discontinuity and crack initiation location producing longitudinal girder edge cracking. As an alternative, the angle can be turned down to eliminate this discontinuity.

Implementation

The recommendations provided through this study can be easily implemented to directly minimize bridge deck cracking. Implementation should proceed primarily through the INDOT Design Division, INDOT Materials and Tests Division, INDOT Contracts and Construction, and INDOT District Construction Engineers. It should be noted that the recommendation regarding curing duration was implemented in March 2001 as a result of this research. In addition, the Design Division will be implementing the recommendations regarding reinforcement amounts and spacings on a trial basis. A bridge on SR 135 will be constructed using #4 longitudinal reinforcement spaced at 6 in. The performance will be compared with that of another bridge being constructed as part the same contract with #4 longitudinal bars spaced at 12 in (current design levels).

Significant benefits can be realized through the implementation of these recommendations. Excessive bridge deck cracking provides a route for intrusion of moisture and chlorides that can lead to corrosion of deck reinforcement, a primary cause of bridge deterioration. In addition, full depth cracking allows water and chlorides to penetrate through the deck and can lead to deterioration of the superstructure as well as the substructure. Minimizing deck cracking has the potential of reducing maintenance and deck replacement costs as well as increasing the lifespan of the bridge.

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