CIVIL ENGINEERING STUDIES
Illinois Center for Transportation Series No. 24-007
UILU-ENG-2024-2007
ISSN: 0197-9191

Concrete Bridge Deck Crack Sealing

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Research Report No. FHWA-ICT-24-007

A report of the findings of

ICT PROJECT R27-SP62
Concrete Bridge Deck Crack Sealing

https://doi.org/10.36501/0197-9191/24-007

Illinois Center for Transportation

March 2024

TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No. FHWA-ICT-24-007	**2. Government Accession No.** N/A	**3. Recipient's Catalog No.** N/A
4. Title and Subtitle Concrete Bridge Deck Crack Sealing		**5. Report Date** March 2024 **6. Performing Organization Code** N/A
7. Authors Mohsen A. Issa (https://orcid.org/0000-0002-0207-5722), Ali F. Alawieh, Hussein A. Daoud		**8. Performing Organization Report No.** ICT-24-007 UILU-2024-2007
9. Performing Organization Name and Address Illinois Center for Transportation Department of Civil and Environmental Engineering University of Illinois at Urbana-Champaign 205 North Mathews Avenue, MC-250 Urbana, IL 61801		**10. Work Unit No.** N/A **11. Contract or Grant No.** R27-SP62
12. Sponsoring Agency Name and Address Illinois Department of Transportation (SPR) Bureau of Research 126 East Ash Street Springfield, IL 62704		**13. Type of Report and Period Covered** Final Report 7/1/23–3/31/24 **14. Sponsoring Agency Code**
15. Supplementary Notes Conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration. https://doi.org/10.36501/0197-9191/24-007		
16. Abstract Bridge decks are prone to various types of cracking due to a combination of factors, including traffic loads, temperature variations, moisture, and chemical exposure. This report tackles the critical issue of bridge deck cracking by systematically dissecting the problem, exploring various crack types, and emphasizing the crucial inspection and categorization of cracks for effective remediation planning. The report focuses on the selection of appropriate sealants, considering regional conditions. It delves into remediation treatments, offering a spectrum of options based on National Bridge Inventory ratings, deck conditions, and crack characteristics. Additionally, the report classifies sealant products and introduces a cost-analysis framework, promoting well-rounded decision-making that balances short-term project costs with ongoing maintenance expenses. Serving as a valuable resource, the report equips decision-makers with knowledge and tools to optimize resource allocation, enhance bridge deck integrity, and improve maintenance practices.		

17. Key Words Bridges, Cracks, Guidance, Decision Trees, Maintenance, Remediation, Sealer, Overlay, Products, Cost, Procedure, NBI, Properties, Epoxy, Silane, Siloxane	**18. Distribution Statement** No restrictions. This document is available through the National Technical Information Service, Springfield, VA 22161.		
19. Security Classif. (of this report) Unclassified	**20. Security Classif. (of this page)** Unclassified	**21. No. of Pages** 94 + appendix	**22. Price** N/A

Form DOT F 1700.7 (8-72) **Reproduction of completed page authorized**

ACKNOWLEDGMENT, DISCLAIMER, MANUFACTURERS' NAMES

This publication is based on the results of **ICT-R27-SP62: Concrete Bridge Deck Crack Sealing**. ICT-R27-SP62 was conducted in cooperation with the Illinois Center for Transportation; the Illinois Department of Transportation; and the U.S. Department of Transportation, Federal Highway Administration.

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EXECUTIVE SUMMARY

This report is a comprehensive guide for addressing the critical issue of bridge deck cracking in transportation infrastructure. It begins by dissecting the problem, delving into the various types of cracks that can manifest, elucidating their underlying causes, and discussing the significance of their orientation and patterns. The report further provides a detailed insight into how these cracks should be inspected and categorized by depth and activity level, which is essential for gauging the extent of deterioration and planning remediation efforts effectively.

A key focus of this report is the selection of appropriate sealants for bridge deck cracks. It outlines the factors that need to be considered when making this decision, emphasizing the importance of considering regional climate conditions, traffic volumes, and the specific characteristics of the cracks. The report includes a comprehensive list of sealants approved by the Illinois Department of Transportation (IDOT) and other pertinent sources, giving decision-makers various solutions to address their unique challenges.

The report then transitions into a thorough exploration of remediation treatment actions. It outlines a spectrum of options, ranging from minimal intervention, like “doing nothing,” to more extensive measures, such as applying penetrating sealers, routing and sealing, or even replacing the entire bridge deck. Each option is analyzed considering factors like National Bridge Inventory (NBI) condition ratings, deck condition states, and specific crack characteristics, enabling bridge engineers to make informed choices based on the condition of their bridge decks and budget constraints.

Moreover, the report includes a detailed classification of sealant products, clarifying the various types available and their suitability for different applications. It extends its scope to have lists of approved concrete sealants in neighboring states such as Wisconsin, Minnesota, and Indiana. This comparative analysis serves as a valuable resource for agencies seeking insights into the practices of nearby jurisdictions, fostering knowledge sharing and regional cooperation.

Finally, the report introduces a comprehensive cost-analysis framework for assessing the long-term economic impact of remediation strategies chosen by agencies. This framework promotes a well-rounded decision-making process that balances short-term project costs with ongoing maintenance expenses.

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CHAPTER 1: INTRODUCTION

Bridge decks are prone to various types of cracking due to a combination of factors, including traffic loads, temperature variations, moisture, and chemical exposure. Cracking in bridge decks can lead to the deterioration of the structure, compromising its safety and longevity.

Several studies have investigated the causes and types of bridge deck cracking and the appropriate methods for repairing and preventing them. Saadeghvaziri and Hadidi (2002) investigated the causes and types of cracking in a reinforced concrete bridge deck in the United States. The study found that the most common types of cracks were transverse and longitudinal, caused by drying shrinkage, autogenous shrinkage, plastic shrinkage, thermal shrinkage, and creep.

In addition, several studies have explored innovative materials and techniques for preventing bridge deck cracking. Amini et al. (2023) investigated using fiber-reinforced concrete overlays to mitigate cracking in bridge decks. The study found that using fiber-reinforced concrete overlays resulted in reduced cracking and improved durability compared to traditional concrete overlays.

Overall, bridge deck cracking is a significant concern for the safety and longevity of bridge structures. Ongoing research is necessary to identify the causes and types of cracking and effective methods for repairing and preventing them.

CHAPTER 2: LITERATURE REVIEW

TYPES OF CRACKS

Bridge deck cracks can occur due to various factors such as shrinkage, thermal expansion and contraction, and traffic loading. Different types of cracks can appear on bridge decks, including longitudinal cracks parallel to the direction of traffic, transverse cracks perpendicular to the traffic flow, diagonal cracks caused by shear stresses or settlement, and map cracks that start at the bottom of the deck and move upwards (Curtis & White, 2007). Epoxy or polyurethane injection grouts can be used to fill the cracks and prevent water infiltration. Additionally, crack sealants like silicone or hot-pour sealants can be applied. Structural repairs may be necessary in some cases, particularly for diagonal cracks. Although they do not affect bridge durability significantly, map cracks can lead to secondary issues like delamination and concrete spalling (Schmitt & Darwin, 1995). Proper concrete curing after construction is crucial in preventing map cracking.

CAUSES OF BRIDGE DECK CRACKING

According to a study by Issa (1999), the cracking of concrete bridge decks at early ages can be attributed to several factors, with some factors having more influence than others. While it is challenging to isolate individual factors, the following list presents the potential causes of cracking, arranged in descending order of importance:

1. Inadequate concrete curing procedures during hot weather conditions lead to a high evaporation rate and significant shrinkage. It is attributed to insufficient concrete cover, inadequate coverage with a curing compound, and delays in applying concrete protection.
2. Use of high-slump concrete.
3. Excess water in the concrete is present due to inadequate mixture proportions and retempering.
4. Insufficient top reinforcement cover resulting from inadequate reinforcing detail plans, improper placement of reinforcement, and shallow deck depth caused by deflections during construction.
5. Inadequate vibration of the concrete.
6. Insufficient reinforcing details at the joint between the new and old deck.
7. Improper sequence of pour.
8. Weight and vibration generated by machinery.
9. Weight of the forms used in the construction process.
10. Deflection of the forms.

It is worth noting that the lack of concrete protection during the early stages of the concrete age is more significant than in later stages. Proper care taken at later periods cannot compensate for the absence of protection during the initial stages. It is also important to mention that the effects of creep and shrinkage are related closely to concrete protection and curing procedures, making it difficult to separate them as distinct categories, as they are highly dependent on curing practices.

Cracking in bridge decks can occur at different stages of their life span. In the early stages, cracking can be attributed to a complex combination of factors related to material properties, structural design, construction practices, and environmental conditions during deck construction. These factors influence the concrete's tendency to shrink or contract. Different elements of the structural design, including the existence of girders and the lengths of spans, along with factors in mix design such as aggregate size and volume, and differences in environmental conditions between the upper and lower surfaces of the deck—like temperature and wind speed—define the boundary conditions or restrictions placed on the deck. These restraints hinder the natural shrinkage of concrete, leading to strain development.

Consequently, this strain induces tensile stress in the concrete, which is influenced by the concrete's modulus of elasticity, itself determined by the concrete mix design. If the tensile stress exceeds the tensile strength of the concrete, the concrete will crack. A significant portion of early-age cracking arises from the interaction between volumetric changes in the concrete of the deck and the restraints placed on the deck, as described above. Specific situations that can cause early-age cracking include:

1. **Autogenous Shrinkage** refers to the natural shrinkage that occurs during the chemical hydration process of cement, where water in the capillary pores is consumed. When the available water is limited (typically when the water-to-cementitious material ratio is below approximately 0.40), the water consumption and subsequent drying of the cement paste lead to a decrease in the overall volume of the concrete, as mentioned by Holt (2001).

2. **Drying Shrinkage** occurs after the concrete has undergone the process of moist curing and exposure to the surrounding environment. As the concrete dries out, the initial loss of free water has minimal impact on the overall volume of the concrete. However, as the drying process continues, the concrete gradually loses adsorbed water until it reaches a state of equilibrium with its surroundings. This results in a contraction or shrinkage of the bulk concrete. The extent of this shrinkage is influenced by factors such as the ambient relative humidity and the specific mix design of the concrete as discussed by Krauss and Rogalla (1996).

3. **Differential Drying** occurs when the surfaces of the concrete dry out faster than the interior of the deck, resulting in greater contraction and subsequent development of stresses within the concrete. Bridge decks are prone to differential drying due to their elongated and thin plate-like structure, giving them a high surface-area-to-volume ratio. Within the first year, differential drying gradients commonly form across the thickness of the deck. These gradients are influenced by factors such as the permeability of the concrete, the ambient relative humidity, occurrences of precipitation, and rates of evaporation from both the top and bottom surfaces of the deck.

4. **Plastic Shrinkage**, as mentioned by Balakumaran et al. (2018), occurs when water present in freshly placed concrete migrates to the surface due to settling of the paste and aggregates caused by gravity. This surface water is further lost through evaporation, and the evaporation rate is influenced by temperature, ambient relative humidity, and wind speed. Plastic shrinkage cracks develop when the rate of evaporation at the concrete surface exceeds the replacement rate through natural bleeding. The rapid drying of the concrete surface leads to localized contraction, causing the concrete to crack at an earlier age in random patterns since it has not yet gained significant strength.

5. **Volumetric Changes Resulting from Thermal Effects** occur when concrete expands or contracts in response to temperature fluctuations. When cement hydration takes place, the heat generated causes temporary heating of the concrete, leading to early-age stresses as the concrete subsequently cools. To minimize these stresses, controlling the maximum temperature reached during hydration and slowing down the initial cooling rate is important. Once the concrete has set, variations in temperature on a seasonal and daily basis result in volumetric changes and induce stresses within concrete decks. The extent of volumetric change depends on the magnitude of temperature fluctuations over time and the coefficient of thermal expansion (CTE) of the concrete used in the deck. The CTE is primarily influenced by the type of aggregate employed in the concrete. By reducing the CTE, the strain and subsequent stresses experienced by the deck can be mitigated. Cracking attributed to thermal effects typically occurs within the first year or two, as the concrete adapts to its environmental and restraint conditions (Portland Cement Association, 1970).

6. **Settlement (subsidence)** occurs during concrete setting as its components naturally settle based on density. Water and paste rise while aggregates settle. The presence of steel reinforcement prevents the constituents from rising or settling, leading to the accumulation of bleed water beneath the rebar. Eventually, this water finds an escape route and rushes to the surface, creating a channel. This channel becomes a weak plane with a high water and paste content, making it prone to cracking after the concrete has set. This crack serves as a direct path to the rebar. The likelihood of settlement and associated cracking increases when using high slump mixes, mixes with an inadequate aggregate gradation, large bars, low concrete cover, and deep concrete placements. Settlement cracks are not commonly observed on bridge decks; their residual effects can still influence the occurrence or orientation of cracking in alignment with the reinforcing bars. It is vital to conduct a proper investigation to avoid mischaracterizing these types of cracks as transverse cracks, as mentioned by Dakhil et al. (1975) and Issa (1999).

Additional factors contributing to early-age cracking include removal of the formwork, bending of the deck, surface crazing caused by excessive water finishing, damage from frost, and other material-related issues. However, it is essential to note that these factors are not the leading underlying causes of the widespread cracking typically observed in bridge decks.

Cracking that occurs at a later stage is usually attributed to material degradation, such as the corrosion of deck reinforcement or structural loading:

1. **Steel Corrosion**: A common issue mentioned by Larosche (2009) is where the application of deicing chemicals during winter leads to the presence of chlorides. Over time, these chlorides initiate the corrosion of the reinforcing steel in bridge decks. As the steel corrodes, rust products are formed, which have a larger volume than the original steel. This expansion creates internal stresses within the concrete, ultimately resulting in cracking that propagates from the area around the reinforcement. The cracks can propagate horizontally, causing delamination, or vertically, resulting in wide surface breaking cracks. These cracks not only compromise the deck's structural integrity, but also accelerate the corrosion process of the reinforcing steel.

2. **Freeze-Thaw Distress**: Deterioration of concrete happens through random cracks and scaling due to repetitive freeze-thaw cycles, especially when the concrete is in a critically saturated state (Larosche, 2009). The presence of salts and chlorides further worsens the degradation process. It is crucial to incorporate certain measures during the concrete mix design to combat freeze-thaw distress. These include appropriate air entrainment, maintaining low to moderately low water-to-cementitious material ratios, and utilizing durable aggregates. Northern states have implemented these requirements in their specifications, leading to a relatively low incidence of freeze-thaw distress on bridge decks.

3. **ASR (alkali-silica reaction) Distress**: ASR distress presents itself like freeze-thaw distress, with the appearance of random cracks. ASR occurs when alkalis in the concrete interact with reactive silica in the aggregates, resulting in the formation of a gel. Concrete deterioration only transpires when this gel comes into contact with moisture, causing swelling, expansive stresses, and subsequent cracking. The occurrence of ASR on bridge decks has become relatively uncommon due to several preventive measures. Aggregates used in construction are now evaluated for reactivity before use, the alkali content in cementitious materials is carefully regulated, and bridge decks are typically shielded from external sources of alkalis, such as soils. Nonetheless, isolated cases of ASR deterioration can still be observed on bridge decks, as mentioned by Larosche (2009).

4. **Structural Loading**: Another cause of bridge deck cracking stems from flexural loads in the negative moment regions of continuous decks or unanticipated movement within the structure, such as differential settlement between piers and abutments. The degree of structural restraint on the deck influences the magnitude of the resulting stresses and requires careful consideration by bridge designers during the structural system design. Additionally, structural cracks may arise from overloading, such as excessive weight imposed by trucks or fatigue-related factors.

CRACKS ORIENTATION AND PATTERN

Longitudinal Cracks

Longitudinal cracks are a common type of distress that can significantly impact the structural integrity and durability of the bridge. These cracks typically run parallel to the direction of traffic, as shown in Figure 1, and can occur due to various factors, including traffic loading, shrinkage, thermal expansion and contraction, and aging of the bridge deck materials.

In bridge engineering, longitudinal cracks are classified into two main types: hairline and wide. Hairline cracks are typically less than 0.3 mm (0.012 in.) in width and may not penetrate through the full depth of the deck, while wide cracks exceed 0.3 mm (0.012 in.) in width and can extend through the entire deck thickness. The presence of longitudinal cracks in bridge decks can lead to several issues. First, they can allow the ingress of water, chloride ions, and other aggressive substances into the concrete deck, which can accelerate the corrosion of reinforcement and compromise the overall durability of the structure. Second, if left untreated, these cracks can propagate and widen over time, leading to increased structural distress and reduced load-carrying capacity of the bridge. Various techniques and materials are commonly used to repair longitudinal cracks in bridge decks. One approach is to inject epoxy or polyurethane grouts into the cracks. These materials have excellent adhesive properties and can effectively seal the cracks, preventing water infiltration and further deterioration. The injection process involves cleaning the crack, injecting the grout under pressure, and allowing it to cure and bond with the surrounding concrete. Another method for crack repair is the use of crack sealants. Silicone-based sealants and hot-pour sealants are commonly employed to fill the cracks. Silicone sealants provide flexibility and adhesion to the crack surfaces, accommodating slight movements and preventing water penetration. Hot-pour sealants, typically composed of rubberized asphalt or polymer-modified asphalt, are heated and applied into the cracks, providing a durable and waterproof seal, as mentioned by Schmitt and Darwin (1995) and Wiss, Janney, Elstner Associates (2017).

Figure 1. Photo. Example of longitudinal cracks (Ahmad & Khawaja, 2018).

Transverse Cracks

Transverse cracks in bridge decks can affect the structural integrity and longevity of the bridge. Unlike longitudinal cracks, transverse cracks run perpendicular to the direction of traffic, as shown in Figure

2. These cracks can occur due to various factors, including traffic loading, shrinkage, temperature fluctuations, and inadequate expansion joint design.

Transverse cracks in bridge decks can lead to several problems. They can allow water, chloride ions, and other harmful substances to penetrate the concrete bridge deck, leading to reinforcement corrosion and reduced durability. Additionally, transverse cracks can compromise the bridge's load-carrying capacity and accelerate the deterioration process if not addressed promptly (Krauss & Rogalla, 1996). Several techniques and materials are commonly employed to repair transverse cracks in bridge decks. One standard method is the use of epoxy injection grouts. These grouts can be injected into the cracks to fill and seal them, preventing water ingress and further deterioration. The process involves cleaning the deck cracks, injecting the grout under pressure, and allowing it to cure and bond with the surrounding concrete. Crack sealants, such as silicone-based or hot-pour sealants, can also be used to repair transverse cracks. Silicone-based sealants provide flexibility and adhesion to accommodate crack movement, while hot-pour sealants, such as rubberized asphalt or polymer-modified asphalt, offer durability and waterproofing, according to the Portland Cement Association (1970).

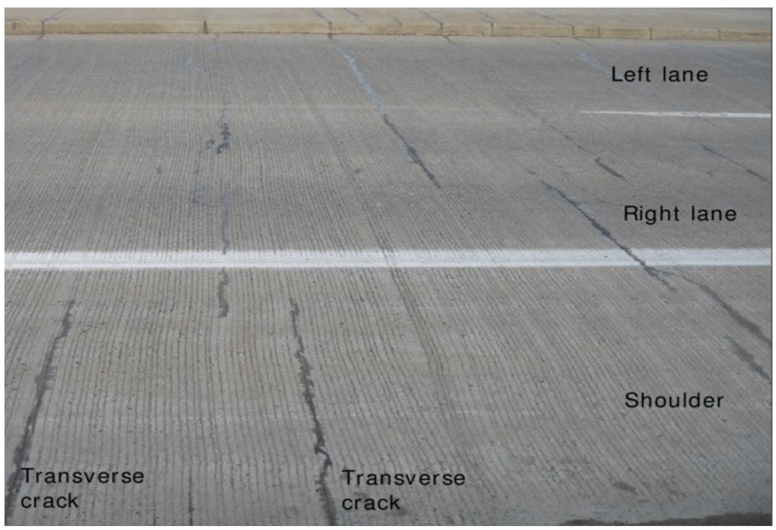

Figure 2. Photo. Example of transverse cracks in bridge decks (Fratta et al., 2015).

Diagonal Cracks

Diagonal cracks in bridge decks can impact the structural integrity and performance of the bridge. These cracks typically appear at an angle to the direction of traffic, as shown in Figure 3, and can result from various factors, including structural settlement, differential movement, inadequate reinforcement, or overloading.

The presence of diagonal cracks in bridge decks can lead to several concerns. These cracks can allow the ingress of water, chlorides, and other corrosive agents into the concrete, which can accelerate the deterioration of the reinforcement and compromise the overall durability of the structure. Diagonal cracks can also indicate potential structural deficiencies and reduce the bridge's load-carrying capacity if left unaddressed (Hopper et al., 2015).

Different repair techniques and materials are used to repair diagonal cracks in bridge decks. One approach is to use epoxy injection grouts, similar to the repair of longitudinal and transverse cracks. Epoxy injection grouts are injected into the cracks, filling and sealing them to prevent further water infiltration and deterioration. Proper surface preparation and crack cleaning are essential for effective repair.

Another method for repairing diagonal cracks is using fiber-reinforced polymer (FRP) composites. FRP materials, such as carbon fiber sheets or fabric, can be applied to the surface of the bridge deck to reinforce the cracked area and restore structural integrity. Using FRP composites can help distribute the loads and limit crack propagation (Chajes et al., 2019).

Figure 3. Photo. Example of diagonal cracks in bridge decks (Weiss et al., 2013).

Map Cracks

Map pattern cracks, also known as alligator cracking or fatigue cracking, refer to a distinct pattern of interconnected cracks that resemble the scales on an alligator's skin, as shown in Figure 4. These cracks typically occur in flexible pavement surfaces, such as asphalt, and are caused by repeated traffic loading, aging, and inadequate design or construction.

The map pattern cracks are characterized by a series of interconnected cracks forming a network of irregularly shaped blocks or polygons on the pavement surface. These cracks usually start as fine, longitudinal, or transverse cracks that propagate and interconnect, forming a series of interconnected polygons. The size and severity of the map pattern cracks can vary, ranging from small, localized areas to extensive coverage across the pavement surface.

Map pattern cracks significantly distress asphalt pavements and can lead to various issues. First, they allow water and moisture to penetrate the pavement layers, leading to further damage, including base course erosion and subgrade weakening. Additionally, these cracks can increase roughness, reduce skid resistance, and accelerate pavement deterioration, ultimately impacting ride quality and safety.

The appropriate repair method for map pattern cracks depends on the extent and severity of the cracking and the condition of the underlying layers. Some common repair approaches include:

- Crack Sealing: This method involves filling the individual cracks with a suitable sealant material to prevent water and debris intrusion. Hot-pour sealants, such as rubberized asphalt, are commonly used for effective crack sealing.

- Crack Filling: Like crack sealing, crack filling involves filling the cracks; however, it is typically used for wider deck cracks. Flexible asphalt-based materials or specialized crack fillers are applied to fill and seal the cracks, restoring the integrity of the pavement surface.

- Overlay or Resurfacing: In cases where the map pattern cracks are extensive and the underlying layers are compromised, an overlay or resurfacing may be necessary. This process involves applying a new asphalt layer on the existing pavement, providing a renewed and smoother surface (Vargas, 2012).

Figure 4. Photo. Example of map/pattern cracks in bridge decks (Wan et al., 2010).

INSPECTION OF DECK CRACKS

Crack inspection assesses whether the observed cracking necessitates repair and determines appropriate remediation options. It is crucial to report crack width and depth, as they influence the potential ingress of moisture and chloride, aiding informed decision-making. Based on findings in published literature (Krauss, 1994; Hopper et al., 2005), it is generally assumed that cracks wider than 5 mil (0.005 in.)—a width typically visible and measurable—allow moisture and chloride penetration. Once cracks reach 10 mil (0.010 in.), the concrete can no longer protect the crack location. The depth of the crack then determines whether chlorides and moisture directly access the reinforcement within the bridge deck. When inspecting bridge deck cracking to assess repair requirements and suitable crack remediation strategies, cracks can be categorized into three groups: shallow cracks, deep cracks reaching the reinforcement, and active cracks that show some change in direction, width, or depth over a measured period of time. The following sections provide an overview of each category and their classification based on observed conditions.

Shallow Cracks

Shallow cracks have a relatively small width, typically equal to or less than 5 mil (0.005 in.), and do not reach the reinforcement within the bridge deck. Although these cracks allow moisture and chlorides to penetrate more rapidly through the top portion of the concrete cover, their extent is limited to a depth of 1 in. for the service life modeling discussed in Chapter 4. The following characteristics can be used to classify cracks as shallow:

- Crack Pattern: Shallow cracks typically exhibit a map cracking pattern characterized by interconnected fine cracks resembling a map or network.
- Crack Width: Shallow cracks are generally narrow, with a width of 5 mil (0.005 in.) or less.
- Activity: Shallow cracks are considered "dormant" or non-active, meaning that the variation in crack width is minimal and can be disregarded.

To summarize, shallow cracks on bridge decks can be identified by their small width (less than 5 mil) and a map cracking pattern.

Deep Cracks

Deep cracks reach the reinforcement bars and, as such, significantly affect the durability of the bridge deck. They are primarily transverse cracks that form over the reinforcing bars and allow moisture and chlorides to have direct access to the steel, which may lead to more rapid corrosion initiation at cracked sections versus uncracked sections. As such, deep cracks tend to reduce the time for corrosion damage to manifest in cracked areas of the bridge deck. These cracks typically have a width of 5 mil (0.005 in.) or greater. The following characteristics can be used to classify cracks as deep:

- Crack Orientation: Determining the depth of cracks without concrete core sampling can be challenging. Therefore, it is assumed that transverse cracks extend to the reinforcing bars. The same assumption applies to other crack orientations and patterns, such as longitudinal cracks, unless a more detailed inspection confirms that they do not reach the reinforcement.
- Crack Width: Deep cracks typically have a width of 5 mil (0.005 in.) or more. Early-age cracks resulting from shrinkage or thermal effects generally range between 5 mil (0.005 in.) and 20 mil (0.020 in.), although larger widths are sometimes possible. In this guide, all observed transverse and longitudinal cracks are assumed to have a width of at least 10 mil (0.010 in.), at which the concrete is deemed to no longer protect the crack location. The maximum crack width considered is 40 mil (0.040 in.). Cracks wider than 40 mil (0.040 in.) require further investigation to determine the underlying cause.
- Activity: This section focuses on dormant deep cracks. It should be noted that these, mainly transverse cracks, may experience movement due to thermal changes in the concrete deck. While these thermal changes are generally insignificant and can be disregarded, wider cracks may impact the effectiveness of specific repair strategies.

Therefore, the selection of crack remediation options depends on the width of deep cracks.

In summary, transverse (and longitudinal) cracks on bridge decks with a width ranging from 10 mil (0.010 in.) to 40 mil (0.040 in.) are assumed to be deep cracks that reach the reinforcing steel.

Active Cracks

Active cracks, also called working cracks, are characterized by their variable widths over time, resulting from changes in deck loads or concrete temperature. These cracks, if deep, pose a significant durability concern for the bridge deck as they provide direct access for moisture and chlorides to reach the reinforcing steel.

For this report, active cracks encompass cracks of any width known to be actively changing or wide cracks with a width of 40 mil (0.040 in.) or greater. These cracks often have structural implications, such as cracking observed in negative moment regions over piers in continuous bridge decks, and their width can fluctuate under the influence of deck loads.

This guide does not explicitly address active cracks, as they typically occur in specific deck areas and require specialized repair approaches. Remediation options for this type of cracking often involve repairs that accommodate crack movement without compromising the structure, such as routing and sealing with a flexible sealant, or repairs that restore the structural integrity of the cracked deck section, such as epoxy injection.

REMEDIATION TREATMENT ACTIONS

Several state departments of transportation (DOTs) and the particular criteria they consider when choosing maintenance tasks for concrete bridge decks are compiled in Table 1. Each DOT assesses many input parameters to determine the best course of action for repair on its bridge decks. Many other maintenance procedures can be done, including thin overlays, epoxy injections, reactive silicate solution applications, crack sealing, sealer applications, and other procedures. The particular requirements and conditions of each state’s bridge decks determine which maintenance tasks should be chosen.

Table 1. Crack-Focused Maintenance Selection Tools/Guidance

Agency	Inputs Considered in Selection	Possible Maintenance Activities
Ohio DOT	Crack location (topside or soffit)	• Do nothing • Seal with a silane sealer • Treat crack with a high molecular weight methacrylate (HMWM), a reactive silicate solution, or a gravity-fed resin • Seal top surface with a HMWM, a reactive silicate solution, or a gravity-fed resin
Michigan DOT	• Deck condition rating • Crack type and depth	• Wash concrete surface • Seal concrete cracks • Apply a thin epoxy overlay
Minnesota DOT	Crack width	• Seal with a methacrylate • Seal with an epoxy
Missouri DOT	Crack width	• Apply a penetrating concrete sealer (silane) • Apply a low-viscosity polymer crack filler • Apply an in-deck bridge deck crack filler • Apply a chip seal
New York State DOT	• Crack width • Crack activity • Deicer exposure	• Do nothing • Apply a penetrating sealer • Seal with a HMWM or by epoxy injection
Virginia DOT	• Crack width • Crack type (cause) • Deck age	• Do nothing • Fill cracks
Wisconsin DOT	• Crack width and extent • Crack activity	• Apply a thin polymer overlay

The criteria and factors that a number of state DOTs took into account when choosing maintenance tasks for their concrete bridge decks are listed in Table 2. Each DOT takes into account various aspects, including age, chloride penetration depth, deterioration percentages, and deck condition rating, in order to make well-informed decisions. They implement a variety of maintenance procedures based on these inputs, including patching, crack sealing, applying sealers, overlays (rigid and flexible), and other treatments. The choices made for maintenance are based on the particular requirements and state of respective bridge decks.

Table 2. General Maintenance Selection Tools

Agency	Inputs Considered in Selection	Possible Maintenance Activities
Indiana DOT	• Deck condition rating • Wearing surface condition rating • Superstructure and substructure condition ratings • Percent deck deterioration	• Penetrating sealer • Seal cracks • Conduct partial and full-depth patching • Apply a flexible overlay • Apply a rigid overlay
Michigan DOT	• Deck condition rating • Percent deck deterioration • Soffit condition rating • Percent soffit deterioration • Increase in deck condition rating • Increase in soffit condition rating • Anticipated fix life	• Hold • Seal cracks • Apply a silane treatment • Apply a healer sealer • Apply an epoxy overlay • Patch the deck • Apply a hot-mix asphalt overlay with a waterproofing membrane
Virginia DOT	• Deck condition rating • Percent deck deterioration • Deck age • Depth of chloride front	• Clean and wash the deck • Fill the cracks • Apply an epoxy overlay • Patch the deck • Apply a rigid overlay
Wisconsin DOT	• Deck condition rating • Percent deck deterioration • Percent soffit deterioration • Benefit to deck from action • Application frequency	• Sweep/wash the deck • Seal the deck • Seal the cracks • Patch the wearing surface • Conduct full-depth patching • Apply a thin polymer overlay • Apply a polyester polymer concrete overlay • Apply a rigid concrete overlay • Apply a hot-mix asphalt overlay with a waterproofing membrane

The options to remediate bridge deck cracks are listed and categorized in Table 3.

Table 3. Remediation Treatment Options to Address Cracks in Bridge Decks

Category	Remediation Treatment Profiles
Judicious Neglect	Do nothing
Penetrating Sealers	Apply a penetrating sealer
Crack Chasing Method	• Apply a gravity-fed polymer by crack chasing • Rout and seal • Pressure inject with epoxy
Flood Coat Methods	Apply a flood coat
Overlays	• Apply a hot-mix asphalt with waterproofing membrane system • Apply a thin polymer overlay • Apply a rigid cementitious overlay • Apply a latex-modified concrete overlay • Apply a premixed polymer concrete overlay
Replacement	Replace the bridge deck

Do Nothing

The "do nothing" alternative involves deliberately deciding to postpone maintenance and repairs for a future time. By not addressing the cracks, their impact on the deterioration process can vary depending on factors such as their proximity to reinforcing steel, the presence of aggressive ions, and the extent to which chlorides and other aggressive ions can enter the cracks. When the deferred period ends and repairs are reconsidered, the deck's condition and the cracks' characteristics must be reassessed, and a fresh analysis must be carried out.

Cracks that are fine and shallow generally do not allow aggressive ions like chlorides to penetrate the concrete, thus having a minimal impact on durability. Among the properties related to cracks, their width is the most easily measured in laboratory and field settings. Numerous studies have explored the relationship between crack width, moisture penetration, chloride infiltration, and corrosion. According to the literature, the critical crack width ranges from 0.002 to 0.008 in. (Balakumaran et al., 2018; Krauss, 1994). Leakage has been observed in cracks as small as 0.002 in., but cracks narrower than 0.002 in. do not affect diffusion (Krauss, 1994; Balakumaran et al., 2018). Hopper et al. (2015) suggested that the critical width below which cracks do not allow moisture ingress is between 0.002 and 0.004 in., while Xi et al. (2003) proposed a range of 0.004 to 0.008 in.

In practice, the ACI 224 committee considers cracks up to a width of 0.007 in. tolerable in environments with deicing chemicals. Similarly, MDOT (2010) and VDOT (2009) require crack sealing only when cracks are at least 0.008 in. wide. On the lower end of the spectrum, NYSDOT (2019) permits a do-nothing approach for dormant cracks narrower than 0.007 in. and active cracks narrower than 0.004 in. Taking a more conservative approach, MoDOT (2016) recommends treating hairline cracks (defined as cracks less than 0.008 in. wide) with a gravity-fed polymer and applying a penetrating sealer to new decks or decks with even more minor cracks. In contrast, Kansas DOT defines hairline cracks as cracks with widths no greater than 0.02 in.

On the other hand, wide and deep cracks may not be a concern depending on the types of ions the deck is exposed to and the location of the cracks relative to the reinforcing steel. Cracks that are far from the reinforcing steel do not provide direct access to it, making it unnecessary to seal the cracks to prevent chloride infiltration. However, these cracks still allow ions to penetrate deeper into the concrete, so sealing may be warranted if the deck is exposed to magnesium-chloride–based deicing salts (which cause concrete degradation) or if the deck concrete is prone to freeze-thaw cycles.

Table 4. Crack Width Range for Do-Nothing Action

Crack Width Range	Source
Less than 0.002 in.	Balakumaran et al. (2018); Krauss (1994)
Tolerable crack width up to 0.007 in.	ACI 224 committee
Less than 0.008 in.	Michigan and Virginia DOTs
"Do nothing" for dormant cracks less than 0.007 in.	New York State DOT
"Do nothing" for active cracks less than 0.004 in.	New York State DOT
Hairline crack definition less than 0.008 in.	Missouri DOT
Hairline crack definition no greater than 0.02 in.	Kansas DOT

Based on the literature, a do-nothing decision is feasible for crack conditions, as shown in Table 5.

Table 5. Crack Type Feasible for Do-Nothing Action

Crack Type	Crack Width	Crack Depth	Crack Shape	Crack Activity	Crack Extent
Craze	< 0.008 in.	Shallow	Not specified	Not specified	Not specified

Apply a Gravity-Fed Polymer by Crack Chasing

Gravity-fed polymers are frequently used to seal cracks, utilizing the force of gravity and their low viscosity to penetrate the cracks effectively. Once inside the cracks, these polymers undergo a polymerization process, creating a seal that prevents moisture and chlorides from entering. These polymers are commonly available as high molecular weight methacrylates (HMWMs) or low-viscosity epoxies. They can be applied in two main ways: through a flood coat, where the polymer is spread over the entire surface to ensure crack filling, or through crack chasing, where the polymer is directly applied into the cracks by following their path. Both methods aim to achieve proper crack sealing and provide protection against the infiltration of moisture and chlorides.

In summary, gravity-fed polymers, such as HMWMs or low-viscosity epoxies, are widely employed to seal cracks. Their ability to flow into cracks due to gravity and low viscosity, followed by polymerization, effectively seals the cracks, safeguarding against the entry of moisture and chlorides. The application methods of these polymers include flood coating the surface or applying them directly into the cracks through crack chasing. The crack-chasing method of applying gravity-fed polymers is generally considered suitable under specific conditions, outlined as follows.

NBI Condition Ratings

INDOT (Indiana Department of Transportation), MDOT (Michigan Department of Transportation), VDOT (Virginia Department of Transportation), and WisDOT (Wisconsin Department of Transportation) have defined minimum NBI (National Bridge Inventory) condition requirements for crack-sealing actions on bridge decks. While INDOT and WisDOT do not provide detailed specifications for the types of actions, VDOT categorizes “crack-filling” actions as crack-sealing methods involving a mesh crossing the crack, polymer fill, “V” groove, or epoxy injection. MDOT differentiates between sealing cracks and applying a healer seal, which falls under the flood coat category. However, the requirements for crack sealing and applying a healer sealer are the same. Note that crack sealing is distinct from using penetrating sealers for deck sealing or applying thin polymer or other types of overlays. Therefore, it is assumed that the criteria established by these states apply to the profiles mentioned, such as “Apply a Gravity-Fed Polymer by Crack-Chasing,” “Rout and Seal,” “Pressure Inject with Epoxy,” and “Apply a Flood Coat.”

In INDOT, decks are eligible for crack sealing if the NBI rating for the bridge is at least 6. VDOT requires crack sealing for bridge decks with a minimum NBI rating of 7, while MDOT and WisDOT permit crack sealing if the deck has a minimum NBI rating of 5.

In summary, the crack-chasing method of applying gravity-fed polymers is typically considered suitable based on NBI condition ratings established by INDOT, MDOT, VDOT, and WisDOT. These ratings focus primarily on the deck’s condition and, in some cases, the condition of other bridge components and the wearing surface.

Deck Condition State

In addition to the minimum NBI condition ratings, VDOT and WisDOT have specified requirements regarding the extent of deck distress. At the same time, INDOT has correlated NBI condition ratings and deck overlay conditions. These requirements are assumed to apply to the profiles mentioned: “Apply a Gravity-Fed Polymer by Crack-Chasing,” “Rout and Seal,” “Pressure Inject with Epoxy,” and “Apply a Flood Coat.”

VDOT allows crack filling only if the deck’s deterioration area does not exceed 5%. The deck deterioration area is defined as the percentage of the deck in CS2 (condition state 2), CS3, and CS4 based on visual inspection, or, in the case of a detailed investigation, the percentage of the deck that is delaminated, spalled, patched, and in CS1 with a half-cell potential reading below −0.35 mV. WisDOT requires that the deck area demonstrating Defect 3220 (cracking) be between 5% and 25% eligible for crack-sealing actions. It is important to note that Defect 3220 refers to the wearing surface, regardless of whether it is a deck or overlay.

According to INDOT’s definitions, a rigid Portland cement overlay is considered to have an NBI condition rating of 6 or higher if no more than 5% of the deck is delaminated, cracks are not wider than 0.021 in., and the crack spacing is at least 3 ft. Semi-rigid overlays made of epoxy or polyester are considered to have an NBI condition rating of 6 or higher if no more than 0.5% of the deck is delaminated, there is no to minor surface wearing, cracks are not wider than 0.016 in., and the crack spacing is at least 10 ft. Therefore, crack sealing is deemed appropriate only if the deck conditions, crack widths, and crack spacings meet these specified thresholds.

Crack Characteristics

Table 6 outlines guidelines for addressing various concrete crack characteristics. MoDOT (Missouri Department of Transportation) recommends gravity-fill polymers, HMWM sealing, or epoxy injection for widths between 0.001 and 0.08 in. NYSDOT (New York State Department of Transportation) mandates HMWM sealing or epoxy for cracks ≥ 0.007 in. (active or deicer exposure) and ≥ 0.012 in. (dormant). MDOT recommends low-viscosity polymer for visible cracks ≥ 0.008 in. MDOT advises against gravity-fill polymers for full-depth cracks reaching reinforcement. MnDOT suggests the gravity-chasing method for cracks with spacing ≥ 3 ft, while VDOT recommends overlay or crack seal for cracks > 0.20 linear feet per square foot.

Table 6. Crack Characteristics for Applying Gravity-Fed Polymer by Crack Chasing

Crack Characteristic	Suitable Crack Width Range	Recommended Polymer	Source
Crack Width	• to 0.08 in. • At least 0.007 in. (active or deicer exposure) • At least 0.012 in. (dormant) • At least 0.008 in. (visible)	• Gravity-fill polymers, HMWM sealing, or epoxy • HMWM sealing or epoxy injection • HMWM sealing or epoxy injection • Low-viscosity polymer	• MoDOT • Required by NYSDOT • Required by NYSDOT • Required by MDOT
Crack Depth	Full-depth cracks reaching reinforcement	Not suitable for gravity-fill polymers	MDOT
Crack Spacing	• At least 3 ft • Exceeding 0.20 linear feet per square foot	• Gravity-chasing method • Overlay or crack seal	• by MnDOT • by VDOT

Rout and Seal

Routing and sealing a crack involves widening the crack's mouth to create a reservoir, cleaning the crack thoroughly, and then filling both the crack and reservoir with a sealant. This repair method is commonly employed for pavements and garage slabs but can also be utilized for addressing wide or active cracks on bridge decks. The reservoir accommodates crack movement, allowing flexible sealants to elongate accordingly. However, in the case of dormant cracks on bridge decks, routing and sealing can also be performed using a more rigid sealant. Different construction procedures may influence the effectiveness of the repair and its suitability for various crack types, but routing and sealing fundamentally constitute a crack-chasing approach.

Routing and sealing, although a commonly used method, has received less attention in the context of bridge decks compared to other crack-chasing repair techniques. Only VDOT specifically mentions routing and sealing cracks among the reviewed state DOT documents. This method is deemed suitable for addressing linear cracks, but not pattern cracks, and it is not recommended for use on bridge decks younger than six months. VDOT employs a V-shaped notch and seals the crack with epoxy, indicating that this approach is primarily intended for dormant cracks.

Routing and sealing may be considered applicable under the following conditions:

NBI Condition Ratings

- INDOT, MDOT, VDOT, and WisDOT define minimum NBI condition rating requirements for deck crack-sealing actions.
- While INDOT and WisDOT do not provide specific details on the types of actions, VDOT groups “crack-filling” actions, including crack sealing with a mesh crossing the crack, polymer fill, V-groove, or epoxy injection.
- MDOT makes a distinction between sealing cracks and applying a healer sealer (classified as a flood coat), but the requirements for crack sealing and applying a healer sealer are the same.
- Crack sealing is considered separate from deck sealing with a penetrating sealer or the application of thin polymer overlays.

Therefore, the criteria established by these state DOTs are assumed to apply to the following profiles: “Apply a Gravity-Fed Polymer by Crack-Chasing,” “Rout and Seal,” “Pressure Inject with Epoxy,” and “Apply a Flood Coat.”

INDOT allows for crack sealing on decks if the NBI ratings of the bridge deck is 6 or higher. VDOT requires crack sealing when the deck has a minimum NBI rating of 7, while MDOT and WisDOT allow crack sealing if the deck’s NBI rating is at least 5. It is worth noting that these state DOTs do not mention the NBI ratings of other bridge components besides the deck.

Deck Condition State

In addition to the minimum NBI condition ratings, VDOT and WisDOT have specified guidelines regarding the acceptable level of deck distress. At the same time, INDOT has established correlations between the NBI condition rating and the condition of the deck overlay. These requirements are assumed to be applicable to the following repair methods: “Apply a Gravity-Fed Polymer by Crack-Chasing,” “Rout and Seal,” “Pressure Inject with Epoxy,” and “Apply a Flood Coat.”

VDOT permits crack filling only if the deck deterioration area does not exceed 5%. Based on visual inspection, the deck deterioration area is determined by the percentage of the deck in distress categories CS2, CS3, and CS4. More detailed investigations include the percentage of the deck that is delaminated, spalled, patched, and in distress category CS1 with a half-cell potential reading below −0.35 mV. WisDOT requires that the deck area demonstrating Defect 3220 (cracking) should range between 5% and 25% to be eligible for crack sealing. It is important to note that Defect 3220 pertains to the wearing surface, regardless of whether it is the deck itself or an overlay.

According to INDOT's definitions, a rigid Portland cement overlay is considered to have an NBI condition rating of 6 or higher if no more than 5% of the deck is delaminated, cracks do not exceed a width of 0.021 in., and the spacing between cracks is at least 3 ft. Semi-rigid overlays made of epoxy or polyester are considered to have an NBI condition rating of 6 or higher if no more than 0.5% of the deck is delaminated, there is minimal to minor surface wearing, cracks do not exceed a width of 0.016 in., and the crack spacing is at least 10 ft. Therefore, crack sealing is only considered an option if the deck conditions, crack widths, and crack spacings meet these thresholds.

Due to the wide range of materials and construction procedures available, routing and sealing are widely applicable, irrespective of the deck or crack characteristics.

Crack Characteristics

Routing and sealing are commonly used for addressing wide and active cracks, as it is one of the few methods to deal with active cracks effectively. However, it is important to note that routing and sealing can be applicable regardless of the crack's width, activity, or depth. According to ACI 224.1R, this repair method is suitable for narrow and wide cracks, indicating that crack width alone would not rule out the consideration of routing and sealing. Additionally, routing and sealing can be performed using rigid materials like epoxies or flexible materials like bituminous sealants, allowing for its application regardless of crack activity.

In cases where cracks are heavily contaminated or filled with debris, routing becomes particularly advantageous as it creates a wider surface opening. This wider opening facilitates easier cleaning operations and promotes a better bond between the sealant and the crack walls.

It is worth noting that routing and sealing are typically employed for discrete linear cracks and are considered impractical for pattern cracking, as stated by VDOT (2009). Although state DOTs do not explicitly specify the minimum crack spacing for routing and sealing, it can be assumed that VDOT's general requirement of a minimum crack density of 0.20 linear feet per square foot of the deck and MnDOT's minimum crack spacing of 3 ft, as compared between crack chasing with a gravity-fed polymer and application of a flood coat, would apply. However, a larger spacing threshold is likely more appropriate for routing and sealing due to the additional costs associated with routing and using a bond breaker.

Pressure Inject with Epoxy

Pressure injection of epoxy is a highly effective technique for repairing cracks in concrete structures, aiming to restore load transfer across the cracks. The typical process involves thorough cleaning and sealing of the cracks, followed by the installation of entry and venting ports through which the epoxy is injected. Once the epoxy cures, the seal is removed, completing the repair. It is worth noting that epoxy injection is not limited to surface cracks on bridge decks but can also be utilized to address delamination in the concrete.

Epoxy injection is generally considered applicable under the following conditions.

NBI Condition Ratings

The use of epoxy injection is generally determined by specific conditions, including NBI condition ratings. State DOTs, namely INDOT, MDOT, VDOT, and WisDOT, have established minimum NBI condition requirements for deck crack-sealing actions. While INDOT and WisDOT do not provide detailed explanations of the actions, VDOT categorizes "crack-filling" actions as crack sealing involving techniques such as mesh crossing the crack, polymer fill, V groove, or epoxy injection. MDOT distinguishes between crack sealing and applying a healer sealer, which falls under the flood coat category. However, the requirements for crack sealing and applying a healer sealer are the same according to MDOT. Note that crack sealing is considered separate from deck sealing with a penetrating sealer or the application of thin polymer overlays. Therefore, the criteria set by these state DOTs are assumed to be applicable to the following methods: "Apply a Gravity-Fed Polymer by Crack Chasing," "Rout and Seal," "Pressure Inject with Epoxy," and "Apply a Flood Coat."

For INDOT, decks are eligible for crack sealing if the NBI ratings of all major bridge components (deck, superstructure, and substructure) and the NBI rating of the wearing surface (if applicable) are at least 6. VDOT requires crack sealing for decks with a minimum NBI rating of 7, while MDOT and WisDOT allow crack sealing if the deck has a minimum NBI rating of 5. None of these state DOTs specifically mention the NBI ratings of other bridge components.

Deck Condition State

Regarding the condition of the deck, there are additional requirements beyond the minimum NBI condition ratings set by VDOT, WisDOT, and INDOT. These requirements are assumed to be applicable to the following repair methods: "Apply a Gravity-Fed Polymer by Crack Chasing," "Rout and Seal," "Pressure Inject with Epoxy," and "Apply a Flood Coat."

VDOT permits crack filling only if the deck's deterioration area does not exceed 5%. The deck deterioration area is determined by the percentage of the deck in CS2, CS3, and CS4 based on visual inspection, or, in more detailed investigations, the percentage of the deck that is delaminated, spalled, patched, or falls under CS1 with a half-cell potential reading less than −0.35 mV. On the other hand, WisDOT requires a deck area between 5% and 25% to exhibit Defect 3220 (cracking) in order to be eligible for crack-sealing actions. It is important to note that Defect 3220 characterizes the wearing surface, regardless of whether it is a deck or overlay.

According to INDOT's definitions, a rigid Portland cement overlay is considered to have an NBI condition rating of 6 or higher if the delamination of the deck does not exceed 5%, cracks are no wider than 0.021 in., and the spacing between cracks is at least 3 ft. For semi-rigid overlays (epoxy or polyester), they are considered to have an NBI condition rating of 6 or higher as long as the deck's delamination does not exceed 0.5%, there is no major surface wearing or only minor wearing, cracks are not wider than 0.016 in., and the crack spacing is at least 10 ft. Therefore, crack sealing is considered a viable option only if the deck meets these conditions regarding its condition, crack widths, and crack spacings.

Crack Characteristics

Specific cracking characteristics as reported by several state DOTs are outlined in Table 7. VDOT is primarily concerned with dormant cracks larger than 0.008 in. and linear or solitary cracks. NYSDOT makes a distinction between functioning cracks that are larger than 0.007 in. and dormant cracks that are larger than 0.012 in. Cracks that are exposed to deicers are given extra attention. Cracks having a width between 0.02 in. and 0.05 in. are the focus of attention for MnDOT. To identify and resolve cracks in concrete structures, each DOT has specific rules that are customized to the local environmental and structural characteristics of their different locations.

Table 7. Crack Characteristics to Pressure Inject with Epoxy

State DOT	Crack Characteristics
VDOT	Linear or singular cracks Dormant cracks > 0.008 in.
NYSDOT	Dormant cracks > 0.012 in. Working cracks > 0.007 in. Cracks exposed to deicers and > 0.007 in.
MnDOT	Cracks with widths between 0.02 and 0.05 in.

Apply a Flood Coat

Flood coat repairs are commonly utilized when the pattern or characteristics of a crack make it impractical to employ crack-chasing methods. These repairs are often preferred because they safeguard the entire surface affected by the crack against moisture and chloride infiltration instead of focusing solely on localized crack protection. Flood coats can be likened to thin overlays, where a polymer or bituminous material is applied to the deck to create a protective coating. Additionally, aggregate is spread across the material's surface to ensure sufficient friction for traffic. This repair technique encompasses various approaches, such as applying gravity-fill polymers through flood coats, using film-forming sealers, or employing chip seals.

Flood coats are generally considered applicable under the following conditions:

NBI Condition Ratings

Minimum NBI condition requirements for deck crack-sealing actions are specified by state transportation departments such as INDOT, MDOT, VDOT, and WisDOT. While INDOT and WisDOT do not provide detailed information on the specific types of actions, VDOT categorizes "crack-filling" actions as crack sealing, involving methods such as using a mesh across the crack, polymer fill, "V" groove, or epoxy injection. MDOT makes a distinction between sealing cracks and applying a healer sealer, which falls under the flood coat category, but the requirements for crack sealing and healer sealer application are the same. It is important to note that crack sealing is different from deck sealing with a penetrating sealer or applying thin polymer overlays. Therefore, the criteria established by these states are assumed to be applicable to the following profiles: "Apply a Gravity-Fed Polymer by Crack Chasing," "Rout and Seal," "Pressure Inject with Epoxy," and "Apply a Flood Coat."

In the case of INDOT, decks are eligible for crack sealing as long as the NBI ratings of all major bridge components (deck, superstructure, and substructure) and the NBI rating of the wearing surface (if applicable) are at least 6. VDOT requires crack sealing when the deck has a minimum NBI rating of 7, while MDOT allows for crack sealing or healer-sealer application. WisDOT permits crack or deck sealing if the deck has a minimum NBI rating of 5. However, none of these state transportation departments discuss the NBI ratings of other bridge components besides the deck; all are illustrated in Table 8.

Table 8. Minimum NBI Rating for Deck Crack Sealing according to State DOTs

State DOT	Minimum NBI Rating for Deck Crack Sealing	Additional Information
INDOT	6	Deck, superstructure, substructure, and wearing surface (if applicable) should have at least a rating of 6.
VDOT	7	Deck should have a minimum NBI rating of 7. VDOT groups crack-filling actions as crack sealing with options such as mesh crossing, polymer fill, "V" groove, or epoxy injection.
WisDOT	5	Deck should have a minimum NBI rating of 5. WisDOT permits crack sealing or deck sealing. Other bridge components' ratings are not discussed.

Deck Condition State

In addition to the minimum NBI condition ratings, VDOT, WisDOT, and INDOT have specified additional requirements related to the distress levels and deck overlay conditions for various profiles, including "Apply a Gravity-Fed Polymer by Crack Chasing," "Rout and Seal," "Pressure Inject with Epoxy," and "Apply a Flood Coat."

VDOT allows crack filling only if the deck deterioration area is below 5%. This area is determined either by visually inspecting the percentage of the deck in certain distress levels (CS2, CS3, and CS4), or by conducting an in-depth investigation that considers delamination, spalling, patching, and CS1 distress with a half-cell potential reading lower than −0.35 mV.

WisDOT requires the deck area to demonstrate Defect 3220 (cracking) in the range of 5% to 25% for eligibility in crack-sealing actions. If any area of the deck is categorized as CS3 or CS4 due to Defect 3220 (cracking), then the deck becomes eligible for deck-sealing actions, which may include flood coats but not crack-chasing methods. It is important to note that Defect 3220 pertains to the wearing surface, regardless of whether it is a deck or overlay.

According to INDOT's definitions, a rigid Portland cement overlay is considered to have an NBI condition rating of 6 or higher if delamination is below 5%, crack widths do not exceed 0.021 in., and crack spacing is at least 3 ft. Semi-rigid overlays (epoxy or polyester) are also considered to have an NBI condition rating of 6 or higher if delamination is below 0.5%, surface wearing is minimal, crack widths do not exceed 0.016 in., and crack spacing is at least 10 ft. As a result, crack sealing is only considered an option if the deck conditions, crack widths, and crack spacings meet these thresholds.

Crack Characteristics

The decision to employ a flood coat repair method often depends on factors such as the type of cracking, crack spacing, and crack density. VDOT suggests overlay or crack seal treatments when the crack density exceeds 0.20 linear feet per square foot of the deck, and they utilize flood coats to address pattern cracking. MnDOT indicates that flood coats are usually more cost-effective when crack spacing is less than 3 ft. In addition to considering crack type and spacing, crack activity and depth also influence the decision to apply a flood coat. VDOT specifically uses flood coats to address dormant cracks. In Michigan, general crack-sealing operations, including the application of a healer sealer, are only performed for cracks expected to reach the depth of the steel reinforcement.

Crack width is typically used to select the appropriate material or to choose between different types of flood coats included in this repair method rather than ruling out the use of flood coats altogether. For instance, MoDOT suggests that a flood coat with a gravity-fill polymer is preferred for hairline cracks less than a width of 0.008 in. but can be applied for cracks of any width. However, MoDOT (2014) recommends using a bituminous material or chip seal for wider cracks. VDOT generally mandates crack treatment actions, including flood coats, for cracks wider than 0.008 in.

While flood coats are commonly used and widely applicable, some states do not utilize them. NYSDOT, for example, prohibits using “surface” sealers (assumed to be film-forming sealers or healer sealers), but they employ thin polymer overlays. NYSDOT may consider these multi-layer overlays a more cost-effective option than a single-layer flood coat. Table 9 summarizes the factors some DOTs take into consideration to use a flood coat.

Table 9. Crack Characteristics to Apply a Flood Coat

State DOT	Factors Influencing Flood Coat Usage	Additional Information
VDOT	• Crack density > 0.20 linear ft/sq ft of deck • Addressing dormant cracks only • Crack width > 0.008 in.	• Flood coats used for pattern cracking
MnDOT	• Crack spacing < 3 ft	• Flood coats are typically more economical in these cases
MDOT	• Crack depth reaching steel reinforcement	• General crack-sealing operations for expected depth
MoDOT	• Crack width < 0.008 in. (preferable) but can be applied to any width.	• Bituminous material or chip seal for wider cracks

Apply a Hot-Mix Asphalt Overlay with Waterproofing Membrane System

HMAWM systems (hot-mix asphalt with waterproofing membranes) can protect cracked concrete from further deterioration. However, these systems are typically applied when the deck is approaching the end of its life span, as they hinder inspection of the underlying deck and are challenging to reapply. The waterproofing membrane can be performed or sprayed onto the deck surface as a liquid. It forms a reliable barrier against moisture and chloride infiltration, as long as the installation is of high quality and there is no trapping of moisture or contaminants beneath it. The HMA overlay is necessary to provide a smooth surface for traffic and safeguard the membrane. It is important to note that an HMA overlay alone does not protect against moisture and ion penetration.

HMAWM systems are generally considered applicable under the following conditions:

NBI Condition Ratings

WisDOT considers HMAWM systems as a viable option for decks with a minimum NBI condition rating of 6, as summarized in Table 10. INDOT, on the other hand, considers flexible bridge deck overlays when all major bridge components (including the wearing surface, deck, superstructure, and substructure) have a minimum NBI condition rating of 5. In contrast, VDOT views HMAWM systems as suitable methods for addressing cracking on decks with a minimum NBI condition rating of 7. In the case of MDOT, HMAWM systems are considered when the deck has a condition rating of 4 or 5 and the soffit has a rating of 4, or when the deck has a rating of 3 or lower and the soffit has a rating of 4 or 5.

Table 10. Minimum NBI Condition Rating to Apply HMAWM According to State DOTs

State DOT	Minimum NBI Condition Rating for HMAWM Systems
WisDOT	Deck: Rating >= 6
INDOT	Wearing surface, deck, superstructure, and substructure: Rating >= 5
VDOT	Deck: Rating >= 7
MDOT	Deck: Rating 4 or 5, Soffit: Rating 4 or Deck: Rating <= 3, Soffit: Rating 4 or 5

Deck Condition State

MDOT and WisDOT have specific recommendations regarding using HMAWM systems based on the wearing surface and deck condition. According to MDOT, HMAWM systems are considered if the top surface of the deck has an NBI rating of 4 or 5, and the percentage of deck deterioration for both the top surface and the soffit falls between 10% and 25%. Suppose the top surface has an NBI rating of 3 or less. In that case, MDOT suggests HMAWM systems when the percent deck deterioration on the top side exceeds 25%, and the percent soffit deterioration ranges between 2% and 25%.

According to Wisconsin, HMAWM systems are recommended when at least 20% of the wearing surface area shows distress in the form of Defect 3210 (delamination/spall/patched area/pothole) or Defect 8911 (abrasion, wear, rutting, or loss of friction). If an existing HMAWM system has cracked in over 50% of its area (Defect 3220, crack), reapplication is considered. Additionally, WisDOT specifies that no more than 5% of the underside of the deck should have defects such as delamination, spalling, or patching (Defect 1080, delamination/spalls/patch areas).

However, INDOT does not permit the placement of flexible overlays on bridge decks if more than 10% of the deck area has been patched. It is worth noting that decks with low chloride contamination are considered suitable for protective membrane systems, as mentioned by Krauss et al. (2009). VDOT, on the other hand, does not provide specific criteria related to deck condition states in this context.

Deck Characteristics

The appropriateness of using HMAWM systems for bridge decks depends on factors such as the deck's age and traffic conditions. These systems are found to have better bonding on new decks compared to existing ones, and some DOTs, like Ohio and Missouri, only allow the use of waterproofing membranes on newly constructed bridge decks (Hunsucker et al., 2018; Russell, 2012). In contrast, many Canadian provinces and European countries require HMAWM systems for all new bridge decks (Russell, 2012).

In the United States, HMAWM systems are more commonly used in rehabilitation projects, and DOTs such as Illinois, South Dakota, Nebraska, Kansas, Michigan, and Virginia exclusively use them on existing decks (Russell, 2012). They are particularly favored for older decks with limited remaining service life scheduled for replacement because HMAWM systems hinder the inspection of the concrete deck and are relatively challenging to remove. According to Russell's survey, Caltrans and NYSDOT utilize HMAWM systems for both new and existing decks, while at that time, WisDOT, MnDOT, NDDOT, and INDOT did not employ such systems.

However, it is important to note that HMAWM systems are not suitable for decks with high average daily traffic (ADT) counts and should not be used in deceleration zones due to the potential for the membranes to shift under these conditions (Krauss et al., 2009). Different states have varying criteria for using HMAWM systems, with some not permitting them on bridges with an ADT exceeding 10,000 vehicles or interstate bridges. Others require the ADT to be below 1,000 vehicles (Russell, 2012).

Crack Characteristics

VDOT mandates using HMAWM systems when a deck exhibits significant active cracking. Generally, VDOT considers cracks wider than 0.008 in. or with a density exceeding 0.2 linear feet per square foot of deck area requiring attention. However, since the width of active cracks can vary with temperature and/or live load, the decision to employ an HMAWM system is left to the discretion of the engineer. One advantage reported for HMAWM systems is their ability to bridge and prevent the propagation of most moving cracks in concrete wearing surfaces due to their elastic properties (Sohanghpurwala, 2006).

Apply a Thin Polymer Overlay

Thin polymer overlays are typically between 0.25 to 0.625 in. thick and are applied in two or three layers. Similar to polymer flood coats, each overlay layer includes a polymer binder and aggregate broadcast onto the surface. The construction methods and materials used for thin polymer overlays are comparable to those of flood coats, and they serve a similar purpose of safeguarding cracked bridge decks from deterioration. However, thin polymer overlays are thicker than flood coats, which makes them more expensive. On the upside, they offer longer-lasting protection against chloride intrusion and moisture penetration. These overlays are particularly suitable for bridge decks that are not currently experiencing active corrosion and exhibit minimal signs of damage or distress.

NBI Conditions

Table 11 summarizes how VDOT typically requires a minimum NBI condition rating of 7 for decks when considering the application of thin polymer overlays. However, in some cases, decks with a rating of 6 may be eligible, pending the results of a thorough investigation. WisDOT also allows for the installation of thin polymer overlays on decks with a minimum NBI condition rating of 7, but they are particularly recommended for decks with ratings of 8 or 9. If a deck has a rating of 6, replacing an existing thin polymer overlay may be considered. Still, decks without overlay and NBI ratings below 7 are not eligible for thin polymer overlays. On the other hand, MDOT employs thin polymer overlays when the deck has an NBI rating of at least 5, and the soffit has a rating of at least 6. However, MDOT does not recommend using thin polymer overlays for decks with NBI ratings of 8 or 9.

Table 11. Minimum NBI Rating to Apply a Thin Polymer Overlay

State DOT	Minimum Deck NBI Rating for Thin Polymer Overlays
VDOT	7 (6 pending in-depth investigation)
WisDOT	7 (recommended for ratings of 8 or 9)
MDOT	5 (6 for soffit NBI rating)

Deck Condition State

MDOT, VDOT, and WisDOT have specific criteria for the deck condition when considering thin polymer overlays. MDOT allows epoxy overlays if the deck deterioration is 10% or less and the soffit deterioration is 2% or less. VDOT avoids placing thin polymer overlays on decks with compromised areas exceeding 5%, which includes delamination, spalling, patching, and certain condition states. VDOT also considers the chloride front and restricts overlays if it exceeds 1 in. In Wisconsin, for first-time applications, the topside deck should have no more than 2% of the area experiencing delamination, spalling, or patching, and the underside should have no more than 1% experiencing delamination. For reapplications, at least 15% of the current overlay area should be in certain condition states, and the underside should have no more than 1% delamination. MDOT generally recommends thin epoxy overlays for decks with minor delamination, spalling, moderate cracking, and situations where other crack treatment methods may affect ride quality.

Deck Characteristics

The deck's age is a key factor states consider when deciding whether to apply a thin polymer overlay. It is widely agreed that overlays should be applied to mature decks to prevent the occurrence of reflective cracking. VDOT specifies epoxy overlays for decks in good condition that were constructed before 2003. WisDOT recommends thin polymer overlays after the deck has aged for 2 years, while KDOT (Kansas Department of Transportation) suggests that overlays are most effective once cracks have fully developed. However, KDOT also uses thin polymer overlays to protect new construction before cracks fully develop. WisDOT does not recommend overlays on decks older than 10 or older than 15 years if a thorough deck washing and sealing program has been implemented. Thin polymer overlays are mandatory for new state-owned decks in densely populated urban areas and recommended for locally owned decks regardless of traffic volume.

Crack Characteristics

Regarding crack treatment methods, VDOT advises addressing cracks wider than 0.008 in. and applying overlays or other treatments if the crack density exceeds 0.2 linear feet per square foot of deck area. Both VDOT and WisDOT state that thin polymer overlays are not suitable for addressing active cracks. Additionally, WisDOT does not recommend thin polymer overlays if there is widespread cracking or if cracks are significant, with widths exceeding 0.04 in. KDOT frequently encounters longitudinal shrinkage cracking on its bridge decks and utilizes thin polymer overlays to protect decks experiencing this type of cracking.

Apply a Rigid Cementitious Overlay

Cementitious overlays can be applied as a preventative measure early in the life span of a deck to prevent significant chloride intrusion and corrosion. They can also be used as a remedial measure after the appearance of deck distress. In the case of remedial application, the overlay involves patching the cracked and unsound concrete and removing the chloride-contaminated cover before installing the overlay.

There are various types of concrete used for overlays, such as regular Portland cement concrete (PCC), low-slump dense concrete (LSDC), high-performance concrete (HPC), and silica fume concrete (SFC). However, these materials are primarily based on Portland cement and do not contain significant quantities of polymer additives like polymer-modified concretes.

Most cementitious overlays include pozzolans, which enhance the chloride penetration resistance of the overlay. This additional concrete cover provided by the overlay helps protect the entire deck area by increasing the time required for chlorides to reach the reinforcing steel.

NBI Condition Rating

INDOT, VDOT, and WisDOT have established specific criteria regarding the NBI conditions for applying rigid cementitious overlays on bridges, as summarized in Table 12. INDOT allows the use of rigid overlays only if the bridge deck has an NBI rating of 3 or higher, and if the other bridge components, including the deck, superstructure, and substructure, have NBI ratings of 4 or higher. On the other hand, VDOT recommends the use of rigid overlays for decks with an NBI rating of 6 or lower. WisDOT considers rigid overlays as an option for decks with NBI ratings of 5 or 6. In certain special circumstances, a rigid overlay may be required regardless of the NBI condition. This is particularly true in Virginia due to the risk of alkali-silica reaction, a chemical reaction that can occur between certain aggregates and cementitious materials.

Table 12. Minimum NBI Rating Conditions to Apply a Rigid Cementitious Overlay

State DOT	NBI Rating for Wearing Surface	NBI Rating for Deck, Superstructure, and Substructure
INDOT	3 or higher	4 or higher
VDOT	6 or lower	–
WisDOT	5 or 6	–

Deck Condition State

INDOT, VDOT, and WisDOT have specific criteria for deck conditions when considering the application of rigid cementitious overlays. In Indiana, rigid overlays are permitted if the deck area that has been patched does not exceed 15%. For first-time applications in Wisconsin, decks with at least 20% of their area showing cracks or abrasion (CS3 or CS4) or at least 15% deterioration (Defect 3210) are considered suitable. When reapplying overlays, a new rigid overlay is recommended if at least 20% of the existing overlay area shows cracks or abrasion (CS3 or CS4) or at least 50% of the area is deteriorated (Defect 3220). In both cases, the underside of the deck should have no more than 5% deterioration (Defect 1080) and no more than 25% cracks (Defect 1130). In Virginia, rigid overlays are considered for decks with a compromised area of up to 20%. However, thin polymer overlays are typically used if the compromised area does not exceed 5%, and the chloride front depth is within 1 in. The compromised area is determined by visual inspection or an in-depth investigation, considering factors such as delamination, spalling, patching, and the condition rating. If the chloride front exceeds 1 in., a rigid overlay is required. In cases where alkali-silica reaction is the primary deterioration mechanism, as confirmed by visible distress and petrographic examination, VDOT requires a rigid overlay if the cracking index (CI) is less than 0.02 in. per yard. Otherwise, deck replacement is recommended. The cracking index is determined by measuring and summing the width of cracks crossing reference grids on the deck, as specified in the *Report on the Diagnosis, Prognosis, and Mitigation of ASR in Transportation Structures* published by the Federal Highway Administration (Fournier et al. 2010).

Rigid cementitious overlays are not automatically excluded from consideration based on specific characteristics of the deck or cracks. However, KDOT no longer utilizes Portland cement concrete overlays due to increased cracking and poorer performance observed in two-course construction compared to single-course construction. Instead, decks are constructed with a 3 in. cover, eliminating the need for an early protective cementitious overlay. Note that rigid cementitious overlays are applied to decks for various reasons beyond crack treatment. However, this review focuses on addressing deck cracking, so some broader criteria related to NBI condition ratings and deck conditions may not be included in the discussion above.

Apply a Latex-Modified Concrete Overlay

Typical concrete mixtures incorporate chemical admixtures like superplasticizers or air entrainers in relatively small quantities, typically around 100 ounces per cubic yard. However, polymer-modified concretes utilize a larger amount of polymer admixture, often several thousand ounces per cubic yard. One commonly used polymer modifier is styrene-butadiene-latex, with some states specifying an application rate of 24.5 gallons per cubic yard. The inclusion of latex modifier increases the cost of the concrete but significantly reduces the permeability of the hardened concrete. This reduction in permeability acts as a barrier, preventing the penetration of chlorides and moisture into the concrete, thereby protecting the reinforcement. Polymer-modified concretes are similar to cementitious overlays and can be applied as a preventive measure or as a repair option for deteriorated bridge decks.

State DOT decision matrices and design manuals usually do not differentiate between latex-modified concrete and rigid cementitious overlays. The selection and eligibility criteria are assumed to be identical, and the engineer is typically given the discretion to choose the specific type of cementitious overlay to be used. Consequently, the applicability discussion related to applying a rigid cementitious overlay can also be applied in these cases.

NBI Condition Ratings

INDOT, VDOT, and WisDOT specify criteria for the bridge NBI conditions. INDOT permits rigid cementitious overlays only if the bridge deck has an NBI rating of at least 3 and the other bridge components (deck, superstructure, and substructure) have NBI ratings of at least 4. In contrast, VDOT recommends rigid overlays for decks with an NBI rating of 6 or less, and WisDOT considers rigid overlays for decks with NBI ratings of 5 or 6. Under special circumstances, a rigid overlay may be required regardless of NBI condition due to the risk of alkali-silica reaction in Virginia, as described below.

Deck Condition State

INDOT, VDOT, and WisDOT have specific criteria for deck conditions when it comes to the application of rigid cementitious overlays. INDOT allows rigid overlays only if the deck has been patched on no more than 15% of its area. For first-time applications, WisDOT considers decks eligible for rigid overlays if they have at least 20% of their area in CS3 or CS4 condition per Defect 3220 (crack) or Defect 8911 (abrasion, wear, rutting, or loss of friction), or if at least 15% of the deck is deteriorated per Defect 3210 (debonding/spall/patched area/pothole). In cases of reapplication, a new rigid overlay is considered if at least 20% of the existing overlay area is in CS3 or CS4 condition per Defect 3210 or if at least 50% of the area has deteriorated per Defect 3220. Additionally, no more than 5% of the underside of the deck may be deteriorated per Defect 1080 (delamination/spalls/patch areas), and no more than 25% may be in CS3 or CS4 condition per Defect 1130 (cracking).

In Virginia, using rigid overlays is considered for decks with a compromised area of up to 20%. However, thin polymer overlays are typically applied if the compromised area does not exceed 5% and the chloride front depth is within 1 in. The compromised area is determined based on visual inspection, considering the percentage of the deck in CS2, CS3, and CS4 conditions, or through an in-depth investigation, considering the percentage of the deck that is delaminated, spalled, patched, and/or in CS1 condition with a half-cell potential reading below −0.35 mV. A rigid overlay is required if the chloride front depth exceeds 1 in.

The criteria mentioned above primarily pertain to chloride-induced corrosion. However, suppose the primary deterioration mechanism is alkali-silica reaction (ASR), as confirmed by visual distress and petrographic examination. In that case, VDOT requires a rigid overlay if the cracking index (CI) is less than 0.02 in. per yard. Otherwise, deck replacement is necessary. The cracking index is a quantitative measurement of cracking extent, determined by drawing reference grids on the deck and measuring the width of each crack crossing the gridlines. The measurement method is detailed in the *Report on the Diagnosis, Prognosis, and Mitigation of ASR in Transportation Structures* published by the Federal Highway Administration (Fournier et al., 2010).

Apply a Premixed Polymer Concrete Overlay

Premixed polymer concrete overlays are unique compared to other polymer overlays due to their thickness. While they may fall under the category of thin polymer overlays, they generally have a minimum thickness of 0.75 in., making them thicker than multi-layer and slurry thin polymer overlays. In some cases, they can be as thick as 2 or 3 in., classifying them as polymer concrete overlays. Unlike other overlays that involve applying polymer and aggregates in multiple layers, premixed polymer concrete overlays have the polymer and aggregates preblended before being placed at the desired thickness. These overlays are ideally installed before corrosion or other forms of degradation begin, but they can also be applied after delamination or spalling have already occurred. While they tend to be more expensive than other types of overlays, they offer high impermeability and provide long-lasting protection against chloride penetration and moisture ingress compared to alternative repair methods.

Among the state DOTs examined, WisDOT is the only one that provides information on premixed polymer concrete overlays. These overlays are deemed suitable under the following circumstances:

NBI Condition Ratings

Premixed polymer concrete overlays are considered only when the deck NBI rating is 7 or greater.

Deck Condition State

To qualify for a premixed polymer concrete overlay, the wearing surface area must have less than 5% deterioration according to Defect 3210, which includes debonding, spalling, patched areas, and potholes. Additionally, the underside of the deck should have less than 1% deterioration per Defect 1080, which includes delamination, spalls, and patch areas. It is important to note that premixed polymer concrete overlays are utilized for various purposes beyond addressing deck cracking. However, since this particular analysis focuses on the treatment of deck cracking, some general criteria related to NBI condition ratings and deck conditions may not be specifically covered.

Replace the Bridge Deck

Deck replacement is considered the most drastic measure in response to deck cracking and is typically undertaken when the deck's capacity is compromised or its service life is limited. Deck replacement is primarily considered in the following scenarios:

1. Extensive Deck Distress: If the deck exhibits extensive distress to the extent that the cost of rehabilitating it with a cementitious overlay is comparable to deck replacement due to the need for partial-depth or full-depth repairs, replacement is often scheduled. Typically, the deck will have an NBI condition rating of 4 or lower, with a significant area requiring repair for delamination and spalls, and crack remediation is no longer the primary objective. For instance, WisDOT (2019) recommends deck replacement when the deck's NBI condition rating is 4 or lower, and over 15% of the soffit shows Defect 1080, indicating delamination, spalls, or patch areas, or when more than 50% of the soffit exhibits Defect 1130, indicating cracking.

2. ASR Degradation: Decks are often scheduled for replacement when ASR causes the cracking. While sealing the deck and reducing moisture ingress can slow down the deterioration caused by ASR, it is impossible to repair ASR or fully prevent moisture ingress. The degradation and loss of strength will persist throughout the affected element until it is replaced.

Apply a Penetrating Sealer

Penetrating sealers derive their name from their ability to penetrate the capillary pore structure of concrete. There are two main types of penetrating sealers: water repellents, such as silanes and siloxanes, and pore blockers, such as silicates. Water repellents react with the cement paste, forming a hydrophobic silica gel on the surfaces of the concrete and cracks. This process discourages the entry of liquid water into the concrete while still allowing water vapor transmission. On the other hand, pore blockers accumulate precipitates within the capillary pores, effectively blocking the passage of both water and water vapor. By impeding moisture infiltration, penetrating sealers generally prevent corrosive conditions and offer protection against chlorides that can be carried by moisture, safeguarding the integrity of the concrete, and are more beneficial when the crack density is low. Penetrating sealers are generally considered applicable under the following conditions.

NBI Condition Ratings

When it comes to the NBI condition ratings for bridge decks, the use of penetrating sealers is recommended under certain conditions. According to Wells et al. (2017), IDOT (2019), and MDOT (2017), penetrating sealers are suggested for decks with a fair or better NBI condition rating. IDOT allows the application of penetrating sealers on decks with a condition rating of 4 at the engineer's discretion but prohibits their use on decks with a condition rating of 3 or lower. Similarly, INDOT (2013) considers the application of penetrating sealers as a scheduled preventative maintenance activity, typically performed when the wearing surface of the deck has an NBI condition rating higher than 5.

Deck Condition State

For decks suitable for penetrating sealers, it is preferred that they have either no cracks or only a few sealed cracks, as Hearn (2020) mentioned. MoDOT (2014) and NYSDOT (2019) require penetrating sealers on decks with minimal or hairline cracking. In contrast, IDOT does not allow the application of penetrating sealers on decks if any portion of the deck's area falls within CS3 or CS4, which likely refers to specific condition states defined by IDOT.

Deck Characteristics

When determining the suitability of a penetrating sealer for a deck, deck condition is generally considered more important than deck age or other deck characteristics. However, specific state DOTs provide additional guidance on particular deck features. For instance, NYSDOT has found that if the deck has epoxy-coated reinforcing steel and the concrete is uncracked, penetrating sealers are deemed uneconomical. However, if the deck has uncoated reinforcing steel, a concrete cover less than the current standard design cover, or hairline cracking, the application of a penetrating sealer is recommended. In contrast, MDOT permits silane penetrating sealers regardless of whether the deck is reinforced with uncoated or epoxy-coated rebar.

Furthermore, although the deck's age does not typically preclude it from receiving a penetrating sealer treatment, there is generally an emphasis on applying penetrating sealers to new or newly rehabilitated decks, as Wells et al. (2017) noted. NYSDOT explicitly requires applying penetrating sealers to new decks, concrete overlays, and repairs with a history of corrosion-related distress. MoDOT mandates penetrating sealers on new decks and requires reapplication within the first three years if new cracks form.

Overall, while deck condition remains the primary factor, considerations such as the presence of epoxy-coated reinforcing steel, concrete cover, hairline cracking, and the timing of deck construction or rehabilitation play a role in determining the appropriateness of applying a penetrating sealer.

Crack Characteristics

Regarding crack characteristics, penetrating sealers are commonly employed for hairline or narrow cracks. NYSDOT provides specific recommendations regarding crack widths for the application of penetrating sealers. They suggest penetrating sealers on decks with cracks up to a width of 0.007 in. if the crack is active or the deck is exposed to deicing chemicals. Additionally, NYSDOT permits penetrating sealers on decks with dormant cracks up to a width of 0.012 in.

In summary, for crack characteristics, penetrating sealers are typically recommended for hairline or narrow cracks. NYSDOT specifies the permissible crack widths for applying penetrating sealers based on crack activity and exposure to deicing chemicals.

FACTORS TO CONSIDER FOR CHOOSING APPROPRIATE SEALERS

Choosing the suitable crack sealer for a specific application involves considering various factors. Crack type, ambient temperature, weather conditions, and application method are crucial in selecting an appropriate crack sealer. The crack type determines the type of sealer required, considering factors like crack width and depth. Ambient temperature affects the sealer's performance, with different sealers responding differently to cold or hot temperatures. Weather conditions, including humidity and precipitation, also impact the sealer's adherence and curing time. The application method guides the choice of sealer, such as sprayable or pourable options for different crack sizes. Several types of sealers are available, including hot-pour sealants for larger cracks, silicone sealants for narrow cracks, polyurethane sealants for larger cracks, and epoxy sealants for structural cracks. Each sealer has its recommended application temperature and curing time. Considering these parameters ensures the selection of an appropriate crack sealer for effective repairs.

SEALANTS FOR BRIDGE DECK CRACKS APPROVED BY IDOT

IDOT provides specifications and guidelines for using hot-poured rubberized asphalt sealant and two-component polymer sealant on bridge decks. Hot-poured rubberized asphalt sealant should meet ASTM D3405 requirements, be heated to 350°F to 400°F, and be applied after cleaning and priming the crack or joint. The sealant is poured or pumped into the crack, leveled, and tooled for a smooth surface, and then allowed to cool and cure for 24 hours before traffic is allowed. Two-component polymer sealant should conform to ASTM C881, with resin and hardener mixed in a 1:1 ratio. After cleaning and priming the crack or joint, the mixed sealant is poured or pumped in, leveled, tooled, and cured for 24 hours before traffic is allowed. These specifications and procedures ensure the practical and effective application of the sealants on bridge decks according to IDOT guidelines.

CONCRETE-SEALING PRODUCTS APPROVED BY IDOT

According to IDOT's Qualified Product List of Concrete Sealers (2023), the approved products are divided into material codes 42725 and 42726. With material code 42725, water-based concrete sealers are formulated with water as the primary carrier and a combination of acrylic, epoxy, or silane/siloxane resins. They are typically applied using a roller, brush, or sprayer and dry quickly. These sealers provide a thin protective coating, offering good resistance against water penetration, staining, and some chemicals. However, their durability and longevity may be lower compared to other sealers. On the other hand, plural component concrete sealers, with material code 42726, are two-part systems comprising a resin component and a hardener or catalyst. They often utilize epoxy or polyurethane resins. Plural component sealers require specialized equipment for proper mixing and application, and they have a shorter working time due to the resin-hardener chemical reaction. These sealers provide a thicker and more durable protective layer, offering excellent resistance to water, chemicals, abrasion, and heavy traffic. They are known for their long life span and high durability.

CONCRETE SEALER PRODUCTS APPROVED BY THE PROVINCE OF ALBERTA, CANADA

Alberta, Canada, and Illinois, United States, share several similarities regarding bridges. Both regions exhibit a high density of bridges due to their extensive transportation networks and urban centers. They also experience diverse weather conditions, including cold winters and freeze-thaw cycles in Alberta and a mix of climates with hot summers and cold winters in Illinois, contributing to bridge deterioration. Additionally, both regions have well-developed highway systems that heavily rely on bridges to support traffic flow. They have established bridge maintenance programs to ensure safety and longevity, with various bridge types requiring specific design considerations. Effective bridge management systems are prioritized to monitor conditions and allocate resources appropriately. Exploring the types of sealers and products used for bridge deck maintenance in Alberta could help significantly in this research.

In the crack treatment guide, various types of sealers are discussed, along with their characteristics and limitations.

1. Type 1 Sealer, a penetrating sealer with three subtypes: type 1a, type 1b, and type 1c.
2. Type 2 Sealer, a clear coating sealer that includes two subtypes: type 2a and 2b.
3. Type 3 Sealer, a pigmented coating sealer, is used for coating areas that are exposed to the public.

PINCHEIRA STUDY

Introduction

During cold seasons, deicing salts, usually blends of sodium chloride and calcium chloride, are commonly applied to bridge decks. As ice melts and interacts with these salts, chloride ions can infiltrate the concrete, leading to corrosion of reinforcing bars. Moreover, they can permeate through cracks, resulting in deterioration of the steel or concrete substructure. Employing deck and crack sealants serves as a preventative measure against chloride ion intrusion and subsequent damage to the deck or substructure. A study done by Pincheira et al. (2005) for the Wisconsin Highway Research Program investigated the performance of several crack sealants under the aforementioned conditions.

Objectives

The primary objective of this study was to assess the effectiveness and relative performance of commercially available concrete bridge decks and crack sealants. To meet this objective, a total of 13 deck sealants and 10 crack sealants were selected for study under laboratory conditions that simulated the exposure to deicing salts and freeze-thaw cycles encountered in practice.

Experimental Methodology

The test method was divided into two tasks. In the first task, deck sealant behavior was applied according to AASHTO T 259 (2004), which covers determining concrete specimens' resistance to chloride ion penetration. Some examples of potential deviations from the concrete specified in the standard are the kind and content of the cement and aggregate, the water-to-cement ratio, admixtures, treatments, curing conditions, and consolidation. In the second task, distinct specimens were cast in order to use a dye technique to quantify the sealants' depth of penetration profile. These findings established a connection between the deck sealants' resistance to chloride ion intrusion and penetration depth.

Additionally, there were two parts to the crack sealant study. The sealant's penetration and filling capacity in predetermined crack widths were measured in the first task to evaluate sealant performance. Four fracture widths—hairline, narrow, medium, and wide cracks—that are typical of those found in practice were considered in this investigation. A durability and bond strength assessment of the sealants was conducted in the second part of the investigation.

The evaluation of the potential deterioration of crack sealants under extreme environmental conditions involved measuring the binding strength of the sealants in specimens exposed to freeze-thaw cycles both with and without IV exposure.

SEALANT PRODUCTS

The concrete sealant products are presented in Table 13, along with their names, chemical families, VOC (volatile organic compound) content, recommended depth of penetration into concrete, surface preparation requirements, application conditions, coverage rates, costs, expected durability, time required before opening to traffic, and suitability for particular environmental conditions. It is a useful tool for selecting the right concrete sealant for various concrete surfaces and project requirements because it provides information on each product's composition, application, suggested conditions, and performance characteristics.

The characteristics and application of various crack sealants for different concrete crack sizes and situations are explained in detail in Table 14. When choosing the best sealant for their particular project requirements, engineers and other professionals involved in concrete maintenance and repair can benefit from the useful information it offers.

The data presented in Table 15 originates from a laboratory study conducted by Pincheira et al. (2005). The study primarily examines the bond performance of different crack sealants. The table presents data pertaining to various types of generic sealer goods, including methacrylate, urethane polyurea hybrid, epoxy, HMWM, and epoxy resin. The provided information includes the measurement of viscosity in centipoise, categorization of crack widths in inches, determination of average bond strength in pounds for samples that were not exposed to freeze-thaw cycles, as well as for samples that were subjected to freeze-thaw cycles. Additionally, the percentage of bond strength retained is also reported. The data presented in the study highlights the diverse performance of these sealants when subjected to varied settings. Notably, aspects such as fracture breadth and the impact of freeze-thaw cycles on bond strength are emphasized. It is worth noting that certain sealants exhibit impressive preservation of bond strength even when exposed to unfavorable conditions.

In order to comprehensively evaluate the efficiency of various crack sealers, a thorough examination of their performance was conducted as outlined in Table 16. The provided material includes a comprehensive analysis of generic sealer products. This analysis includes details regarding the sources from which the data is derived, the specific methods employed for testing (whether conducted in controlled laboratory settings or field conditions), the categorization of crack widths, the average depth of penetration, and the ratio between the strength of mended areas compared to that of uncracked regions. The table displays a range of sealers, including high molecular weight methacrylate sealers, polyurethane, epoxy, and other varieties. The data presented in this study demonstrates the impact of fracture width on the effectiveness of different sealers. Certain sealers exhibit significant strength ratios, while others are known for their capacity to infiltrate fractures. Table 16 presents the performance of certain sealers in terms of the repaired-to-uncracked strength ratio. This study enhances its utility as a valuable tool for evaluating the effectiveness of various crack-sealing methods in different crack width situations.

A thorough comparison of the impact of several silane deck sealants is shown in Table 17. The table mainly looks at variables like viscosity, average penetration depth (in inches), source of reference (lab or field tested), and percentage of chloride content (between sealed and unsealed surfaces) in relation to each other. A range of silane sealant formulations are shown in the table, each with unique characteristics like deep penetration potential, low viscosity for optimal penetration, and hydrophobic protective qualities. The study highlights the potential of sealants for protecting concrete or masonry surfaces by demonstrating how well they work to reduce chloride content. Some sealants are notable for their ability to penetrate deeply and provide excellent protection, while other sealants have unique characteristics, such as being appropriate for use in cold climates.

Table 13. Deck Sealant Properties by Pincheira et al. (2005)

Product Name	Chemical Family	VOC Content	Manufacturer Reported Depth of Penetration	Surface Preparation Requirements	Application Conditions	Coverage Rate & Cost	Expected Durability	Time to Open Traffic	Environmental Conditions
Aquanil Plus 40 (prev. SpallGuard 40)	silane, solvent based	less than 350 g/L	unknown	clean and dry, powerwash min pressure of 2500 psi	40<T<100°F, do not use if rain within 4 hours	100-150 sf/gal; $28/gal	10-year max life	1-2 hours	developed to protect in freeze-thaw conditions
V-seal 102-V4	Siliconate	0 g/L	0.75–1.0 in.	clean, powerwash suggested	T>35°F, do not use if rain within 5 hours	150-200 sf/gal; $12/gal	5 years	2-4 hours	superb for freeze-thaw climates
Aqua-Trete BSM 20	silane, water based	350 g/L	0.125–0.25 in.	clean all traces of dirt, dust, by shotblasting, sandblasting, waterblasting, and chemical cleaners	40<T<100°F do not use if T<40 within 12 hours, or precipitation expected within 4 hours	125–175 sf/gal; $15/gal	bridge decks 5–7 years	when visibly dry—usually 2 hours at 70°F	New York DOT uses this—resists freeze/thaw
TK-290 Tri-Siloxane (or TK-290)	siloxane, solvent based	741 g/L	0.125–0.25 in.	sound, dry, cleaned thoroughly, may need mech. abrasion.	T>40°F, do not use if rain within 4–6 hours	100-175 sf/gal on bridge decks; $13/gal	5 years excellent 10-15 year depends on traffic	4 hours	unaffected by freeze-thaw conditions
TK-290 WB Tri-Siloxane (or TK-290 WBG)	siloxane, water based	140 g/L	0.125–0.25 in.	sound, dry, cleaned thoroughly, may need mech. abrasion to get max penetration	T>40°F, do not use if rain within 4–6 hours	100-200 sf/gal on bridge decks; $15/gal	5 years excellent 10–15 years, depends on traffic	4 hours	unaffected by freeze-thaw conditions

Product Name	Chemical Family	VOC Content	Manufacturer Reported Depth of Penetration	Surface Preparation Requirements	Application Conditions	Coverage Rate & Cost	Expected Durability	Time to Open Traffic	Environmental Conditions
Baracade WB 244	siloxane/ silane oligomers water based	50 g/L	0.375 in.	clean, dry, structurally sound; pressure washing works well, sandblasting usually not required	T>40°F, do not use if rain within 12 hours	100-150 sf/gal; $20–24/gal	10 years under heavy traffic	4-6 hours for T~70s°F	very effective in climates with drastic temp. if used correctly
Penseal 244 40%	silane, solvent based	496 g/L	0.125–0.25 in.	Older concrete—power washed with cleaners to remove contaminants; may be damp but absorbent for good penetration.	T>20°F, protect from rain and foot traffic for 4–6 hours	125-250 sf/gal, Older: 95-140 sf/gal; $23/gal	10 years	8 hours	effective in freeze-thaw conditions
Hydrozo Enviroseal 20	silane, water based	399 g/L	0.14 in.	clean, sound, and dry for best performance; may need to sandblast, shotblast	T>40°F, do not use if T<40 or inclement weather within 12 hours	100-175 sf/gal; $20/ga	5–7 years; still some protection after 10–15 years	dry in 4–6 hours at 70°F	unaffected by freeze-thaw

Product Name	Chemical Family	VOC Content	Manufacturer Reported Depth of Penetration	Surface Preparation Requirements	Application Conditions	Coverage Rate & Cost	Expected Durability	Time to Open Traffic	Environmental Conditions
Powerseal 40%	silane, water based	260 g/L	0.125–0.25 in.	Older concrete—power washed with cleaners to remove contaminants	Protect from rain for 4–6 hours, T>40°F	125–250 sf/gal, Older: 95–140 sf/gal; $23/gal	10 years	8 hours	effective in freeze-thaw conditions
Sonneborn Penetrating Sealer 40 VOC	silane, solvent based	589 g/L	0.2 in.	must be clean, may need to sandblast, shotblast; may be slightly damp	T>40°F, do not use if T<20 within 12 hours, rain within 4 hours, or inclement weather within 12–24 hours	125–225 sf/gal; $30/gal	5–7 years	dry in 4–6 hours at 70°F	unaffected by freeze-thaw
Hydrozo Enviroseal 40	silane, water based	399 g/L	0.24 in.	clean, sound, and dry for best performance; may need to sandblast, shotblast	40<T<110°F, do not use if T<40, or inclement weather within 12 hours	100–200 sf/gal; $27/gal	5–7 years	dry in 4–6 hours at 70°F	unaffected by freeze-thaw
Eucoguard 100	siloxane, solvent based	723 g/L	0.3–0.4 in.	dry for 24 hours, pressure wash with water or other cleaners where appropriate	T>40°F	125 sf/gal; $20/gal	5–7 years before re-applicatio n	10–12 hours	unaffected by freeze-thaw

Table 14. Crack Sealant Properties by Pincheira et al. (2005)

Product Name	Chemical Family	VOC Content	Crack Width	Surface Preparation Requirements	Application Conditions	Coverage Rate & Cost	Expected Durability	Time to Open Traffic	Environmental Conditions
Degadeck Crack Sealer	Metha-crylate	150 g/L	hairline –0.125″	cleaned by mechanical means, dry	40<T<100°F	$30–40/gal	should last life of the structure	35–45 minutes	effective in freeze-thaw conditions
Denedeck Crack Sealer	Methacry late	100 g/L	hairline –0.125″	cleaned by mechanical means, sound, and nearly dry	14<T<104°F	$75/gal	25–30 years, will depend on service conditions	45 minutes–1 hour	effective in freeze-thaw conditions
Duraguard 401	HMWM	0 g/L	0.001 and larger	cleaned by mechanical means, structurally sound, visibly dry	40<T<120°F do not use if rain within 12 hours or previous 24 hours	$55/gal	depend on amount of traffic wear, material in crack should last the life	2 hours	would be suitable for Wisconsin-type conditions
TK-9010	Epoxy	0.6 g/L	up to 0.125″	cracks must be clean, moisture tolerant	good adhesion to damp concrete, flexible, low temp application	$31/22 oz. or $180/g	10–20 years	tack free in 1 hour	material in crack unaffected by freeze-thaw
TK-9030	Urethane Polyurea Hybrid	423 g/L	up to 0.125″	cracks must be clean and dry	dry, flexible, low temp. application	$22/22 oz. or $128/ gal	10–20 years	tack free 1 hour	unaffected by freeze-thaw

Product Name	Chemical Family	VOC Content	Crack Width	Surface Preparation Requirements	Application Conditions	Coverage Rate & Cost	Expected Durability	Time to Open Traffic	Environmental Conditions
TK-9000	Epoxy	<400 g/l	0.0625″ and larger	must be clean and dry	T>40°F	$35/gal	material penetrating crack should last for 20 years	4 hours at 70°F	unaffected by freeze-thaw
Sikadur 55SLV	Epoxy resin	112 g/L	0.004–0.25″	cleaned by mechanical means, sound, may be damp	T>40°F	$130/gal	depends highly on degree of deterioration of the deck ~20 years	6 hours	unaffected by freeze-thaw
Dural 335	Epoxy	<10 g/l	hairline cracks	cleaned by mechanical means, sound, and dry	50<T<90°F	$35/gal	5–15 years	4–6 hours at 75°F	used for many years in freeze-thaw conditions
Sikadur 52	Epoxy	73 g/L	0.0001–0.125″	clean and sound, dry for best performance	T>40°F	$100/gal	Depends on degree of deterioration of the deck ~20 years	10-12 hours	unaffected by freeze-thaw
SikaPronto 19	HMWM		hairline –0.125″	cleaned by mechanical means, sound, may be damp	T>35°F	$180/gal	depends highly on degree of deterioration of the deck ~20 years	12 hours max	unaffected by freeze-thaw

Table 15. Bond Performance of Crack Sealants from a 2005 Laboratory Study by Pincheira

Generic Sealer	Product Name	Viscosity (cP)	Crack width (in.)	Average Bond Strength (lb) not subjected to freeze-thaw cycles	Average Bond Strength (lb) subjected to freeze-thaw cycles	Average Bond Strength (lb) percent retained
Methacrylate	**Degadeck Crack Sealer**	5–15	• < 0.059 • 0.059–0.098 • 0.098–0.2	• 5585 • 5680 • 4129	• 3902 • 3521 • 3625	• 69.9 • 62.0 • 87.8
Methacrylate	**Denedeck Crack Sealer**	–	• < 0.059 • 0.059–0.098 • 0.098–0.2	• 5191 • 5101 • 5257	• 4152 • 3695 • 2498	• 80.0 • 72.4 • 47.5
Urethane Polyurea Hybrid	**TK-9030**	50	0.098–0.2	1227	620	50.5
Epoxy	**TK-9010**	–	0.059–0.098	2291	990	43.2
HMWM	**SikaPronto 19**	<25	• < 0.059 • 0.059–0.098 • 0.098–0.2	• 3637 • 3552 • 2772	• 2887 • 2210 • 2249	• 79.4 • 62.2 • 81.1
Epoxy Resin	**Sikadur 55 SLV**	105	• < 0.059 • 0.059–0.098 • 0.098–0.2	• 8560 • 7994 • 6321	• 6020 • 5876 • 5572	• 70.3 • 73.5 • 88.2
Epoxy	**Sikadur 52**	200	• < 0.059 • 0.059–0.098 • 0.098–0.2	• 7350 • 6140 • 6012	• 3845 • 4352 • 2463	• 52.3 • 70.9 • 41.0
Epoxy	**Dural 335**	80–100	< 0.059	8329	6599	79.2
Epoxy	**TK-9000**	150	• 0.059–0.098 • 0.098–0.2 • > 0.2	• 2955 • 2829 • 1938	• 1249 • 981 • 900	• 42.3 • 34.7 • 46.4
HMWM	**Duraguard 401**	< 25	• < 0.059 • 0.059–0.098 • 0.098–0.2 • > 0.2	• 3545 • 3051 • 4082 • 3409	• 0 • 196 • 0 • 0	• 0 • 6.4 • 0 • 0

Table 16. Crack Sealers Performance

Generic Sealer	Reference Lab-[l], Field-[f]	Crack width (in.)	Ave. Depth of Penetration (in.)	Repaired-to-Uncracked Strength Ratio (%)
HMWM	Lasa (1990) [f]	• < 0.0039 • 0.0039–0.011 • > 0.11	• 0.76 • 0.933 • 0.95	90.5
HMWM 1	Rodler (1989) [l]	–	3.62*	75.5
HMWM 2	Rodler (1989) [l]	–	3.47*	85.5
HMWM 3	Rodler (1989) [l]	–	3.76*	96.5
HMWM (T70M/T70X)	Sprinkel (1991) [f]	–	–	11.1
Polyurethane	Sprinkel (1995) [l]	• 0.007 • 0.019 • 0.031 • 0.039	NA	• 94 • 114 • 79 • 118
Epoxy 1	Sprinkel (1995) [l]	• 0.007 • 0.019 • 0.031 • 0.039	NA	• 110 • 114 • 119 • 103
Epoxy 2	Sprinkel (1995) [l]	• 0.007 • 0.019 • 0.031 • 0.039	NA	• 115 • 123 • 104 • 114
Epoxy 3	Sprinkel (1995) [l]	• 0.007 • 0.019 • 0.031 • 0.039	NA	• 118 • 93 • 95 • 95
HMWM	Sprinkel (1995) [l]	• 0.007 • 0.019 • 0.031 • 0.039	NA	• 131 • 102 • 128 • 108
Epoxy	Meggers (1998) [f]	0.0157 ꜛ	1.33 (2.16*)	–
HMWM A	Meggers (1998) [f]	0.012 ꜛ	1.57 (2.44*)	–
HMWM B	Meggers (1998) [f]	0.015 ꜛ	1.26 (2.36*)	–
***- Results given in percent penetration of crack (%)**				
ꜛ - Average crack width				

Table 17. Silane Deck Sealant Performance

Product Name	Viscosity	Reference Lab-[l], Field-[f]	Ave. Depth of Penetration (in.)	Sealed-to-Unsealed Chloride Content Ratio (%)
Hydro Silane 40 VOC	low viscosity and small molecular size allow maximum penetration into the concrete or masonry surfaces	Pincheira et al. (2005) [l]	0.149606	0.37
Sonneborn Penetrating Sealer 40 VOC	N/A	Pincheira et al. (2005) [l]	0.122047	0.46
Anuanil Plus 40	Low viscous that allows penetration deeply for maximum protection	Pincheira et al. (2005) [l]	0.098425	0.50
Penseal 244	The material's small molecular structure allows for maximum penetration into new concrete (14-day minimum) or existing concrete.	Pincheira et al. (2005) [l]	0.106299	0.57
Powerseal 40%	The material's small molecular structure allows for maximum penetration into new concrete (14-day minimum) or existing concrete.	Pincheira et al. (2005) [l]	0.074803	0.77

Product Name	Viscosity	Reference Lab-[l], Field-[f]	Ave. Depth of Penetration (in.)	Sealed-to-Unsealed Chloride Content Ratio (%)
Aqua-Trete BSM 20	Provide a high level of repellency with penetration. The active components are unique because they chemically bond to the silica in the substrate and set up a hydrophobic layer of protection	Pincheira et al. (2005) [l]	0.07874	0.84
Hydrozo Enviroseal 40	Excellent penetration	Pincheira et al. (2005) [l]	0.082677	0.88
Hydrozo Enviroseal 20	N/A	Pincheira et al. (2005) [l]	0.055118	1.05
Hydozo 100	Excellent for cold weather applications	Whiting (2005) [f]	0.161417	–
TK-590-40	Deep penetration, very low viscosity	Whiting (2005) [f]	0.145669	–
Enviroseal 40	N/A	Whiting (2005) [f]	0.090551	–

Information on the siloxane deck sealants' performance is shown in Table 18. It contains information about the goods, their names, the sources from which the data came (lab or field testing), the average penetration depth in inches, and the % difference in chloride content between sealed and unsealed settings. The effectiveness of various siloxane sealants in lowering chloride content and protecting masonry or concrete surfaces is evaluated in the table.

Table 18. Siloxane Deck Sealant Performance

Product Name	Reference Lab-[l], Field-[f]	Ave. Depth of Penetration (in)	Sealed-to-Unsealed Chloride Content Ratio (%)
TK 290-WDOT	Pincheira et al. (2005) [l]	0.070866	0.86
TK 290-WB	Pincheira et al. (2005) [l]	0.059055	1.11
Eucoguard 100	Pincheira et al. (2005) [l]	0.070866	1.27
TK-290-12 TriSiloxane	Whiting (2005) [f]	0.09055	

A useful tool for professionals working with concrete in construction and maintenance, Table 19 offers a quick reference guide for choosing the best crack sealer based on the width of the cracks found in concrete structures.

Deck Sealant Conclusions

- Common acceptance tests often include 90-day ponding (conducted following AASHTO T259) and absorption tests (based on ASTM C642).
- The NCHRP 244 Series II test is widely utilized to quantify performance, with specific requirements that demand a 75% reduction in water absorption and chloride intrusion while maintaining 100% vapor transmission.
- The most frequent quality assurance/quality control (QA/QC) tests conducted on bridge decks, though they may exhibit high variability and scattered field results, involve the examination of depth of penetration and chloride content.
- Silane products typically exhibit superior performance compared to siloxane products.
- Water-based products are generally unsuitable for reapplication.
- In comparison, solvent-based products usually outperform their water-based counterparts.
- A higher solids content is typically considered desirable.
- S40Si is the most commonly manufactured sealant that aligns with this criterion.
- To ensure effective application, sealants should be applied within the temperature range of 40°F to 100°F.
- If the deck is damp, it is advisable to enforce a drying period of at least two days before applying the sealant.

Crack Sealant Conclusions

- Acceptance tests for evaluating suitable crack-sealing products are not commonly conducted in many states.
- Typically, product selection is based on established research, such as the work conducted by Pincheira et al. (2005).
- The most common QA/QC tests performed on bridge decks, though results may vary and be scattered, focus on the examination of depth of penetration and chloride content.
- HMWM products typically offer improved penetration, which is advantageous for smaller cracks.
- Epoxy products usually deliver higher bond strength.
- While variable, epoxy sealers often exhibit good resistance to freeze-thaw effects.
- Opt for a crack sealer with a viscosity of less than 500 cP (or 25 cP for HMWM sealers).
- Select a crack sealer with a tensile strength exceeding 8 MPa.
- Choose a crack sealer with a tensile elongation greater than 10%.
- Crack sealers should be applied within the temperature range of 45°F to 90°F.
- If feasible, apply the crack sealer between 11:00 p.m. and 7:00 a.m.
- Employ some form of surface preparation to clean the cracks effectively.
- Enforce a drying period of two to three days if the deck is moist.

Table 19. Crack Sealants Tested with Each Crack Width by Pincheira et al. (2005)

Hairline (< 0.06″)	**Narrow (0.06″ to 0.1″)**	**Medium (0.1″ to 0.19″)**	**Wide (> 0.2″)**
1/32″	1/16″	1/8″	1/5″
Degadeck Crack Sealer	Degadeck Crack Sealer	Degadeck Crack Sealer	TK 9000
Denedeck Crack Sealer	Denedeck Crack Sealer	Denedeck Crack Sealer	Duraguard 401
Sikadur 52	Sikadur 52	Sikadur 52	
Sikadur 55 SLV	Sikadur 55 SLV	Sikadur 55 SLV	
SikaPronto 19	SikaPronto 19	SikaPronto 19	
Dural 335	TK 9000	TK 9000	
Duraguard 401	TK 9030	TK 9010	
	Duraguard 401	Duraguard 401	

A selection matrix for recommended concrete bridge deck sealers based on different conditions of the decks is shown in Table 20.

Table 20. Recommended Concrete Bridge Deck Sealer Selection Matrix According to MoDOT

Recommended Concrete Bridge Deck Sealer Selection Matrix	
New decks and decks with minimal cracking	EPG 771.16 Penetrating Concrete Sealer—Silane
Decks with hairline cracks < 1/128” (0.008 in.) wide	EPG 771.17 Concrete Crack Filler—Low Viscosity Polymer (LVP)
Decks with cracks >1/128” (0.008 in.) wide	EPG 771.18 In-Deck Bridge Deck Crack Filler
Decks with cracks >1/64” (0.016 in.) wide	EPG 771.19 Chip Seal to Entire Deck

By forming a hydrophobic barrier that keeps water and chlorides from penetrating the bridge deck, silane surface treatment aids in sealing bridge decks. When using silane, the following circumstances need to be taken into account:

Silane Sealer:

- The surfaces of concrete bridge decks should be coated with silane. Silane should not be used on surfaces with epoxy or bituminous sealants.
- Applying before using crack fillers might help the concrete adhere better and stay protected.
- Surface temperatures should range from 40°F to 90°F while the work is done. Cooler temperatures will stop product loss from evaporation, but the curing process will take longer. Applications throughout the summer are encouraged at night.
- Decks need to be dry and clean before application. Moisture will entirely halt silane penetration if it is present.
- The application rate is 200 square feet per gallon. Avoid getting product overspray on automobiles when applying it. Before opening to traffic, let the substance cure and permeate the bridge deck.
- All freshly constructed concrete bridge decks need to be treated with silane. Reapplication should be considered in the first three years if more cracking develops. More applications are advised at intervals of 7 to 10 years.

Low Viscosity Polymer:

Bridge decks with hairline shrinkage cracks are sealed with low-viscosity polymer (LVP) bridge deck crack fillers to stop the infiltration of water and chlorides into the bridge deck or overlay. When using polymer crack fillers, the following should be considered.

- Any size of crack can be filled using LVP crack fillers. It is best utilized on an as-needed basis for hairline cracks that are narrower than 1/128.

- The task should be carried out at a temperature lower than 75°F. The solution penetrates cracks more effectively when used at lower temperatures.
- Decks need to be cleaned, pressure washed (at a minimum of 2500 psi), and given time to dry three days before applying polymer and two days after any measurable precipitation.
- Cover any features or expansion devices that should not be sealed off.
- Apply polymer to deck surfaces at 100 square feet per gallon.
- The bridge surface should be covered with polymer using a squeegee or brush.
- Before curing, sand should be applied to the deck surface at 1 to 2 lb per square yard.

In-Deck Bridge Deck Crack Filler:

To stop water and chlorides from penetrating the bridge deck or overlay, the In-Deck Bridge Deck Crack Filler aids in sealing bridge decks with wider-width cracks.

- In-Deck is applied on bridge decks with deck fractures that are 1/128″ to 1/64″ or wider.
- The task should be carried out at a temperature lower than 75°F. The solution penetrates cracks more effectively when used at lower temperatures.
- Lower temperatures may necessitate longer dry times.
- Ensure that the deck's surface is dry and clean. Before applying the product, use compressed air to blow out any loose particles.
- Cover any features or expansion devices that should not be sealed off.
- On the job site, thoroughly combine In-Deck and water to create a 50/50 mixture. One hundred square feet per gallon of mixed stuff should be applied.
- Direct application of material or other methods of application are both acceptable. Distribute the product evenly across the deck surface with stiff-bristle brooms, avoiding leaving any puddles. To prevent material from filling in the texturing, broom in parallel with the already-existing tine markings. Return often and sweep up any puddles that might reappear.
- Before allowing traffic on the surface, let the product air dry entirely. Sand can be sprinkled on the surface to help blot excess material, stop tracking, and improve short-term skid resistance if necessary while the substance is still sticky. This is especially advised in locations with more traffic, where the decks are smooth from wear, or where braking action can be expected.
- Reapplication should be taken into consideration every three to five years.

Considering crack width and density to ascertain the proper treatment or action required for each unique case, Table 21 acts as a decision-making guide for resolving concrete cracking concerns within a lot.

Table 21. Decision Matrix Depending on Crack Width and Crack Density by Rettner et al. (2014)

Average Crack Width Range, inches	Isolated (< 0.005%)	Occasional (0.005% to < 0.017%)	Moderate (0.017% to < 0.029%)	Extensive (> 0.029%)
< 0.004 0.004 to < 0.008 0.008 to < 0.012 0.012 to < 0.016	No treatment	• No treatment • Epoxy or MM*	• No treatment • Epoxy or MM*	MM* Investigate
0.016 to < 0.020 0.020 to < 0.024 0.024 to < 0.028	Epoxy or MM* Epoxy Epoxy	Investigate	Investigate	• MM* Investigate • Remove and replace
>=0.028	Investigate	Investigate	Investigate	Remove and replace

*MM: methyl methacrylate

A4.1 Type 1a

Penetrating silane sealers are used in sheltered areas where the relative humidity of the concrete is less than 55%. The typical solids content range for Type 1a sealer is 14% to 32%. These sealers are applied on concrete surfaces that are 28 days or older. Penetrating sealers are used for traffic-bearing surfaces in sheltered conditions where the relative moisture content is less than or equal to 55%. Concrete sealer type 1a product specifications are summarized in Table 22.

Table 22. Concrete Sealer Type 1a Product Specifications

Product Name	Manufacturer	Dry Time	Cost	Appl. Rate (mL/m^2)
Sikagard SN-40 Lo-VOC	Sika Canada Inc.	4–6 hours	$3,000 per drum	320
Baracade Silane 40 EX	Euclid Canada Inc.	2–4 hours	310$/5G	204

<u>Limitations for Sikagard N-40 Lo-VOC Sealer</u>

- It has high alkali resistance. It is possible to apply it earlier, though lower penetration might be expected.
- It is not recommended for exterior applications if rain is expected within 12 hours.
- It is not intended for waterproofing under hydrostatic pressure.

Limitations for Baracade Silane 40 EX

- Store material between 40°F and 85°F (4°C and 29°C). Protect from moisture, direct sunlight, and freezing.
- Baracade Silane 40 IPA contains isopropyl alcohol and is flammable, with a flash point of 53°F (12°C). Avoid fire, open flame, and sparks.
- Use in a well-ventilated area.
- Do not dilute.
- Do not allow puddles. All products should penetrate the substrate with no surface build-up.
- Do not apply to a frost-filled surface or when the temperature is below 20°F (0°C).
- Do not apply if rain is expected within 4 to 6 hours.

A4.2 Type 1b

Penetrating silane sealers used in traffic-bearing areas are for outdoor use. The relative humidity of the concrete is 75% or less. The application rate is usually higher than the Type 1a for the same brand of sealer. These sealers are generally called 40% silane sealer, which has a solids content range of 25% to 33%. These sealers are used on concrete decks that are cured for 28 days or older. Penetrating sealers are used for traffic-bearing surfaces in outdoor conditions where the relative moisture content is less than or equal to 70%. Concrete sealer type 1b product specifications are summarized in Table 23.

Table 23. Concrete Sealer Type 1b Product Specifications

Product Name	Manufacturer	Dry Time	Cost	Appl. Rate (mL/m^2)
MasterProtect H400 (Hydrozo 100)	BASF	Typical drying time for MasterProtect H400 is 4 hours at 70°F	250$/5G (18.9L)	314
Protectosil BHN	Evonik Degussa Corporation	Quick dry time after application (1 hour)	380$/5G	174
Sikagard SN-40 Lo-VOC	Sika Canada Inc.	4–6 hours	$3,000 per drum	224
Baracade Silane 100C	Euclid Canada Inc.	2–4 hours	310$/5G	326

Limitations for MasterProtect H400 (Hydrozo 100):

As mentioned in the BuildSite (2016) MasterProtect H400 (Hydrozo 100) data sheet, the limitations are the following:

- MasterProtect H 400 may leave a temporary slippery surface for several hours after application. Therefore, traffic-bearing surfaces should not be reopened until the treated surface is dry.
- Variations in the substrate's texture and porosity will affect the product's coverage and performance.
- MasterProtect H 400 will not inhibit water penetration through unsound or cracked surfaces or surfaces with defective flashing, caulking, or structural waterproofing.

Limitations for Protectosil BHN

- It is not intended for below-grade waterproofing. It should not be applied if the surface temperature is below 20°F (−7°C) or above 100°F (40°C), if rain is expected within 2 hours following application, or if high winds or other conditions prevent proper application. If rain has preceded the application, the surface should be allowed to dry for at least 24 hours.

Limitations for Baracade Silane 100 C

- Store at temperatures below 32°C.
- Baracade Silane 100 C is a DOT combustible liquid. Avoid fire, open flame, and sparks.
- Do not dilute.
- Do not allow puddles. All products should penetrate the substrate with no surface build-up.
- Do not apply to a frost-filled surface or when the temperature is below 0°C.
- Do not apply if rain is expected within 4 to 6 hours.
- It is not intended for use on below-grade applications or applications where hydrostatic pressures exist.
- May not be effective on certain types of limestone or marble. Test application is always recommended to confirm performance and appearance. Use in a well-ventilated area.

A4.3 Type 1c

A penetrating sealer, known as a 100% silane sealer, is characterized by a solids content that typically ranges between 65% and 72%. It is recommended for use on precast concrete structures that have been steam-cured for one to five days, with 28 days being the preferred curing time, provided the relative humidity of the concrete is 85% or less. It is a low VOC penetrating sealer that is designed for use on new bridges and overlays with low water-to-cement ratios (typically ranging from 0.30 to 0.45), provided the relative moisture content of the concrete is 80% or less. It is a high-performance sealer known for its effectiveness in protecting concrete surfaces. Concrete sealer type 1c products specifications are summarized in Table 24.

Table 24. Concrete Sealer Type 1c Product Specifications

Product Name	Manufacturer	Dry Time	Cost	Appl. Rate (mL/m²)
MasterProtect H1000	BASF	4–6 hours at 70°F (21°C) and 50% relative humidity	400$/5G (18.9L)	155
Protectosil BHN	Evonik Degussa Corporation	Quick dry time after application (1 hour)	380$/5G	261
SIL-ACT ATS 100	Advanced Chemical Technologies	1 hour at 70°F	$1,025 per drum	246
Certi-Vex Penseal 244 100%	Vexcon Chemicals	1 to 4 hours	370$/5G	186.6
PENTREAT™ 244-100	W.R MEADOWS Inc.	Product dries quickly; usually at 70°F (21.1°C) in one hour.		202.7

Limitations for MasterProtect H1000 (Hydrozo 100)

- MasterProtect H 1000 will not inhibit water penetration through unsound or cracked surfaces or surfaces with defective flashing, caulking, or structural waterproofing.
- Windows or other non-absorbent substrates subject to overspray should be clean and contaminate free at the time of application. Cleaning may be required after application if dirt or dust is present for the silane to react with.
- Do not apply during inclement weather or when inclement weather is anticipated within 12 hours.

Limitations for Cwerti-Vex Penseal 244 100%

- Do not apply unless substrate and ambient temperatures are 20°F (−6°C) and rising at installation time.
- Do not apply above 90°F (32°C) or below 20°F (−6°C).
- Do not apply in rain or when rain is expected within 4 hours before or after application.
- Protect plant life and landscaping from overspray.
- Line stripping can be done after the application of sealer. Contact ChemMasters Technical Service for additional information.

Limitations for Pentreat 244-100

The treated surface must be protected from rain for 6 hours minimum, but 12 hours is preferable. Do not overapply. For optimum performance, the residual moisture of the substrate must not exceed

4%. The surface temperature should be between 40°F (4.4°C) and 95°F (35°C). Should it suddenly start to rain, stop treatment and cover impregnated areas. Do not overapply. Do not allow puddling or running to occur. On vertical applications, protect windowpanes.

A4.4 Type 2a

It is a one-component clear coating type sealer that is used on curbs. Depending upon the type of sealer that was first applied, using a different product of the sealer type may not be compatible and may react and deboned. These sealers are used on concrete that is cured for 28 days or older. One component clear coating for vertical and non-traffic bearing concrete surfaces where the relative moisture content is less than or equal to 70%. Concrete sealer type 2a products specifications are summarized in Table 25.

Table 25. Concrete Sealer Type 2a Product Specifications

Product Name	**Manufacturer**	**Cost**	**Dry Time**	**Appl. Rate (mL/m^2)**
Sikagard A28 Lo-VOC	Sika Canada Inc.	688$ per 18.9 L	At 10°C (50°F) with drying time being approximately 60 minutes.	336
Master Kure CC 250XX	BASF	190$ per 18.9 L	At 65 to 85°F (18 to 29°C) at 50% relative humidity: 3 hours maximum hardness: 7 days	263
TK-Achro Seal AS-1 VOC	TK Products Construction Coatings	250$ per 5 Gallons	Tack Free: 1 hour Open to Traffic: 2 hours	185.2

<u>Caution</u>

On previously sealed concrete surfaces, the sealer product to be applied should be checked for compatibility. Smooth-textured, vertical concrete surfaces may not retain the required coverage rates, and more than two applications may be needed. A reduction in the required coverage rate generally results in a reduction in the waterproofing performance as an increase in the breathability performance of the sealed surface.

<u>Limitations for Sikagard A28 Lo-VOC</u>

- Allow sufficient time for the substrate to dry after water-jetting, rain, or before coating.
- Not designed for use on heavily trafficked surfaces.
- Do not use over-moving cracks; either seal cracks with Sikaflex® or apply Sikagard®-550 W Elastic.
- The minimum age of SikaTop®, SikaRepair® or Sika MonoTop® mortars is 3 days before the application of Sikagard® A-28 Lo-VOC. (Moisture content must be below 4%.)

- Overcoating existing paints with clear coatings is not typical, but compatibility and adhesion testing is essential if this is required.
- Regular wet film thickness and material consumption monitoring are advised to ensure the correct thickness is achieved during application.

Limitations for Master Kure CC 250 XX (Kure-N-Seal 25ES)

As mentioned in Master Kure CC 250 XX data sheet, the limitations are the following:

- If MasterKure CC 250 SB is to be applied in or near areas containing foodstuffs, they must be removed before application; do not return foodstuffs until MasterKure CC 250 SB has fully dried and all solvent vapors have dissipated.
- Do not apply to surfaces of joints to be caulked with sealants. Mask joints to avoid sealant adhesion problems.
- Do not use on surfaces that are to receive concrete overlays or additional toppings or coatings.

Limitations for TK-Achro Seal AS-1 VOC

- Apply in temperatures above 40°F. Colder weather applications may be made under prescribed conditions and procedures specified by TK Products.
- Not for use on asphalt or surfaces subjected to immersion or constant liquid contact.
- Not for use where spillage of solvents, fuels, brakes, transmission, hydraulic fluids, etc. are expected.
- Sprayers must be equipped with neoprene hoses, washers, and gaskets, as rubber or other materials will disintegrate from the solvent.
- Apply this product according to recommended coverage rates. Over-application may cause discoloration.
- The material will not freeze and may be stored outdoors in cold weather; however, it must be allowed to warm to approximately 50°F before use.

A4.5 Type 3

These pigmented sealers are used for coating areas exposed to the public, covering graffiti, and offering good esthetics. These sealers are used on concrete that are cured for 28 days or older. Colored coatings are used for vertical non-traffic-bearing concrete surfaces where esthetics is a primary consideration and the relative moisture content is less than or equal to 70%. Concrete sealer type 3 product specifications are summarized in Table 26.

Table 26. Concrete Sealer Type 3 Product Specifications

Min. DFT - mils (Min. WFT mils)	Product Name	Manufacturer	Cost	Dry Time
4.5 (9.0)	Sikagard Color A50 Lo-VOC **	Sika Canada Inc.	310$ per 5 Gallons	0°C (32°F) Approx. 60 min 25°C (77°F) Approx. 30 min

Caution

The manufacturer's recommended surface preparation must be followed closely to ensure the durability of the coating. At a minimum, the application requirements of Section 4 of the Standard Specifications for Bridge Construction shall be met.

APPROVED CONCRETE SEALANTS IN WISCONSIN

Table 27 provides a list of concrete sealant products, their respective manufacturers, and approval dates. It provides essential details for tracking and identifying these products and their approval status. WisDOT-approved concrete protective surface treatments are summarized in Table 27.

Table 27. WisDOT-approved Concrete Protective Surface Treatments

Product Name	Manufacturer	Date Approved
Aqua-Trete BSM 20	Degussa, Inc	3/16/2001
Baracade WB 244		Pre-1999
Penseal 244 40%	Vexcon Chemical	Pre-1999
Eucoguard 100		Pre-1999
Hydrozo Enviroseal 20	ChemRex, Inc.	Pre-1999
Hydrozo Enviroseal 40	ChemRex, Inc.	Pre-1999
Hydrozo Silane 40 VOC	ChemRex, Inc.	3/16/2001
Masterseal SL 40 VOC	ChemRex, Inc.	12/30/2002
NitecoteDekguard P-40		Pre-1999
Spall-Guard 40	ChemMasters	3/16/2001
TK-290-WDOT (or TK-290-16)	TK Products	Pre-1999
TK-290-WDOT E	TK Products	3/16/2001
TK-290-WBG	TK Products	3/16/2001
Powerseal 40%	Vexcon Chemical	Pre-1999
Sonneborn Penetrating Sealer 40 VOC	ChemRex, Inc.	12/30/2002

APPROVED CONCRETE SEALANTS IN MINNESOTA

Information about three different construction or repair products, including their names, manufacturers, additional contract requirements for application, and approval dates can be found in Table 28–30.

Table 28. Crack Chase Method—High Elongation Epoxy Crack Sealers

Product	Manufacturer	Additional Contract Requirements for Application	Approval Date
Paulco TE-2501 Clear (Fast Set or Standard)	Viking Paints, Inc.	None	07/06/2015
Dural 50 LM	Euclid Chemical Co.	Apply two times per crack	08/04/2015
TK-9000	TK Products	None	06/25/2018

Table 29. Crack Chase Method—High-Strength Epoxy Crack Sealers

Product	Manufacturer	Additional Contract Requirements for Application	Approval
TK-2110	TK Products	None	07/22/2015

Table 30. Deck Flood Method—Methacrylate Resin Crack Sealers

Product	Manufacturer	Additional Contract Requirements	Approval
MasterSeal 630 (formerly Degadeck Crack Sealer Plus)	BASF	Pre-treat / fill cracks 0.025” and larger	06/01/2015
T-78	Transpo Industries	Pre-treat / fill cracks 0.025” and larger	06/01/2015
KBP 204 P SEAL	Kwik Bond Polymers	Pre-treat / fill cracks 0.025” and larger	11/30/2015
Protectosil Degadeck CSS	Evonik Industries	Pre-treat / fill cracks 0.025” and larger	04/27/2023

APPROVED CONCRETE SEALANTS IN NEW YORK

Penetrating Type Protective Sealers (717-03)

The various concrete sealant materials that are available are fully described in Table 31, together with information about their brands, carriers or solvents, percentages of solids, coverage rates in square meters per liter and square feet per gallon, and the sources or locations associated with each product. Different concrete sealants are included in the table, each suitable for different needs and applications. Many businesses in different parts of the nation make these sealants.

Table 31. Concrete Bridge Deck Sealants and Coatings: Product Specifications and Suppliers

Brand Name(s)	Carrier/ Solvent	Solids (%)	Cover Rate in (m^2/l)	Cover Rate in (s.f./gal.)	Supplier/ Location
Aquanil Plus 40A	Acetone/ Isopropyl	40	3.1	125	ChemMasters, Inc. Madison, OH
Aquanil Plus 55 IPA	None	55	4.3	175	ChemMasters, Inc. Madison, OH
Aquanil Plus 100	None	100	6.1	250	ChemMasters, Inc. Madison, OH
Aridox 40	Alcohol	40	3.1	125	Anti Hydro International, Inc. Flemington, NJ
Baracade Silane 100C	None	100	6.1	250	The Euclid Chemical Company Cleveland, OH
Certi-Vex Penseal, 244 100%	None	100	6.1	250	Vexcon Chemicals, Inc. Philadelphia, PA
Certi-Vex Penseal, 244-400	Alcohol	55	4.3	175	Vexcon Chemicals, Inc. Philadelphia, PA
Certi-Vex Penseal 244 BTS-100% (Fast Dry)	None	100	6.1	250	Vexcon Chemicals, Inc. Philadelphia, PA
Iso-Flex 618-100	None	90	6.1	250	Lymtal International, Inc. Orion, MI
KlereSeal® 9100-S	None	100	6.1	250	Pecora Corporation Harleysville, PA
MasterProtect H400	Water	40	3.1	125	Master Builders Solutions US LLC Shakopee, MN
MasterProtect H 1000	None	100	6.1	250	Master Builders Solutions US LLC Shakopee, MN
PowerSeal 40	Water	40	3.1	125	Vexcon Chemicals, Inc. Philadelphia, PA
Protectosil® BH-N	None	100	6.1	250	Evonik Degussa Corporation Parsippany, NJ

Brand Name(s)	Carrier/ Solvent	Solids (%)	Cover Rate in (m^2/l)	Cover Rate in (s.f./gal.)	Supplier/ Location
Protectosil®300S	None	100	6.1	250	Evonik Degussa Corporation Parsippany, NJ
Sikagard® 705L	None	100	6.1	250	Sika Corporation Lyndhurst, NJ
Sikagard® 740 W	Water	40	3.1	125	Sika Corp Lyndhurst, NJ
SIL-ACT™ ATS-100	None	100	6.1	250	Advanced Chemical Technologies Oklahoma City, OK
SIL-ACT™ ATS-100 LV	None	100	6.1	250	Advanced Chemical Technologies Oklahoma City, OK
SIL-ACT™ ATS-200	None	100	6.1	250	Advanced Chemical Technologies Oklahoma City, OK
Weather Worker S-100 (J29A)	Alcohol	90	6.1	250	Dayton Superior Pine Plains, NY

Coating Type Protective Sealers (717-04)

Several concrete coating systems are summarized in Table 32, along with information about their brands, types of coating (primer or topcoat), coverage rates in square meters per liter and square feet per gallon, color changes (if any), surface textures (smooth or none), and suppliers or locations where these coating systems can be purchased. The table includes a variety of coating products that various manufacturers offer. Each product has a unique surface texture, coverage rates, color change requirements, and application type (primer or topcoat).

Table 32. Concrete Bridge Deck Coating Systems and Specifications

Brand Name(s)	Coat	Cover Rate in (m^2/l)	Cover Rate in (s.f./gal)	Color Change	Surface Texture	Supplier/ Location
Duraguard System Safe-Cure & Seal EPX Duraguard 310 CRU	Primer Top	5.0 8.0	200 330	None Lt. Gray	Smooth	ChemMasters, Inc. Madison, OH
Safe-Cure & Seal EPX GreenThane™ 310WB	Primer Top	4.9 7.4	200 300	NoneLt. Gray	Smooth	ChemMasters, Inc. Madison, OH
Si-Prime Si-Rex 03	Primer Top	4.9 7.9	200 320	None Gray	Smooth	Klaas Coatings (North America) LLC Dallas, TX

SUMMARY OF SEALERS USED BY NEIGHBORING STATES

- WisDOT's *2016 Bridge Preservation Manual* recommends sealing 25% of eligible concrete decks and slabs with waterproofing penetrating sealants every four years.
- MnDOT applies crack sealants every three to five years, considering life-cycle cost, and based on a 2014 research study that evaluated 12 concrete bridge deck crack sealants (Oman, 2014).
- Iowa DOT uses saline with two different mixtures for sealing, with a life expectancy of three to four years. They utilize 100% saline (MasterProtect H 100, manufactured by BASF) and 90% saline with 10% mineral spirits concrete sealer (TK-590-90, manufactured by TK Products).
- Michigan DOT is considering using saline in the future, and they are currently searching for a product for maintenance crews to use.
- Iowa DOT uses two water-based sealers with an expected life of 3 to 4 years. However, penetration tests have shown that none of these sealants are highly effective, leading to less satisfactory results.
- Star Macro-Deck: Designed to protect concrete bridge decks from salt and chemical damage by inhibiting chloride deicing chemicals, salt, and chemical damage while maintaining the concrete's flexural and tensile strength.
- Pavix CCC100 Chem-Crete is a water-based chemical product protecting large-scale concrete layers against temperature and water-related issues like thermal cracking, freeze-thaw cycles, chloride ion penetration, and alkali-silica reaction. It offers benefits similar to saline sealers while delivering additional advantages for structures, construction workers, and the environment.
- Healer sealers are commonly used as sealants by Michigan DOT. They have a lower viscosity than thin overlay materials and are effective for crack penetration sealing.
- MnDOT uses methyl methacrylate as a concrete bridge seal due to its ultra-fast cure time and strong physical characteristics.
- KDOT has used polymer sealers with a life expectancy of 10 to 15 years for urban areas and 25 years for others. However, the experience has not been consistent, and cost-effectiveness is questioned.
- North Dakota DOT and INDOT recommend epoxy sealants with a service life of 3 years to prevent chloride ion ingress into concrete bridge decks. MnDOT uses two epoxy sealers: high-elongation and high-strength epoxy crack sealers.

- Silane is a commonly used surface treatment in North Dakota and Minnesota to reduce water entry into concrete bridge decks. Retreatment with silane is recommended on a 6-year cycle in North Dakota and a 3-year cycle in INDOT and Minnesota.

The types of concrete sealers used in various states, their projected performance, and precise application specifics are shown in Table 33. The recommended sealer or sealant mixture for each state varies, and depending on the product, the projected performance can range from 3 to 15 years. Specific factors for the application in each state are highlighted in the table, including the need for a certain temperature, compatibility with patching materials, surface preparation, and contamination avoidance.

Table 33. Summary of Sealers Used by Neighboring States

State	Sealer	Expected Performance	Application Details
Iowa	Saline Star Macro-Deck Pavix CCC100	3–4 3–4 3–4	Iowa DOT is not satisfied with the results from its sealants.
Michigan	Saline Healer Sealer	8–10	
Indiana	Epoxy Silane		
Kansas	Polymer (Two courses)	10–15	Temperature must be above 40°F. Must remove shallow voids in the deck. Epoxies must be compatible with patching materials. Contamination must be avoided. Not to be placed directly over a new concrete deck without allowing for adequate cure time.
North Dakota	Epoxy Silane	3 6	Getting the surface prepped, particularly for crack sealing, is important to get a good result.
Minnesota	MMA Epoxy Silane	3–5 3–5 3–5	For sealants, air-blown test sections perform better than sand-blasted test sections.

Figure 5 shows a map illustrating the type of sealers each neighboring state uses.

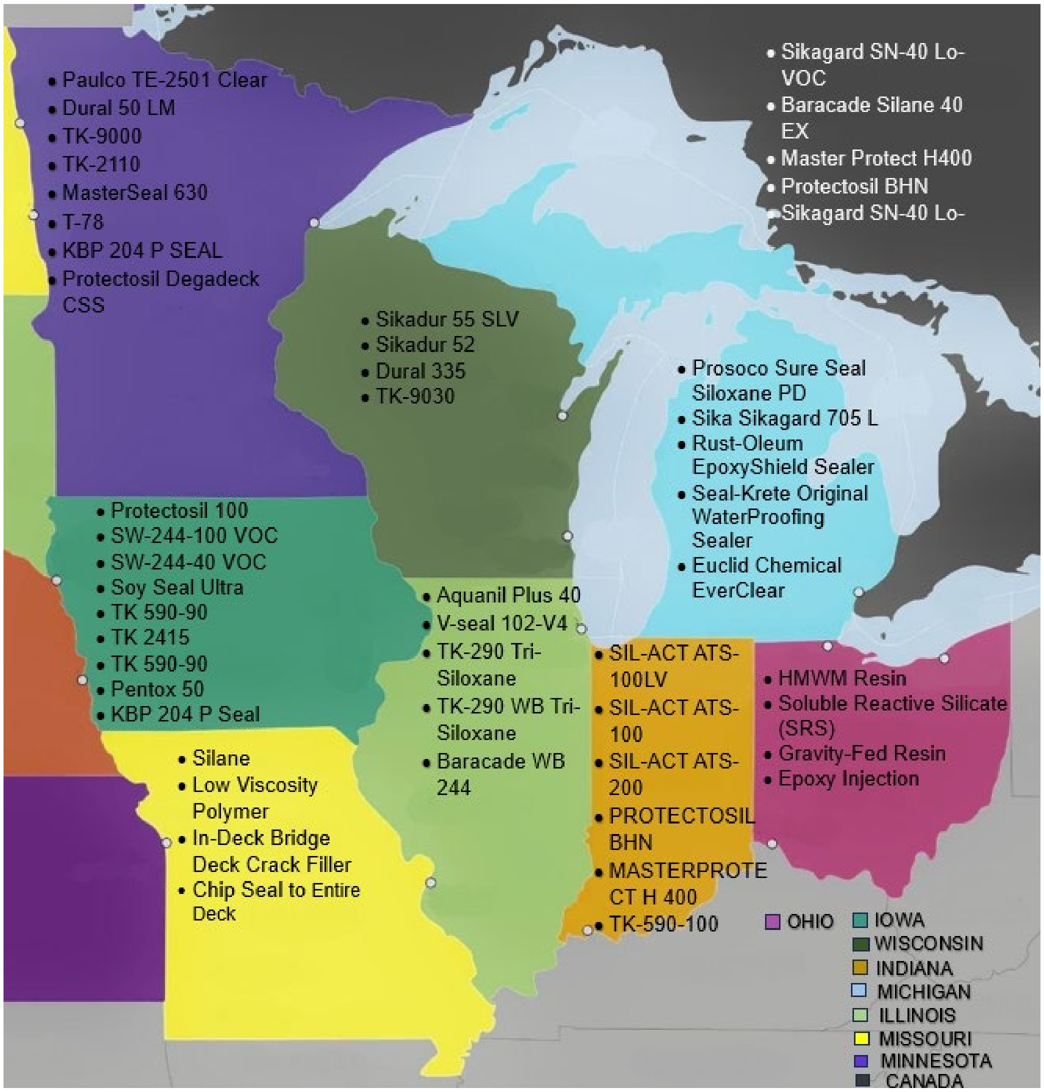

Figure 5. Map. Map showing sealers used by neighboring states.

SURVEY ON SEALERS USED BY DIFFERENT DOTS

Krauss et al. (2009) conducted a survey on the guidelines for the selection of bridge deck overlays, sealers, and treatments. Krauss summarizes the responses of the following 12 states: Arkansas, Colorado, Illinois, Maine, Minnesota, North Carolina, Oklahoma, Oregon, Pennsylvania, South Dakota, Utah, and West Virginia, and their practices regarding using sealers for bridge deck maintenance. The particular types of sealers that respondents referenced are epoxy, silane, and polyurethane sealers.

Advantages

- Low cost—6 agencies (50%)
- Effectiveness—5 agencies (42%)
- In contrast, 2 agencies commented on the short duration of effectiveness.

- Ease of installation—4 agencies (33%)
- Quick installation with little disruption to traffic—3 agencies (25%)

Disadvantages

- Short lifetime—4 agencies (33%)
- Performance issues—4 agencies (33%)
  - Do not work well with cracked concrete
  - Not effective after concrete cracks
  - Over-application can result in a slick surface
  - Do not necessarily shut out water and salts on traffic surfaces
- Installation problems—2 agencies (17%)
  - Contractor issues
  - Warm temperature requirements

Use History

The commencement of sealer utilization by responding agencies exhibits significant variation. Two agencies (17%) initiated sealer usage over 25 years ago, five agencies (42%) adopted sealer application between 10 to 25 years ago, three agencies (25%) started employing sealers between 5 to 10 years ago, and an additional two agencies (17%) began applying sealers within the last 5 years.

The extent of sealer usage among agencies is relatively widespread. Five agencies (42%) have employed sealers on 100 or more bridges within their jurisdiction. Three agencies (25%) have used sealers on 50 to 100 bridges, three agencies (25%) have applied sealers to 10 to 50 bridges, and only one agency (8%) has used sealers on 10 or fewer bridges.

Among the agencies that responded to the question, five agencies (42%) specify sealers as a component of their standard specifications. Four agencies (33%) incorporate sealers as part of a standard special provision, while one agency (8%) views sealers as an experimental practice.

In terms of the trend in sealer usage, seven agencies (58%) report an increasing use of sealers within their jurisdiction. In comparison, four agencies (33%) indicate that the benefit remains static, and one agency (8%) reports a decrease in the utilization of sealers within its jurisdiction.

Selection

All agencies selected sealers for the ease of installation, and 11 (92%) selected sealers because of their low cost. The reasons for selecting sealers by agency are summarized in Table 34.

Table 34. Reasons for Selecting Sealers by Agency

Reasons for Selection of Sealers	Yes	No
Easy to install	12	0
Long-anticipated service life	2	10
Good track record on similar projects	5	7
Already approved by your department	9	3
Recommended by a colleague	1	11
Research findings were positive	5	7
Inexpensive	11	1
Short lane closures (rapid return of traffic)	7	5
Dead load considerations	3	9
Personal experience	2	10
Presentation by manufacturer's representative	0	12

Among the agencies that employ sealers, four (33%) apply sealers during new construction projects, while 10 (83%) utilize sealers for proactive maintenance purposes. Additionally, six (50%) of these agencies employ sealers to tackle existing problems on bridge decks. Table 35 details the deck conditions commonly requiring sealer application. The existing deck conditions addressed according to agencies are summarized in Table 35.

Table 35. Existing Deck Conditions Addressed According to Agencies

Existing Deck Conditions Addressed by Sealers	Yes	No
Newer deck in good condition (preventative)	7	5
Deck with cracking in good condition with no significant active corrosion	10	2
Deck with cracking and active corrosion (<5% delamination, no spalling)	7	5
Deck with cracking and active corrosion (>5% delamination and some spalling)	4	8
Deck with cracking and active corrosion (>10% spalling/patching)	2	10
Deck with surface deterioration or abrasion loss	3	9

Particular sealers are typically chosen over similar materials because of cost by four of the agencies responding to the question, because of ease of use by one agency, because of low traffic impacts by one agency, and for good performance by two responding agencies.

Anticipated Lifespan

- Range: 1 to 20 years
- Mean: 4 to 10 years
- Median: 4 to 8 years

Cost

- Range: $0.33 to $15 per square foot
- Mean: $3 to $5 per square foot
- Median: $2 to $4 per square foot

Installation

The main methods utilized for surface preparation in the application of sealers encompass brooming, air sweeping, and sandblasting. It is worth noting that hydro demolition or milling techniques are not commonly employed by agencies. Table 36 presents a summary of the various techniques employed for surface preparation in conjunction with sealers.

Table 36. Surface Preparation Methods Used with Sealers by the Agencies

Surface Preparation Techniques	Yes	No
No preparation	1	9
Air sweep	6	4
Broom	6	4
Sand blast	5	5
Shot blast	1	9
Water blast	2	8
Water/grit blast	1	9
Hydrodemolition	0	10
Milling	0	10
Crack routing	1	9

All responding agencies use visual examination to evaluate the prepped deck surface before sealers are applied. Table 37 provides a brief summary of the agencies' evaluation processes.

Table 37. Methods of Evaluation Used by Agencies

Methods Used to Evaluate Prepared Substrate for Sealers	Typically	Occasionally	Never
Visual inspection	10	0	0
Hammer or chain-sounding	4	2	1
Adhesion test to the bare substrate	1	2	2

GENERAL RECOMMENDATIONS

The suggestions provided by the participants regarding sealer usage were diverse. One individual suggested scattering sand in the epoxy sealer when applying it over a large expanse might be necessary. Another respondent emphasized that film-forming sealers should not be used on road surfaces. A third contributor mentioned that the concrete should undergo abrasive blasting and be dry and warm, and they recommended installing the sealer in hot weather. Yet another respondent remarked on the challenges of obtaining product approvals due to the many available products in the market.

APPLICATION OF THIN POLYMER OVERLAYS BY OTHER STATES

Thin polymer overlays are employed on decks to diminish chloride ion penetration, thereby reducing corrosion, and to enhance skid resistance by increasing friction. Their thinness, typically ranging from 0.25 to 0.75 inches, results in less additional dead weight and allows for faster application compared to alternative overlay types. States may employ varying criteria when determining the suitability of overlays, which could encompass chloride levels at the reinforcing bar, delamination percentage of the deck, and depth of cover over reinforcement. For instance, research conducted in Virginia (Sprinkel et al., 1993) recommended removing all concrete with chloride contents exceeding 1.0 lb/yd^3 before overlay placement. This recommendation is rooted in the understanding that significant chloride contamination beneath the overlay may perpetuate corrosion activity unabated.

Wilson et al. (1995) suggested that there might be a necessity for further polymer applications every 5 to 10 years. They found that thin polymer overlays could serve as a practical substitute for rigid concrete overlays in situations where swift construction is crucial or where adding extra dead load is undesirable.

Krauss et al. (2009) conducted a nationwide survey on bridge deck overlays, sealers, and treatments as part of their NCHRP study. In this survey, they included polymer overlays (specifically thin-bonded polymer concrete) and received responses from 23 states: Alaska, California, Colorado, Georgia, Idaho, Illinois, Kansas, Massachusetts, Maine, Missouri, New Mexico, Nevada, New York, Oklahoma, Oregon, Tennessee, Utah, Vermont, and Wyoming.

The survey respondents highlighted several advantages of polymer overlays, as follows:

- Swift installation leading to rapid return to traffic (65%)
- Simple installation process without requiring modifications of approaches or redoing expansion joints (39%)
- Lightweight with low dead load, noted by 7 respondents (30%)
- Effective waterproofing and low chloride permeability, acknowledged by 6 respondents (26%)
- Demonstrated durability or long lifespan, cited by 6 respondents (26%)
- Enhanced skid resistance or favorable friction characteristics, recognized by 5 respondents (22%)

According to Krauss et al. (2009), the following were identified as disadvantages of polymer overlays:

- Cost, with 11 respondents (48%) expressing concerns.
- Installation issues, noted by 30% of respondents, including problems related to inadequate surface preparation affecting adhesion and binder preparation.
- Lower durability, cited by 17% of respondents, particularly under high traffic loads and in the wheel path.
- Challenges in correcting problems that arise during installation, mentioned by 13% of respondents.
- Inability to use polymer concrete as a direct replacement for bridge deck concrete, mentioned by 4% of respondents.

Krauss et al. (2009) further noted that the use of polymer overlays has seen a nationwide increase, particularly over the last decade. Massachusetts has been utilizing polymer overlays for more than 25 years. Among the respondents, 30% reported using polymer overlays within the last 10 to 25 years, while 39% began using them 5 to 10 years ago. Additionally, 26% of respondents adopted polymer overlays within the last five years. The mean and median anticipated lifespan reported by respondents for polymer overlays were 9 to 18 years and 10 to 18 years, respectively.

The Krauss et al. (2009) study outlined several general recommendations provided by the respondents:

- Three respondents advised having a manufacturer's representative present on-site during installation.
- Surface preparation concerns were mentioned by three respondents, emphasizing the importance of high-quality surface preparation, and achieving a dry surface. It was noted that the system may not adhere well to green concrete.
- Two respondents discussed cure time, with one mentioning a cure time of more than four hours per layer and another suggesting the use of these overlays if construction time is a concern.
- Weather conditions can affect the cure of some systems, and it was suggested that installers adhere to temperature and humidity tolerances.
- One respondent cautioned against using thin bonded epoxy overlays to repair decks with active corrosion.
- Another respondent recommended against using polymer concrete for partial replacement of a bridge deck section and suggested the use of volumetric mixing trucks and paving machines for large areas.
- It was advised to assess if cracks are active and evaluate ride quality.

Table 38 shows the survey responses regarding surface preparation used. The most common surface preparation is shot blasting.

Table 38. Surface Preparation Techniques in Polymer Overlays (Krauss et al., 2009)

Surface Preparation Techniques	Yes	No
No Preparation	0	19
Air Sweep	3	16
Broom	3	16
Sand Blast	5	14
Shot Blast	16	3
Water Blast	1	18
Water/Grit Blast	0	19
Hydrodemolition	1	18
Milling	4	15
Crack Routing	1	18

Table 39 presents a list of available commercial products for thin polymer overlays that are commonly used in conjunction with polymer overlays.

Table 39. Thin Polymer Overlays Available Products

Manufacturer	Product Trade Name	Generic Type	Usage
BASF	Trafficguard EP35	Epoxy Overlay	Deck overlay
Dayton Superior	Pro-Poxy Type III	Epoxy and Urethane Overlay	Deck overlay
International Coating, Inc.	ICO Flexi-Coat BD	Epoxy Overlay	Deck overlay
Sika Corporation	Sikadur 22 Lo-Mod	Epoxy Overlay	Deck overlay
TK Products	TK 2109	Epoxy Overlay	Deck overlay
Transpo	Transpo T-48	Polysulfide Epoxy Overlay	Deck overlay

CHAPTER 3: GUIDE FOR TREATING BRIDGE DECK CRACKS

CRACK-FOCUSED DECISION TREES AND TABLE SUMMARIZES MECHANICAL CHARACTERISTICS OF SEALER PRODUCTS

To use the decision tree in Figure 7, the following information are needed:

- **NBI:** Bridge Deck Rating
- **Crack Classification:** The majority of the cracks observed were transverse cracks.
- **Crack width:** Typical transverse crack widths measured.
- **Crack Spacing**
- **Crack Density:** A crack density ranging from 0.22 ft/ft^2 to 0.37 ft/ft^2 corresponds to a NBI condition rating of 6 within the decision tree. If the density is below 0.22 ft/ft^2, the NBI rating is 7, while a density exceeding 0.37 ft/ft^2 results in an NBI rating of 5 or less. Notably, crack density is influenced by the crack width at specified intervals, a factor also integrated into the decision tree. Determining crack density, as shown in Figure 6, involves considerations of crack length and the bridge area inspected, crucial for informed decisions regarding sealing interventions. For example, the crack density highly depends on the assumed inspected area. If deck area = 12,000 ft^2, total crack width = 40 ft, and length = 300 ft, then crack density = 300/12,000 ft/ft^2 = 0.025 ft/ft^2.

$$Crack\ Density\ = \frac{Total\ Length\ of\ Cracks}{Area\ of\ Bridge\ Decks}\left[\frac{ft}{ft^2}\right] \text{or} \left[\frac{m}{m^2}\right]$$

Figure 6. Equation. Crack density equation.

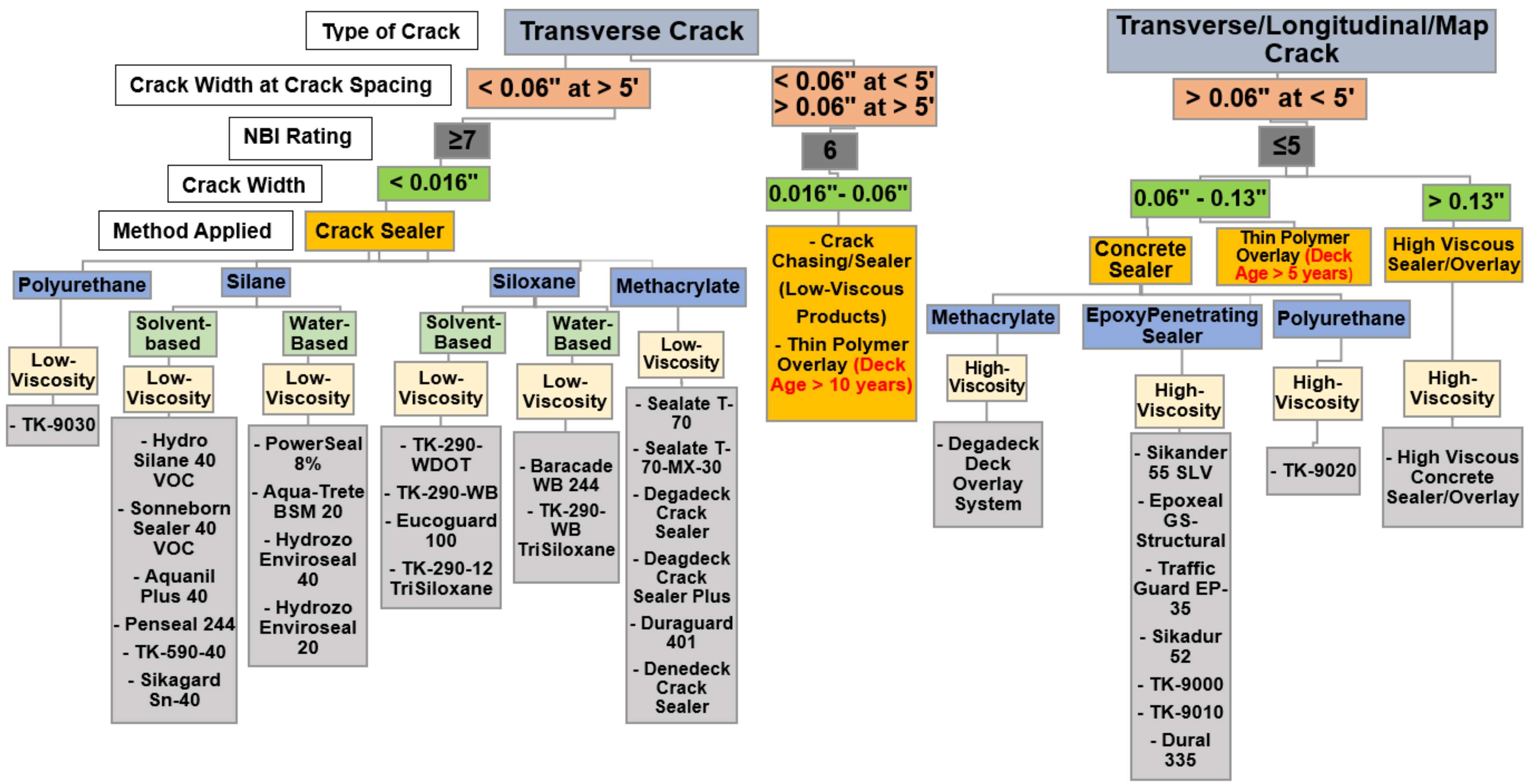

Figure 7. Flowchart. Decision tree for treating cracks in a concrete bridge deck.

Decision Tree Notes

Based on the definition of wearing surface condition states provided in the AASHTO Elements, Defects, and Condition States (2015 Interims) in Appendix A, a condition state is defined as follows:

- A good condition state (CS 1) is when cracks in reinforced concrete are smaller than 0.012 in. or have a spacing greater than 3 ft.
- A fair condition state (CS 2) is characterized by crack widths ranging from 0.012 to 0.05 in. or spacing between 1 ft and 3 ft.
- A poor condition state (CS 3) is indicated by cracks larger than 0.05 in. or spacing less than 1 ft.
- A severe condition state (CS 4) is reached when the wearing surface is no longer effective.

In the decision tree, application of thin polymer overlay concrete methods is recommended if the bridge deck age is > 5 years. This is specifically for instances where:

- Crack width falls within the range of 0.06 to 0.13 in.
- NBI is less than 5.
- Crack spacing is less than 5 ft.
- Crack exhibits a transverse, longitudinal, or mapping pattern.

Also, if the bridge deck age is > 10 years, the utilization of thin polymer overlay is advised for:

- Cracks ranging from 0.06 to 0.13 in. and 0.016 to 0.06 in.
- NBI criterion is adjusted to 6 or less.
- Crack patterns are limited to transverse only or a combination of transverse, longitudinal, and mapping orientations.

EXAMPLES OF USING DECISION TREES FOR CRACK MAINTENANCE

Figure 7 presents a decision tree for crack remediation options for different types of cracks, crack width at crack spacing, and NBI condition rating combinations for remediation options for a bridge between zero to five years. Applying crack sealer and penetrating sealer are the most suitable solutions.

Below is an example of a maintenance program for a bridge deck age between 0 and 5 years:

- Type of Crack Observed: Transverse Crack

- Crack Width at Crack Spacing: < 0.06″ at > 5′
- NBI Condition Rating: 7
- Crack width: < 0.016″
- Method Applied: Crack Sealer (apply low-viscosity concrete sealer)
- Products that can be applied: Hydro Silane 40 VOC, Sonneborn Sealer 40 VOC, Aquanil Plus 40, TK-9030, PowerSeal 8%, Aqua-Trete BSM 20, Hydrozo Enviroseal 40, Hydrozo Enviroseal 20

According to the decision tree, there are crack remediation options for different types of cracks, crack width at crack spacing, and NBI condition rating combinations. Applying crack sealer and penetrating sealer are the most suitable solutions for small crack widths at large crack spacing (< 0.06″ at > 5′), with the addition of applying thin polymer overlay if the deck age is > 5 years and for large crack widths and small crack spacings (>0.06″ at <5′).

Below is an example of a maintenance program for a bridge deck age between 5 and 10 years:

- Type of Crack Observed: Longitudinal Crack
- Crack Width at Crack Spacing: > 0.06″ at < 5′
- NBI Condition Rating: 5
- Crack width: 0.06″–0.13″
- Method Applied: Crack Penetrating Sealer, Thin Polymer Overlay (if deck age > 5 years)
- Products that can be applied: Sikander 55 SLV, Epoxeal GS-Structural, Traffic Guard EP-35, Sikadur 52, TK-9000, TK-9010, Dural 335.

Bridge Deck Age Greater than or Equal to 10 Years Old

To determine optimal crack remediation options based on various factors such as crack type, width, spacing, and NBI condition ratings, the most appropriate solutions for small crack widths at large spacing involve the application of crack sealer and penetrating sealer. Additional recommendations for small and larger crack widths and spacings include applying thin polymer overlay if the deck age is > 10 years (< 0.06″ at > 5′ and > 0.06″ at > 5′ or < 0.06″ at < 5′).

Below is an example of a maintenance program for a bridge deck age greater than or equal to 10 years:

- Type of Crack Observed: Transverse Crack
- Crack Width at Crack Spacing: < 0.06″ at < 5′

- NBI Condition Rating: 6
- Crack width: 0.016”–0.06”
- Method Applied: Crack Chasing/Sealer, Thin Polymer Overlay (if deck age > 10 years)
- Products that can be applied: TK-290-WDOT, TK-290-WB, Eucoguard 100, TK-290-12 TriSiloxane, Baracade WB 244, TK-290-WB TriSiloxane.

A thorough comparison of different sealant products is given in Table 40, along with a description of their salient features. Methacrylate, epoxy, polyurethane, silane, siloxane, and cementitious material are examples of sealant kinds. Important attributes are listed, including cost ($/gal), tack-free time, pot life (F) with time, bond strength (psi), elongation (%), viscosity (cps), and tensile strength (psi). TK-9030, Hydro Silane 40 VOC, Aqua-Trete BSM 20, Sealate T-70, Duraguard 401, Sikander 55 SLV, Traffic Guard EP-35, Sikadur 52, and Zero-C Horizontal Extended Mortar are a few of the noteworthy items. These goods come in a range of qualities, uses, and price points, giving customers a choice of solutions for various sealing requirements.

Table 40. Mechanical Properties of Sealant Products

Product Name	Sealant Type	Viscosity (cps)	Elongation (%)	Bond Strength (psi)	Tensile Strength (psi)	Flash Point (F)	Pot Life (F) with Time	Tack Free Time	Cost $
Sealate T-70	Methacrylate	<25	3–5	615	N/A	> 210	70: 25–40 min	70: 4–7 hours	75 $/gal
Sealate T-70-MX-30	Methacrylate	5–20	30	615	N/A	200	70: 40–60 min	70: 5–8 hours	75 $/gal
Duraguard 401	Methacrylate	5–20	40–50	N/A	2,800	> 200	45 min	6 hours	145 $/gal
Degadeck Crack Sealer	Methacrylate	5–15	5	N/A	7,775	40–100	N/A	N/A	184 $/gal
Denedeck Crack Sealer	Methacrylate	N/A	N/A	3,902	N/A	N/A	N/A	N/A	N/A
Degadeck Deck Overlay System	Methacrylate	N/A	13	N/A	1,290–1,380	48	N/A	1 hour	N/A
Degadeck Crack Sealer Plus	Methacrylate	5–15	5.5	N/A	8,100	48	15–20 min	1 hour	163 $/gal
Sikander 55 SLV	Two-Component (Epoxy/Penetrating Sealer)	105	10	2,500 at (14 days)	7,100	N/A	20 min	73: 6 hours 90: 2.5 hours	241 $/gal
Epoxeal GS–Structural	Epoxy Sealer	95	2.9	3,450 at (14 days)	7,100	> 200	45 min	70: 12 hours 80: 6 hours	100 $/gal
Traffic Guard EP-35	Epoxy	10–25	30	2,500	2,500	200	15–25 min	2 hours	75 $/gal
Sikadur 52	Epoxy	200	3.1	2,200	7,900	N/A	30 min	N/A	106 $/gal

Product Name	Sealant Type	Viscosity (cps)	Elongation (%)	Bond Strength (psi)	Tensile Strength (psi)	Flash Point (F)	Pot Life (F) with Time	Tack Free Time	Cost $
TK-9000	Epoxy	150	20–30	> 5,000	N/A	N/A	20–30 min	N/A	N/A
Dural 335	Epoxy	80–120	1–5	2,300	7,500–8,500	N/A	20–25 min	N/A	139 $/gal
Degadur 332	Methyl Methacrylate (MMA)	95	8.8	> 300	1,200	48	25 min	70: 1 hour	N/A
Protectosil Degadeck CSS	Methyl Methacrylate (MMA)	5–15	4	N/A	N/A	10	10–20 min	N/A	N/A
TK-9020	Polyurethane	200	N/A	N/A	N/A	N/A	N/A	70: 30 min	N/A
TK-9030	Polyurethane	50	3.3	4,154	4,230	N/A	3–6 min	70: 10 min	46 $/cartridge kit
Hydro Silane 40 VOC	Silane (Solvent-Based)	< 20	N/A	N/A	N/A	32	N/A	N/A	21 $/gal
Sonneborn Penetrating Sealer 40 VOC	Silane (Solvent-Based)	< 20	N/A	N/A	N/A	N/A	N/A	N/A	12 $/gal drum
Aquanil Plus 40	Silane (Solvent-Based)	< 25	N/A	N/A	N/A	105	N/A	2–4 hours	28 $/gal
Penseal 244	Silane (Solvent-Based)	< 20	N/A	N/A	N/A	149	N/A	N/A	23 $/gal

Product Name	Sealant Type	Viscosity (cps)	Elongation (%)	Bond Strength (psi)	Tensile Strength (psi)	Flash Point (F)	Pot Life (F) with Time	Tack Free Time	Cost $
TK-590-40	Silane (Solvent-Based)	< 20	N/A	N/A	N/A	-4	N/A	70: 1 hours	40 $/gal pails
Sikagard SN-40	Silane (Solvent-Based)	< 20	N/A	N/A	N/A	102	N/A	70: 24 hours	54 $/gal
Powerseal 8%	Silane (Water-Based)	< 15	N/A	N/A	N/A	214	N/A	N/A	66 $/gal
Aqua-Trete BSM 20	Silane (Water-Based)	< 30	N/A	N/A	N/A	>=200	N/A	N/A	N/A
Hydrozo Enviroseal 40	Silane (Water-Based)	< 20	N/A	N/A	N/A	> 200	N/A	70: 4 hours	75 $/gal
Hydrozo Enviroseal 20	Silane (Water-Based)	< 25	N/A	N/A	N/A	> 200	N/A	70: 4 hours	50 $/gal
TK 290-WDOT	Siloxane (Solvent-Based)	< 20	N/A	Good Bond	N/A	N/A	N/A	N/A	71 $/gal
TK 290-WB	Siloxane (Solvent-Based)	< 25	N/A	Good Bond	N/A	N/A	N/A	N/A	70 $/gal
Eucoguard 100	Siloxane (Solvent-Based)	< 25	N/A	N/A	N/A	105	N/A	Dry: 1 to 2 hours Foot Traffic: 4 to 6 hours Wheel Traffic: 10 to 12 hours	44 $/gal
TK-290-12 TriSiloxane	Siloxane (Solvent-Based)	< 20	N/A	N/A	N/A	N/A	N/A	N/A	45 $/gal

Product Name	Sealant Type	Viscosity (cps)	Elongation (%)	Bond Strength (psi)	Tensile Strength (psi)	Flash Point (F)	Pot Life (F) with Time	Tack Free Time	Cost $
Baracade WB 244	Siloxane (Water-Based)	50	N/A	N/A	N/A	> 200	N/A	70: 1–2 hours	70 $/gal
TK-290 WB Tri-Siloxane (or TK-290 WBG)	Siloxane (Water-Based)	< 50	N/A	N/A	N/A	N/A	N/A	N/A	58 $/gal
Zero-C Horizontal Extended Mortar	Cementitious Material	N/A	N/A	> 2,000	500	N/A	N/A	N/A	49 $/bag

Flash Point: the lowest temperature of a liquid at which its vapors will form a combustible mixture with air.

Pot Life: often thought of as the length of time that a mixed (catalyzed) coating system retains a viscosity low enough to be applied to a surface.

Tack Free: a coating condition whereby a coating is completely dry with little or no moisture left after application on the surface to be protected.

Elongation: the increase in length, expressed numerically, as a percent of initial length.

APPLICATION PROCEDURE

The application procedure for a penetrating sealer involves the following steps, summarized in Figure 8:

1. Start with a clean and dry deck. According to MnDOT, using a wire bristle broom or compressed air to sweep the deck is necessary. Johnson et al. (2009) suggest removing curing compounds for better penetration, as specified by NYSDOT, which requires light sandblasting. Although some moisture is needed for the sealer to react, it is generally recommended to have a dry deck during application, as moisture can hinder penetration (Wells et al., 2017).

2. Apply the penetrating sealer using a low-pressure, high-volume sprayer, as recommended by MoDOT. It is advised to avoid hand pump sprayers. MoDOT suggests an application rate of 200 ft^2/gal, while MnDOT recommends a rate of 250 to 300 ft^2/gal. Higher application rates improve chloride ion resistance (Johnson et al., 2009). MnDOT, however, has had to apply the sealer in two layers at 500 to 600 ft^2/gal due to drying issues. Some PennDOT districts recommend two coats for small cracks (less than 0.007 in.) (Hopper et al., 2015). After application, spread the sealer across the deck using brooms or squeegees.

3. Penetrating sealer application is sensitive to moisture, wind, and temperatures. The ideal temperature range is between 40°F and 100°F. Higher temperatures can lead to premature evaporation, resulting in poor penetration, while lower temperatures extend drying time.

4. Quality assurance/quality control procedures typically involve assessing penetration depth through coring. Wells et al. (2017) recommend specifying a minimum penetration depth of 3 mm.

Regarding materials, penetrating sealers are categorized as water repellents (including silanes, siloxanes, and siliconates) or pore blockers (consisting of silicates). Water repellents are further classified as water-based or solvent-based. Silanes with high solids content are preferred due to deeper penetration, whereas siloxanes have reported shallower penetration depths. Silanes evaporate quickly and are not recommended for hot, windy conditions (Johnson et al., 2009).

Water repellents can be water-based or solvent-based. Products that are 100% silane are preferred over lower percent solids due to silane's high volatility. Water-based sealers are not recommended for reapplication projects as they are repelled by any existing water repellents in the concrete. Pore blockers, like sodium, potassium, or lithium silicates, fill capillary pores and block both liquid water and water vapor.

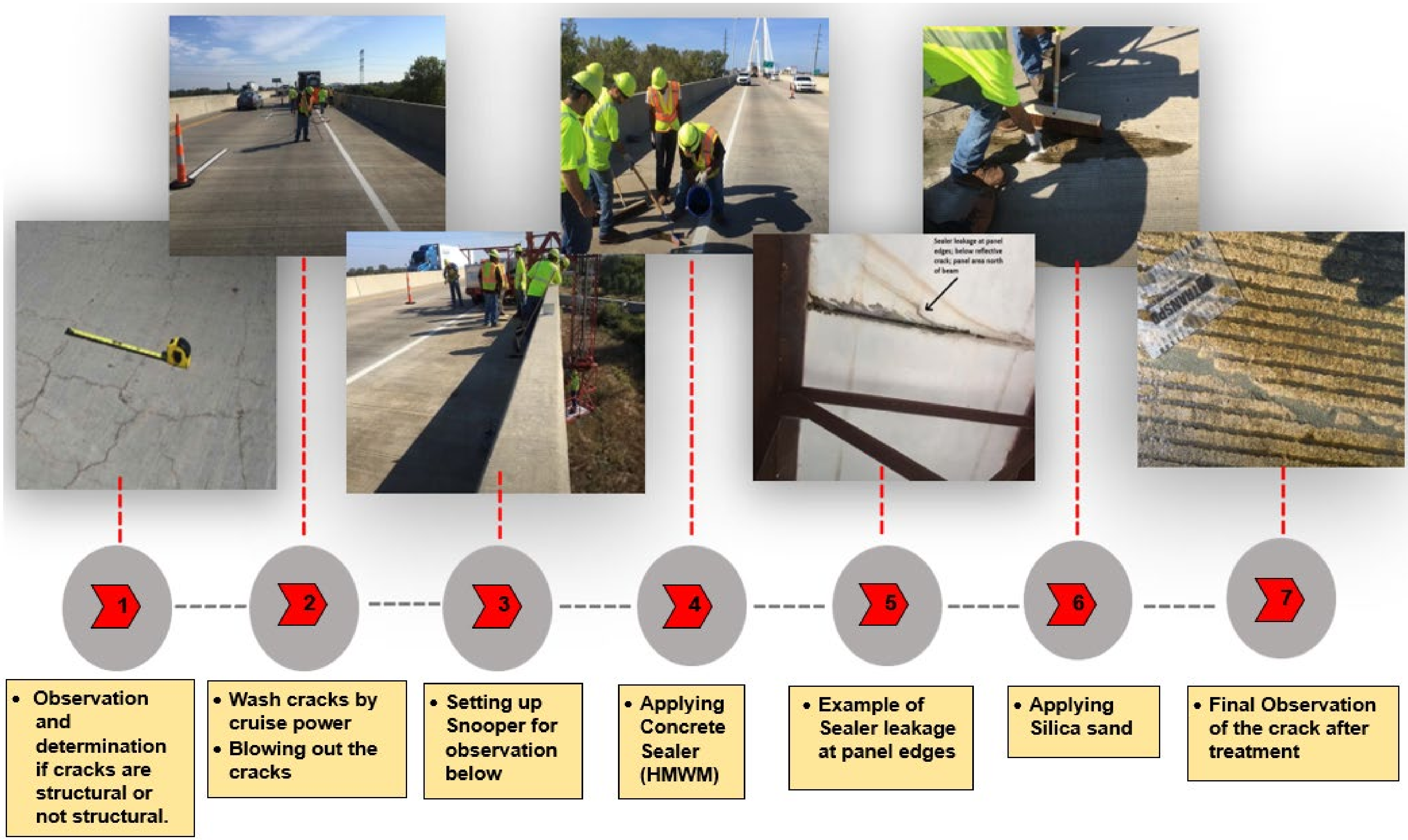

Figure 8. Flowchart. Application procedure to seal bridge deck cracks.

CHAPTER 4: COST ANALYSIS

Recognizing the crucial role of cost considerations in decision-making, the study also covers a cost analysis and approximation for sealing bridge deck cracks. This financial perspective equips decision-makers with the necessary tools to plan and allocate resources, ensuring the sustainability of bridge maintenance efforts. The cost analysis includes estimations for direct and indirect costs to obtain a final budget for a typical bridge deck concrete-sealing maintenance project.

Direct Costs: These are costs directly associated with the project, such as sealant products, labor, equipment, and lane closures fees.

Indirect Costs: Overhead costs that cannot be directly attributed to the project but are incurred as part of the overall operation. Examples include administrative expenses, utilities, and facility rent.

Contingency Costs: Include a contingency budget for unexpected issues or changes in the project scope. Typically, this is a percentage of the total project cost (e.g., 10%).

Opportunity Costs: Consider any potential revenue or cost savings from the maintenance project.

Quantity Estimation: The quantities of materials, labor hours, and lane closure hours will be estimated as accurately as possible to avoid underestimating costs.

Cost Calculation: total costs can be calculated using the equation in Figure 9.

$$Total\ Cost\ =\ Direct\ Costs\ +\ Indirect\ Costs\ +\ Contingency\ Costs\ +\ Opportunity\ Costs$$

Figure 9. Equation. Calculation of total costs.

Direct Costs: direct costs can be calculated using the equations in Figure 10, 11, and 12.

- Direct Labor Costs (DL): Labor cost required for the project:

$$DL\ =\ Number\ of\ Labor\ Hours\ x\ Hourly\ Labor\ Rate$$

Figure 10. Equation. Calculation of labor costs.

- Direct Material Costs (DM): materials cost and supplies needed for the project:

$$DM\ =\ Quantity\ of\ Materials\ x\ Unit\ Price\ per\ Material$$

Figure 11. Equation. Calculation of direct material costs.

- Other Direct Costs (ODC): additional direct expenses specific to the project:

$$ODC\ =\ Sum\ of\ All\ Other\ Direct\ Costs$$

Figure 12. Equation. Calculation of other direct costs.

Indirect Costs:

- Overhead Costs (OH): Overhead expenses related to the overall operation of the organization can be calculated as in Figure 13:

$$OH = Sum\ of\ All\ Overhead\ Costs$$

Figure 13. Equation. Calculation of overhead costs.

- General and Administrative Costs (G&A): Costs associated with the management and support functions of the organization as in Figure 14:

$$G\&A = Sum\ of\ All\ G\&A\ Costs$$

Figure 14. Equation. Calculation of administrative costs.

Contingency Costs:

- Contingency Budget (CB): A reserve set aside to cover unforeseen circumstances or risks can be calculated using the equation in Figure 15:

$$CB = Contingency\ Percentage\ x\ (DL + DM + ODC)$$

Figure 15. Equation. Calculation of contingency costs.

To calculate the total cost for your maintenance project, use the main formula in Figure 16:

$$\boldsymbol{Total\ Cost\ (TC) = DL + DM + ODC + OH + G\&A + CB}$$

Figure 16. Equation. Calculation of total costs.

Maintenance Program Life Cycle:

The maintenance program life cycle includes the following steps and is illustrated in Figure 17:

- Deck sealing every 5 years since year 0.
- Deck overlay at year 35.
- Bridge service life is 75 years.

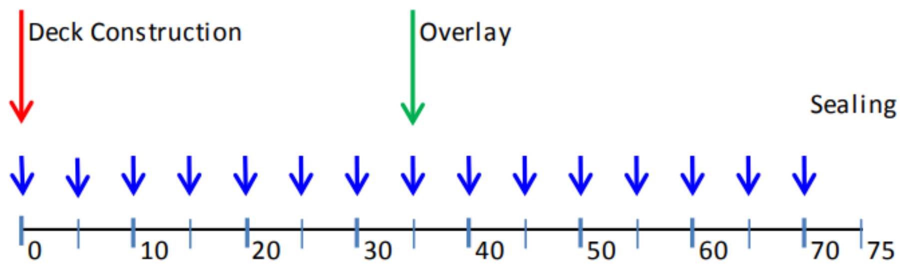

Figure 17. Frequency of sealing bridge deck cracks.

Lane Closure Fees

The prices for the closure of maintenance lanes are presented in Table 41. The prices vary if the closure is on a weekday or during the weekend, depending on how many lanes should be closed and if it is an expressway or non-expressway. The lane closure fees from the Barricade Lites Company are presented in Table 41.

Distribution of product prices based on their type is shown in Figure 18.

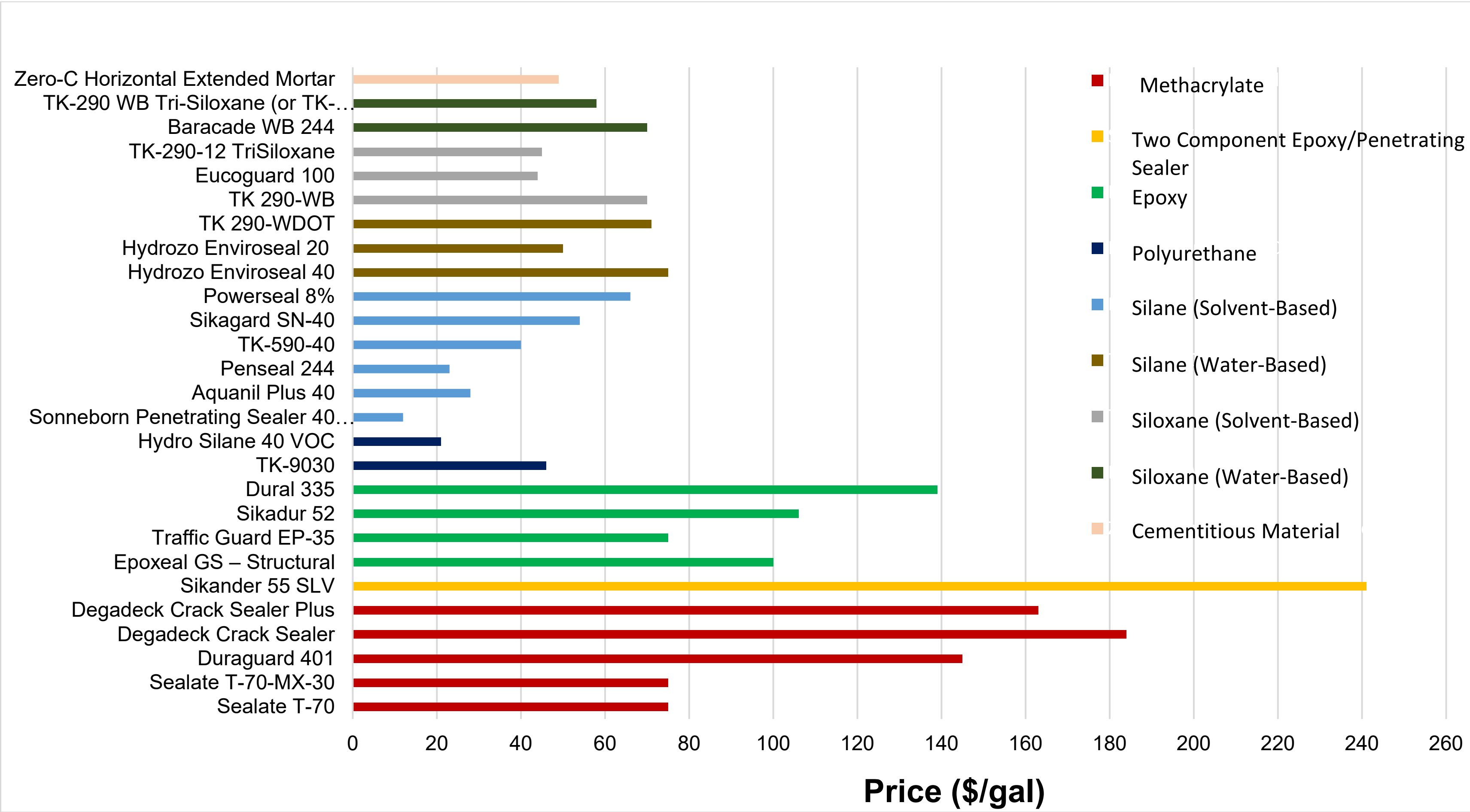

Figure 18. Chart. Sealant type price distribution.

Table 41. Lane Closures Fees from Barricade Lites Company

Description	UNIT	M-F	SAT	SUN
2022 Temporary IDOT Expressway Closure Prices				
1 Lane, 1 Direction, 1 Location, up to 1 Mile	Each	$2,500.00	$3,000.00	$3,500.00
2 Lane, 1 Direction, 1 Location, up to 1 Mile	Each	$3,000.00	$3,500.00	$4,000.00
3 Lane, 1 Direction, 1 Location, up to 1 Mile	Each	$3,500.00	$4,000.00	$4,500.00
Shoulder Closure, 1 Direction, 1 Location, up to 1/2 Mile	Each	$750.00	$1,000.00	$1,250.00
Partial or Full Ramp Closure, 1 Direction, 1 Location	Each	$750.00	$1,000.00	$1,250.00
Each Additional 1/2 Mile	Each	$100.00	$125.00	$150.00
Weave within a Lane Closure or a Lane-To-Lane Shift	Each	$500.00	$750.00	$1,000.00
Truck with Mounted Attenuator Trailer and Driver	Hourly	$150.00	$175.00	$200.00
2022 Temporary IDOT Non-Expressway Closure Prices				
1 Lane, 1 Direction, 1 Location, up to 1 Mile	Each	$900.00	$1,200.00	$1,500.00
2 Lane, 1 Direction, 1 Location, up to 1 Mile	Each	$1,200.00	$1,500.00	$1,800.00
Each Additional 1/2 Mile	Each	$100.00	$125.00	$150.00
Truck with Mounted Attenuator Trailer and Driver	Hourly	$125.00	$150.00	$175.00

Laborer Cost Hours Rate

According to the 2021 RSMeans Heavy Construction Cost Data Book, the Laborer cost hourly rate is $66.25, including overhead and profit. The total fees can be calculated as (hourly rate) * (city cost index).

City Cost Indices are from the 2021 RSMeans City Cost Indices found in the RSMeans Heavy Construction Cost Data Book 2021 version. The indices for some cities in Illinois are presented in Table 42.

Table 42. Cost Indices for Installing Wall Finishing and Painting/Coating for Cities in Illinois

Cities	Installation of Wall Finishes and Painting/Coating Cost Indices
Carbondale	99.9
Centralia	106.3
Champaign	109.4
Chicago	162.4
Decatur	112.2
East St. Louis	110.9
Rockford	144.2
Springfield	114.0

Projecting prices for a 5-year interval for 75 years involves making assumptions about the future price trends for each product. One common method is to use historical price trends and apply a growth rate. Here is a simple example using an annual growth rate:

Assuming a constant annual growth rate:

$$Future\ Price = \ Current\ Price\ \times\ (1 + Growth\ Rate)^{Number\ of\ Years}$$

Figure 19. Equation. Simplified equation to calculate future price using current price and growth rate.

Here is an example projection for the average price of methacrylate over a 5-year interval for 75 years, assuming a growth rate of 3%:

$$\text{Methacrylate Future Price} = 128.4 \times (1 + 0.03)^{75}$$

This calculation is repeated for each cost and each 5-year interval.

After computing the average of the aforementioned costs, aggregating them, and extrapolating the values for an assumed bridge life span of 75 years at 5-year intervals, the resulting prices and corresponding projections are illustrated in Figure 20.

A historical view of prices for different sealant materials and related expenses over a 70-year period is given in Table 43. Methacrylate, two-component epoxy, polyurethane, solvent- and water-based silane, solvent- and water-based siloxane, and cementitious material are among the materials. An annual presentation of prices for each item shows how expenses have changed over time. The table also provides information on labor costs and lane closure fees, providing a thorough summary of the financial implications of sealant applications. The data makes it possible to recognize patterns and variations in the cost of these materials and related expenses.

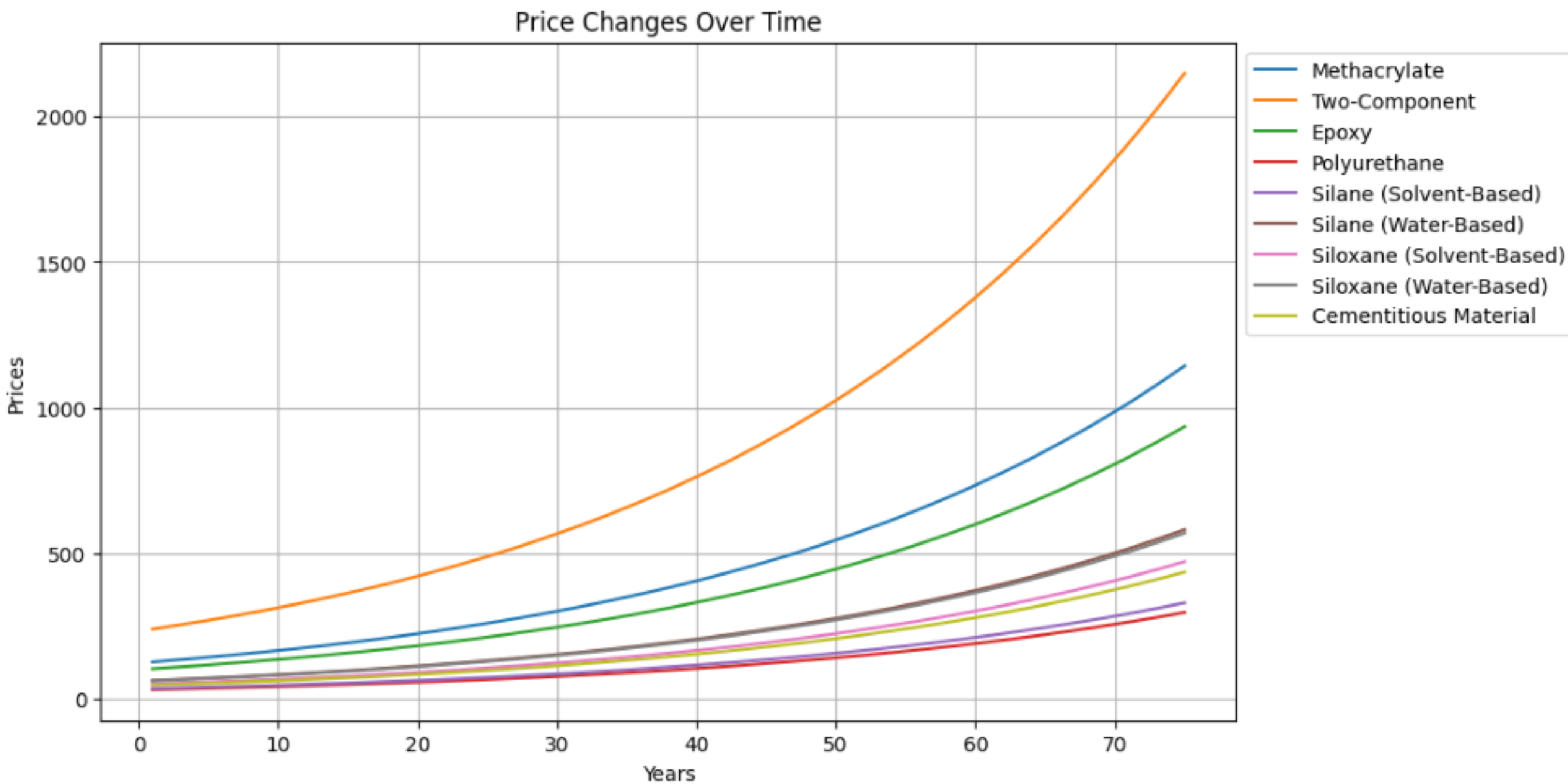

Figure 20. Graph. Projection of prices for an interval of 5 years for a total bridge service life of 75 years.

Table 43. Price Projections

Year	Methacrylate Prices ($)	Two-Component Prices ($)	Epoxy Prices ($)	Polyurethane Prices ($)	Silane (Solvent-Based) Prices ($)	Silane (Water-Based) Prices ($)	Siloxane (Solvent-Based) Prices ($)	Siloxane (Water-Based) Prices ($)	Cementitious Material Prices ($)
5	132.25	248.23	108.15	34.51	38.28	67.29	54.59	65.92	50.47
10	153.32	287.77	125.38	40.00	44.38	78.01	63.28	76.42	58.51
15	177.74	333.60	145.34	46.37	51.45	90.44	73.36	88.59	67.83
20	206.04	386.73	168.49	53.76	59.64	104.84	85.05	102.70	78.63
25	238.86	448.33	195.33	62.32	69.14	121.54	98.60	119.06	91.15
30	276.91	519.74	226.44	$72.25	80.15	140.90	114.30	138.02	105.67
35	321.01	602.52	262.51	83.75	92.92	163.34	132.50	160.01	122.50
40	372.14	698.49	304.32	97.09	107.72	189.35	153.61	185.49	142.02
45	431.41	809.74	352.79	112.56	124.88	219.51	178.07	215.03	164.64
50	500.12	938.71	408.98	130.48	144.77	254.48	206.44	249.28	190.86
55	579.78	1,088.22	474.12	151.27	167.82	295.01	239.32	288.99	221.26
60	672.12	1,261.54	549.63	175.36	194.55	341.99	277.43	335.02	256.50
65	779.18	1,462.47	637.18	203.29	225.54	396.47	321.62	388.37	297.35
70	903.28	1,695.41	738.66	235.67	261.46	459.61	372.85	450.23	344.71

COST-ESTIMATION WORKSHEET

A comprehensive Excel spreadsheet has been designed to facilitate the computation of the overall budget required for sealing cracks in bridge decks. This tool incorporates both direct and indirect costs, requiring input values for quantities of materials, labor hours, traffic control measures, contingency provisions, mobilization efforts, and inflation factors.

In the example shown in Figure 21, various expenses associated with deck repair and treatments, traffic control, and labor are meticulously detailed. For deck treatments, epoxy for an area of 200 square feet is used. Traffic control expenses cover lane closure fees based on distance, additional charges for extra mileage, and costs for a truck with a mounted attenuator trailer and driver. Labor costs are calculated by multiplying the labor rate by the number of workers and hours, adjusted for the city index. The total direct costs with mobilization of 10%, encompass all these direct expenses, resulting in **$9,246.33**.

A contingency of 15% and inflation of 3% are then factored in, bringing the total budget for the project to **$10,911**. These comprehensive estimates provide a thorough overview of the expected financial requirements, accounting for potential uncertainties, project mobilization, and inflationary impacts.

BRIDGE CRACK SEALING COST ESTIMATE WORKSHEET

DATE: 12/18/2023

WORK ACTIVITY		QUANTITY	UNIT	UNIT COST		TOTAL
DECK REPAIR / TREATMENTS						
Epoxy		200.0	SFT	$0.93	/SFT	$186.00
Silane Treatment (Water Based)			SFT	$0.22	/SFT	
Siloxane (Water Based)			SFT	$0.22	/SFT	
Silane Treatment (Solvent Based)			SFT	$0.17	/SFT	
Siloxane (Solvent Based)			SFT	$0.27	/SFT	
Methacrylate			SFT	$1.30	/SFT	
Polyurethane			FT	$0.65	/FT	
TRAFFIC CONTROL						
Lane Closure Fees (Up to 1 mile)		2.0	Days	$2,200.00	/Day	$4,400.00
Each Additional 1/2 mile			1/2 Mile	$100.00	/ 1/2 Mile	
Truck with Mounted Attenuator Trailer and Driver		2.0	Hour/day	$150.00	/(Hour/Day)	$600.00
Labor	*Unit Cost to be determined by Rate per hour and Cost Indices for each city*					
Labor Rate		5.0	Hour	$66.25	/Hour	$331.25
City Index		162.0	%			
Laborers		3.0				
Total						$3,219.75
MOBILIZATION	(estimate at 10%)	10	%			$841
				Total Direct Costs		$9,246.33
CONTINGENCY	(10% - 20%) (use higher contingency for small projects)	15	%			$1,387
INFLATION	(assume 3% per year, beginning in 2024)	3	%			$277
				TOTAL BUDGET		**$10,911**

Figure 21. Photo. Bridge deck sealing cost-estimation worksheet.

CHAPTER 5: SUMMARY AND CONCLUSIONS

In the course of this research study, coupled with a literature review on the pervasive issue of bridge deck cracking and the various remediation strategies employed across the United States, valuable insights were obtained into the practices of state departments of transportation and the specific sealer products they deploy for the maintenance of bridge decks. This synthesis of information has yielded a better understanding of critical factors and prompted a series of recommendations tailored for decision-makers navigating the complications of treating bridge deck cracks.

The findings underscore the significance of key parameters such as crack width, National Bridge Inventory ratings, bridge deck age, crack spacing, and viscosity in the decision-making process. Through a thorough analysis of these factors, recommendations that provide a strategic framework for optimal bridge deck maintenance were revealed. This study not only outlines the pertinent considerations, but also offers practical guidance on selecting appropriate sealer products based on the unique characteristics of each bridge.

To enhance usability, detailed tables and decision trees have been compiled, showing the properties and crucial attributes of various sealer products. This comprehensive resource is designed to empower maintenance engineers, aiding them in making informed decisions aligned with the specific requirements of their bridge structures.

In the broader context of efficient bridge maintenance, this study extends beyond mere recommendations to encompass actionable insights into the application of identified products. By presenting a comprehensive view of the bridge deck maintenance landscape, this research serves as a guide for the Illinois Department of Transportation and engineers across the state, facilitating a more streamlined and effective approach to bridge preservation.

Recognizing the crucial role of cost considerations in decision-making, the study also covers a cost analysis and approximation for sealing bridge deck cracks. This financial perspective equips decision-makers with the necessary tools to plan and allocate resources, ensuring the sustainability of bridge maintenance efforts.

In summary, this study achieves its objectives by providing a robust foundation for decision-makers in Illinois. By offering a synthesis of best practices, product recommendations, and cost considerations, it significantly enhances the efficiency of bridge maintenance initiatives, thereby contributing to the longevity and resilience of Illinois' bridge infrastructure.

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APPENDIX A

NBI RATING FOR CONCRETE BRIDGE DECKS

CONDITION RATING GUIDES FOR SPECIFIC DECK MATERIALS

CONCRETE BRIDGE DECKS

General Note: For slab and precast prestressed concrete (PPC) deck beam bridges, the deck condition rating (Item 58) shall be rated the same as the superstructure (Item 59) using the superstructure criteria, except for PPC deck beam with 4" or more of reinforced concrete overlay, in which case the overlay shall be rated as the deck.

Code	Description
8	VERY GOOD. Transverse cracks < 0.06" at > 15' intervals may be present but no spalling, scaling, pop-outs or delamination.
7	GOOD. Some transverse cracks < 0.06" at > 5' intervals over the majority of the deck, light scaling (less than 1/4" depth) or pop-outs may be present, no spalling.
6	SATISFACTORY. Transverse cracks < 0.06" at < 5' or > 0.06" at > 5' intervals over a majority of the deck, isolated longitudinal cracks, spalls and delaminations may be present on up to 5% of the deck riding surface or soffit area, up to 10% of the deck soffit may be spalled, delaminated, and map cracked.
5	FAIR. Transverse cracks > 0.06" at < 5' intervals with or without leaching in the majority of the deck, longitudinal cracks < 0.06" in majority of deck, spalls and delaminations may be present on up to 10% of the deck surface or soffit area, up to 25% of the deck surface or soffit may be spalled, delaminated and map cracked, up to 10% loss of primary reinforcement in any 6' bay length.
4	POOR. Longitudinal cracks > 0.06" in majority of deck, spalls and delaminations may be present on up to 25% of the deck surface or soffit area, up to 50% of the deck surface or soffit may be spalled, delaminated and map cracked, up to 30% loss of primary reinforcement in any 6' bay length.
3	SERIOUS. Condition is similar to the description for a condition rating of "4", though more extensive full depth failures are evident to the point that wheel loads may need restricted or temporary measures implemented.
2	CRITICAL. Full depth failures needing patching over much of the deck on a regular basis which requires special inspections to keep the bridge open, possibly with reduced load limits, temporary measures may be needed to allow continued use of the structure. The Bureau of Bridges and Structures shall be notified immediately.

Figure 22. NBI rating for concrete bridge decks from Illinois Highway information system.

AASHTO ELEMENTS, DEFECTS, AND CONDITION STATES (2015 INTERIMS)

Wearing Surface - Condition State Definitions

Defect	CS 1 – Good	CS 2 - Fair	CS 3 - Poor	CS 4 - Severe
Delamination / Spall / Patched Area / Pothole (3210)	None.	Delaminated. Spall less than 1 in. deep or less than 6 in. diameter. Patched area that is sound. Partial depth pothole.	Spall 1 in. deep or greater or 6 in. diameter or greater. Patched area that is unsound or showing distress. Full depth pothole.	The wearing surface is no longer effective.
Crack (3220)	Width less than 0.012 in. or spacing greater than 3.0 ft.	Width 0.012–0.05 in. or spacing of 1.0–3.0 ft.	Width of more than 0.05 in. or spacing of less than 1.0 ft.	
Effectiveness (3230)	Fully effective. No evidence of leakage or further deterioration of the protected element.	Substantially effective. Deterioration of the protected element has slowed.	Limited effectiveness. Deterioration of the protected element has progressed.	
Damage (7000)	Not applicable.	The element has impact damage. The specific damage caused by the impact has been captured in condition state 2 under the appropriate material defect entry.	The element has impact damage. The specific damage caused by the impact has been captured in condition state 3 under the appropriate material defect entry.	The element has impact damage. The specific damage caused by the impact has been captured in condition state 4 under the appropriate material defect entry.

Bearings - Condition State Definitions

Defect	CS 1 - Good	CS 2 - Fair	CS 3 - Poor	CS 4 - Severe
Corrosion (1000)	None.	Freckled Rust. Corrosion of the steel has initiated.	Section loss is evident or pack rust is present but does not warrant structural review.	The condition warrants a structural review to determine the effect on strength or serviceability of the element or bridge; OR a structural review has been completed and the defects impact strength or serviceability of the element or bridge.
Connection (1020)	Connection is in place and functioning as intended.	Loose fasteners or pack rust without distortion is present but the connection is in place and functioning as intended.	Missing bolts, rivets, broken welds, fasteners or pack rust with distortion but does not warrant a structural review.	
Movement (2210)	Free to move.	Minor restriction.	Restricted but not warranting structural review.	
Alignment (2220)	Lateral and vertical alignment is as expected for the temperature conditions.	Tolerable lateral or vertical alignment that is inconsistent with the temperature conditions.	Approaching the limits of lateral or vertical alignment for the bearing but does not warrant a structural review.	
Bulging, Splitting or Tearing (2230)	None.	Bulging less than 15% of the thickness.	Bulging 15% or more of the thickness. Splitting or tearing. Bearing's surfaces are not parallel. Does not warrant structural review.	
Loss of Bearing Area (2240)	None.	Less than 10%.	10% or more but does not warrant structural review.	
Damage (7000)	Not applicable.	The element has impact damage. The specific damage caused by the impact has been captured in condition state 2 under the appropriate material defect entry.	The element has impact damage. The specific damage caused by the impact has been captured in condition state 3 under the appropriate material defect entry.	The element has impact damage. The specific damage caused by the impact has been captured in condition state 4 under the appropriate material defect entry.

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Joints - Condition State Definitions

Defect	CS 1 - Good	CS 2 - Fair	CS 3 - Poor	CS 4 - Severe
Leakage (2310)	None.	Minimal. Minor dripping through the joint.	Moderate. More than a drip and less than free flow of water.	Free flow of water through the joint.
Seal Adhesion (2320)	Fully Adhered.	Adhered for more than 50% of the joint height.	Adhered 50% or less of joint height but still some adhesion.	Complete loss of adhesion.
Seal Damage (2330)	None.	Seal abrasion without punctures.	Punctured or ripped or partially pulled out.	Punctured completely through, pulled out, or missing.
Seal Cracking (2340)	None.	Surface crack.	Crack that partially penetrates the seal.	Crack that fully penetrates the seal.
Debris Impaction (2350)	No debris to a shallow cover of loose debris may be evident but does not affect the performance of the joint.	Partially filled with hard-packed material, but still allowing free movement.	Completely filled and impacts joint movement.	Completely filled and prevents joint movement.
Adjacent Deck or Header (2360)	Sound. No spall, delamination or unsound patch.	Edge delamination or spall 1 in. or less deep or 6 in. or less in diameter. No exposed rebar. Patched area that is sound.	Spall greater than 1 in. deep or greater than 6 in. diameter. Exposed rebar. Delamination or unsound patched area that makes the joint loose.	Spall, delamination, unsound patched area or loose joint anchor that prevents the joint from functioning as intended.
Metal Deterioration or Damage (2370)	None.	Freckled rust, metal has no cracks, or impact damage. Connection may be loose but functioning as intended.	Section loss, missing or broken fasteners, cracking of the metal or impact damage but joint still functioning.	Metal cracking, section loss, damage or connection failure that prevents the joint from functioning as intended.
Damage (7000)	Not applicable.	The element has impact damage. The specific damage caused by the impact has been captured in condition state 2 under the appropriate material defect entry.	The element has impact damage. The specific damage caused by the impact has been captured in condition state 3 under the appropriate material defect entry.	The element has impact damage. The specific damage caused by the impact has been captured in condition state 4 under the appropriate material defect entry.

Concrete Protective Coating - Condition State Definitions

Defect	CS 1 - Good	CS 2 - Fair	CS 3 - Poor	CS 4 - Severe
Wear (3510)	None.	Underlying concrete not exposed, coating showing wear from UV exposure, friction course missing.	Underlying concrete is not exposed, thickness of the coating is reduced.	Underlying concrete exposed, treated cracks are exposed.
Chalking (3520)	None.	Surface Dulling.	Loss of Pigment.	Not Applicable.
Peeling / Bubbling / Cracking (3530)	None.	Finish coats only.	Finish and primer coats.	Exposure of bare concrete.
Effectiveness (3540)	Fully effective.	Substantially effective.	Limited effectiveness.	The protective system has failed or is no longer effective.
Damage (7000)	Not applicable.	The element has impact damage. The specific damage caused by the impact has been captured in condition state 2 under the appropriate material defect entry.	The element has impact damage. The specific damage caused by the impact has been captured in condition state 3 under the appropriate material defect entry.	The element has impact damage. The specific damage caused by the impact has been captured in condition state 4 under the appropriate material defect entry.

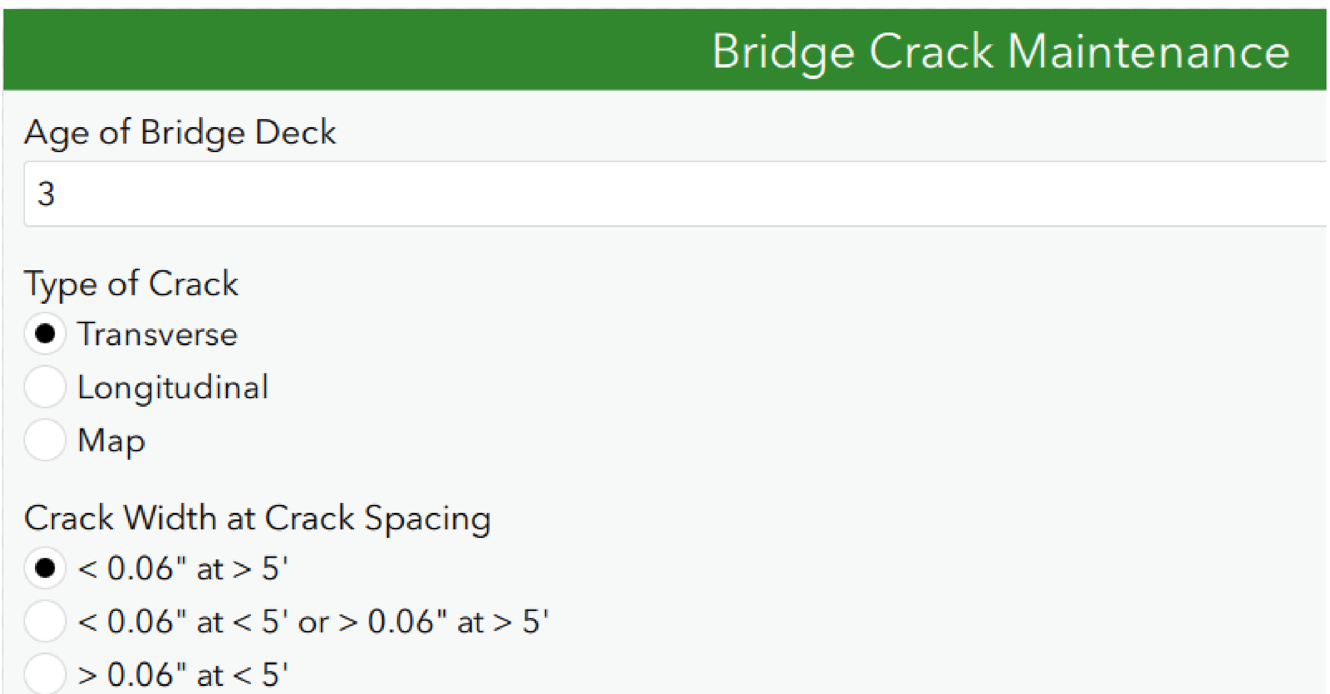
DECISION SYSTEM

A decision-making system was developed that utilizes data on the bridge deck's condition, cracks, and various influencing factors as input parameters. This system will recommend the most suitable sealant for maintenance and provide a list of available products for purchase.

The decision-making system developed for bridge maintenance seamlessly integrates **ArcGIS Survey123 with Excel.** To begin, users need to install ArcGIS Survey123 Connect by downloading the appropriate version for their operating system from the Esri website (https://www.esri.com). Creating an ArcGIS account on the ArcGIS Online platform is the next step, providing the necessary credentials for signing in to Survey123 Connect. Using this tool, users can design and create surveys with a user-friendly interface, incorporating various question types and integrating Excel for additional data management.

The decision-making system relies on an array of factors akin to the decision trees shown before, particularly when focusing on aspects related to the bridge deck condition. Parameters such as bridge deck age, crack width, and NBI (National Bridge Inventory) condition are meticulously selected. Upon choosing these factors, the system adeptly recommends the optimal method for sealing bridge deck cracks, accompanied by a curated list of suggested products for implementation. The ensuing figures provide a tangible illustration of the system's functionality, offering insight into its decision-making process, suggestions, and the diverse range of factors it takes into account.

Example 1



NBI Condition Rating

- (•) >=7
- ( ) 6
- ( ) <=5

Crack Width

- (•) < 0.016"
- ( ) 0.016"- 0.06"
- ( ) 0.06" - 0.13"
- ( ) > 0.13

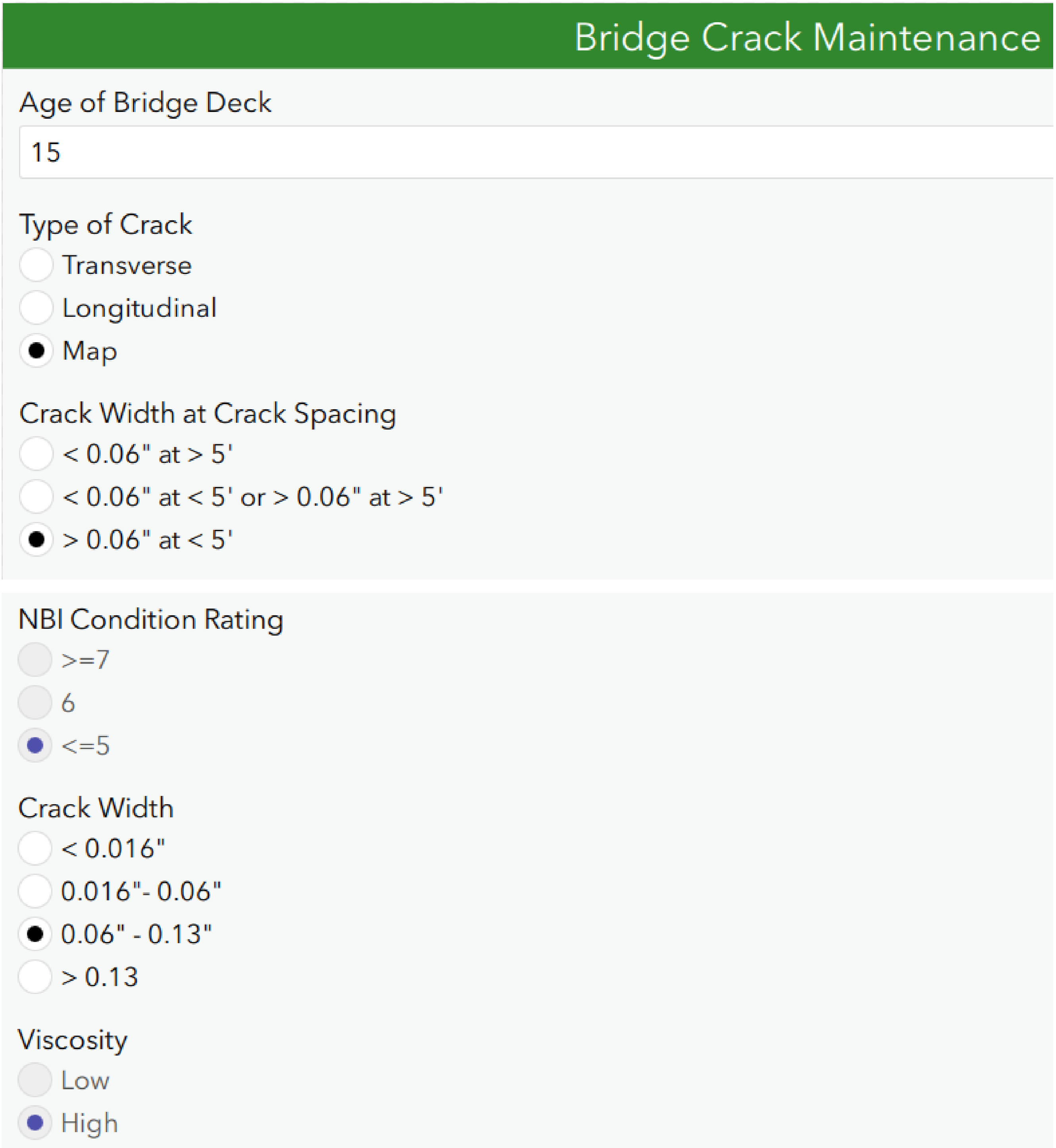
Viscosity

- (•) Low
- ( ) High

Suggestions

Crack Sealer:
Some products that can be used:
Polyurethane: TK-9030
Solvent based Silane: Hydro Silane 40 VOC, Sonneborn Sealer 40 VOC, Aquanil Plus 40
Penseal 244, TK-590-40, Sikagard Sn-40
Water based Silane: PowerSeal 40%, Aqua-Trete BSM 20, Hydrozo Enviroseal 40
Solvent based Siloxane: TK-290-WDOT, TK-290-WB, Eucoguard 100, TK-290-12 TriSiloxane
Water based Siloxane: Baracade WB 244, TK-290-WB TriSiloxane

Example 2


Bridge Crack Maintenance

Age of Bridge Deck

15

Type of Crack

○ Transverse
○ Longitudinal
● Map

Crack Width at Crack Spacing

○ < 0.06" at > 5'
○ < 0.06" at < 5' or > 0.06" at > 5'
● > 0.06" at < 5'

NBI Condition Rating

○ >=7
○ 6
● <=5

Crack Width

○ < 0.016"
○ 0.016"- 0.06"
● 0.06" - 0.13"
○ > 0.13

Viscosity

○ Low
● High

Suggestions

Apply a High Viscosity Concrete Sealer, Thin Polymer Overlay or Premixed Polymer Concrete:
Some products that can be used:
Polyurethane: TK-9020
Mythacrylate: Degadeck Deck Overlay System
Epoxy Penetrating Sealer: Sikander 55 SLV, Epoxeal GS-Structural
Traffic Guard EP-35, Sikadur 52, TK-9000, TK-9010, Dural335

Example 3

Bridge Crack Maintenance

Age of Bridge Deck

8

Type of Crack

- ○ Transverse
- ● Longitudinal
- ○ Map

Crack Width at Crack Spacing

- ○ < 0.06" at > 5'
- ○ < 0.06" at < 5' or > 0.06" at > 5'
- ● > 0.06" at < 5'

NBI Condition Rating

- >=7
- 6
- <=5 (selected)

Crack Width

- < 0.016"
- 0.016"- 0.06"
- 0.06" - 0.13" (selected)
- > 0.13

Viscosity

- Low
- High (selected)

Suggestions

Apply a High Viscosity Concrete Sealer, Thin Polymer Overlay or Premixed Polymer Concrete:
Some products that can be used:
Polyurethane: TK-9020
Mythacrylate: Degadeck Deck Overlay System
Epoxy Penetrating Sealer: Sikander 55 SLV, Epoxeal GS-Structural
Traffic Guard EP-35, Sikadur 52, TK-9000, TK-9010, Dural335

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