DEVELOPMENT AND LAYOUT OF A PROTOCOL FOR THE FIELD PERFORMANCE OF CONCRETE DECK AND CRACK SEALANTS

Project 07-13
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16. Abstract

The main objective of this project was to develop and layout a protocol for the long-term monitoring and assessment of the performance of concrete deck and crack sealants in the field. To accomplish this goal, a total of six bridge decks were chosen for study. The decks have ages that vary from 4 to 30 years old, are all in good condition, though some presented a variety of longitudinal, transverse and diagonal cracking. In each deck, test segments were laid out along one lane in four of the six bridges. Drill powder samples were extracted in each segment in order to determine the in-situ, near-surface chloride ion content of the deck. Laboratory analyses of the samples showed that the chloride ion content varied between 3.2 lb/cy for the younger decks (3 years old) and 20.8 lb/cy for the older decks (28 years old). Based on the recommendations of a previous laboratory investigation, a pool of the best performing deck and crack sealants were selected to be applied in the decks. In two bridges, deck segments were sealed with four deck sealants while one segment was left unsealed to be used as a control segment. Additionally, the cracks in each of these segments were sealed with five crack sealants. While two other decks were also scheduled for sealing as part of this phase of the project, they were not done because the required curing time for some of the products was longer than deemed acceptable by DOT crews for these high traffic bridges. It is recommended, however, that every effort be made to have these decks be sealed in the near future. The remaining two bridges had been sealed at the time of construction. While no specific information could be secured about the product used in these decks, the low chloride ion content in these decks suggested that the applied product has helped reduce the ingress of chloride ions. Therefore, it is recommended that these decks continue to be monitored over time. Based on the inspections and the data collected in the field, a protocol and schedule for the continuing monitoring of sealant performance is presented.

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EXECUTIVE SUMMARY

The main objective of this project was to develop and layout a protocol for the long- term monitoring and assessment of the performance of concrete deck and crack sealants in the field. To accomplish this goal, a total of six bridge decks were chosen for study, all located in the state of Wisconsin. The decks have ages that vary from 4 to 30 years old, but are all in good condition. The older decks presented a variety of longitudinal, transverse and diagonal cracking and were chosen to study the performance of crack sealants.

Following visual inspection of the decks, five test segments were laid out along one lane in four of the six bridges. Each segment had a length of 20’ and a width equal to distance of the guard rail to the center line. Drill powder samples were extracted in each segment in order to determine the in-situ chloride ion content near the surface of the deck. Laboratory analyses of the samples showed that the chloride ion content varied between 3.2 lb/cy for the younger decks (3 years old) and 20.8 lb/cy for the older decks (28 years old).

Based on the recommendations of a previous laboratory investigation, a pool of the best performing deck and crack sealants were selected to be applied in the decks. In two bridges, deck segments were then sealed with four deck sealants, namely: Penseal 244, Hydrozo 40 VOC, Powerseal 40%, and V-Seal. One segment was left unsealed, a control segment, in order to be used a benchmark for later monitoring and comparison of deck sealant performance. Additionally, the cracks in each of these segments were sealed with five crack sealants, namely: Sikadur 55 SLV, Dural 335, Sikadur 52, Degadeck, and Denedeck. While two other decks were also scheduled for sealing as part of this phase of the project, they were not done because the required curing time for some of the products was longer than deemed acceptable by DOT crews for these high traffic bridges. It is recommended, however, that every effort be made to have these decks be sealed overnight or at least with those products that do not require such long curing times. The remaining two bridges had been sealed at the time of construction. While no specific information could be secured about the product used in these decks, the low chloride ion content for the age of these decks suggested that the applied product has indeed helped reduce the ingress of chloride ions. Therefore, it is recommended that these decks continue to be monitored over time.

Based on the inspections and the data collected in the field, a protocol and schedule for the continuing monitoring of sealant performance is presented. The protocol include periodic site visits (which could be done concurrently with bridge inspections), extraction and testing of powder samples for chloride ion content as well as core extraction for later examination in the laboratory. The effectiveness of the deck sealants shall be determined by comparing the chloride ion content in the sealed segments with that measured in the control sections, and by measuring the depth of penetration of the sealants from extracted cores. Crack sealant effectiveness shall be determined by conducting ponding tests on core samples extracted at crack locations and by measuring the depth of penetration of the sealants in the field and in the laboratory.

ACKNOWLEDGEMENTS

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CHAPTER 1
Introduction

1.1 Background

Deicing salts, mixtures of sodium chloride and calcium chloride, are commonly broadcast over bridge decks during the winter in the Midwest. As ice melts and mixes with the deicing salt, chloride ions enter into the concrete by diffusion or penetrate through cracks which may induce corrosion of the reinforcing bars and deterioration of the steel or concrete substructure. In recent years, some Departments of Transportation (e.g., WIDOT, Mn/DOT) have begun using deck and crack sealants as one method to prevent chloride ion intrusion and the subsequent deterioration of the deck or the substructure. Although sealants are commonly used, little is known about their field performance.

In an earlier study (Pincheira and Dorshorst, 2005), the laboratory performance of commercially available deck and crack sealants was investigated at the University of Wisconsin. It was concluded that the performance of deck sealants depended largely on the type (water-based or solvent-based) and their depth of penetration. Generally, sealants with larger depth of penetrations performed better, but also required longer application and curing times. This will translate in practice in a longer time to open to traffic a bridge deck upon application of the sealants. The study also pointed out that the laboratory evaluation, which followed closely current standards, may not necessarily translate in the same field performance, in particular, concerning the abrasion applied to the sealants in the specimens. As a result, deck sealants with lower depths of penetration, which did not perform as well in laboratory tests, could perform well in the field in bridge decks with low abrasion.

The crack sealants studied were all capable of fully penetrating the cracks prepared in the laboratory, but many deteriorated significantly under freeze-thaw cycles and may not be able to keep the crack sealed under an aggressive environment. These sealants were not recommended for use in the field. The laboratory prepared cracks were all clean and free of debris. In reality, however, bridge deck cracks are expected to be filled with dirt and debris. Although they have to be cleaned before application of a crack sealant, it is virtually impossible to leave it completely clean. The impact of partially clean cracks on the ability of a sealant to fully penetrate and seal the crack has not been studied in the field.

Furthermore, the reapplication of less expensive sealants every few years because of the loss of effectiveness of a deck or a crack sealant may be a viable maintenance program. Therefore, the decision to selecting an appropriate sealant in practice cannot be based only on the observed performance in the laboratory, but also to its performance in the field and the cost/benefit ratio it provides in the long term.

1.2 Objectives

The overall purpose of this project was to develop and layout a protocol for the long-term monitoring and assessment of the field performance of concrete deck and crack sealants. To accomplish this goal, selected bridge decks were sealed with different types of sealants whose effectiveness will be monitored over a period of several years (5 years or more). The first phase of the project, which is described in this report, focused on the selection of the bridge decks and sealants for study, the deployment of the sealants in the field, and the assessment of the condition of the decks before and after application of the sealants for a period one year. It is envisioned that the performance of the sealants will be monitored and assessed by the DOT in subsequent years.

1.3 Research Approach

The work conducted in this study included both field and laboratory work as described below. In conjunction with DOT officials, a myriad of bridges were identified for study. The selection of the bridge decks was initially based on three main criteria: geographic/environmental location, average daily traffic and deck age and condition. However, because maintenance practices vary among regions and the constraints associated with stopping traffic to conduct the inspections, sample retrieval and later application of the sealants, not all the bridges initially chosen could be selected for further study. The chosen bridges were visited for a preliminary inspection where powder concrete samples were retrieved for later laboratory tests of the in-situ chloride ion content.

Once a pool of bridges was selected, a myriad of deck and crack sealants were chosen for the field study in conjunction with DOT officials. Application of the sealants was done by dividing the deck area into sections of approximately equal surface where a different type of sealant will be applied. One section was left without treatment as a control. Application of the sealants was done according the manufacturer’s specifications using a local contractor so as to emulate as close as possible the actual field conditions.

Based on the inspections and the data collected in the field, a protocol and schedule for the continuing monitoring of the decks was developed.

CHAPTER 2
Background and Sealants Selected for Study

2.1 Introduction

In this chapter, the main characteristics of deck and crack sealants are briefly discussed. A more exhaustive description has been presented elsewhere (Pincheira and Dorshorst, 2005). In addition, recent field studies on the use of deck and crack sealants are and their results are reviewed.

2.2 Main Characteristics and Application Procedures

Several criteria must be considered when selecting a deck or crack sealant for use on a bridge deck. Characteristics such as depth of penetration and weather resistance provide information on the expected performance of a product, while others offer information related to field preparation and application procedures.

2.2.1 Chemical Family

Deck sealants – Most concrete deck sealers in use are based on silicone technology, primarily silanes and siloxanes. These materials are derivatives of silicone with molecules small enough to penetrate and bond to the concrete, creating a hydrophobic layer in the treated region. Since they are sealers and not membranes, they do not provide an impenetrable physical barrier, but rather reduce water inflow by inducing a chemical repulsion of the concrete to water (Aitken and Litvan, 1989). Silanes and siloxanes are usually supplied as a solution or as a suspension in a solvent.

Crack sealants – Currently available crack sealant products include High Molecular Weight Methacrylates (HMWM) resins, epoxy resins, and urethane resins among others. Crack sealant products must be able to bridge and seal fine cracks by creating a barrier that prevents water and water-borne contaminants from entering the concrete.

2.2.2 Volatile Organic Compound (VOC) Content

Volatile Organic Compounds (VOCs) are emitted as gases from certain solids or liquids. VOCs include a variety of chemicals, some of which are commonly found in concrete sealers and treatments, and may have short- and long-term adverse health effects. In addition, ground level ozone, a major component of "smog," is formed in the atmosphere when VOCs and oxides of nitrogen react in the presence of sunlight. A study conducted by the United States Environmental Protection Agency (EPA) found that architectural coatings were one of the largest VOC emission sources among consumer and commercial product categories (U.S. Environmental Protection Agency, 1998). In an effort to reduce the harmful health effects associated with VOC exposure and the production of ozone, the EPA imposed VOC content limits for architectural coatings, including waterproofing sealers and treatments. Waterproofing sealers and treatments were limited to 5.0 pounds per gallon, or 600 grams per liter, with an exceedance fee charged to manufacturers whose products exceeded the limit. The VOC content, listed on technical data sheets (TDS) and material safety data sheets (MSDS), can be used as a general indicator of the health risks associated with a product. The VOC content of similar performing products should be considered when selecting a product for use to avoid unnecessary overexposure to VOCs.

2.2.3 Recommended Surface Preparation Requirements

The amount and surface preparation required before a product is applied to a surface or a crack is an important consideration when selecting a sealant. Recommended surface preparation requirements are provided by the manufacturer for each product. Typical surface preparation requirements for deck and crack sealants range from no specific requirements, to pressure washing or mechanical abrasion to clean the deck surface and remove debris from cracks. Some districts in Wisconsin, for example, use a grinder to enlarge the surface at the top of the crack and then compressed air to clean the crack, thus allowing for better entrainment of the sealer. In addition, the necessary moisture content of the substrate at the time of application can be included in the surface preparation category and can range from completely dry to slightly damp.

The temperature of the deck during and immediately after application of a sealant as well as expected precipitation conditions after application are both important factors. While products with broader ranges of temperature and environmental conditions during and after application of the product are more attractive, it is generally recognized that cracks should be sealed in the spring or in the fall, preferably early in the morning, when temperatures are low and crack widths are widest.

The application method is a key aspect to consider when evaluating crack sealants because it directly affects the time and equipment required to seal cracks. While gravity feeding sealant into cracks is suitable for many products on the market, some products are designated as pressure injection only. Pressure injecting cracks requires special equipment and will often be more time consuming than gravity feeding cracks. While pressure injection may be a viable option for some Departments of Transportation (DOTs), the equipment used to pressure inject cracks is not readily available to all. In addition, the cost to rent or purchase the necessary equipment, or hire a contractor to pressure injects cracks, combined with the extra time the deck would need to be closed to traffic could make a product with relatively inexpensive material costs become extremely expensive.

Freeze-thaw resistance is crucial to effective performance of sealant products applied to crack of bridge decks. Since there is not a standard test used by the manufacturers to measure freeze-thaw resistance, the manufacturers' recommendations on freeze-thaw may vary widely. Clearly, sealants which are not recommended for use in freeze-thaw conditions should not be considered for used in northern climates.

2.3 Mn/DOT Field Study of Penetrating Sealers (1995)

In the early 1990s, the Minnesota Department of Transportation (Mn/DOT) conducted a field study of deck penetrating sealants over a period of 3 years. While the products and applications procedures used in the Mn/DOT study are different than those employed here, the decks and environmental conditions are similar to those considered in the present study.

A total sixteen concrete deck sealers were tested and evaluated. No crack sealers were evaluated. All sealants were applied to a single bridge deck in St. Paul, MN. The bridge was built in 1991 and had a slow slump dense concrete overlay. At the time the sealers were applied, the age of the overlay was greater than 28 days.

While the length of the study was very limited (3 years), the results suggested that silanes (solvent- or water-based) and siloxanes offered the best performance as a group, though considerable variability was observed among products. They also concluded that good laboratory results do not necessarily translate into good performance in the field. Field performance tended was lower than that measured in the laboratory, though possible causes for this result were not cited. It may be recalled, however, that the sealants were applied to a low slump, dense concrete overlay which will reduce the effectiveness of the sealants to penetrate into the concrete. It should be noted that Hydrozo Silane 40, which is on the approved list of sealants for Wisconsin, was found among the best performing sealants. This result agrees well with the results of the laboratory tests conducted by Pincheira and Dorshorst in 2005.

2.4 Selection Deck and Crack Sealants

In an earlier study (Pincheira and Dorshorst, 2005), a total of thirteen deck sealants and ten crack sealants were tested in the laboratory under current AASHTO standards. Based on the test results, the sealants were assigned to a performance group category I, II or III, for the sealants that offered a high, moderate or poor protection level, respectively. However, a sealant that offered the best protection in the laboratory tests may not necessarily the best alternative for field application from a cost/benefit ratio point of view. Other factors, such as time to open to traffic and depth of penetration, may influence the decision to use a given sealant if it offers an acceptable, but not necessarily the best protection.

Based on the results from laboratory tests, the first five products assigned to a performance group category I and II were initially selected as candidates to be used in this project. The chosen candidates to seal the decks are shown in Table 2.1, while those selected to seal cracks are shown in Table 2.2. All these products are VOC compliant according to EPA 2005, i.e., VOC below 5.0 pounds per gallon, or 600 grams per liter.

Table 2.1 Deck sealant candidates

Performance Group Category	Sealant Name	VOC (g/L)
I	Sonneborn Penetrating Sealer 40 VOC *	589
	Hydrozo Silane 40 VOC *	589
II	Powerseal 40%	260
	V-Seal	0
	Penseal 244	496

* These products are today (2009) the same (Hydrozo Silane 40 VOC)

Table 2.2 Crack sealant candidates

Performance Group Category	Sealant Name	VOC (g/L)
I	Sikadur 55 SLV	112
	Dural 335	<10
II	Sikadur 52	73
	Degadeck Crack Sealer Or Denedeck Crack Sealer	150

The research team met with the Advisory Committee to the project to discuss the proposed program and the tentative list of sealants chosen for study. The committee agreed with the general plan of work and had the following suggestions to add if the time and the budget would permit it:

- Apply crack sealants in the fall while the cracks are open.
- The effectiveness of deck sealants are affected by the pore water humidity. It would be useful to install a humidity gage in the deck and report the variation of humidity over time.

The benefits of applying deck sealants on older decks were also discussed. If the chlorides are already there, why seal the decks? On the other hand, the presence of chloride ions causes corrosion only if oxygen and moisture are also present to sustain the chemical reaction. Deck sealants will serve to deter the ingress of moisture and thus stop or reduce the rate of corrosion, which should help extend the service life of the deck.

CHAPTER 3
Bridges Selected for Study

3.1 General

In this chapter, the criteria used in the selection of the bridges are presented. Then, a description, the main characteristics and the condition of the bridges selected for study are presented.

3.2 Bridge Selection Criteria

The main factor in assessing the performance of deck sealants is their ability to deter chloride ion intrusion over time. Clearly, bridge decks with a higher salt application rate and frequency are expected to experience a higher rate of change in chloride content over a given time period. On the other hand, the chloride ion content also depends of the coefficient of diffusion and the age of the bridge deck.

Figure 3.1 shows the estimated diffusion of chloride ion content with depth over a period of 100 years. The diffusion curves were obtained using Fick's law (Mindness et al., 2003) assuming a surface chloride ion concentration of 20 lbs/cy and a coefficient of diffusion of 0.05 in^2/year, values that are representative of bridge decks with high salt application rates built with the concrete types used nowadays. At a depth of 0.5 in., for example, the chloride content changes significantly within the first 10 to 20 years, but it varies slightly thereafter. The same is true at greater depths, though the rate of change and the chloride concentrations are smaller. This means that the effectiveness of deck and crack sealants is likely to be more evident in the early ages of a bridge deck, i.e., when the rate of increase in the amount of chloride ion content at a given depth is higher.

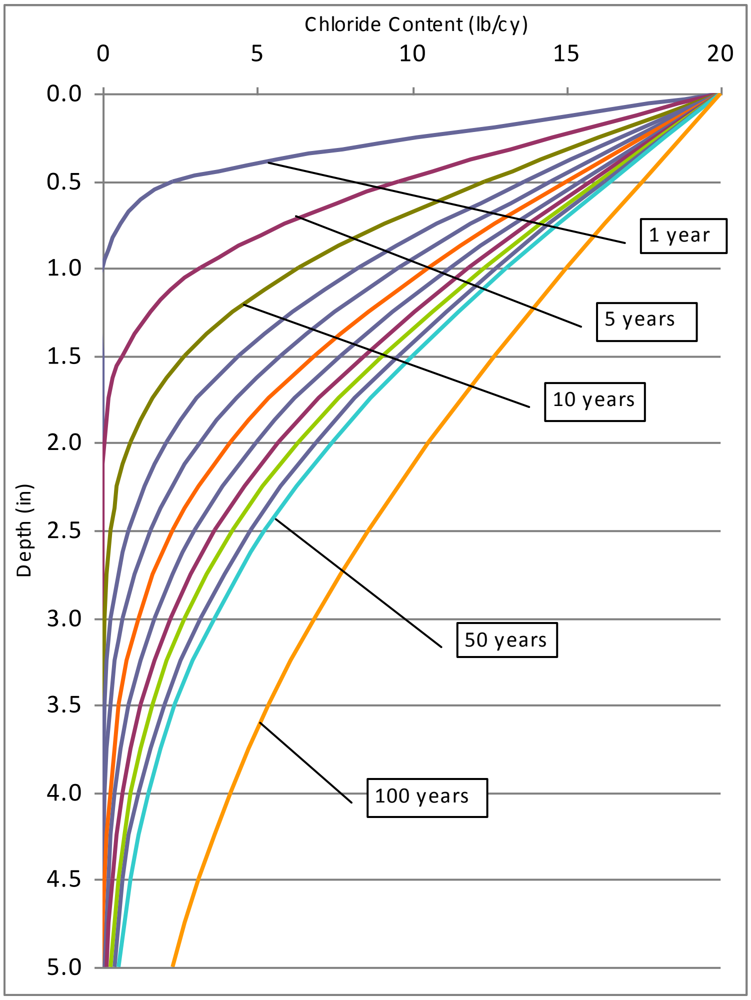

Figure 3.1 Estimated diffusion of chloride ion content with depth over a 100 year period for a surface chloride ion concentration of 20 lbs/cy.

For this reason, early age bridge decks with high salt application rates were sought for this study. In addition, decks with a larger number of cracks and a diverse range of crack widths were favored for the evaluation of crack sealers. Based on these two criteria, and in consultation with local district bridge maintenance engineers and the project advisory committee, a list of approximately 12 candidate bridges in the Madison area were considered for the study. Another six candidate bridges located in northern Wisconsin (Marathon and Shawano counties), where environmental conditions are expected to be more severe, were also considered. Of these, nine bridges were initially chosen as shown in Table 3.1.

The older bridges in Dane County (B-13-0244 and B-13-0337) were chosen mainly because of the number and type of cracks obtained from inspection reports, and would be used to study the crack sealants. During the site visit, however, it was found that Bridge B-13-

0244 actually had few, barely visible hairline cracks, and thus not well suited to study crack sealers. As a result, it was decided not to crack seal this deck. The newer bridges in Dane and Dodge counties (B-13-0553, B-13-0554 and B-14-0034) were expected to have lower chloride ion contents and thus better suited to study the effectiveness of deck sealants.

The last four bridges chosen in Shawano County are relatively young bridges. Preliminary information indicated that two of these decks had been sealed immediately after construction, while the other two had not. Thus, they were ideal candidates to compare the effectiveness of deck sealants in the field. Shortly before the site visit scheduled to these decks, the research team was informed that, in fact, all four decks had been sealed at the time of construction. Since these bridges are of the same age, have nearly identical configuration, have about the same ADT, and are exposed to same amount of salt application rate, it was decided to select only two of these for study, namely, B-58-0080 and B-58-0081. Also, since all had been sealed at the same time, presumably with the same type of deck sealant (inspection reports had no record of the sealant type used), the decks were chosen to establish a benchmark today (2009) in order to monitor the performance and the effectiveness of a specific deck sealant since the time of construction.

Table 3.1 Location and main characteristics of bridges considered for study.

Bridge No	County	Feature On	Feature Under	Year of Construction	ADT (Year)
B-13-0244	Dane	USH 14 WB	CTH MM	1978	8143 (2003)
B-13-0337*	Dane	STH 69-River St.	Sugar River	1979	7300 (2006)
B-13-0553*	Dane	USH 12 EB	USH 14	2004	21800 (2005)
B-13-0554*	Dane	USH 12 WB	USH 14 EB	2005	19100 (2005)
B-14-0034*	Dodge	USH 151 NB	STH 49	1997 (New Deck)	5100 (2004)
B-58-0080*	Shawano	STH 29 EB	T	1997	6770 (2003)
B-58-0081*	Shawano	STH 29 EB	Valley Rd.	1997	6760 (2003)
B-58-0082	Shawano	STH 29 WB	Valley Rd.	1997	5990 (2003)
B-58-0090	Shawano	STH 29 WB	T	1997	5990 (2003)

* bridges selected for continued monitoring and study.

In summary, a total of six decks were chosen as part of this project for continued monitoring of their performance over the years. These are: B-13-0337, B-13-0553, B-13-0554, B-14-0034, B-58-0080 and B-58-0081.

3.3 Description of Bridges Selected for Study

A detailed visual inspection was performed on each bridge deck during the visits. The purpose of this survey was to document the condition of the bridge decks and relate these data with laboratory results. Some of the data collected included: photographs, structure dimensions, surface condition, deck configuration and superstructure type. In addition, a sketch indicating transverse and longitudinal cracks were recorded and measured.

Overall, the decks were in good condition, though all of them had longitudinal, transverse or diagonal cracks of various lengths and widths. Crack widths varied within a given deck and among decks, but they typically ranged between hairline (< 0.06 in.) and narrow (0.06 – 0.10 in.) cracks.

Following visual inspection, five segments were laid out along one lane of the bridge. Each segment had a length of 20’ and the width of the guard rail to the center line. The segments were labeled A through E for later sealing of the deck with different sealants. In each segment, concrete powder samples were extracted at various locations in order to measure the in-situ chloride ion content near the surface of the deck. Details of the site inspection are given for each bridge in the sections below.

3.3.1 Bridge B-13-0337

This bridge, built in 1979, is a two lane, three span continuous haunched slab over the Sugar River in Dane County with an overall length of 142 ft. 10 in. (see Fig. 3.2). It was built in 1979 and, according to inspection reports, it has undergone only minor repair work. The deck was reinforced with black bars. For the purposes of this study, the southbound lane was closed and visually inspected. Overall, the deck was in good condition (NBI rating of 7 in 2007), but it presented several longitudinal and transverse cracks that varied in length, as shown in Figure 3.3. The crack depth was unknown, but inspection of the underside of the deck showed no evidence of cracks, and therefore none of these cracks extended the full depth of the deck.

The middle 100 ft of the deck was divided into five 20 ft. segments and labeled A, B, C, D and E, as shown in Fig. 3.3. Each of these 20 ft. segments was to be sealed with a different type of sealant in order to compare the performance of the sealants under same conditions over time. Also, two concrete powder samples were taken in each segment at the approximate location of the wheel paths for a typical vehicle. These samples were labeled according to the location of the segment and wheel path as A1, A2, B1, B2 and so forth, as shown in Fig. 3.3.

Figure 3.2 Overall view of bridge B-13-0337.

3.3.2 Bridge B-13-0553

This bridge is a relatively new structure built in 2004 and it is located on highway 12 EB in the city of Middleton. The bridge is a two span concrete deck supported on prestressed concrete girders with an overall length of 159 ft. For this study, the right lane was closed during the site visit and visually inspected. The deck was in excellent condition (NDI rating of 8 in 2006) with only a few minor transverse cracks in the center of the bridge and minor diagonal cracking toward the end of the exit abutment (see Fig. 3.4). Deck reinforcement consisted of epoxy-coated bars.

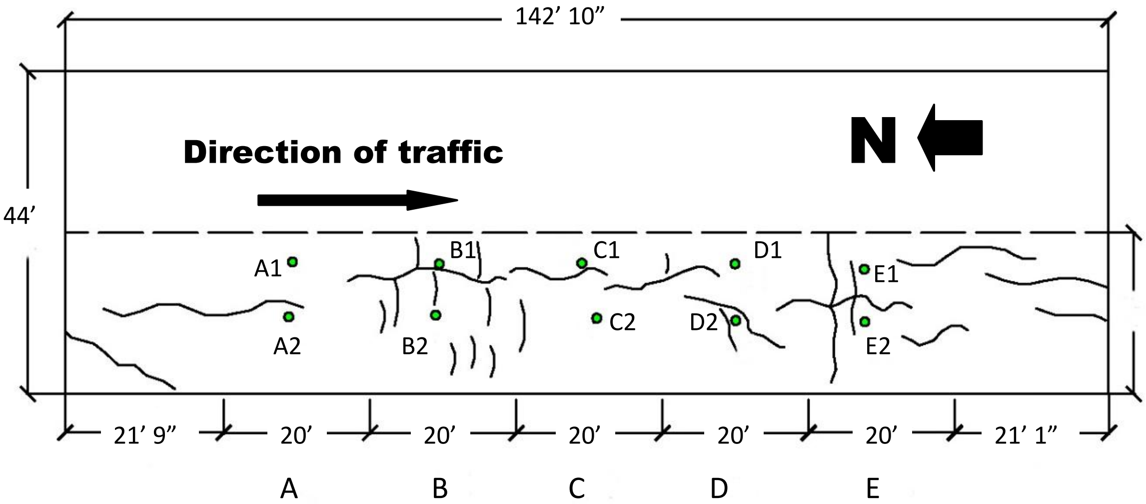

Figure 3.3 Dimensions, crack pattern, and sample retrieval location on southbound lane of bridge B-13-0337.

As before, the center portion of the deck was divided into five 20 ft. segments (A, B, C, D and E) where concrete powder samples were taken for analysis of the chloride ion content and for later application of the sealants. The crack pattern observed during the site visit as well as the approximate location of the retrieved samples in each of the 20 ft. segments are shown in Fig. 3.4.

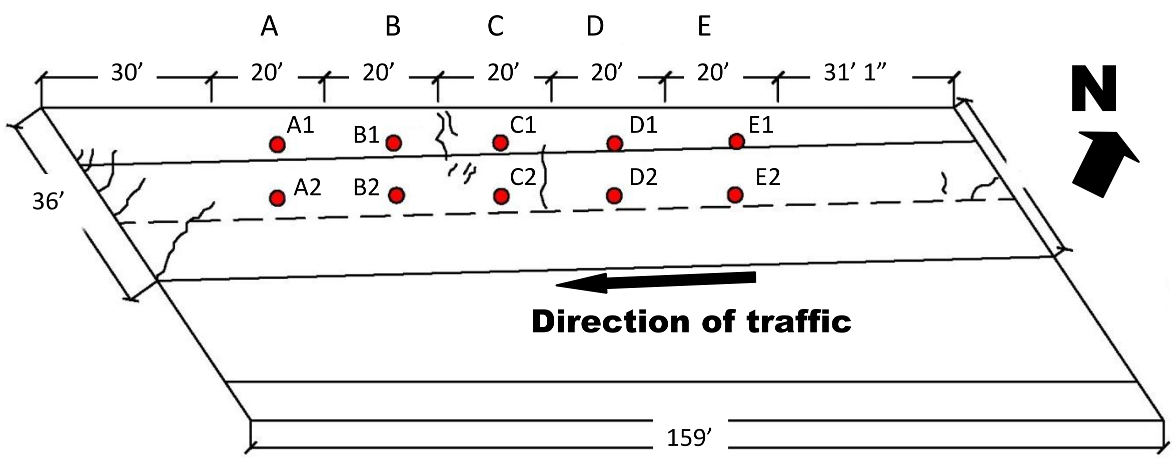

Figure 3.4 Dimensions, crack pattern, and sample retrieval location on the right lane of bridge B-13-0553.

3.3.3 Bridge B-13-0554

This bridge is also located on highway 12 WB in the city of Middleton. The bridge was built in 2004 and is a two span concrete deck supported on prestressed concrete girders with an overall length of 158 ft. The deck was in very good condition (NDI rating of 8 in 2006) with only a few minor transverse cracks and a few longitudinal cracks (see Fig. 3.5). Deck reinforcement consisted of epoxy-coated bars.

For this bridge, the left lane was chosen for study. Figure 3.5 shows the crack pattern observed, as well as the subdivision of segments in the center portion of the deck and the location of the concrete powder samples retrieved for analyses of chloride ion content.

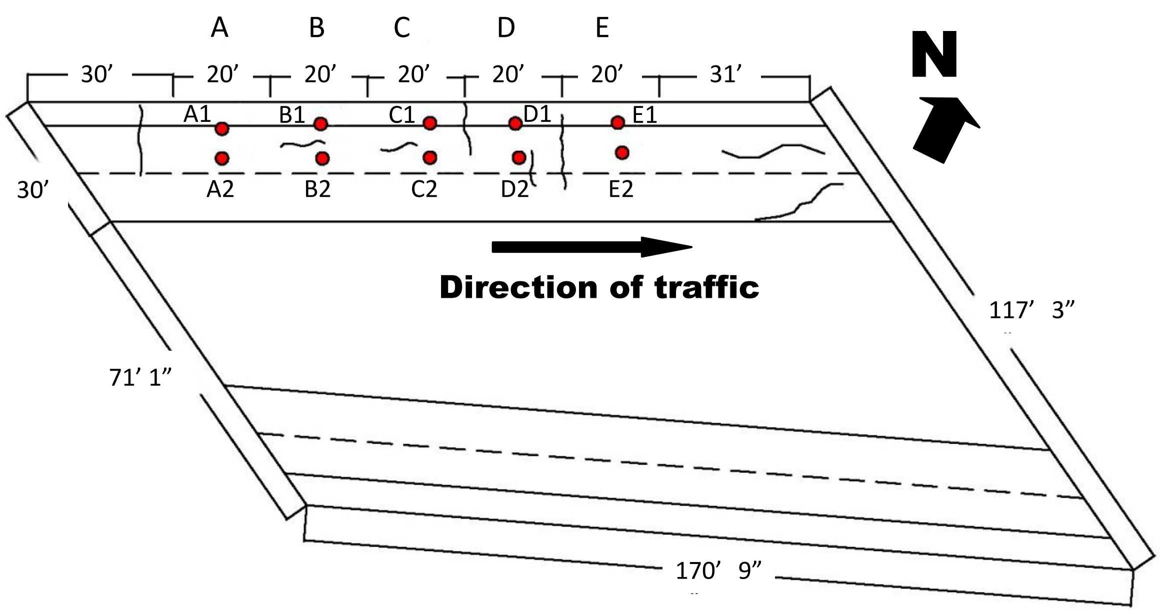

Figure 3.5 Dimensions, crack pattern, and sample retrieval location on the left lane of bridge B-13-0554.

3.3.4 Bridge B-14-0034

This bridge is a two lane on USH 151 NB originally built in 1961, but was provided with a new deck in 1997. The bridge is a three span concrete deck supported on prestressed concrete girders with an overall length of 132 ft, as shown in Fig. 3.6. Deck reinforcement consisted of epoxy-coated bars. The deck was in very good condition (NDI rating of 7 in 2006) but it had a few transverse cracks and a few longitudinal cracks in all three spans, as shown in Fig. 3.7 for the left lane. Some of these cracks extended through the depth of the deck, as evidence by efflorescence and rust stains on the underside of the deck (see Fig. 3.8).

During the site visit, the left lane of the bridge was closed for retrieval of concrete samples and marking of the segments for later application of the sealants. The crack pattern, the segments chosen for sealing the deck, as well as the approximate location of the retrieved concrete samples are illustrated in Fig. 3.7.

Figure 3.6 Overall view of bridge B-13-0034.

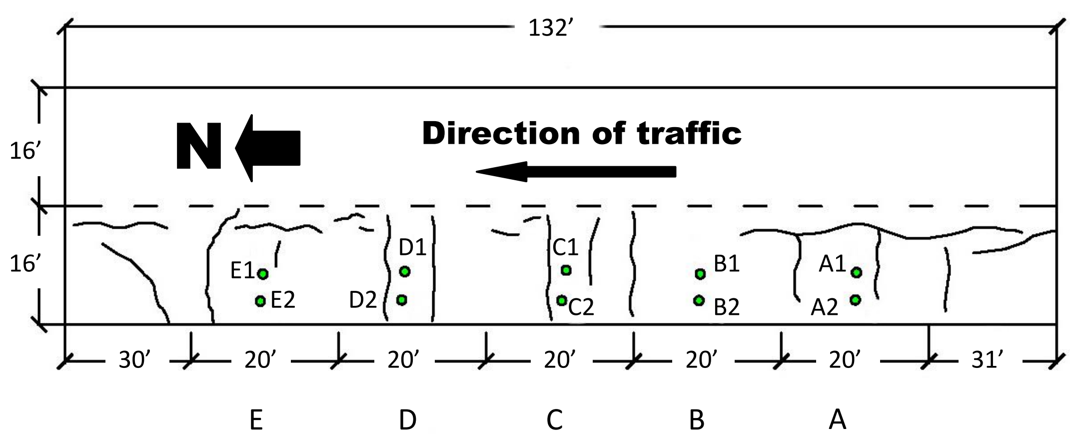

Figure 3.7 Dimensions, crack pattern, and sample retrieval location on the left lane of bridge B-13-0034.

Figure 3.8 Evidence of efflorescence and rust stains on the underside of the deck of bridge B-13-0034.

3.3.5 Bridge B-58-0080

This bridge is a two lane on STH 29 EB built in 1997. The bridge is a three span concrete deck reinforced with epoxy coated bars. The deck is supported on prestressed concrete girders with an overall length of 102 ft. as shown in Fig. 3.9. The deck was in very good condition (NDI rating of 7 in 2007) but it had longitudinal, transverse and diagonal cracks, as shown for the right lane in Fig. 3.10. These cracks, however, are believed to superficial as visual inspection showed no evidence of cracking on the bottom of the deck.

As noted earlier in section 3.2, shortly before the site visit it was learned that the deck had already been sealed at the time of construction. Therefore, the decks were not scheduled for sealing, but rather to establish a benchmark today (2009) and monitor the performance and the effectiveness of the specific deck sealant applied. For this purposes, concrete powder samples were taken on the shoulder and the right lane as shown in Fig. 3.10.

Figure 3.9 Overall view of bridge B-58-0080.

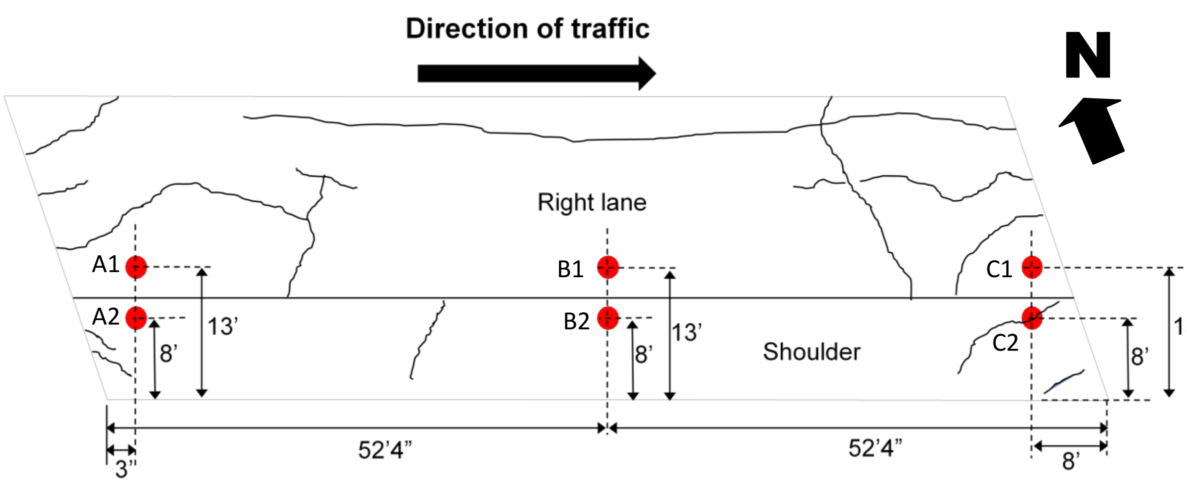

Figure 3.10 Dimensions, crack pattern, and sample retrieval location on the right and shoulder of bridge B-58-0080.

3.3.6 Bridge B-58-0081

This bridge is a two lane, single span deck supported on prestressed concrete girders with an overall length of 83 ft. The bridge was built in 1997 and was reinforced with epoxy coated bars. The deck was in very good condition (NDI rating of 7 in 2007) but it had a few longitudinal and diagonal cracks near the abutments. It also had a few minor transverse cracks, as shown for the shoulder and right lane in Fig. 3.11. Visual inspection of the

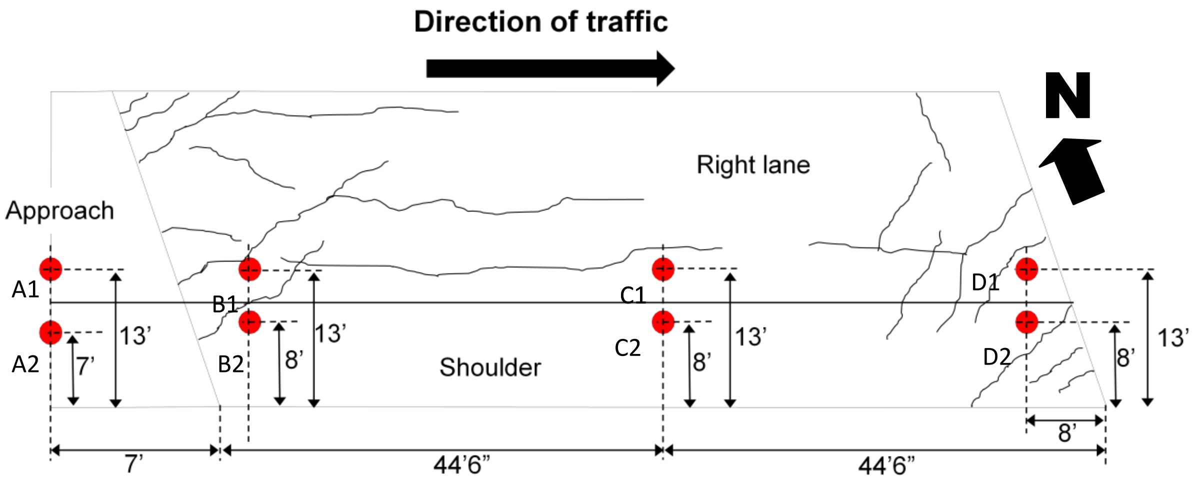

Figure 3.11 Dimensions, crack pattern, and sample retrieval location on the right lane and shoulder of bridge B-58-0081.

underside of the deck showed that the majority of these cracks did not extend over the depth of the deck, except for evidence of efflorescence in two of the diagonal cracks near the east abutment, as shown in Fig. 3.12.

Similar to bridge B-58-0080, the deck of this bridge was sealed at the time of construction. As a result, the deck was not scheduled for sealing, but powder concrete samples were retrieved to establish a benchmark of the chloride ion content today (2009) and later monitoring of the performance of the deck.

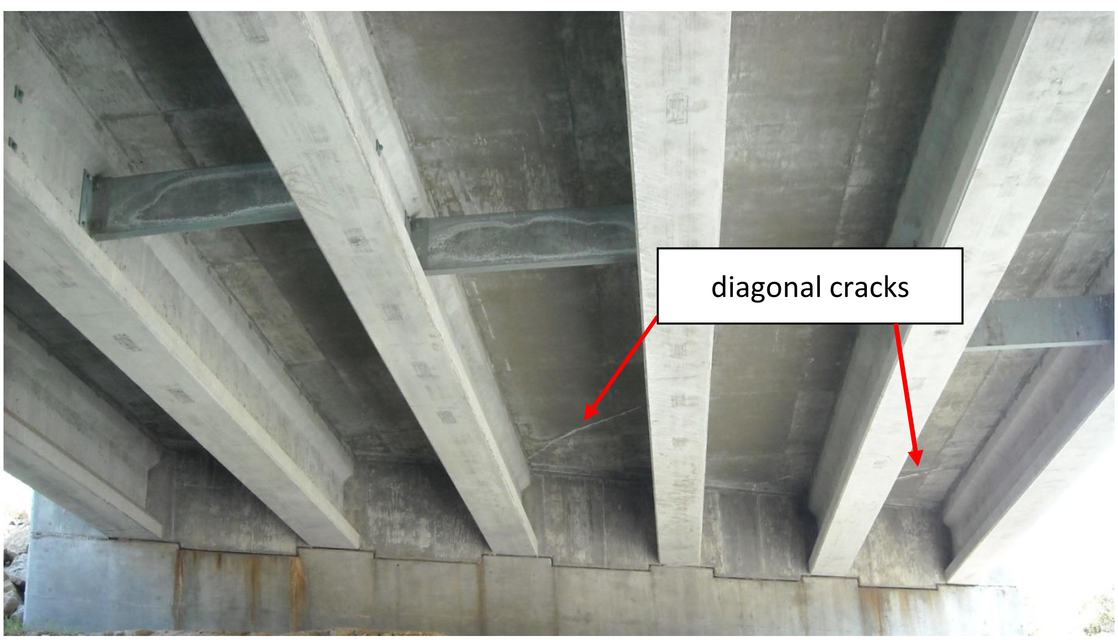

Figure 3.12 Evidence of efflorescence in diagonal cracks of deck of bridge B-58-0081.

CHAPTER 4
Test Results, Sealant Layout, and Monitoring Protocol

4.1 Introduction

In this chapter, the chloride ion tests results obtained from the powder samples extracted in the field are presented. A brief description of the sample extraction as well as the test procedures employed are provided as a reference for future testing and monitoring of the chloride ion content of the sealed decks. The layout of the test sections with the deck and crack sealants chosen for study in each deck is also presented. Also, a protocol for the continuing monitoring of sealant performance is suggested.

4.2 Sample Extraction Procedure

Concrete powder samples were taken at several locations during the site visit to the bridges. The approximate location of the sample extraction is shown in Figs. 3.3, 3.4, 3.5, 3.7, 3.10, and 3.11, for bridges B-13-0337, B-13-0553, B-13-0554, B-14-0034, B-58-0080 and B-58-0081, respectively.

In selecting the location to extract the samples, areas with cracks or missing material were avoided. A hammer drill with a 0.9 in. diameter bit was used to drill a pilot hole approximately ¼ in. in depth. Each hole was air-pressured cleaned of all powder and debris. Then, a smaller, ¾ in. diameter bit was used to drill an additional 1 in. in depth, as shown in Fig. 4.1. The material extracted between ¼ and 1 in. deep from the surface of the deck was placed in a plastic bag sealed and labeled as shown in Fig. 4.2. This material was then used for later measurement of the chloride ion content in the laboratory. To avoid cross contamination, all tools were thoroughly cleaned after drilling each hole.

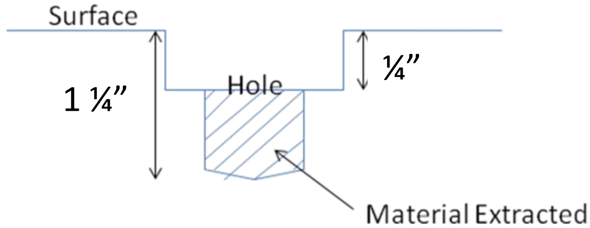

Figure 4.1 Dimensions of the holes drilled in the decks for extraction of powder samples.

Figure 4.2 Extraction of powder samples in the field.

In addition, three cores in B-13-0337 and two cores in B-14-0034 were extracted for later examination in the laboratory. The cores were 3" in. diameter and between 3 and 4 in. deep, and were removed directly above the wider cracks, including the bar when possible. The cores were stored in a sealed plastic bag and labeled with the recorded location on the deck.

4.3 Chloride Ion Content Test Results

Measurement of the chloride ion content was done using potentiometric tritation as permitted by the AASHTO T 260 Standard (2004). The procedure, equipment, instrumentation and data collection used in this study is described in detail elsewhere (Pincheira and Dorshorst, 2005). Using the powder samples extracted in the field, the acid-soluble chloride ion content was measured from at least two samples per hole.

The near surface, measured chloride ion content for each location in the deck is shown in Tables 4.1 through 4.6. A summary of the average measured chloride ion content in each deck is shown in Table 4.7. Also shown in Table 4.7 is the age of the deck at the time the sample was retrieved and the average daily traffic.

Overall, the data show the anticipated general trends. The deck with the highest chloride ion content was, as expected, the oldest deck of this group, i.e., bridge B-13-0337. Similarly, bridges B-13-0553 and B-13-0554, the newest decks, have the lowest chloride ion content among the unsealed decks.

The effectiveness of early sealing of a deck may be observed by comparing the results for bridges B-14-0034, B-58-0080 and B-58-0081. The last two decks were sealed at the time of construction, while B-14-0034 has remained unsealed. All three decks are of about the same age (about 10 years) and have a similar ADT, as shown in table 4.7. Also, exposure to deicing salts may be assumed to be nearly the same for all of them, although because bridge B-14-0034 is located in the southern part of the state, it exposure to deicing salts may be somewhat lower. As a result, a similar chloride ion content could be expected for all these bridges had they all been unsealed. The data show, however, that bridge B-14-0034 had a higher chloride ion content than B-58-0080 and B-58-0081 (note that the sample taken from hole A2 of bridge B-58-0081 had a very high content in comparison with the other samples as shown in Table 4.6. This could be an outlier which if left out of the average, the average chloride ion content for this deck would be even lower, i.e., 8.4 lb/cy). This result is significant as it shows that early sealing of the decks B-58-0080 and B-58-0081 has been an effective measure in reducing chloride ion intrusion these decks.

Table 4.1 Measured chloride ion content in deck of bridge B-13-0337

Hole	**Chloride Ion Content (lb/cy)**
	Average
A1	24.5
A2	22.4
B1	23.1
B2	24.6
C1	17.8
C2	23.9
D1	14.5
D2	17.1
E1	19.4
E2	20.8
Deck Ave. =	**20.8**

Table 4.2 Measured chloride ion content in deck of bridge B-13-0553

Hole	Chloride Ion Content (lb/cy) Average
A1	4.0
A2	3.4
B1	2.9
B2	2.6
C1	3.2
C2	4.2
D1	3.5
D2	4.2
E1	3.0
E2	1.7
Deck Ave. =	**3.2**

Table 4.3 Measured chloride ion content in deck of bridge B-13-0554

Hole	Chloride Ion Content (lb/cy) Average
A1	10.9
A2	9.1
B1	9.3
B2	6.8
C1	10.9
C2	10.3
D1	11.5
D2	8.6
E1	10.7
E2	8.2
Deck Ave. =	**9.6**

Table 4.4 Measured chloride ion content in deck of bridge B-14-0034

Hole	**Chloride Ion Content (lb/cy)**
	Average
A1	10.7
A2	15.3
B1	12.8
B2	14.0
C1	12.3
C2	17.5
D1	15.2
D2	11.6
E1	15.3
E2	12.5
Deck Ave. =	**13.7**

Table 4.5 Measured chloride ion content in deck of bridge B-58-0080

Hole	**Chloride Ion Content (lb/cy)**
A1	5.1
A2	4.3
B1	3.3
B2	9.7
C1	3.5
C2	7.3
Deck Ave. =	**5.6**

Table 4.6 Measured chloride ion content in deck of bridge B-58-0081	
Hole	**Chloride Ion Content (lb/cy)**
A1	14.2
A2	22.5*
B1	7.2
B2	11.3
C1	6.5
C2	12.1
D1	7.1
D2	8.7
Deck Ave. =	**11.2**

*suspect data point.

Table 4.7 Summary of the average measured chloride ion content in all decks

Bridge No.	**Age at time of sampling**	**ADT**	**Average Chloride Ion Content (lb/cy)**
B-13-0337	28	7300	20.8
B-13-0553	3	21800	3.2
B-13-0554	2	19100	9.6
B-14-0034	10	5100	13.7
B-58-0080*	11	6770	5.6
B-58-0081*	11	6760	11.2

*decks sealed at the time of construction.

4.4 Visual inspection of core samples

Three cores were extracted from bridges B-13-0337 and two cores from B-14-0034. The cores were extracted directly above crack locations to examine the condition of the crack faces and that of the bars.

Fig. 4.3 shows a photograph through a crack in one of the cores extracted from bridge B-13-0337. This deck contained black bars. Although carbonation depth was not measured, it can be seen that carbon dioxide has penetrated through the crack to a depth of approximately 3-1/2 in., i.e. the full depth of the core. Although no bars were severed with the core, rust stains on the bottom of the core at the bar level (see Fig. 4.4) show that bar corrosion activity is present. This result was expected since the chloride ion content level at the bar level in a crack should be about the same as that at the surface (Pincheira et al., 2008). For bridge B-13-0337, the average chloride ion content near the surface was measured at about 21 lb/cy which far exceeds the corrosion threshold content level of 1 to 1.5 lb/cy commonly for black bars (Pincheira et al., 2008).

Fig. 4.5 shows a photograph through a crack in a core extracted from bridge B-14-0034. Again, the penetration of carbon dioxide through the crack is evident (approximately 3-1/2 in.). This deck, however, is newer than that of B-13-0034 and is reinforced with epoxy coated bars. No bars were extracted with the core shown in Fig. 4.5. However, a second core extracted from this bridge severed a portion of the top bar of the top mat. In addition, the bar markings of the bottom bar of the top mat could be clearly seen on the bottom face of the core as shown in Fig. 4.6. As can be seen, there was no evidence of corrosion in this case, despite the fact that this bridge had a chloride ion content near the surface of about 14 lb/cy and significant carbon dioxide penetration through cracks.

Figure 4.3 Evidence of carbon dioxide penetration through cracks in bridge B-13-0337.

Figure 4.4 Rust stains on the bottom of a core extracted from B-13-0337.

Figure 4.5 Evidence of carbon dioxide penetration through cracks in bridge B-14-0034.

Figure 4.6 Bar markings (clean) on the bottom of a core extracted from bridge B-14-0034.

4.5 Layout of deck and crack sealants

Based on the site visit observations and the results of the chloride ion content a schedule for sealing the decks was developed. Because of the difference in age, chloride ion content found in the decks and the extent of cracking, the proposed schedule for deck and crack sealing as well as future monitoring of sealant performance was tailored according to existing condition of the deck, as described below.

4.5.1 Bridge B-13-0337

This bridge is 30 years old (2009) and had an average measured chloride ion content near the surface of 21 lb/cy in 2007. The deck had a number of longitudinal and transverses cracks of varying width, though none of them appeared to extend through the deck thickness as mentioned in section 3.3.1. Also, inspection of the cores revealed significant penetration of carbon dioxide through the cracks as well as evidence of corrosion activity in the top mat (this deck is reinforced with black bars).

The benefits of sealing a deck of such an age (30 years) are unclear because enough time has elapsed for chloride ions to penetrate deep into the concrete. Using Fick's law, assuming a diffusion coefficient of 0.05 in^2/yr, and the measured near-surface chloride ion content of 21 lb/cy at an average depth of about ¾ in., it is possible to estimate the chloride ion content profile over depth as shown in Fig. 4.7. The calculations show that the chloride ion content at the bar level (about 3-1/2 in.) for this deck would be about 1.2 lb/cy, a value that approximately corresponds to the onset of corrosion for black bars (Mindness et al., 2003). This result supports the observations from the cores which indicated that corrosion activity has already started.

Since the level of chloride ion content at the bar level is expected to have reached the threshold level for the onset of corrosion, the benefits of sealing the deck would be mainly to deter the ingress of moisture. Thus, sealing the deck will not prevent corrosion, but could significantly reduce the corrosion rate and therefore extend its service life.

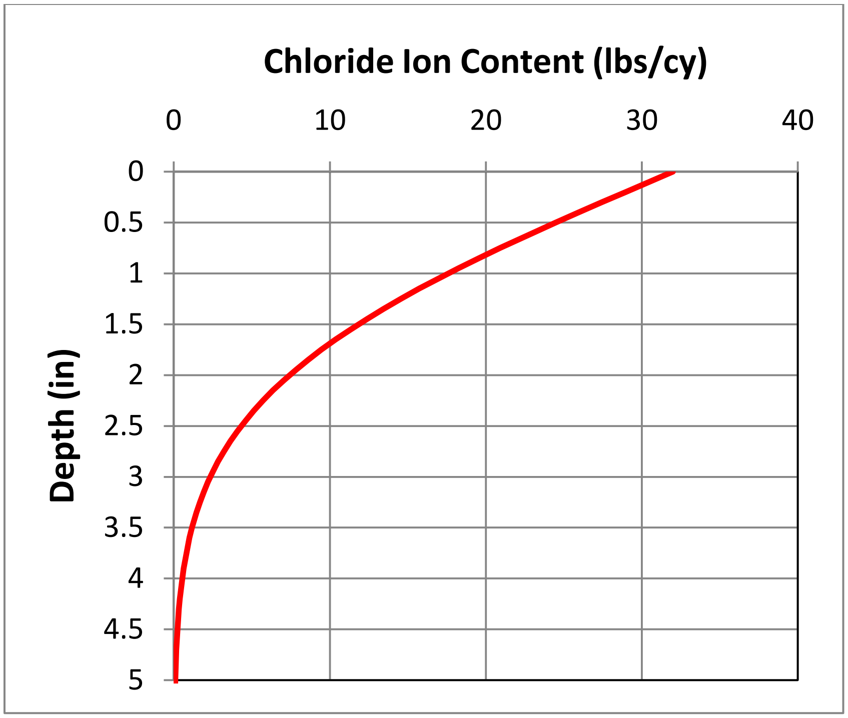

Figure 4.7 Estimated diffusion of chloride ion content with depth at 28 years (2007) using field data for bridge B-13-0337.

More important, however, is to seal the cracks observed on this deck. While the cracks did not extend through the thickness of the deck, the extracted cores revealed that some cracks did extend at least to the bar level. Again, since corrosion activity has started, the main objective of crack sealing this deck will be to prevent the ingress of moisture to stop, or at least reduce the corrosion rate. Clearly, sealing the cracks will also prevent further ingress of chlorides.

It was decided then that both the surface as well as the cracks would be sealed. The layout of the test sections with deck sealants chosen for field study (see section 2.4) is shown in Fig. 4.8. Sealing of the deck was done by DOT crews according to the manufacturers' specifications, without any special requirements or recommendations. Section A was left unsealed and is intended to serve as the control section to monitor sealant performance over time.

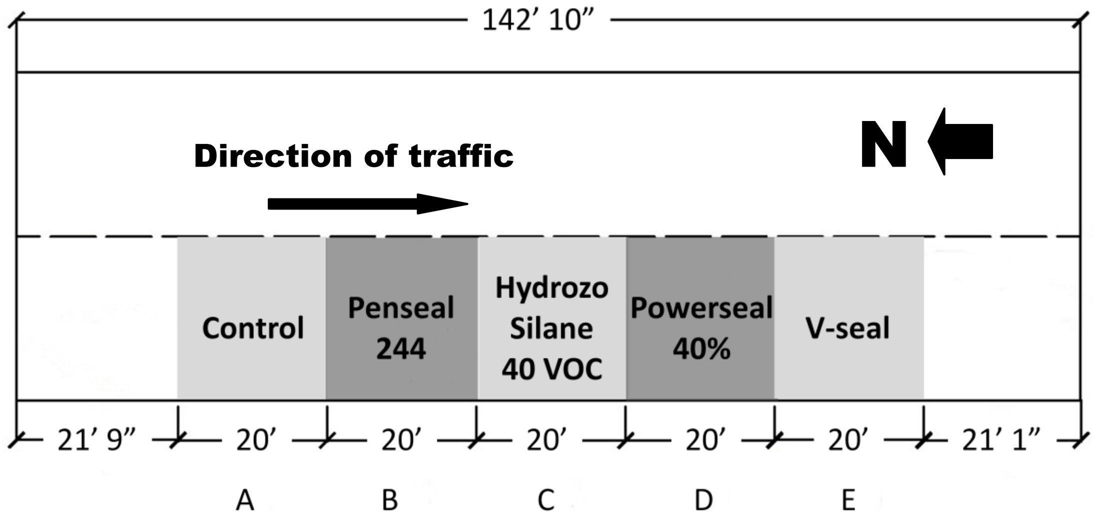

Figure 4.8 Layout of test sections with deck sealants for bridge B-13-0337.

Similarly, the layout of the test sections with the crack sealants is shown in Fig. 4.9. As for the deck sealants, crack sealants were applied according to the manufacturers' specifications by DOT crews, without any special requirements or recommendations.

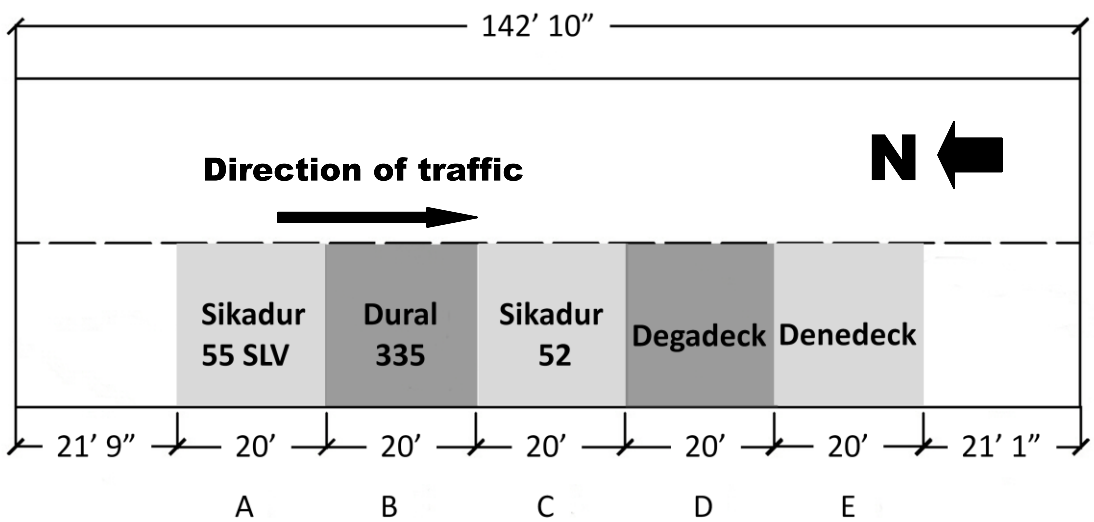

Figure 4.9 Layout of test sections with crack sealants for bridge B-13-0337.

4.5.2 Bridge B-14-0034

The deck of this bridge is 12 years old (2009) and had an average measured chloride ion content near the surface of 13.7 lb/cy in 2007. The deck had a number of transverse cracks and some longitudinal cracks. Some of the transverse cracks extended through the thickness of the deck. Inspection of the cores revealed significant penetration of carbon dioxide through the cracks, but no evidence of corrosion activity in the top mat (this deck was reinforced with epoxy coated bars). On the other hand, rust stains observed on the underside of the deck (see Fig. 3.8) suggest the presence of corrosion activity at some locations.

Fig. 4.10 shows chloride ion content profile over depth estimated based on the average measured chloride ion content of 14 lb/cy at an average depth of about ¾ in., an assumed diffusion coefficient of 0.05 in^2/yr using Fick's law. The calculations show that the chloride ion content at the bar level (about 3-1/2 in. deep) would be very low.

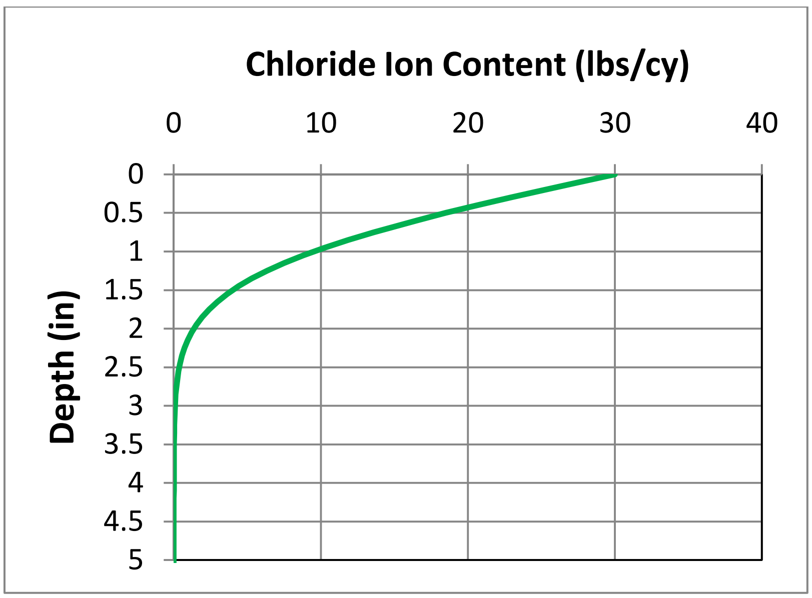

Figure 4.10 Estimated diffusion of chloride ion content with depth at 10 years (2007) using field data for bridge B-14-0034.

The chloride ion content at the bar level is much less than the threshold of corrosion for black bars and thus no corrosion activity was expected for this deck reinforced with epoxy-coated bars. However, rust stains observed along transverse cracks on the bottom of the deck suggest otherwise. A separate study (Pincheira et al., 2008) has shown that corrosion activity may be present in decks reinforced with epoxy-coated bars at chloride ion content levels of 5 lb/cy or higher. In this deck, such chloride ion content levels may be present at the bar level at crack locations which may explain the rust stains observed on the bottom of the deck.

Using Fick's law, it may be estimated that it will take about 50 years to reach the onset of corrosion for epoxy-coated bars at the bar level through diffusion of chloride ions into the uncracked concrete regions of the deck. Thus, the benefits of sealing the deck surface do not appear to be cost-effective maintenance strategy for this deck. Sealing the cracks in this deck, however, may significantly extend its service life since the deck already shows signs of corrosion activity at transverse cracks. Sealing the cracks will prevent the ingress of moisture and serve as a deterrent of corrosion.

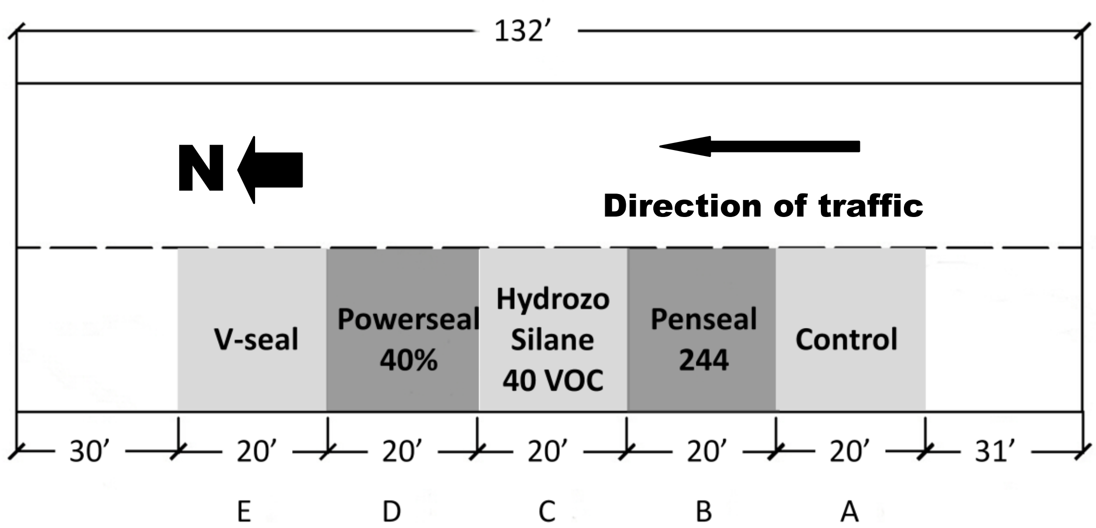

Figure 4.11 Layout of test sections with deck sealants for bridge B-14-0034.

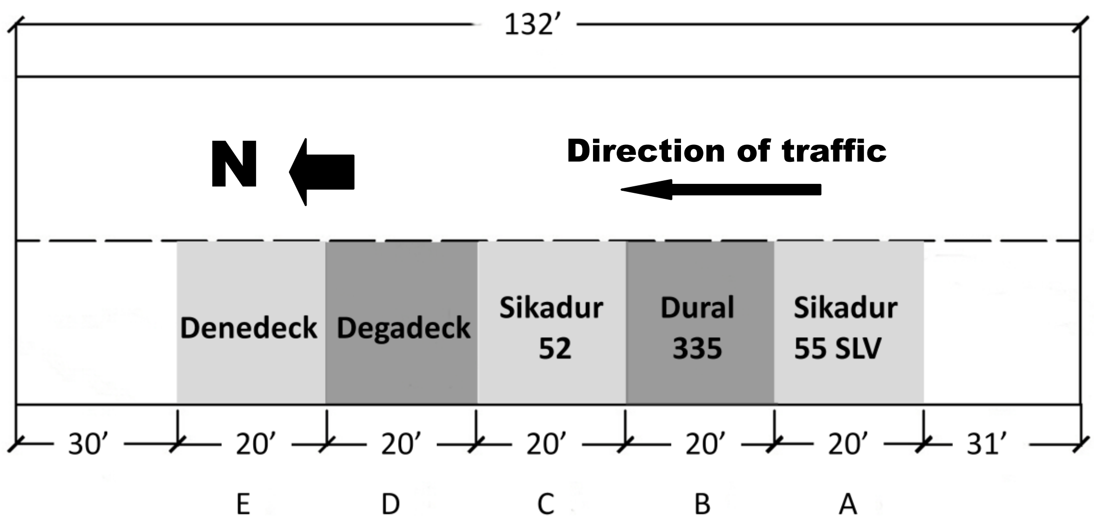

Figure 4.12 Layout of test sections with crack sealants for bridge B-14-0034.

Similar to bridge B-13-0337, both the deck surface and cracks were sealed for study. The layout of the test sections with deck sealants and crack sealants are shown in Fig. 4.11 and 4.12, respectively. As before, sealing of the deck was done by DOT crews following the manufacturers’ specifications, without any special requirements or recommendations.

4.5.3 Bridges B-13-0553 and B-13-00554

These bridges are five and four years old, respectively, and as was expected, they have relatively low chloride ion content (see Table 4.7). While some transverse and diagonal cracking of the deck was observed, their width was small and they do not extend through the depth of the decks.

Because of the low chloride content and the young age of these decks, they are ideally suited for a long term study of the sealants. For this reason, both decks were scheduled for deck and crack sealing. However, some sealants required a curing time (approximately 8 to 10 hrs.) longer than deemed acceptable for these bridges to be shut down to traffic, and thus the DOT maintenance crew decided not to seal these decks. Nonetheless, it is recommended that the DOT consider the possibility of sealing these decks, with at least those sealants that require a shorter curing time.

4.5.4 Bridges B-58-0080 and B-58-0081

These decks are about 12 years old (2009) and were sealed at the time of construction. Though they are of similar age as bridge B-14-0034, they have a lower average chloride ion content. This result suggests that the sealing of the deck has been effective at reducing the ingress chloride ions. Although the decks were sealed 12 years ago, resealing these decks does not appear to be necessary or useful for the present study. The type of sealant used on these decks is unknown and resealing the decks with a different product will not allow to make meaningful conclusions concerning sealant performance. For this reason, it was decided not to reseal these decks, although they should be monitored to assess the effectiveness of a sealed deck over time.

4.6 Suggested Protocol for Measuring and Monitoring Sealant Performance

a) Deck Sealers

Concrete powder samples should be extracted (using the procedure and at depths as described in section 4.2) every two years from the time the decks were sealed. Samples should be extracted from a minimum of two holes per sealed section. Also, enough material should be retrieved to be able to test at least two samples for chloride ion content per hole. The chloride ion content thus measured will allow a comparison of the ingress of chlorides between the unsealed (control) and the sealed sections to establish the effectiveness and performance of the sealants over time.

Core samples should be obtained at selected locations within in the control and sealed sections of the deck. Because of the strong relationship between a sealant's depth of penetration and the abrasion of concrete surface of the laboratory specimens, sealant depth of penetration should be measured from the extracted cores. In addition, extracted cores should be used to determine the distribution of chloride ion content with depth, by extracting samples at various depth locations as suggested in Fig. 4.13.

b) Crack Sealers

For decks with cracks extending the full depth of the deck, a ponding test should be conducted in-situ to determine how well the sealants have sealed the cracks. Note, however, that absence of percolation through the cracks in such a test does not ensure adequate performance of the sealants. However, it does serve to provide an indication of how well or poor the behavior might be. The test should ideally be conducted in early spring or late fall when the cracks are expected be at their maximum width.

For sealants that fail the in-situ test, no further tests would be required. In such cases, the cracks should be resealed. For sealants that passed the in-situ test and for decks with cracks that do not extend the full depth of the deck, core samples cut through cracks should be obtained in the control and sealed sections of the deck. Ideally, cores should be taken at cracks of various widths and should be taken at least to the bar level.

Cores should be taken to the laboratory to conduct a permeability test of the sealed crack by ponding. Afterwards, the cores should be cut transversely to the cracks and record the depth of penetration of the sealants.

Furthermore, powder samples should be collected from the cores at different depths at and away from the cracks, for example, as shown in Fig. 4.13. This would provide additional measurements of the chloride ion content for the control panel and those with deck sealants (samples obtained away from the cracks) and of the chloride ion content for the control and crack sealed sections (samples obtained at cracks).

Because of the invasive nature of the core extraction, the number and location of the cores should be selected with caution. Also, it is suggested that the first cores be extracted 2 or 3 years after sealing, and every five or six years thereafter.

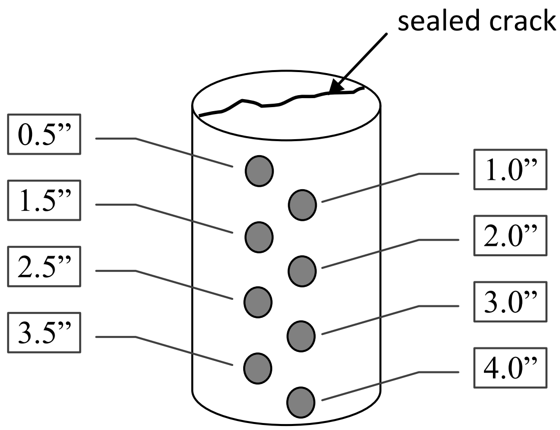

Figure 4.13 Proposed location for chloride ion analysis from extracted cores away from cracks (a similar location may be used at a crack).

In addition to these measurements, information concerning the environmental conditions (temperature and amount of snow), traffic conditions, amount and frequency of salt sprayed on the decks over the year must be recorded and stored.

CHAPTER 5
Summary

In an earlier study, the laboratory performance of commercially available deck and crack sealants was investigated at the University of Wisconsin. It was concluded that the performance of deck sealants depended largely on the type (water-based or solvent-based) and their depth of penetration. Generally, sealants with larger depth of penetrations performed better, but also required longer application and curing times. The crack sealants studied were all capable of fully penetrating the cracks prepared in the laboratory, but many deteriorated significantly under freeze-thaw cycles and may not be able to keep the crack sealed under an aggressive environment. The study pointed out, however, that the laboratory evaluation, which followed closely current standards, would not necessarily translate in similar performance in the field. In particular, deck sealants with lower depths of penetration, which did not perform as well in laboratory tests, could perform well in the field in bridge decks with low abrasion. Also, the laboratory prepared cracks were all clean and free of debris. In reality, however, bridge deck cracks are expected to be filled with dirt and debris. Although they have to be cleaned before application of a crack sealant, it is virtually impossible to leave it completely clean. The impact of partially clean cracks on the ability of a sealant to fully penetrate and seal the crack has not been studied in the field.

The main objective of this project was to develop and layout a protocol for the long-term monitoring and assessment of the performance of concrete deck and crack sealants in the field. To accomplish this goal, a total of six bridge decks were sealed with different types of sealants whose effectiveness will be monitored over a period of several years.

The bridges are all located in the state of Wisconsin. Four of them are located in the southern part of the state, while the other two are located in northern Wisconsin. The decks have ages that vary from 4 to 30 years old, but are all in good condition. The older decks presented a variety of longitudinal, transverse and diagonal cracking and were chosen to study the performance of crack sealants.

Following visual inspection of the decks, five test segments were laid out along one lane in four of the six bridges. Each segment had a length of 20' and a width equal to distance of the guard rail to the center line. Prior to sealing the decks, concrete powder samples were extracted in each segment in order to determine the in-situ chloride ion content near the surface of the deck. The analysis showed that the chloride ion content varied between 3.2 lb/cy for the younger decks (3 years old) and 20.8 lb/cy for the older decks (28 years old).

Based on the recommendations of the previous laboratory investigation, a pool of the best performing deck and crack sealants were chosen for this study. In two bridges, deck segments were then sealed with four deck sealants, namely: Penseal 244, Hydrozo 40 VOC, Powerseal 40%, and V-Seal. One segment was left unsealed (control segment) in order to be used a benchmark for later monitoring and comparison of deck sealant performance. Additionally, the cracks in each of these segments were sealed with five crack sealants, namely: Sikadur 55 SLV, Dural 335, Sikadur 52, Degadeck, and Denedeck. While two other decks were also scheduled for sealing, they were not done because the required curing time for some of the products was longer than deemed acceptable by DOT crews for these high traffic bridges. It is recommended, however, that these decks be sealed overnight or at least with those products that do not require such long curing times.

The remaining two bridges had been sealed at the time of construction and therefore they were not scheduled for sealing. While no specific information could be secured about the product used in these decks, the low chloride ion content for the age of these decks suggested that the applied product has indeed helped reduce the ingress of chloride ions. Therefore, it is recommended that these decks continue to be monitored over time.

Based on the inspections and the data collected in the field, a protocol and schedule for the continuing monitoring of sealant performance is developed. The protocol include periodic site visits (which could be done concurrently with bridge inspections), extraction and testing of powder samples for chloride ion content as well as core extraction for later examination in the laboratory. The effectiveness of the deck sealants shall be determined by comparing the chloride ion content in the sealed segments with that measured in the control sections, and by measuring the depth of penetration from extracted cores. Crack sealant effectiveness shall be determined by conducting ponding tests on core samples extracted at crack locations and by measuring the depth of penetration of the sealants in the field and in the laboratory.

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