Guide to Remediate Bridge Deck Cracking

Tech Transfer Summary

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TR-782: Guide to Remediate Bridge Deck Cracking

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Background & Problem Statement

Many concrete bridge decks experience cracking within a few months or years of construction. Early-age cracking may occur due to a variety of reasons and can be mitigated through material and structural design and the implementation of best practices during construction, but preventive strategies are not always successful at eliminating early-age cracking. When early-age cracking occurs, the cracks facilitate the ingress of water and, in northern states such as Iowa, chlorides from deicing chemicals, which accelerate corrosion and corrosion-induced distress, i.e., delaminations and spalls. Cracks are undesirable because they increase maintenance needs, traffic disruptions, and costs.

Crack repairs, such as crack-chasing with a polymer resin, and deck treatments, such as floodcoats or overlays, can restore durability and mitigate the impacts of cracking to varying degrees, but identifying the most cost-effective strategy that mitigates future maintenance needs and costs for a reasonable up-front or initial cost can be challenging. Bridge owners would benefit from having institutional guidance and decision-making aids for selecting cost-effective remediation strategies to address early-age bridge deck cracking.

Objective

The primary objective of this study was to develop a comprehensive guide for remediating cracks in bridge decks in Iowa that users could reference for guidance on the selection and implementation of crack repairs. The guide was to include decision matrices and tables for selecting crack remediation strategies based on existing deck condition, deck age, and crack characteristics and provide discussion on choosing between potential strategies based on practical concerns, such as ease of installation.

Research Description

This study consisted of a literature review of bridge deck crack repairs, their costs and service life benefits, and existing decision-making aids for selecting crack repairs; extensive service life modeling of generic bridge decks in Iowa with a variety of cracking scenarios and crack remediation strategies to develop quantitative estimates of the service life benefits of the remediation strategies; and life-cycle cost analysis of the crack remediation strategies. The practices and selection criteria identified in the literature review, estimated service life benefits, and initial and life cycle costs were synthesized to develop informative tables and decision matrices for the selection of crack remediation strategies for Iowa bridge decks up to 10 years of age based on deck age, crack density, and crack width. A series of crack remediation treatment profiles containing discussion of when the crack repair or deck treatment is considered appropriate based on deck condition and crack characteristics, a description of the construction procedures and materials, and estimated service life and repair costs based on DOT letting data and literature was developed as well.

Crack Remediation Strategies for Bridge Decks

When considering repairs for a cracked bridge deck, options include judicious neglect, penetrating sealers, crack-chasing methods, floodcoat methods, overlays, and replacement. Judicious neglect, or "do nothing," is appropriate when cracking has little to negligible impact on performance. A full deck replacement is extreme, but may be appropriate if distress is so extensive that remediation would be comparable in cost to a deck replacement or if on-going deterioration would cause an unacceptably short bridge deck life and could not be prevented. The remaining crack remediation methods fall somewhere between these two extremes in effectiveness at restoring deck durability and life-cycle cost. Crack-chasing methods include applying a gravity-fed polymer by crack-chasing, routing and sealing cracks, and pressure injecting cracks with epoxy. Overlays considered for crack remediation in the guide included thin polymer overlays, premixed polymer concrete overlays, and hot-mix asphalt overlays with waterproofing membranes (HMAWMs). The initial unit costs estimated for each crack remediation strategy based on bid data from the California, Illinois, Iowa, Michigan, Minnesota, and South Dakota Departments of Transportation (DOTs) are shown in the table below.

Summary of initial unit costs of different crack remediation options considered for decision trees

Crack Remediation Option	Average Unit Cost
Penetrating Sealer	$8.6 per SY
Crack Chasing	$8.4 per LY
Flood Coat	$24.5 per SY
HMAWM	$82.7 per SY
Thin Polymer overlay	$66.4 per SY
Premixed Polymer Overlay*	$135.9 per SY
Deck Replacement	$900 per SY

*Cost assumes an overlay thickness of 3/4 inch

Decision-making aids found in literature generally considered the NBI (National Bridge Inventory) condition rating, deck condition state, deck characteristics, crack characteristics, and/or repair characteristics to guide the user to an appropriate crack repair. Deck characteristics included deck age and chloride exposure while the crack characteristics considered included the crack type, location, depth, width, density, and activity. Repair characteristics were often related to the repair's cost, service life, and ease of installation.

Service Life Benefits of Crack Remediation Strategies

Chloride-induced corrosion of generic Iowa bridge decks was modeled using WJE CASLE™, a mechanistic service life modeling software. An uncracked bridge deck was modeled as a baseline scenario, followed by bridge decks with a variety of cracking scenarios and the remediation treatments identified in literature. The cracking scenarios included bridge decks with "mild," "moderate," "severe," and "very severe" cracking, defined based on crack density as shown in the table below. Crack density in this study was defined as the sum of the length of all the visible cracks divided by the area of the bridge deck under evaluation. Additionally, both "shallow" cracks, assumed to be less than 1 inch in depth, and "deep" cracks, assumed to penetrate to the depth of the top mat of reinforcing steel, were modeled. The impact of applying the crack remediation treatments when the cracked bridge decks were at 0, 2, 5, and 10 years of age was investigated. Because penetrating sealers must be applied at regular intervals for a benefit to be realized, the use of three applications of a penetrating sealer at regular intervals of 4 and 6 years was also evaluated.

Model inputs were determined based on the Iowa DOT's standard practices, the guidance document *fib Bulletin 34: Model Code for Service Life Design*, and results from previous inspections and studies conducted on bridges across the United States. Bridge deck repair was assumed to be initiated at a threshold value of 5% damaged area and bridge replacement at 20% damaged area.

Category	Crack Density (ft/ft^2)
Mild Cracking	Less than 0.10
Moderate Cracking	Between 0.10 and 0.22
Severe Cracking	Between 0.22 and 0.37
Very Severe Cracking	Greater than 0.37

The service life modeling showed that penetrating sealers can extend the time-to-5% damage and time-to-20% damage by up to 2 to 6 years for Iowa bridge decks. Floodcoats can extend the time-to-5% damage and time-to-20% damage by up to 12 to 18 years, HMAWMs by up to 5 to 10 years, thin polymer overlays by up to 17 to 22 years, and premixed polymer concrete overlays by up to 35 years. The service life benefits of the crack remediation treatments varied with the crack density and bridge deck age at application. For example, floodcoats performed at their best when applied at early ages of 0 to 2 years, but could still increase the time-to-5% damage and time-to-20% damage by at least 5 years when applied at a deck age of 5 years and at crack densities greater than 0.10 ft/ft^2. The cracking scenarios and application times at which each crack remediation treatment provided its best service life benefit varied between treatments. The key parameters that controlled when the treatments were effective were the corrosion initiation time of the untreated deck and the threshold damage percentages at which repair and replacement are triggered.

Data-Driven Decision Trees

Data-driven decision trees were developed to aid Iowa bridge owners in selecting effective and cost-efficient crack remediation strategies when dealing with cracked bridge decks. The particular tree to be used depends on the depth of the cracks and the age of the deck. Within each decision tree, for a given crack density, the user is provided a list of crack remediation options that could be implemented and is provided the following supporting information:

- The maximum crack width for which the repair or treatment is applicable,
- The initial cost of the repair or treatment,
- The service life benefit of the repair or treatment, and
- The life cycle cost of the bridge deck if treated or repaired.

Two of the trees are for addressing shallow cracks for bridge decks up to 5 years of age. The first tree for addressing shallow cracking assumes the user's objective is to achieve the same service life as an uncracked and untreated generic Iowa bridge deck, i.e., the Base Case scenario, and as such shows the service life and life cycle cost benefits with respect to the Base Case scenario. The second tree assumes the user's objective is to optimize the service life of the cracked bridge deck under consideration and, therefore, shows the benefits of treating cracked bridge decks with respect to the Do Nothing scenario, i.e., cracked but untreated. The remaining decision trees are for addressing deep cracks. These decision trees were presented in terms of bridge deck age at the time of remediation strategies application for bridge decks between 0 and 2 years of age, 5-year-old bridge decks, and 10-year-old bridge decks. The service life and life cycle cost benefits of each remediation strategy are expressed relative to both the Base Case and Do Nothing scenarios in each of the trees to be used for addressing deep cracks.

A set of three summary decision trees that do not show the cost and service life benefits but have better utility were also developed. The summary decision tree for bridge decks between 0 and 2 years in age is shown as an example. While the more informative data-driven decision trees permit users to select a crack remediation strategy based on available funds and desired service life, the summary decision trees simply require the user to know the crack density and crack widths and then provide a list of suitable crack remediation strategies in order of recommendation.

All of the decision trees are subject to the following limitations:

1. Crack densities exceeding 0.37 ft/ft^2 shall be investigated prior to implementation of repairs.
2. Crack widths between 30 and 40 mils with a crack density exceeding 0.10 ft/ft^2 shall be investigated prior to implementation of repairs.
3. The decision trees do not apply to crack densities exceeding 0.50 ft/ft^2 or crack widths exceeding 40 mils.
4. The decision trees were developed based on the performance of Iowa bridge decks with respect to chloride-induced corrosion and with consideration for the bridge deck maintenance practices familiar to contractors who conduct work in Iowa, and as such are not necessarily directly applicable to other states.

Recommendations for Future Work

Future work should consider how shifts in standard practice, particularly changes in the deck concrete mix designs, will affect the service life and cost benefits of the crack remediation strategies and if these changes will influence the strategies' cost-effectiveness. Additional studies that measure the impact of repairs and treatments on bridge deck life, particularly in the field, are also needed to help the industry develop and refine methods for quantitative modeling of bridge deck repairs and treatments and extrapolating future costs with better accuracy.

Summary decision tree for crack remediation options implemented at a bridge deck age between 0 and 2 years.

<table>
<tr><th rowspan="2">Crack Width</th><th colspan="4">Crack Density (ft/ft^2)</th></tr>
<tr><th>Mild
< 0.10</th><th>Moderate
0.10 to 0.22</th><th>Severe
0.22 to 0.37</th><th>Very Severe
0.37 <</th></tr>
<tr><td rowspan="3">Shallow cracks (Map cracks)</td><td>Do Nothing</td><td>Do Nothing</td><td>Do Nothing</td><td>Do Nothing</td></tr>
<tr><td>Penetrating Sealer</td><td>Penetrating Sealer</td><td>Penetrating Sealer</td><td>Penetrating Sealer</td></tr>
<tr><td>Flood Coat</td><td>Flood Coat</td><td>Flood Coat</td><td>Flood Coat</td></tr>
<tr><td rowspan="5">5 to 15 mils</td><td>Do Nothing</td><td rowspan="2">Penetrating Sealer +/- Reapplication</td><td rowspan="2">Flood Coat</td><td rowspan="2">Flood Coat</td></tr>
<tr><td>Penetrating Sealer +/- Reapplication</td></tr>
<tr><td>Crack Chasing, Flood Coat</td><td>Flood Coat</td><td rowspan="2">Thin Polymer Overlay</td><td rowspan="2">Thin Polymer Overlay</td></tr>
<tr><td rowspan="2">Thin Polymer Overlay</td><td>Thin Polymer Overlay</td></tr>
<tr><td>Premixed Polymer Overlay</td><td>Premixed Polymer Overlay</td><td>Premixed Polymer Overlay</td></tr>
<tr><td rowspan="3">15 to 30 mils</td><td>Crack Chasing, Flood Coat</td><td>Flood Coat</td><td>Flood Coat</td><td>Flood Coat</td></tr>
<tr><td rowspan="2">Thin Polymer Overlay</td><td>Thin Polymer Overlay</td><td>Thin Polymer Overlay</td><td>Thin Polymer Overlay</td></tr>
<tr><td>Premixed Polymer Overlay</td><td>Premixed Polymer Overlay</td><td>Premixed Polymer Overlay</td></tr>
<tr><td rowspan="2">30 to 40 mils</td><td>Crack Chasing</td><td>Thin Polymer Overlay</td><td>Thin Polymer Overlay</td><td>Thin Polymer Overlay</td></tr>
<tr><td>Thin Polymer Overlay</td><td>Premixed Polymer Overlay</td><td>Premixed Polymer Overlay</td><td>Premixed Polymer Overlay</td></tr>
<tr><td>Greater than 40 mils</td><td colspan="4">Investigate</td></tr>
</table>

Green indicates most suitable option; Yellow indicates suitable option; orange indicates least suitable option; blue indicates a thin polymer overlay or a premixed concrete polymer overlay is the most suitable option; pink indicates need for additional investigation.

It is assumed that if 25% of the deck cracks exceed the crack width limit for a given option, then that option should be excluded from viable options.

Implementation and Benefits

The contents developed for the final report are intended to be used as general guidelines for the Iowa DOT to choose optimal crack remediation options for bridge decks with different ages and different extents of cracking. Portions of the final report, specifically the decision trees as well as the discussion on crack inspection and classification, can be included in the Iowa DOT Bridge Maintenance Manual and/or Standard Specifications for Highway and Bridge Construction, as appropriate. The crack remediation treatment profiles and specifications for crack remediation treatments compiled from other state DOTs can also be referenced to update or develop standard specifications or special provisions for the Iowa DOT. By implementing the information and material developed in this study, the Iowa DOT will decrease unexpected maintenance needs of cracked bridge decks, which will decrease life-cycle costs and provide better service by decreasing the number of future traffic disruptions.