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INDIANA DEPARTMENT OF TRANSPORTATION AND PURDUE UNIVERSITY

Development of a Cost-Effective Concrete Bridge Deck Preservation Program

Volume 1—Development and Implementation of the Experimental Program

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16. Abstract

The deterioration of bridge decks has been identified as a major problem in Indiana. The primary cause of this deterioration is salt water ingress from the application of deicing salts during the winter. Deicing chemicals placed on the road mix with water and enter the deck through cracks and the pore structure of the concrete. This results in corrosion of the reinforcing steel and scaling of the surface, which leads to a shortened bridge deck life and costly deck replacement. The objective of this study is to investigate potentially effective and economic bridge deck preservation methods to significantly extend the service life of bridge decks, and as a result, extend the life of bridge structures in the State of Indiana. The research is presented in two volumes. Volume 1 focuses on the development and implementation of the experimental program. A survey of State Departments of Transportation identified the types of bridge deck preservation programs that are currently in use, the methods that they have employed in the past, and the perceived level of success with these programs and methods. A literature review provided information regarding specific products that performed well, characteristics of broader chemical families and their best uses, and other variables that may influence the effectiveness of sealers. The results of the DOT survey and literature review were used to determine the materials and methods to be further investigated in the experimental study. Based on this background, a series of macrocell specimens were constructed, and a salt water exposure regimen was initiated to examine the effectiveness of deck/crack sealer materials and application methods that were identified. Volume 2 presents the results of this study which were developed through the analysis of the recorded electrical activity after 1600 days of exposure followed by autopsy of the specimens. A visual rating scheme was used to assess the specimens during autopsy and to demonstrate the correspondence between the observed severity of corrosion and the recorded electrical activity. In addition, a deck sealer was applied to specimens with preexisting corrosion to evaluate the sealer's effectiveness in slowing the rate of corrosion. The deck sealer products were studied further by correlating both the sealer penetration depth and the chloride penetration profile with the products' effectiveness in resisting corrosion activity. A preliminary field application of crack sealer to an existing bridge deck was completed to evaluate processes, equipment, and other required resources. Finally, recommendations are provided regarding product selection and application to enable cost effective implementation of a bridge deck sealing program across the State of Indiana.

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EXECUTIVE SUMMARY

DEVELOPMENT OF A COST-EFFECTIVE CONCRETE BRIDGE DECK PRESERVATION PROGRAM: VOLUME 1—DEVELOPMENT AND IMPLEMENTATION OF THE EXPERIMENTAL PROGRAM

Introduction

Concrete bridge decks across the state of Indiana have experienced ongoing degradation caused by applications of deicing salts during the winter. Salt water collects on the deck and permeates the concrete through the cracks and the deck surface, allowing chlorides to initiate corrosion of the reinforcing steel. Over time, corrosion of the reinforcement leads to the need for costly deck repairs or even deck replacement prior to the expected service life of the bridge. The use of localized crack sealers and deck surface sealers has the potential of providing a cost-effective method of deck preservation that could be implemented across the state to prolong the life of bridge decks.

The objective of this study is to investigate potentially effective and economic bridge deck preservation methods to significantly extend the service life of bridge decks, and as a result, extend the life of bridge structures in Indiana. A literature review and survey of state departments of transportation were completed to guide the development of the experimental program and construction of the test specimens. The experimental program included continual monitoring of the specimens exposed to a salt water ponding regimen for a period of 1600 days, autopsy of the specimens to correlate observed interior corrosion with measured corrosion activity, and application of a deck sealer to specimens with preexisting corrosion to evaluate the sealer's effectiveness in slowing the rate of corrosion. Deck sealer performance was investigated further by correlating the occurrence of corrosion with sealer penetration depth and chloride penetration profiles. A preliminary field test of sealer applications was also completed to inform the development of field application methods. The research is presented in two volumes. Volume 1 presents the development and implementation of the experimental program while Volume 2 presents the results of the experimental program.

Findings

Volume 1

Based on the literature review and survey, the following findings were developed:

- Both epoxy and methacrylate products have been identified as effective localized crack sealers. Epoxy crack sealers generally are shown to have stronger bond strength and better durability in wider cracks, while methacrylate crack sealers provided better crack penetration particularly for narrower cracks.
- Silicone-based products, such as siloxanes and silanes, have been determined to be high-performing deck surface sealers. Silanes were found to be the most effective in most cases, especially solvent-based products with higher solids content.
- Water-based silane products also performed well as deck sealers and would be useful as a substitute in an environmentally sensitive situation. It is important to note, however, that reapplication of a water-based product may not be effective as water-based products repel themselves wherever traces of the sealer remain from previous applications.
- Linseed oil has been used as a deck sealer with varying success rates.
- Products within the same chemical family have been capable of very different performance; therefore, the specific product used is important.
- If a bridge deck is expected to be exposed to deicing salts, any cracks should be sealed, as well as the full deck surface. Sealing should be completed as soon as possible in the life of the bridge to prevent as much chloride intrusion as possible.
- A variety of methods and materials exist and are in use today for protecting bridge decks. Different states have varying thoughts on the effectiveness of different types of products and whether their use is economically beneficial.
- Both epoxy and methacrylate products are commonly used as crack fillers/sealers and currently are the only products in use by responding states. Silane and linseed oil are the most commonly used deck sealers by responding states. Other preservation approaches include barrier membranes and overlays.

Volume 2

Based on completion of the 1600-day experimental program and the field test, the following findings were developed:

- Sikadur 55 SLV and Dural 335, low-viscosity epoxies, were shown to be effective in reducing corrosion in cracked concrete by as much as 80 to 100%. The methacrylate crack sealer MasterSeal 630 exhibited contradictory performance. It was found that it has the potential to effectively seal cracks; however, its performance in this experimental program may have been sensitive to installation procedures due to its lower viscosity as compared with the epoxies. Furthermore, methacrylate crack sealers have been shown to be more effective in narrower cracks (<0.016 in.) than those investigated in this experimental program.
- The deck sealers MasterProtect H 440 HZ, MasterProtect H 400, and linseed oil were not effective at preventing salt water intrusion in cracked concrete. The use of a deck sealer does not prevent salt water intrusion at cracks; moreover, the deck sealer may actually inhibit evaporation of moisture from the deck, causing even more corrosion than in an unsealed deck.
- The four crack and deck sealer combinations investigated were extremely successful in reducing chloride ingress and preventing corrosion activity for the duration of the experimental program. The only exception to this performance was the varied results of the sealer combination comprised of crack sealer MasterSeal 630 and deck sealer MasterProtect H 440 HZ, which again suggests that MasterSeal 630 may have been sensitive to installation methods.
- Simulation of traffic wear on uncracked concrete with applied deck sealer revealed that the likelihood of corrosion increases as the depth of sealer penetration is abraded over time. Therefore, reapplication of deck sealers over time is warranted.
- Application of a deck sealer to reinforced concrete with preexisting corrosion did not appear to slow the rate of corrosion. This finding was likely due to the presence of surface cracks, which are not effectively sealed by use of a deck sealer alone. However, given the observed effectiveness of applying both a crack and deck sealer to reduce salt water ingress, it is expected that the use of such a sealer combination would effectively slow the rate of preexisting corrosion.

- When installing a two-part epoxy crack sealer, the use of a two-component joint sealer pump such as the model used in the field test provides an effective and efficient means of crack sealer application.
- Deck sealer application can be accomplished effectively and efficiently by use of a truck-mounted sprayer bar, such as the one developed for the field test.

Implementation

It is recommended that both localized crack sealers and deck surface sealers are used to resist chloride ingress in the deck and to reduce corrosion of the reinforcing steel. First, it is recommended that wide cracks be sealed using epoxy crack sealers (Sikadur 55 SLV or Dural 335) and narrow cracks be sealed using a methacrylate crack sealer (MasterSeal 630). Completion of crack sealing should be followed by application of a deck sealer to prevent/reduce ingress through the deck surface. Although all three deck sealers in this experimental program were shown to be effective, it should be noted that the use of MasterProtect H 440 HZ is no longer permitted in the state of Indiana. It should also be noted that MasterProtect H 400 is a water-based product. While this product can be effective for initial application, it is not recommended for reapplication as water-based products repel themselves wherever penetrating deck sealers remain from previous applications.

To prepare for installation, it is recommended that dust and debris be cleaned from the cracks and the deck surface prior to application of crack sealers and deck sealers. Surface preparation in the form of roughening or sandblasting, however, is not required prior to sealer applications because the preexisting roughness of the bridge deck from surface tining and traffic abrasion allow for sufficient sealer penetration.

To maintain effectiveness of the sealer over time, it is recommended that decks are resealed every 5 years. Traffic abrasion was found to significantly reduce the effectiveness of deck sealers as it removed the layer of protection provided by the sealer. Extended reapplication times may be appropriate for bridges with low traffic volumes. As discussed previously, reapplication of a water-based product (such as MasterProtect H 400) is only effective in locations where the sealer has been removed as water-based products repel themselves wherever traces of the sealer remain from previous applications. For this reason, reapplication using non-water-based sealers is recommended. If a water-based sealer is used, the remaining penetration depth of the previous sealer should be removed through preparation of the surface such as sandblasting to ensure that the full penetration depth of the sealer can be achieved.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

1. INTRODUCTION

1.1 Background

Corrosion of reinforcement in bridge decks is a significant problem throughout the world. As the nation's inventory of bridges continues to age, the number of bridges classified as structurally deficient is increasing. Funds to refurbish or replace bridges are limited making it difficult to bring their conditions up to an acceptable level. Therefore, the development of a program to extend the lifespan of bridges in an economical manner and maintain the functional capability of this important piece of the infrastructure would be very beneficial.

The current lifespan of a bridge deck in Indiana is approximately 30 years, which includes the installation of a bridge deck overlay at some point during its life. This overlay of latex-modified concrete has a lifespan of approximately 15 to 20 years. The Indiana Department of Transportation's (INDOT) current policy calls for sealing new bridge decks with a penetrating epoxy sealer or other approved portland cement concrete sealer, and regular flushing of the bridge's joints, bearings, and supports to resist corrosion. These methods do not completely protect the bridge, however, and repairs or retrofits in the form of the installation of integral supports, a deck overlay, deck replacement, or even a full superstructure replacement are needed to extend the lifespan of a structurally deficient bridge. Federal funds are available for these repairs, but are limited for use once every 10 years for the same bridge. Work performed before 10 years have elapsed must be paid for entirely by the State. Additionally, closing a high volume bridge for this repair work results in cost to the State and users. It would therefore be beneficial to extend the lifespan of a bridge deck through a more economical sealing program that would reduce the likelihood the State of Indiana would need to cover in full the cost of more serious repair work.

1.2 Bridge Deck Cracking

Cracks form in bridge decks when stresses exceed the tensile strength of the concrete, which can occur for a variety of reasons. Some primary causes are shrinkage, thermal effects, heavy loads, and corrosion. The most common type of cracking in bridge decks is transverse cracking (see Figure 1.1), which typically forms full-depth cracks perpendicular to the girder lines.

Once cracks form they can create a conduit for salt water to reach the reinforcing steel. According to ACI 224R-01 (2001), the maximum crack width recommended for concrete that is exposed to deicing chemicals is 0.007 in., as shown in Table 1.1.

Cracks found on bridge decks can be highly variable, but widths of 0.025 in. are commonly found (Frosch, Gutierrez, & Hoffman, 2010), which is larger than the 0.007 in. recommended, and would therefore allow salt water ingress. Though there are steps that can be taken to reduce the amount of cracking, it is not possible to prevent all cracks. It is apparent then that these cracks need to be sealed to protect the lifespan of the deck.

Figure 1.1 Transverse deck crack (Frosch et al., 2010).

TABLE 1.1
Maximum recommended crack widths (ACI 224R-01, 2001).

Environment	Maximum Crack Width (in.)
Dry air or protective membrane	0.016
Humidity, moist air, soil	0.012
Deicing chemicals	0.007
Seawater and seawater spray, wetting and drying	0.006
Water-retaining structures	0.004

1.3 Effect of Deicers on Concrete and Steel

Deicing chemicals have a negative effect on both the concrete and reinforcing steel in a bridge deck. Salts such as sodium chloride (NaCl), calcium chloride ($CaCl_2$), and magnesium chloride ($MgCl_2$), as well as calcium and magnesium acetate (CMA) are ionized and create a solution with ice, snow, or water. This solution then enters the deck though cracks and through the pore structure of the concrete.

1.3.1 Damage to Concrete

The deicers listed above have been shown to have negative effects on the quality of the concrete, especially when used in high concentrations (Darwin, Browning, Gong, & Hughes, 2008). A section of concrete that had been exposed to a deicing chemical in the study by Darwin et al. (2008) is shown in Figure 1.2.

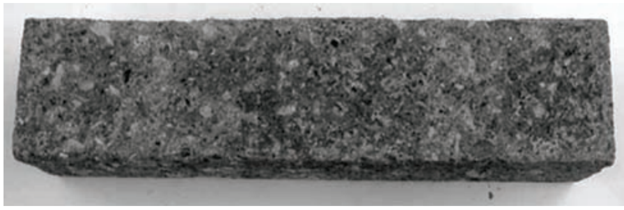

Figure 1.2 Concrete subjected to high concentrations of NaCl (Darwin et al., 2008).

Deicers can affect the chemistry of the cement paste of the concrete. Chemicals that create chloride solutions commonly form calcium chloride hydrate and calcium oxychloride, and in addition $MgCl_2$ and CMA result in the transformation of calcium silicate hydrate to magnesium silicate hydrate. These end products create non-cementitious material in the cement paste, resulting in weaker concrete (Lee, Cody, Cody, & Spry, 2000). Another major issue caused by these chemicals is the formation of salt crystals within the pore structure. If sufficient moisture is present, the crystals grow to a large enough volume to create increased pressure that leads to cracking and scaling of the concrete surface (Charola, 2000). Lastly, if water enters the pore structure, scaling of the concrete surface due to freeze-thaw cycling can occur if the concrete is not properly mixed and placed. Good quality concrete has sufficient entrained and entrapped air to accommodate the expanding water and prevent damage, but this cannot always be guaranteed.

1.3.2 Damage to Reinforcing Steel

The most destructive force to the reinforcing steel is chloride ions from deicing salts. Reinforcing steel inside concrete is normally protected by a passive film that forms around the bar due to the highly alkaline environment of the concrete. Chloride ions break down this film, allowing corrosion of the steel to occur. Corrosion of the steel is an electrochemical process that takes place with the help of oxygen and water, which are readily available in the atmosphere. There are two main processes by which corrosion occurs, in the form of a microcell or macrocell. The two chemical processes are similar, but involve different portions of the reinforcement embedded in the concrete. They both involve an anode where the iron of the steel is oxidized leaving free electrons that pass through the steel to the cathode where they reduce oxygen to hydroxyl ions (hydroxide). The hydroxide then passes back to the anode through the damp concrete pores forming a short-circuited corrosion cell (Elsener, 2002).

A microcell occurs when the anode and the cathode form adjacent to each other on the same reinforcing bar. This process is shown in Figure 1.3.

A macrocell is formed when the reinforcing bar that is actively corroding is linked to another bar that is still passive or corroding at a slower rate, as shown in Figure 1.4. A macrocell is found in a bridge deck where the top mat of steel (active) and the bottom mat of steel

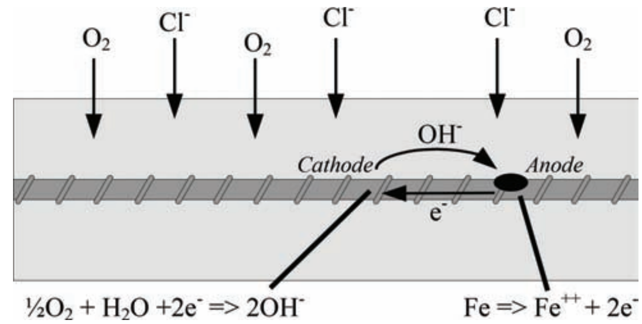

Figure 1.3 Microcell corrosion process.

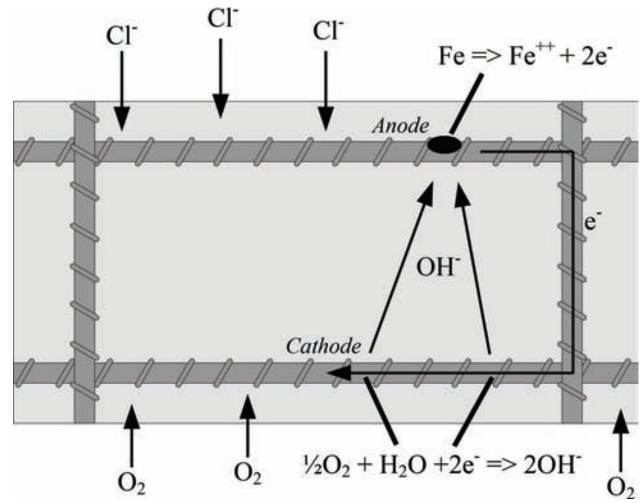

Figure 1.4 Macrocell corrosion process.

(passive) are linked by vertical reinforcement or chair supports. In the case of a macrocell, the active steel corrodes at a faster rate than it would under microcell conditions, and the passive steel corrodes at a slower rate. Macrocells are the predominant corrosion process when multiple rebar layers are present (Hansson, Pourasee, & Laurent, 2006).

The result of this corrosion activity is a loss of steel cross-sectional area due to oxidation, which in turn reduces the strength of the deck. In addition, the corrosion products created are expansive, creating tensile stresses within the deck that can lead to more cracking, further exacerbating the problem.

In an effort to reduce this problem, epoxy-coated reinforcement steel is commonly used in bridge decks today; however, it is still susceptible to corrosion. Defects in the epoxy coating allow water and chloride ions to reach the steel, allowing corrosion to occur inside of the epoxy coating.

1.4 Bridge Deck Protection

A wide variety of methods and materials have been used to protect bridges from corrosion. The success of each of these methods is dependent on many variables and the specific condition of the bridge. Determining which products perform the best under different conditions has been the focus of many studies. An overview of the different materials available for sealing cracks and concrete surfaces is provided here, along with the properties that generally provide the best performance. Discussion on the environmental factors that can influence the performance of sealing products is also provided.

1.4.1 Sealing Products

The types of products available for sealing can be broken down into those that only seal cracks, products that only seal the surface of the concrete, and products that accomplish both.

1.1.4.1 Crack Sealers. Crack sealers, or crack repair products, are best suited for situations with readily visible cracks that are spaced relatively far apart, or for any large cracks. The state of the crack influences how it may be dealt with.

If the crack is still active and is expected to continue to grow, then routing and sealing is likely the best choice. With this repair, the crack is enlarged and cleaned out, then filled with a low-strength waterproofing material such as epoxy or silicone, as shown in Figure 1.5. The low-strength material is used to accommodate the expected future crack movement; therefore, this is not a structural repair method (ACI 224.1R-07, 2007) and is not well suited for use in bridge decks.

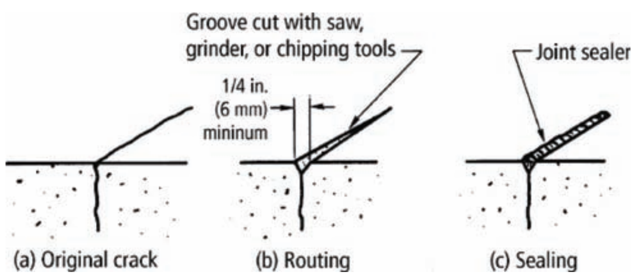

Figure 1.5 Routing and sealing of a crack. (Source: ACI 224.1R-07, 2007.)

If a structural repair is desired, or the crack is dormant, then crack injection or a gravity feed product is the best choice. These methods both fill and seal the crack, and are referred to as filler/sealer materials for much of this report. If the crack is active and these methods are used, then a new crack will likely form in the deck. Crack injection uses a high-strength and relatively low-viscosity epoxy that is pressure injected into a crack. Injection access holes need to be drilled and a careful process followed to create a quality repair. Because of this required process, epoxy injection is a labor intensive method requiring trained personnel and special equipment. Gravity feed products are available in several different forms, with epoxy and high molecular weight methacrylates (HMWM) being the most common. They have a very low viscosity and low surface tension, and when pooled over cracks, will penetrate to large depths by the force of gravity alone (ACI E706 RAP-2, 2003). An example of the application of a gravity feed crack filler/sealer is shown in Figure 1.6.

There are several material factors to consider when choosing which product to use to seal a crack. The bond strength between the sealing material and the crack sides is important, because the crack needs to stay sealed under any possible movement. Even if the crack is dormant, loading from traffic can stress the repaired area, so the repair product needs to have a bond strength at least equal to that of the tensile strength of the concrete. Viscosity must also be considered, because the lower the viscosity, the deeper the product will penetrate into the crack, and the stronger the repair will be. Viscosity should be a maximum of 200 centipoises (cP) (ACI E706 RAP-2, 2003). Flexibility is important to consider, because the repair will experience stresses and crack movement as the bridge deck is loaded by traffic or thermal effects. If the repair material is not sufficiently flexible it will crack under these loads,

Figure 1.6 Placement of gravity feed crack filler/sealer (Soriano, 2002).

Figure 1.7 Application of surface sealer (Soriano, 2002).

allowing access for chlorides. It has been recommended that crack sealing products have a tensile elongation of at least 10 percent (Johnson, Schultz, French, & Reneson, 2009). Lastly, the time for the sealer to become tack free so that the bridge can be opened to traffic should be considered. Most crack injection and gravity feed sealing methods will be sufficiently dry after several hours to allow traffic on the bridge.

1.4.1.2 Deck Sealers. Deck sealers, also called surface sealers, prevent water from entering the concrete pore structure to keep out chlorides that might be in solution in the water. They are typically applied by sprayer, as shown in Figure 1.7. They can be divided into two groups, film formers and penetrating sealers.

Film formers stay on the surface of the concrete and create a somewhat waterproof barrier that helps keep water out of the deck. Linseed oil, epoxy, and methacrylate products are some common film-forming products (Johnson et al., 2009). Because they stay on the surface, they are susceptible to wear from traffic and can lose effectiveness over time. Precautions must also be taken to ensure that a film-forming product does not create an unsafe, slippery deck surface.

The most commonly marketed penetrating sealants include silicates, siliconates, silanes, and siloxanes, all of which are silicon-based products. They can be further divided into water repellents and pore blockers. Siliconates, silanes, and siloxanes are water repellants, which work by penetrating into the concrete and reacting with the hydroxyl groups on the pore walls, creating a hydrophobic surface. This surface prevents moisture ingress, but still allows water vapor to pass through (Attanayake, Liang, Ng, & Aktan, 2006). The passage of vapors is important because if the deck contains a significant amount of moisture, or is open on the bottom allowing water vapor to enter, the water can escape through the top surface. Silicate is a pore blocking penetrating sealer. It functions by penetrating into the concrete and filling the pores. Filling the pores prevents any moisture ingress as well as any water vapor transmission. If water is present in the deck and then exposed to freeze-thaw cycles, scaling damage can occur, because the water cannot escape from the top surface (Attanayake et al., 2006).

Penetration depth is one of the most important properties governing the effectiveness of a surface sealer. By penetrating into the substrate, the sealer is protected from degradation due to UV light, and on a wearing surface, it provides extended protection as the top surface is slowly worn off. The depth of penetration depends on several factors based on the concrete substrate: the porosity, moisture content, pH, and silica content (McGettigan, 1992). The relationship between the porosity and size of the sealer molecule has a significant effect on penetration depth. Film formers are not able to penetrate into the pores because their molecules are too large. Of the penetrating sealers, water repellants have a smaller molecule than pore blockers and are able to penetrate deeper (Cady, 1994).

1.4.1.3 Crack and Surface Sealers. Some methods serve the dual purpose of sealing cracks and the surface of the deck at the same time. If a bridge deck has very high density cracking, making it impractical to individually fill them, then coating the entire surface should be conducted. A full surface coating also has the advantage of sealing any cracks that might not be visible or could be overlooked. Gravity feed products, as listed above, are commonly used in this method. With the use of this method, larger, visible cracks are typically prestriped by applying the material directly to the crack before flooding the entire surface, as shown in Figure 1.8. In addition to the crack sealing properties listed earlier, flood coats of gravity feed products act as a film-forming surface sealer for the deck. However, this thin film may not last long under wear from traffic, and is considered a sacrificial surface.

Another sealing method that can be used is overlays, which are available in a variety of different types. The most common overlay is made with a waterproof membrane topped with asphalt concrete. Other types involve

Figure 1.8 Applying a prestripe of crack filler/sealer material (Frosch et al., 2010).

topping the deck with several inches of a special concrete mix, such as a low slump and low water-cement ratio concrete, or high-performance concrete. Other concrete mixes modified with fly-ash, silica-fume, or other materials are also used (Krauss, Lawler, & Steiner, 2009). These types of overlays are expensive and do not repair the cracks but instead cover them up. They do, however, provide an effective barrier against chloride intrusion. An additional consideration when applying an asphalt or concrete overlay is the additional weight placed on the bridge.

A less expensive overlay alternative uses epoxy spread over the surface of the deck, followed by a broadcasting of aggregate while the epoxy is still wet. This is sometimes completed in several coats to ensure proper coverage. This method uses a very viscous material that has little or no crack penetration, so the strength of the overlay over a crack is not always sufficient to resist recracking under loads. However, if the overlay has sufficient strength and flexibility, it creates a waterproof barrier for the entire deck.

1.4.2 Application Conditions

The conditions and methods in which sealing products are applied with can have a significant effect on the performance of the material. The manufacturer's instructions should contain detailed information on surface and product preparation, application steps, and any finishing procedures. Some of the most important considerations related to the application of both crack and surface sealers are the surface preparation, temperature, and the presence of moisture. Surface preparation is important for sealing cracks to ensure that a strong bond is formed between the sealer and the concrete. Generally, cleaning with a power washer, compressed air, or sandblasting is needed to remove any deleterious material. For surface sealers, cleaning with a power brush or compressed air to remove excess dirt is usually the only surface preparation needed. The allowable temperature and moisture of the deck and surrounding environment during application are provided by the manufacturer and should be followed to ensure that the chemicals react properly. General temperature ranges are suggested as 45°–90° F for crack fillers/sealers and 40°–100° F for surface sealers (Johnson et al., 2009). Too much moisture in the deck can be detrimental to crack filler/sealer bond strength or to the penetration depth of surface sealers. General recommendations include a drying time of at least two days before any sealing if the deck is moist (Johnson et al., 2009), as well as limitations if rain or very high humidity is expected soon after sealer application.

1.5 Objective and Scope

Although a number of products and techniques exist to protect bridge decks from deterioration due to deicing chemicals, the problem still persists throughout the United States. Variability found in past studies and field uses have shown that the selection of a type of sealing product and the application methods that should be used to apply it are not always clear or consistent. A lack of use of currently available materials and methods also exists. The objective of this study is to develop an experimental program that will investigate the most effective methods of preserving bridge decks through the use of concrete crack and deck sealers. This study will be conducted in several phases. A review of the literature will be conducted in the first phase. Specific products as well as broader chemical families that have been highly effective in past studies will be determined. The application methods used and any recommendations made will also be noted. Different laboratory tests that were used to evaluate products will be compared, to assist in selecting testing methods for this study. The second phase will consist of a survey of state DOT's to determine which products are currently in use, what types of preservation programs have been used in the past and are currently in place in other states, and what is the perceived effectiveness of those programs. Finally, utilizing the information gathered in the first two phases, an experimental program will be designed and implemented to evaluate different products and application methods as possible solutions to bridge deck deterioration.

2. SURVEY OF PREVIOUS RESEARCH

A literature survey was performed to review the previous research in the area of deck sealers and crack fillers/sealers. Previous performance of general material types and specific products was of key interest along with typical testing methods used and their effectiveness. Important factors that affected the performance of the materials and their costs were noted.

2.1 Pfeifer and Scali (1981)

Funded by the National Cooperative Highway Research Program (NCHRP 244), this was the first major study to compare a variety of deck sealers in order to determine the most effective product and material type. Twenty-one sealers of many different chemical types were included, and four tests were created to compare their performance. From a review of the literature, linseed oil was found to be one of the most widely used materials, while silane was considered a new product. A list of possible deck sealer materials was compiled from a survey of states and chemical manufacturers.

The testing program referred to as Series I evaluated the differences in water absorption, water vapor transmission, and chloride intrusion of the various deck sealer materials. From this test series, the top five performing materials were chosen to be included in subsequent tests. The five materials selected were an epoxy, methyl methacrylate, urethane, silane, and a methacrylate. The Series II test was similar to that used for Series I, but included the variable of drying time of the new concrete (after a 21-day cure) before applying the sealer. Series III testing examined differences in application rates of the sealers. Series IV testing created two accelerated weathering procedures to simulate conditions that might be found in a southern and northern climate. The "Southern Climate Exposure" test subjected the specimens to cycling of saltwater ponding followed by ultraviolet light and infrared heat. The "Northern Climate Exposure" test used cycles that included acid, saltwater, infrared heat, ultraviolet light, fresh water rinse, and freezing and thawing. The top performing products identified through the testing programs were the silane, methyl methacrylate, and epoxy, which all significantly reduced the amount of chloride content in the concrete compared to the control specimens.

Wear was not investigated in the study and penetration depth was not accounted for (silane was the only true penetrant used), nor was surface traction after application, though all these possible concerns were mentioned. Material cost was also noted and compared, but an economic study was not part of the project. It was recommended that for evaluating sealers, the Series II test method be used for preliminary screening, and the Series IV "Southern Climate Exposure" procedure be followed for additional testing. The authors also recommended deck surface cleaning with light sandblasting and drying of the deck for about five days before application of the sealer. Future research was suggested in the area of sealers designed to protect and repair deck cracks, and to investigate the use of linseed oil in combination with ultraviolet light as a curing accelerator.

2.2 Smutzer and Chang (1993)

A study was performed in Indiana to test deck sealers in the field and to compare their performance with results from a laboratory study that used the NCHRP 244 Series IV "Southern Climate Exposure" testing procedure (Pfeifer & Scali, 1981). The materials tested were a silane, two siloxanes, a blend of silane and siloxane, a modified aluminum siloxane, and two epoxies. The field test site was a concrete pavement section along I-69 with an average daily traffic count of 7,700. After the concrete had cured for more than 28 days, it was sandblasted to remove the curing compound and contaminants, then was swept and blown clean. The products were applied at a coverage rate that was judged to be necessary to completely cover the surface uniformly (usually the bottom of the manufacturer's range for application or slightly heavier). The concrete was sampled at approximately one, two, and three years for chloride content using an average of four sample locations per product. The NCHRP 244 testing was completed on all but the epoxies, and results were compared to the field results. The results are presented in Table 2.1 as the percent reduction of chloride content compared to that in the control.

It was found that the laboratory and field results did not always correlate well. Each year it was determined

TABLE 2.1
Sealer performance in the laboratory and field (Smutzer & Chang, 1993).

	% Reduction of Chloride Compared to Control			
		INDOT Field Performance Based on 0″–1.5″ Sample Section		
Material	Laboratory Performance, NCHRP 244 Series IV SCE	1 Year	2 Year	3 Year
Silane	98.4%	50.1%	60.5%	64.0%
Epoxy #1	–	38.1%	43.8%	50.6%
Epoxy #2	–	28.2%	35.7%	46.1%
Siloxane #2	92.0–93.0%	40.2%	24.6%	33.7%
Silane-Siloxane Blend	96.0%	34.4%	19.3%	22.9%
Modified Aluminum Siloxane	98.7%	30.2%	12.8%	10.0%
Siloxane #1	89.3%	43.6%	34.6%	38.6%

that silane was the most effective sealer in the field, with the two epoxies as the second most effective in the second and third years.

2.3 Hagen (1995)

The Minnesota Department of Transportation (MnDOT) carried out a field investigation of 16 different sealing products in parallel with a laboratory study of 11 of the 16 products using the NCHRP 244 Series II test. A new bridge constructed in 1991 with a low slump concrete overlay was used in the field investigation. The bridge deck was first sandblasted to remove any curing compounds, and the materials were applied to sections of the deck by the supplier, if possible, or otherwise by MnDOT personnel. Three sample cores of each sealer were taken at one, two, and three years for use in determining the chloride content. Base chloride levels were subtracted from those determined each year and the increase in chloride content was compared to that for the control. The top performing sealing products after three years included a water-based silane (Enviroseal 40), two solvent-based silanes (Fosroc Dekguard P-40 and Hydrozo Silane 40), and a siloxane (Paragon 15). It was noted that Fosroc Dekguard P-40 was also found to be one of the better sealers in two previous studies. The study demonstrated that although there is some variability, silanes and siloxanes (penetrating sealers) appeared to be the best performing groups, providing protection for approximately three years, while surface sealers were not effective after one year. The NCHRP 224 Series II test results were a reasonably good predictor for the one-year performance of penetrating sealers in the field; however, positive laboratory results didn't necessarily correlate with positive extended field performance. It was recommended that laboratory tests include abrasion, such as the modified NCHRP 244 developed by Alberta (Kottke, 1987).

2.4 Weyers, Zemajtis, and Drumm (1995)

The service lives of concrete surface sealers were estimated based on a study that involved both laboratory specimens and two active bridges with the goal of determining the most cost effective material and application methods. Using Fick's second law (a method of calculating how diffusion changes the concentration over time [Broomfield, 1997]) and data from the tests, service lives of the sealers under varying conditions were estimated. Factors to consider that affect the service life of a sealer were believed to be traffic conditions, geographical location (weather or exposure to salt water), and exposure to and intensity of ultraviolet light.

Two products were chosen from each type of sealing mechanism; silane and siloxane from the penetrating sealers group, and a water-based and solvent-based epoxy from the pore blocking group. In the laboratory, horizontal and vertical slabs (walls) were sealed and exposed to salt water (through ponding of flowing saltwater) for three days followed by four days of drying. These wetting and drying cycles were continued for 30 weeks. The specimens were also exposed to ultraviolet light for a duration similar to what would be experienced by either a horizontal or vertical surface in the field. In the field study, deck sections were sealed on two bridges in Virginia; one on a secondary route with an annual average daily traffic (AADT) count of 12,430, and the other on Interstate 81 with an AADT count of 24,270. Both laboratory and field concrete surfaces were lightly grit blasted before sealing. The wear rate on the deck was determined by measuring the wear profile of the deck using a straightedge placed on the deck surface and comparing the total depth to the time in service. The deck on the secondary route had only been in service for two years, and no wear was yet measurable. The deck on Interstate 81 had been in service for 27 years, and the wear rate was estimated to be 0.17 mm/year.

Based on these findings and typical sealer penetration depths, a penetrating sealer's service life was estimated to be nine to ten years. However, because of uneven penetration depth, it was noted that reduced effectiveness of the sealer was possible sooner and a service life of eight years was more conservative. Pore blocking sealers were observed to have a service life of less than one year. Based on the experimental findings, Fick's Second Law was used to estimate the service life and time to reapplication of a sealer that would maintain protection of the deck reinforcement for up to 50 years, based on the type of environment the deck is exposed to and the concrete properties.

2.5 Soriano (2002)

A study was performed to determine the strategies that should be used to effectively seal bridge decks to reduce salt water ingress in the state of South Dakota. The methods of protection available at the time included application of linseed oil on older decks, using epoxy for crack filling/sealing, and using an epoxy chip seal to seal the entire deck surface when severe cracking was present. The epoxy chip seal method consisted of a flood coat of epoxy material followed by broadcasting with fine aggregate before the epoxy cured. The main objectives of the study were to determine when, what, and how to apply treatments to bridge decks. Researchers examined current literature, conducted a simple survey with state DOT's, and performed a field trial of several different materials and methods of application.

In the survey, 25 states and Canadian provinces responded to basic questions related to what types of products were used in their state or province, and when and how they were applied. The results of the literature review and survey were used to create a list of products for use in the field experiment. The products were applied to three bridges that had different surface preparations: sandblasting, power broom/forced air cleaning, or nothing. After the application, three cores were taken from each differently sealed section of the bridges, and penetration depth of each treatment material was measured.

The main conclusions of the study were that applying deck sealers and crack fillers/sealers was most beneficial before chloride ingress began, and that crack fillers/sealers with a viscosity less than 15 cP demonstrated good penetration. It was also noted that linseed oil should not be considered a penetrating sealer because its molecules are too large to actually penetrate the concrete, and it functions only as a temporary surface membrane sealer. It was recommended that bridge deck cracks and surfaces be sealed three to six months after construction, and every five years thereafter. It was also recommended that penetrating sealers be used instead of linseed oil, and crack fillers/sealers with a viscosity less than 15 cP be used. Product use guidelines were provided in table form. The recommended products are shown in Table 2.2, and their suggested use is shown in Table 2.3.

2.6 Pincheira and Dorshorst (2005)

Laboratory experiments were performed with crack and deck sealers to identify the best materials in terms of durability and effectiveness at resisting chloride penetration. Materials to be included in the study were chosen from a large preliminary list based on properties provided by the manufacturers such as recommended surface preparation, coverage rate and cost, expected durability, as well as other properties. The sealers with the most favorable overall properties were chosen for the study and ranked by anticipated performance.

TABLE 2.2
Recommended products (Soriano, 2002).

Product #	Product	Use
1	100% Silane–Degussa	Deck Sealer
2	40% Silane–Hydrozo	Deck Sealer
3	40% Silane–Masterbuilders	Deck Sealer
4	Reactive Methyl Methacrylate–Degussa	Crack Sealer
5	Modified Polyurethane–Roadware	Crack Sealer
6	Two-Component Epoxy–Unitex Pro-Seal	Crack/Surface Sealer
7	SDDOT Epoxy Chip Seal	Crack/Surface Sealer

The deck sealers were tested using the AASHTO T259 and T260 test procedures and were also evaluated based on the depth of penetration. The AASHTO testing subjected the specimens to abrasion and saltwater ponding, then measured the change in chloride content in the concrete. An addition was made to this test by subjecting some of the specimens to freeze-thaw cycling while ponded with the saltwater. The depth of penetration was determined, and the results compared to each manufacturer's claim. The materials were ranked based on the test results and penetration data, and compared to the initial rankings. The results were separated into categories I, II, and III, with I being the best. The results are shown in Table 2.4.

Crack sealers underwent testing to determine the bond strength of the sealing material with and without freeze-thaw cycling and to determine the depth of penetration. Concrete specimens were constructed with prescribed crack widths, and crack filling/sealing materials were applied only to cracks of the widths recommended by the manufacturer. Depth of penetration was measured by cutting through the ends of the specimen. A test similar to that used to determine the splitting tensile strength of concrete cylinders was used to measure the bond strength. Some specimens were first subjected to freeze-thaw cycling according to ASTM C666 before the bond strength testing. Each material was then ranked in a similar manner as for the deck sealants; first based on properties provided by the manufacturer, then by the test results. The products were grouped into three categories based on the test results. An additional category for the crack fillers/sealers was ranking by crack width as not all products were used on all crack widths. The final results are shown in Table 2.5.

Some of the most significant findings for deck sealants were that solvent-based silanes had the deepest penetration depths, but after freeze-thaw cycling, their performance was not distinguishable from water-based silanes. Freeze-thaw cycles decreased the effectiveness of most of the deck sealers. None of the deck sealants reached the penetration depth stated by the manufacturer, and there was considerable scatter in penetration depth in a given specimen. It was concluded that the large abrasion depth required by AASHTO T259 was the main factor that limited the effectiveness of many sealants with shallower penetration, and those sealants may perform better in the field under true abrasion. It was recommended that the depth of penetration be used

TABLE 2.3
Product use guidelines (Soriano, 2002).

Crack Width in.	Crack Frequency		
	>10 ft	5–10 ft	<5 ft
<0.04	(1, 2, or 3)	(1, 2, or 3) **OR** (1, 2, or 3) and (4, 5, or 6)	(1, 2, or 3) and (4 or 6) **OR** 7
0.04–0.08	(1, 2, or 3) **OR** (1, 2, or 3) and (4, 5, or 6)	(1, 2, or 3) and (4, 5, or 6) **OR** 7	(1, 2, or 3) and (4 or 6) **OR** 7
>0.08	(1, 2, or 3) and (4 or 5)	(1, 2, or 3) and (4 or 5) **OR** 7	(1, 2, or 3) and (4) **OR** 7

TABLE 2.4
Deck sealant test results (Pincheira & Dorshorst, 2005).

Sealant*	Chemical Family	Performance Group Category
Sonneborn Penetrating Sealer 40 VOC (6)	silane, solvent-based	I
Hydrozo Silane 40 VOC (9)	silane, solvent-based	
Powerseal 40% (11)	silane, water-based	II
V-Seal 102-V4 (2)	siliconate	
Penseal 244 40% (8)	silane, solvent-based	
TK-290 Tri-Siloxane (4)	siloxane, solvent-based	
Enviroseal 40 (12)	silane, water-based	
Aqua-Trete BSM 20 (3)	silane, water-based	
TK-290WB Tri-Siloxane (5)	siloxane, water-based	III
Enviroseal 20 (10)	silane, water-based	
Baracade WB 244 (7)	siloxane/silane oligomers, water-based	
Eucoguard 100 (13)	siloxane, solvent-based	
Aquanil Plus 40 (1)	silane, solvent-based	

*The number in parentheses indicates the initial product ranking.

TABLE 2.5
Crack filler/sealer test results (Pincheira & Dorshorst, 2005).

Hairline Crack Width (<0.06 in.)*	Narrow Crack Width (0.06–0.10 in.)	Medium Crack Width (0.10–0.19 in.)	Wide Crack Width (>0.20 in.)	Performance Group Category
Sikadur 55 SLV (4)[E]	Sikadur 55 SLV (4)[E]	Sikadur 55 SLV (4)[E]	No products tested	I
Dural 335 (5)[E]				
Sikadur 52 (6)[E]	Sikadur 52 (6)[E]	Sikadur 52 (7)[E]	No products tested	II
Degadeck Crack Sealer (1)[M]	Degadeck Crack Sealer (1)[M]	Degadeck Crack Sealer (1)[M]		
Denedeck Crack Sealer (2)[M]	Denedeck Crack Sealer (2)[M]	Denedeck Crack Sealer (2)[M]		
SikaPronto 19 (7)[H]	SikaPronto 19 (8)[H]	SikaPronto 19 (8)[H]		III
Duraguard 401 (3)[H]	Duraguard 401 (3)[H]	Duraguard 401 (3)[H]	Duraguard 401 (1)[H]	
	TK 9000 (6)[E]	TK 9000 (6)[E]	TK 9000 (2)[E]	
	TK 9030 (5)[U]	TK 9010 (5)[E]		

*The number is the initial product ranking, the letter is the chemical family of the product. [E]: epoxy, [M]: methacrylate, [H]: HMWM, [U]: urethane polyurea hybrid.

as a prescreening tool for deck sealants before more extensive tests are conducted.

For crack fillers/sealers, all of the products penetrated the full specimen depth of 2.5 in. For most of the products there was a strength reduction because of freeze-thaw cycles, but the degree of damage was highly variable. The width of the crack did not appear to have a large effect on performance. It was recommended that more testing be conducted with Sikadur 55 SLV on wide crack widths given its good performance for all smaller cracks. No products were placed in Category I for wide cracks, though the authors speculated that some of the products that performed well for medium width cracks (such as Sikadur 55 SLV) might also perform well for wide crack widths. It was recommended for both crack fillers/sealers and deck sealers that future testing include freeze-thaw cycles and monitoring of field-applied products.

2.7 Wenzlick (2007)

The Missouri DOT performed various tests on several different deck sealers to determine the effectiveness of the proposed sealers compared to the standard at that time of linseed oil. A secondary goal of the study was to establish which testing method(s) should be used to qualify future products for use in the state. The sealers tested were linseed oil double boiled and mixed 1:1 with mineral spirits, two reactive silicates made by Chem Tec One and Radcon #7, "Water Soluble 1:1" made by Star Macro-Deck, and a silane made by Sil-Act ATS-55. The tests performed and results were as follows:

- AASHTO T259: Salt water was ponded on sealed slabs for 90 days. Slabs sealed with linseed oil performed similarly to the control, which had no sealer applied to it, and specimens treated with all other sealers performed much worse.

- ASTM C672: Specimens were subjected to 50 freeze-thaw cycles after sealing. Specimens coated with linseed oil performed very well, and the performance of specimens treated with the other sealers varied but was as good as or better than the performance of the control specimen (which had no sealer applied).
- AASHTO T277: The electrical conductance of the concrete was measured to provide an indication of its resistance to chloride ion penetration; the lower the conductance the better. The Water Soluble 1:1 achieved a "Low" rating. The rest, including the control, were given a "Moderate" rating.
- ASTM C642: The full standard covers the determination of the density, absorption, and percent voids of hardened concrete. Only the absorption portion of the standard was used, with a limit for acceptance of 1% absorption at 48 hours and 2% at 50 days. All the sealers failed the first time, so the test was conducted again using epoxy to seal the sides and bottom of the specimens instead of the paraffin wax which was used in the first attempt. The Water Soluble 1:1 was the only sealer to pass the re-test, although the silane was close to passing.
- AASHTO T259 modified by the Ohio DOT: This test measured the ability of the sealers to seal a crack in concrete. Water was ponded on top of the specimen and the time required for the water to seep through the crack was recorded. The sealer was then applied to the specimen and the water was ponded again. If the water took at least twice as long to seep through, the sealer was deemed to have passed the test. Linseed oil, Water Soluble 1:1 and the silane passed. The silane far surpassed the other sealers. The test for silane was stopped at nine days because no seepage had yet occurred.

Based on the results of the various tests, it was recommended that only AASHTO T259 (modified to use epoxy instead of paraffin wax) and ASTM C642 be used as acceptance tests for new sealers. Linseed oil was to be maintained in the standard specifications and new qualified sealers could be added to this standard. Given these two tests and the recommended limits within them, Water Soluble 1:1 was the only tested sealer to pass, though the silane was very close. It was also noted that after the study was completed, it came to the attention of MoDOT that the Water Soluble 1:1 supplied by the manufacturer for testing was twice the concentration strength of that sold on the market (40% solids versus 20%). This information should be taken into account when considering the test results.

2.8 Johnson, Schultz, French, and Reneson (2009)

The University of Minnesota performed an extensive literature review and a survey of state and district transportation agencies to determine the current "state-of-the-art" in the protection of bridge decks through the use of deck sealers and crack fillers/sealers. The results of these were summarized and recommendations were made for how products should be selected and applied.

2.8.1 Literature Review

The scope of the literature review is provided below and is separated into findings on deck sealers and crack fillers/sealers. The results and top performing products are summarized in the conclusions.

2.8.1.1 Deck Sealers. The different types of deck sealers were first described. The main categories were penetrating sealants and film formers (linseed oil, epoxies, methacrylates). Penetrating sealants were broken down further into either water repellants (silane, siloxane, siliconate) or pore blockers (silicate). Film formers stay on the concrete surface and form a somewhat impenetrable barrier. Penetrating sealers actually enter the concrete pore structure, where pore blockers fill the pores and do not allow water vapor to escape, while water repellants coat the pore walls and do allow water vapor to escape. Next the primary measures of performance were discussed. The four primary methods were: chloride ingress, absorption, depth of penetration, and vapor transmission. There were several testing methods for measuring these qualities in the laboratory, the most common being the NCHRP 244 Series II and the AASHTO T259/T260 procedures. Performance of deck sealants in the literature was broken down by the four measures of performance mentioned above, with different applicable studies compared and contrasted, including differences from laboratory studies and field studies. Many other variables that might affect performance were also considered: moisture content of the deck at time of application, water-cement ratio of the concrete, a tined or smooth surface, the presence of curing compounds, surface preparation, coverage rate, drying time, surface abrasion, freeze-thaw exposure, weather conditions during application, and reapplication.

2.8.1.2 Crack Fillers/Sealers. Some of the most common products for sealing cracks were epoxies, reactive methyl methacrylates (MMA), methacrylates, HMWM and polyurethane. Of these, epoxies and HMWM were the most commonly used. For the crack fillers/sealers, there were again four main performance measures considered: depth of penetration, bond strength, seepage, and chloride ingress. Studies that investigated these different measures were compared and contrasted. Many other variables discussed in the literature were also presented: temperature at application, moisture content of the deck, cleaning of the crack, crack age, temperature effect on crack width, and the type of initiator used for HMWM resin. Several other parameters important to understanding crack fillers/sealers were discussed such as lifespan of the sealing material, recracking of the deck, and the track-free time (time before the deck may be opened to traffic).

2.8.2 Performance Survey

About 20 people from states and districts around the United States were surveyed to determine current and past practices as well as materials used in sealing concrete bridge decks. The main products found to be used were linseed oil, silane, and siloxane for deck sealing and epoxy and HMWM for crack filling/sealing.

Linseed oil was more widely used in the past, but due to various shortcomings was discontinued in most states, with the exception of Missouri. These shortcomings included short sealer lifespan, unclear results in performance, difficulties in application, and its typical combination with environmentally harmful materials such as kerosene. Silane was the most commonly used deck sealant, with a solvent-based 40 percent solids product being the most popular. Only two states regularly used siloxane for sealing; North Dakota and Wisconsin. Epoxy was the most commonly used crack filler/sealer, with advantages such as lower cost and fewer health concerns. HMWM was the second most common crack filler/sealer, with the main advantage of being more viscous and therefore providing deeper penetration. Sand or shot blasting, high pressure water, or compressed air were the most common methods for cleaning a deck before applying sealing materials. The amount of cleaning was dependent on the age of the deck. Deck sealants were typically applied by sprayer from a truck or by hand, sometimes in multiple passes. Crack fillers/sealers were applied as a flood coat or to individual cracks. Deck sealers were typically applied immediately after construction, and about half of the states surveyed reapplied sealant, typically every three to five years. Other methods for maintaining decks that were mentioned included overlays and deck replacement. Indiana reported using both overlays and deck replacement methods, as it did not have a crack sealing program.

2.8.3 Product Assessment

An overview of the different materials including their selection and use was provided. For deck sealants, the deck should be dry before application, and the only available study on surface preparation showed that not cleaning the surface resulted in the best deck sealant performance. Silane products usually penetrated deeper than siloxane products and were easy to apply. Tests showed that silane products that were solvent-based and have 40 percent solids resulted in some of the best penetration depths. This type of silane was also identified in the survey as the most commonly used product for deck sealing. Water-based silanes did not penetrate quite as deep, but still showed similar performance to solvent-based products. Because of their lower volatile organic compound (VOC) content they may be necessary in environmentally sensitive situations. It is important to note, however, that reapplication of a water-based product may not be effective as water-based products repel themselves wherever traces of the sealer remain from previous applications. Silane products that are 100 percent solids showed only slightly better performance compared to the 40-percent products. They have little or no VOC content unless they are mixed with a carrying agent. Siloxane products were less common and had less penetration than silane. However, they are applied in a similar manner and work in the same manner.

For crack fillers/sealers, gel time is an important consideration; a deck that is too hot will cause the sealer to cure too quickly and limit penetration, while a deck that is too cold will not cure the sealer fast enough allowing it to drain out the bottom of the slab if there is no formwork to retain it. It is best to seal cracks at night, when the crack is largest, so that later thermal expansion and contraction cycles will result in the least amount of tensile stress on the sealant. The amount of moisture in the deck at the time of application should be kept to a minimum and, although literature is limited, it is thought that cleaning of the cracks before application would result in better bond strength. Epoxies were the most commonly used crack fillers/sealers in the Midwest, and tests showed that they have the highest bond strength. HMWM sealers were the second most common sealer; they were characterized by a larger penetration depth but a weaker bond, especially in freeze-thaw conditions. There is little research on methacrylates and polyurethanes, but they generally had very low bond strength after freeze-thaw cycles.

2.8.4 Conclusions

The following conclusions and recommendations for deck sealers and crack fillers/sealers were made. For deck sealants, a high solids content is typically desired and silane products typically outperform siloxane products. Solvent-based products typically perform better than water-based products. It is also important to note that reapplication of a water-based product may not be effective as water-based products repel themselves wherever traces of the sealer remain from previous applications.

Based on these findings, a 40 percent solvent-based silane was recommended. Deck sealants should be applied between 40 and 100°F and in low wind conditions. Before applying sealant, the deck should have any curing compounds removed and should dry for at least two days if the deck surface is moist. Deck sealants should be reapplied to continue protection; time between applications is dependent on the traffic volume on the bridge. More research is recommended to correlate laboratory and field results of penetration depth and chloride ingress. Freeze-thaw effects and UV degradation should also be further investigated.

For crack fillers/sealers, HMWM products typically have better penetration but epoxy products usually have higher bond strength and better freeze-thaw resistance. Crack fillers/sealers chosen for use should have a viscosity of less than 500 cP (25 cP for HMWM), tensile strength greater than 8 MPa (1.16 ksi), and tensile elongation greater than 10 percent. Crack fillers/sealers should be applied at a temperature of 45°–90° F and between the hours of 11 pm and 7 am if possible. Before application, the cracks should be cleaned in some manner and the deck should dry for two to three days if the top surface is moist. More research should be performed testing the field application of epoxy products and on the correlation of laboratory to field experiments. There is also a lack of knowledge on the lifespan of crack filling/sealing products.

2.9 Krauss, Lawler, and Steiner (2009)

A decision tool was developed for a department of transportation or similar agency to use to determine the best steps to take in bridge maintenance, based on a bridge's current conditions and any future work plans for it. Although steel and timber decks were also considered, only the results from the concrete decks are relevant to this study. The guidelines were developed based on a survey of US and Canadian DOT's, as well as through a literature review and the experience of the authors.

The main survey findings on deck sealers and crack repair included the following. The majority of the responding agencies expected a lifetime of five or fewer years for deck sealers. The most common deck sealers (in order of use) were silane, epoxy, methacrylate, and several others (linseed oil was not a survey option). The majority of the responding agencies expected a lifetime of 5–15 years for crack repairs. The most common materials used were epoxy injection and HMWM. The authors noted that there is a lack of field research on deck sealers and their effectiveness in protecting cracks. There is also some uncertainty about the resilience of deck sealers under freeze-thaw conditions.

The results were simple tables with few equations, making them easy for maintenance personnel without engineering training to use. The first step in the decision process is to determine the condition of the deck, assessed mainly by the following factors:

- Percent deck deterioration and NBI condition ratings – The total non-overlapping deteriorated deck area of patches, spalls, delaminations, and copper-sulfate half-cell potentials along with NBI ratings based on the top and bottom surface of the deck.
- Estimated time to corrosion – An estimate how long until corrosion is initiated on the steel, based on current chloride levels, chloride diffusion rate, and the threshold level of chloride around the steel.
- Deck surface condition – A rating based on potential issues such as poor drainage, grade problems, uneven joints, scaling, or poor skid resistance that might make an overlay or structural rehabilitation a better choice for a deck than basic maintenance. Several ASTM and AASHTO tests are available to help determine deck surface quality.
- Concrete quality – Includes a check for air entrainment, strength, and any other signs of deterioration of the concrete.

The repair options based on these factors are listed in Table 2.6. Crack repair and deck sealers fall under maintenance, along with patching. Maintenance is recommended if the deck shows little or no distress, with little risk of deterioration in the near future. If the deck is cracked and is exposed to deicers, it is recommended that the cracks be repaired or a penetrating sealer be applied. Cracks can be filled individually or as part of a flood coat if they are numerous. Deck sealers should be used if the level of chlorides at the bar depth is below the corrosion threshold (chloride content of about 0.03% of the weight of the concrete with black bars, 0.30% with epoxy bars) and the concrete has moderate to high permeability. If the concrete deck has a low permeability, it may not be cost effective to use a deck sealer.

2.10 Morse (2009)

The Illinois Department of Transportation (IDOT) performed a five-year field study to determine the effectiveness of a variety of bridge deck sealers (penetrating sealers) and laminates (film-forming surface sealers). Based on the results of the study and the cost of each product, recommendations for bridge protection policy were made. For the study, materials were applied to bridges throughout the state and annual core samples were taken at multiple locations on the deck. Samples were analyzed for chloride levels and results were compared to previous years and control specimens. Results showed that hard deck overlays provided the best protection, but cost and added load to the structure limit their use. A deck sealer that provided five years of protection at a much lower cost was suggested as an alternative. Linseed oil was determined to be the most cost effective product in the study, followed by penetrating silane/siloxanes in combination or individually. Carrier solvent and percent solids were not investigated in this study, but references to previous studies showed that sealers that are solvent-based with a higher solids content usually performed better.

It was recommended that a sealant or laminate be used on all bridges in Illinois, the specific type being dependent on cost and required service life needed from the protective measure. Finally, it was recommended that new specifications and maintenance procedures be created for all the product types, based on suggested policies. Some suggested future research included the development of a laboratory test procedure that more closely represents field conditions, as well as testing protocol to determine effectiveness of a material based on its chemical nature. It was also suggested that IDOT consider the use of gravity feed crack sealers.

2.11 Frosch, Gutierrez, and Hoffman (2010)

Testing was carried out at Purdue University to identify the most effective crack sealers. Sixteen different sealers were included in the study; both gravity feed repair products and overlay products, which were selected based on results of previous studies and industry research. A modified version of ASTM G109 was used to evaluate the effectiveness of the sealers in a corrosion setting. Cracks were introduced to the specimens and were then sealed with the various products. Control specimens with differing crack widths were also created. The level of corrosion activity was measured through wetting and drying cycles of saltwater ponding

TABLE 2.6
Primary repair category guidelines based on deck characterization (Krauss et al., 2009).

	Deck Characterization Factor				
Primary Repair Category	**Deck Distress (% Distress, Half-Cell Potentials < -0.35 V (CSE), and Visual Condition Ratings)**		**Time-to-Corrosion Initiation**	**Deck Surface Problems (Drainage, Scaling, Abrasion Loss, Skid Resistance)**	**Concrete Quality Problems (ASR, DEF, Freeze-Thaw, Strength)**
Do Nothing [2]	i. % Distress	<1%	>10 years [9]	None	None
	ii. % Distress + 1/2 cell [1]	<5%			
	iii. NBI Deck [1]	7 or greater			
	iv. Deck Underside Rating [1]	7 or greater			
Maintenance	i. % Distress	1 to 10%	>5 years or >10 years	None [3]	None [4]
	ii. % Distress + 1/2 cell	1 to 15%			
	iii. NBI Deck	5 or greater			
	iv. Deck Underside Rating	5 or greater			
Overlay [7]	i. % Distress	2 to 35% [5]	Ongoing to >5 years [10]	Yes [3]	Yes [6]
	ii. % Distress + 1/2 cell				
	iii. NBI Deck	4 or greater			
	iv. Deck Underside Rating	5 or greater			
Structural Rehabilitation	i. % Distress	>35%	Ongoing	Yes	Yes
	ii. % Distress + 1/2 cell	>50%			
	iii. NBI Deck	3 or less			
	iv. Deck Underside Rating	4 or less [8]			

[1] Evaluation criteria (preferred methods: ii, iii and iv).
i. % Distress includes non-overlapping area of % patches, spalls, and delaminations.
ii. % Distress plus half-cell < -0.35 V (vs. copper sulfate). Less negative half-cell values may be used if determined to better represent actively corroding areas.
iii. NBI condition rating of deck.
iv. Condition rating of bottom of deck made using NBI condition rating scale.
[2] Select "Do Nothing" only if all conditions apply.
[3] If only skid resistance is a concern, consider grooving or chip seal instead of overlay.
[4] If cracking due to ASR/DEF is present, deck life can be prolonged 2 to 5 years with HMWM treatment.
[5] If deck has existing overlay, replace overlay if overlay distress is greater than about 15 to 20%.
[6] Overlays may prolong deck life of decks with ASR; however, close monitoring is suggested. Compare partial and full depth replacement to cost of overlay and assess overall structure condition and the service life goals.
[7] The value of an overlay should be compared to future replacement costs, funding constraints, and traffic disruption if the deck is allowed to continue to deteriorate. Overlays are good options whenever deck replacements are burdensome. If the deck already has been overlaid several times previously and concrete cover is a problem, consider partial or full depth deck replacement.
[8] Replace deck full depth. Partial depth replacement is an option if condition rating of Deck Underside is 6 or greater. Assess corrosion condition of lower mat of reinforcing steel due to cracks and leakage.
[9] If the deck is subjected to deicers and has cracks, repair cracks.
[10] Review the chloride content data with depth and determine the optimum depth of concrete removal prior to placing the overlay. If chloride concentrations at most bar depths are below threshold, remove concrete where chloride concentration is greater than 0.04 to 0.07% for black steel or 0.15% for epoxy-coated reinforced decks. Overlays can be applied directly to heavy chloride contaminated decks, but additional service life may be reduced. Consider cathodic protection for heavily salt contaminated decks where chloride cannot be removed by milling.
Note: If the deck is in a northern environment subject to deicing salts and has an asphalt overlay without a waterproofing membrane, the overlay should be removed and the bare deck examined.

that continued for approximately one year. The specimens were then autopsied and reinforcing bar conditions were compared. The top rated products based on both corrosion rate measurement from the macrocell circuit and visual examination are shown in Table 2.7. None of the methacrylates tested were placed in the list of top performers, and their use was not recommended. There was no clear trend by product type or manufacturer.

TABLE 2.7
Top performing products (Frosch et al., 2010).

Product	Manufacturer	Repair Type
MARK 163 FlexoGrid	Poly-Carb	Epoxy Overlay
Dural 335	Euclid / Tamms	Epoxy
Sikadur 55 SLV	SikaCorp	Epoxy
Epoxesl GS Structural	BASF	Epoxy
Pro-Poxy Type III D.O.T.	Unitex	Epoxy Overlay
HMSLV	Kaufman Products	Epoxy
Dural 50	Euclid / Tamms	Epoxy
Bridge Seal	Unitex	Epoxy

There was also no correlation between crack size and corrosion level based on the performance of the control specimens.

3. SURVEY OF STATE DEPARTMENTS OF TRANSPORTATION

A survey was distributed through the Indiana Department of Transportation to each state through their respective representative serving on the AASHTO Research Advisory Committee. The survey's goal was to determine the current state of use of sealers for bridge decks in the United States. An email message describing the goals of the study along with a link to the online survey and instructions on its use was sent to the representative from each state.

3.1 Survey Goals

The goal of the survey was to determine what materials and methods other states presently employ or have used in the past to protect bridge decks from deicing chemicals. The perceived level of success that each state has had in their sealing program was also assessed. The findings of the survey were used to help determine what variables were included in the durability study as bridge deck preservation techniques.

3.2 Response Summary

The online survey that was sent to all states is provided in Appendix A, along with the responses. A summary of response is provided here for states that responded as using deicers and having some type of sealer program. The states of Nebraska and Kansas both responded as using deicers on their roads, but neither uses sealers on bridge decks. The states of Georgia, Washington, Louisiana, and Florida responded as using neither deicers nor sealers. A map of responding states is shown in Figure 3.1.

3.2.1 Alaska

High molecular weight methacrylate (HMWM) is used to fill all joints and visible cracks. If the crack is wider than 1/16 in., then two applications are used. After curing of the HMWM is completed, cracks are sealed but no deck sealer is used. A waterproof membrane with an asphalt overlay is used on new bridge decks and on old decks when possible.

3.2.2 Connecticut

All bridges receive a waterproof membrane followed by an asphalt overlay. A ground-penetrating radar (GPR) survey is performed to check for delaminations. Repairs are then accomplished by patching the deck at damaged areas only or in full, depending on the required patching amount, or by milling the surface to apply a new waterproof membrane and asphalt overlay.

3.2.3 Illinois

Cracks are not filled initially after construction. Linseed oil (referred to as protective coat) is used as a deck sealer after construction. Resealing hasn't been done in the past, but funding was recently allocated to start a resealing program based on a four-year cycle. The State recommends that this resealing be done with linseed oil. Decks are to be cleaned with compressed air prior to resealing. A link was provided to a research report on a study carried out by the Illinois DOT (Morse, 2009).

3.2.4 Minnesota

After construction, cracks are filled with a 1:1 epoxy or sometimes a flood coat of methyl methacrylate. Silane or siloxane sealers are sometimes applied after traffic has worn off the curing compound, but they are not thought to be cost effective, so Minnesota is now experimenting with thin overlays (including Safelane, Polycarb, and Nova chip). Cracks are expected to be refilled every five years using the same procedure as used initially. In the past, before resealing with silane, the deck was washed, air–blasted, or shot blasted. This resealing occurred biannually, but has been discontinued. The experimental overlays have not been in place sufficiently long to estimate service life. Recent changes in sealing methods make use of an automatic mix-applicator for applying crack fillers. In addition, the humidity is more closely monitored when applying silane.

3.2.5 Missouri

Linseed oil is applied 28 days after the deck is cast. A second and final coat of linseed oil is applied one year after construction. Further resealing is carried out on a three to five-year rotation. The filling of cracks and sealing of the deck is usually carried out in only one step, with the product used dependent on the condition of the deck. Star Macro-Deck is applied as a flood coat when fine cracks appear and Pavon Indeck is used when the cracks are wider. Pavon Indeck is used either to only fill the cracks or is applied as a flood coat. Linseed oil is used to minimize scaling, and silane, siloxane, methyl methacrylates, and epoxies are applied on a limited basis. The deck is cleaned and flushed

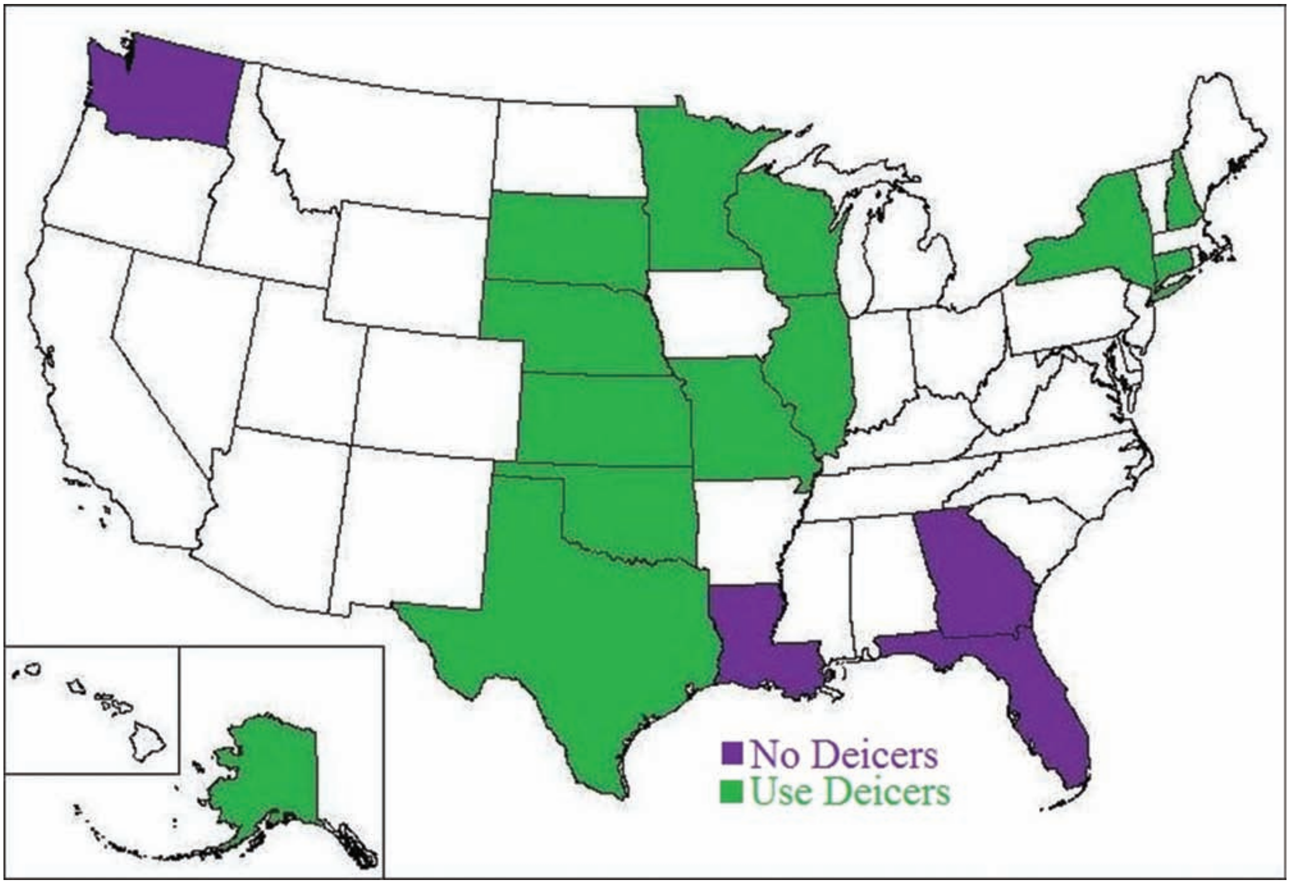

Figure 3.1 States that responded to the DOT survey.

before resealing. Links were provided to a research report on a study carried out by the Missouri DOT (Wenzlick, 2007) as well as to the Missouri DOT online engineering policy guide.

3.2.6 New Hampshire

Virtually all bridges have a "barrier membrane" applied to them. This consists of a waterproof membrane applied to the deck surface followed by a 2 in. hot mix asphalt wearing surface laid on top of the membrane. This membrane is either hand or machine applied and a torch is used to melt the bitumen underside of the membrane while it is being rolled onto the deck. In the past a "peel-and-stick" type of membrane was used, but concerns about the bond of the membrane to the deck surface led to discontinuing its use. A spray adhesive product has also been used in the past, but was discontinued because of its higher cost compared to the current method where the bitumen underside is melted with a torch.

3.2.7 New York

A silane/siloxane sealer is applied to all new decks no sooner than 14 days after the completion of curing. The deck must be dry 24 hours before and 12 hours after application of the sealer. Cracks are also filled initially, based on their severity, and before deck sealing takes place. Cracks less than 0.012 in. are filled with a silane/siloxane sealer, in which case the sealer is applied directly into each crack until refusal, then given the manufacturer's recommended drying time before the process is repeated (up to four or more times until the crack no longer readily accepts sealer). If the cracks occur often and are greater than 0.012 in. in width, then this would require removal of the cracked concrete and replacement with a thin bonded overlay. If the cracks are of a larger width and are not closely spaced, then they are routed and filled. This procedure is used with silicone for very large cracks or epoxy injection for smaller cracks. Flood coats of methyl methacrylate with fine aggregates have also been used. Decks and cracks are resealed approximately every five years with very little prep work done in order to minimize closure time. The state has recently standardized coverage rates based on percent active ingredients/solids. The state has observed that bridges seem to scale less early in their life with their sealing program, and the use of penetrating sealers has been very successful.

3.2.8 Oklahoma

Cracks are filled with HMWM or epoxy, and silane is used as a deck sealer. Crack and deck sealing is conducted in the summer months, so the first coat usually is applied six to twelve months after construction. They have used silane since the late 1970's and it appears to be helpful.

3.2.9 South Dakota

Cracks are filled with a methacrylate or epoxy sealer that is hand applied, and the deck is sealed with a silane sealer within six months of construction. Decks are resealed every five years, with a surface preparation of cleaning with a power washer. Cracks are filled with the same method as used initially or if the crack density is sufficiently high, a flood coat is applied to the deck using a polysulfide epoxy chip seal system.

3.2.10 Texas

A super-low-viscosity epoxy or methacrylate is applied as a flood coat or poured over large cracks. Silane or linseed oil is then applied as a deck sealer. This is conducted immediately after curing is completed. Resealing of the deck is rarely done, however cracks are filled using the same method as is initially used.

3.2.11 Wisconsin

A link was provided to a research report on a study carried out by the University of Wisconsin for the Wisconsin DOT (Pincheira & Dorshorst, 2005). No additional information was provided.

4. DEVELOPMENT OF EXPERIMENTAL PROGRAM FOR EVALUATION OF SEALERS, CRACK FILLERS, AND APPLICATION METHODS

4.1 Introduction

An experimental program was designed and implemented to evaluate materials and methods for sealing concrete bridge decks. The results of this study are anticipated to result in a sealing program that will protect bridge decks against deicing salts and extend their life.

4.2 Consideration of Previous Findings

The findings from the first two phases of the study were used to assist in designing the experimental program. Products that have demonstrated positive attributes for protecting reinforced concrete against deicing salts and/or have been commonly used by DOT's were considered for use in the study.

4.2.1 Literature Review

The findings in the literature review were used to reduce the number of potential products and testing methods to include in this study. Guidelines for selecting the best products and methods to apply these products were suggested by several reports. The most common crack filling products tested were epoxy and methacrylate based. Epoxy products generally create a stronger bond and have better durability, while methacrylate products usually are less viscous and provide deeper penetration into cracks. Methacrylates are also able to seal finer cracks than epoxy, but are not recommended for use to fill larger cracks. Overall, epoxy products generally performed better. There was significant variance in the performance of crack filling products within the same chemical family, so specific products that performed well in multiple studies were noted.

Deck sealing was commonly accomplished in one of several ways. Epoxy or methacrylates seal the surface when used as a flood coat, of either a crack filling/sealing material, or sometimes as a product designed only for surface sealing. Silanes, siloxanes, and linseed oil are also commonly used to seal decks. Because silane and siloxane are the only penetrating sealants of these three products, they have shown the best performance, especially when used where there is abrasion. Other factors, such as the solvent used and the percent solids of the silicone-based products, also played a factor in their performance. Silane consistently was found to be the best performing deck sealer. Variance within the same chemical family was a common occurrence, so specific products that performed well in several studies were once again noted.

In previous investigations, it was frequently concluded that cracks in bridge decks should be sealed as soon as possible to prevent any chloride ingress. Surface sealers were found to reduce the ingress of chlorides in nearly all cases and should be applied as early in the life of the bridge as possible, usually after curing has been completed. These findings reinforce the need for a study that will result in the development and implementation of a bridge deck preservation program.

Many of the testing procedures used in previous studies only examined one characteristic of a crack filler or deck sealer, such as penetration depth or bond strength. This can be useful for state DOT's as an acceptance test of a product, but is not ideal for the primary goal of this study which is to identify a complete sealing program. The specimens used in this study need to be capable of evaluating crack fillers and surface sealers individually and in combination, as well as under the effects of other variables such as surface condition and type of reinforcing steel. The macrocell specimens used in the accelerated durability study performed by Frosch et al. (2010) were chosen as best able to meet the needs of this study. Because the intent of this study was to design a laboratory experimental program, many of the procedures used in field studies, such as taking core samples over many years and in differing locations on a bridge deck, were not considered. However, one useful note from the field studies was that surface preparation procedures recommended by the manufacturer were usually followed.

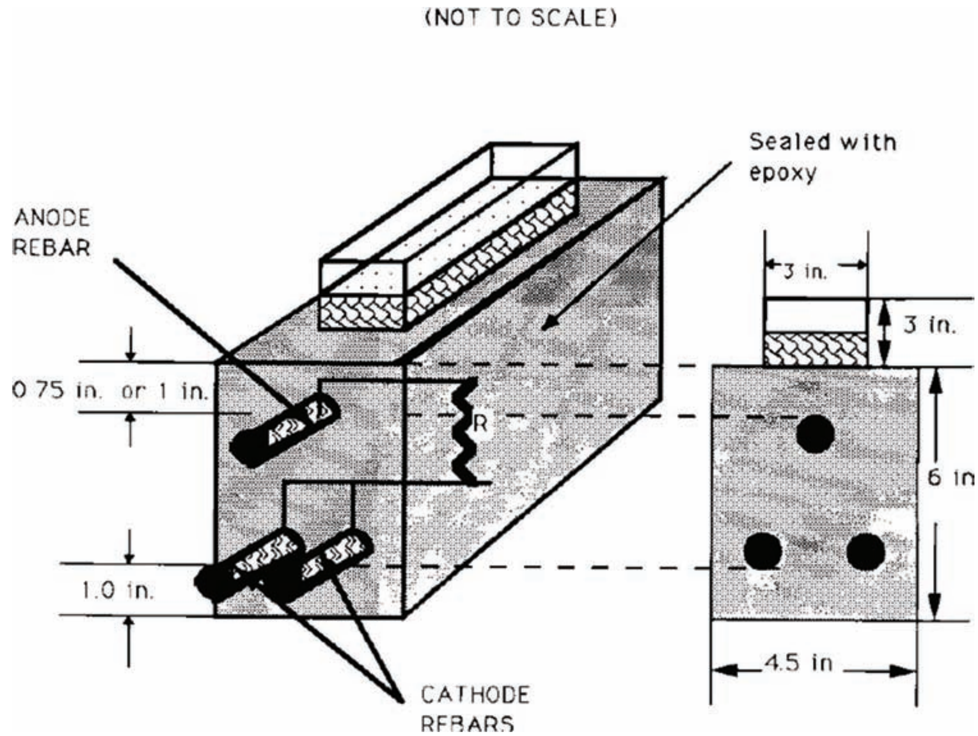

Figure 4.1 ASTM G109 specimen. (Source: ASTM G109-07, 2007.)

4.2.2 State DOT survey

The state DOT survey revealed that many different materials and methods have been or are currently in use. There is also a variety of thought on what types of products and methods are truly effective. Most of the methods in use by the surveyed states were chosen for inclusion in the durability testing program described later in this chapter. The barrier membrane and asphalt overlay used by Connecticut and New Hampshire were considered a much more extensive sealing and rehabilitation method and are not suitable for comparison to the crack fillers and deck sealers used by other states. In addition, such a sealing method would not be practical in a laboratory setting using relatively small specimens. Therefore, it was not included in this study.

4.3 Testing Procedure and Specimen Design

The testing procedure chosen for this study was a modified version of the ASTM Standard G109, as used by Frosch et al. (2010). This procedure allows for the evaluation of crack fillers and deck sealers both individually and in combination using only one type of specimen. In addition, other variables that are found in actual bridge decks, such as epoxy-coated reinforcement and tine marks, can be incorporated easily with the same specimen type. This test procedure allows for monitoring of the corrosion activity as it occurs, and provides an evaluation of the crack filler and sealer performance over an extended period of time. Three replicates were constructed for each variable set that was included.

4.3.1 ASTM Standard Test

The ASTM Standard G109, "Standard Test Method for Determining Effects of Chemical Admixtures on Corrosion of Embedded Steel Reinforcement in Concrete Exposed to Chloride Environments," uses a macrocell where the corrosion activity within the reinforced concrete specimen is directly related to the electrical current measured in the specimen (ASTM G109-07, 2007). As described in Section 1.3.2, when macrocell corrosion takes place within a bridge deck, the transfer of electrons creates an electrical current. The current is directly related to the amount of corrosion taking place within the deck. In the standard, specimens are composed of concrete beams with reinforcing steel embedded inside, but exposed at one end, as shown in Figure 4.1.

There is an upper and lower layer of reinforcing steel which are connected by a resistor at the end where reinforcement is exposed. A pond of salt water is placed on the top surface of the specimen. When the salt water penetrates the specimen and the reinforcing steel begins to corrode, a macrocell electrical circuit it formed. By measuring the change in voltage across the resistor, the amount of current flowing from the top bars to the bottom bars can be determined, indicating the level of corrosion activity. Comparing the current generated by different specimens indicates which specimens are corroding at a higher or lower rate.

4.3.2 Specimen Design

Several modifications were made to the ASTM standard specimen to better fit the needs of this study.

The specimen was designed to represent a section of a typical bridge deck.

4.3.2.1 Dimensions. A depth of 8 in. was selected because it is representative of the thickness used for a bridge deck. Because cracks would need to be introduced in the specimens to be able to test the crack fillers, a length of 24 in. was chosen to allow for the development of multiple cracks. The width of the specimen was chosen as 8 in. for easy handling, and to be consistent with the previous study. The dimensions of the specimen are illustrated in Figure 4.2.

4.3.2.2 Reinforcement. Reinforcement in the specimen was representative of that found in the steel mats in a bridge deck. Longitudinal No. 4 bars were spaced at 5 in. with a top and bottom cover of 2 in. These bars extended out of each end of the specimen by 12 in., which was needed later to facilitate cracking of the specimens. Exposed reinforcing steel is also needed to connect instrumentation used to measure the macrocell activity. Transverse No. 4 bars were spaced evenly at 6 in. along the specimen to encourage the formation of cracks at these locations in all specimens, and to represent the transverse reinforcement that would be found in a bridge deck. The transverse bars were 6 in. in length. The reinforcement locations are shown in Figure 4.3.

The reinforcement used was ASTM A615 Grade 60 steel, commonly known as "black" steel, and all was taken from the same heat. Although epoxy-coated bars are normally used in bridge decks where deicers are used, the intent of the study is to compare the relative performance of different crack filler and sealing products to determine which are most effective. The use of black steel allows corrosion to occur sooner, and differences in performance of crack fillers, sealers, and application methods to be more readily apparent. Therefore, black steel was used in most of the test specimens in this study.

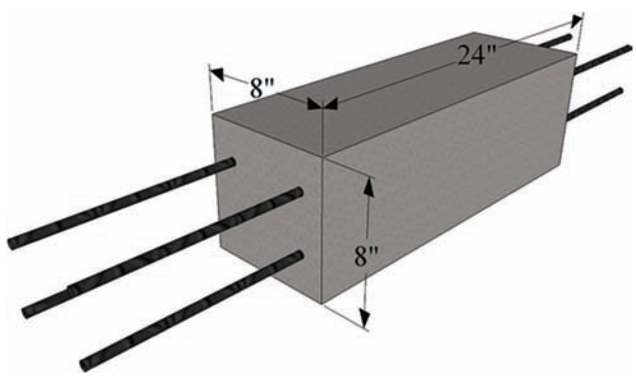

Figure 4.2 Specimen dimensions.

4.3.2.3 Concrete. The concrete used for the construction of the specimens was INDOT Class C concrete; the type used for bridge decks constructed in Indiana.

4.3.3 Cracking

To evaluate the crack filling products and determine when it is beneficial to apply them, the specimens were designed so that cracks representative of those found in bridge decks could be initiated in them. Full-depth cracks with widths of up to 0.025 in. are commonly observed in bridge decks. The specimens were therefore designed to have a target crack width of 0.020 in. This width was commonly observed in the field in previous studies (Frosch et al., 2010).

4.3.4 Testing Procedure

The following procedure was used for preparing specimens for testing. The anticipated protocol for testing is also presented. After the specimens had cured for at least 28 days, the initial cracks were introduced. Some specimens remained uncracked in order to evaluate deck sealers. Crack filling and sealing activities were then conducted. To simulate the tensile stresses incurred in a bridge deck from traffic loading after crack filling, the previously-cracked specimens were stressed to a maximum level expected in an in-service bridge deck. As inferred from AASHTO Bridge Design Specifications 5.7.3.4-1, approximately 2/3 of the yield strength of the reinforcement can be considered the maximum service stress in the reinforcement in the bridge deck (AASHTO, 2010). Stressing the reinforcement again provides important information about the characteristics of bond strength and flexibility of the crack fillers/sealers, because this relates to their ability to resist recracking under service loads. Each specimen then had a plastic dam secured to the top surface,

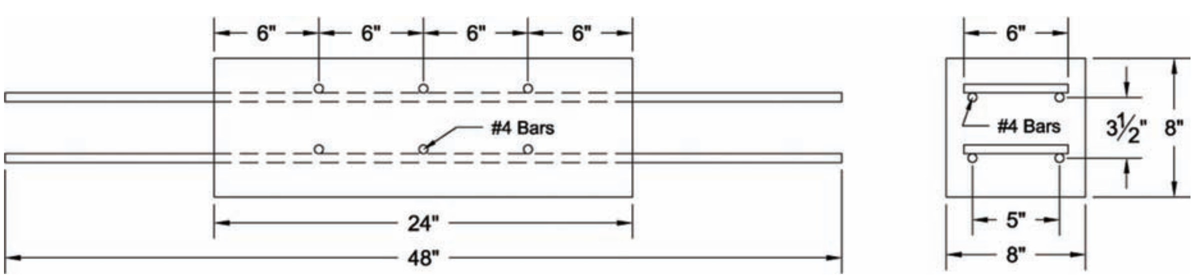

Figure 4.3 Specimen dimensions and reinforcement locations.

exterior surfaces (except for most of the top) were waterproofed, and each was wired for recording the current in the macrocell circuit during corrosion. Lastly, the specimens will have a solution of 3% NaCl ponded inside the dams. This solution will be maintained for two weeks, then it will be removed for a two-week dry period. This cycle of wet then dry is expected to continue for 12 months, though the actual duration may be shortened or lengthened depending on the corrosion activity measured. During the wet-dry cycling period, voltage readings will be taken every 6 hours. Once wet-dry cycling is completed, the specimens will be autopsied to document the amount of corrosion on the reinforcing steel. Any damage to the concrete material will also be assessed.

4.4 Filler and Sealing Materials

The classes of materials chosen for testing were gravity feed crack filling/sealing products and penetrating deck sealers. Because of the relative ease of the gravity feed application of crack fillers/sealers, compared to crack injection, and the more widespread use for this type of application, it was decided that there was no clear reason to include crack injection in the study. Film-forming sealing methods, such as epoxy overlays, were not used because of several disadvantages when compared to penetrating sealers. They stay on the surface and are therefore susceptible to traffic wear. They also have a much higher installation and material cost, and require longer bridge closure durations. In addition, asphalt and concrete overlays were considered outside the scope of this study.

4.4.1 Crack Fillers/Sealers

It was decided that both epoxy and methacrylate products should be included in the study, because they are the highest performing and most commonly used types of crack fillers/sealers. Of these, epoxy generally performs better than a methacrylate, so several epoxies were included. The crack filling/sealing products that were tested in studies in the literature review were compiled and ranked based on performance. This compilation can be found in Appendix B. From this list, the following products were chosen:

- **Sikadur 55 SLV**, from Sika USA. An epoxy product, it was chosen because of its very high ranking in the studies performed by Pincheira and Dorshorst (2005) and Frosch et al. (2010).
- **Dural 335**, from Euclid. An epoxy product, it was chosen because of its very high ranking in the studies performed by Pincheira and Dorshorst (2005) and Frosch et al. (2010), and to study a second epoxy from a different company.
- **Degadeck Crack Sealer Plus**, from BASF. A methacrylate product, it demonstrated only moderate performance in the study by Pincheira and Dorshorst (2005), and was a low performer in the study by Frosch et al. (2010). It was, however, the highest ranked methacrylate in Pincheira and Dorshorst's study, and it was desired to include a methacrylate in this study.

4.4.2 Deck Sealers

Silane products were the clear top performing penetrating surface sealers in studies in the literature review. Linseed oil was also commonly tested and sometimes performed quite well. Both of these products were commonly used by the state DOT's that responded to the survey. The study by Johnson et al. (2009) recommended the use of a solvent-based silane with 40% active ingredients. It was noted that solvent-based products generally performed better than water-based products, and a solids content of at least 40% provided the best performance. Krauss et al. (2009) also found that silane was the most commonly used deck sealer in an extensive survey of state DOT's. The deck sealing products that were tested in studies in the literature review were compiled and ranked by performance. This compilation can be found in Appendix B. From this list, the following products were chosen:

- **Hydrozo Silane 40 VOC** by BASF. A solvent-based silane, it was chosen because it received the highest ranking in the study by Pincheira and Dorshorst (2005) and also showed good performance in the study by Hagen (1995).
- **Enviroseal 40** by BASF. A water-based silane, it was chosen because it received a moderate ranking in the study by Pincheira and Dorshorst (2005) and showed good performance in the study by Hagen (1995). Overall, it was the best performing water-based silane in the literature that was reviewed, and it was desired to include both a solvent and water-based silane in this study.
- **Linseed Oil** (available from many sources, the Euclid product was used). Though technically a film-forming deck sealant and not a penetrating sealant, it was chosen because of good performance in the study by Morse (2009) and because several states that responded to the survey used it in their programs.

4.4.3 Crack and Deck Sealer Combinations

The crack fillers and deck sealers included were tested individually and in combination. Because the performance of the crack fillers/sealers and deck sealers could be individually compared, the particular combinations used were not necessarily as important, and pairings of each crack filler/sealer with each deck sealer were not required. The chosen sealer combinations are shown in Table 4.1. For all combinations, the crack filler/sealer would be applied first, followed by the deck sealer.

The first combination chosen was Sikadur 55 SLV and Hydrozo Silane 40 VOC, because both products were ranked highest in the compiled lists. The second combination chosen was Dural 335 and Enviroseal 40. The third combination was chosen to include linseed oil and represent one of the methods used by the Texas DOT, which is epoxy sealing of the cracks followed by sealing of the deck with linseed oil. Therefore, Sikadur 55 SLV and linseed oil were paired. The Sikadur 55 SLV was chosen over Dural 335 because it was the

TABLE 4.1
Sealer combinations.

	Crack Sealer	Deck Sealer
Combination #1	Sikadur 55 SLV	Hydrozo Silane 40 VOC
Combination #2	Dural 335	Enviroseal 40
Combination #3	Sikadur 55 SLV	Linseed Oil
Combination #4	Degadeck Crack Sealer Plus	Hydrozo Silane 40 VOC

highest-ranked crack filling/sealing product. The final combination was chosen to include the Degadeck Crack Sealer Plus, which was paired with Hydrozo Silane 40 VOC, the highest-ranked deck sealer. Degadeck Crack Sealer Plus is applied as a flood coat, creating a seal over the entire deck surface, so one might initially think that a deck sealer should not be used with it. However, it is stated in the product data sheet that Degadeck Crack Sealer Plus left on the surface is a sacrificial film that will wear off over time. Therefore, if the applied deck sealer is able to penetrate the Degadeck Crack Sealer Plus, it will remain in the concrete substrate after the film is worn away.

Comparison of the performance of the deck sealers relative to each other will be accomplished through the use of uncracked specimens. Any variable set requiring the testing of a crack filler/sealer required a cracked specimen. In addition, the application of only a deck sealer to a cracked specimen was included in the study to determine whether any benefits are gained from sealing a bridge deck surface without first filling/sealing the cracks.

A set of control specimens that have no sealers applied to them were also constructed. Control sets were made with and without cracks.

4.5 Additional Test Variables

In addition to determining the effectiveness of filling/sealing cracks and sealing the deck surface, several other variables that play a role in the performance of sealing products and the methods indicating how they should be applied, were chosen for inclusion in the study.

4.5.1 Service Load Stress

All of the specimens that had cracks introduced before sealing were stressed again after crack filling/sealing took place. This restressing was performed to simulate the stresses experienced by a repaired crack due to traffic loads on the bridge deck. To determine the effect that this restressing had, it was decided to include a subset of specimens that were not restressed. Because this is an unrealistic field condition, the goal was not to individually evaluate each crack filler/sealer under this condition, but rather to determine if any effects were noticeable on the group as a whole. It was therefore not necessary to test all the crack filling/sealing products in this way, so only the first sealer combination of Sikadur 55 SLV and Hydrozo Silane 40 VOC, as well as Sikadur 55 SLV by itself, were used on the set of specimens that were not restressed.

4.5.2 Surface Preparation

Surface preparation is usually suggested by the manufacturer so that the product is able to perform to its full potential. In many cases, the amount and type of preparation is dependent on the condition of the deck. To save on labor costs, equipment needs, and bridge closure time, the least amount of preparation is desirable.

Recommended surface preparation for the silane products (deck sealers) in the study was to clean the surface of any sand, surface dust and dirt, oil, grease, chemical films and coatings, or other contaminants, using waterblast, sandblast, or shotblast as necessary. Because of the good condition of the specimen surfaces, simply brushing the surface was sufficient to remove excess sand and dust. Recommended surface preparation for the linseed oil was a concrete surface free of oil, dirt, loose scale, or other contaminants. The surface should be swept clean and oil or grease removed as completely as possible. New concrete with a curing agent should not be sealed until the curing agent has been weathered away or removed by other means. Based on the condition of the specimens, simply brushing the surface to remove excess sand and dust was once again all that was required.

Recommended surface preparation for the crack fillers/sealers was more varied. The manufacturer of Degadeck Crack Sealer Plus recommended using shotblasting or gritblasting on the full surface, followed by cleaning visible cracks with oil-free compressed air. The manufacturer of Dural 335 recommended a clean surface, free of laitance, dust, dirt, oil, coatings, form release agents and other contaminants. Those contaminants should be removed by sandblasting or shotblasting. In addition, smooth, precast, or formed concrete surfaces must be roughened and made absorptive by sandblasting or shotblasting. Finally, debris should be blown out of the cracks with moisture-free and oil-free compressed air. The recommendations for the Sikadur 55 SLV are more general, stating that dust, laitance, grease, oils, curing compounds, waxes, impregnations, foreign particles, coatings, and disintegrated materials should be removed by mechanical means. Based on the recommendations for these products, it was determined that according to the manufacturer, the specimens receiving

Degadeck Crack Sealer Plus and Dural 335 should be sandblasted. However, it was not required that specimens receiving the Sikadur 55 SLV be sandblasted. Because sandblasting the bridge surface would be time and cost intensive, it would be desired that this surface preparation not be required for any crack sealing activity. In order to determine the role that this recommended sandblasting had on the performance of the Degadeck Crack Sealer Plus and Dural 335, it was decided that an additional subset of specimens would receive the sandblasting preparation before crack filling/sealing, while the rest of the specimens would receive only compressed air cleaning of the cracks.

4.5.3 Deck Resealing Intervals

Abrasion of the surface over time is the main factor that can lead to a decrease in the performance of penetrating sealers. Because traffic on a bridge will slowly wear off the surface, the deeper a sealer can penetrate, the longer it will be able to provide protection. Penetration depth is limited though, with an average of less than 4 mm (0.16 in.) achieved with the best products (Pincheira & Dorshorst, 2005). It is therefore likely that resealing of the deck surface will be required at regular intervals in the life of a bridge.

Several test methods attempt to simulate this abrasion in the laboratory. The AASHTO test method T259 calls for sandblasting 3.2 $\pm$ 1.6 mm (0.125 $\pm$ 0.062 in.) from the surface of test specimens (AASHTO T259-02, 2006). Pincheira and Dorshorst used this test method, and noted that the large amount of abrasion may have reduced the effectiveness of some sealers more than would be experienced in the field. The study by Hagen (1995) suggested using the procedure developed by Edgar Kottke (1987) to simulate traffic abrasion. This simulation involved removing only 1 mm (0.04 in.) from the surface of the specimen by sandblasting. The study by Weyers, Zematijis, and Drumm (1995) found that the abrasion rate on a U.S. interstate was approximately 0.17 mm/year (0.0067 in./year). Based on this rate, the AASHTO T259 procedure would represent about 19 years of wear, while the Kottke procedure would represent approximately 6 years of wear.

Because Pincheira and Dorshorst (2005) determined the penetration depth from a variety of sealers to be 1.4 to 3.8 mm (0.055 to 0.150 in.), it was decided that the lower end of the AASHTO T259 standard of 1/16 in. of sandblasting would be used to simulate traffic abrasion on the specimens. This abrasion would eliminate the effectiveness of sealers with a low penetration depth, and simulate approximately 10 years of traffic wear. It should be noted that abrasion does not need to reach the maximum penetration depth of the sealer to affect its performance. Because penetration depth is variable, reduced effectiveness will occur much earlier. The sandblasting of 1/16 in. was used to simulate traffic abrasion in two different scenarios. The first scenario had specimens sandblasted before being sealed with a deck sealer. This represented an older bridge deck that had not been previously sealed, or had been sealed previously but traffic abrasion had removed all of the penetration depth. The second scenario had specimens that were sealed and then sandblasted to represent a bridge deck that had been sealed, but then underwent many years (approximately 10 years) of traffic abrasion. These two scenarios were used for all three of the deck sealers in this study. Lastly, a group of control specimens was sandblasted to simulate a bridge deck with no sealers subject to traffic abrasion. All specimens investigating resealing intervals were not cracked.

4.5.4 Epoxy-Coated Reinforcement

Epoxy-coated reinforcing bars are the most common reinforcement used in bridge decks where deicers are used, due to their improved resistance to corrosion compared to conventional black bars. However, imperfections and damage to the epoxy coating still allow corrosion to occur. To compare the performance of sealers in this study to how they might perform in field conditions on a bridge using epoxy-coated reinforcement, a set of specimens was included that incorporated epoxy-coated reinforcement. Epoxy-coated bars that are placed in a bridge deck commonly have imperfections in the coating from manufacturing as well as damage from transportation and handling in the field. To simulate epoxy-coated reinforcement as it is found in a cast deck, the bars were damaged to a level of 2%, which is the maximum allowed by ASTM Standard D3963 (ASTM D3963-01, 2007) for placed bars. The ASTM standard calls for all discernible damage to be repaired in the field; however not all damage will be detected or necessarily repaired by the contractor as required. In addition, some damage occurs during placement of the concrete, so 2% damage was considered a reasonable level.

After being cut to length, the ends of the epoxy-coated bars were repaired to a pristine state with a patching material provided by the manufacturer. Damage in the form of 1/4 x 1/4 in. areas, and some 1/8 x 1/8 in. areas on transverse bars, was introduced using a grinder as shown in Figure 4.4, and totaled 2% of the surface area of the bars. This area of damage was decided on after reviewing previous research on the topic of epoxy-coated reinforcement corrosion (Kahhaleh, 1994). Twelve 1/4 x 1/4 in. damage locations were placed on the longitudinal bars, and two 1/4 x 1/4 in. plus four 1/8 x 1/8 in. damage spots were placed on the transverse steel. The smaller areas were used on the transverse bars to better distribute the damage. These damage areas were evenly distributed along each bar, including at points of contact between the transverse and longitudinal bars. Damage to the longitudinal bars and the transverse bars is shown Figures 4.5 and 4.6, respectively. The placement of the bars in the formwork is shown in Figures 4.7 and 4.8.

The first sealer combination of Sikadur 55 SLV and Hydrozo Silane 40 VOC was applied to these specimens. A control set of specimens was also included that used epoxy-coated reinforcement, but no sealers.

4.5.5 Surface Tining

Bridge decks constructed in Indiana are required to have tine marks made on the surface. This is a common practice throughout the United States. Tine marks consist of shallow grooves placed into the surface of the concrete while it is in the plastic state, or saw cut after the concrete has hardened. To determine whether the presence of these tine marks have an effect on the placement and/or performance of the sealers when applied in the field, a set of specimens was included that were tined on the surface during casting. The specifications for the tine marks were found in the INDOT Construction Specifications 504.03 (INDOT, 2010). The tine marks were to be 3/32 in. to 1/8 in. in width and 1/8 in. to 3/16 in. in depth. The spacing of the marks was as specified in Figure 4.9.

The tining tool available (made by Flexi-Glide Tines of Anderson, IN) had the correct tine widths, but did not have the specified spacings. The spacing of the tine marks plays an important role in reducing road noise. It was decided that for the purpose of this study, the depth and width of the tine marks were the important factor, and the difference in spacing would not affect the outcome. The tining tool was attached to a sled that slid along the formwork (shown in Figure 4.10) placing the tine marks at the specified depth. The depth of the tine marks is shown in Figure 4.11, and the width of the tines are 1/8 in. for reference.

During the tining process, the tines were not consistently reaching the depth required and were pulling rough aggregate to the surface when the full depth was met, as shown in Figure 4.12. To obtain a better finish, the tining process was adjusted to result in shallower grooves with less aggregate pulled to the surface, as shown in Figure 4.13. After removal from the formwork, the tined specimens were washed with a pressure washer to remove the loose aggregate to better represent tine marks on a bridge in the field. The final grooves had a depth of approximately 1/16 in. to 1/8 in.

The first sealer combination of Sikadur 55 SLV with Hydrozo Silane 40 VOC was applied to these specimens. A control set of specimens was also included that had tine marks applied, but no sealers.

4.6 Test Matrix

The full matrix of the test variables is shown in Figure 4.14 and Figure 4.15. Each variable set is represented by an “X.” Three replicates were made for each set resulting in a total of 90 specimens.

Figure 4.4 Introducing damage to epoxy-coated bar.

Figure 4.5 1/4 x 1/4 in. damage areas on longitudinal bar.

Figure 4.6 1/8 x 1/8 in. damage areas on transverse bar.

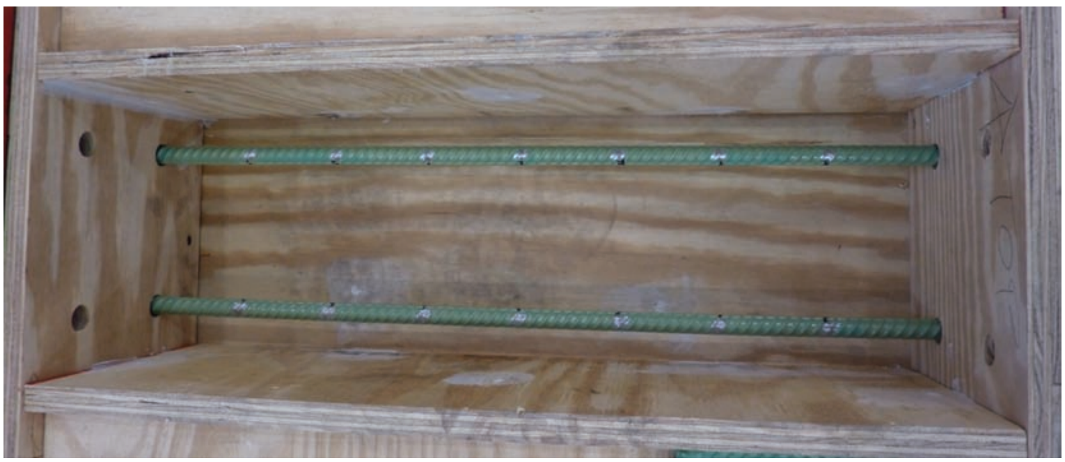

Figure 4.7 Bottom longitudinal epoxy-coated bars in formwork.

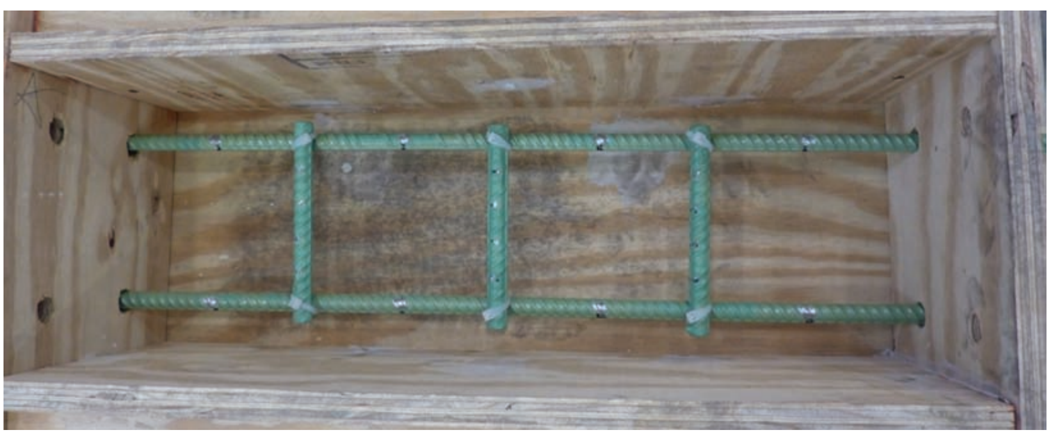

Figure 4.8 Transverse epoxy-coated bars in formwork.

Tine Spacings													
Start:	5/8	1	7/8	5/8	1 1/4	3/4	1	1	1	1	3/4	7/8	1 3/4
Continued:	7/8	3/8	1	1	1 1/4	1 1/2	7/8	3/4	7/8	1	7/8	1	

Figure 4.9 Tine mark spacing.

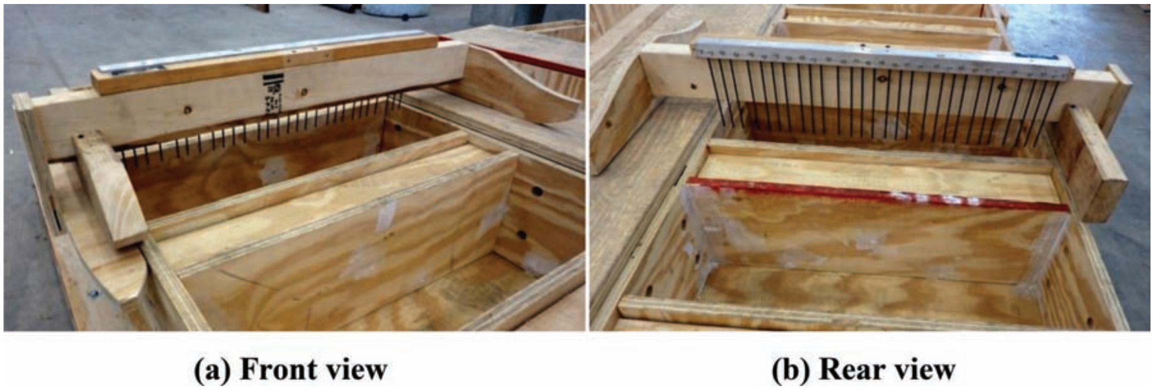

Figure 4.10 Tining sled on formwork.

Figure 4.11 Specified depth of tine marks.

Figure 4.12 Full-depth tine marks.

Figure 4.13 Modified shallow tine marks.

4.7 Specimen Preparation

Formwork was constructed to cast all specimens at one time. Holes were drilled in the sides of the formwork to allow for insertion of the reinforcing steel in the forms and to hold the bars in the correct location during casting, as shown in Figure 4.16.

Before inserting the black bars, the portion of the bar that would extend outside the specimen, and not be cut off after cracking, was painted with Rust-Oleum Stops Rust brand paint to resist any corrosion that might occur as a result of the moisture present during casting and curing. The longitudinal bars were inserted, and the transverse bars were tied to them with plastic zip ties, one mat at a

Variable Set Description	Sealer(s) Used	Cracked*				Uncracked	
		No Sealers	Crack Sealer Only	Deck Sealer Only	Crack and Deck Sealer	No Sealers	Deck Sealer Only
Control		X				X	
Sealer Combination #1	Epoxy (**Sikadur 55 SLV**) Silane (**Hydrozo Silane 40 VOC**)		X	X	X		X
Sealer Combination #2	Epoxy (**Dural 335**) Silane (**Hydrozo Enviroseal 40**)		X	X	X		X
Sealer Combination #3	Epoxy (**Sikadur 55 SLV**) **Linseed Oil**			X	X		X
Sealer Combination #4	Methacrylate (**Degadeck Crack Sealer Plus**) Silane (**Hydrozo Silane 40 VOC**)		X		X		

*And restressed after sealing.

Figure 4.14 Matrix of crack and deck sealing products and combinations.

Variable Set Description	Sealer(s) Used	Cracked*				Uncracked	
		No Sealers	Crack Sealer Only	Deck Sealer Only	Crack and Deck Sealer	No Sealers	Deck Sealer Only
Service Load Stress Not restressed after sealing	Epoxy (**Sikadur 55 SLV**) Silane (**Hydrozo Silane 40 VOC**)		X		X		
Surface Preparation Surface sandblasted before sealer application	**Dural 335**		X				
	Degadeck Crack Sealer Plus		X				
Resealing Intervals Simulate traffic before sealer application	**Hydrozo Silane 40 VOC**						X
	Hydrozo Enviroseal 40						X
	Linseed Oil						X
Resealing Intervals Simulate traffic after sealer application	**Hydrozo Silane 40 VOC**						X
	Hydrozo Enviroseal 40						X
	Linseed Oil						X
Resealing Intervals Simulate traffic with no sealer application						X	
Epoxy-Coated Reinforcement	Epoxy (**Sikadur 55 SLV**) Silane (**Hydrozo Silane 40 VOC**)	X			X		
Surface Tining	Epoxy (**Sikadur 55 SLV**) Silane (**Hydrozo Silane 40 VOC**)	X			X		

*And restressed after sealing, unless noted.

Figure 4.15 Matrix of additional test variables.

time. Plastic ties were used instead of tie wire because they would not corrode and contribute any variability to the test. Specimens ready for casting are shown in Figure 4.17, and the full set of formwork is shown in Figure 4.18.

The specimens were cast on September 19, 2010. An INDOT Class C mix from Irving Materials, Inc., was used. The mix component quantities from the batch ticket for the concrete that was delivered is provided in Table 4.2. The concrete was cast directly into the formwork from the truck, where it was spread with a shovel and lightly vibrated. The specimens were then screeded and finished with a magnesium float.

The specimens were covered with wet burlap and plastic sheeting approximately two hours after finishing was completed. This time corresponds to that when marring of the surface would no longer occur. The burlap was maintained wet for the seven-day wet cure period required by INDOT Specifications, after which the formwork was stripped from the specimens. A typical specimen after removal from the formwork is shown in Figure 4.19.

Figure 4.16 Holes for placement of reinforcing steel.

Figure 4.17 Example of black bar specimens ready for casting.

4.7.1 Cracking

Cracks were introduced though a system that applied direct, uniform tension to the specimen. An overview of the setup is shown in Figures 4.20 and 4.21. The specimen was placed between two steel beams that were bolted to the laboratory strong floor. Rods were placed through holes in the beams and connected to the exposed reinforcing steel of the specimen through transfer plates. The plates were connected to the rod with a nut, shown in Figure 4.22, and to the reinforcing steel using mechanical wedges designed for pulling No. 4 bars in tension (obtained from Howlett Machine Works), as shown in Figure 4.23. The transfer plates were machined with conical holes to receive the wedges and force them to engage the reinforcing steel under tension loading. This setup allowed equal load to be applied to each bar, which resulted in full depth cracks with relatively uniform width. Load was applied to the specimen using a hydraulic ram that reacted against one of the steel beams. The ram was operated with a hand pump. Although the hand pump had a pressure gauge providing the approximate pressure within the system, it was desired to obtain a more accurate reading of the load being applied. A load cell was calibrated and placed in the load path, reacting against the opposing steel beam. Real-time readings from the load cell were displayed on a laptop computer.

The first crack usually formed in the specimens at a load of 22 to 25 kips, or a tensile stress in the concrete of approximately 340 to 390 psi. Other cracks formed shortly afterward, generally at the location of transverse reinforcement. The majority of the specimens had a total of three cracks form. Loading of the specimens continued past the yield point of the steel so that the cracks would not close upon removal of the tension force. It was found that a load of 58 kips (a steel stress of 72.5 ksi) produced cracks at the target width of 0.020 in. Because uniform crack width was desired rather than a specific stress in the reinforcement, this load was varied slightly as needed to produce the target crack width. Although nominally a Grade 60 bar, the epoxy-coated reinforcement had a higher yield stress of 83 ksi (compared to 66 ksi for the black bars), and required a load of approximately 70 kips (a steel stress of 87.5 ksi) to reach the desired crack width. A typical cracked specimen with three cracks is shown in Figure 4.24. The widths of cracks from all specimens ranged from 0.005 in. to 0.045 in. (82% of the crack widths fell within the range of 0.015 in. to 0.025 in.), with an overall average of 0.021 in. A crack width of 0.020 in. is shown in Figure 4.25. Appendix C contains data on the formation of the cracks, including the number of cracks, final crack widths, and the total load applied for each cracked specimen.

4.7.2 Grouping and Assignment of Test Variables

After the specimens were cracked they were placed in groups of three, with each group representing one variable set. The specimens were grouped so that no group had more than one specimen with four cracks, and so that the average crack width within the group was as close to 0.020 in. as possible. The grouping of the cracked specimens is shown in Figure 4.26. The uncracked specimens were also placed into groups of three. Each group was then randomly assigned to a variable set. Variables assigned to each group are shown in Figure 4.27.

4.7.3 Pre-Sealing Preparation

Before application of the sealers, work was performed on several sets of specimens. The surface preparation variable for the crack filler/sealers Degadeck Crack Sealer Plus and Dural 335 required a light sandblasting before application. The resealing intervals variable required sandblasting 1/16 in. off the top of the specimen surface before sealing to simulate wear caused by traffic. This sandblasting work was performed by Nicon, Inc., in West

Figure 4.18 Formwork with specimen reinforcement.

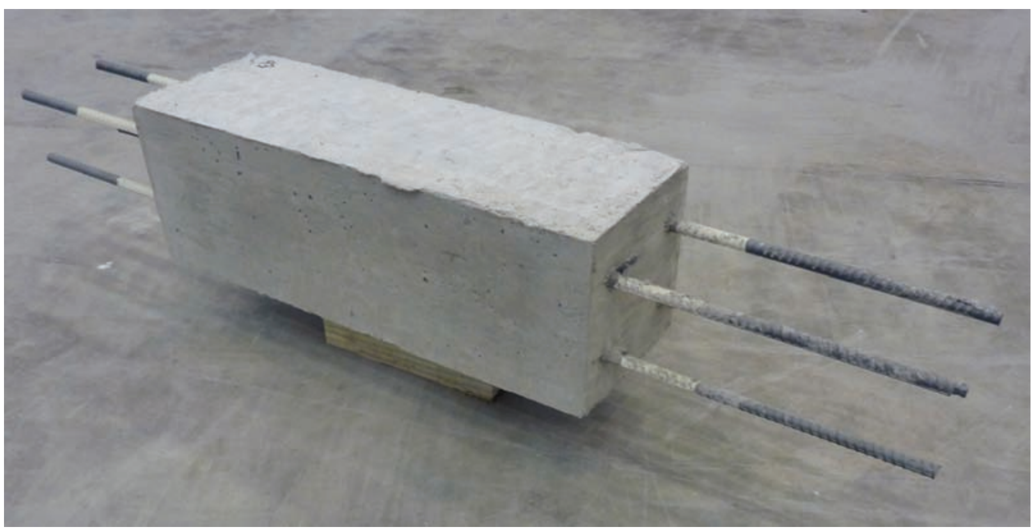

Figure 4.19 Typical cast specimen.

Lafayette, Indiana. Representative specimen surfaces before and after sandblasting are shown in Figure 4.28.

4.7.4 Sealer Application

The product data sheets for the selected sealers can be found in Appendix B. They contain the mixing instructions, recommended application methods, and physical properties of the sealer. Appendix D contains a log of work performed on each specimen group. The crack filler/sealing products were applied first to all applicable specimens. A consistent application process was attempted for all the products. Cracks were first cleaned with compressed air, and tape was placed on the sides of the specimens over the cracks to prevent loss of filler material. The sealing products were prepared according to the manufacturers' instructions. The correct quantities were measured, and mixed in a pail with a mixing paddle and a drill operating at medium speed. The typical elements used in this process are shown in Figure 4.29.

Some of the mixed material was then poured into a cup, and material was placed on the top surface of specimens by pouring from the cup. A stripe of the prod-

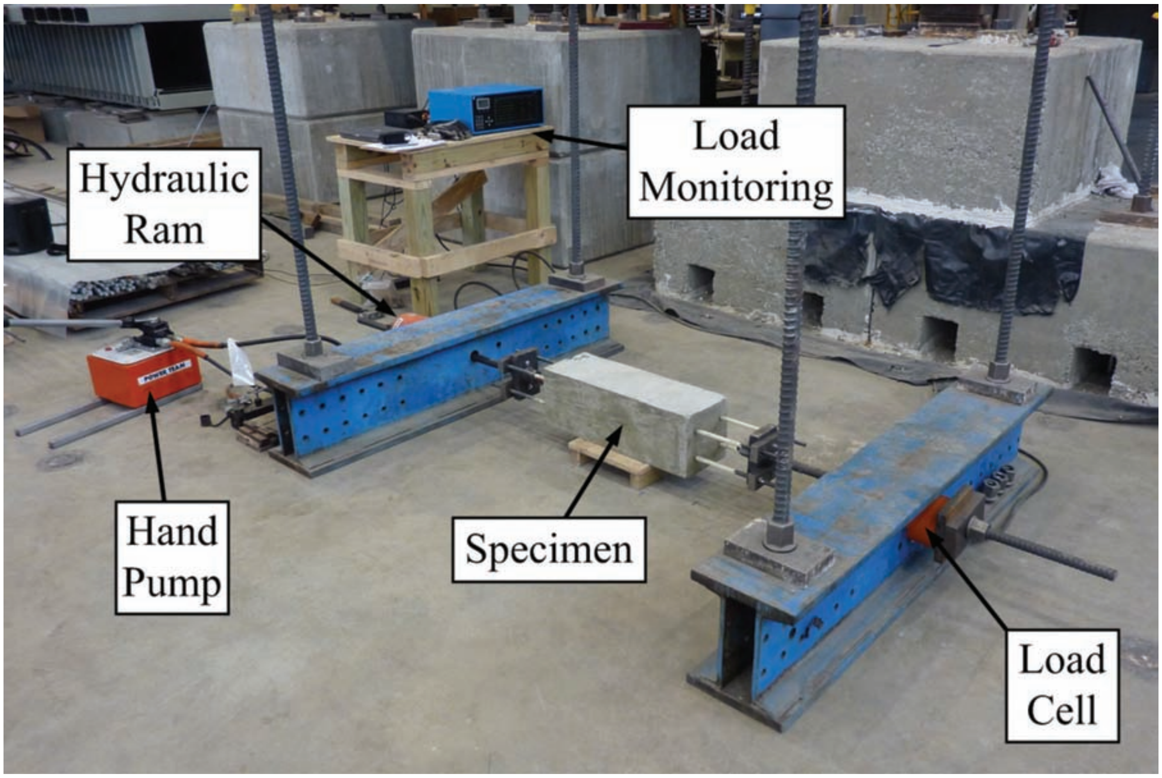

Figure 4.20 System used to crack specimens.

TABLE 4.2
Delivered concrete mix.

Material	Quantity (per cubic yard)
Cement	658 lbs
Water	202 lbs
#8 Stone	1785 lbs
#23 Sand	1236 lbs
Water Reducer	13.1 oz
Air Entrainer	4.6 oz
Slump	4 in.
Water-Cement Ratio	0.365

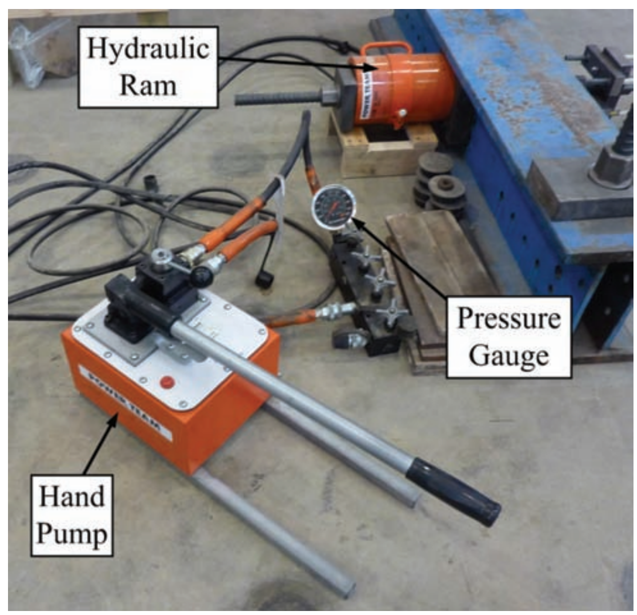

Figure 4.21 Loading end of system used to crack specimens.

uct was poured along each crack, shown in Figure 4.30. Using a squeegee, the crack filling/sealing product was ponded over the crack, shown in Figure 4.31. More material was added as needed until refusal. At this point, the application method for the individual products varied slightly.

4.7.4.1 Epoxies. Application of the two epoxy products was very similar. Only the individual cracks were sealed; the option of flooding the full surface was not investigated because surface sealing will be tested with the deck sealers. During striping, it became apparent that some product was being lost from the side of the crack at the bottom end of the tape, causing the material to be pulled down from the top of the crack, leaving an unfilled appearance. Some product was also escaping through the sides of the tape. After striping, excess material was wiped away, and the material was allowed to set up, to ensure that future added sealer would not escape from the sides and bottom of the specimen and that the crack would be filled to the surface.

A second stripe was applied and excess wiped away, but some leaking still occurred, preventing the cracks from staying filled to the top. After waiting for the second stripe to set up, a third striping was applied, which filled the cracks completely. However, wiping

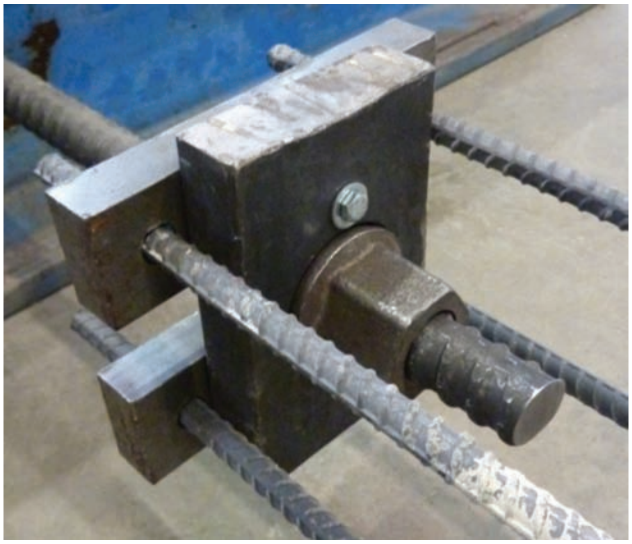

Figure 4.22 Nut connecting rod to transfer plates.

Figure 4.23 Wedges connecting reinforcing steel to transfer plates.

away the excess resulted in drawing out a small amount of material from the crack which left a very shallow crack, which was not considered ideal because it would allow for the ponding of water. Therefore, a fourth coat was added and excess was not wiped away to leave a small amount of material over the crack. After the fourth striping, the Dural 335 did draw down a small amount, but in order to keep the number of applications for the two epoxies consistent, no more product was added.

It is believed that because field application will not have the issue of product running out the bottom or sides of the deck, due to deck pans below and termination of the ends of the crack within the deck, filling the cracks to refusal in two stripings would be possible. A small amount of excess directly over the crack could also be left, and be covered with sand while still wet to avoid a slick surface. Tack-free time was about 12 hours for both products, though the Sikadur 55 SLV did cure faster than the Dural 335.

4.7.4.2 Methacrylate. There were several obvious differences between the epoxy and the methacrylate products. Although the epoxy products used had a very low viscosity (about 100 cP for both according to the manufacturers) and penetrated the full depth of the cracks, the methacrylate had an even lower viscosity (about 10 cP according to the manufacturer), similar to water, and flowed into the cracks with great ease. The methacrylate also set-up at a much faster rate and was capable of setting-up within the specimen before flowing out the sides. After striping the cracks, the product was spread over the full surface as called for in the manufacturer's instructions. Approximately 15 minutes after the striping and flood coat, a final stripe of material was added over cracks where the material had pulled down some to result in a smooth surface over the crack. Full cure was achieved in one hour.

4.7.4.3 Deck Sealers. The application of the deck sealers was very straightforward. The mid-range of the suggested application rate provided by the manufacturer was the target application rate. The manufacturers' suggested range, target, and final application rate for the sealers are shown in Table 4.3. The actual amount applied is based on the average applied to all specimens. The textured surfaces, those that had been sandblasted or contained tining marks, appeared to need more material for a consistent appearance following application. It was also noted that the applied materials penetrated into the cracks of cracked specimens at least a small amount because the product was noticed being pulled into the cracks and flowing out the sides of the specimens a short distance from the top.

The two silane products were applied so that the surface was wetted, but no material was left ponded. To apply a total amount near the target, half the target amount was applied twice, waiting for the first coat to appear dry before applying the second coat. The Hydrozo Silane 40 VOC was applied as a slightly heavier coat, though still within the manufacturer's suggested range; some extra material was needed to uniformly complete the two back-to-back coats on all specimens. This wait time was approximately 15 minutes for the Hydrozo Silane 40 VOC and approximately 30 minutes for the Enviroseal 40. The linseed oil was applied similarly but as two true coats as recommended by the manufacturer. These two coats were separated by a wait time of three hours, which was the time required for a dry surface condition to return. All the

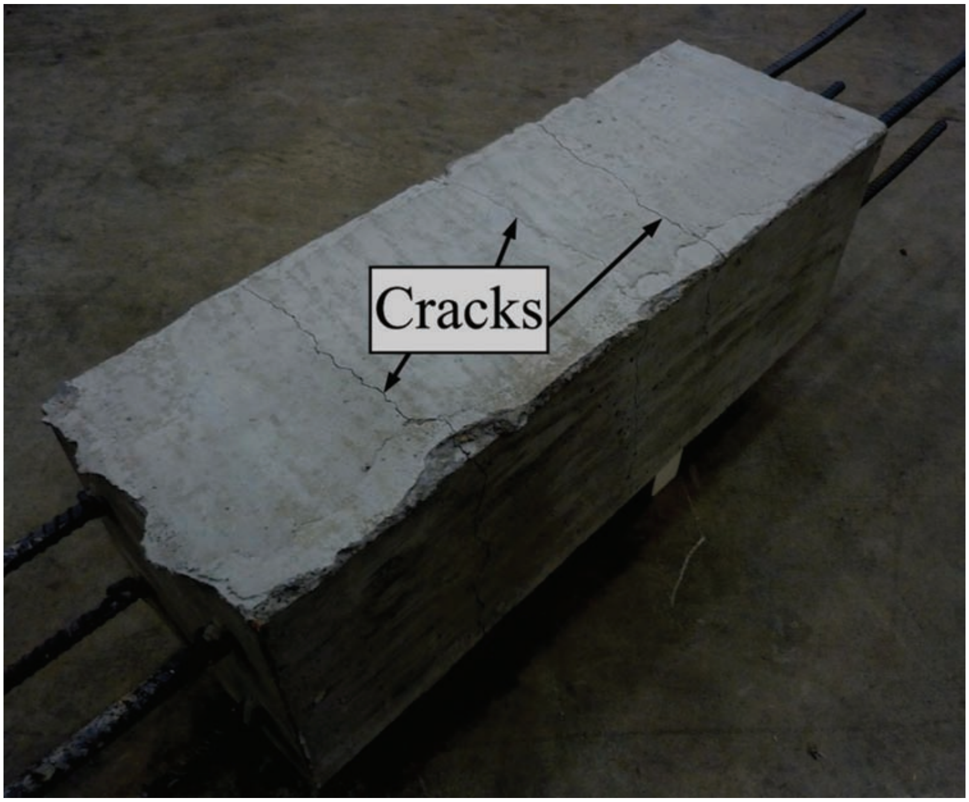

Figure 4.24 Typical cracked specimen.

Figure 4.25 Specimen crack measured with crack width gauge.

deck sealing products were applied with a brush, as shown in Figure 4.32. A sprayer could also be used to apply all of the deck sealing products, which would result in less time required for application. Proper metering would be required to obtain the correct coverage rate.

Group*	Specimen #	# of Cracks	Cracks (in./1000)				Specimen Crack Average (in./1000)	Group Crack Average (in./1000)
1	9	4	15	25	40	45	31	23
	25	3	15	20	25		20	
	35	3	10	15	20		15	
2	3	4	25	35	35	40	34	24
	19	3	15	15	15		15	
	23	3	15	20	25		20	
3	10	3	20	25	30		25	21
	11	3	20	20	25		22	
	15	4	5	15	20	25	16	
4	13	3	15	20	25		20	20
	18	4	10	10	15	20	14	
	36	3	20	25	40		28	
5	7	3	20	25	30		25	21
	12	3	15	25	25		22	
	42	4	10	15	15	25	16	
6	14	3	20	30	35		28	20
	16	3	10	15	35		20	
	49	4	5	15	15	20	14	
7	46	3	15	20	20		18	19
	47	3	20	20	25		22	
	51	4	15	15	15	25	18	
8	6	4	10	15	20	25	18	20
	24	3	20	20	30		23	
	52	3	15	20	20		18	
9	5	4	15	15	15	15	15	20
	20	3	15	20	25		20	
	40	3	25	25	25		25	
10	27	3	25	25	25		25	20
	50	4	15	20	20	25	20	
	53	3	10	15	20		15	
11	22	3	15	20	30		22	20
	44	4	15	15	15	20	16	
	48	3	20	20	30		23	
12	1	3	15	20	25		20	20
	26	4	10	15	15	20	15	
	28	3	25	25	25		25	
13	21	3	10	20	20		17	20
	39	3	20	25	25		23	
	43	4	15	20	20	20	19	
14	8	3	15	20	20		18	20
	37	4	10	15	25	25	19	
	45	3	20	20	25		22	
15	4	3	10	15	35		20	19
	17	3	15	15	25		18	
	41	3	15	20	20		18	
16	29	3	15	15	20		17	21
	33	3	15	20	20		18	
	34	3	15	30	35		27	
17	30	3	15	15	20		17	21
	31	3	20	25	30		25	
	32	3	15	20	25		20	
18	54	3	10	15	15		13	19
	55	3	20	20	20		20	
	57	3	20	25	30		25	
19	56	3	15	15	25		18	18
	58	3	15	20	25		20	
	59	3	15	15	20		17	
20U	60							
	61	N/A						
	62							
21U	63							
	64	N/A						
	65							
22U	66							
	67	N/A						
	68							
23U	90							
	91	N/A						
	92							
24U	72							
	73	N/A						
	74							
25U	75							
	76	N/A						
	77							
26U	78							
	79	N/A						
	80							
27U	81							
	82	N/A						
	83							
28U	84							
	85	N/A						
	86							
29U	87							
	88	N/A						
	89							
30U	69							
	70	N/A						
	71							

*Groups names ending with a "U" are uncracked.

Figure 4.26 Grouping of specimens.

4.7.5 Restressing

To simulate the stresses placed on the deck by traffic loads after sealing activities, the cracked specimens were restressed to a level of 2/3 that of the yield stress of the reinforcement. Because Grade 60 reinforcement was used, the design yield stress would be 60 ksi. A load of 32 kips was used to reload the specimens, which corresponds to a stress level of 40 ksi in the reinforcing steel. Reopening of cracks sealed with Sikadur 55

Group*	Specimens	Group Description	Group*	Specimens	Group Description
1	9 25 35	**Sealer Combination #1**, Sikadur 55SLV Only	16	29 33 34	**Epoxy-Coated Reinforcement**, Control
2	3 19 23	**Sealer Combination #1**, Hydrozo Silane 40 VOC Only	17	30 31 32	**Epoxy-Coated Reinforcement**, Sikadur 55SLV and Hydrozo Silane 40 VOC
3	10 11 15	**Sealer Combination #1**, Sikadur 55SLV and Hydrozo Silane 40 VOC	18	54 55 57	**Surface Tining**, Control
4	13 18 36	**Sealer Combination #2**, Dural 335 Only	19	56 58 59	**Surface Tining**, Sikadur 55SLV and Hydrozo Silane 40 VOC
5	7 12 42	**Sealer Combination #2**, Enviroseal 40 Only	20U	60 61 62	**Sealer Combination #1**, Hydrozo Silane 40 VOC Only
6	14 16 49	**Sealer Combination #2**, Dural 335 and Enviroseal 40	21U	63 64 65	**Sealer Combination #2**, Enviroseal 40 Only
7	46 47 51	**Sealer Combination #3**, Linseed Oil Only	22U	66 67 68	**Sealer Combination #3**, Linseed Oil Only
8	6 24 52	**Sealer Combination #3**, Sikadur 55SLV and Linseed Oil	23U	90 91 92	**Control**
9	5 20 40	**Sealer Combination #4**, Degadeck Crack Sealer Plus Only	24U	72 73 74	**Resealing Intervals**, Sandblast then seal surface, Hydrozo Silane 40 VOC
10	27 50 53	**Sealer Combination #4**, Degadeck Crack Sealer Plus and Hydrozo Silane 40 VOC	25U	75 76 77	**Resealing Intervals**, Sandblast then seal surface, Enviroseal 40
11	22 44 48	**Control**	26U	78 79 80	**Resealing Intervals**, Sandblast then seal surface, Linseed Oil
12	1 26 28	**Service Load Stress**, Not restressed, Sikadur 55SLV Only	27U	81 82 83	**Resealing Intervals**, Seal surface then sandblast, Hydrozo Silane 40 VOC
13	21 39 43	**Service Load Stress**, Not restressed, Sikadur 55SLV and Hydrozo Silane 40 VOC	28U	84 85 86	**Resealing Intervals**, Seal surface then sandblast, Enviroseal 40
14	8 37 45	**Surface Preparation**, Sandblast then seal cracks, Dural 335	29U	87 88 89	**Resealing Intervals**, Seal surface then sandblast, Linseed Oil
15	4 17 41	**Surface Preparation**, Sandblast then seal cracks, Degadeck Crack Sealer Plus	30U	69 70 71	**Resealing Intervals**, Sandblasted, Control

*Groups names ending with a "U" are uncracked.

Figure 4.27 Test variable assignments.

SLV was not observed. Recracking was noticed in some of the cracks sealed with Dural 335 and Degadeck Crack Sealer Plus. Whether or not a specimen was recracked during the stressing was difficult to discern in some cases.

4.7.6 Salt Water Ponding Preparation

Several steps were taken to prepare the specimens for the salt water wetting and drying cycles exposure testing. Excess reinforcing steel at the ends of the

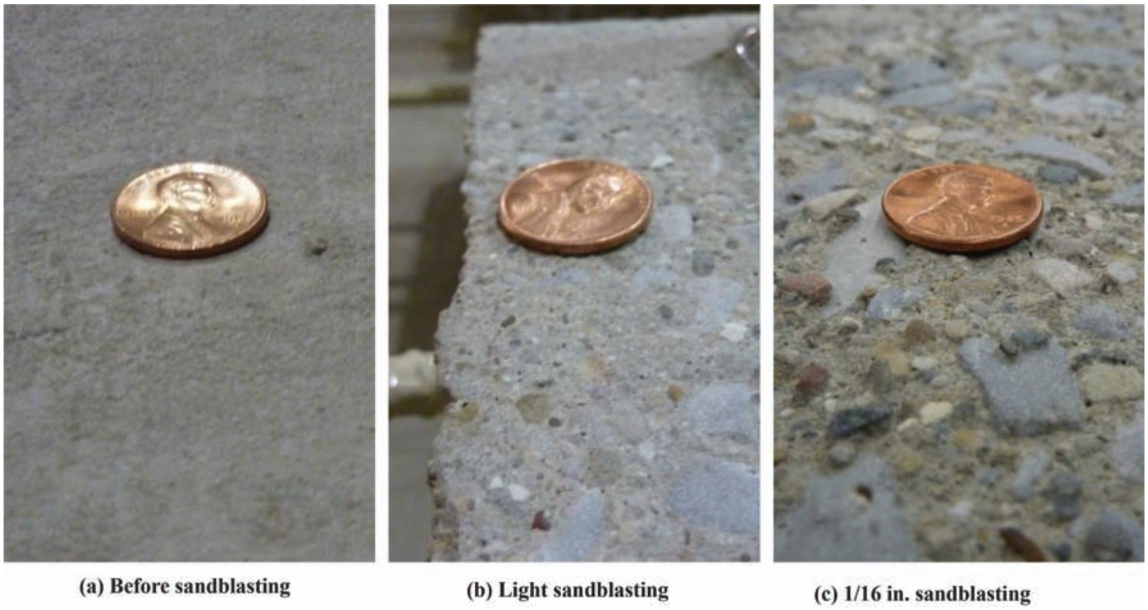

Figure 4.28 Sandblasted specimens.

Figure 4.29 Measured quantities of component materials for Degadeck Crack Sealer Plus.

specimens was first removed. Most of the excess protruding steel was only needed for cracking and restressing of the specimens, which had been completed. If corrosion were to occur on some portions of this exposed steel during the wetting and drying cycles, the readings of the macrocell corrosion activity would be inaccurate. It was therefore desired to remove as much of the protruding reinforcement as possible. On one end of the specimen, the bars were cut to leave 6 in. of exposed steel for both layers, which would be needed for instrumenting and for handling. On the opposite end, 3¼ in. of exposed steel was left on the top layer, to facilitate handling of the specimens, and 1¼ in. was left exposed on the bottom layer because this was the shortest that the bars could be cut with the saw that was used. All exposed steel was then painted with Rust-Oleum Stops Rust brand paint to further protect from corrosion.

Figure 4.30 Pouring of Sikadur 55 SLV.

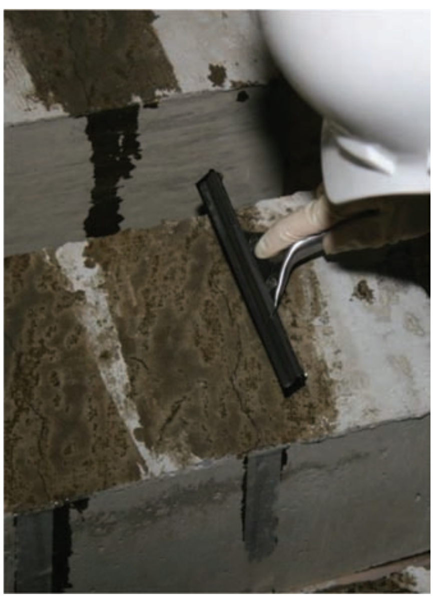

Figure 4.31 Squeegee used to pond product over crack.

An acrylic clear plastic dam was subsequently attached to the top with 100% silicone. The dimensions of the dams were 7 x 20 in. in plan and were 3 in. tall. The dam was centered on the specimen. Cracks on the sides and bottom of specimens were also sealed with silicone to prevent leaking during salt water ponding. A typical

TABLE 4.3
Deck sealer application rates.

Product	Manufacturer's Suggested Range (ft^2/gal.)	Target (ft^2/gal.)	Actual Applied (ft^2/gal.)
Hydrozo Silane 40 VOC	125–225	175	134
Enviroseal 40	100–200	150	155
Linseed Oil	150 (Applied as two coats of 300)	150	142

Figure 4.32 Application of Enviroseal 40.

uncracked specimen with trimmed bars and installed dam is shown in Figure 4.33, and a typical specimen that also has sealed cracks on the sides and bottom is shown in Figure 4.34.

Lastly, in accordance with the ASTM G109 standard, the sides and top surface outside the dam for each specimen were sealed with a waterproofing epoxy product. Sikagard 62, a high-build epoxy coating, was used for this waterproofing because it has been successfully used at Purdue University for this purpose in previous ASTM G109 testing. The bottom of the specimens was also coated with the epoxy waterproofer to simulate the enclosure provided by stay-in-place metal deck forms. This product was intended to protect the specimen surfaces that were not intended for exposure to the salt water from any unintended salt water contact and the salt water vapor that would be present in the testing room. A typical specimen following coating with this epoxy is shown in Figure 4.35.

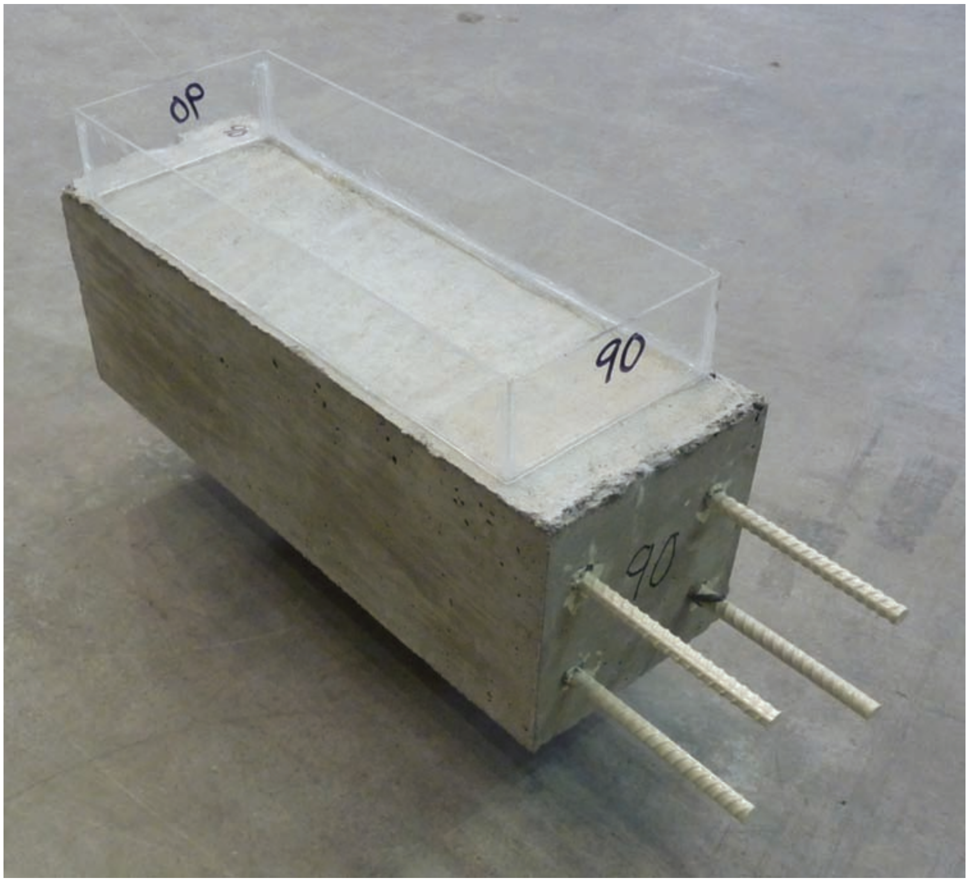

Figure 4.33 Typical uncracked specimen with plastic dam.

Figure 4.34 Typical specimen with cracks sealed on sides and bottom with silicone.

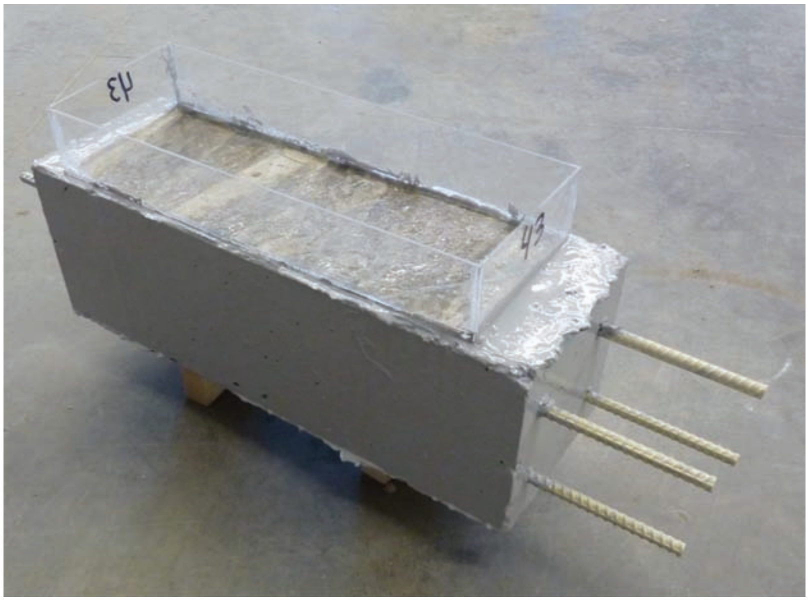

Figure 4.35 Typical specimen with epoxy coating on exterior.

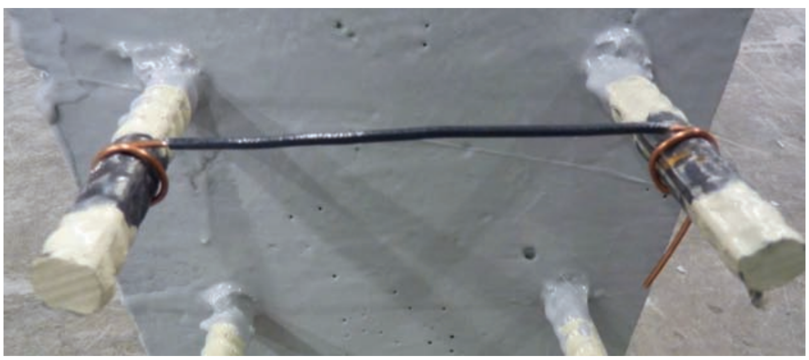

Figure 4.36 Wire connecting the top mat of reinforcement.

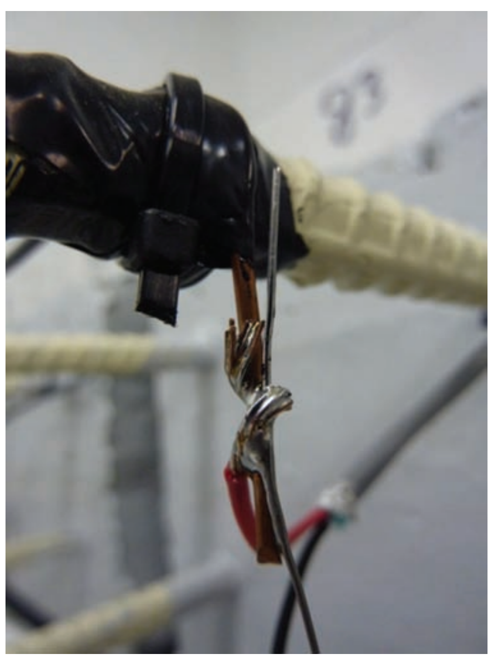

Figure 4.37 Connection of wires and resistor.

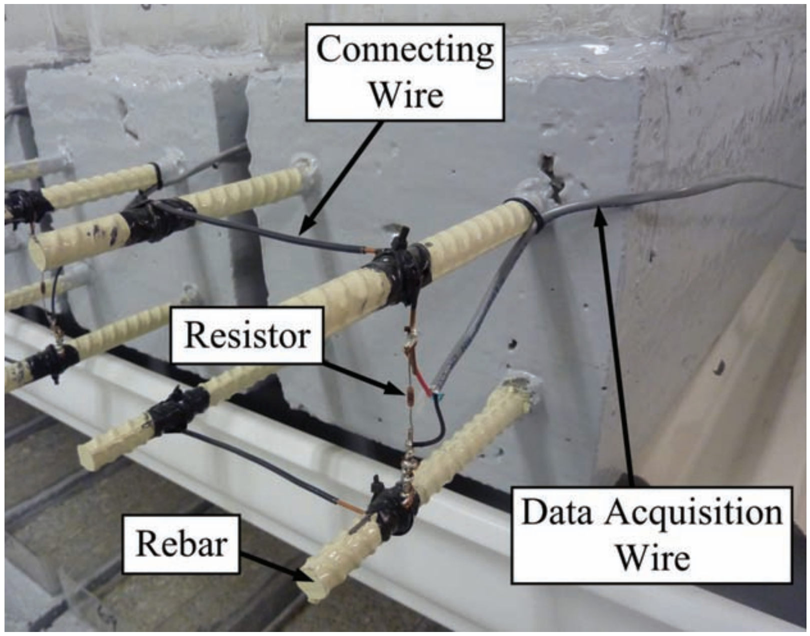

Figure 4.38 Instrumentation of a typical specimen.

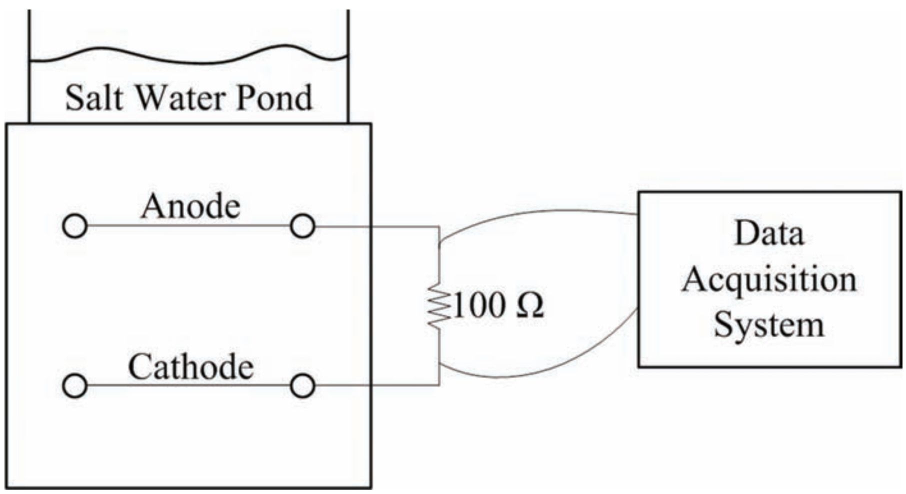

Figure 4.39 Schematic of macrocell electrical circuit.

4.8 Testing Procedure

The specimens were placed in a room and were instrumented to facilitate corrosion readings during wetting and drying cycles. The two bars of the top mat were electrically connected by wrapping a 14-gauge copper wire tightly around the bars as shown in Figure 4.36. At the contact point, the wire was wrapped with electrical tape and secured using a plastic tie. The same process was repeated for the two bottom bars.

The two mats were then connected with a 100-ohm precision resistor having a variance of $\pm$ 0.1 ohm. An 18-gauge copper wire was connected to each specimen that connects back to the datalogger. This connection was made by wrapping the ends of the datalogger wire around both the resistor and 14-gauge connection wire and then soldering the connection (Figure 4.37).

The voltage drop across the resistor is measured using a Campbell Scientific CR10X data logger. The completed wiring of a typical specimen is shown in Figure 4.38. The electrical circuit formed is shown in Figure 4.39 while the room housing all the completed specimens is shown in Figure 4.40.

Corrosion is initiated according to the ASTM G109 procedure. A 3%-by-weight solution of sodium chloride is placed in the plastic dam at a depth of 1.5 in. This solution is maintained on the specimens for two weeks, at which point it is removed with a vacuum and a two-week dry period begins. After two weeks of drying, the solution is added again. This cycling of wet and dry periods is expected to continue for 12 months. During the wet periods, the depth of solution will be maintained by periodically adding more solution as needed.

Figure 4.40 All specimens prepared for durability testing.

Voltage readings across the resistors will be automatically recorded every 12 hours.

5. SUMMARY AND CONCLUSIONS

5.1 Introduction

The deterioration of bridge decks is an issue being faced in the state of Indiana and across the United States. The primary cause of bridge deck deterioration is the application of deicing salts which allows chlorides to enter the deck through cracks and the concrete pore structure. This deterioration can result in a shortened bridge life with costs incurred to either repave or replace the structure. Therefore, a preservation program is needed that will provide protection to bridge decks from corrosive deicing chemicals, thus extending their service life and providing savings to the State.

5.2 Study Findings

The portion of the overall research project that is reported here was conducted in three phases.

5.2.1 Phase 1

The first phase was an in-depth review of the literature on materials and methods used to preserve bridge decks. The tests commonly used to evaluate these materials in the laboratory were also investigated. Based on this review, the following conclusions were made:

- Epoxy and methacrylate-based crack filling/sealing products are the most commonly tested. Epoxy generally has a stronger bond strength and better durability, while methacrylate provides better crack penetration. Both are recommended for use as crack fillers/sealers, with epoxy being more effective at sealing distinct and larger cracks, and methacrylates being more effective for sealing smaller and denser crack distributions.
- Silicone-based products were the top performer as a deck sealer. Siloxane and silane products are the most commonly tested of this group, with silane being the most effective in most cases. Solvent-based products with higher solids content generally performed better, and a 40-percent solids solvent-based silane was recommended as an ideal deck sealing product. Water-based silane products also performed well and would be useful as a substitute in an environmentally sensitive situation. It is important to note, however, that reapplication of a water-based product may not be effective as water-based products repel themselves wherever traces of the sealer remain from previous applications.
- Linseed oil has been used as a deck sealer with varying success rates. However, it is not a penetrating sealant, and should not be classified as one.
- Products within the same chemical family can demonstrate very different performance; therefore, the specific product used is important.
- If a bridge deck is expected to be exposed to deicing salts, any cracks should be sealed, as well as the full deck surface. Sealing should be completed as soon as possible in the life of the bridge to prevent as much chloride intrusion as possible.
- Many of the laboratory tests used in previous studies focused on a specific product property as an indicator of the performance capabilities of the material. Most of these tests were for deck sealing materials. Crack filling/sealing materials selected by states are commonly chosen based on performance in other studies (such as Pincheira and Dorshorst (2005)) or from field experience.

5.2.2 Phase 2

The second phase of this study was a survey of preservation methods used by other state DOT's on their bridges to determine the current state of bridge deck preservation programs in the United States. The survey produced the following findings:

- A variety of methods and materials exist and are in use today for protecting bridge decks. Many states have made changes to their programs within the recent

past based on their experiences with product performance in the field, as well as to evaluate newer promising materials.
- Both epoxy and methacrylate products are commonly used as crack fillers/sealers, and currently the only products in use by responding states. Silane and linseed oil are the most commonly used deck sealers by responding states. Other preservation approaches include barrier membranes and overlays.
- Different states have varying thoughts on the effectiveness of different types of products and whether their use is economically beneficial.

5.2.3 Phase 3

The final phase of this study was to develop and implement an experimental program to evaluate various preservation methods and materials. The variables to be investigated included different crack and deck sealing products, stressing of the crack sealers, surface preparation techniques, resealing intervals, epoxy-coated reinforcement, and surface tining. Specimens were designed to represent a section of a bridge deck. Both cracked and uncracked specimens were considered which then were sealed with both crack and deck sealing products. The specimens will be subjected to wetting and drying cycles of salt water to initiate macrocell corrosion. No corrosion data is available at the time of this report. Preliminary findings related to the sealing products used are as follows:

- Multiple stripings of all cracks is needed to ensure they are filled and sealed as best as the product's penetration depth will allow. This procedure will result in the strongest bond possible for that sealing product.
- The application of epoxy and methacrylate products demonstrated several noticeable differences. The methacrylate filled the cracks much quicker than the epoxies, requiring less work and fewer prestripings. Lastly, the methacrylate cured much faster, which would allow a bridge to be opened to traffic sooner.
- Some cracking under restressing was observed in specimens sealed with Dural 335 and Degadeck Crack Sealer Plus; therefore, the bond strength of these materials may not be as high as the Sikadur 55 SLV.
- The silane-based deck sealers dried much faster than linseed oil, which would permit a bridge to be opened to traffic sooner.
- Non-smooth surfaces required slightly more deck sealer to result in a consistent application based on appearance. Applying these products with a metered sprayer would result in a more uniform application rate and require only one application.

5.3 Recommendations

Bridge decks that are exposed to deicing salts should be sealed to prevent corrosion caused by chlorides. The effectiveness of high performing crack and deck sealers has been shown to significantly decrease the amount of chloride ingress. A preservation program should be developed based on the outcome of the experimental program designed and implemented in this study. Both epoxy and methacrylate products can easily be applied using a gravity feed method. Prestriping should be used on all visible cracks to achieve maximum penetration depth and a stronger bond. If time required to reopen to traffic is an important factor, a methacrylate product should be considered for crack filling/sealing, and a silane product should be used for deck sealing. It should be noted, however, that methacrylates are not as effective as epoxies at filling larger crack widths. The results of this experimental program should be used to decide which products are the most effective and durable as a sealer. Surface preparation should be minimized to keep costs related to labor, equipment, and closure time at a minimum. The experimental program implemented in this study will continue to be monitored and autopsies of the test specimens will be performed to evaluate the sealing products and different application methods used.

5.4 Future Research

It is recommended that the following future research be conducted:

- Determine which sealing methods are the most cost-effective. Based on the costs of the sealing products and application methods used, compared to the money saved by extending the life of a bridge deck, it can be determined which type of sealing program would be the most cost-effective.
- Evaluate the effectiveness of bridge deck overlays. As mentioned in the discussion of the state DOT survey and the literature review, the use of waterproofing membranes with an asphalt overlay or a special concrete mix overlay have been used with perceived success by other states. An overlay created with layers of epoxy and aggregate have also been used by state DOT's such as South Dakota. These overlays are a much more intensive protective method than the products tested in this study and could provide a higher level of protection.
- Test the performance of the sealer products in the field. It is not possible to recreate all the possible variables present in the field in a laboratory study. Therefore, the sealing products used in this study should also be evaluated using bridges in the field. The results of the field study and the laboratory study can then be compared to determine how well they correlate and determine whether the laboratory procedure effectively simulates field performance.
- Determine the effect of crack width on the performance of crack fillers/sealers. Cracks in bridge decks are not of the same size, and not all crack filling/sealing products necessarily work well to seal all cracks encountered. Previous research in this area is limited. Crack width was not included in this study due to the number of other variables considered. To properly investigate this variable, a more extensive study of this variable should be performed.

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APPENDICES

APPENDIX A. STATE DEPARTMENTS OF TRANSPORTATION SURVEY AND RESPONSES

The email message that the invited participants received explaining the purpose of the study and the survey is shown below. The full survey as viewed by the users who completed it online is shown in Figure A.1. The full responses provided by the responding states are shown in Figure A.2 through Figure A.10. Any follow-up communication with a survey participant is provided following Figure A.10.

Invitation email message:

Dear State Transportation Official:

A research team from the Indiana Department of Transportation (INDOT) and Purdue University are undertaking a multi-year experimental study to develop a cost-effective, concrete deck sealer program to extend the service life of bridge decks. To accomplish this, the research team will determine what type of sealers should be applied to a new bridge deck surface and when. In addition, researchers will determine if the applications of sealers at regular intervals extend the service life of bridge decks and are cost-effective. State DOTs are being surveyed to identify coating materials and application techniques that might differ from those currently being used by the Indiana Department of Transportation. The research team intends to incorporate multiple coating scenarios from the survey results into a series of accelerated exposure tests. Results of the research program will be made available at the conclusion of the study. The research team hopes you will be able to provide a response within the next four weeks.

Please access the short survey at the following web address –

https://engineering.purdue.edu/CE/Surveys/DOT

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Bridge Deck Sealer Systems Survey

The Indiana DOT's current approach for preserving its bridge inventory includes sealing new bridge decks with an epoxy penetrating sealer or an approved Portland cement concrete sealer immediately after construction. INDOT also conducts regular flushing of joints, bearings, and supports. Despite these precautions, the application of deicing salts and chemicals often leads to premature deterioration of bridge decks. The Indiana DOT's current approach for extending the service life of bridges includes but is not limited to the installation of deck overlays and replacement of bridge decks. All too often, deicing chemicals leak through a damaged bridge deck and result in deterioration of bridge girders and, sometimes, the substructure. Extending the service life of new or existing bridge decks through application and perhaps reapplication of an appropriate sealer system will reduce the amount of state funds required for bridge rehabilitation. Furthermore, it will reduce the risk that state funding will be needed to completely cover the cost of repair or replacement of bridge structures that become deficient prematurely.

A Purdue University research team, headed by Co-PI's Mike Kreger and Robert Frosch, is undertaking a multi-year experimental study to develop a cost-effective concrete deck sealer program to significantly extend the service life of bridge decks, and as a result, extend the life of bridge structures in the State of Indiana. To accomplish this, the research team will determine what class of sealer should be applied to a new bridge deck surface, and when that material should be applied. In addition, researchers will determine if application of sealers at regular intervals will extend the life of bridge decks.

The survey that follows is intended to identify the products and procedures that have been effective in other states and to assist the research team in establishing the test variables that will be incorporated in macrocell specimens used in a durability study.

Results of the research program and this survey will be made available to all DOT's at the conclusion of the study.

If you would prefer to complete this survey by telephone, or wish to further discuss the survey, please call John Lyrenmann at 763-228-5647.

*** What state DOT are you employed by?** (required)

Name (optional)

Contact Email (optional - if you'd like to receive an email with a link to the results of this survey, as well as a link to the final project report, please enter your email address)

Contact Phone (optional)

#1) Do you use any type of deicing chemicals on bridges in your state?

- Yes
- No

If you answered "No" to #1, please skip to the bottom of the survey and click the submit button.

Figure A.1 State DOT survey.

- **Initial Treatment After Construction** -

If you currently apply any type of sealer or coating material to bridge decks after construction, please continue. Otherwise, please proceed to question #4.

#2) Are deck cracks filled prior to application of a sealer or coating material?

- Yes
- No

If yes, what product is used and how is it applied?

#3) Instead of, or in addition to filling cracks, how do you treat the bridge deck?

- Just fill cracks
- Other treatment

If other treatment, what sealer or coating material do you use?

How soon after construction is this material applied, and what procedure is taken? Please be as specific as you can and list the steps taken.

- **Periodic Retreatment of Bridge Deck** -

If you periodically reapply a sealer or coating material to bridge decks after construction, please continue. Otherwise, please proceed to question #9.

#4) How often do you retreat/reseal the bridge deck?

#5) Do you do any type of preparation before retreating the bridge deck?

#6) When retreating, do you fill any cracks in the bridge deck?

- No
- Yes

#7) If yes, what product do you use to fill cracks and how is it applied?

- Same as after original construction
- Other material or application method

If other material or application method, please explain in detail.

#8) Instead of, or in addition to filling cracks, how do you retreat the bridge deck?

- Just fill cracks
- Other treatment

If other treatment, what sealer or coating material do you use?

- Same as after original construction
- Other material

If other material, which material and how is this material applied? Please be as specific as you can and list the steps taken.

Figure A.1 (cont.) State DOT survey.

- Recent Changes in Bridge Deck Treatment -

#9) Have you changed the sealer or coating material you use, or the application procedure, in recent years?

- Yes
- No/Not sure

If you answered "yes," please continue. Otherwise, please proceed to question #18.

#10) What prompted the change in sealer material or application procedure?

- Past Treatment After Construction -

If in the past you applied a sealer or coating material to bridge decks after construction, please continue. Otherwise, please proceed to question #13.

#11) In the past, were deck cracks filled prior to the application of a sealer or coating material?

- No
- Yes

If yes, what product was used and how was it applied?

#12) Instead of, or in addition to filling cracks, how did you treat the bridge deck?

- Just filled cracks
- Other treatment

If other treatment, what sealer or coating material did you use?

How soon after construction was this material applied, and what procedure was taken? Please be as specific as you can and list the steps taken.

Figure A.1 (cont.) State DOT survey.

- Past Periodic Retreatment of Bridge Deck -

If in the past you periodically reapplied a sealer or coating material to bridge decks after construction, please continue. Otherwise, please proceed to question #17.

#13) How often did you retreat/reseal the bridge deck?

#14) Did you do any type of preparation before retreating the bridge deck?

#15) When retreating, did you fill any cracks in the bridge deck?

- No
- Yes

If yes, what product was used and how was it applied?

- Same as after original construction
- Other material or application method

If other material or application method, please explain in detail what was used.

#16) Instead of, or in addition to filling cracks, how did you retreat the bridge deck?

- Just filled cracks
- Other treatment

If other treatment, what sealer or coating material did you use?

- Same as after original construction
- Other material

If other material, which material and how was this material applied? Please be as specific as you can and list the steps taken.

#17) Do you perceive an improvement in bridge deck performance because of the change in material and/or application procedure? (If you are unfamiliar with previous materials/methods, please state so.)

- Closing Thoughts -

#18) Is there anything else you'd like to tell us about protective bridge deck sealants/coatings and their use in your state?

If you were unsure about responses to any of the questions in this survey and know of someone in your department that would be able to answer any of these questions, we would greatly appreciate you forwarding the survey email message to them.

Figure A.1 (cont.) State DOT survey.

Submission Id	Submission: 1	Submission: 2
Timestamp	3/4/2010 14:19	3/5/2010 8:16
What state DOT are you employed by?	Nebraska	New Hampshire
Name	Moe Jamshidi	Glenn Roberts
Contact Email	mjamshidi@nebraska.gov	groberts@dot.state.nh.us
Contact Phone		603-271-3151
#1) Do you use any type of deicing chemicals on bridges in your state?	Yes	Yes
#2) Are deck cracks filled prior to application of a sealer or coating material?		No
If yes, what product is used and how is it applied?		
#3) Instead of, or in addition to filling cracks, how do you treat the bridge deck?		Other treatment
If other treatment, what sealer or coating material do you use?		Barrier membrane is utilized on most bridge decks.
How soon after construction is this material applied, and what procedure is taken? Please be as specific as you can and list the steps taken.		During construction.
#4) How often do you retreat/reseal the bridge deck?		
#5) Do you do any type of preparation before retreating the bridge deck?		
#6) When retreating, do you fill any cracks in the bridge deck?		
#7) If yes, what product do you use to fill cracks and how is it applied?		
If other material or application method, please explain in detail.		
#8) Instead of, or in addition to filling cracks, how do you retreat the bridge deck?		
If other treatment, what sealer or coating material do you use?		
If other material, which material and how is this material applied? Please be as specific as you can and list the steps taken.		
#9) Have you changed the sealer or coating material you use, or the application procedure, in recent years?	No/Not sure	
#10) What prompted the change in sealer material or application procedure?		
#11) In the past, were deck cracks filled prior to the application of a sealer or coating material?		
If yes, what product was used and how was it applied?		
#12) Instead of, or in addition to filling cracks, how did you treat the bridge deck?		
If other treatment, what sealer or coating material did you use?		
How soon after construction was this material applied, and what procedure was taken? Please be as specific as you can and list the steps taken.		
#13) How often did you retreat/reseal the bridge deck?		
#14) Did you do any type of preparation before retreating the bridge deck?		

Figure A.2 Survey response from Nebraska and New Hampshire.

#15) When retreating, did you fill any cracks in the bridge deck?		
If yes, what product was used and how was it applied?		
If other material or application method, please explain in detail what was used.		
#16) Instead of, or in addition to filling cracks, how did you retreat the bridge deck?		
If other treatment, what sealer or coating material did you use?		
If other material, which material and how was this material applied? Please be as specific as you can and list the steps taken.		
#17) Do you perceive an improvement in bridge deck performance because of the change in material and/or application procedure? (If you are unfamiliar with previous materials/methods, please state so.)		
Is there anything else you'd like to tell us about protective bridge deck sealants/coatings and their use in your state?	We don't have much experience in using sealers on bridge decks. A study by MNDOT a long time ago concluded that generally sealers on bridge decks don't last a long time, and are not cost effective. I don't have acopy of that study anymore.	

Figure A.2 (cont.) Survey response from Nebraska and New Hampshire.

Submission Id	Submission: 3	Submission: 4
Timestamp	3/5/2010 9:46	3/5/2010 11:30
What state DOT are you employed by?	Kansas DOT	Minnesota
Name	Rodney Montney	Jim Lilly
Contact Email	Rodney@ksdot.org	Jim.Lilly@state.mn.us
Contact Phone	782-291-3841	651.366.4508
#1) Do you use any type of deicing chemicals on bridges in your state?	Yes	Yes
#2) Are deck cracks filled prior to application of a sealer or coating material?		Yes
If yes, what product is used and how is it applied?		Primarily 1:1 epoxy, machine applied, although we have used methylmethacralates in flood seals
#3) Instead of, or in addition to filling cracks, how do you treat the bridge deck?		Other treatment
If other treatment, what sealer or coating material do you use?		We have used some silane and siloxane sealers, but do not believe they are cost effective. We have several experimental thin overlays in place. They include Safelane (not performing well), Polycarb, and Nova chip. Surface preparation varied for each of these products, from only sweeping in the case of Novachip, light surface blasting for some of the polymer applications
How soon after construction is this material applied, and what procedure is taken? Please be as specific as you can and list the steps taken.		When used, typically silane is applied after enough traffic has removed the curing compound. The thin overlays have been applied on bridges with high accident rates, primarily as an accident reduction measure.
#4) How often do you retreat/reseal the bridge deck?		We expect to reseal cracks every five years. We are experimenting with various types friction wearing course as deck sealers, but with the exception of Safelane which we have had to remove after a few as four years, none of the products have been down long enough to enable us to determine a service life.
#5) Do you do any type of preparation before retreating the bridge deck?		In the case of silane the preparation varies from washing and air-blast, to light shot blast.
#6) When retreating, do you fill any cracks in the bridge deck?		Yes
#7) If yes, what product do you use to fill cracks and how is it applied?		Same as after original construction
If other material or application method, please explain in detail.		All of our crack filling (with a few exceptions) have been maintenance procedures and not associated with new construction.
#8) Instead of, or in addition to filling cracks, how do you retreat the bridge deck?		Just fill cracks
If other treatment, what sealer or coating material do you use?		
If other material, which material and how is this material applied? Please be as specific as you can and list the steps taken.		
#9) Have you changed the sealer or coating material you use, or the application procedure, in recent years?		Yes
#10) What prompted the change in sealer material or application procedure?		For applying epoxy crack fillers, we have purchased automatic mixer-applicators which reduces waste, gives a more uniform product, is fast and more labor efficient. Our silane seal coats application have remained the same except we monitor the humidity more closely and have sand available to broadcast in case of delay in set/dry time.
#11) In the past, were deck cracks filled prior to the application of a sealer or coating material?		Yes
If yes, what product was used and how was it applied?		As described earlier.

Figure A.3 Survey response from Kansas and Minnesota.

#12) Instead of, or in addition to filling cracks, how did you treat the bridge deck?		
If other treatment, what sealer or coating material did you use?		As described earlier
How soon after construction was this material applied, and what procedure was taken? Please be as specific as you can and list the steps taken.		As described earlier
#13) How often did you retreat/reseal the bridge deck?		Silane -when retreated was done on a biennial basis. This has been discontinued.
#14) Did you do any type of preparation before retreating the bridge deck?		Wash and airblow deck
#15) When retreating, did you fill any cracks in the bridge deck?		Yes
If yes, what product was used and how was it applied?		Same as after original construction
If other material or application method, please explain in detail what was used.		
#16) Instead of, or in addition to filling cracks, how did you retreat the bridge deck?		Just filled cracks
If other treatment, what sealer or coating material did you use?		
If other material, which material and how was this material applied? Please be as specific as you can and list the steps taken.		
#17) Do you perceive an improvement in bridge deck performance because of the change in material and/or application procedure? (If you are unfamiliar with previous materials/methods, please state so.)		We have no data to demonstrate the effectiveness of these products. We will be placing crack filling material for a three year study this summer. This will measure ability to stop through deck cracks from leaking.
Is there anything else you'd like to tell us about protective bridge deck sealants/coatings and their use in your state?	We do not bridge deck sealants in Kansas.	Contact Mark Spafford (mark.spafford@state.mn.us) for copy of Material specifications.

Figure A.3 (cont.) Survey response from Kansas and Minnesota.

Submission Id	Submission: 5	Submission: 6
Timestamp	3/5/2010 11:57	3/8/2010 9:23
What state DOT are you employed by?	Georgia	Oklahoma
Name	Georgene Geary	Walter Peters
Contact Email		wpeters@odot.org
Contact Phone		(405) 521-2606
#1) Do you use any type of deicing chemicals on bridges in your state?	No	Yes
#2) Are deck cracks filled prior to application of a sealer or coating material?		Yes
If yes, what product is used and how is it applied?		HMWM or epoxy product
#3) Instead of, or in addition to filling cracks, how do you treat the bridge deck?		Other treatment
If other treatment, what sealer or coating material do you use?		Silane
How soon after construction is this material applied, and what procedure is taken? Please be as specific as you can and list the steps taken.		A secondary project is done in the summer months in all 8 of our field division (usually 6 months to 1 year after the original construction) to seal the cracks and silane the bridge decks.
#4) How often do you retreat/reseal the bridge deck?		
#5) Do you do any type of preparation before retreating the bridge deck?		
#6) When retreating, do you fill any cracks in the bridge deck?		
#7) If yes, what product do you use to fill cracks and how is it applied?		
If other material or application method, please explain in detail.		
#8) Instead of, or in addition to filling cracks, how do you retreat the bridge deck?		
If other treatment, what sealer or coating material do you use?		
If other material, which material and how is this material applied? Please be as specific as you can and list the steps taken.		
#9) Have you changed the sealer or coating material you use, or the application procedure, in recent years?	No/Not sure	No/Not sure
#10) What prompted the change in sealer material or application procedure?		
#11) In the past, were deck cracks filled prior to the application of a sealer or coating material?		Yes
If yes, what product was used and how was it applied?		HMWM or epoxy for the last 10 or 15 years
#12) Instead of, or in addition to filling cracks, how did you treat the bridge deck?		Other treatment
If other treatment, what sealer or coating material did you use?		Silanes
How soon after construction was this material applied, and what procedure was taken? Please be as specific as you can and list the steps taken.		A secondary project is done in the summer months in all 8 of our field division (usually 6 months to 1 year after the original construction) to seal the cracks and silane the bridge decks.
#13) How often did you retreat/reseal the bridge deck?		
#14) Did you do any type of preparation before retreating the bridge deck?		

Figure A.4 Survey response from Georgia and Oklahoma.

#15) When retreating, did you fill any cracks in the bridge deck?		
If yes, what product was used and how was it applied?		
If other material or application method, please explain in detail what was used.		
#16) Instead of, or in addition to filling cracks, how did you retreat the bridge deck?		
If other treatment, what sealer or coating material did you use?		
If other material, which material and how was this material applied? Please be as specific as you can and list the steps taken.		
#17) Do you perceive an improvement in bridge deck performance because of the change in material and/or application procedure? (If you are unfamiliar with previous materials/methods, please state so.)		The silane treatment seems to help
Is there anything else you'd like to tell us about protective bridge deck sealants/coatings and their use in your state?		We have been using silanes since the late '70s

Figure A.4 (cont.) Survey response from Georgia and Oklahoma.

Submission Id	Submission: 7	Submission: 8
Timestamp	3/8/2010 12:04	3/8/2010 15:35
What state DOT are you employed by?	Texas	Maryland
Name	Brian D Merrill, PE	Bruce Nelson
Contact Email	bmerrill@dot.state.tx.us	bnelson@sha.state.md.us
Contact Phone	512-416-2232	443-572-5289
#1) Do you use any type of deicing chemicals on bridges in your state?	Yes	Yes
#2) Are deck cracks filled prior to application of a sealer or coating material?	Yes	
If yes, what product is used and how is it applied?	Rarely fill cracks -use super low voscocity epoxy or methacrylate -either flood coat or pour on lg cracks	
#3) Instead of, or in addition to filling cracks, how do you treat the bridge deck?	Other treatment	
If other treatment, what sealer or coating material do you use?	silane or linseed oil	
How soon after construction is this material applied, and what procedure is taken? Please be as specific as you can and list the steps taken.	immediately after completion of curing	
#4) How often do you retreat/reseal the bridge deck?	rarely	
#5) Do you do any type of preparation before retreating the bridge deck?	NA	
#6) When retreating, do you fill any cracks in the bridge deck?	No	
#7) If yes, what product do you use to fill cracks and how is it applied?	Same as after original construction	
If other material or application method, please explain in detail.		
#8) Instead of, or in addition to filling cracks, how do you retreat the bridge deck?	Just fill cracks	
If other treatment, what sealer or coating material do you use?		
If other material, which material and how is this material applied? Please be as specific as you can and list the steps taken.		
#9) Have you changed the sealer or coating material you use, or the application procedure, in recent years?	No/Not sure	
#10) What prompted the change in sealer material or application procedure?		
#11) In the past, were deck cracks filled prior to the application of a sealer or coating material?		
If yes, what product was used and how was it applied?		
#12) Instead of, or in addition to filling cracks, how did you treat the bridge deck?		
If other treatment, what sealer or coating material did you use?		
How soon after construction was this material applied, and what procedure was taken? Please be as specific as you can and list the steps taken.		
#13) How often did you retreat/reseal the bridge deck?		
#14) Did you do any type of preparation before retreating the bridge deck?		

Figure A.5 Survey response from Texas and Maryland.

#15) When retreating, did you fill any cracks in the bridge deck?		
If yes, what product was used and how was it applied?		
If other material or application method, please explain in detail what was used.		
#16) Instead of, or in addition to filling cracks, how did you retreat the bridge deck?		
If other treatment, what sealer or coating material did you use?		
If other material, which material and how was this material applied? Please be as specific as you can and list the steps taken.		
#17) Do you perceive an improvement in bridge deck performance because of the change in material and/or application procedure? (If you are unfamiliar with previous materials/methods, please state so.)		
Is there anything else you'd like to tell us about protective bridge deck sealants/coatings and their use in your state?		

Figure A.5 (cont.) Survey response from Texas and Maryland.

Submission Id	Submission: 9	Submission: 10
Timestamp	3/9/2010 11:50	3/9/2010 18:13
What state DOT are you employed by?	Wisconsin	WSDOT
Name		
Contact Email	travis.mcdaniel@dot.wi.gov	
Contact Phone		
#1) Do you use any type of deicing chemicals on bridges in your state?	Yes	No
#2) Are deck cracks filled prior to application of a sealer or coating material?	Yes	
If yes, what product is used and how is it applied?		
#3) Instead of, or in addition to filling cracks, how do you treat the bridge deck?	Just fill cracks	
If other treatment, what sealer or coating material do you use?	Various. See WHRP report for more details.	
How soon after construction is this material applied, and what procedure is taken? Please be as specific as you can and list the steps taken.		
#4) How often do you retreat/reseal the bridge deck?		
#5) Do you do any type of preparation before retreating the bridge deck?		
#6) When retreating, do you fill any cracks in the bridge deck?		
#7) If yes, what product do you use to fill cracks and how is it applied?		
If other material or application method, please explain in detail.		
#8) Instead of, or in addition to filling cracks, how do you retreat the bridge deck?		
If other treatment, what sealer or coating material do you use?		
If other material, which material and how is this material applied? Please be as specific as you can and list the steps taken.		
#9) Have you changed the sealer or coating material you use, or the application procedure, in recent years?		
#10) What prompted the change in sealer material or application procedure?		
#11) In the past, were deck cracks filled prior to the application of a sealer or coating material?		
If yes, what product was used and how was it applied?		
#12) Instead of, or in addition to filling cracks, how did you treat the bridge deck?		
If other treatment, what sealer or coating material did you use?		
How soon after construction was this material applied, and what procedure was taken? Please be as specific as you can and list the steps taken.		
#13) How often did you retreat/reseal the bridge deck?		
#14) Did you do any type of preparation before retreating the bridge deck?		

Figure A.6 Survey response from Wisconsin and Washington State.

#15) When retreating, did you fill any cracks in the bridge deck?		
If yes, what product was used and how was it applied?		
If other material or application method, please explain in detail what was used.		
#16) Instead of, or in addition to filling cracks, how did you retreat the bridge deck?		
If other treatment, what sealer or coating material did you use?		
If other material, which material and how was this material applied? Please be as specific as you can and list the steps taken.		
#17) Do you perceive an improvement in bridge deck performance because of the change in material and/or application procedure? (If you are unfamiliar with previous materials/methods, please state so.)		
Is there anything else you'd like to tell us about protective bridge deck sealants/coatings and their use in your state?	Please check the following report from WisDOT on sealers: http://www.whrp.org/research-areas/structures/downloads/03-09_FR_crack_sealers.pdf	

Figure A.6 (cont.) Survey response from Wisconsin and Washington State.

Submission Id	Submission: 11	Submission: 12
Timestamp	3/11/2010 14:11	3/11/2010 14:22
What state DOT are you employed by?	Alaska	New York State
Name	Drew Sielbach	Edward Collins
Contact Email	drew.sielbach@alaska.gov	ecollins@dot.state.ny.us
Contact Phone	907-465-6942	518-457-4589
#1) Do you use any type of deicing chemicals on bridges in your state?	Yes	Yes
#2) Are deck cracks filled prior to application of a sealer or coating material?	Yes	Yes
If yes, what product is used and how is it applied?	high-molecular-weight methacrylate	It depends on the severity of the crack, both dimensionally and nature/cause of the crack
#3) Instead of, or in addition to filling cracks, how do you treat the bridge deck?	Just fill cracks	Other treatment
If other treatment, what sealer or coating material do you use?		A pre-approved silane/siloxane based penetrating sealer is always applied to new bridge decks irregardless of the presence of cracks
How soon after construction is this material applied, and what procedure is taken? Please be as specific as you can and list the steps taken.	After curing, fill and seal all joints and visible cracks with a high-molecular-weight methacrylate resin. Use two applications of HMWM in cracks 1/16 inch and wider.	The penetrating sealers are applied no sooner than 14 days after curing completed. The deck must also not be exposed to water 24 hours prior to sealing and 12 hours after sealing.
#4) How often do you retreat/reseal the bridge deck?		Approximately every 5 years
#5) Do you do any type of preparation before retreating the bridge deck?		We do very little preparation to keep the lane closure time to a minumum
#6) When retreating, do you fill any cracks in the bridge deck?		No
#7) If yes, what product do you use to fill cracks and how is it applied?		
If other material or application method, please explain in detail.		
#8) Instead of, or in addition to filling cracks, how do you retreat the bridge deck?		Other treatment
If other treatment, what sealer or coating material do you use?		Same as after original construction
If other material, which material and how is this material applied? Please be as specific as you can and list the steps taken.		
#9) Have you changed the sealer or coating material you use, or the application procedure, in recent years?	No/Not sure	Yes
#10) What prompted the change in sealer material or application procedure?		We standradized coverage rates based on percent active ingredients/solids. This was more for making bids more competitive and assuring required performance
#11) In the past, were deck cracks filled prior to the application of a sealer or coating material?		Yes
If yes, what product was used and how was it applied?		This would again depend on the severity and nature/cause of the crack. Wider cracks had been filled with Methyl Methacrylates by hand applicaions for localized cracking
#12) Instead of, or in addition to filling cracks, how did you treat the bridge deck?		Other treatment
If other treatment, what sealer or coating material did you use?		Retreat with a penetrating silane sealer
How soon after construction was this material applied, and what procedure was taken? Please be as specific as you can and list the steps taken.		The penetrating sealers are applied no sooner than 14 days after curing has been removed. Also sealers cannot be applied with 24 hours of any exposure to water.

Figure A.7 Survey response from Alaska and New York State.

#13) How often did you retreat/reseal the bridge deck?		Approximately every 5 years
#14) Did you do any type of preparation before retreating the bridge deck?		very little
#15) When retreating, did you fill any cracks in the bridge deck?		No
If yes, what product was used and how was it applied?		
If other material or application method, please explain in detail what was used.		
#16) Instead of, or in addition to filling cracks, how did you retreat the bridge deck?		Other treatment
If other treatment, what sealer or coating material did you use?		Same as after original construction
If other material, which material and how was this material applied? Please be as specific as you can and list the steps taken.		
#17) Do you perceive an improvement in bridge deck performance because of the change in material and/or application procedure? (If you are unfamiliar with previous materials/methods, please state so.)		Bridge seemed to scale less early in their lifecycle.
Is there anything else you'd like to tell us about protective bridge deck sealants/coatings and their use in your state?	Waterproof membranes with an asphalt overlay are used to protect new concrete bridge decks and older concrete bridge decks where possible.	The penetrating sealers have been successful in NY state. We have seen a reduction in allowable VOC's which are making less products available for use. The penetraring sealers have given us cheap insurance to help further protect bridge decks from distress from deicing salts

Figure A.7 **(cont.)** Survey response from Alaska and New York State.

Submission Id	Submission: 13	Submission: 14
Timestamp	3/11/2010 14:47	3/15/2010 12:30
What state DOT are you employed by?	Missouri	Louisiana
Name	Scott Stotlemeyer	Tyson Rupnow
Contact Email	scott.stotlemeyer@modot.mo.gov	Tyson.Rupnow@la.gov
Contact Phone	573-522-8752	
#1) Do you use any type of deicing chemicals on bridges in your state?	Yes	No
#2) Are deck cracks filled prior to application of a sealer or coating material?	No	No
If yes, what product is used and how is it applied?	We do not typically fill and seal (i.e., 2 processes). We either fill the cracks with Pavon Indeck or fill them as part of the total deck sealing application of Pavon Indeck.	
#3) Instead of, or in addition to filling cracks, how do you treat the bridge deck?	Other treatment	
If other treatment, what sealer or coating material do you use?	Linseed Oil to minimize scaling; Star Macro-Deck to seal; Pavon Indeck to fill and seal; Other products like Silanes, Siloxanes, Methyl Methacrylates, etc. are only applied on limited basis.	
How soon after construction is this material applied, and what procedure is taken? Please be as specific as you can and list the steps taken.	Linseed Oil is applied 28 days after deck is poured and one year later. Star Macro-Deck is applied when fine cracks appear. Indeck is applied if the cracks widen. Our procedures for these applicationsas well as all of our bridge preventative guidelines, can be viewed at http://epg.modot.org/index.php?title=Category:771_Bridge_P reventative_Maintenance_Guidelines.	
#4) How often do you retreat/reseal the bridge deck?	We apply reapply Star MacroDeck and Indeck on a 3 to 5-year rotation.	N/A
#5) Do you do any type of preparation before retreating the bridge deck?	Clean and flush.	No
#6) When retreating, do you fill any cracks in the bridge deck?	Yes	No
#7) If yes, what product do you use to fill cracks and how is it applied?	Same as after original construction	
If other material or application method, please explain in detail.	See answer to question #2.	
#8) Instead of, or in addition to filling cracks, how do you retreat the bridge deck?	Other treatment	
If other treatment, what sealer or coating material do you use?	Same as after original construction	
If other material, which material and how is this material applied? Please be as specific as you can and list the steps taken.	See anwer to question #3.	
#9) Have you changed the sealer or coating material you use, or the application procedure, in recent years?	No/Not sure	
#10) What prompted the change in sealer material or application procedure?		
#11) In the past, were deck cracks filled prior to the application of a sealer or coating material?		
If yes, what product was used and how was it applied?		
#12) Instead of, or in addition to filling cracks, how did you treat the bridge deck?		
If other treatment, what sealer or coating material did you use?		

Figure A.8 Survey response from Missouri and Louisiana.

How soon after construction was this material applied, and what procedure was taken? Please be as specific as you can and list the steps taken.		
#13) How often did you retreat/reseal the bridge deck?		
#14) Did you do any type of preparation before retreating the bridge deck?		
#15) When retreating, did you fill any cracks in the bridge deck?		
If yes, what product was used and how was it applied?		
If other material or application method, please explain in detail what was used.		
#16) Instead of, or in addition to filling cracks, how did you retreat the bridge deck?		
If other treatment, what sealer or coating material did you use?		
If other material, which material and how was this material applied? Please be as specific as you can and list the steps taken.		
#17) Do you perceive an improvement in bridge deck performance because of the change in material and/or application procedure? (If you are unfamiliar with previous materials/methods, please state so.)		
Is there anything else you'd like to tell us about protective bridge deck sealants/coatings and their use in your state?	Our Organizational Results section prepared a report on bridge deck sealers in 2007 that may be of benefit to your research. You can access it at http://library.modot.mo.gov/RDT/reports/Ri04051/or0700 9.p df.	

Figure A.8 (cont.) Survey response from Missouri and Louisiana.

Submission Id	Submission: 15	Submission: 16
Timestamp	3/17/2010 15:42	3/27/2010 21:57
What state DOT are you employed by?	Florida	Illinois DOT
Name	Richard J. Kessler	Carl Puzey
Contact Email	richard.kessler@dot.state.fl.us	Carl.Puzey@illinois.gov
Contact Phone	352-955-6686	
#1) Do you use any type of deicing chemicals on bridges in your state?	No	Yes
#2) Are deck cracks filled prior to application of a sealer or coating material?		No
If yes, what product is used and how is it applied?		
#3) Instead of, or in addition to filling cracks, how do you treat the bridge deck?		Other treatment
If other treatment, what sealer or coating material do you use?		Linseed oil, referred to as Protective Coat in IDOT's Standard Specifications for Road and Bridge Construction.
How soon after construction is this material applied, and what procedure is taken? Please be as specific as you can and list the steps taken.		See IDOT's Standard Specifications for Road and Bridge Construction.
#4) How often do you retreat/reseal the bridge deck?		Have not resealed in the past, but just designated funding for FY11 for a sealing program intending to reseal decks every four years.
#5) Do you do any type of preparation before retreating the bridge deck?		Remove debris with compressed air.
#6) When retreating, do you fill any cracks in the bridge deck?		Yes
#7) If yes, what product do you use to fill cracks and how is it applied?		Other material or application method
If other material or application method, please explain in detail.		Just getting started with this so not one specific material. Material is chosen by District office.
#8) Instead of, or in addition to filling cracks, how do you retreat the bridge deck?		Other treatment
If other treatment, what sealer or coating material do you use?		Same as after original construction
If other material, which material and how is this material applied? Please be as specific as you can and list the steps taken.		Districts will have other options, but we are currently recommending they use Linseed Oil, the same material used after construction.
#9) Have you changed the sealer or coating material you use, or the application procedure, in recent years?		No/Not sure
#10) What prompted the change in sealer material or application procedure?		
#11) In the past, were deck cracks filled prior to the application of a sealer or coating material?		
If yes, what product was used and how was it applied?		
#12) Instead of, or in addition to filling cracks, how did you treat the bridge deck?		
If other treatment, what sealer or coating material did you use?		
How soon after construction was this material applied, and what procedure was taken? Please be as specific as you can and list the steps taken.		

Figure A.9 Survey response from Florida and Illinois.

#13) How often did you retreat/reseal the bridge deck?		
#14) Did you do any type of preparation before retreating the bridge deck?		
#15) When retreating, did you fill any cracks in the bridge deck?		
If yes, what product was used and how was it applied?		
If other material or application method, please explain in detail what was used.		
#16) Instead of, or in addition to filling cracks, how did you retreat the bridge deck?		
If other treatment, what sealer or coating material did you use?		
If other material, which material and how was this material applied? Please be as specific as you can and list the steps taken.		
#17) Do you perceive an improvement in bridge deck performance because of the change in material and/or application procedure? (If you are unfamiliar with previous materials/methods, please state so.)		
Is there anything else you'd like to tell us about protective bridge deck sealants/coatings and their use in your state?		See the results of our recent research on deck sealers at: http://www.dot.il.gov/materials/research/pdf/prr155.pdf

Figure A.9 (cont.) Survey response from Florida and Illinois.

Submission Id	Submission: 17
Timestamp	5/17/2010 16:24
What state DOT are you employed by?	South Dakota
Name	Tom Gilsrud
Contact Email	tom.gilsrud@state.sd.us
Contact Phone	605.773.4456
#1) Do you use any type of deicing chemicals on bridges in your state?	Yes
#2) Are deck cracks filled prior to application of a sealer or coating material?	Yes
If yes, what product is used and how is it applied?	Methacrylates and Epoxy crack sealer applied by hand
#3) Instead of, or in addition to filling cracks, how do you treat the bridge deck?	Other treatment
If other treatment, what sealer or coating material do you use?	Silane
How soon after construction is this material applied, and what procedure is taken? Please be as specific as you can and list the steps taken.	Within six months
#4) How often do you retreat/reseal the bridge deck?	Five years
#5) Do you do any type of preparation before retreating the bridge deck?	Power Wash
#6) When retreating, do you fill any cracks in the bridge deck?	Yes
#7) If yes, what product do you use to fill cracks and how is it applied?	Same as after original construction
If other material or application method, please explain in detail.	
#8) Instead of, or in addition to filling cracks, how do you retreat the bridge deck?	Other treatment
If other treatment, what sealer or coating material do you use?	Other material
If other material, which material and how is this material applied? Please be as specific as you can and list the steps taken.	Sometimes based on crack density and we flood coat the deck/slab with a polysulfide epoxy chip seal system
#9) Have you changed the sealer or coating material you use, or the application procedure, in recent years?	No/Not sure
#10) What prompted the change in sealer material or application procedure?	
#11) In the past, were deck cracks filled prior to the application of a sealer or coating material?	
If yes, what product was used and how was it applied?	
#12) Instead of, or in addition to filling cracks, how did you treat the bridge deck?	
If other treatment, what sealer or coating material did you use?	
How soon after construction was this material applied, and what procedure was taken? Please be as specific as you can and list the steps taken.	
#13) How often did you retreat/reseal the bridge deck?	

Figure A.10 Survey response from South Dakota.

#14) Did you do any type of preparation before retreating the bridge deck?	
#15) When retreating, did you fill any cracks in the bridge deck?	
If yes, what product was used and how was it applied?	
If other material or application method, please explain in detail what was used.	
#16) Instead of, or in addition to filling cracks, how did you retreat the bridge deck?	
If other treatment, what sealer or coating material did you use?	
If other material, which material and how was this material applied? Please be as specific as you can and list the steps taken.	
#17) Do you perceive an improvement in bridge deck performance because of the change in material and/or application procedure? (If you are unfamiliar with previous materials/methods, please state so.)	
Is there anything else you'd like to tell us about protective bridge deck sealants/coatings and their use in your state?	No

Figure A.10 (cont.) Survey response from South Dakota.

A.1. Phone Survey with Connecticut

For the state of Connecticut, the survey was conducted over the phone with Ravi Chandran, the chief of the Division of Research and Materials (860-258-0371). A summary of this phone conversation is as follows:

- All bridges receive a membrane and are paved over with HMA.
- Ground Penetrating Radar surveys are used to check for delaminations within the deck.
- Repairs include patching the deck at damaged areas only or in full, depending on the required patching amount. For more serious conditions, the surface is milled and a new membrane and HMA topping are applied.
- No sealers or other treatments are used.
- The state is considering changing to a "bare deck" approach, as there are concerns over whether current methods are effective or necessary.

A.2. Follow-up with New York

The following email communication contains follow-up questions sent to Mr. Edward Collins of the New York State DOT and his response.

> Dear Mr. Collins:
>
> Thank you for taking time to respond for the New York DOT to the Purdue University (JTRP) survey regarding bridge deck crack and deck sealing.
>
> It would be quite beneficial to the survey effort if you could clarify one of your responses. You indicated that a pre-approved silane or siloxane is always applied to a new deck regardless of the number of cracks that are present in the deck. If there are cracks in the deck before the initial deck seal is applied, are they filled before application of the seal coat, or are the cracks filled at a later date? If they are filled at a later date, approximately how much time elapses before this work is performed?
>
> Thank you again for taking time to participate in our survey. Your responses as well as those of other state DOT representatives will be quite useful in helping us define the testing matrix to be implemented in our macrocell testing program.
>
> Best regards,
Mike Kreger
>
> Professor, School of Civil Engineering
Purdue University
765-494-9340
>
> Mike,
>
> If the cracks were less than 0.012 inches in width the silane/siloxane sealer would be sufficient for remediation. The sealer would be applied within 48 hours of blast cleaning of the cracks. No water including any form of precipitation may be introduced to the deck after this blast cleaning. Using a squeeze bottle or sprayer, the sealer is applied directly into each crack until refusal. We repeat this process for each crack allowing each application to dry in accordance to manufacturer's recommendations between applications, until each crack no longer readily accepts sealer. Four or more applications may be required to effectively seal the cracks depending on the width.
>
> If the cracks were frequent and greater than 0.012 inches in width, we generally would require removal of the cracked concrete and replaced with a thin bonded overlay. If the cracks were of the larger width and only occurred occasionally then we would consider rout and seal with silicone for larger cracks or epoxy injection for smaller cracks.
>
> We have also performed flood coats of methyl methacrylate with fine aggregates.
>
> Let me know if this is sufficient information.
>
> Thanks,
Ed Collins

A.3. Follow-up with New Hampshire

The following email communication contains a follow-up question sent to Mr. Glenn Roberts of the New Hampshire DOT and his response.

Dear Mr. Roberts:

Thank you for taking time to respond for the New Hampshire DOT to the Purdue University (JTRP) survey regarding bridge deck crack and deck sealing.

It would be quite beneficial to the survey effort if you could clarify one of your responses. You indicated that a barrier membrane is used on most bridge decks after they are constructed. Could you be more specific as to what this barrier membrane is—perhaps a specific product or type of material? Any details related to how this barrier membrane is applied would also be helpful.

Thank you again for taking time to participate in our survey. Your responses as well as those of other state DOT representatives will be quite useful in helping us define the testing matrix to be implemented in our macrocell testing program.

Best regards,
Mike Kreger

Professor, School of Civil Engineering
Purdue University
765-494-9340

Mike:

At this time virtually all of the membrane used on NHDOT jobs is what we refer to as "Barrier Membrane, Welded by Torch". There are currently two products qualified under this category—Sopralene Flam Antirock by Soprema Roofing & Waterproofing and Armour Bridge/Pont 4.5 mm by IKO Industries. The products themselves are almost identical and have their origins in the roofing industry. They are widely used in Canada and by several State DOTs.

This link will give you some basic information related to the product:

http://www.soprema.ca/en/technical-references/documentation/card/9/ANTIROCK.aspx

There are two ways to apply this membrane. The hand method is what we were originally introduced to (c. 1996) and is still used on small bridges and around scuppers, joints, etc. The Applicator melts the underside of the roll with a torch and pulls the membrane into the liquid bitumen. Here is an example from the web (I couldn't find a good picture of our own).

On larger bridges, the membrane is typically applied by machine. Please see attached photos for examples.

In the mid-1990s, our standard barrier membrane was the peel-and-stick variety. You may be familiar with some of these products—they are/were manufactured by companies such as WR Grace (Bituthene), Protecto Wrap, Royston, and NEI. Concerns at that time regarding the bond between the membrane and the concrete deck led us to investigate alternative products. In addition to the torch-applied products, we utilized a spray-applied product from Stirling Lloyd called Eliminator for about 10 years:

http://www.stirlinglloyd.com/uk_worldwide/products/bridges/seamless/eliminator/eliminator-1-of-3.htm

The cost of the Eliminator was quite high (up to 3 times higher than torch-applied). We ultimately decided we probably weren't getting 3x the value so for the past few years we've gone exclusively with the torch-applied.

In all cases, 2″ of HMA is applied over the membrane as the final wearing surface.

Hope this helps. If you'd like more information, don't hesitate to contact me.

Best regards,
Glenn

****

Glenn E. Roberts, P.E.
Chief of Research
NHDOT Bureau of Materials & Research
PO Box 483, 5 Hazen Drive
Concord, NH 03302-0483
Tel: (603) 271-3151
Fax: (603) 271-8700
Email:groberts@dot.state.nh.us

On the Web:www.nh.gov/dot/research

Attached Photos:

Figure A.11 IKO machine.

Figure A.12 Small Soprema machine.

Figure A.13 Membrane application machine.

A.4. Follow-up with Missouri

The following email communication contains a follow-up question sent to Mr. Scott Stotlemeyer of the Missouri DOT and his response.

Dear Mr. Stotlemeyer;

Thank you for taking time to respond for the Missouri DOT to the Purdue University (JTRP) survey regarding bridge deck crack and deck sealing.

It appears from your survey response that the product “Pavon Indeck” is an integral part of your bridge maintenance program. We are interested in learning more about this product, but are having trouble finding any information. Can you provide any information about what type of material this is or provide a link to where this information can be obtained?

Thank you again for taking time to participate in our survey. Your responses as well as those of other state DOT representatives will be quite useful in helping us define the testing matrix to be implemented in our macrocell testing program.

Best regards,
Mike Kreger

Professor, School of Civil Engineering
Purdue University
765-494-9340

From Scott Stotlemeyer:

Pavon Indeck is an asphalt-based crack sealer. I attached a copy of Pavon’s brochure which includes some information on this particular product. I also provided a link to our preventative maintenance guidelines for sealing decks with Indeck. On this page you will find additional links to a MoDOT report bridge deck concrete sealers and a brief on Indeck. We are currently paying about $17.50/gallon with an application rate of 180 ft^2/gal.

http://epg.modot.org/index.php?title=771.17_Bridge_Deck_Total_Surface_Treatment_-_In_Deck

Attached PDF:

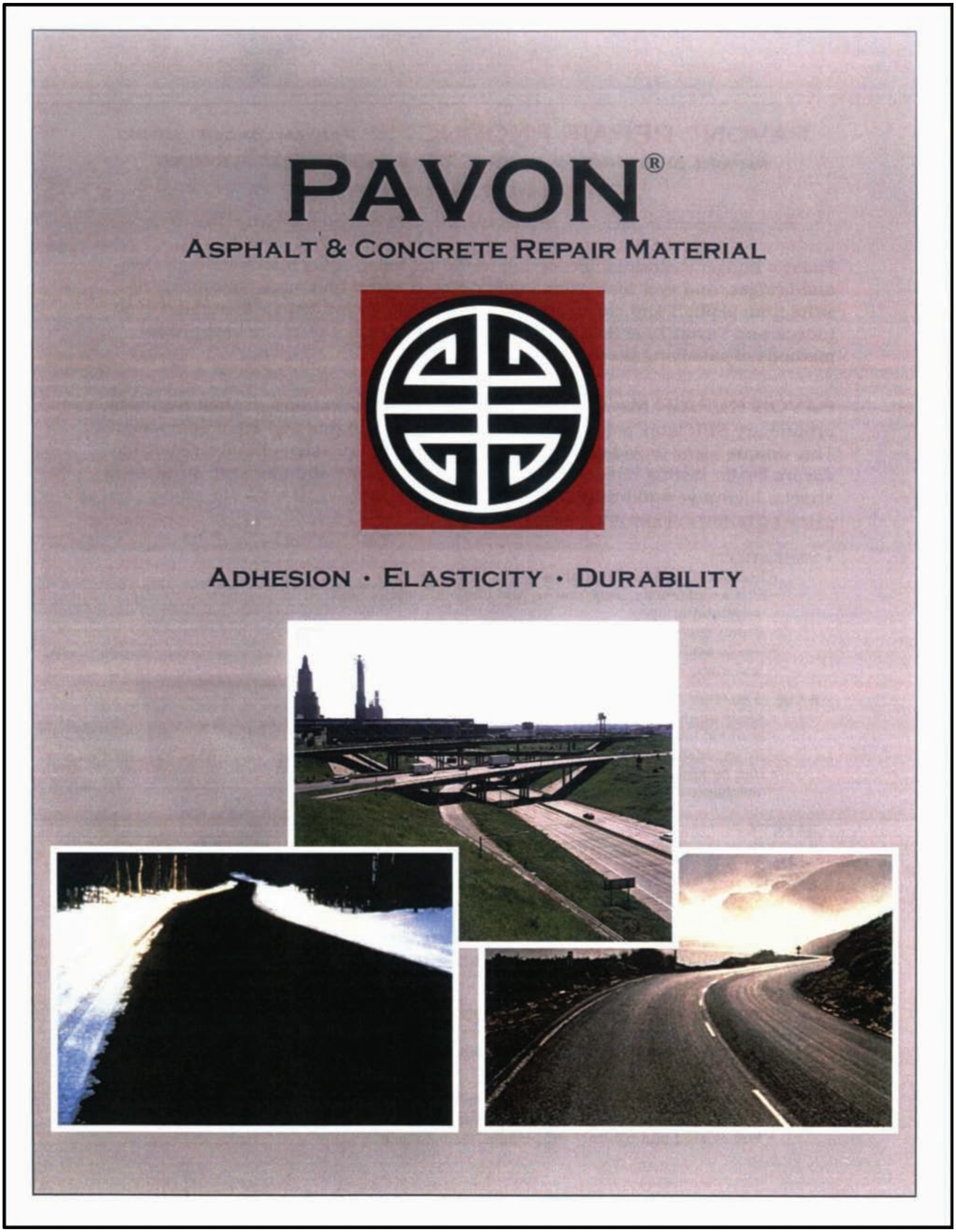


Figure A.14 Pavon brochure.

PAVON® REPAIR PRODUCTS: PROVEN LONGER LASTING REPAIRS OF POT HOLES, CRACKS, JOINTS AND DAMAGED SURFACES IN ASPHALT AND CONCRETE

Today's budget restraints, increasing traffic volumes, aging Interstate highways and bridges, and ever increasing loads demand better and more permanent results from asphalt and concreate repair materials. Pavon Repair Material, Pavon Indeck and Pavon Type II Crack FIller and Joint Sealant offer the best proven methods of satisfying these demands.

PAVON REPAIR MATERIAL contains a blend of cationic asphalt emulsion, proprietary SBR latex polymers, acrylic resins, surfactants and other components. This unique blend provides maximum elasticity and adhesion characteristics to assure longer lasting repairs of pot holes, cracks, joints and damaged surfaces in streets, highways and bridges.

CHARACTERISTICS AND PROPERTIES:

- **VERSATILITY** -
  - Equally effective on asphalt and concrete
  - Fills small cracks, large cracks, and joints in streets, highways and bridges
  - Repair spalding areas, cracked surfaces and pot holes
  - Use to seal paving cuts and to seal cold mix pot hole repairs
  - And many other uses
- **EASE & SIMPLICITY OF APPLICATION** -
  - Apply at ambient temperature
  - Minimal labor costs
  - No expensive equipment required
  - Can be applied with a brush, squeegee or mechanical equipment
- **SAFETY** -
  - No personal injury due to burning or harmful fumes
- **ENDURANCE** -
  - Increased resistance to thermal and fatique cracking
  - Improved temperature susceptibility
  - Minimized effect of aging
  - Maximum durability
- **ADHESION** -
  - Catonic ingredients adhere to the negative charged aggregate, asphalt or concrete
  - Contains adhesive components to enhance gluing

Greater adhesion, elasticity and durability with Pavon products.

- **ELASTICITY** -
  - Contains rubber components to provide a high degree of elasticity and ductility
  - Expands and contracts with pavement movement
  - Will expand and contract with temperature change

Figure A.14 (cont.) Pavon brochure.

- **PREVENTS WATER MIGRATION -**
  - Whether from surface or sub grade - seals and glues the repairs
- **RESISTANT -**
  - Formulated to withstand attack by water, sun, oxidation, freeze/thaw cycles and traffic
- **QUICK DRYING -**
  - Little or no tracking - dries in minutes (blotter material is optional)
- **TEST OF TIME -**
  - For over 10 years, Pavon Repair Material has been used by the Missouri Highway and Transportation Department on roads and bridges throughout the state.

Illustration of Pavon Indeck's sealing and penetration characteristics

PAVON® INDECK has all the characteristics and properties of Pavon Repair Material, but contains substantially more rubber and glue to achieve maximum adhesion, elasticity and ductility.

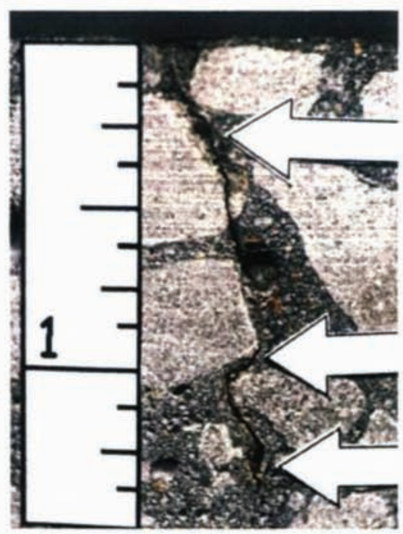
WHAT IS PAVON INDECK?

It is a penetrator and sealant used on multi-level parking decks and bridges to prevent water intrusion and migration. Through gravity flow and the strong electrochemical charge of Pavon Indeck, the liquid finds and follows the microcracks and other voids in the deck surface. When the heavy glue and rubber ladened Pavon Indeck dries, the waterways are plugged with "rubber gaskets". Pavon Indeck is a cost effective way to prolong the surface and subsurface life of parking decks and bridges.

HOW IS IT APPLIED?

Depending upon the type of bridge or parking lot and its age and condition, Pavon Indeck is applied full strength or diluted up to two parts water to one part Pavon Indeck. It may be applied with brush, squeegee or mechanical equipment.

Friction tests on bridge surfaces treated with Pavon Indeck show very acceptable numbers and in close range to the adjoining pavement.



Highway Department core sample taken March 1996 • Pavon Indeck applied October 1995 • Continuous slab with regular concrete • Map cracking and T-cracking • Crack width 2.75mm at surface to 0.25mm deeper in core • Cracks coated completely with Pavon Indeck • Indeck was pliable • Further evaluation data available upon request

Figure A.14 (cont.) Pavon brochure.

PAVON TYPE II CRACKFILLER & JOINT SEALANT* is a blend of asphalt, proprietary thermoplastic rubbers, solvents and other chemicals to form a thick viscous crack and joint sealant.

CHARACTERISTICS AND PROPERTIES:

- Apply at ambient temperature ranges of below freezing to above 100° F
- Apply on flat, slope or vertical surfaces and on all sides of box culverts or drainage pipes
- Formulated to fill small cracks to wide joints on highways and bridges
- Fill joints on slope protectors
- Will not track, sag or soften in hot weather
- No heating or melting required
- Will not freeze
- Applied with an air operated pump

* Patent pending

All Pavon products available in 5 gallon pails or 55 gallon drums.

PAVON®

ADHESION · ELASTICITY · DURABILITY

FOR MORE INFORMATION ON
PAVON® ASPHALT & CONCRETE REPAIR PRODUCTS CONTACT:

PAVON CORPORATION
P.O. BOX 34748
NORTH KANSAS CITY, MO 64116-1148
TEL: 816·221·7721
816·455·4496
FAX: 816·221·8402

Figure A.14 (cont.) Pavon brochure.

APPENDIX B. PRODUCT RANKING AND MATERIAL DATA SHEETS

The compiled performance of the crack sealers is shown in Figure B.1, and the product data sheets for the selected crack sealers are shown in Figure B.2 through Figure B.4. The compiled performance of the deck sealers is shown in Figure B.5 and the product data sheets for the selected deck sealers are shown in Figure B.6 through Figure B.8.

B.1. Crack Sealing Products

Products were ranked first by how they were ranked in their original study. These lists were then merged based on product performance across studies. The types of studies included laboratory studies, field studies, and literature reviews, broken down as follows:

- Laboratory Studies—Pincheira and Dorshorst (2005), Frosch et al. (2010)
- Field Studies—Morse (2009), Soriano (2003)
- Literature Reviews—Johnson et al. (2009), Krauss et al. (2009)

The general findings from the literature review were:

- Johnson et al. (2009) noted that methacrylates generally have better penetration, while epoxy generally provided better bond strength.
- Krauss et al. (2009) found that epoxy and HMWM were, respectively, the first and second most popular crack sealers.

Performance Level	Chemical Type	Product Name	Brand Name (Former Company)	Comments
Good	Epoxy	Sikadur 55 SLV	Sika USA	Was given the highest ranking by Pincheira (2005) [for cracks < 0.06 - 0.19 in], Also a top performer in study by Hoffman/Gutierrez (2010)
	Epoxy	Dural 335	Euclid Chemical (Tamms Industries)	Was given the highest ranking by Pincheira (2005) [for cracks < 0.06in], Also a top performer in study by Hoffman/Gutierrez (2010)
	Epoxy Overlay	MARK 163 FlexoGrid	Poly-Carb	A top performer in study by Hoffman/Gutierrez (2010), Showed moderate performance in Morse (2009) w/ 4yr lifetime
	Epoxy	Epoxeal GS Structural	BASF	A top performer in study by Hoffman/Gutierrez (2010)
	Epoxy Overlay	Pro-Poxy Type III D.O.T.	Unitex	A top performer in study by Hoffman/Gutierrez (2010)
	Epoxy	SurePoxy HM SLV	Kaufman Products	A top performer in study by Hoffman/Gutierrez (2010)
	Epoxy	Dural 50	Euclid Chemical (Tamms Industries)	A top performer in study by Hoffman/Gutierrez (2010)
	Epoxy	Bridge Seal	Unitex	A top performer in study by Hoffman/Gutierrez (2010)
	Methyl Methacrylate	Reactive Methyl Methacrylate	Degussa, Inc.	Recommended in study by Soriano (2003)
	Polyurethane	Modified Polyurethane	Roadware	Recommended in study by Soriano (2003)
	Epoxy	Two-Component Epoxy	Unitex Pro-Seal	Recommended in study by Soriano (2003)
		SDDOT Epoxy Chip Seal		Recommended in study by Soriano (2003)

Figure B.1 Crack sealer product compilation.

Performance Level	Chemical Type	Product Name	Brand Name (Former Company)	Comments
Moderate	Epoxy	Sikadur 52	Sika USA	Was given a moderate ranking by Pincheira (2005) [for cracks < 0.06 - 0.19 in]
	Methacrylate	Degadeck Crack Sealer Plus	BASF (Degussa, Inc.)	Was given a moderate ranking by Pincheira (2005) [for cracks < 0.06 - 0.19 in], Also a low/poor performer in study by Hoffman/Gutierrez (2010)
	Methacrylate	Denedeck Crack Sealer	DeNeef Construction Chemicals	Was given a moderate ranking by Pincheira (2005) [for cracks < 0.06 - 0.19 in]
	Epoxy	FX-770 HM LV	Fox Industries	A moderate/low performer in study by Hoffman/Gutierrez (2010)
	Methacrylate	FX-821 MMA	Fox Industries	A moderate/low performer in study by Hoffman/Gutierrez (2010)
	Epoxy	Dural 50 LM	Euclid Chemical (Tamms Industries)	A moderate/low performer in study by Hoffman/Gutierrez (2010)
	Laminate Material	Mark 154	Poly Carb, Inc.	Showed moderate performance in Morse (2009) w/ 4yr lifetime
	Laminate Material	Mark 135.3	Poly Carb, Inc.	Showed moderate performance in Morse (2009) w/ 4yr lifetime
	Laminate Material	Thin Polymer Overlay	Poly Carb, Inc.	Showed moderate performance in Morse (2009) w/ 4yr lifetime
Poor	HMWM	SikaPronto 19	Sika USA	Was given a poor ranking by Pincheira (2005) [for cracks < 0.06 - 0.19 in]
	HMWM	Duraguard 401	ChemMasters	Was given a poor ranking by Pincheira (2005) [for cracks < 0.06 - > 0.2 in]
	Epoxy	TK-9000	TK Products	Was given a poor ranking by Pincheira (2005) [for cracks 0.06 - > 0.2 in]
	Epoxy	TK-9010	TK Products	Was given a poor ranking by Pincheira (2005) [for cracks 0.1 - 0.19 in]
	Polyurethane/ Polyurea	TK-9030	TK Products	Was given a poor ranking by Pincheira (2005) [for cracks 0.06 - 0.1 in]
	Epoxy	MARK 135 Safe-T-Seal	Poly-Carb	A low/poor performer in study by Hoffman/Gutierrez (2010), Showed moderate performance in Morse (2009) w/ 4yr lifetime
	Epoxy	MARK 127	Poly-Carb	A low/poor performer in study by Hoffman/Gutierrez (2010)
	Methacrylate	SikaPronto 19 TF	Sika USA	A low/poor performer in study by Hoffman/Gutierrez (2010)

Figure B.1 (cont.) Crack sealer product compilation.

Product Data Sheet
Edition 7.1.2008
Identification no. 389-35N
Sikadur 55 SLV

Construction

Sikadur 55 SLV

Super low-viscosity, moisture-tolerant epoxy resin, crack healer/penetrating sealer

Description

Sikadur 55 SLV is a 2-component, 100% solids, moisture-tolerant, epoxy crack healer / penetrating sealer, having a fast tack-free time to minimize downtime. It is a super low-viscosity, high-strength adhesive formulated specifically for sealing both dry and damp cracks. It conforms to the current ASTM C-881 and AASHTO M-235 specifications.

Where to Use

- Sikadur 55 SLV structurally repairs cracked concrete.
- For interior slabs and exterior above-grade slabs.
- For elevated horizontal decks, parking garages and other structures exposed to foot and pneumatic tire traffic.

Advantages

- Super low viscosity/low surface tension for excellent penetration into cracks.
- Penetrates cracks by gravity down to 2 mils (0.002" / 0.05 mm) in width.
- Prolongs life of cracked concrete.
- Penetrates/seals surface of slabs from water absorption, chloride-ion intrusion, and chemical attack.
- **Structurally** improves concrete surface.
- Can be open to traffic in 6 hours at 73°F (23°C).
- High bond strength, even in damp cracks.
- **U.S. Patent No. (pending)** for ultra low viscosity healer/sealer to strengthen cracked concrete.

Coverage

1 gal. (3.8 Liters) yields 231 cu. in. (3,785 cm^3)
Typical coverage is 150-175 sq. ft./gal. (3.7-4.3 m^2/L) for surface sealing. Coverage varies with porosity and surface profile of substrate. Higher porosity concrete will reduce coverage. For crack healing, follow Application instructions and allow to pond over cracks.

Packaging

3 gal. (11.35 l) unit = 'A' = 2 gal. (7.6 l) + 'B' = 1 gal. (3.8 l)

Typical Data *[Material and curing conditions @ 73°F (23°C) and 50% R.H.]*

Shelf Life 2 years in original, unopened containers

Storage Conditions Store dry at 40°-95°F (4°-35°C). **Condition material to 65°-75°F (18°-24°C) before using.**

Color Clear, amber

Mixing Ratio Component 'A' : Component 'B' = 2:1 by volume

Viscosity (Mixed) Approximately 105 cps

Pot Life Approximately 20 minutes

Tack-Free Time	**40°F (4°C)***	**60°F (15°C)***	**73°F (23°C)***	**90°F (32°C)***
	> 11 hrs.	11 hrs.	6 hrs.	2.5 hrs.

Tensile Properties (ASTM D-638) 73°F (23°C)

7 day	Tensile Strength	7,100 psi (48.9 MPa)
	Elongation at break	10%

Bond Strength (ASTM C-882)

Hardened Concrete to Hardened Concrete	**2 day (moist cure)**	2,500 psi (17.2 MPa)
	14 day (moist cure)	2,500 psi (17.2 MPa)
Hardened Concrete to Steel	**2 day (moist cure)**	1,500 psi (10.3 MPa)
	14 day (moist cure)	1,600 psi (11.0 MPa)

Flexural Properties (ASTM D-790)

7 day	Flexural Strength	8,500 psi (58.6 MPa)
	Tangent Modulus of Elasticity	3.2 x 10^5 psi (2,206 MPa)

Shear Strength (ASTM D-732) **7 day** 5,800 psi (40.0 MPa)

Heat Deflection Temperature (ASTM D-648) **7 day**
[fiber stress loading = 264 psi (1.8 MPa) 110°F (43°C)

Water Absorption (ASTM D-570) **7 day** (24 hour immersion) 0.60%

Compressive Properties (ASTM D-695)

Compressive Strength, psi (MPa)	**40°F (4°C)***	**60°F (15°C)***	**73°F (23°C)***	**90°F (32°C)***
1 day	-	320 (2.2)	1,100 (7.6)	4,800 (33.1)
3 day	2,000 (13.8)	6,500 (44.8)	8,300 (57.2)	8,000 (55.2)
7 day	7,800 (53.8)	10,400 (71.7)	10,900 (75.1)	8,300 (57.2)
14 day	9,600 (66.2)	11,000 (75.8)	11,800 (81.4)	10,000 (68.9)
28 day	11,700 (80.7)	12,000 (82.7)	12,000 (82.7)	10,000 (68.9)

Compressive Modulus **7 day** **3.0 x 10^5 psi (2,068 MPa)**

*Material cured and tested at the temperature indicated.

C60

Figure B.2 Product data sheet for Sikadur 55 SLV by Sika.

Product Data Sheet
Edition 7.1.2008
Identification no. 389-35N
Sikadur 55 SLV

Sikadur 55 SLV

Super low-viscosity, moisture-tolerant epoxy resin, crack healer/penetrating sealer

Description Sikadur 55 SLV is a 2-component, 100% solids, moisture-tolerant, epoxy crack healer / penetrating sealer, having a fast tack-free time to minimize downtime. It is a super low-viscosity, high-strength adhesive formulated specifically for sealing both dry and damp cracks. It conforms to the current ASTM C-881 and AASHTO M-235 specifications.

Where to Use
- Sikadur 55 SLV structurally repairs cracked concrete.
- For interior slabs and exterior above-grade slabs.
- For elevated horizontal decks, parking garages and other structures exposed to foot and pneumatic tire traffic.

Advantages
- Super low viscosity/low surface tension for excellent penetration into cracks.
- Penetrates cracks by gravity down to 2 mils (0.002" / 0.05 mm) in width.
- Prolongs life of cracked concrete.
- Penetrates/seals surface of slabs from water absorption, chloride-ion intrusion, and chemical attack.
- **Structurally** improves concrete surface.
- Can be open to traffic in 6 hours at 73°F (23°C).
- High bond strength, even in damp cracks.
- **U.S. Patent No. (pending)** for ultra low viscosity healer/sealer to strengthen cracked concrete.

Coverage 1 gal. (3.8 Liters) yields 231 cu. in. (3,785 cm³)
Typical coverage is 150-175 sq. ft./gal. (3.7-4.3 m²/L) for surface sealing. Coverage varies with porosity and surface profile of substrate. Higher porosity concrete will reduce coverage. For crack healing, follow Application instructions and allow to pond over cracks.

Packaging 3 gal. (11.35 l) unit = 'A' = 2 gal. (7.6 l) + 'B' = 1 gal. (3.8 l)

Typical Data *[Material and curing conditions @ 73°F (23°C) and 50% R.H.]*

Shelf Life 2 years in original, unopened containers

Storage Conditions Store dry at 40°-95°F (4°-35°C). **Condition material to 65°-75°F (18°-24°C) before using.**

Color Clear, amber

Mixing Ratio Component 'A' : Component 'B' = 2:1 by volume

Viscosity (Mixed) Approximately 105 cps

Pot Life Approximately 20 minutes

Tack-Free Time	40°F (4°C)*	60°F (15°C)*	73°F (23°C)*	90°F (32°C)*
	> 11 hrs.	11 hrs.	6 hrs.	2.5 hrs.

Tensile Properties (ASTM D-638) 73°F (23°C)

7 day	Tensile Strength	7,100 psi (48.9 MPa)
	Elongation at break	10%

Bond Strength (ASTM C-882)

Hardened Concrete to Hardened Concrete	**2 day (moist cure)**	2,500 psi (17.2 MPa)
	14 day (moist cure)	2,500 psi (17.2 MPa)
Hardened Concrete to Steel	**2 day (moist cure)**	1,500 psi (10.3 MPa)
	14 day (moist cure)	1,600 psi (11.0 MPa)

Flexural Properties (ASTM D-790)

7 day	Flexural Strength	8,500 psi (58.6 MPa)
	Tangent Modulus of Elasticity	3.2×10^5 psi (2,206 MPa)

Shear Strength (ASTM D-732) 7 day 5,800 psi (40.0 MPa)

Heat Deflection Temperature (ASTM D-648) 7 day
[fiber stress loading = 264 psi (1.8 MPa) 110°F (43°C)

Water Absorption (ASTM D-570) 7 day (24 hour immersion) 0.60%

Compressive Properties (ASTM D-695)

Compressive Strength, psi (MPa)

	40°F (4°C)*	60°F (15°C)*	73°F (23°C)*	90°F (32°C)*
1 day	-	320 (2.2)	1,100 (7.6)	4,800 (33.1)
3 day	2,000 (13.8)	6,500 (44.8)	8,300 (57.2)	8,000 (55.2)
7 day	7,800 (53.8)	10,400 (71.7)	10,900 (75.1)	8,300 (57.2)
14 day	9,600 (66.2)	11,000 (75.8)	11,800 (81.4)	10,000 (68.9)
28 day	11,700 (80.7)	12,000 (82.7)	12,000 (82.7)	10,000 (68.9)

Compressive Modulus 7 day 3.0 x 10⁵ psi (2,068 MPa)

*Material cured and tested at the temperature indicated.

Construction

C60

Figure B.2 (cont.) Product data sheet for Sikadur 55 SLV by Sika.

DURAL® 335

ULTRA LOW VISCOSITY, PENETRATING EPOXY CRACK HEALER-SEALER

COATINGS - TRAFFIC DECK

DESCRIPTION

DURAL 335 is a solvent free, two component, moisture insensitive, ultra low viscosity epoxy penetrating sealer. It is also a healer for damp and dry cracks.

PRIMARY APPLICATIONS

Used interior and exterior to structurally seal slabs. Gravity feed and pressure inject cracks on:

- Bridge decks
- Roadways
- Airport runways
- Parking garage decks and ramps

FEATURES/BENEFITS

- Penetrating epoxy crack healer-sealer
- Alternative to hazardous methylmethacrylates
- Solvent free, no odor
- Ultra low viscosity
- High strength
- Moisture insensitive
- Protects treated surface from salts, chemicals, and water absorption

TECHNICAL INFORMATION

Material Properties @ 75°F (24°C), 50% R.H.	
Mixing Ratio (A : B) by volume	4:1
Mixed Viscosity, cps	80 to 100
Gel Time (100 gms), mins.	40 to 50
Pot life (1.25 gal unit), mins.	20 to 25
Tensile Strength, ASTM D 638, psi (MPa)	7,000 to 8,000 (48.3 to 55.2)
Tensile Modulus, psi (MPa)	300,000 (2068)
Tensile Elongation, %, ASTM D 638	1 to 5
Compressive Strength, psi (MPa), mortar ASTM C 109 (3 parts sand)	8,000 to 9,000 (55.2 to 62.1)
Slant Shear Bond Strength, psi (MPa) ASTM C 882	1,800 to 2,000 (12.4 to 13.8)
Flexural Strength, psi (MPa), ASTM D 790	9,000 to 10,500 (62.1 to 72.4)

Values presented are typical laboratory data

PACKAGING

DURAL 335 is available in 1.25 gal 2 pack/case (4.73 L) and 5 gal (19.9 L) units.

SHELF LIFE

1 year in original, unopened package.

COVERAGE

Slab sealing: 100 to 200 ft²/gal (2.45 to 4.91 m²/L) for typical concrete surfaces. **Crack grouting:** Coverage depends on extent and depth of cracking.

DIRECTIONS FOR USE

Surface Preparation: Surface must be structurally sound, clean, dry and free of laitance, dust, dirt, oil, coatings, form release agents and other contaminants. Remove contamination by sandblasting or shotblasting.

DURAL® 335

Master Format #: 03 64 23

The Euclid Chemical Company
19218 Redwood Rd. • Cleveland, OH 44110
Phone: [216] 531-9222 • Toll-free: [800] 321-7628 • Fax: [216] 531-9596
www.euclidchemical.com

An RPM Company

Figure B.3 Product data sheet for Dural 335 by Euclid.

Remove defective concrete, honeycomb, cavities, joint cracks and voids by routing to sound material. Rebuild areas with suitable patching materials.Smooth, precast and formed concrete surfaces must be cleaned, roughened and made absorptive by sandblasting or shotblasting. Blow debris and residue out of cracks and from the surface with a moisture-free and oil-free air jet. Mask expansion joint sealants to prevent adhesion of DURAL 335 to the joint surface. Surfaces and cracks must be completely dry before DURAL 335 application to obtain maximum penetration. For further information contact your local Euclid Chemical representative.

Mixing: Premix Part A and Part B. Combine 4 parts by volume of Part A (Base) to 1 part by volume of Part B (Hardener) in a clean container, and mix thoroughly with a slow speed motor and "Jiffy" mixer. Scrape the bottom and side of the mixing container at least once. Do not aerate mixture.

Application: Sealing slabs: Pour the mixed DURAL 335 onto the prepared surface in a wave form and distribute evenly with a short nap roller or squeegee to fill voids, cracks and porous areas. Before the resin becomes tacky, use a squeegee on a smooth surface and a broom on textured surfaces to remove any excess resin that has not penetrated the surface. To improve skid resistance of the surface or where subsequent topping or coating application is desired, broadcast 0.2 to 0.8 lbs/yd² (.11 to .43 kg/m²) of silica sand not earlier than twenty minutes (at 75°F [24°C]) after application of DURAL 335 but before the DURAL 335 begins to become tack free. Ensure that the coating or toppings are applied within the recoat window of the application conditions. **Grouting cracks: Gravity feed**: Pour neat mixed DURAL 335 into vee-notched cracks until completely filled. **Pressure injection:** Set appropriate injection ports depending on the system used. Seal around port and surface of crack using a Euclid Chemical Fast Set Epoxy Gel. Inject neat resin using automated (2 part injection unit) or manual methods (caulking gun). Maintain slow steady pressure until the crack is filled with the injection resin.

CLEAN-UP

Clean tools and equipment immediately following use with methyl ethyl ketone or acetone. Clean spills or drips while still wet with the same solvent. Dried DURAL 335 will require mechanical abrasion for removal.

PRECAUTIONS/LIMITATIONS

- Store at tempatures between 50°F to 90°F (10°C to 32°C).
- Do not store below 50°F (10°C).
- Apply DURAL 335 when surface and ambient temperatures are between 50°F to 90°F (10°C to 32°C).
- In some cases, on highly porous surfaces, a second coat may be required.
- If a second coat is required contact your local Euclid Chemical representative for a recommendation.
- Multiple applications of DURAL 335 at 75°F (24°C) must be within 24 hours of the preceding application.
- Excess DURAL 335 left on the concrete surface will reduce skid resistance.
- Apply a test area to confirm suitability. DURAL 335 is not intended for sealing cracks under hydrostatic pressure.
- Allow new concrete to cure 28 days before DURAL 335 application.
- In all cases, consult the Material Safety Data Sheet before use.

Rev. 10.09

Figure B.3 (cont.) Product data sheet for Dural 335 by Euclid.

BASF

The Chemical Company

PRODUCT DATA

7 07 18 00 **Concrete Rehabilitation**

DEGADECK® CRACK SEALER PLUS

Reactive methacrylate resin for sealing cracks and concrete decks

Description

DEGADECK® Crack Sealer Plus is a very low viscosity, low surface tension, solvent free, rapid curing reactive methacrylate resin formulated to penetrate, repair and seal cracks in concrete substrates.

POWDER HARDENER is 50% dibenzoyl peroxide (BPO) in granulated powder form to initiate the cure of the DEGADECK® resin.

Yield

100 ft²/gallon (2.5 m²/L), depending on number and volume of cracks as well as porosity of concrete.

Powder Hardener:
See mixing charts for the appropriate products.

Packaging

DEGADECK® Crack Sealer Plus is sold by weight and packaged in 38 lb (17.3 kg) pails and 396 lb (180 kg) drums. This is equivalent to 4.7 gallons (17.8 L) and 49 gallons (185.5 L) respectively.

Powder Hardener:
2.5 lb bottle
50 lb box

Color

Clear liquid

Shelf Life

1 year when properly stored

Storage

Store in cool, clean, dry area. Keep out of direct sunlight. Maximum storage temperature is 86° F (30° C). Store in original and unopened container.

Features	Benefits
• Fast curing (1 hour)	On highway and bridge projects, allows fast return of traffic flow, contributing directly to worker and driver safety
• UV resistance	Exposure to sunlight does not affect product performance
• Weather and aging resistant	Provides long-lasting service life
• 2 component	User friendly; ease of installation; shelf life stable
• Compatible with other DEGADECK® methacrylate systems	Provides complete systems approach to concrete protection
• Protects against water and chloride ion ingress	Prevents premature deterioration
• Can be used at temperatures ranging from 14 to 104° F (-10 to 40° C)	Extended application season

Where to Use

APPLICATION

- Bridge decks
- Parking structures
- Civil engineering applications
- Penetrating flood coat sealer to prevent moisture and ion ingress into substrate

LOCATION

- Exterior
- Horizontal

SUBSTRATE

- Concrete

How to Apply

Surface Preparation

1. Inspect the concrete substrate before preparation. Note the location of surface cracks and the presence of contaminants. Concrete surfaces must be dry and free of dust, dirt, oil, wax, curing compounds, efflorescence, laitance, and all other bondbreaking materials.
2. Inspect the underside of the deck for signs of leakage due to full depth cracks.
3. Check weather forecast to ensure dry conditions. Wet substrates must be allowed to dry prior to beginning work.
4. Using a dust-free, mobile shotblaster or gritblaster, brush-blast the substrate to expose surface cracking.
5. Do not use wet preparation methods.
6. Perform a second inspection, noting newly-found surface cracks. Mark these for pre-treatment. Clean out cracks and the deck surface with oil-free compressed air.

Figure B.4 Product data sheet for Degadeck Crack Sealer Plus by BASF.

MBT® PROTECTION & REPAIR PRODUCT DATA
DEGADECK® CRACK SEALER PLUS

Technical Data

Composition

DEGADECK® Crack Sealer Plus is a reactive methacrylate resin.

Compliances

- DEGADECK® Crack Sealer Plus is classified under DOT regulations as Resin Solution, UN 1866, Class 3, PG II.

Test Data

PROPERTY	RESULTS	TEST METHODS
Appearance	Liquid	
Specific gravity	0.97	ASTM D 4669
Viscosity, cP (mPa-sec), at 73° F (23° C)	5-15	ASTM D 2393
Flash point, ° F (° C)	48 (9)	ASTM D 3278
Tensile strength, psi (MPa)	8,100 (56.4)	ASTM D 638
Compressive, psi (MPa)	12,800 (88.2)	ASTM D 638
Flexural Strength, psi (MPa)	11,550 (79.6)	ASTM D 638
Elongation at break, %	5.5	ASTM D 638
Hardness, Shore D	> 80	ASTM D 2240
Water absorption, % / 24 hrs	0.60	ASTM D 570

Mixing

DEGADECK® Crack Sealer Plus must be mixed with the appropriate amount of Powder Hardener just prior to application. Air/substrate temperature determines the amount as follows:

DEGADECK CRACK SEALER (1 GALLON)

TEMPERATURE ° F (° C)	WEIGHT %	VOLUME OUNCES
41 (5)	5	11
50 (10)	4	8.5
59 (15)	3	6.5
68 (20)	2	4
86 (30)	1	2

* Please consult BASF Technical Services for applications outside this temperature range.

At temperatures below 40° F, the DEGADECK® Crack Sealer Plus requires the addition of a cold weather additive for proper curing. Below are the instructions for use.

- Add 12 vol. oz. DEGADECK® CW Additive to 1 gallon DEGADECK® Crack Sealer Plus. Mix approximately 1 minute.
- Add hardener powder (BPO) to above mixture per ratios below. Quantities are calculated per 1 gallon batch of a (above).

TEMPERATURE ° F	VOLUME OUNCES	CURING TIME (MIN)
40	4	35
32	6.5	40
23	11	60
14	11	90

CAUTION: DO NOT MIX HARDENER POWDER (BPO) INTO DEGADECK® CW ADDITIVE, ONLY ADD PREMIXED BATCH AS IN (a) ABOVE.

Using clean, dry plastic buckets, add Powder Hardener to DEGADECK® Crack Sealer Plus and mix until dissolved (approximately 1 minute). Mixed DEGADECK® Crack Sealer Plus must be applied immediately. Do not exceed 5-gallon (20 L) batch mixes.

Application

1. DEGADECK® Crack Sealer Plus is applied as a flood coat in a gravity-fed process by broom or roller.
2. The contents of the mixed batch should be immediately poured onto the substrate and worked into cracks by distributing with 1/2" to 3/4" (13 – 20 mm) nap solvent grade rollers or broom. Do not allow material to pond. Application rate is 100 ft²/gal (2.5 m²/L).
3. Do not allow the mixed batch to remain in the mixing vessel. It is advisable to randomly broadcast a 30 mesh (600 μm), dry aggregate into the wet, uncured resin at the rate of approximately 4 lb/100 ft² (200 g/m²).
4. Working time for ® Crack Sealer Plus is between 10 and 15 minutes once it has been applied to the substrate. Full cure to specification will be between 45 minutes and 1 hour.

Pre-Treat Wide Cracks

Cracks over 1/8" (3 mm) should be treated individually prior to deck application. Full depth cracks may require alternative treatment to prevent runoff of resin. Fill wider cracks with dry, 30 mesh silica sand. Mix a small amount of ® Crack Sealer Plus, pour into cracks and distribute with a paint brush. Squeeze bottles can also be used.

Drying Time

Allow one hour for DEGADECK® Crack Sealer Plus to gain full mechanical properties. Check for dry-to-touch condition. End result should be a darker-colored, matte finish with a minimal surface film and some loose broadcast aggregate. Open to traffic.

Figure B.4 (cont.) Product data sheet for Degadeck Crack Sealer Plus by BASF.

MBT® PROTECTION & REPAIR PRODUCT DATA
DEGADECK® CRACK SEALER PLUS

Clean Up

Clean tools as needed with MMA, acetone, ethyl acetate or similar solvents.

For Best Performance

- Application temperature range of substrate is between 14 and 104° F (-10 and 40° C).
- DEGADECK® Crack Sealer Plus is NOT a high molecular weight methacrylate (HMWM).
- DO NOT use for vertical surface treatments.
- DEGADECK® Crack Sealer Plus is a sacrificial film that will wear out over time, however the cracks will continue to be protected.
- Periodically inspect the applied material and repair localized areas as needed. Consult a BASF representative for additional information.
- Make certain the most current versions of product data sheet and MSDS are being used; call Customer Service (1-800-433-9517) to verify the most current version.
- Proper application is the responsibility of the user. Field visits by BASF personnel are for the purpose of making technical recommendations only and not for supervising or providing quality control on the jobsite.

Health and Safety

DEGADECK® CRACK SEALER PLUS

Warning

DEGADECK® Crack Sealer Plus contains methyl methacrylate; acrylic polymer; and methacrylic acid ester.

Risks

FLAMMABLE LIQUID AND VAPOR. May cause skin and eye irritation. Ingestion may cause irritation. Inhalation of vapors may cause irritation and intoxication with headaches, dizziness and nausea. Repeated exposure may cause injury to the kidneys and liver. Repeated or prolonged overexposure may cause central nervous system damage. May cause dermatitis and allergic responses. Repeated or prolonged contact with skin may cause sensitization.

Precautions

KEEP AWAY FROM HEAT, FLAME AND SOURCES OF IGNITION. Heat, aging, or contamination may lead to violent rupture of sealed containers. Vapors are heavier than air. Keep container closed. Check periodically for warm or bulging containers. Use only with adequate ventilation. DO NOT get in eyes, on skin or on clothing. Wash thoroughly after handling. DO NOT breathe vapors. DO NOT take internally. Use impervious gloves, eye protection and if the TLV is exceeded or used in a poorly ventilated area, use NIOSH approved respiratory protection in accordance with applicable Federal, state and local regulations. Empty container may contain hazardous residues. All label warnings must be observed until container is commercially cleaned or reconditioned.

First Aid

FIRST AID MEASURES: In case of eye contact, flush thoroughly with water for at least 15 minutes. SEEK IMMEDIATE MEDICAL ATTENTION. In case of skin contact, wash affected areas with soap and water. If irritation persists, SEEK MEDICAL ATTENTION. Remove and wash contaminated clothing. If inhalation effects occur, remove to fresh air. If discomfort persists or any breathing difficulty occurs, or if swallowed, SEEK IMMEDIATE MEDICAL ATTENTION.

Refer to Material Safety Data Sheet (MSDS) for further information.

VOC Content

< 250 g/L or 2.09 lbs/gallon, less water and exempt solvents.

POWDER HARDENER

Danger - Organic Peroxide

Powder Hardener contains dibenzoyl peroxide; and dicyclohexyl phthalate.

Risks

May cause skin, eye and respiratory irritation. May cause dermatitis and allergic responses. Repeated or prolonged contact with skin may cause sensitization. May cause dermatitis and allergic responses. Ingestion may cause irritation.

Precautions

KEEP AWAY FROM HEAT, FLAME AND SOURCES OF IGNITION. Use only with adequate ventilation. Avoid contact with skin, eyes and clothing. Keep container closed when not in use. Wash thoroughly after handling. DO NOT take internally. Prevent inhalation of dust. Use impervious gloves, eye protection and if the TLV is exceeded or used in a poorly ventilated area, use NIOSH/MSHA approved respiratory protection in accordance with applicable Federal, state and local regulations. Empty container may contain hazardous residues. All label warnings must be observed until container is commercially cleaned or reconditioned.

First Aid

In case of eye contact, flush thoroughly with water for at least 15 minutes. In case of skin contact, wash affected areas with soap and water. If irritation persists, SEEK MEDICAL ATTENTION. Remove and wash contaminated clothing. If inhalation causes physical discomfort, remove to fresh air. If discomfort persists or any breathing difficulty occurs or if swallowed, SEEK IMMEDIATE MEDICAL ATTENTION.

Refer to Material Safety Data Sheet (MSDS) for further information.

VOC Content

0 g/L or 0 lbs/gallon, less water and exempt solvents when components are mixed and applied per manufacturer's instructions.

DEGADECK® CRACK SEALER PLUS CW

Warning

DEGADECK® Crack Sealer Plus CW contains n,n-Dimethyl-p-toluidine.

Risks

Toxic by inhalation, in contact with skin or by ingestion. May cause skin, eye and respiratory irritation. Prolonged exposure to vapors or repeated skin exposures may effect liver, nervous system and blood-forming system and may cause fatigue, loss of appetite, headache and dizziness. Can be absorbed through skin and may cause loss of oxygen-carrying capacity of blood.

Figure B.4 (cont.) Product data sheet for Degadeck Crack Sealer Plus by BASF.

MBT® PROTECTION & REPAIR PRODUCT DATA
DEGADECK® CRACK SEALER PLUS

Precautions

Avoid contact with skin, eyes and clothing. Wash thoroughly after handling. DO NOT breathe vapors. Use only with adequate ventilation. Keep container closed. Use impervious gloves, eye protection and if the TLV is exceeded or if used in a poorly ventilated area, use NIOSH/MSHA approved respiratory protection in accordance with applicable Federal, state and local regulations. Empty container may contain hazardous resides.

First Aid

In case of eye contact, flush thoroughly with water for at least 15 minutes. SEEK IMMEDIATE MEDICAL ATTENTION. In case of skin contact, wash affected areas with soap and water. If irritation persists, SEEK MEDICAL ATTENTION. Remove and wash contaminated clothing. If inhalation causes physical discomfort, remove to fresh air. If not breathing, give artifical respiration. If breathing is difficult, administer oxygen. SEEK IMMEDIATE MEDICAL ATTENTION. If swallowed, SEEK IMMEDIATE MEDICAL ATTENTION. Refer to Material Safety Data Sheet (MSDS) for further information.

VOC Content

0 g/L or 0 lbs/gal less water and exempt solvents.

For medical emergencies only,
Call ChemTrec (1-800-424-9300).

® = registered trademark
DEGADECK® = trademark of Evonik Röhm GmbH, Darmstadt / Germany

BASF Construction Chemicals, LLC – Building Systems
889 Valley Park Drive
Shakopee, MN, 55379
www.BuildingSystems.BASF.com

Customer Service 800-433-9517
Technical Service 800-243-6739

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Figure B.4 (cont.) Product data sheet for Degadeck Crack Sealer Plus by BASF.

B.2. Deck Sealing Products

Products were ranked first by how they were ranked in their original study. These lists were then merged based on product performance across studies. The types of studies included laboratory studies, field studies, and literature reviews, broken down as follows:

- Laboratory Studies—Pincheira and Dorshorst (2005)
- Field Studies—Morse (2009), Hagen (1995), Soriano (2003)
- Literature Reviews—Johnson et al. (2009), Krauss et al. (2009)

The general findings from the literature review were:

- Johnson et al. (2009) recommended solvent-based silane with 40% solids as the best category of sealant, though water-based silane would be acceptable if environmental restrictions are present.
- Krauss et al. (2009) found that silane, epoxy, and methacrylates were respectively, the first, second, and third most popular deck sealers.

Performance Level	VOC	Chemical Type	Product Name	Brand Name (Former Company)	Comments
Good	589 g/L	Silane, solvent (40%)	Sonneborn Penetrating Sealer 40 VOC	Discontinued by BASF (ChemRex., Inc.)	Was given the highest ranking by Pincheira (2005)
	589 g/L	Silane, solvent (40%)	Hydrozo Silane 40 VOC	BASF (ChemRex, Inc.)	Was given the highest ranking by Pincheira (2005), Showed good performance in Hagen (1995)
	399 g/L	Silane, water (40%)	Hydrozo Enviroseal 40	BASF (ChemRex, Inc.)	Was given a moderate ranking by Pincheira (2005), Showed good performance in Hagen (1995)
		Silane	100% Silane	BASF (Degussa, Inc.)	Recommended in study by Soriano (2003)
		Silane	Hydrozo 40	BASF (ChemRex, Inc.)	Recommended in study by Soriano (2003)
		Silane	40% Silane	BASF (Masterbuilders)	Recommended in study by Soriano (2003)
		Silane/Siloxane, solvent (40%)	Dekguard P-40		Showed good performance in Hagen (1995)
		Siloxane, solvent (15%)	Paragon 15		Showed good performance in Hagen (1995)
		Linseed Oil	Protective Coat		Showed good performance in Morse (2009) w/ 5yr lifetime
Moderate	260 g/L	Silane, water (40%)	Powerseal 40%	Vexcon Chemical	Was given a moderate ranking by Pincheira (2005)
	0 g/L	Siliconate	V-Seal	TARA Distribution Group	Was given a moderate ranking by Pincheira (2005)
	496 g/L	Silane, solvent (40%)	Certi-Vex® Penseal 244 40%	Vexcon Chemical	Was given a moderate ranking by Pincheira (2005)
	741 g/L	Siloxane, solvent	TK-290 WDOT (or TK-290 Tri-Siloxane)	TK Products	Was given a moderate ranking by Pincheira (2005), Showed good performance in Morse (2009) w/ 4yr
	350 g/L	Silane, water (20%)	Aqua-Trete BSM 20	BASF (Degussa, Inc.)	Was given a moderate ranking by Pincheira (2005)
	140 g/L	Siloxane, water	TK-290 WB	TK Products	Was given a poor ranking by Pincheira (2005), Showed good performance in Morse (2009) w/ 5yr lifetime
	245 g/L	Silane/Siloxane (20%)	Dur A Pell 20	Chemprobe Technologies, Inc.	Showed moderate performance in Morse (2009) w/ 4yr lifetime
	344 g/L	Silane (>95%)	Dur A Pell 100	Chemprobe Technologies, Inc.	Showed moderate performance in Morse (2009) w/ 4yr lifetime
		Silane, water (40%)	Sil-Act Multiguard	Advanced Chemical Technologies	Showed moderate performance in Morse (2009) w/ 4yr lifetime, Showed poor performance in Hagen (1995)
		Silane/Siloxane, water	BARACADE WB 244	Euclid Chemical (Tamms Industries)	Showed moderate performance in Morse (2009) w/ 4yr lifetime
		Epoxy, water	Horsey Set WDE		Showed moderate performance in Hagen (1995)
		Silane, solvent (20%)	Deck Seal PD 20		Showed moderate performance in Hagen (1995)
		Silane, solvent (40%)	Stifel H		Showed moderate performance in Hagen (1995)

Figure B.5 Deck sealer product compilation.

Performance Level	VOC	Chemical Type	Product Name	Brand Name (Former Company)	Comments
Poor	399 g/L	Silane, water (20%)	Hydrozo Enviroseal 20	BASF (ChemRex, Inc.)	Was given a poor ranking by Pincheira (2005)
	50 g/L	Siloxane/Silane, water	Baracade WB 244	Euclid Chemical (Tamms Industries)	Was given a poor ranking by Pincheira (2005)
	723 g/L	Siloxane, solvent	Eucoguard 100	Euclid Chemical Company	Was given a poor ranking by Pincheira (2005)
	< 350 g/L	Silane, solvent (40%)	Aquanil Plus 40	Chemmasters	Was given a poor ranking by Pincheira (2005)
	701 g/L	Silane/Siloxane (15%)	Deck A Pell (15%)	Chemprobe Technologies, Inc.	Showed poor performance in Morse (2009) w/ 3yr lifetime
		Silicate	ChemTec One	ChemTech International Inc.	Showed poor performance in Morse (2009) w/ 1yr lifetime
		Silane, solvent (30%)	Deck Seal PD 30		Showed poor performance in Hagen (1995)
		Silane, solvent (40%)	Sil Act ATS 42		Showed poor performance in Hagen (1995)
		Siloxane, solvent (9.2%)	Sikaguard 70	Sika USA	Showed poor performance in Hagen (1995)
		Silane, water and acrylic	Dekguard WB		Showed poor performance in Hagen (1995)
			Genii 315 + 615		Showed poor performance in Hagen (1995)
		Silicate	Trojan Masonary Sealer		Showed poor performance in Hagen (1995)
		Thermoplastic resins, water (25%)	Genii 115		Showed poor performance in Hagen (1995)
		Thermoplastic resins, naphtha (16%)	Genii 315		Showed poor performance in Hagen (1995)

Figure B.5 (cont.) Crack sealer product compilation.

BASF

The Chemical Company

PRODUCT DATA

7 07 19 16 **Water Repellents**

HYDROZO® SILANE 40 VOC

Clear, solvent-based, VOC-compliant, silane penetrating sealer

Description

Hydrozo® Silane 40 VOC is a clear, breathable, solvent-based, VOC-compliant, greater than 40% alkylakoxysilane penetrating sealer. It penetrates deeply and chemically reacts with concrete to form a long-lasting water-repellent surface.

Yield

Poured in place and precast concrete: 125 – 225 ft²/gallon (3.1 – 5.5 m²/L)

Coverage may vary greatly with porosity of the substrate; extremely porous substrates may require 2 coats. Perform test panels to ensure desired results and coverage rates.

Packaging

5 gallon (18.9 L) pails

53 gallon (201 L) drums

Color

Clear

Shelf Life

18 months when properly stored.

Storage

Store in unopened containers in a clean, dry area between 35 and 110° F (2 and 43° C).

Features	Benefits
• Greater than 40% silane	Penetrates deeply into the substrate
• Water repellent	Helps to protect from damage caused by chloride intrusion, extends life of structures
• Solvent based	Excellent for cold-weather applications
• Breathable	Allows interior moisture to escape without damaging sealer
• Transparent, nonstaining	Does not alter the natural surface appearance
• Surface sealing	Helps reduce efflorescence, atmospheric staining, and mildew
• VOC compliant	Environmentally friendly

Where to Use

APPLICATION

- Parking decks
- Bridges
- Stadiums

LOCATION

- Horizontal
- Exterior
- Above grade

SUBSTRATE

- Concrete: precast, prestressed, and poured in place

How to Apply

Surface Preparation

1. Verify substrate has properly cured. Concrete should obtain 80% of design strength, typically achieved within 14 – 28 days.
2. Clean all surfaces of all sand, surface dust and dirt, oil, grease, chemical films and coatings, and other contaminants prior to application. Use waterblast, sandblast, or shotblast as necessary to achieve the desired surface condition.
3. Air, material, and surface temperatures should be 40° F (4° C) or higher during application. Do not apply sealer when temperatures are expected to fall below 20° F (-7° C) within 12 hours or when rain is expected within 4 hours following the application.
4. Hydrozo® Silane 40 VOC may be applied to slightly damp surfaces.
5. Caulking and sealant work may be done before or after the application of the sealer. Allow sealant to cure fully cured before application of Hydrozo® Silane 40 VOC.

HYDROZO

Figure B.6 Product data sheet for Hydrozo Silane 40 VOC by BASF.

HYDROZO® PRODUCT DATA
HYDROZO® SILANE 40 VOC

Technical Data

Composition

Hydrozo® Silane 40 VOC is an alcohol-based alkylalkoxysilane product.

Typical Properties

PROPERTY	VALUE
Active alkylalkoxysilane content, % by weight	> 40
Penetration, in (mm), average depth, depending upon substrate	0.20 (5)
Surface appearance after application	Unchanged

Test Data

PROPERTY	RESULTS	TEST METHODS
Flash point, ° F (° C)	53 (12)	SETA, IPA
Waterproofing after abrasion, %, at 225 ft²/gal (5.6 m²/L)	88.4	Alberta Transportation and Utilities Type 1B
Resistance to chloride, lb/yd³ Criteria of 1.5 at 1/2" Criteria of 0.75 at 1"	 < 0.2 < 0.00	
Water weight gain, % reduction, at 200 ft²/gal (5 m²/L)	86 – exceeds criteria	NCHRP 244 Series II-cube test
Absorbed chloride, % reduction, at 200 ft²/gal (5 m²/L)	92 – exceeds criteria	NCHRP 244 Series II-cube test
Absorbed chloride, % reduction, at 200 ft²/gal (5 m²/L)	99 – exceeds criteria	NCHRP 244 Series IV - Southern climate
Moisture-vapor transmission rate, %	102	OHD-L-35

Test results are averages obtained under laboratory conditions. Reasonable variations can be expected.

Figure B.6 (cont.) Product data sheet for Hydrozo Silane 40 VOC by BASF.

Application

1. Test a small area of the surface (generally a 5 by 5 ft [1.5 by 1.5 m] section) before starting general application of any clear penetrating sealer to ensure desired results and coverage rates. Allow 5 – 7 days for the product to fully react before evaluating. Refer to Appendix HY-3: Test Area Application.

2. Stir material thoroughly before and during application.

3. Apply to saturation using low-pressure non-atomizing spray or pouring, followed by a squeegee or a broom for even distribution.

Drying Time

Typical drying time for Hydrozo® Silane 40 VOC is 4 hours at 70° F (21° C) and 50% relative humidity. Cooler temperatures or higher relative humidity can extend the drying time.

Clean Up

Clean equipment with mineral spirits or xylene.

For Best Performance

- Do not apply during inclement weather or when inclement weather is anticipated within 12 hours.
- Protect asphalt-based products, such as roofing materials, plastic products, shrubbery, and plant life from overspray.
- Take caution with specially coated glass. Test small areas before application to ensure the product does not discolor the coating.
- To prevent damage to nearby shrubbery and landscaping, cover or protect with drop cloth.
- Paint line striping after the application of the sealer.
- Plastic windows will turn opaque when sprayed with this product.
- Variations in the texture and porosity of the substrate will affect the coverage and performance of the product.
- Hydrozo® Silane 40 VOC will not inhibit water penetration through unsound or cracked surfaces, or surfaces with defective flashing, caulking, or structural waterproofing.
- Make certain the most current versions of product data sheet and MSDS are being used; call Customer Service (1-800-433-9517) to verify the most current versions.
- Proper application is the responsibility of the user. Field visits by BASF personnel are for the purpose of making technical recommendations only and not for supervising or providing quality control on the jobsite.

Health and Safety

HYDROZO® SILANE 40 VOC

Warning

Hydrozo® Silane 40 VOC contains isopropyl alcohol and alkoxysilane.

Risks

Flammable liquid and vapor. May cause skin and eye irritation. Inhalation of vapors may cause irritation and intoxication with headaches, dizziness and nausea. Reports associate repeated or prolonged occupational overexposure to solvents with permanent brain, nervous system, liver and kidney damage. Ingestion may cause irritation of the mouth, throat and stomach with nausea and abdominal pain. INTENTIONAL MISUSE BY DELIBERATELY INHALING THE CONTENTS MAY BE HARMFUL OR FATAL.

Precautions

KEEP OUT OF THE REACH OF CHILDREN. KEEP AWAY FROM HEAT, FLAME AND SOURCES OF IGNITION. Avoid contact with skin, eyes, and clothing. Wash thoroughly after handling. Avoid breathing vapors. Keep container closed. Use only with adequate ventilation. DO NOT take internally. Use impervious gloves, eye protection and if the TLV is exceeded or used in a poorly ventilated area, use NIOSH/MSHA approved respiratory protection in accordance with applicable federal, state and local regulations. DO NOT cut or weld on or near empty container. Empty container may contain explosive vapors or hazardous residues. All label warnings must be observed until container is commercially cleaned or reconditioned.

First Aid

In case of eye contact, flush thoroughly with water for at least 15 minutes. SEEK IMMEDIATE MEDICAL ATTENTION. In case of skin contact, wash affected areas with soap and water. If irritation persists, SEEK MEDICAL ATTENTION. Remove and wash contaminated clothing. If inhalation causes physical discomfort, remove to fresh air. If discomfort persists or any breathing difficulty occurs, SEEK IMMEDIATE MEDICAL ATTENTION. If swallowed, SEEK IMMEDIATE MEDICAL ATTENTION. Should vomiting occur, keep victim's head below hips to avoid aspiration of vomitus into victim's lungs.

Refer to Material Safety Data Sheet (MSDS) for further information.

Proposition 65

This product does not knowingly contain chemicals listed by the state of California as known to cause cancer, birth defects or other reproductive harm.

VOC Content

Less than 5.01 lbs/gal or 600 g/L, less water and exempt solvents.

For medical emergencies only, call ChemTrec (1-800-424-9300).

Figure B.6 (cont.) Product data sheet for Hydrozo Silane 40 VOC by BASF.

HYDROZO® PRODUCT DATA
HYDROZO® SILANE 40 VOC

BASF Construction Chemicals, LLC – Building Systems

889 Valley Park Drive
Shakopee, MN, 55379

www.BuildingSystems.BASF.com

Customer Service 800-433-9517
Technical Service 800-243-6739

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Figure B.6 (cont.) Product data sheet for Hydrozo Silane 40 VOC by BASF.

BASF

The Chemical Company

PRODUCT DATA

7 07 19 16 **Water Repellents**

HYDROZO® SILANE 40 VOC

Clear, solvent-based, VOC-compliant, silane penetrating sealer

Description

Hydrozo® Silane 40 VOC is a clear, breathable, solvent-based, VOC-compliant, greater than 40% alkylakoxysilane penetrating sealer. It penetrates deeply and chemically reacts with concrete to form a long-lasting water-repellent surface.

Yield

Poured in place and precast concrete:

125 – 225 ft²/gallon (3.1 – 5.5 m²/L)

Coverage may vary greatly with porosity of the substrate; extremely porous substrates may require 2 coats. Perform test panels to ensure desired results and coverage rates.

Packaging

5 gallon (18.9 L) pails

53 gallon (201 L) drums

Color

Clear

Shelf Life

18 months when properly stored.

Storage

Store in unopened containers in a clean, dry area between 35 and 110° F (2 and 43° C).

Features	Benefits
• Greater than 40% silane	Penetrates deeply into the substrate
• Water repellent	Helps to protect from damage caused by chloride intrusion, extends life of structures
• Solvent based	Excellent for cold-weather applications
• Breathable	Allows interior moisture to escape without damaging sealer
• Transparent, nonstaining	Does not alter the natural surface appearance
• Surface sealing	Helps reduce efflorescence, atmospheric staining, and mildew
• VOC compliant	Environmentally friendly

Where to Use

APPLICATION

- Parking decks
- Bridges
- Stadiums

LOCATION

- Horizontal
- Exterior
- Above grade

SUBSTRATE

- Concrete: precast, prestressed, and poured in place

How to Apply

Surface Preparation

1. Verify substrate has properly cured. Concrete should obtain 80% of design strength, typically achieved within 14 – 28 days.

2. Clean all surfaces of all sand, surface dust and dirt, oil, grease, chemical films and coatings, and other contaminants prior to application. Use waterblast, sandblast, or shotblast as necessary to achieve the desired surface condition.

3. Air, material, and surface temperatures should be 40° F (4° C) or higher during application. Do not apply sealer when temperatures are expected to fall below 20° F (-7° C) within 12 hours or when rain is expected within 4 hours following the application.

4. Hydrozo® Silane 40 VOC may be applied to slightly damp surfaces.

5. Caulking and sealant work may be done before or after the application of the sealer. Allow sealant to cure fully cured before application of Hydrozo® Silane 40 VOC.

Figure B.7 Product data sheet for Enviroseal 40 by BASF.

HYDROZO® PRODUCT DATA
HYDROZO® SILANE 40 VOC

Technical Data

Composition

Hydrozo® Silane 40 VOC is an alcohol-based alkylalkoxysilane product.

Typical Properties

PROPERTY	VALUE
Active alkylalkoxysilane content, % by weight	> 40
Penetration, in (mm), average depth, depending upon substrate	0.20 (5)
Surface appearance after application	Unchanged

Test Data

PROPERTY	RESULTS	TEST METHODS
Flash point, °F (°C)	53 (12)	SETA, IPA
Waterproofing after abrasion, %, at 225 ft²/gal (5.6 m²/L)	88.4	Alberta Transportation and Utilities Type 1B
Resistance to chloride, lb/yd³ Criteria of 1.5 at 1/2" Criteria of 0.75 at 1"	 < 0.2 < 0.00	
Water weight gain, % reduction, at 200 ft²/gal (5 m²/L)	86 – exceeds criteria	NCHRP 244 Series II-cube test
Absorbed chloride, % reduction, at 200 ft²/gal (5 m²/L)	92 – exceeds criteria	NCHRP 244 Series II-cube test
Absorbed chloride, % reduction, at 200 ft²/gal (5 m²/L)	99 – exceeds criteria	NCHRP 244 Series IV - Southern climate
Moisture-vapor transmission rate, %	102	OHD-L-35

Test results are averages obtained under laboratory conditions. Reasonable variations can be expected.

Figure B.7 (cont.) Product data sheet for Enviroseal 40 by BASF.

HYDROZO® PRODUCT DATA
ENVIROSEAL® 40

Application

1. Test a small area of surface (generally a 5 by 5 ft [1.5 by 1.5 m] section) before starting general application of any clear penetrating sealer to ensure desired results and coverage rates. Allow 5 – 7 days for the product to fully react before evaluating.

2. Stir material thoroughly before and during application.

3. Apply to saturation. Apply by low-pressure non-atomizing spray or, if desired on horizontal surfaces, by pouring, followed by a squeegee or a broom for even distribution.

Drying Time

Typical drying time for Enviroseal® 40 is 4 hours at 70° F (21° C) and 50% relative humidity. Cooler temperatures or higher relative humidity can extend the drying time.

Clean Up

Clean equipment and tools with hot soapy water. Overspray can be cleaned immediately with hot soapy water. Dried residue can be cleaned with a mild citric acid or very hot water, then scrubbed with a plastic sponge.

For Best Performance

- Keep material from freezing.
- Do not dilute Enviroseal® 40.
- Do not apply during inclement weather or when inclement weather is anticipated within 12 hours.
- To prevent damage to nearby shrubbery and landscaping, cover or protect with drop cloth.
- Enviroseal® 40 may leave a temporary slippery surface for up to several hours after application. Therefore, traffic-bearing surfaces should not be reopened until the treated surface is dry.
- Variations in the texture and porosity of the substrate will affect the coverage and performance of the product.
- Enviroseal® 40 will not inhibit water penetration through unsound or cracked surfaces or surfaces with defective flashing, caulking, or structural waterproofing.
- Line striping can be done after application of the sealer.
- Make certain the most current versions of product data sheet and MSDS are being used; call Customer Service (1-800-433-9517) to verify the most current versions.
- Proper application is the responsibility of the user. Field visits by BASF personnel are for the purpose of making technical recommendations only and not for supervising or providing quality control on the jobsite.

Health and Safety

ENVIROSEAL® 40

Caution

Enviroseal® 40 contains alkoxysilane.

Risks

May cause skin, eye or respiratory irritation. Ingestion may cause irritation.

Precautions

KEEP OUT OF THE REACH OF CHILDREN. Avoid contact with skin, eyes, and clothing. Wash thoroughly after handling. Keep container closed when not in use. DO NOT take internally. Use only with adequate ventilation. Use impervious gloves, eye protection and if the TLV is exceeded or used in a poorly ventilated area, use NIOSH/MSHA approved respiratory protection in accordance with applicable federal, state and local regulations.

First Aid

In case of eye contact, flush thoroughly with water for at least 15 minutes. In case of skin contact, wash affected areas with soap and water. If irritation persists, SEEK MEDICAL ATTENTION. Remove and wash contaminated clothing. If inhalation causes physical discomfort, remove to fresh air. If discomfort persists or any breathing difficulty occurs or if swallowed, SEEK IMMEDIATE MEDICAL ATTENTION.

Refer to Material Safety Data Sheet (MSDS) for further information.

Proposition 65

This product contains material listed by the state of California to cause cancer, birth defects, or other reproductive harm.

VOC Content

Less than 2.92 lbs/gal or 350 g/L, less water and exempt solvents.

For medical emergencies only, call ChemTrec (1-800-424-9300).

Figure B.7 (cont.) Product data sheet for Enviroseal 40 by BASF.

HYDROZO® PRODUCT DATA
ENVIROSEAL® 40

BASF Construction Chemicals, LLC – Building Systems

889 Valley Park Drive
Shakopee, MN, 55379

www.BuildingSystems.BASF.com

Customer Service 800-433-9517
Technical Service 800-243-6739

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Figure B.7 (cont.) Product data sheet for Enviroseal 40 by BASF.

LINSEED OIL TREATMENT

CONCRETE SEALER

PENETRATING SEALERS & LIQUID DENSIFIERS

DESCRIPTION

LINSEED OIL TREATMENT is a blend of boiled linseed oil and solvents. When applied in a thin coating to concrete surfaces, it protects them from winter damage due to freeze-thaw cycling and the effects of de-icing salts. Two applications of the oil compound will protect concrete and increase its resistance to winter damage.

PRIMARY APPLICATIONS

- Roads and bridge decks
- Parking ramps and curbs
- Sidewalks and driveways
- Concrete exposed to freeze/thaw cycles
- Exterior concrete surfaces

FEATURES/BENEFITS

- Deep penetration
- Salt protection
- Ease of application
- Rapid drying

TECHNICAL INFORMATION

Typical Engineering Data

The following results were developed under laboratory conditions.

Suitable for exposure to traffic: ......4 to 6 hours

Viscosity: .... 25 to 35 secs. #1 Zahn Cup

Percent Solids by Volume .... Min: 50%

Flash Point: ....Above 112°F (44°C) TCC

VOC Content .... <400 g/L

Drying Time: 2 hours, depending on humidity and other climatic conditions.

Appearance

LINSEED OIL TREATMENT is a light brown material which will slightly darken concrete.

PACKAGING

LINSEED OIL TREATMENT is packaged in 55 gal (208 L) drums, and 5 gal (18.9 L) pails.

SHELF LIFE

2 years in original, unopened container.

SPECIFICATIONS/COMPLIANCES

- Linseed Oil Portion meets ASTM D 260
- Mineral Spirits Portion meets ASTM D 235

COVERAGE

Troweled Smooth	300 ft²/gal (7.4 m²/L)
Broomed Textured	400 ft²/gal (9.8 m²/L)

Material Requirements

A two coat application using a coverage rate of 300 ft²/gal (7.4 m²/L) for each coat will require approximately 6.7 gal (25.4 L) of material per 1000 ft² (92.9 m²) of area.

LINSEED OIL TREATMENT

Master Format #: 07 19 00

The Euclid Chemical Company
19218 Redwood Rd. • Cleveland, OH 44110
Phone: [216] 531-9222 • Toll-free: [800] 321-7628 • Fax: [216] 531-9596
www.euclidchemical.com

An RPM Company

Figure B.8 Product data sheet for Linseed Oil Treatment by Euclid.

DIRECTIONS FOR USE

Surface Preparation: Concrete surfaces to receive treatment shall be clean, dry and free of oil, dirt, loose scale and any other contaminants. Surfaces shall be swept clean by hand or by mechanical means. Oil and grease shall be removed as completely as possible. New concrete shall cure at least twenty-eight (28) days prior to application. New concrete cured with wax, resin base or chlorinated rubber or other curing agents shall not be treated until such agents have completely weathered away, or been removed by other means.

Mixing: LINSEED OIL TREATMENT is a one component product which requires no pre-blending prior to placement. LINSEED OIL TREATMENT should be used directly from the container.

Placement: LINSEED OIL TREATMENT shall be applied sparingly in two coats, at the average rate of 300 ft^2/gal (7.4 m^2/L) per coat. Application may be done by medium nap paint rollers or garden sprayers, using a wide fan nozzle. The second coat may be applied as soon as the first coat is dry to touch. In warm, dry weather this requires only one to four hours, but in cool weather, drying times up to 24 hours may be required. The preferred time for application is late afternoon so that when the concrete cools, the compound penetrates deep into the pores. Further treatment is recommended in form of a single application annually on surfaces subject to de-icing chemicals and wear. This application rate shall be at a rate of 400 ft^2/gal (9.8 m^2/L).

CLEAN-UP

Mineral spirits should be used for cleaning equipment.

PRECAUTIONS/LIMITATIONS

- Flammable. Keep away from matches, cigarettes and fires.
- All rags soaked with the compound must be stored in air-tight covered steel drums.
- In all cases, consult the Material Safety Data Sheet before use.

Rev. 10.09

WARRANTY: The Euclid Chemical Company ("Euclid") solely and expressly warrants that its products shall be free from defects in materials and workmanship for one (1) year from the date of purchase. Unless authorized in writing by an officer of Euclid, no other representations or statements made by Euclid or its representatives, in writing or orally, shall alter this warranty. EUCLID MAKES NO WARRANTIES, IMPLIED OR OTHERWISE, AS TO THE MERCHANTABILITY OR FITNESS FOR ORDINARY OR PARTICULAR PURPOSES OF ITS PRODUCTS AND EXCLUDES THE SAME. If any Euclid product fails to conform with this warranty, Euclid will replace the product at no cost to Buyer. Replacement of any product shall be the sole and exclusive remedy available and buyer shall have no claim for incidental or consequential damages. Any warranty claim must be made within one (1) year from the date of the claimed breach. Euclid does not authorize anyone on its behalf to make any written or oral statements which in any way alter Euclid's installation information or instructions in its product literature or on its packaging labels. Any installation of Euclid products which fails to conform with such installation information or instructions shall void this warranty. Product demonstrations, if any, are done for illustrative purposes only and do not constitute a warranty or warranty alteration of any kind. Buyer shall be solely responsible for determining the suitability of Euclid's products for the Buyer's intended purposes.

Figure B.8 (cont.) Product data sheet for Linseed Oil Treatment by Euclid.

APPENDIX C. SPECIMEN CRACKING DATA

Data collected regarding the cracking of the test specimens is shown in Figure C.1.

Specimen #	Date Cracked (yr. 2010)	Cracks (in./1000)				Average	Maximum Load (kips)	Notes
		1	2	3	4			
1	12/8	15	20	25		20	58	4 cracks on 1 side
2	12/9	20	25	55		33	53	Very large crack, specimen discarded
3	12/9	25	35	35	40	34	56	End of specimen has cracking, was repaired
4	12/15	10	15	35		20	58	5+ cracks on one side
5	12/16	15	15	15	15	15	58	
6	12/16	10	15	20	25	18	58	
7	12/16	20	25	30		25	58	
8	12/16	15	20	20		18	58	
9	12/16	15	25	40	45	31	58	
10	12/17	20	25	30		25	58	End of specimen has cracking, was repaired
11	12/17	20	20	25		22	58	
12	12/17	15	25	25		22	58	
13	12/17	15	20	25		20	58	
14	12/17	20	30	35		28	58	
15	12/17	5	15	20	25	16	58	
16	12/17	10	15	35		20	55	
17	12/20	15	15	25		18	58	
18	12/20	10	10	15	20	14	58	
19	12/20	15	15	15		15	56	
20	12/20	15	20	25		20	58	
21	12/20	10	20	20		17	58	
22	12/20	15	20	30		22	58	
23	12/20	15	20	25		20	58	
24	12/20	20	20	30		23	58	
25	12/20	15	20	25		20	58	
26	12/20	10	15	15	20	15	58	
27	12/20	25	25	25		25	58	
28	12/20	25	25	25		25	58	
29	12/20	15	15	20		17	69	Epoxy-coated reinforcement
30	12/20	15	15	20		17	70	Epoxy-coated reinforcement

Figure C.1 Specimen cracking data.

Specimen #	Date Cracked (yr. 2010)	Cracks (in./1000)				Average	Maximum Load (kips)	Notes
		1	2	3	4			
31	12/20	20	25	30		25	70	Epoxy-coated reinforcement, end of specimen has cracking, was repaired.
32	12/20	15	20	25		20	69	Epoxy-coated reinforcement
33	12/21	15	20	20		18	69	Epoxy-coated reinforcement
34	12/21	15	30	35		27	69	Epoxy-coated reinforcement, end of specimen has cracking, was repaired
35	12/21	10	15	20		15	56	
36	12/21	20	25	40		28	55	
37	12/21	10	15	25	25	19	58	
38	12/21	20	20	40		27	55	Damaged corner, specimen discarded
39	12/21	20	25	25		23	58	
40	12/21	25	25	25		25	58	
41	12/21	15	20	20		18	55	End of specimen has cracking, was repaired
42	12/21	10	15	15	25	16	58	5 cracks on one side, end of specimen has cracking, was repaired
43	12/21	15	20	20	20	19	57	
44	12/21	15	15	15	20	16	58	
45	12/22	20	20	25		22	57	End of specimen has cracking, was repaired
46	12/22	15	20	20		18	56	
47	12/22	20	20	25		22	57	
48	12/22	20	20	30		23	57	
49	12/22	5	15	15	20	14	56	
50	12/22	15	20	20	25	20	57	End of specimen has cracking, was repaired
51	12/22	15	15	15	25	18	58	
52	12/22	15	20	20		18	57	
53	12/22	10	15	20		15	56	
54	12/22	10	15	15		13	56	
55	12/22	20	20	20		20	58	
56	12/22	15	15	25		18	58	
57	12/22	20	25	30		25	58	
58	12/22	15	20	25		20	58	End of specimen has cracking, was repaired
59	12/22	15	15	20		17	56	End of specimen has cracking, was repaired

Figure C.1 (cont.) Specimen cracking data.

APPENDIX D. RECORD OF SPECIMEN ACTIVITY

A log of the work performed on each specimen or group is shown in Figure D.1 through Figure D.3.

Group	Specimen #	Date	Activity	Date	Activity	Date	Activity	Date	Activity
1	9 25 35	2/14/11	11AM Apply Sikadur 55 SLV, 55° F	2/15/11	10AM Apply more Sikadur 55 SLV, 57° F	2/15/11	4PM Apply more Sikadur 55 SLV, 59° F	2/16/11	4PM Apply more Sikadur 55 SLV (small amount for smooth surface), 61° F
2	3 19 23								
3	10 11 15	2/14/11	11AM Apply Sikadur 55 SLV, 55° F	2/15/11	10AM Apply more Sikadur 55 SLV, 57° F	2/15/11	4PM Apply more Sikadur 55 SLV, 59° F	2/16/11	4PM Apply more Sikadur 55 SLV (small amount for smooth surface), 61° F
4	13 18 36	3/1/11	11AM Apply Dural 335, 59° F	3/1/11	3PM Apply Dural 335, 59° F	3/3/11	10AM Apply Dural 335, 57° F	3/3/11	5PM Apply Dural 335, 60° F
5	7 12 42								
6	14 16 49	3/1/11	11AM Apply Dural 335, 59° F	3/1/11	3PM Apply Dural 335, 59° F	3/3/11	10AM Apply Dural 335, 57° F	3/3/11	5PM Apply Dural 335, 60° F
7	46 47 51								
8	6 24 52	2/14/11	11AM Apply Sikadur 55 SLV, 55° F	2/15/11	10AM Apply more Sikadur 55 SLV, 57° F	2/15/11	4PM Apply more Sikadur 55 SLV, 59° F	2/16/11	4PM Apply more Sikadur 55 SLV (small amount for smooth surface), 61° F
9	5 20 40	3/7/11	1:30PM Apply Degadeck Crack Sealer Plus, 57° F						
10	27 50 53	3/7/11	1:30PM Apply Degadeck Crack Sealer Plus, 57° F						

Figure D.1 Log of specimen activity, groups 1 through 10.

Group	Specimen #	Date	Activity	Date	Activity	Date	Activity
1	9 25 35	3/14/11	Restressed, 32 kips (40ksi in bars)				
2	3 19 23	3/8/11	3:30PM Apply Silane 40 VOC, 59° F	3/14/11	Restressed, 32 kips (40ksi in bars)		
3	10 11 15	3/8/11	3:30PM Apply Silane 40 VOC, 59° F	3/14/11	Restressed, 32 kips (40ksi in bars)		
4	13 18 36	3/14/11	Restressed, 32 kips (40ksi in bars)				
5	7 12 42	3/9/11	11AM Apply Enviroseal, 59° F	3/14/11	Restressed, 32 kips (40ksi in bars)		
6	14 16 49	3/9/11	11AM Apply Enviroseal, 59° F	3/14/11	Restressed, 32 kips (40ksi in bars)		
7	46 47 51	3/8/11	3:30PM Apply Linseed Oil, 59° F	3/8/11	6:30PM Apply Linseed Oil, 61° F	3/14/11	Restressed, 32 kips (40ksi in bars)
8	6 24 52	3/8/11	3:30PM Apply Linseed Oil, 59° F	3/8/11	6:30PM Apply Linseed Oil, 61° F	3/14/11	Restressed, 32 kips (40ksi in bars)
9	5 20 40	3/14/11	Restressed, 32 kips (40ksi in bars)				
10	27 50 53	3/8/11	3:30PM Apply Silane 40 VOC, 59° F	3/14/11	Restressed, 32 kips (40ksi in bars)		

Figure D.1 (cont.) Log of specimen activity, groups 1 through 10.

Group	Specimen #	Date	Activity	Date	Activity	Date	Activity	Date	Activity
11	22 44 48								
12	1 26 28	2/14/11	11AM Apply Sikadur 55 SLV, 55° F	2/15/11	10AM Apply more Sikadur 55 SLV, 57° F	2/15/11	4PM Apply more Sikadur 55 SLV, 59° F	2/16/11	4PM Apply more Sikadur 55 SLV (small amount for smooth surface), 61° F
13	21 39 43	2/14/11	11AM Apply Sikadur 55 SLV, 55° F	2/15/11	10AM Apply more Sikadur 55 SLV, 57° F	2/15/11	4PM Apply more Sikadur 55 SLV, 59° F	2/16/11	4PM Apply more Sikadur 55 SLV (small amount for smooth surface), 61° F
14	8 37 45	2/24/11	Roughened before crack sealer applied	3/1/11	3PM Apply Dural 335, 59° F	3/3/11	10AM Apply Dural 335, 57° F	3/3/11	5PM Apply Dural 335, 60° F
15	4 17 41	2/24/11	Roughened before crack sealer applied	3/7/11	1:30PM Apply Degadeck Crack Sealer Plus, 57° F				
16	29 33 34								
17	30 31 32	2/14/11	4PM Apply Sikadur 55 SLV, 57° F	2/15/11	10AM Apply more Sikadur 55 SLV, 57° F	2/15/11	4PM Apply more Sikadur 55 SLV, 59° F	2/16/11	4PM Apply more Sikadur 55 SLV (small amount for smooth surface), 61° F
18	54 55 57								
19	56 58 59	2/14/11	4PM Apply Sikadur 55 SLV, 57° F	2/15/11	10AM Apply more Sikadur 55 SLV, 57° F	2/15/11	4PM Apply more Sikadur 55 SLV, 59° F	2/16/11	4PM Apply more Sikadur 55 SLV (small amount for smooth surface), 61° F

Figure D.2 Log of specimen activity, groups 11 through 19.

Group	Specimen #	Date	Activity	Date	Activity
11	22 44 48				
12	1 26 28				
13	21 39 43	3/8/11	3:30PM Apply Silane 40 VOC, 59° F		
14	8 37 45	3/14/11	Restressed, 32 kips (40ksi in bars)		
15	4 17 41	3/14/11	Restressed, 32 kips (40ksi in bars)		
16	29 33 34				
17	30 31 32	3/8/11	3:30PM Apply Silane 40 VOC, 59° F	3/14/11	Restressed, 32 kips (40ksi in bars)
18	54 55 57				
19	56 58 59	3/8/11	3:30PM Apply Silane 40 VOC, 59° F	3/14/11	Restressed, 32 kips (40ksi in bars)

Figure D.2 (cont.) Log of specimen activity, groups 11 through 19.

Group	Specimen #	Date	Activity	Date	Activity	Date	Activity
20U	60 61 62			3/8/11	3:30PM Apply Silane 40 VOC, 59° F		
21U	63 64 65			3/9/11	11AM Apply Enviroseal, 59° F		
22U	66 67 68			3/8/11	3:30PM Apply Linseed Oil, 59° F	3/8/11	6:30PM Apply Linseed Oil, 61° F
23U	90 91 92						
24U	72 73 74	2/24/11	Roughened initially before applying deck sealer (traffic)	3/8/11	3:30PM Apply Silane 40 VOC, 59° F		
25U	75 76 77	2/24/11	Roughened initially before applying deck sealer (traffic)	3/9/11	11AM Apply Enviroseal, 59° F		
26U	78 79 80	2/24/11	Roughened initially before applying deck sealer (traffic)	3/8/11	3:30PM Apply Linseed Oil, 59° F	3/8/11	6:30PM Apply Linseed Oil, 61° F
27U	81 82 83			3/8/11	3:30PM Apply Silane 40 VOC, 59° F		
28U	84 85 86			3/9/11	11AM Apply Enviroseal, 59° F		
29U	87 88 89			3/8/11	3:30PM Apply Linseed Oil, 59° F	3/8/11	6:30PM Apply Linseed Oil, 61° F
30U	69	1/28/11	1/16th inch sandblasted				
	70 71	2/24/11	Roughened initially before applying deck sealer (traffic)				

Figure D.3 Log of specimen activity, groups 20U through 30U.

About the Joint Transportation Research Program (JTRP)

On March 11, 1937, the Indiana Legislature passed an act which authorized the Indiana State Highway Commission to cooperate with and assist Purdue University in developing the best methods of improving and maintaining the highways of the state and the respective counties thereof. That collaborative effort was called the Joint Highway Research Project (JHRP). In 1997 the collaborative venture was renamed as the Joint Transportation Research Program (JTRP) to reflect the state and national efforts to integrate the management and operation of various transportation modes.

The first studies of JHRP were concerned with Test Road No. 1—evaluation of the weathering characteristics of stabilized materials. After World War II, the JHRP program grew substantially and was regularly producing technical reports. Over 1,500 technical reports are now available, published as part of the JHRP and subsequently JTRP collaborative venture between Purdue University and what is now the Indiana Department of Transportation.

Free online access to all reports is provided through a unique collaboration between JTRP and Purdue Libraries. These are available at: http://docs.lib.purdue.edu/jtrp

Further information about JTRP and its current research program is available at: http://www.purdue.edu/jtrp

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