JOINT TRANSPORTATION RESEARCH PROGRAM

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Increasing Bridge Deck Service Life *Volume I—Technical Evaluation*

Introduction

Deterioration of bridge decks is a primary factor limiting the lifespan of bridges, especially in cold climates where deicing salts are commonly used. Research has been previously performed to mitigate deterioration by controlling deck cracking using improved design methods, such as bar spacing and cover requirements, or by decreasing the permeability and porosity of concrete through the use of high performance concrete. While these methods can improve performance and extend service life, chloride and moisture ingress, as well as cracking, cannot be eliminated. Full-depth cracks that are caused by restrained shrinkage allow for corrosive conditions at early ages in both the top and bottom reinforcement mats. Therefore, corrosion of the reinforcing steel ultimately occurs. However, the service life of the deck has the potential of being significantly improved if corrosion resistant reinforcement is used.

While epoxy-coated reinforcement has become standard practice to improve corrosion resistance, this reinforcement type is not immune to corrosion. Its performance is highly dependent on the condition of coating. The coating can be damaged even with special care during manufacturing, transportation, and construction. Therefore, the use of other corrosion reinforcing materials has significant potential to provide improved performance. The objective of this research program was to examine the efficacy of using alternative materials in a bridge deck from both technical and economic perspectives. Technical criteria include bond strength, cracking performance, and corrosion resistance, while economic criteria comprise agency and user costs associated with construction, replacement, and rehabilitation over the life cycle.

Findings

The technical evaluation was conducted in three phases and considered a wide range of corrosion resistant reinforcing materials. These materials included stainless steel (316LN, Duplex 2205, Duplex 2304, XM-28), MMFX II microcomposite steel, and coated steel (epoxy, dual-coated zinc and epoxy (Z-bar), hot-dipped galvanized, and zinc-clad).

Bond Strength

The bond strength of corrosion resistant reinforcing materials was tested to ensure that current design procedures for the calculation of splice and development lengths are appropriate. Stainless-steel, MMFX II microcomposite, hot-dip galvanized, and Zbar (dual-coated) reinforcing bars have bond strengths comparable to black bars. Coated bars other than galvanized and dual-coated have reduced bond strengths. Epoxy-coated bars had on average 11% less bond strength than black while un-plated zinc-clad and tin-plated zinc-clad bar had on average 18% and 26% less bond strength than black bars, respectively. Modification factors were developed for development and splice length calculations when other bar types are used. The test data were also combined with other data available in literature to construct a simple model for development and splice length calculations that consider a wide range of corrosion resistant bar types as well as confined and unconfined conditions.

Cracking Performance

Because the variations in the surface roughness of different corrosion-resistant reinforcement, cracking performance was evaluated by testing slab specimens. The effect of bar spacing and the effect of high reinforcement stresses that can be obtained by high-strength reinforcement (stainless steel or MMFX II) were evaluated. The bar types affected the spacing and width of primary cracks. For the control of crack widths, it is recommended that crack widths be calculated based on black bars and multiplying modification factors. Design code approaches can directly incorporate these factors to reduce the spacing of corrosion-resistant bars by dividing the black bar spacing by the modification factors. Epoxy-coated, galvanized, and MMFX II microcomposite reinforcing bars do not need modification. Recommendations are provided for the control of crack widths for the other bars evaluated in this study. Spacing of the reinforcement affected both crack spacing and crack widths. As the reinforcement spacing increased, the number of primary cracks decreased and the crack spacing increased. This trend is consistent with previous test

results. Crack spacing and crack width, however, did not increase significantly after spacing of the reinforcement became greater than 12 in. For design purposes, the crack spacing can be considered to be constant for bar spacing greater than 12 in. For a given stress, this results in the same crack widths for spacings greater than 12 in. In addition, crack widths of high-strength bars (stainless steel and MMFX II) that have a roundhouse stress-strain curve will increase nonlinearly at high stresses (>80 ksi). However, the crack widths of high-strength bars can be conservatively calculated using the model for conventional black bars up to bar stresses of 80 ksi.

Corrosion Resistance

While all uncracked specimens showed relatively very low currents at 503 days of exposure, several cracked specimens demonstrated high corrosion activity, which was electronically measured by the macrocell test and confirmed by visual examination through an autopsy of the specimen. Autopsy results demonstrated that the longitudinal steel (secondary reinforcement in a bridge deck) corroded at the intersection with the transverse steel (primary reinforcement in a bridge deck) while the transverse reinforcement corroded over its entire length. The transverse steel, typically located parallel to the cracks, was under direct chloride exposure over its entire length while the longitudinal steel had direct exposure only at the location of the cracks. When corrosion-resistant chromium-based reinforcing steel was used in the top mat and black bars were used in bottom mats, a galvanic couple resulted where the bottom black steel corroded to protect the top corrosion-resistant reinforcement. This galvanic couple occurred because the cracks in the macrocells were formed full depth where chlorides can easily reach the bottom black bars from the first day of testing. This condition is realistic as bridge decks have full-depth cracks that are formed at early ages (<28 days) due to restrained shrinkage. Both the electrical current measurements and autopsy results demonstrated that mixing reinforcement where black bars are provided in the bottom mat is detrimental to corrosion resistance. Specimens that were tied with black ties indicated more corrosion than specimens with plastic ties. In addition, tying reinforcing steel with dissimilar metallic materials resulted in galvanic coupling. When stainless steel ties were used to connect black reinforcement, increased damage of the black bars resulted. In addition, black ties used to connect stainless bars

resulted in crevice corrosion and pitting of the stainless steel bar. Only similar metallic or inert (plastic) materials should be used to tie reinforcement.

Implementation

Based on the research conducted in the technical evaluation, a number of recommendations were developed that address the selection and design of corrosion-resistant reinforcing bars and are appropriate for adoption into the INDOT Bridge Design Manual. First, guidance is provided to assist in the selection of corrosion-resistant reinforcement based on the duration of testing completed in this study. Extended corrosion exposure is required to provide improved estimates as well as differentiation of the materials. It is recommended that both the top and bottom mats of the bridge deck be constructed of the same reinforcing material. Mixing of reinforcing material causes galvanic corrosion. It is recommended that reinforcement be tied with only inert (plastic) ties or ties made of the same material as the reinforcing bar to avoid galvanic coupling between tie material and reinforcement. Second, design recommendations are provided for the calculation of development and splice lengths including modification factors required for the use of corrosion-resistant reinforcement. It was found that stainless-steel, MMFX II, hot-dipped galvanized, and Zbar perform similarly to black bars and do not require modification. Finally, design recommendations are provided for the control of cracking and the calculation of crack widths. The control of cracking is also of importance, even with the use of corrosion-resistant reinforcement, and is essential for durability of the bridge deck.

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