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Implementation of Performance-Based Bridge Deck Protective Systems

Robert J. Frosch

Purdue University, frosch@purdue.edu

Michael E. Kreger

Purdue University, kreger@purdue.edu

Brad V. Strandquist

Purdue University, bstrandq@purdue.edu

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AUTHORS

Robert J. Frosch, PhD

Professor of Civil Engineering
School of Civil Engineering
Purdue University
(765) 494-5341
frosch@purdue.edu
Corresponding Author

Michael E. Kreger, PhD

Professor of Civil Engineering
School of Civil Engineering
Purdue University
(765) 494-9340
kreger@purdue.edu
Corresponding Author

Brad V. Strandquist

Graduate Research Assistant
School of Civil Engineering
Purdue University

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JOINT TRANSPORTATION RESEARCH PROGRAM

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16. Abstract <p>When considering the durability of a bridge, the concrete deck is often the most vulnerable component and can be the limiting factor affecting service life. To enhance the durability of both new and existing bridge decks, a protective system is often provided to prevent or delay the ingress of chlorides and moisture to the reinforcing steel. In the state of Indiana, this protective system typically comes in the form of a concrete overlay or a thin polymer overlay. Another protective system widely used in the United States and in many countries internationally consists of a waterproofing membrane overlaid with asphaltic concrete. Due to a history of poor performance in the 1970's and the 1980's, a moratorium has been placed on the installation of waterproofing membranes in Indiana. This study reevaluates the state-of-the-practice of bridge deck protection in Indiana with the goal of enhancing the Indiana Department of Transportation's toolbox of bridge deck protective systems. Consideration was given to the state-of-the-art and state-of-the-practice in bridge deck protective systems used by other state transportation agencies as well as by international transportation agencies. Research focused on the practice of installing waterproofing membranes and the latest technologies being used. Based on the information gathered, various protective systems were evaluated, and recommendations are provided on the selection of the most appropriate systems for various bridge conditions. Furthermore, a recommendation is provided to remove the moratorium on membrane systems so that the benefits of this system can be more fully explored and realized.</p>			
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EXECUTIVE SUMMARY

IMPLEMENTATION OF PERFORMANCE-BASED BRIDGE DECK PROTECTIVE SYSTEMS

Introduction

When considering the durability of a bridge, the concrete deck is often the most vulnerable component and can be the limiting factor affecting service life. To enhance the durability of both new and existing bridge decks, a protective system is often provided. The main requirements of an effective bridge deck protective system are the following:

- Create a physical barrier to prevent the ingress of chlorides and moisture
- Provide a sacrificial wearing surface
- Extend the life of the bridge deck for both new and existing bridges

In the state of Indiana, this protective system typically comes in the form of a latex-modified concrete overlay or a thin polymer overlay. Another protective system widely used in the United States and in many countries internationally consists of a waterproofing membrane overlaid with asphaltic concrete. Due to a history of poor performance in the 1970's and the 1980's, a moratorium has been placed on the installation of waterproofing membranes and asphalt overlays in Indiana.

While there are a variety of techniques and systems that can be used for bridge deck protection, history and experience have resulted in limited practices in the state of Indiana in this regard. Therefore, the objective of this research is to provide the Indiana Department of Transportation (INDOT) with an enhanced toolbox of bridge deck protective systems that can extend the life of a bridge deck for both new and existing construction.

Findings

A review of the state-of-the-art and state-of-the-practice in bridge deck protective systems was conducted with an emphasis on membrane systems and their use domestically and internationally. Indiana experiences with various protective systems were also documented. Based on this information, the various technologies were evaluated and the most promising technologies and practices were identified. Recommendations are provided on the use of bridge deck protective systems for both new and existing bridge decks. The major findings are as follows.

Waterproofing Membranes

Indiana Usage. Although historically, membrane systems have not performed successfully on Indiana bridges, the Indiana Toll Road Concession Company, the operating and maintaining agency for the Indiana Toll Road, installed membrane systems on eight bridges along the toll road which have been in service for two years. These bridges serve as a wealth of knowledge about membrane systems for INDOT, and their performance should be monitored over time and documented.

Domestic Usage. Since its first use as a protective system, states in the US have been greatly divided over the merits of membrane systems. States in the northeast and along the west coast have had a generally positive experience with membrane systems, whereas many Midwestern states, including Indiana, avoid their usage due to a

history of poor performance. Currently, 29 states use membrane systems, 14 of which provide a list of approved membrane products.

International Usage. Although the individual systems being used vary in many ways, all of the countries investigated as part of this study use waterproofing membranes with asphalt overlays as the primary protective system for bridge decks. The countries that were studied are Canada, the United Kingdom, Spain, Germany, Sweden, Denmark, Australia, and Japan.

Other Bridge Deck Protective Systems

The use of concrete overlays as a bridge deck protective strategy is extensive in the US. Latex-modified concrete overlays have been used since the 1970's and are still used by many state transportation agencies. Silica fume overlays have also been used for over 30 years but have been generally phased out due to early age cracking and difficulty in construction. In addition, the following concrete overlays have been used experimentally in several states: high-reactivity metakaolin concrete overlays, early-strength latex-modified concrete overlays, and fibrous concrete overlays. In the US, thin polymer overlays became a widely used system in the 1990's and this system has experienced a rapid increase in usage in the past two decades. This system was found to provide many benefits which include a quick installation time, a thin application, and a straightforward installation process. Two other systems, SafeLane® by Cargill, Inc. and Rosphalt® by Royston Laboratories, which have been implemented occasionally in the US, have been used with mostly positive responses.

Comparison of Systems

Installation. It was recognized that the most important factor leading to the success of any protective system is the quality of the installation. Of the three main systems evaluated, thin polymer overlays require the least intensive installation process, whereas membrane systems require a very extensive installation process. Additionally, because of the large thickness of an asphalt overlay, auxiliary work is required to reconstruct the joints, drains, and approaches on existing bridges when a membrane system is installed. Other concerns regarding the installation of membrane systems became evident throughout the study. These concerns include the added dead load of the asphalt overlay and the loss of ability to inspect the top-side of the concrete deck.

Service Life. While latex-modified concrete overlays have been observed to provide the longest expected service life in surveys completed by US and Canadian transportation agencies, membrane systems are also expected to provide long service lives. As an example, Danish engineers expect membranes to provide a service life of 50 years. Thin polymer overlays are expected to provide the shortest service life of the three systems.

Cost. Although they provide the shortest service life, thin polymer overlays have the lowest initial cost and the lowest life cycle cost. The costs associated with installing a concrete overlay or membrane system are comparable to each other and are both higher than that of a thin polymer overlay.

Implementation

Based on these findings, the following recommendations are provided.

Current Protective Systems

The practice of installing latex-modified concrete overlays and thin polymer overlays has been successful in Indiana; therefore, it

is recommended that these two systems continue to be implemented.

- Latex-modified concrete overlays are recommended for bridge decks where more extensive damage is observed. Because these systems provide a long service life, they are also recommended for more critical bridges as both a preventative maintenance and a rehabilitation measure.
- Thin polymer overlays are recommended for situations where quick installations are required and where a thin protective system is needed. It is also recommended that thin polymer overlays be considered as a preventative maintenance system on new bridge decks.

Moratorium

It is strongly recommended that INDOT uphold the moratorium on asphalt overlays used without a waterproofing membrane.

However, it is recommended that the moratorium on waterproofing membranes with asphalt overlays be removed. This system has significant potential for increasing the service life of bridge decks.

Membrane Systems

Due to the large amount of auxiliary work that is necessary to install a membrane system on an existing bridge (i.e. reconstruction of joints, drains, and approaches), it is recommended that membrane systems be installed on new bridges or on existing bridges that require reconstruction of approaches and joints. However, it is recommended that membrane systems be avoided where extensive patching is required. It is also recommended that INDOT develop an installation specification and a product approval process. By performing a pilot study which involves the installation of a membrane system on a new bridge, the new specification can be tested and any necessary changes can be made prior to standardizing.

CONTENTS

1. INTRODUCTION	1
1.1 Background	1
1.2 Overview of Protective Systems	1
1.3 INDOT Experiences	2
1.4 Previous Research	3
1.5 Reports, Guides, and Specifications	5
1.6 Objectives and Scope of Research	6
2. WATERPROOFING MEMBRANES	6
2.1 Introduction	6
2.2 Membrane Systems	6
2.3 INDOT History with Membranes	12
2.4 Domestic Usage of Membranes	15
2.5 International Usage of Membranes	21
2.6 Service Life of Membranes	30
2.7 Cost of Membranes	31
2.8 Factors Affecting Membrane Usage	31
3. OTHER BRIDGE DECK PROTECTIVE SYSTEMS	35
3.1 Introduction	35
3.2 Concrete Overlays	35
3.3 Thin Polymer Overlays	36
3.4 Polymer Modified Asphaltic Concrete	40
4. EVALUATION AND COMPARISONS	41
4.1 Introduction	41
4.2 Service Life Comparisons	41
4.3 Cost Comparisons	42
4.4 Deck Characteristics	43
4.5 System Characteristics	44
4.6 Summary of Advantages	45
4.7 Summary of Disadvantages	46
5. CONCLUSIONS AND RECOMMENDATIONS	46
5.1 Conclusions	46
5.2 Recommendations	46
5.3 Future Research	48
REFERENCES	49
APPENDIX A. INDOT Asphalt Overlay Moratorium	53
APPENDIX B. MDOT Bridge Deck Preservation Matrix	55
APPENDIX C. Approved or Qualified Products	57
APPENDIX D. Installation Specifications	63

LIST OF TABLES

Table	Page
Table 2.1 Comparison of Different Membrane Systems	8
Table 2.2 Indiana Toll Road Bridges with Membranes	14
Table 2.3 Inspection Report Information	18
Table 2.4 Chemicals Used for Winter Maintenance	19
Table 2.5 Accepted Combined Waterproofing Systems	29
Table 2.6 Expected Service Life Data	31
Table 4.1 Expected Service Life	42
Table 4.2 Virginia Life Cycle Cost Data	42
Table 4.3 Life Cycle Cost Data	43
Table C.1 List of Approved Products in the US	62

LIST OF FIGURES

Figure	Page
Figure 2.1 Typical preformed membrane system	6
Figure 2.2 Typical liquid applied membrane system	7
Figure 2.3 Application of co-polymer primer	7
Figure 2.4 Installation of liquid applied membrane	7
Figure 2.5 Installation of preformed membrane	7
Figure 2.6 Classification of materials used in liquid systems	8
Figure 2.7 Classification of materials used in preformed systems	9
Figure 2.8 Partial depth patch	10
Figure 2.9 Crew member operates shotblasting equipment	10
Figure 2.10 Partially shotblasted deck	11
Figure 2.11 Blistering (Okuda 2009)	11
Figure 2.12 Typical UK bridge cross section	12
Figure 2.13 Chase details	13
Figure 2.14 Typical strip seal expansion joint	13
Figure 2.15 Indiana bridge deck drain	14
Figure 2.16 Map of Indiana Toll Road	14
Figure 2.17 Grant Street Bridge membrane installation	15
Figure 2.18 Expansion joint detail	16
Figure 2.19 Expansion joint detail—zoomed	16
Figure 2.20 Membrane turned down at end of deck slab	16
Figure 2.21 Abutment detail	17
Figure 2.22 Deck drain with flush asphalt overlay	17
Figure 2.23 Deck drain with tapered asphalt overlay	17
Figure 2.24 Current use of membranes in the US	18
Figure 2.25 Freeze thaw cycle frequency	20
Figure 2.26 Waterproofing system used on Illinois bridge decks	20
Figure 2.27 Standard expansion joint detail	22
Figure 2.28 Standard joint detail	22
Figure 2.29 MTO standard subsurface drainage detail	22
Figure 2.30 Waterproofing detail at sidewalk	23
Figure 2.31 Wick drain detail at curb face	23
Figure 2.32 Schematic of European bridge waterproofing system	24
Figure 2.33 Schematic of UK system	24
Figure 2.34 Schematic of waterproofing system at curb	25
Figure 2.35 Detail of drainage system	26
Figure 2.36 Terminal joint	26
Figure 2.37 Detail of typical bridge terminal joint	27
Figure 2.38 German detail of membrane at curb	27
Figure 2.39 Typical Danish waterproofing system	28

Figure 2.40 Danish detail at drainage channel	28
Figure 2.41 Danish detail at concrete edge beam	29
Figure 2.42 Queensland bridge end joint detail	30
Figure 2.43 Japanese bridge deck deterioration	30
Figure 2.44 Japanese polymer-modified bitumen sheet system	30
Figure 2.45 Japanese spray-applied polyurethane system	30
Figure 2.46 Polyurethane system sprayed by robot	31
Figure 2.47 Expected service life of membranes	32
Figure 2.48 Expected service life data by region	33
Figure 2.49 Typical overlay thickness	33
Figure 2.50 Stirling Lloyd expansion joint	34
Figure 3.1 TPO installation on SR 26 over the Wabash River	37
Figure 3.2 Details of TPO installation on SR 26	38
Figure 3.3 TPO installation on US 231 over the Wabash River	38
Figure 3.4 Details of TPO installation on US 231	39
Figure 3.5 Damage at expansion joint	40
Figure 3.6 Debonding over asphalt patch	40
Figure 3.7 Separation of Rosphalt® at joints	41
Figure A.1 INDOT asphalt overlay moratorium (Page 1)	53
Figure A.2 INDOT asphalt overlay moratorium (Page 2)	54
Figure B.1 MDOT bridge deck preservation matrix (Page 1)	55
Figure B.2 MDOT bridge deck preservation matrix (Page 2)	56
Figure C.1 Maine DOT product qualification criteria (Page 1)	57
Figure C.2 Maine DOT product qualification criteria (Page 2)	58
Figure C.3 Maine DOT qualified product list (Page 1)	59
Figure C.4 Maine DOT qualified product list (Page 2)	60
Figure C.5 Maine DOT qualified product list (Page 3)	61
Figure D.1 New Hampshire installation specification (Page 1)	63
Figure D.2 New Hampshire installation specification (Page 2)	64
Figure D.3 New Hampshire installation specification (Page 3)	65
Figure D.4 New Hampshire installation specification (Page 4)	66

1. INTRODUCTION

1.1 Background

When considering the durability of a bridge, the concrete deck is often the most vulnerable component. In most cases, the bridge deck is the limiting factor regarding the life of the bridge structure. In cold regions where deicing salts are used, bridge deck deterioration is a serious issue plaguing the national bridge stock. Deicing salts are carried along with water through permeable concrete to the reinforcing steel which causes accelerated rates of corrosion. Furthermore, cracks in the deck provide an uninterrupted path to the reinforcing steel through which chlorides and moisture can penetrate. Due to corrosion and the fact that the corrosion product is more voluminous than the original steel, spalling can occur in the concrete above. This deterioration reduces both the load-carrying capacity of the bridge as well as the quality of the riding surface.

The first report addressing concerns about the durability of bridge decks was published in 1970 (1). From this synthesis, a more extensive understanding of the causes of bridge deck deterioration was developed. With this new understanding as the driving force, the Federal Highway Administration (FHWA) in 1972 mandated that any federally funded bridge have a protected bridge deck (1). This mandate became the major impetus for advances in bridge deck protective systems in the US.

In the broad topic of bridge deck durability, protective systems fall into one of four general strategies used to lengthen the service life of a bridge deck. The first strategy is to physically or chemically protect the steel which is typically accomplished by using epoxy-coated reinforcing steel or by cathodic protection. The second strategy is to prolong the time it takes for moisture and chlorides to reach the steel reinforcement which is most often achieved by increasing the concrete cover over the reinforcement. The third option is to take advantage of enhanced concrete properties, such as using concrete mixes that are less permeable. The fourth option involves the use of protective systems, typically applied to the top of the deck, that attempt to completely prevent the penetration of moisture and chlorides. For new bridge construction, the employment of multiple protection strategies is most effective. However, for many older bridges the steel reinforcement in place is not typically epoxy coated and the concrete cover can be partially deteriorated. As a result, the concrete deck and the steel imbedded within must be protected through other means, such as a protective system.

The main requirements of an effective bridge deck protective system are the following:

- Create a physical barrier to prevent the ingress of chlorides and moisture
- Maintain a safe level of skid resistance for traffic
- Provide a sacrificial wearing surface
- Extend the life of the bridge deck for both new and existing bridges

A number of details are involved with making these requirements a possibility, but if these four requirements are satisfied, then a protective system is considered successful.

1.2 Overview of Protective Systems

Following the FHWA mandate regarding bridge deck protection, significant resources were devoted to developing strategies to mitigate bridge deck deterioration. Despite one exception mentioned later, these strategies can be divided into the following three categories.

- Waterproofing Membrane Systems
- Concrete Overlays
- Thin Polymer Overlays

1.2.1 Waterproofing Membrane Systems

In the 1960's several New England states were alarmed by the discovery of deteriorated concrete hidden underneath asphalt overlays. As a solution to the problem, membranes, consisting of bituminous tar emulsions, were placed on the concrete deck before an asphalt overlay was installed. This waterproofing layer was intended to prevent the gathering of water at the interface of the asphalt overlay and the concrete substrate.

Although this membrane usage occurred in New England and a few Canadian provinces before the FHWA mandate, membranes became a nationwide focus due to the mandate. Efforts were focused on developing new materials and construction methods for the installation of waterproofing membranes. Because the surface of most membrane materials is not adequate for traffic, an additional riding surface is necessary to provide skid resistance. This riding surface is usually composed of multiple layers of asphaltic concrete. Many US states gained valuable experience installing waterproofing membranes due to governmental funding. However, it seems that state transportation agencies have either had successes with membranes or they have experienced failures and as a result, many states are divided over the merits of waterproofing membranes. States that were successful with membranes from the outset appear to be continuing the deployment of waterproofing membranes. They have become confident with the process and continue to gain valuable experience. Those that were not successful have since resorted to other options in bridge deck protection.

Although the technology has greatly advanced and much has been learned about perfecting the installation process, many state transportation agencies continue to avoid the use of membranes. If these transportation agencies choose to install membranes in the future, they face several difficulties. Much of the effectiveness of waterproofing membranes relies on proper installation. Furthermore, proper installation often requires quality

work performed by an experienced installer. The state transportation agencies that have continued installing membranes have gained the most experience and have acquired a trusted network of experienced installers. States that have long abandoned installing membranes typically lack the experience needed to install membranes properly.

1.2.2 Concrete Overlays

Other protective systems are widely used in the US and deserve mention. The other system that sees a majority of the usage is the concrete overlay, which makes use of enhanced concrete properties. This category includes latex-modified concrete (LMC), silica fume concrete, and low slump concrete overlays. In these systems, the impermeability and added durability of the concrete is relied upon to prevent water and chlorides from making contact with the reinforcing steel. One variation of a concrete overlay involves the addition of short unattached fibers into the concrete mix. This process is thought to offer beneficial toughness characteristics to the overlay. Other variations of concrete overlays involve the use of admixtures that allow for early high strength as well as the addition of wax beads which have been used in “internally sealed” concrete overlays.

1.2.3 Thin Polymer Overlays

Another common system utilized in the United States is a thin polymer overlay (TPO). These systems involve one or two thin layers of polymer concrete, which can be described as aggregate bound together by a polymer substance. Typically, the polymer consists of either an epoxy or a methyl methacrylate (MMA). Impermeability is achieved through the redundant nature of a multiple layer polymer overlay. Many advances have been made in the installation process of TPO's, increasing their constructability and improving their acceptance with transportation agencies. One variation of the thin polymer overlay is a proprietary product that makes use of an atypical aggregate that has deicing benefits. This specific product, produced by Cargill, Incorporated, is called SafeLane®.

1.2.4 Miscellaneous Systems

There is one other recent advancement in bridge deck protection that does not fit in any of the previously mentioned categories: Rosphalt® by Chase Corporation. Rosphalt® is a system that involves the mixture of polymer additives at the asphaltic concrete mixing plant. It can be best described as a polymer modified asphaltic concrete. This product is paved, with typical paving equipment, directly onto a bridge deck surface. It is expected to provide an impermeable riding surface. This product has gained favor in several Midwestern states.

1.2.5 Summary of Systems

Considering all of the systems mentioned, waterproofing membranes are the most frequently used bridge protection strategy internationally. In many ways, European countries have had more experience in the use of waterproofing membranes and have become confident in the technology. However, while membranes are standard practice internationally, their use in the US is limited. On the other hand, the use of concrete overlays and polymer overlays is very common in the US, but somewhat limited internationally.

1.3 INDOT Experiences

Like most other US states, INDOT installed several membranes in the 1970's and the early 1980's to comply with the FHWA mandate that all bridge decks be protected. While INDOT found some success in installing waterproofing membranes, there were many more failures, some of which had serious implications. Several other Midwest states, including Illinois and Kansas, also reported failures of waterproofing membrane systems. As a result, a moratorium was placed on all asphalt overlays in Indiana. This moratorium, which can be found in Appendix A, limited the use of membranes to projects approved by INDOT's Director of Bridges (2). The moratorium is still active today and continues to prevent the installation of membranes on Indiana bridges.

With membranes not being an available option, INDOT currently allows the installation of three different systems for bridge deck protection. The most commonly used options are latex-modified concrete overlays and thin polymer overlays. The third option, silica fume concrete overlays, have been installed in Indiana, but early age cracking, attributed to its unreliable installation procedure, has been observed. Consequently, silica fume concrete overlays are no longer a preferred practice in Indiana.

INDOT has been installing thin polymer overlays (TPOs) since 1986. Its current practice is to use TPOs on newer bridge decks. Also, since TPO's are installed relatively quickly, they are preferred on decks that have lane closure limitations such as bridges that are heavily traveled (3). For this reason, several TPO's have been installed on bridges serving high volume roads in Indianapolis. INDOT is confident in this rehabilitation technique and continues the installation of TPOs. INDOT has also had experience installing overlays of both the SafeLane® and Rosphalt® products.

1.3.1 INDOT Standards and Specifications

Current state-of-the-practice for bridge deck protection in Indiana is outlined in both the INDOT Design Manual (4) and the INDOT Standard Specifications (5). Chapter 404 of the INDOT Design Manual, which covers the design of bridge decks, does not mention the durability of a concrete deck or protective systems.

However, it does require that all steel reinforcement in newly constructed bridge decks be epoxy-coated. Chapter 412, which covers bridge rehabilitation, provides a summary of the typical practices utilized by INDOT for bridge deck protection. These practices include latex-modified concrete overlays, silica fume concrete overlays, low-slump concrete overlays, and sheet membranes with asphalt overlays. This chapter also indicates the extent to which these protective systems have been used.

In use since the 1970's, the LMC overlay is the most common option and is expected by INDOT to provide a service life of 15 years. Latex-modified concrete overlays are placed at a thickness of 1-¾ in. after ¼ in. of the concrete deck is removed by milling or hydrodemolition. Low-slump concrete overlays have been used as an alternative to latex-modified concrete overlays for over 25 years, but they provide the same qualities while being more expensive. As a result, low-slump overlays are no longer preferred. Silica fume concrete overlays have been used since the 1990's, but as mentioned before, have fallen out of favor. In regards to waterproofing membranes, this chapter reiterates INDOT's dissatisfaction with waterproofing membranes, citing trapped chlorides as the main cause for failure.

The INDOT Standard Specifications direct the installation of both latex-modified and silica fume concrete overlays in Sections 722 and 736, respectively. Additionally, documents are currently being produced by INDOT to include specifications for a "Polymeric Concrete Overlay for Bridge Decks" and an "Anti-Icing Surface Overlay System." Although thin polymer overlays have already become standard practice in Indiana, the first of these documents will outline the specifications for their installation. The second specification is being written for the SafeLane® product.

1.4 Previous Research

Extensive research has been conducted on the topic of bridge deck protective systems. Bridge deck durability is not a recently discovered problem and therefore has been revisited many times since its first consideration in the 1960's and 1970's. Along with nationally affiliated research, many state transportation agencies have implemented their own research and testing programs. The following includes the most essential research that has been performed on the topic of bridge deck durability and more specifically the use of waterproofing membranes. A brief summary of each is provided.

1.4.1 National Cooperative Highway Research Program (NCHRP)

NCHRP Synthesis of Highway Practice 4, Concrete Bridge Deck Durability (6). This synthesis is the first substantial report on the causes of bridge deck deterioration and their effect on bridge deck performance.

Spalling of concrete due to the corrosion of steel reinforcement was recognized as the most serious form of damage observed on bridge decks. Suggested methods to limit spalling were waterproofing membranes, thicker concrete cover, and less permeable concrete. This publication is credited for providing the initial motivation for the development of bridge deck protective systems.

NCHRP Report 165, Waterproof Membranes for the Protection of Concrete Bridge Decks, Laboratory Phase (7). A study of 49 field installations, representing 25 different membrane systems was conducted. The data acquired included electrical resistance, which served as an indicator of permeability, and bond test results. While none of the membranes exhibited issues bonding to the substrate, they were all deemed permeable to some degree according to the electrical resistivity tests. It was reasoned that these membranes were performing unsatisfactorily due to material insufficiencies such as an inability to bridge cracks or a tendency to blister or soften under high temperatures.

A laboratory evaluation and subsequent categorization of 147 different membrane systems was also conducted. After three rounds of screening in the laboratory, nine systems were deemed the most qualified and were subjected to a field application test. Of these nine systems, five were found to be most effective at preventing the penetration of moisture and chlorides. All five of the surviving systems were preformed membrane systems, which are manufactured in sheets and rolled onto the deck surface. As a result of the field application tests, it was recognized that proper installation is an important factor in the performance of a membrane.

NCHRP Synthesis of Highway Practice 57, Durability of Concrete Bridge Decks (1). A survey of 48 states regarding bridge deck construction and repair was conducted in 1977 and published in 1979. At the time of the survey, membranes were the most widely used protective system. However, it was documented that states were sharply divided over the merits of membrane systems. Results of this survey indicate that latex-modified concrete overlays were the second most widely used system at the time. Other measures to ensure durability are also mentioned, including coated steel reinforcement, increased concrete cover, effective drainage, and cathodic protection.

NCHRP Report 297, Evaluation of Bridge Deck Protective Strategies (8). An evaluation of the five most extensively used bridge deck protection strategies was conducted. The five strategies used most extensively at the time of publication were 1) increased concrete cover, 2) low-slump concrete overlays, 3) latex-modified concrete overlays, 4) membranes with asphalt overlays, and 5) epoxy-coated steel reinforcement. According to an assessment of survey data, a literature review, and an inspection of in-service bridge decks, the strategies of increased concrete cover, low-slump concrete overlays,

and latex-modified concrete overlays are expected to postpone the corrosion of the reinforcement for 50 years. Of these three options, increased cover thickness was the least expensive based on an assessment of lifetime costs. The most expensive options were latex-modified and low-slump concrete overlays which were considered to be slightly more expensive than membranes with asphalt overlays. According to the assessment, membranes are expected to deteriorate and require replacement after 15 years of service.

NCHRP Synthesis of Highway Practice 220, *Waterproofing Membranes for Concrete Bridge Decks* (9). A survey regarding the state-of-the-practice in bridge deck waterproofing membranes was issued in 1994. The responses to this survey by 48 states, the District of Columbia and six Canadian agencies were assessed in this NCHRP synthesis. The survey results indicated that states were still sharply divided over the merits of membrane systems, signifying no change in overall opinion since the 1979 synthesis (1).

Several other points of information deserve mention. The first is that, in the US, membranes were used more extensively for rehabilitation work than for new construction. The bridge deck surface area with membranes installed for rehabilitation work was around six times greater than the area for new construction. The second point is that 22 different proprietary products were identified as being used in the US, the majority of which were preformed membrane products. The third point is that service life estimates ranged from 10 to 30 years with the higher estimates provided by New England states. Lastly, the report illustrates the need for more thorough and detailed performance requirements including prequalification procedures, provisions that assure quality installation, and field performance requirements. The objective of these performance requirements is to encourage the development of products that offer better lifetime cost benefits rather than products with lower upfront costs and shorter service lives.

NCHRP Report 381, *Report on the 1995 Scanning Review of European Bridge Structures* (10). In an attempt to gain insight on the state-of-the-practice in bridge design and construction in Europe, five countries were scanned: Denmark, Germany, France, Switzerland, and the UK. It was indicated that all five of the countries implemented waterproofing membranes as the primary method for bridge deck protection. The Danish Road Directorate expects 30 years of service life from their membrane systems assuming that they are properly maintained. The German Ministry of Transport expects 20 to 25 years of protection out of their waterproofing system, which accounts for 5% of the total bridge cost in Germany. In the UK, typical membrane systems are expected to provide a 20 year service life; however, the widely used "Eliminator" system by Stirling Lloyd is expected to perform for 60 years.

NCHRP Synthesis of Highway Practice 333, *Concrete Bridge Deck Performance* (11). Based on the results of a survey regarding the design and construction of bridge decks, information for improving bridge deck performance was compiled. The main focus of the report is the effect of different concrete and reinforcing materials on the performance of bridge decks. Chapter 4 of this synthesis, titled "Bridge Deck Protective Systems," summarizes the responses of US and Canadian transportation agencies to survey questions regarding bridge deck protection strategies. The results indicate that latex-modified overlays are the most widely used system and exhibit satisfactory performance. The results also indicate that waterproofing membranes are used with mixed results and are limited by the life of their protective asphalt surfacing.

NCHRP Synthesis of Highway Practice 423, *Long-Term Performance of Polymer Concrete for Bridge Decks* (12). This synthesis documents the current state-of-the-practice in the use of thin polymer overlays (TPO). The document highlights the large recent growth in the use of thin polymer overlays citing that TPO use has quadrupled between the years of 1999 and 2008. It is also stated that thin polymer overlays can be implemented as either a preventative measure or a repair technique and are expected to exhibit a service life of 20 to 25 years. Thin polymer overlays are an attractive solution because of their short installation time, thin application, and competitive cost.

NCHRP Synthesis of Highway Practice 425, *Waterproofing Membranes for Concrete Bridge Decks* (13). This synthesis updates NCHRP Synthesis 220 (9). The findings of this synthesis do not indicate significant change in the state-of-the-practice of bridge deck waterproofing membranes since the issue of Synthesis 220. While the survey results indicate that 60% of US states use membranes, the majority of membrane installations are intended to lengthen the service life of existing bridge decks rather than to protect new decks.

1.4.2 Strategic Highway Research Program (SHRP)

SHRP-S-344, *Rapid Concrete Bridge Deck Protection, Repair, and Rehabilitation* (14). Included in this study is an evaluation of rapid treatment methods for bridge deck rehabilitation which is based on the inspection of 50 in-service bridge decks, a literature review, and survey results from various transportation authorities in North America. Rapid treatment methods are defined as repair techniques that can be implemented during off-peak traffic periods. Included in this group are asphalt overlays with or without membranes, thin polymer overlays, and high-early-strength concrete overlays. Although all of the techniques discussed can be performed within 8 hours, it was advised that longer lane closures are used to ensure more careful construction practices.

Based on the information gathered, thin polymer overlays are expected to have a service life of 10 to 25 years and high-early-strength concrete overlays are believed to yield a service life of 25 years. Although their use is limited, high-early-strength concrete overlays are considered to have tremendous potential. To reach their full potential, it is suggested that the installation process receives more development.

1.5 Reports, Guides, and Specifications

Along with the extensive research that has been performed on this topic, several reports, guides, and specifications provide information relevant to bridge deck protective systems.

1.5.1 American Concrete Institute (ACI)

ACI 222R-01, *Protection of Metals in Concrete Against Corrosion* (15). The corrosive process and its harmful effect on concrete decks, especially ones with significant cracking, are described in detail. An overview of potential prevention strategies is also given. These potential prevention strategies include waterproofing membranes, polymer impregnation, polymer concrete overlays, portland cement concrete overlays, silica-fume-modified concrete overlays, and latex-modified concrete overlays.

ACI 345R-11, *Guide for Concrete Highway Bridge Deck Construction* (16). As part of an overview of concrete bridge deck construction, the general needs and requirements for bridge deck overlays are discussed. Bridge deck overlays are classified into one of three categories: thin polymer overlays, hydraulic cement concrete overlays, or membranes with asphalt overlays. Thin polymer overlays typically have a thickness of ¼ to 1 in., hydraulic cement concrete overlays have a thickness of 1-¼ to 2-½ in., and membranes with asphalt concrete overlays have a thickness of 2 to 4 in.

The reasons cited for needing a bridge deck overlay are the following: to provide a waterproof barrier, to increase skid resistance, to provide a sacrificial wearing course, and to reduce the effect of wheel loads. To achieve these goals, the performance requirements of bridge deck overlays include proper bond to the concrete substrate, resistance to high shearing stresses due to braking or turning of vehicles, sufficient skid resistance, and sufficient durability. For the waterproofing barrier in particular, the following properties are required: impermeability, crack resistance, and flexibility under changes in temperature.

ACI 548.5R-94, *Guide for Polymer Concrete Overlays* (17). The use of polymer concrete overlays and their application in bridge deck work is discussed extensively in this guide. Included in the guide is information regarding material characteristics, surface preparation,

installation procedures, methods for performance evaluation, and maintenance measures.

Other specifications. Specifications have also been developed by ACI which address the installation of latex-modified concrete overlays and each type of polymer concrete. These specifications are the following:

- ACI 503.3-10, *Specification for Producing a Skid-Resistant Surface on Concrete by the Use of Epoxy and Aggregate* (18)
- ACI 548.4-11, *Specification for Latex-Modified Concrete Overlays* (19)
- ACI 548.8-07, *Specification for Type EM (Epoxy Multi-Layer) Polymer Overlay for Bridge and Parking Garage Decks* (20)
- ACI 548.9-08, *Specification for Type ES (Epoxy Slurry) Polymer Overlay for Bridge and Parking Garage Decks* (21)
- ACI 548.10-10, *Specification for Type MMS (Methyl Methacrylate Slurry) Polymer Overlays for Bridge and Parking Garage Decks* (22)

1.5.2 American Association of State Highway and Transportation Officials (AASHTO)

The AASHTO LRFD Bridge Construction Specifications (23,24) provide little guidance on the application of bridge deck protective strategies. Chapter 21 of the specifications provides directions for the use of waterproofing membranes on bridge decks. These directions include general requirements for surface preparation, installation, special details at edges and joints, and patching of damaged membranes.

Chapter 28 includes specifications for the materials and installation of a concrete bridge deck wearing surface. Despite the large variety of concrete overlays currently in use, the only option provided for in these specifications is a latex-modified concrete overlay.

The LRFD Bridge Design Specifications also provide limited guidance on the application of bridge deck protective strategies. The design specifications simply suggest that the durability of the concrete bridge deck is important, but they do not offer extensive guidance on how durability can be ensured.

Additionally, as part of a joint committee with representatives from the Associated General Contractors of America (AGC) and the American Road and Transportation Builders Association (ARTBA), AASHTO developed the “Guide Specifications of Polymer Concrete Bridge Deck Overlays” which was published in 1995 (25). This document provides extensive details for the installation of thin polymer overlays on concrete bridge decks.

1.5.3 NCHRP

As part of NCHRP Project 20-07 Task 234 a document titled “Guidelines for Selection of Bridge Deck Overlays, Sealers, and Treatments” was developed

(26). This document provides a general method for choosing which bridge deck protection strategy is most appropriate for different situations. The factors affecting the decision making process are “traffic constraints, dead load or overhead limitations, remaining service life, general exposure conditions, application constraints, skid resistance, concrete cover, contractor experience, planned future work, cost, or other conditions.”

1.6 Objectives and Scope of Research

While there are a variety of techniques and systems that can be used for bridge deck protection, history and experience have resulted in limited practices in the state of Indiana in this regard. Therefore, the objective of this research is to provide INDOT with an enhanced toolbox of bridge deck protective systems that can extend the life of a bridge deck for both new and existing construction. The latest technologies will be cataloged and evaluated.

The research was divided into several phases. First, a review of the state-of-the-art of bridge deck protective systems was conducted with an emphasis on membranes and overlays. Second, a review of the state-of-the-practice in bridge deck protective systems was conducted. This review complements NCHRP Synthesis 425 on waterproofing membranes by obtaining information on international practice. Third, Indiana experiences with protective systems are documented. These phases are outlined in Chapter 2 on waterproofing membranes and Chapter 3 on other bridge deck protective systems. Through these reviews, the various technologies are evaluated and the most promising technologies and practices are identified as discussed in Chapter 4. Finally, recommendations are provided in Chapter 5 on the use of bridge deck protective systems for both new and existing bridge decks.

2. WATERPROOFING MEMBRANES

2.1 Introduction

Waterproofing membrane systems have been a strategy for bridge deck protection in the US since the 1960's. In several New England states and Canadian provinces, the common practice was to overlay a concrete bridge deck with an asphalt overlay without a waterproofing membrane to provide a sacrificial wearing surface. It was recognized, however, that chlorides and moisture were being trapped at the interface of the asphalt overlay and the concrete substrate causing harmful deterioration. Therefore, waterproofing membranes were initially installed beneath the asphalt overlays as a simple measure to prevent this deterioration of underlying concrete (6).

Bridge deck waterproofing membranes differ from most other waterproofing efforts because the membranes must be able to withstand a more aggressive environment. This more aggressive environment includes increasingly

heavy traffic as well as the application of chlorides during winter maintenance. In addition, because bridge decks are horizontal surfaces, drainage of water is more difficult, allowing for the possibility of standing water.

While membrane systems currently in use vary in many ways, the typical system is composed of several parts. The typical system from bottom to top, as shown in Figure 2.1 and Figure 2.2, includes the following: concrete substrate, primer, membrane, protection layer, tack coat, and asphalt pavement. Each of these components will be described further in Section 2.2 of this report.

The life of a membrane system can be severely limited by the weakest component. In addition, as a system, the performance relies heavily on the compatibility between adjacent components. A reoccurring theme in existing literature is that the most common failure in membrane systems is due to insufficient bond between the concrete and the membrane or between the membrane and the asphalt pavement. However, if the bond performance is sufficient, most literature indicates that the overlying asphalt pavement is the limiting factor on the life of a system. To mitigate the issues presented by an aging asphalt overlay, most membrane installing agencies plan to rehabilitate the pavement one or two times before replacing the waterproofing system entirely.

2.2 Membrane Systems

The following sections outline the general components involved in the installation of membrane systems. These components include the materials used, the procedures involved in preparing the concrete deck, and the different aspects of the installation process. Different agencies typically have different specifications for waterproofing membranes. Many agencies base their specifications on what has been successful in the past, and in many cases, agencies default to the specifications provided by the manufacturer of the waterproofing product.

2.2.1 Materials

2.2.1.1 Primer. Primers are often used to ensure adequate bond between the concrete substrate and the waterproofing layer. Historically, one of the most critical aspects of a membrane system is the bond between the concrete deck and the membrane, thus

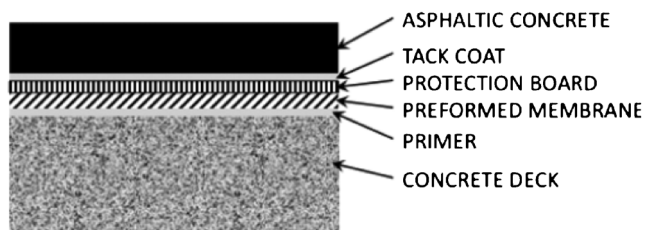


Figure 2.1 Typical preformed membrane system (13).

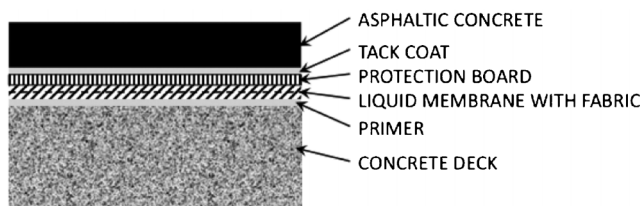


Figure 2.2 Typical liquid applied membrane system (13).

further stressing the importance of an effective primer. Primers also provide the function of preliminarily sealing and bridging fine cracks in the concrete deck. One of the main requirements of a primer is that it has a low viscosity which allows it to penetrate the textured surface of the concrete deck.

A primer can be specified for either liquid applied or preformed membranes and can either be poured and spread by squeegee or sprayed. Figure 2.3 shows the application of a primer by squeegee. Many membrane manufacturers offer a complementary primer that has proven to function well with their product. If a complementary primer is not offered, testing may be conducted to choose a proper priming material for the specific membrane product to be used.

2.2.1.2 Membrane. The primary function of the membrane is to serve as a barrier between the concrete substrate and the ingress of moisture and chlorides. To accomplish this, the membrane must provide a seamless impermeable layer. It must also have the ability to deform due to temperature fluctuations, crack movements, and traffic loads.

Two types of membranes are offered and each has its share of advantages and disadvantages. The two types of membranes are liquid applied membranes and preformed membranes. Liquid applied systems can be sprayed onto the deck, or they can be poured and then spread by squeegee. The installation of a liquid applied system can be seen in Figure 2.4. Preformed membranes, which are also called sheet membranes, are typically produced in sheets and rolled out onto the deck surface. The installation of a preformed system can be seen in Figure 2.5. The merits of these two types of membranes are presented in Table 2.1.



Figure 2.3 Application of co-polymer primer (27).



Figure 2.4 Installation of liquid applied membrane (28).

Liquid applied systems can vary in temperature and are classified as either hot or cold systems. They can also include a layer of reinforced fabric. This fabric, which gives the membrane better crack-bridging capabilities, is pressed into the membrane while still tacky. In some cases the membrane fabric is employed over the entire membrane. However, as a minimum, the reinforcing fabric should be installed at critical locations such as cracks, cold joints, and along any curbs.

Sheet-applied membranes are produced in rolls that are typically one meter wide or larger, of varying lengths, and are typically approximately 1/8th in. thick. Membrane sheets are rolled and bonded to the deck surface either through heat or by an adhesive on the underside of the membrane. Membranes with a built-in adhesive are often called “peel and stick” membranes.

In the late 1980's, extensive research on different waterproofing materials was performed at the Transportation Research Laboratory (TRL) in the United Kingdom. This work evaluated the merits of 48 different materials used in the UK. As part of the work, the materials used were classified into different categories (30,31). Figure 2.6 and Figure 2.7 present



Figure 2.5 Installation of preformed membrane (29).

TABLE 2.1
Comparison of Different Membrane Systems

Liquid Applied Membranes	Preformed Membranes
Easy to install on skewed or otherwise irregularly shaped bridge decks	Difficult to install on skewed or otherwise irregularly shaped bridge decks
On largely sloped bridge decks, the liquid might flow upon placement	Sheet systems are not sensitive to varying slopes
It is difficult to install a liquid membrane layer of constant thickness	All sheets are the same thickness
A seamless layer of membrane product can be installed	Sheets come in a predetermined size, laps are necessary
Liquid materials can release harmful fumes in the air	Sheet systems do not pose the threat of releasing harmful fumes
Often mixed on site providing potential for inconsistencies in the product	Production of the product is factory controlled

the classifications that were developed as part of the study at TRL (9).

As can be seen from these two classification trees, many types of materials are used to produce waterproofing membranes. Over 25 different proprietary membrane products are currently in use, some of which have several variations for different installation conditions. Due to the competitive market surrounding membrane technology, manufacturers continue to improve their products and develop new materials for different situations. This wide variability in membrane products makes it difficult to discuss the merits of membrane systems without investigating each proprietary product individually. For example, it is conceivable that a sheet membrane from “company X” might perform very well while a sheet membrane from “company Y” might perform poorly even though they are both sheet membranes.

2.2.1.3 Tack coat. The tack coat, or bond coat, is placed between the waterproofing layer and the surfacing above and is intended to strengthen the

bond. If a protection layer is provided, a tack coat can be specified for the interface of the membrane and the protection layer, as well as the interface between the protection layer and the asphalt overlay. Conventional waterproofing practices in the UK indicate that the thickness of the tack coat is often dictated by the size of the aggregate used in the asphalt overlay. If a larger aggregate is used, then a thicker tack coat is specified. Conversely, if smaller aggregate is used, then a thinner tack coat is specified. Ideally, upon compaction, the aggregate will fully penetrate the tack coat but will not penetrate the membrane layer (32).

The most critical issue for the tack coat is its durability against potential damage caused by construction vehicles. During placement and compaction of the asphalt overlay, the tack coat is in danger of being stripped and damaged. Strategies must be implemented to mitigate this problem. Firstly, the tack coat should not be driven on until it has set completely and is tack free. It is also beneficial to thoroughly clean the rubber wheels of the surfacing vehicle and cover them in a soapy solution. If the tack coat is damaged

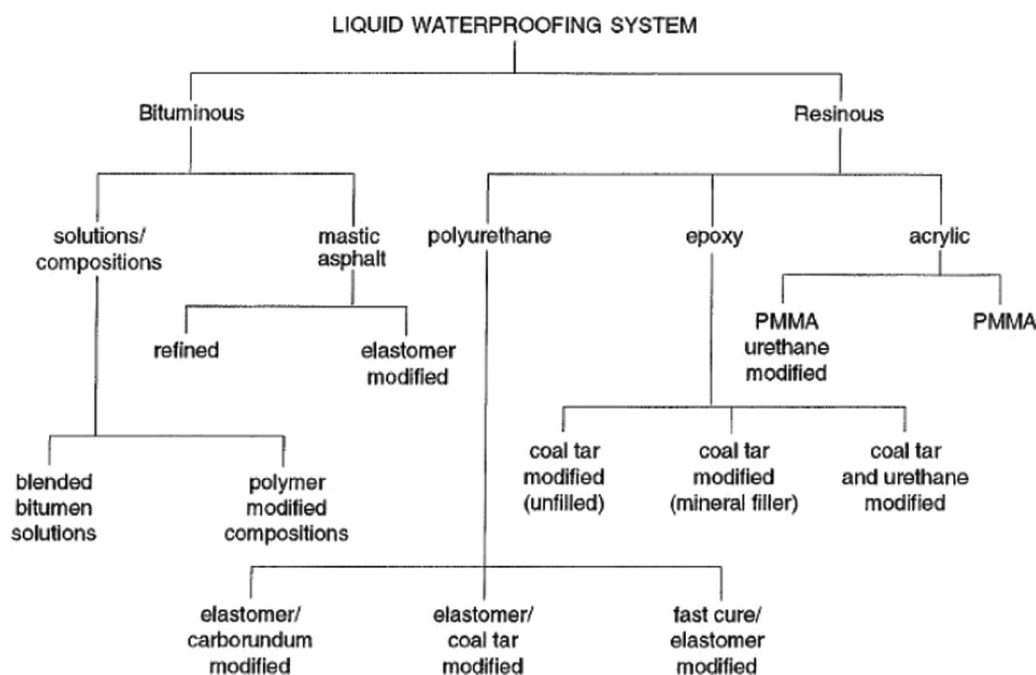


Figure 2.6 Classification of materials used in liquid systems (9).

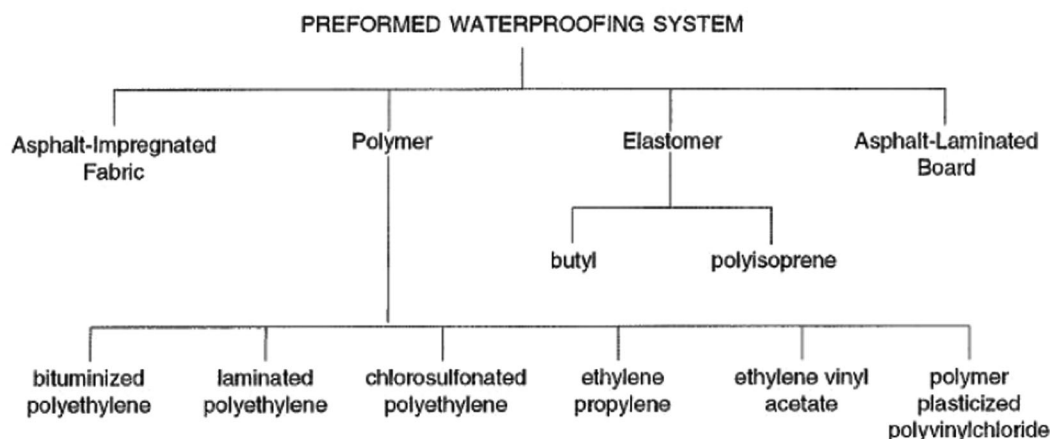


Figure 2.7 Classification of materials used in preformed systems (9).

during surfacing, repair patches can be placed immediately behind the rear tires of the surfacing vehicle before any asphaltic concrete is placed (33).

As is the same with primers, many membrane manufacturers also offer a complementary tack coat that has proven to function well with their membrane product. If a tack coat material is not offered, testing may be conducted to choose a proper material for the specific membrane product to be used.

2.2.1.4 Protection layer. This layer is provided to protect the membrane from impact and compaction of the wearing surface. It is also meant to protect the membrane from indentation by sharp aggregate or damage from construction vehicles. Protection layers are installed frequently in Canada and the UK, but their use in the US is limited. In all Canadian provinces and New Hampshire, this protection layer is achieved by a protection board which is installed in the form of sheets placed over the membrane.

As for membrane products, there are a variety of materials used in the production of protection boards. The New Brunswick Department of Transportation (NBDOT) solely uses protection boards made of a core of fortified asphalt, sandwiched between two layers of asphalt-impregnated fiberglass mat (34). The New Hampshire Department of Transportation specifies the same system as the NBDOT but also offers other options made of polystyrene board (35).

Many membrane products used on bridges may also be used for below grade waterproofing of structures which also requires the use of a protection board. As a result, several manufacturers of protection board products qualify their materials by the ASTM Standard Specification for Asphalt Based Protection for Below-Grade Waterproofing, ASTM D6506 (36).

In the UK, an “additional protection layer (APL)” is used to protect the membrane. This APL is typically made of a layer of sand asphalt which is simply asphalt concrete that uses fine sand aggregate. This layer is sometimes tinted red or is overlaid with a red mesh which acts as an indicator of depth during resurfacing

efforts. To leave the membrane intact during any resurfacing work, this red layer indicates the depth at which any deeper milling might damage the underlying membrane (33).

Additionally, several specifications for liquid applied membranes call for a thin layer of aggregate broadcast on the top of the membrane layer. This loose aggregate is slightly indented into the still viscous membrane layer. This aggregate protection course also provides additional bond strength between the membrane and the asphalt overlay. Similarly, there are some sheet products that include a granulated top surface to provide traction for surfacing vehicles as well as additional bond strength.

2.2.1.5 Wearing surface. A waterproofing membrane, both liquid-applied and preformed, cannot serve as the driving surface for a highway bridge. It simply does not provide sufficient skid resistance and would deteriorate under the pressures of traffic. To remedy this situation, a membrane is paired with one or more layers of asphaltic concrete. The durability of the asphalt wearing surface often dictates the life of the membrane. Theoretically if the asphalt wearing surface is properly maintained, the underlying membrane can last the entire life of the bridge. While this is most often not the case, there are several ways to ensure longevity of the wearing course and in effect the underlying membrane.

One of the ways to enhance the durability of the system is to increase the thickness of the asphalt overlay. Thicker pavements are more durable and permit a lower shear force at the interface of the membrane and the asphalt overlay. The thickness of this asphalt pavement can range between 2 in. to over 4.5 in. Thicker overlays often consist of two layers of hot-mix asphalt: a base course and a surface course. Despite its extensive use, it has been suggested that using typical hot-mix asphalt on bridges may be insufficient. To acquire proper density, which dictates durability, hot-mix asphalt is intended to be compacted by vibratory roller. Because vibratory rollers pose a danger considering the strength of bridges, they are not

used, and hot-mix asphalt overlays are not compacted to the desired density. As a solution to this problem, stone mastic asphalts (SMAs) have been used because they require static rollers instead of vibratory rollers to achieve proper compaction. SMA's also rely on stone-on-stone contact to provide increased rutting resistance and durability.

2.2.2 Preparation

The following sections provide information regarding the preparation of a concrete deck for the installation of a membrane system. Sections 2.2.2.1 and 2.2.2.2 regarding inspection and patching apply only to the preparation of an existing bridge deck and Sections 2.2.2.3 and 2.2.2.4 regarding substrate preparation and quality testing apply to the preparation of both new and existing bridge decks.

2.2.2.1 Inspection. Prior to any work, an inspection of the deck is typically performed. The intent of this inspection is to identify any areas on the deck that require removal and patching due to delamination or otherwise unsound concrete. There are several non-destructive techniques that are used to inspect a concrete bridge deck which include visual inspection, chain dragging, ground penetrating radar, impact-echo testing, infrared thermography, and ultrasonic pulse velocity, among others. Most agencies perform visual inspection and chain dragging as a minimum and supplement with more involved inspection techniques if needed.

2.2.2.2 Patching. After an inspection is conducted, unsound concrete can be removed and repaired. In some cases, unsound concrete will extend below the top layer of reinforcement requiring partial depth patching (Figure 2.8). While performing a partial depth patch, concrete should be removed to a depth that is 0.5 in. to 1 in. below the steel reinforcement so that the steel can be cleaned thoroughly and the patching material can be properly bonded to the reinforcement. Some membrane



Figure 2.8 Partial depth patch.

manufacturers offer proprietary patching materials, but any typical patching material that will return the deck to its newly constructed condition is satisfactory. The membrane should not be placed until the patch has been given sufficient time to set.

2.2.2.3 Substrate preparation. As has been reiterated several times, the bond between the concrete substrate and the membrane is often the most critical part of the system. To ensure an effective bond between the substrate and the membrane, attention must be paid to the condition of the concrete surface. If debris, dirt, moisture, or any other foreign objects exist on the surface, the quality of the bond will be jeopardized. Crews should work meticulously to remove anything that might cause local failure of the bond.

Shotblasting is the preferred method to clean and prepare the surface for a waterproofing membrane (Figure 2.9). This is a departure from the preparation technique commonly used for concrete overlays (hydro-demolition) because, unlike concrete overlays, membrane systems require a dry deck before installation. Upon completion of shotblasting, the deck should look noticeably cleaner because the dirt, grease, and grime that build up on the surface of a highway bridge are removed. Figure 2.10 shows a deck that has been partially shotblasted. The portion in the left-hand side of the photo is noticeably cleaner because it has been shotblasted.

Milling is another method used for preparing the deck surface for an overlay and can be used to compensate for the weight of a future overlay if additional dead load is prohibited. However, because an asphalt overlay is considered to have negligible load carrying capacity in bending, the strength of the deck will be decreased. Caution should be exercised when milling to avoid the removal of an excessive amount of concrete.

After shotblasting and/or milling are completed, the deck must be thoroughly cleaned of any remaining dust or other unwanted material. This process is completed



Figure 2.9 Crew member operates shotblasting equipment.



Figure 2.10 Partially shotblasted deck.

by industrial sweeping equipment and compressed air, which can be used to blow any unwanted material off the surface. If it rains any time after the deck preparation is completed and before the placement of the membrane, the deck needs to be properly dried and cleaned again before continuing. In addition, if traffic is permitted onto the deck after the deck preparation is completed and before the placement of the membrane, the deck should be shotblasted and cleaned again.

If a concrete deck already has an overlay that needs replacing, the existing overlay should be completely removed before a new one is installed. After removal of the old system, the original concrete deck should be evaluated again for unsound concrete before installing a new overlay.

2.2.2.4 Quality testing. The completion of the surface preparation process is a major milestone in the installation process. To prove that the deck has been prepared properly and that the bond will be successful, it is often required that the contractor successfully complete a series of pull-off tests. Agencies installing liquid applied membranes may use ASTM D4541 (Standard Test Method for Pull-Off Strength of Coatings Using Portable Adhesion Testers)(37) as the standard method for performing a pull-off test. The frequency and desired strength of the pull-off tests is typically included in the contract documents.

Along with pull-off testing, agencies might also require tests that check the moisture content of the deck surface. Surface moisture can be harmful to bond with the membrane. If surface moisture underneath a membrane evaporates, either by a hot-applied membrane, hot surfacing material, or if the air temperature is high, it can cause blistering (Figure 2.11). If unwanted moisture exists on the deck surface, installers are typically required to allow it to dry or to actively remove it by heaters or other methods.



Figure 2.11 Blistering (38).

2.2.3 Installation

2.2.3.1 Personnel. It is common for a transportation agency to require that a representative of the membrane manufacturer be present for all or at least a portion of the installation. Some agencies might also require that the membrane product be installed by a certified crew or contractor. If the membrane manufacturer does not have an in-house installation crew, it may also have its own list of qualified installers.

2.2.3.2 Temperature considerations. Many products that are used in membrane systems are sensitive to variations in temperature. Under high temperatures, materials like liquid applied membranes are in danger of softening and flowing which can cause inconsistencies in the thickness of the membrane layer. Under cold temperatures, materials, such as primers, may have quicker set times preventing them from fully penetrating the concrete deck. For this reason, not only are ambient temperatures tracked, but the temperature of the materials and the deck surface are also monitored. It is common that contract documents default to the manufacturer's specification regarding proper installation temperatures.

For some of the steps involved in the installation process, it may be a requirement to perform the step continuously until a stopping point such as a joint in the bridge deck is reached. If there is reason for the installer to believe that temperatures may change significantly in the middle of the step, the process will be delayed until the installer can be sure that he will experience the necessary temperatures throughout the entire process.

One of the most crucial temperature concerns is the temperature of the asphalt pavement during compaction. Because most membrane products become soft under higher temperatures, an overlay with excessively high temperatures may cause unwanted damage to the bond coat or the membrane. To prevent unwanted damage, the heat of the asphalt overlay should activate the tack coat material enough to allow for embedment

of the aggregate but not excessively so as to cause flowing of the tack coat or the liquid applied membrane.

2.2.3.3 Laps (for sheet membranes). Placement of sheet membranes should always proceed from the low side of the deck to the high side. This ensures that, at a lap joint, the high side membrane overlaps the low side membrane thus creating an uninterrupted path for the travel of water. If the sheets are installed in the reverse order, there is a possibility that water can collect at the joint of two membranes and penetrate underneath the low side membrane. Depending on what membrane product is being used, the laps might be welded by torch or by a sealing material. If two membrane layers are specified, the laps should be staggered so that they do not occur at the same location.

2.2.3.4 Membrane termination. The outside edge of the membrane layer can be a critical point in the waterproofing seal. If water gathers at the edge it can threaten to seep underneath the membrane and cause it to debond from the substrate. To prevent this problem, it is important to enact proper detailing at joints, curbs, and drains. Details provided by the Highways Agency of the UK are shown in Figure 2.12 and Figure 2.13. Figure 2.12 shows the typical cross section of a UK bridge which incorporates the sidewalk, curb, and the location of the chase where the membrane is terminated. Figure 2.13 illustrates the various ways to terminate a membrane in the chase.

2.2.3.5 Repair. Before placing the asphalt overlay, it is important to evaluate the condition of the membrane. A punctured membrane can result in a severe local failure if it is not repaired before the asphalt overlay is placed. Patching of the membrane may be done, as long as a sufficient amount of overlap is provided. Many agencies default to the recommendations of the membrane manufacturer on how a repair can be conducted (13).

2.3 INDOT History with Membranes

Like most other US states, INDOT installed several membranes in the 1970's and the early 1980's to comply with the FHWA mandate that all bridge decks be

protected. While INDOT found some success in installing waterproofing membranes, there were many more failures, some of which had serious implications. Several failures occurred within the first five years of service with a number of them occurring on concrete box girder bridges (40). These failures were a result of the inadequate ability of the membrane to withstand differential displacement between adjacent box members (41). With a deteriorated membrane, the top flange on several concrete box beams experienced full depth deterioration which allowed water to enter into the cavities of the girders. Other problems that were encountered include rutting of the asphalt pavement due to braking forces as well as large concentrations of chlorides at locations where membranes had been damaged (42).

Most failures were considered to have occurred because moisture and chlorides had penetrated the pavement and became trapped at the bottom of the asphalt pavement layer. The trapped water proceeded to deteriorate the membrane, corrode the steel reinforcement, and damage the concrete. Another possible cause of the failures was the use of an improper primer and bond coat. At the time of installation, INDOT was using the same bond coat material used in typical highway asphalt pavement efforts which may have been insufficient for this application. It is also speculated that the emulsified asphalt prime coat was not given the proper amount of time to set before the membrane layer was applied (43).

A report of the failures of waterproofing membranes on Indiana bridges was produced by INDOT research engineer, Sedat Gulen, in the 1980's (40). This report is no longer available, which limits the amount of knowledge that can be gained from these past failures. Following the report by Gulen, a moratorium was placed on all asphalt overlays. This moratorium limited the use of membranes to projects approved by INDOT's Director of Bridges (2). The moratorium is still active today and continues to prevent the installation of membranes on Indiana bridges.

2.3.1 Indiana Membrane Issues

When contemplating the use of membranes as standard practice, several issues, somewhat specific to

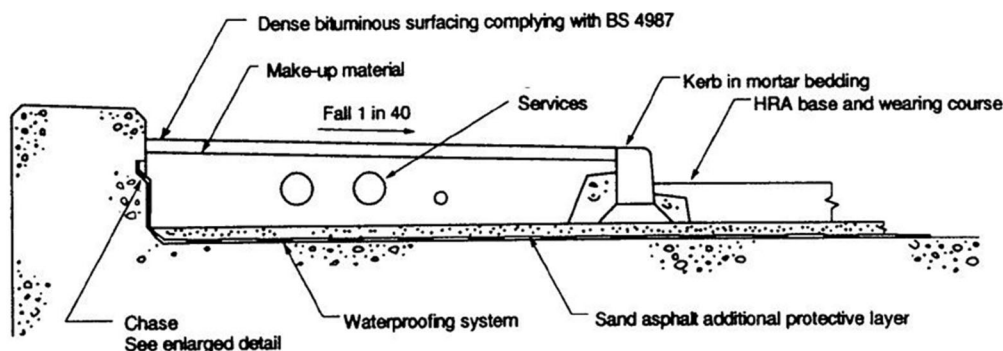


Figure 2.12 Typical UK bridge cross section (39).

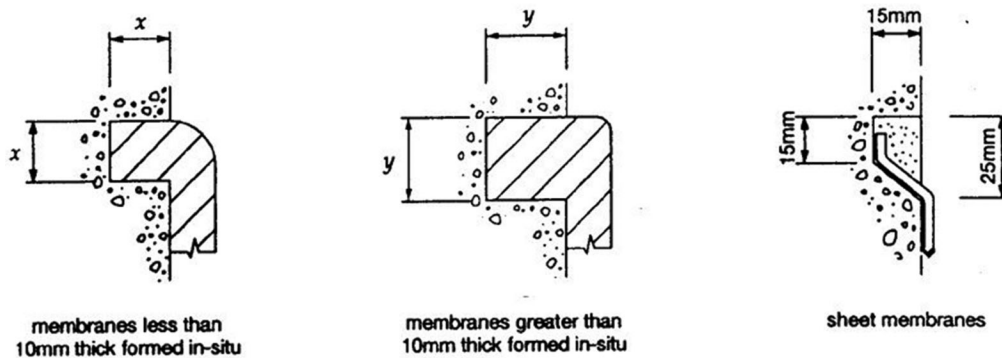


Figure 2.13 Chase details (39).

the situation in Indiana, should be considered. To provide a framework for the remainder of this chapter, in which the merits of membrane systems will be discussed, the issues that INDOT faces will be discussed here.

2.3.1.1 Pavement thickness. Indiana bridges are currently designed for 35 psf of additional dead load to account for a future wearing surface (4). Depending on the thickness of the asphalt overlay used in a membrane system, it is possible that the weight may be greater than the amount for which the bridge was designed.

2.3.1.2 Details at joints. In Indiana, new bridges are not designed to accommodate future installation of a thick overlay. This presents a problem for any rehabilitative work involving membranes. If a thick asphalt pavement is to be installed, additional work must be performed to reconcile the grade at joints. A typical strip seal joint used in Indiana is shown in Figure 2.14. If several inches were added on top of the existing roadway surface, the joint hardware would have to be relocated to match the elevation of the new roadway surface. The costs of this additional work might outweigh the benefits of a membrane system.

2.3.1.3 Drainage. In the same way that additional work must be conducted to reconcile the elevation at

joints, proper detailing is necessary to ensure sufficient drainage after a thick asphalt overlay is installed. Figure 2.15 shows a deck drain on the westbound SR 26 bridge over the Wabash River. There are significant difficulties involved with detailing a waterproofing membrane and asphalt overlay around this drain while still ensuring that surface and subsurface water can be properly removed from the deck.

2.3.1.4 Inspection. Standard INDOT practice in bridge construction includes the use of stay-in-place forms for concrete bridge decks which prevent inspection of the underside of a bridge deck. If a membrane system is also installed, both the top and the bottom of the deck cannot be inspected. If problems exist in the concrete deck, warning signs may not be observed until the problem has escalated to an extreme stage. It is for this same reason that many state transportation agencies refuse to install membrane systems in preference for a bare deck.

2.3.2 Indiana Toll Road

The Indiana Toll Road extends east to west for 157 miles along the northern border of the state, between Ohio and Illinois (Figure 2.16). This highway is a major connector for traffic between the east coast and Chicago. For most of the toll road's history, maintenance and operations were performed by INDOT.

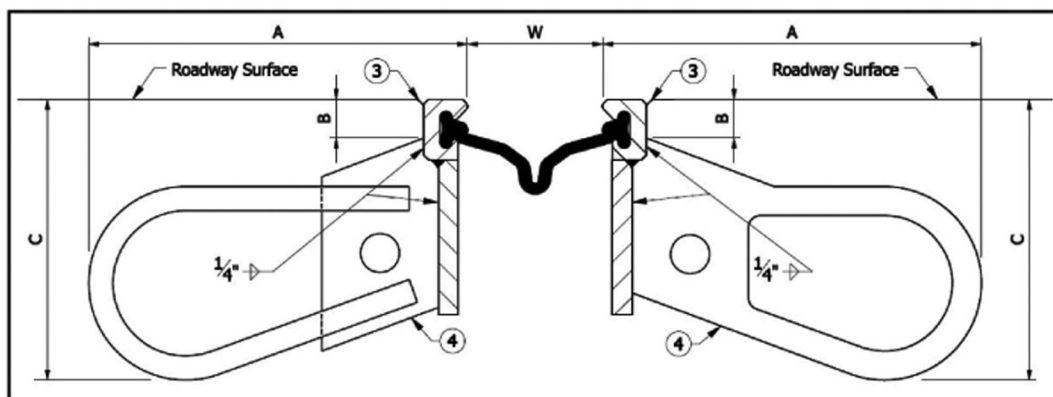


Figure 2.14 Typical strip seal expansion joint (44).



Figure 2.15 Indiana bridge deck drain.

However, in 2005, the toll road was leased to a private company. Control of the Indiana Toll Road was passed on to the joint venture between Cintra Concesiones de Infraestructuras de Transporte SA (Cintra) and Macquarie Infrastructure Group (MIG) in January of 2006. In June of 2006, this joint venture formed the Indiana Toll Road Concession Company (ITRCC) which assumed the duties of maintaining and operating the toll road during the 75 year lease (45).

Cintra and MIG are headquartered in Spain and Australia respectively, both of which are countries where waterproofing membranes are standard practice. Consequently, in 2009, the ITRCC requested that, despite the 1999 moratorium on asphalt overlays, INDOT allow the installation of waterproofing membranes on bridges along the toll road. The ITRCC was granted permission to install membranes and proceeded to install them on eight bridges, several of which are twin structures. A list of these bridges, which are all located along the western end of the toll road, is presented in Table 2.2.

The membranes were installed in 2009 on newly constructed bridge decks and at the time of reconstruction, all eight of the bridges were 52 years old. The



Figure 2.16 Map of Indiana Toll Road (46).

TABLE 2.2
Indiana Toll Road Bridges with Membranes

Description	Milepost	Structure Number
Gary Sanitary Plant	11.6 to 12.0	8-3
Grand Calumet River West	12.3	8-5
Bridge Street	12.7	8-7
Grant Street	13.3	9-6
Buchanan Street	13.7	9-4
Grand Calumet River East	13.9	9-3
Broadway Street	14.5 to 15.2	9-1
Tennessee Street	15.4	10-7

product used to waterproof these decks was Antirock by Soprema which was protected by 2.5 in. of stone mastic asphalt. The maintenance plan for the membrane systems calls for the asphalt to be milled and replaced every 7 years, therefore rehabilitating the riding surface while maintaining the integrity of the underlying membrane. These installations serve as a good reference for how some of the issues presented in Section 2.3.1 can be resolved.

Figure 2.17 outlines several steps of the installation process on the Grant Street Bridge (Structure 9-6). The process is outlined below:

- Primed joint receiving a layer of Antirock
- Rolling the bituminous primer onto the prepared surface
- Torch welding the membrane as it is rolled into place
- Two sheets being lapped
- Nearly completed deck
- Soprema's Alsan Flashing being installed up the face of the parapet

At expansion joints, contract documents called for the use of the Watson Bowman Wabo®Crete Strip Seal expansion joint (Figure 2.18 and Figure 2.19). A 2.5 in. deep (depth of the overlay) nosing was constructed with an elastomeric concrete product (Wabo®Crete II) on both sides of the joint. A neoprene seal was installed in between these two concrete nosings.

At the abutment, where the approach slab meets the bridge deck, the membrane is turned down the end of the deck slab (Figure 2.20), and the SMA overlay is extended over the INDOT-specified Type 1A joint. The SMA overlay is extended past the terminal joint until a practical stopping point is reached. Over the joint, the SMA overlay is saw-cut to half of its depth and then filled with an asphalt rubber sealant (Figure 2.21). This detail is intended to prevent the development of a crack in the pavement over this joint.

As was discussed previously, proper detailing is necessary to ensure sufficient drainage after a thick asphalt concrete overlay is installed. Construction specifications for the Indiana Toll Road bridges regarding the detailing of the membrane and the asphalt overlay at the location of drains was not found. However, several photos, taken during the routine inspection of structure number 8-7 over Bridge Street, indicate that the detailing at the drains was not



(a)



(b)



(c)



(d)



(e)



(f)

Figure 2.17 Grant Street Bridge membrane installation (47).

consistent. Figure 2.22 shows the top of the asphalt overlay flush with the top surface of the deck drain. Figure 2.23 shows the results of poor construction practices at the location of the deck drain. It seems as if the intent was to taper the asphalt overlay to the edge of the drain, but proper measures were not taken to prevent the asphalt from encroaching over the drain cover during compaction.

2.3.3 Toll Road Bridge Inspection Reports

Under federal requirements, these bridges will be inspected every two years. The information from the inspections will be shared with INDOT to allow for constant feedback on the effectiveness of the membrane systems. The results of the most recent inspections are

shown in Table 2.3. At the time of these inspections, the bridge decks were between two and three years old. In all cases, the bridge deck received a condition rating of nine, indicating excellent condition. The wearing surfaces on the toll road bridges received either a seven or an eight, indicating good condition and very good condition respectively. Additionally, for all of the bridges inspected, it was reported that the remaining life of the wearing surface is 7 years and the remaining life of the deck is 25 years.

2.4 Domestic Usage of Membranes

In 2011, as a part of NCHRP Synthesis 425, a survey was issued to the transportation agencies of each US state, the District of Columbia, and each Canadian

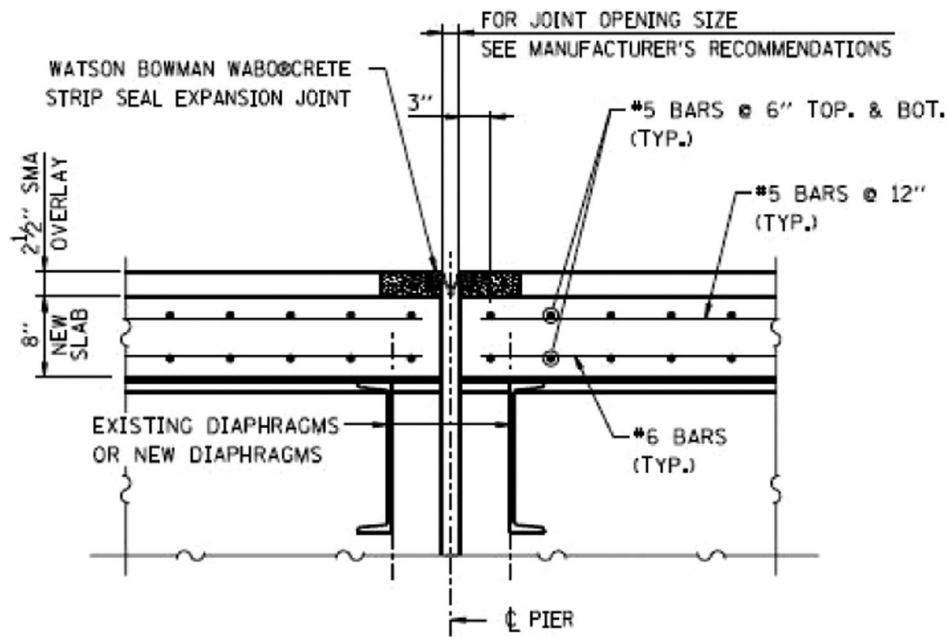


Figure 2.18 Expansion joint detail.

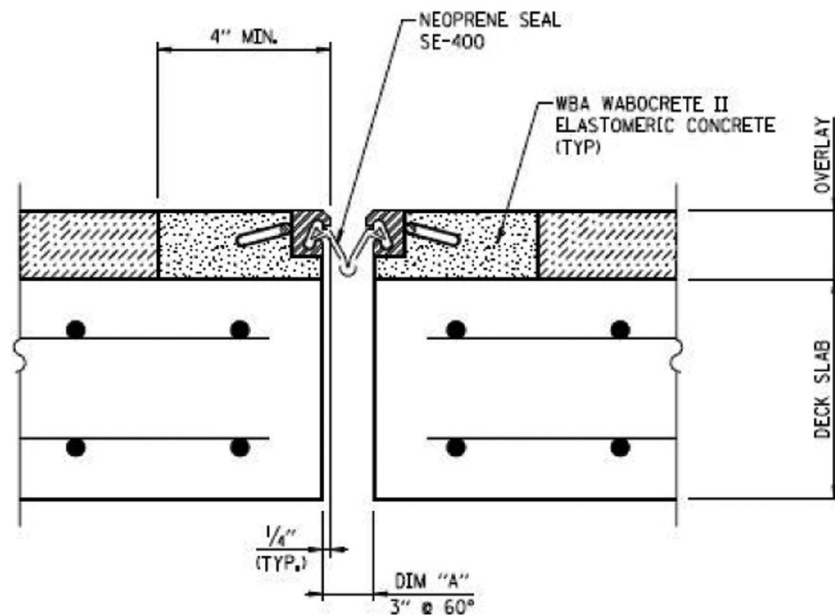


Figure 2.19 Expansion joint detail—zoomed.

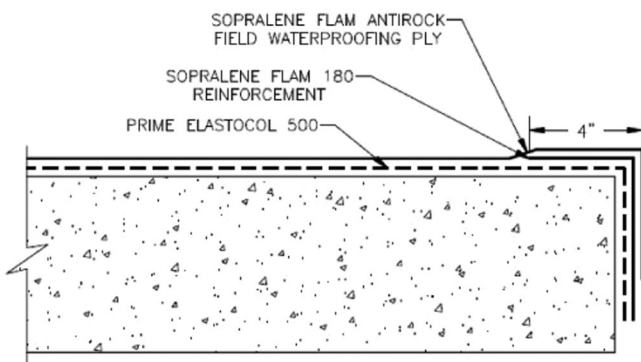


Figure 2.20 Membrane turned down at end of deck slab.

province. The results of this survey provide the most comprehensive and most recent report of the state-of-the-practice in waterproofing membranes in North America. Based on the results of this survey, the following map was constructed, detailing the extent of waterproofing membrane use in the US.

With the interest of completing the map provided in NCHRP Synthesis 425, it was determined, as a part of the current study, to investigate whether or not the unresponsive states, Maine, Massachusetts, Montana, Ohio, Rhode Island, Vermont, and West Virginia, use membranes. All of these states provide specifications for the installation of waterproofing membranes which

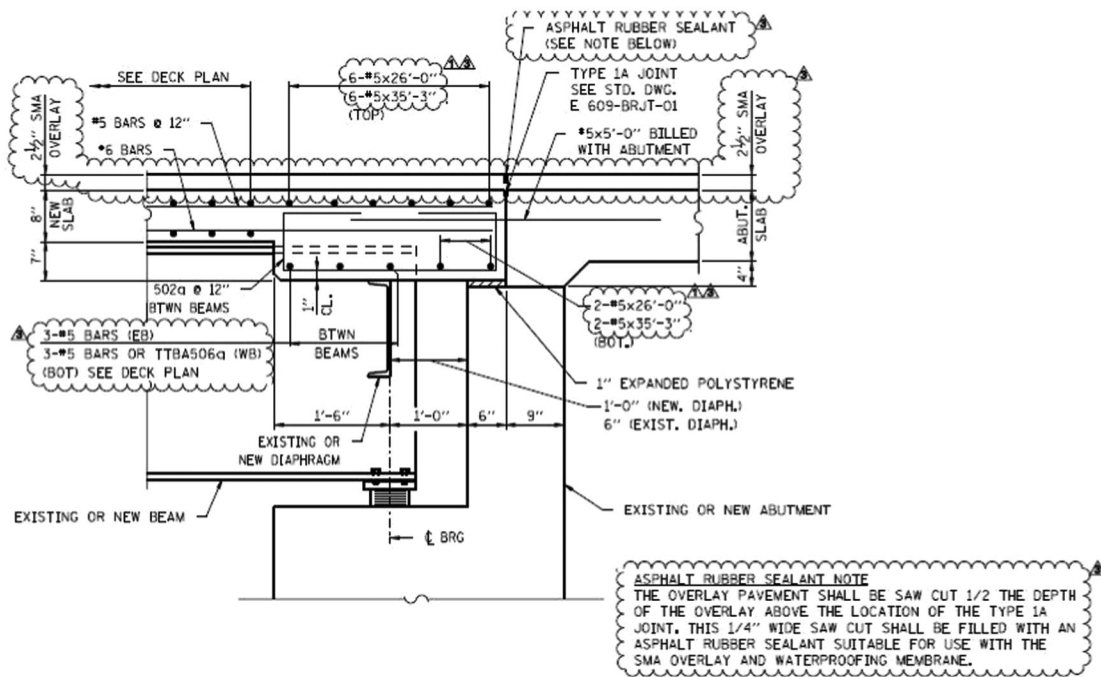


Figure 2.21 Abutment detail.

can be assumed to be an indicator of membrane usage. With this added information it is presumed that the total number of US states that use membranes is 29 (58%).

Before unwarranted emphasis is placed on this number, it should be noted that this percentage and the map in Figure 2.24 can both be deceiving. While 29 states use membranes, several of these states do not use them as standard practice for bridge work. For example, one state that is in the category of using membranes is Kansas. Although membranes are used in Kansas, they are used very rarely. Currently, the Kansas Department of Transportation (KSDOT) only specifies membranes as a “last resort” option to extend

the life of the deck until sufficient funds are available for more extensive work (13).

In addition, several other states that indicated that they use membranes only use them on rural, short span bridges. These bridges are often hollow core, voided slab bridges which require an additional asphalt concrete riding surface. Because an asphalt overlay is already being used on these bridges, some states require that a membrane also be installed (13).

Despite these deceiving facts, several trends can be recognized from Figure 2.24. The first is that states in the southern US do not use membranes. This is simply due to the fact that many receive very little amounts of snowfall and thus do not use deicing salts. Without deicing salts, the threat of steel reinforcement corrosion



Figure 2.22 Deck drain with flush asphalt overlay.



Figure 2.23 Deck drain with tapered asphalt overlay.

TABLE 2.3
Inspection Report Information

Description	Structure Number	Lane	Inspection Date	Condition Rating	
				Deck	Wearing Surface
Gary Sanitary Plant	8-3	Eastbound	8/1/2011	9	7
		Westbound	8/1/2011	9	8
Grand Calumet River West	8-5	Eastbound	2/13/2012	9	7
		Westbound	2/13/2012	9	7
Bridge Street	8-7	Eastbound	8/8/2011	9	8
		Westbound	8/8/2011	9	8
Grant Street	9-6	—	8/1/2011	9	7
Buchanan Street	9-4	Eastbound	8/1/2011	9	7
		Westbound	8/1/2011	9	7
Grand Calumet River East	9-3	Eastbound	2/13/2012	9	7
		Westbound	2/13/2012	9	7
Broadway Street	9-1	Eastbound	8/1/2011	9	7
		Westbound	8/1/2011	9	7
Tennessee Street	10-7	Eastbound	8/1/2011	9	7
		Westbound	8/1/2011	9	7

in the deck is limited. These states also prefer bare concrete decks for inspection purposes.

One other trend is that New England states use membranes extensively but states in the Midwest do not. Many states in the Midwest have discontinued membrane usage due to poor performance in the past. There is not clear evidence for why states in the Midwest have experienced poor performance while New England states have experienced satisfactory

performance. Although unclear, it is likely due to the extensive experience that New England states have acquired.

Overall this survey indicated that not much has changed in the amount of use and the type of products being used since the previous survey issued 18 years prior in 1994. Unlike most other countries, US agencies do not have consensus on the best type of membrane. For example, nearly all Canadian agencies prefer a

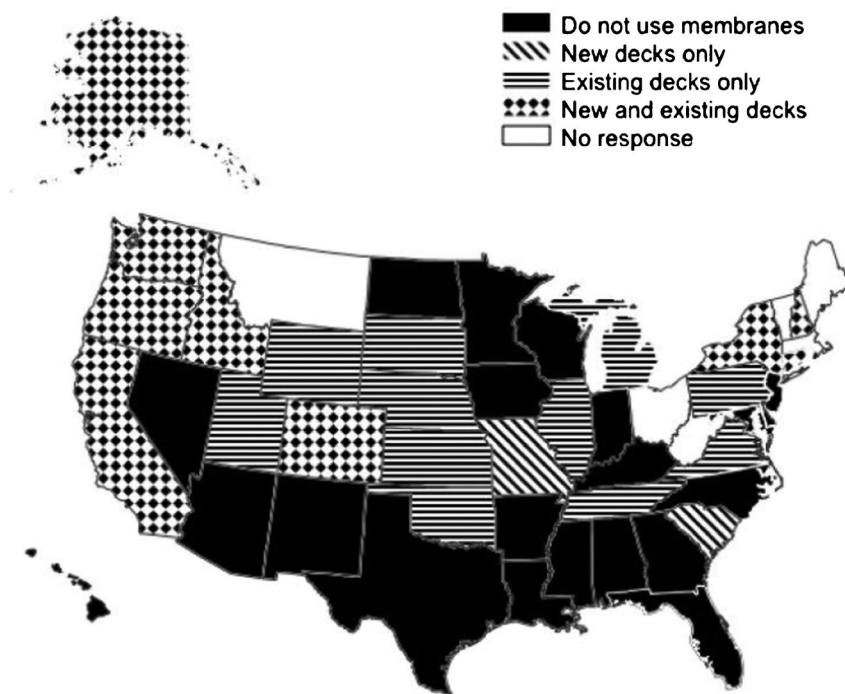


Figure 2.24 Current use of membranes in the US (13).

rubberized asphalt membrane, Spanish agencies prefer sheet membranes, UK agencies prefer spray applied membranes, but US states are divided on the topic.

2.4.1 Regional Differences

2.4.1.1 Winter maintenance. States in the Midwest may have had poor performance relative to New England states and Canadian provinces because of different winter maintenance practices. Both a higher concentration of chlorides and more frequent use of deicing salts might create a more aggressive environment for concrete bridge decks.

In 2005 the NCHRP published a report synthesizing winter highway operations throughout North America. As it relates to the corrosion of reinforcing steel, interest should be given to the deicing chemicals used by various state agencies. Table 2.4 provides a matrix of the US state transportation agencies that responded to the survey and the types of deicing chemicals that are used in their state.

In order to make a judgment on whether or not deicing chemicals play a part in the performance of waterproofing membranes, the chemicals used in successful states must be compared with the chemicals used in unsuccessful states. Of the states that responded to the survey only one is a New England state: Connecticut. Connecticut DOT utilizes a sodium chloride brine solution. The results of the survey show that Midwestern states such as Indiana, Illinois, and Missouri, who have experienced difficulties with membrane system durability, use a combination of sodium chloride and sodium chloride brine. Additionally, these states reported that they also use either calcium chloride or a calcium chloride with a corrosion inhibiting additive. From this information alone, it cannot be determined whether or not the type of deicing chemicals used has an effect on the performance of membrane systems.

2.4.1.2 Freeze thaw cycles. It can be assumed that a bridge that experiences more freeze thaw cycles will deteriorate faster than a bridge that experiences fewer freeze thaw cycles. If Indiana, or more generally, the Midwest, experiences more freeze thaw cycles than New England, it may be reasoned that New England states should have more success with membrane systems.

Figure 2.25 shows a contour map of the frequency of freeze thaw cycles throughout the US. Data to create the contour map, which covers the 30 year period from 1971 to 2000, was acquired from the National Climatic Data Center of the National Oceanic and Atmospheric Administration. To compile this data, one freeze thaw cycle is described as occurring when the temperature range during one day has a maximum temperature above freezing ($> 32^{\circ}\text{F}$) and a minimum temperature below freezing ($< 32^{\circ}\text{F}$). From Figure 2.25, it can be gathered that the state of Indiana experiences approximately 100 to 120 freeze thaw cycles per year. New England states like Maine, Vermont, and New Hampshire, all of which use membranes extensively, experience between 80 and 140 freeze thaw cycles per year. Based on this data, it does not appear that membrane performance would be more negatively affected by the climate in Indiana than the climate in New England states.

2.4.1.3 Summary. It has been shown that there are no clear regional differences with regards to the deicing chemicals used or the frequency of freeze thaw cycles. Based on these two factors, there is no evidence indicating that there should be a difference in the performance of waterproofing membranes between New England states and Midwestern states. Yet, it is possible that differences in the application rate of deicing chemicals may have an effect on membrane performance. However, comprehensive information comparing the application rate of deicing chemicals used by different state DOTs was not available at the time of this study.

TABLE 2.4
Chemicals Used for Winter Maintenance (48)

Agency	NaCl			CaCl				Kac	MgCl	
	NaCl	NaCl Brine	NaCl Inhibited	CaCl	CaCl Inhibited	Complex Cl	CMA		MgCl	MgCl Inhibited
California DOT	x	x					x			
Connecticut DOT		x								
Idaho TD	x			x	x				x	x
Illinois DOT	x	x		x						
Indiana DOT	x	x			x					x
Maryland State Highway Admin	x	x		x				x	x	x
Minnesota DOT	x	x		x			x	x	x	x
Missouri DOT	x	x		x						
Montana DOT										x
Nebraska DOT	x			x				x	x	x
Nevada DOT	x	x								x
Oregon DOT							x			x
Washington DOT			x		x	x	x			x

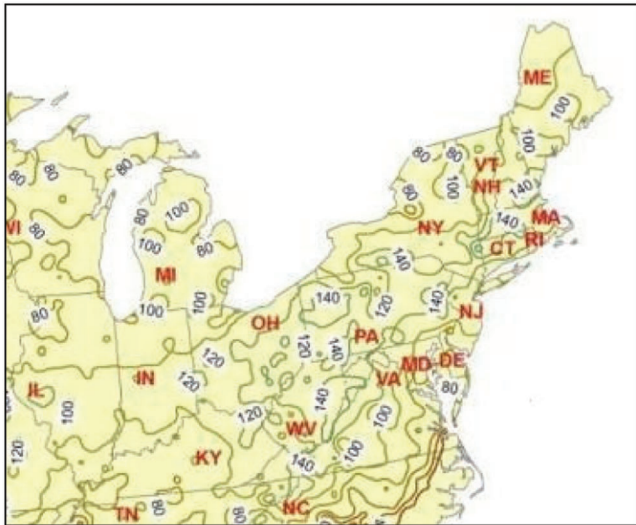


Figure 2.25 Freeze thaw cycle frequency (49).

2.4.2 Case Studies

NCHRP Synthesis 425 provides valuable information regarding the installation of membrane systems. To supplement the synthesis, a more in-depth study of experiences of several state transportation agencies is provided.

2.4.2.1 Illinois. As part of a long-term deck condition study, 20 Illinois bridge decks were waterproofed in 1977 and 1978. Before the installation of membranes, results of copper sulfate electrode tests showed that 15 of the 20 decks exhibited 40% or more of the top mat of steel reinforcement actively corroding. All of the bridge decks were waterproofed using the same membrane system which is shown in Figure 2.26. The system currently specified in IDOT's standard specifications is essentially the same system used in the late 1970's for this study (50).

The investigators concluded that at the end of 7 years all of the decks had performed satisfactorily. The lowest

score, which was given to five of the 20 bridges, was a 5 on the FHWA rating scale used at the time of the study. A rating of 5 on this scale has the following description: "generally fair condition – potential exists for minor rehabilitation" (51).

According to the NCHRP survey, the Illinois Department of Transportation (IDOT) currently only specifies membranes on existing bridge decks with ADT's below 10,000. IDOT engineers expect the membrane system to have a service life of 11 to 15 years or to last only as long as the asphalt overlay (13).

Along with Indiana, IDOT has also had a history of membrane failures on concrete bridge decks. IDOT engineers speculate that these failures were due to hot-mix asphalt pavements that were not compacted properly. As a continuation of surfacing work on the pavement adjacent to the bridge, the bridge decks also received typical hot-mix asphalt which is intended to be compacted by a vibratory roller. Due to the damaging effects that a vibratory roller can cause on a bridge, the asphalt overlays were compacted by a static roller and as a result they did not reach their necessary density. This compaction procedure caused issues for the durability of the pavement (52).

2.4.2.2 Kansas. In a study published in 1995, it was reported that waterproofing membrane systems in Kansas, installed between 1967 and 1971, exhibited satisfactory long-term performance (53). In this study, the waterproofing systems installed on six different bridge decks proved to be effective after 20 to 25 years of service. Additionally, in 1985, waterproofing membranes were experimentally installed on two heavily traveled bridge decks in Wichita, Kansas. Over a period of 14 years, annual inspections of these overlays proved that they performed well. From the evaluation it was suggested that membranes could extend the service life of a bridge deck by 15 years (54).

Despite the fact that Kansas has had successes such as these, the Kansas Department of Transportation (KDOT) discontinued the use of membranes as standard

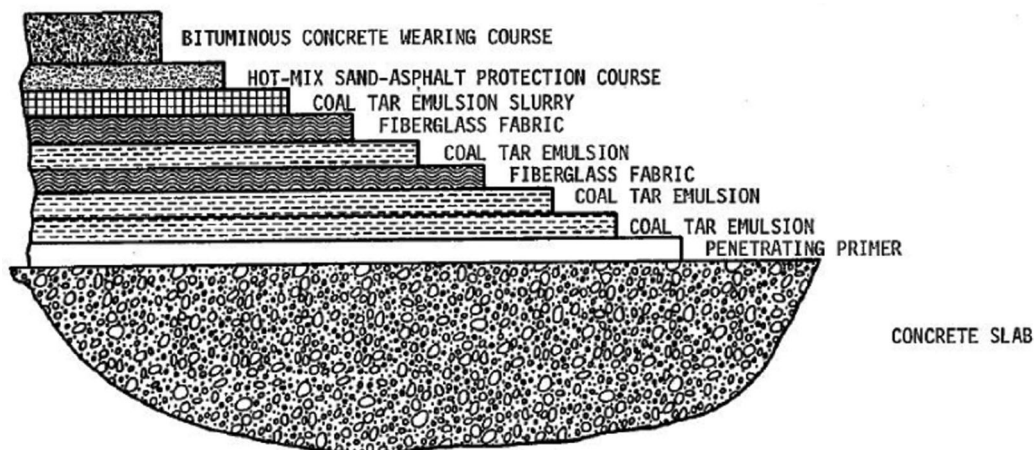


Figure 2.26 Waterproofing system used on Illinois bridge decks (51).

practice in 1977 due to many reports of failures in nearby states and one particularly discouraging immediate failure on a bridge in Barton County, Kansas. The committee that reviewed the failure of the membrane system on the Barton County bridge decided to rely on waterproofing systems that offered more certainty. Currently, KDOT has a strict policy restricting the use of membranes to bridges in desperate need of rehabilitation. Membrane systems are only expected to provide one to three years of service until necessary funds are available for a more extensive rehabilitation (54).

2.4.2.3 Michigan. The Michigan Department of Transportation (MDOT) approaches waterproofing membranes in a similar way to KDOT. Engineers at MDOT expects less than 10 years of service for a membrane system. As such, membranes are used on decks with fair amounts of damage which is quantified as 10% deficiencies on both the top-side and bottom-side of the deck.

To assist in determining the proper rehabilitation technique for deteriorated deck surfaces, MDOT publishes a “Bridge Deck Preservation Matrix,” which is shown in Appendix B. Using data from bridge safety inspection reports (BSIRs) and visual surveys of surface deficiencies, this document offers guidance on which repair option should be used. It also presents the anticipated service life of that repair. There are two different matrices available; one is for decks with coated reinforcing steel and the other is for decks with uncoated reinforcing steel.

2.4.2.4 New Hampshire, Maine, Vermont. In 1993, an investigation of 15 bridges in three states, New Hampshire, Maine, and Vermont, was conducted. The bridges that were investigated ranged from 2 to 32 years of age, and they all received preformed membrane systems when they were newly constructed. Using both non-destructive testing (ultrasonic pulse velocity) and inspection of cores, it was determined that the preformed membranes performed satisfactorily and reduced the penetration of chlorides. It was proposed that preformed membranes could have a service life of 40 years and could extend the service life of a bridge by 25 years. It was also determined that the membranes performed best if they were installed properly and if the asphalt overlay had a sufficient thickness (55).

2.4.2.5 Alaska. In 1996, five preformed membrane products were tested in Alaska as a result of previous failures of the asphalt overlay. These failures were attributed mostly to high ADT's as well as high horizontal shear forces due to braking and turning. Based on the investigation, it was determined that preformed membranes can perform excellently if overlaid with four inches of asphalt (56).

2.4.3 Product Qualification Procedures

To assure that quality products are being used and that quality installation processes are in place, several

states that use membrane systems have criteria in place to evaluate new membrane products. Of the 29 states that use membrane systems, 14 states have a list of approved products. A list of all of the products approved by state DOTs is provided in Appendix C.

The Maine Department of Transportation has a particularly intensive qualification process that is divided into three phases. The first phase requires that the manufacturer submit a summary of successful case studies and make a presentation of the system to representatives of the Maine DOT. The second phase requires that the qualified installers of the product conduct a test demonstration to prove that they are able to perform a proper installation. The third phase requires that the proposed system be experimentally installed on an in-service bridge deck. Upon successful completion of all three phases, a product is qualified as either a standard or high-performance membrane product. High-performance membranes are used for bridge decks that pose more critical conditions for a membrane such as greater ADTs and steeper slopes. The Maine DOT product qualification criteria and qualified products list is also provided in Appendix C.

2.5 International Usage of Membranes

The state-of-the-practice in bridge deck waterproofing membranes internationally is outlined in this section. Information was acquired on the state-of-the-practice in the following countries: Canada, The United Kingdom, Spain, Germany, Sweden, Denmark, Australia, and Japan.

2.5.1 Canada

The unique aspects of a typical Canadian waterproofing membrane system are the use of a protection board and membrane reinforcing fabric. The protection board is used to protect the asphalt membrane from the harsh installation conditions of the overlying asphalt concrete. The aim of the reinforcing fabric is to prevent cracks or joints in the substrate from reflecting upwards through the membrane and the asphalt overlay.

The Ministry of Transportation in Ontario (MTO), much like most transportation agencies in the other Canadian provinces, specifies the use of a hot applied rubberized asphalt membrane. Immediately after the membrane is applied, it is reinforced with a “spun bonded sheet structure composed of 100% continuous filament polyester fibers bonded together at their crossover points.” The membrane reinforcement is pressed into the membrane while still tacky and is then covered by another layer of liquid asphalt membrane and the protection board. Figure 2.27 to Figure 2.29 illustrate joint and drainage details for membrane installations in Ontario (57).

Figure 2.27 shows the standard detail used by MTO for waterproofing at expansion joints. It should be recognized that the membrane, which is covered by the protection board, extends up the face of the ballast

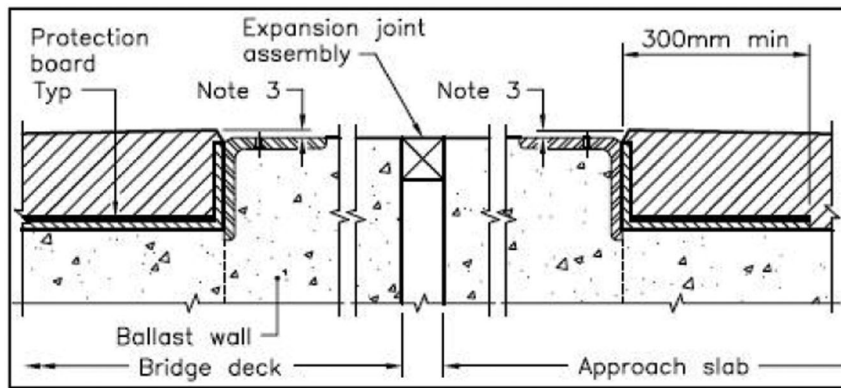


Figure 2.27 Standard expansion joint detail (58).

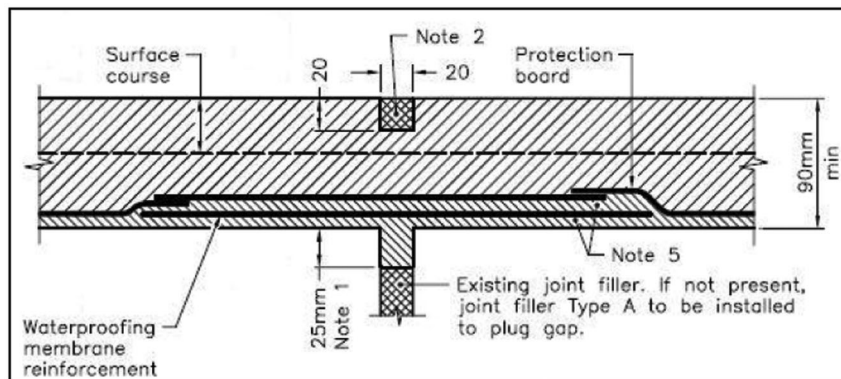


Figure 2.28 Standard joint detail (58).

wall. Figure 2.28 shows the standard detail for waterproofing over cracks or non-expansion joints in the deck where membrane reinforcement is used. Note 2 in this detail is described as a saw cut groove extending along the length of the joint and filled with a hot-poured rubberized asphalt joint sealing compound. The

minimum thickness of the entire system is 90 mm or about 3.5 in. (Figure 2.28). Figure 2.29 shows the detail used for providing subsurface drainage in which the drain is installed flush with the top of the concrete deck. This detail is suggested at all low points of the bridge where water is expected to collect.

The province of Alberta specifies a very similar system to the one implemented in Ontario. In fact, the Alberta Ministry of Transportation's specifications for bridge deck waterproofing often refer to the material specifications developed by MTO. The only notable difference is that the Alberta Ministry of Transportation specifies the use of wick drains at all curbs (60). Wick drains are installed to facilitate the movement of subsurface moisture to the proper drainage channels (Figure 2.30 and Figure 2.31).

2.5.2 European Standards

There are two European organizations that provide standards for installing waterproofing systems. These two organizations are the European Committee for Standardization (Comité Européen de Normalisation, CEN) and the European Organization for Technical Approvals (EOTA). The CEN provides guidance on the installation of preformed membranes and the EOTA provides guidance on the installation of liquid applied membranes.

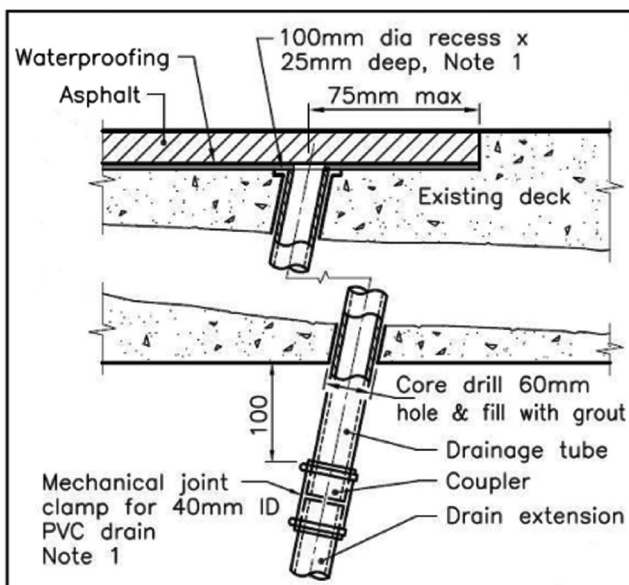


Figure 2.29 MTO standard subsurface drainage detail (59).

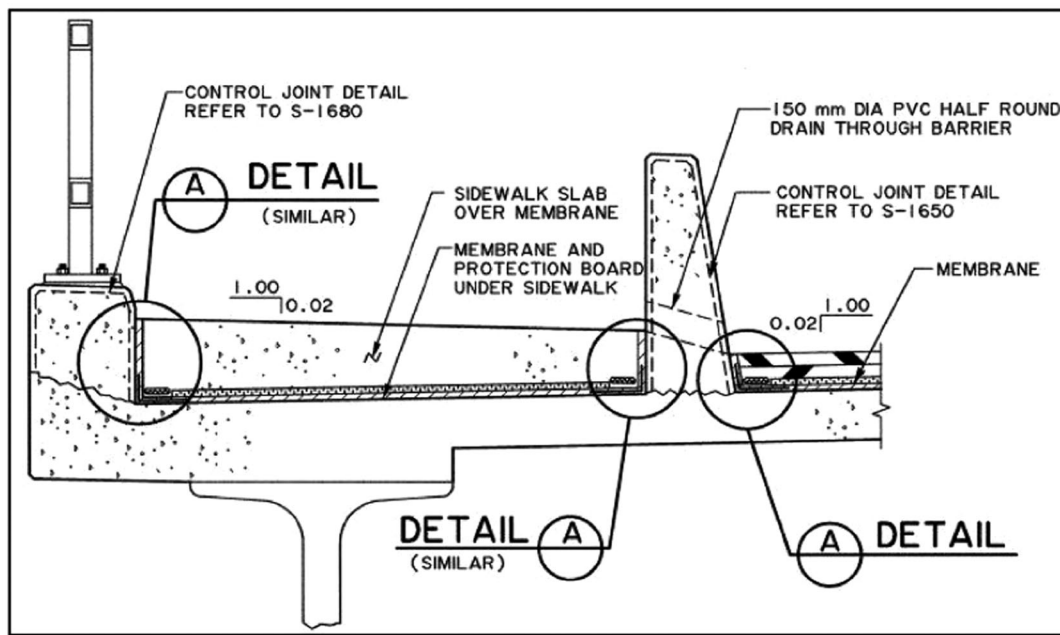


Figure 2.30 Waterproofing detail at sidewalk (61).

The CEN represents the interests of 33 European member nations in developing a set of standards for many sectors of industry. These standards are created to provide a more seamless European market of goods and services. The CEN standard, EN 14695 “Flexible Sheets for Waterproofing,” standardizes the materials and performance characteristics necessary for using reinforced bitumen sheets for waterproofing concrete bridge decks in Europe. Figure 2.32 shows a schematic of the typical preformed sheet waterproofing system provided in this standard.

The EOTA represents the interests of 28 European countries in performing technical evaluations of construction products. Upon acceptance of a product, that

product will receive a European Technical Approval (ETA). To evaluate the material and performance characteristics of a product, the EOTA uses an ETA Guideline (ETAG). While specific waterproofing systems have not been evaluated and given an ETA, there is an ETAG for liquid applied waterproofing systems. ETAG 033, the guideline for “Liquid Applied Bridge Deck Waterproofing Kits” covers in great detail the test procedures used to assess various material and performance characteristics associated with liquid applied waterproofing membranes (63).

2.5.2.1 United Kingdom. The governing authority on the design and construction of bridges in the United

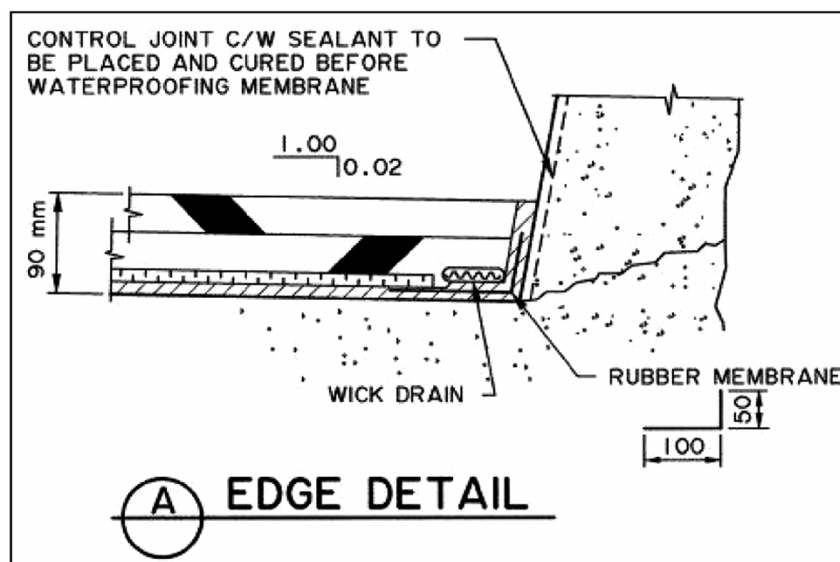


Figure 2.31 Wick drain detail at curb face (61).

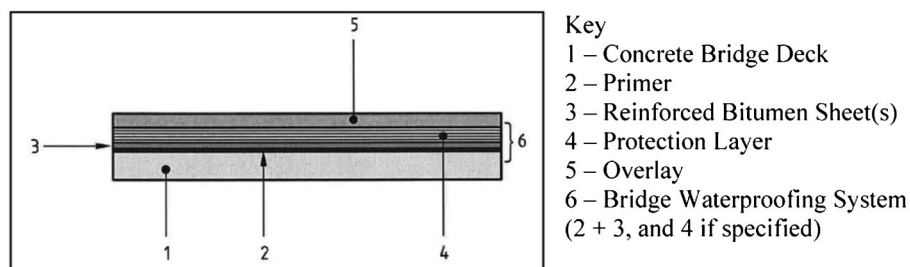


Figure 2.32 Schematic of European bridge waterproofing system (62).

Kingdom is the Highways Agency of the UK Department for Transport. Waterproofing membranes have been used by The Highways Agency in the UK since the early 1950's (64) and became mandatory on UK bridges in 1965 (65). The Highways Agency offers two documents that govern the installation of waterproofing membranes in the UK. These coupled documents are identified as BD 47/99 and BA 47/99 and are titled "Waterproofing and Surfacing of Concrete Bridge Decks."

The typical UK waterproofing system is comprised of a membrane, a 20 mm sand asphalt protection layer and both a binder course and surface course which combine for a thickness of 100 mm. A schematic of this system is shown in Figure 2.33.

All waterproofing membranes are required to be certified with a HAPAS (Highway Authorities Product Approval Scheme) Roads and Bridges Certificate issued by the British Board of Agrément (BBA). Currently, four different systems are certified by the BBA, all of which are spray applied systems. Fittingly, spray applied membranes are the most frequently used system in the UK (64).

The 20 mm sand asphalt layer is referred to as an "additional protective layer" or APL. This layer is installed to protect the membrane from incurring damage during the paving process. Using asphalt concrete with smaller aggregate (sand) eliminates the threat that large aggregate poses to indent and puncture

the membrane. This layer is sometimes tinted red or is overlaid with a red mesh which acts as an indicator of depth during resurfacing efforts. To leave the membrane intact during any resurfacing work, this red layer indicates the depth at which any deeper milling might damage the underlying membrane (33).

Several research efforts have been made since the publishing of the Highways Agency's specification for bridge deck waterproofing in 1999 (39). In 2007, the Highways Agency published an Interim Advice Note titled "Guidance on implementing results of research on bridge deck waterproofing" to serve as an update for BD 47/99 (67). This document compiles research efforts in UK bridge deck waterproofing and offers suggestions to improve current practices. Many of the suggestions offered in the Interim Advice Note were gathered from studies performed by the Transport Research Laboratory (TRL). Much of the focus of these research efforts has been placed on the materials used and the applied thicknesses of the asphalt pavement overlay.

One issue that has received considerable attention is the effectiveness and necessity of the 20 mm thick sand asphalt layer. A survey of bridge maintaining agencies indicated that if the red sand asphalt layer is compacted properly, it performs as expected. However, if it is not compacted properly, it becomes permeable and collects water, which reduces the strength of the bond between the membrane and the asphalt overlay. Most of the

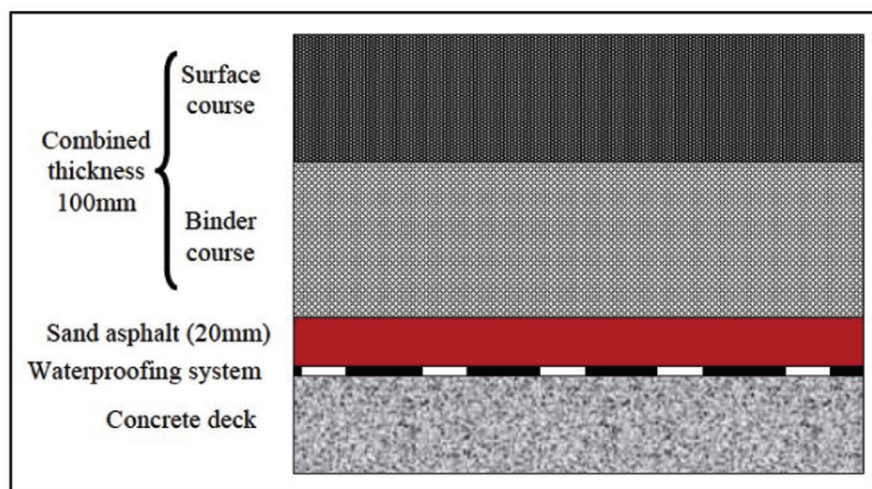


Figure 2.33 Schematic of UK system (33).

surveyed agencies indicated that they do not use the protection layer as an indicator of depth during repaving. Instead, they prefer trial holes to gauge the depth of the pavement. Based on these factors, it has been suggested by TRL researchers that the sand asphalt layer be omitted (33).

Another point of interest in UK bridge deck waterproofing has been the overall thickness of the asphalt pavement. Questionnaire results indicate that most manufacturers and installers expect to gain a service life of 15 years out of the asphalt surfacing if it is installed to the specified thickness of 120 mm. Additionally, it has been fairly well observed that if a membrane is overlaid with less than 120 mm of material it is more likely to experience earlier failure (32). Unfortunately, there are several situations where a thinner pavement is required, and within the past 15 years, they have been used more frequently. In order to prevent early failure, these new thinner systems utilize stone mastic asphalts (SMA), thin surface course systems (TSCS), proprietary binder courses (PBC), and heavy duty macadam (HDM) instead of the traditional hot rolled asphalt (33). More recently, some agencies have installed systems that use a combination of 20 mm of stone mastic asphalt and 45 mm of hot rolled asphalt equaling 65 mm (2.5 in.) of overlay material (66).

By the standards set by the Highways Agency, membrane installation work requires that the concrete surface receive a class U4 finish. A class U4 finish is achieved by leveling, screeding, and then lightly texturing with a wooden float or by grit blasting. Along with specifying the necessary texture, the Highways Agency also specifies an acceptable moisture content below 6% (67).

2.5.2.2 Spain. Spanish transportation agencies typically adhere to the European standard published by the CEN. Prefabricated bitumen sheets are considered to be the most durable and thus the preferred waterproofing system (68). The Spanish system also allows for the use of a protection layer when needed. There are three different options that can be employed. The first option involves spreading mineral granules on the top surface of the waterproofing membrane. The second option involves a similar protection board to the type used in Canada which features asphalt sandwiched between fiberglass mats. The final option involves a polyester non-woven felt (69).

The guidance for waterproofing bridge decks in Spain places a lot of emphasis on the requirement for proper drainage. The schematic in Figure 2.34 shows that drainage may be permitted through the use of gutters that run lengthwise along the outer edge of the bridge. Figure 2.35 presents another possible drainage detail. The hardware in this detail allows for drainage along the top of the asphalt pavement as well as for subsurface drainage between the riding surface and the membrane.

A bridge terminal joint is shown in Figure 2.36 and Figure 2.37. If this detail were to be used on an existing bridge such as in Indiana, the joint hardware could be directly anchored to the concrete deck once the pre-existing hardware is removed. The height of the joint hardware must be similar in thickness to the pavement that is specified.

2.5.2.3 Germany. Bundesanstalt für Straßenwesen (BASt), or the Federal Highway Research Institute, offers guidance on the detailing of waterproofing

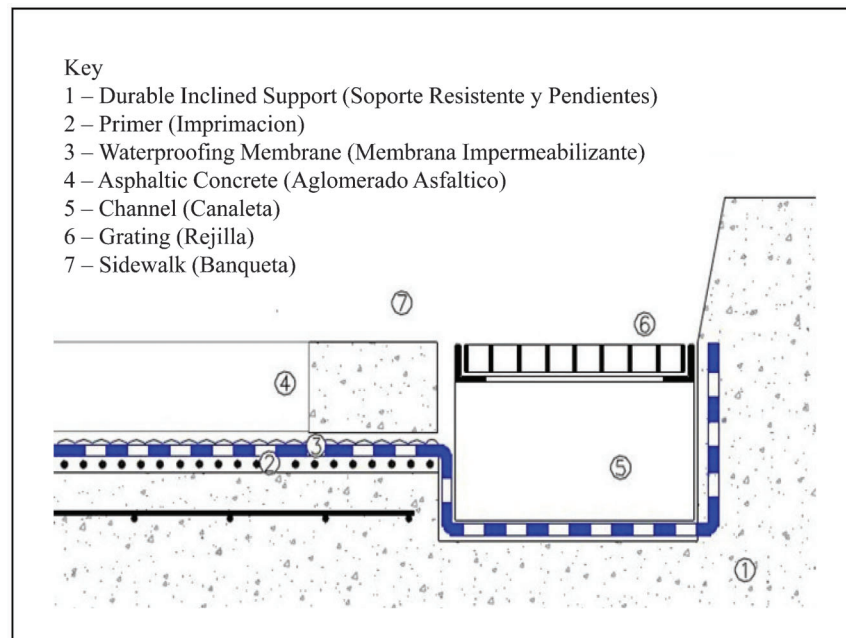
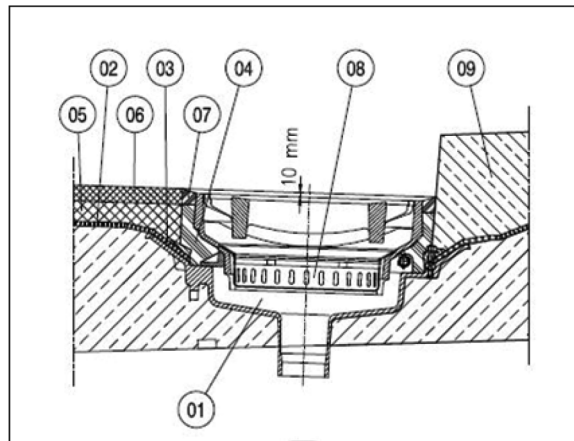


Figure 2.34 Schematic of waterproofing system at curb (70).



Key

- 1 – Drain Body (Cuerpo del Desague)
- 2 – Waterproof Membrane (Membrane Impermeable)
- 3 – Delivery of the Membrane into the Drain (Entrega de la Membrane en la Pestana del Desague)
- 4 – Filter Layer (Capa filtrante)
- 5 – Binder (Binder)
- 6 – Riding Surface (Rodadura)
- 7 – Perimeter Sealing (Sellado Perimetral)
- 8 – Sludge Bucket (Cubo de Lodos)
- 9 – Sidewalk (Acera)

Figure 2.35 Detail of drainage system (69).

membranes in Germany. German standards specify an asphalt surfacing layer with a total thickness between 70 mm (~2.75 in.) and 80 mm (~3.15 in.). This thickness consists of a base course of “Gussasphalt” with a thickness of 35 mm and a surface course between 35 mm and 45 mm. Gussasphalt is the European equivalent to the stone mastic asphalts used in the US. It is a pavement which is self-compacting and rut resistant, has a low void ratio, and is more durable than typical hot-mix asphalt pavement. Although German standards are lower compared to the UK when it comes to pavement thickness, they have more stringent bond strength (tensile and shear) requirements (32).



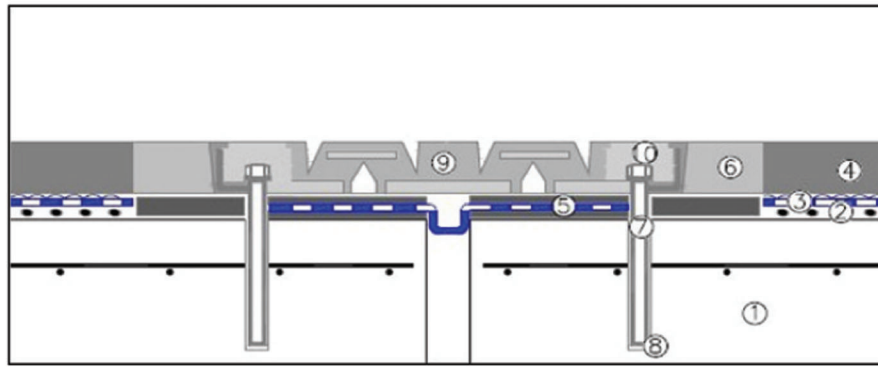
Figure 2.36 Terminal joint (68).

German bridges are constructed slightly different from those constructed in Indiana. As illustrated in Figure 2.38, the deck of the bridge is constructed prior to the placement of the “kap,” which includes the curb, parapet, and railing. The waterproofing membrane is then installed across the entirety of the bridge deck, and the “kap” is constructed over the top of the membrane. Once the “kap” is in place, the base course and surface course are placed.

2.5.2.4 Sweden. Swedish engineers are most confident in designing systems that incorporate a 40 mm wearing course, a 50 mm binder course of polymer modified coarse aggregate mastic asphalt, and one layer of polymer modified flexible sheet that is 5 mm thick. This is considered to be the most reliable system available (72).

The Swedish specification provides three different material options which are bitumen-based sheets, mastics, and thermosetting liquid-applied materials such as epoxy, polyurethane, polyurea, or acrylate. The prepared deck can be primed using a bitumen-based product, an epoxy, or a methyl methacrylate. Methyl methacrylate primers are thought to provide the best performance (73).

2.5.2.5 Denmark. Over 85% of the total bridge deck area in Denmark is protected by a waterproofing membrane and an asphalt overlay (74). If designed according to Danish standards, the service life of the wearing course is expected to be 25 years, and the service life of both the base course and the waterproofing membrane is expected to be 50 years



Key

- 1 – Durable Inclined Support (Soporte Resistente y Pendientes)
- 2 – Primer (Imprimacion)
- 3 – Waterproofing Membrane (Membrana Impermeabilizante)
- 4 – Aggregate (Aglomerado)
- 5 – Leveling (Nivelacion)
- 6 – Transition (Transicion)
- 7 – Stud with Nut and Washer (Esparrago con Tuerca y Arandela)
- 8 – Chemical Anchor (Anclaje Quimico)
- 9 – Elastomeric Profile (Perfil Elastomerico)
- 10 – Seal (Sellado)

Figure 2.37 Detail of typical bridge terminal joint (70).

(75). If a bridge has an expected life of 100 years, as considered in Denmark, then the wearing course is expected to be replaced three times, whereas the base course and the waterproofing only need to be replaced once over the lifetime of the bridge. To achieve this longevity, Danish transportation agencies utilize the system shown in Figure 2.39.

The waterproofing sheets are made of polymer-modified bitumen reinforced with impregnated non-woven polyester reinforcement. The polyester reinforcement in

the lower sheet has equal amounts of polymer-modified bitumen on both sides. However, the upper sheet has polyester reinforcement at the top of the sheet so that the bitumen does not flow during compaction and obstruct the drainage layer. These sheets are torch applied to the surface.

The drainage layer is used to prohibit water from collecting at the interface of the overlay and the waterproofing sheets which is achieved by allowing for quick movement of subsurface water. This layer

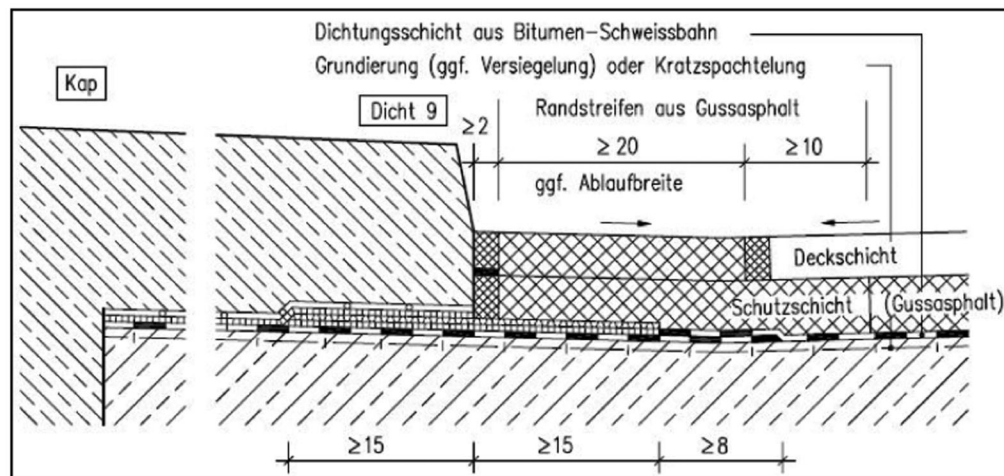


Figure 2.38 German detail of membrane at curb (71).

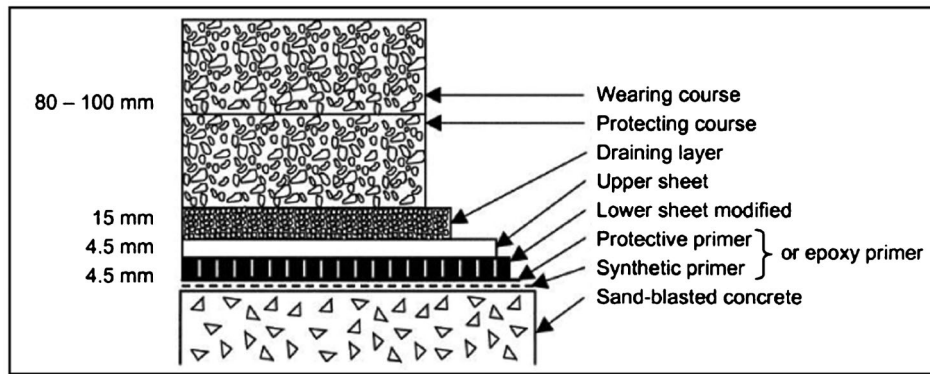


Figure 2.39 Typical Danish waterproofing system (75).

consists of open-graded asphalt with approximately 20% air voids. Proper drainage is also ensured by the use of drainage channels which are installed at the low point of the deck and run parallel to edge beams and on the high side of each joint (Figure 2.40). Special attention is also given to the detailing at the curb face where the membrane is terminated (Figure 2.41).

2.5.3 Australia

2.5.3.1 New south wales roads and maritime services (NSW RMS). The NSW RMS specifies three possible combined waterproofing systems in their specification titled “Sprayed Bituminous Waterproofing Membrane for Concrete Bridge Decks” (76). Table 2.5, which outlines these three systems, is found in the specification.

A sprayed bituminous waterproofing membrane (SBWM) is defined as “a seal consisting of polymer-modified binder and aggregate, hot-sprayed with a mechanical sprayer.” This definition is similar to what might be described as a thin polymer overlay, except that a polymer-modified bitumen is used instead of an epoxy or methyl methacrylate binder. Table 2.5 describes the first two systems (I and II) as an SBWM

covered with 10 mm of aggregate which is then overlaid by an asphaltic concrete layer. This is slightly different from most other membrane installations in that aggregate is incorporated into the membrane layer.

The third system (III) is virtually the same as a thin polymer overlay system. The first layer is an SBWM and the second layer is a “sprayed seal” which is defined in the specification as “a thin layer of binder sprayed onto the primed concrete deck with a layer of aggregate incorporated and which is impervious to water.” The difference between an SBWM and a “sprayed seal” is that an SBWM uses a polymer-modified bitumen which is expected to prevent reflective cracking by bridging cracks in the concrete substrate. A “sprayed seal” uses an unmodified bitumen binder which does not have the same crack bridging ability (73).

The NSW RMS specification is unique in two ways. The first, which was previously mentioned, is that the membrane layer includes broadcast aggregate. The second is that the aggregate is precoated. Precoating the aggregate eliminates the threat of aggregate covered in dust, water, or other contaminants which can reduce the bond strength between the binder and the aggregate. Typical precoating consists of thoroughly cleaning the

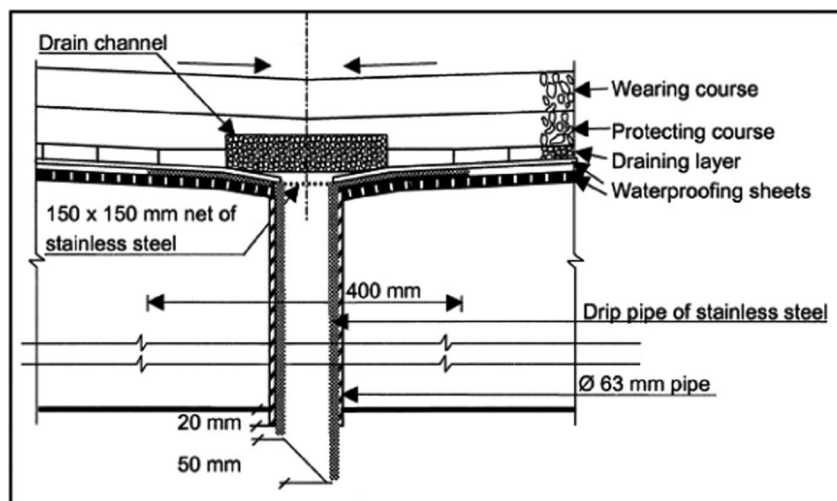


Figure 2.40 Danish detail at drainage channel (75).

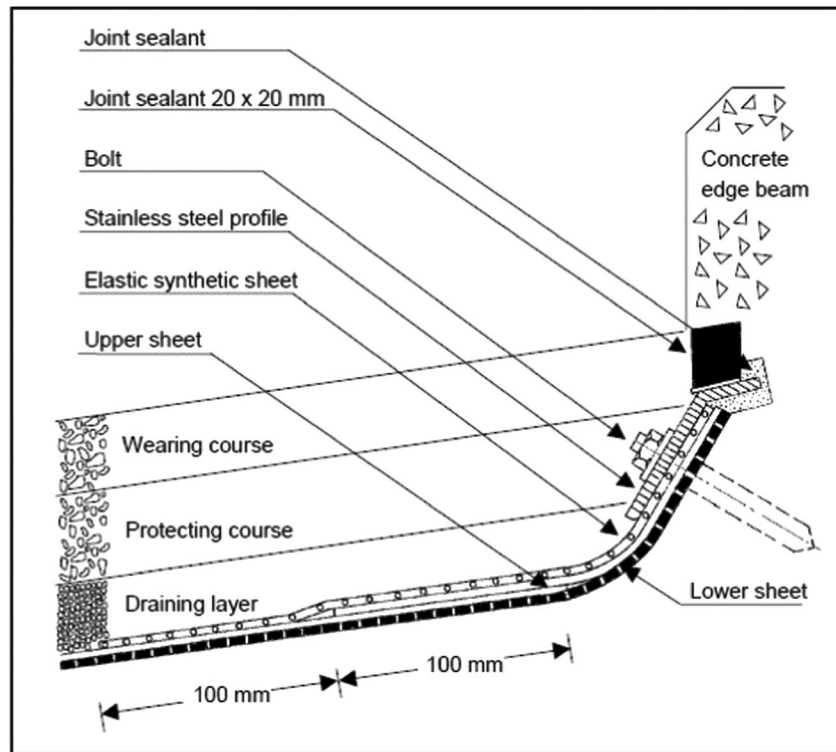


Figure 2.41 Danish detail at concrete edge beam (75).

aggregate and covering it with a thin film of petroleum based material (77).

2.5.3.2 Queensland transport and main roads. The waterproofing system used in Queensland is similar to that used in New South Wales. It consists of a primer and a sealing layer of binder (bitumen or polymer modified) covered by precoated aggregate. The membrane layer is then surfaced by a “correction course” of dense graded asphalt and a second asphalt wearing course (78).

A typical detail at the end of the concrete deck is shown in Figure 2.42. This detail shows that the asphalt

wearing surface is continued over the joint where a 30 mm deep saw-cut is made and filled with a bitumen product. This detail is similar to the one used on the Indiana Toll Road.

2.5.4 Japan

Waterproofing membranes have been used in Japan since 1978. Despite having been waterproofed, several Japanese bridge decks have required replacement after thirty years, due to the deterioration of the membrane layer and infiltration of moisture and chlorides (80). Figure 2.43 shows severe deterioration of a 30-year-old

TABLE 2.5
Accepted Combined Waterproofing Systems (76)

ID	System	Details	Use
I	SBWM/DGA	SBWM with 10 mm cover aggregate and 70 mm DGA. Total thickness 75 mm.	High traffic areas where SBWM/DGA is practical and economic and DGA or PCC wearing surface on the approaches.
II	SBWM/DGA/OGA	SBWM with 10 mm cover aggregate, nominal 35 mm DGA and 35 mm OGA. Total thickness 75 mm.	Where OGA is used on approaches and a SBWM is practical.
III	SBWM double/double seal	Double/double sprayed seal. First layer consists of 14 mm SBWM. Second layer consists of a 7 mm bitumen sprayed seal. Both layers may be applied on the same day. Total thickness 14 mm. (Deck joints should be set 15 mm high to accommodate the seals).	Where asphalt is uneconomic to construct or maintain. A 10 mm SBWM seal can be used to maintain the system after 7–10 years.

NOTE: SBWM = sprayed bituminous waterproofing membrane; DGA = Dense graded asphalt; OGA = open graded asphalt; PCC = Portland cement concrete.

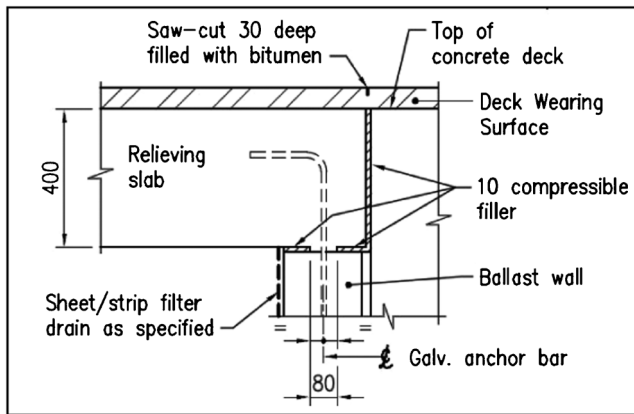


Figure 2.42 Queensland bridge end joint detail (79).

bridge deck with 15-year-old waterproofing. Failures, like the one illustrated in Figure 2.43, are thought to be a result of insufficient primer and insufficient waterproofing products.

In 2008 a new standard for high-performance bridge deck waterproofing was proposed by the Nippon Expressway Company (NEXCO). As part of the development of this new standard, several test installations were conducted. Four installations were performed using the system shown in Figure 2.44 which uses a polymer-modified bitumen sheet. One installation was performed using the system shown in Figure 2.45 which uses a spray-applied polyurethane membrane developed by Mitsubishi Plastics.

During these test installations, it was found that the primer used for the bitumen sheet system was insufficient, causing blistering of the membrane. The polyurethane system did not experience the same problem and is believed to be a more flexible and durable system compared to the polymer-modified bitumen sheet system. As a result the polyurethane system is expected to offer a longer service life. However, there are two disadvantages that prevent the growth of polyurethane systems in Japan. The first is that the required installation time is much greater, restricting installations to new construction. The second



Figure 2.43 Japanese bridge deck deterioration (38).

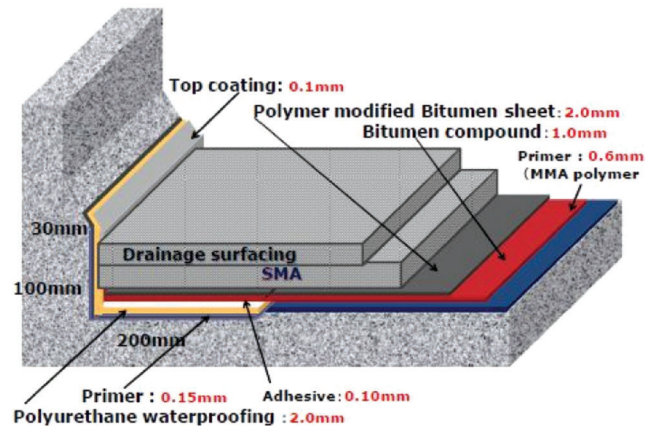


Figure 2.44 Japanese polymer-modified bitumen sheet system (80).

disadvantage is that the initial cost is more than three times the cost of the current bitumen sheet system (80). Figure 2.46 shows a polyurethane membrane being sprayed onto a concrete deck using a robot.

2.6 Service Life of Membranes

It is difficult to estimate the service life of a membrane system because there are many factors that affect how the system performs. Most notable is the quality of the installation, which in itself can be quite unpredictable. Despite the fact that the service life of membrane systems is difficult to determine, information on life expectancy is important for transportation officials. Therefore, it is worthwhile to discuss the expected service life data that have been gathered from a variety of sources and presented in Table 2.6.

As can be seen from this compilation of data, the range of expected service life is quite large with the minimum being 0 years and the maximum being 60 years for the "Eliminator" system. Although the international scan conducted as part of NCHRP Report 381 indicated that Danish membrane systems were expected to last 30 years, another report, published by a Danish engineer, mentions that a 50 year service life is expected (75).

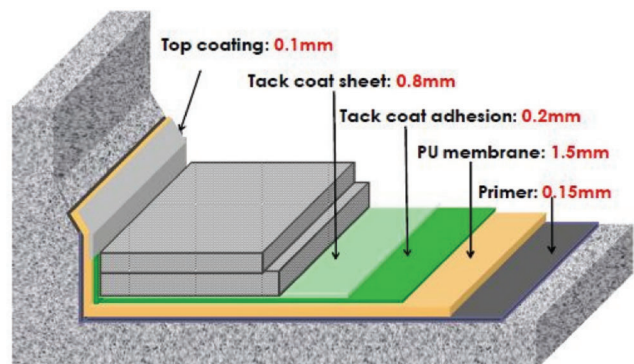


Figure 2.45 Japanese spray-applied polyurethane system (80).



Figure 2.46 Polyurethane system sprayed by robot (80).

NCHRP Synthesis 425, which represents the most recent collection of survey data, was published in 2012. Responses from the survey indicate that service life expectancies range from 0 years to over 25 years for both new and existing bridges (Figure 2.47). For new bridge decks, most responses were received for 16 to 20 years. For existing bridges, most responses were received for 11 to 15 years. All of the agencies that responded to the survey indicated that they expected membranes to have a longer service life on new bridge decks than on existing bridge decks.

These data may be deceptive because they include the expected service life from agencies that do not typically install membranes. These agencies have experienced unsatisfactory performance with membranes and do not expect them to have very long service lives. To present this information in a more straightforward manner, the results are shown in tabular form with the data separated by geographical region (Figure 2.48). Most notable about this representation of the data is that Canadian agencies expect the longest service life and Western states (CA, NM, UT) expect the shortest service life.

2.7 Cost of Membranes

In the 2008 survey by Krauss et al., transportation officials were asked about costs of installing membranes

on existing bridge decks. The survey results indicated that the cost of membranes ranged from \$1.5 per ft² to \$23.5 per ft². The mean was \$3.1 per ft² to \$7.6 per ft² (26).

Cost data were also gathered from the NCHRP 425 survey conducted in 2012. Results of the survey also indicated a wide range of costs of membrane systems ranging from less than \$1 per ft² in one case to over \$40 per ft² in another. The responses given by Canadian provinces were less sporadic, showing a range of C\$1.69 per ft² to C\$8.55 per ft² (13).

2.8 Factors Affecting Membrane Usage

2.8.1 Epoxy-Coated Steel Reinforcement

As previously discussed, applying epoxy coating to steel reinforcement is one method to increase the durability of a bridge deck. This practice has become standard in many US states, but is not used as extensively in other countries. For example, neither of the governing bodies in the UK or Australia specifies epoxy-coated steel reinforcement in their concrete bridge decks. In fact, both groups expressly prohibit the use of epoxy-coated steel. In cases where epoxy-coated steel reinforcement is not used, protection of reinforcement from salt intrusion is only provided by the waterproofing membrane. In this case, waterproofing membranes have a more important role in addressing bridge deck durability. In cases where epoxy-coated steel reinforcement is used, using a waterproofing membrane is not as important for addressing bridge deck durability. However, the use of multiple bridge deck protection strategies, both epoxy-coated steel reinforcement and a waterproofing membrane, should provide redundancy to the protection scheme and increase the service-life of a bridge deck.

2.8.2 Quality of Installation

The quality of the installation is the most important factor determining the performance of a membrane system. Listed below are considerations to ensure a quality installation.

TABLE 2.6
Expected Service Life Data

Document	Year	Expected Service Life of Membrane System in Years	Notes
NCHRP Report 297 (8)	1987	15	—
Al-Qadi et al. (55)	1993	40	Bridge life expected to increase 25 yrs
NCHRP Synthesis 220 (9)	1995	10–30 (new), 3–30 (existing)	Survey of 48 US States, the District of Columbia, and 6 Canadian Provinces
Wojakowski and Hossain (53)	1995	20–25	Study by Kansas DOT
NCHRP Report 381 (10)	1996	30 (Denmark), 20–25 (Germany), 20 (UK)	“Eliminator” system (UK) is expected to last 60 yrs
Krauss et al. (26)	2008	3–40 (existing)	Survey of 11 US States and 3 Canadian Province; mean = 12–19 yrs
Distlehorst (54)	2009	15	Study by Kansas DOT
NCHRP Synthesis 425 (13)	2012	0–25+	Survey of 42 US States, the District of Columbia, and 10 Canadian Provinces

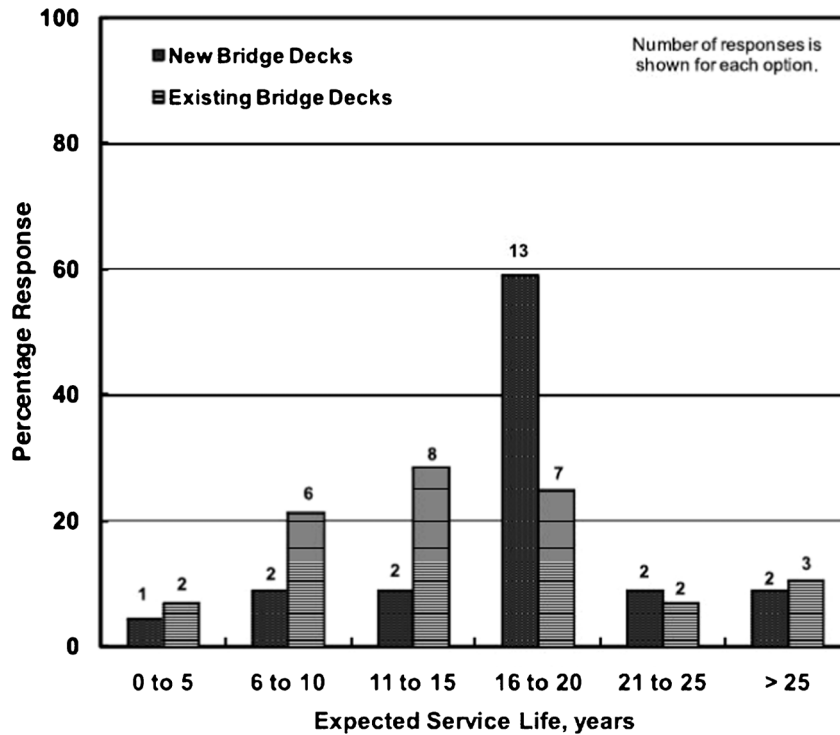


Figure 2.47 Expected service life of membranes (13).

- Conduct test installations.
- Use manufacturer suggested complementary products (i.e. primers, etc.).
- Choose a qualified or otherwise experienced installer to perform the work.
- Use manufacturer or more stringent specifications.
- Provide well-defined specifications to the installer.
- Require that the membrane manufacturer provide oversight of the work.
- Provide DOT oversight of the work.
- Proceed with installation only in proper weather conditions.

2.8.3 Pavement Thickness

Indiana bridges, as typical in many states, are currently designed for 35 psf of additional dead load to account for a future wearing surface (4). The AASHTO LRFD Bridge Design Specifications estimate the weight of a bituminous wearing surface to be 140 pcf (24). Therefore, approximately 3 in. (75 mm) in depth of material can be applied. Depending on the thickness of the asphalt overlay used in a membrane system, it is possible that the weight may be greater than the amount for which the bridge was originally designed.

European transportation agencies rely heavily on the durability of the asphalt surfacing to prolong the life of the underlying membrane and in many cases multiple layers of pavement are specified. Figure 2.49 shows the typical thickness of the asphalt overlays used in various countries. Cells highlighted in red indicate pavements

that are thicker than the allowed thickness in Indiana. Cells highlighted in green indicate pavement thicknesses that would be acceptable in Indiana.

Not only does a thick overlay present possible dead load issues, but it also suggests that the process of installing membranes is quite involved. Two layers of asphalt pavement require that several passes of surfacing vehicles must be made for the asphalt to be placed and compacted.

Stone mastic asphalt (SMA) overlays, such as the one used on the Indiana Toll Road bridges, are typically thinner overlays and would be permissible on Indiana bridges. However, because the use of SMA overlays is a fairly new development, it is unclear how they have performed on bridge decks. As a new procedure, it will be several years before their performance can be evaluated.

2.8.4 Details at Joints

Although the installations occurred on new bridge decks, the work on the Indiana Toll Road provides a wealth of knowledge on the topic of detailing for both new and existing bridge decks. Expansion joints on existing bridge decks can be reconstructed similar to the expansion joints used on the toll road. First, existing joint hardware must be removed, and the cavities from the removed anchorage must be filled. Elastomeric concrete can subsequently be applied to the deck.

The details used on the toll road bridges provide one option. There are many other options, some of which were identified in the international state-of-the-practice

Region	Agency	New Bridge Decks						Existing Bridge Decks					
		0 to 5	6 to 10	11 to 15	16 to 20	21 to 25	>25	0 to 5	6 to 10	11 to 15	16 to 20	21 to 25	>25
Canada	Alberta						x						x
	Manitoba				x						x		
	New Brunswick					x						x	
	Newfoundland and Labrador				x						x		
	Nova Scotia				x					x			
	Ontario						x						x
	Prince Edward Island				x				x				
	Quebec				x						x		
	Saskatchewan				x						x		
East	Virginia				x						x		
Midwest	Illinois			x						x			
	Kansas							x					
	Michigan								x				
	Missouri				x								
	Nebraska									x			
Northeast	Connecticut				x						x		
	New Hampshire			x						x			
	New York												
	Pennsylvania												x
Northwest	Alaska				x					x			
	Idaho		x						x				
	Oregon				x						x		
	South Dakota				x					x			
	Washington					x						x	
	Wyoming									x			
South	Texas									x			
	Oklahoma				x				x				
	Tennessee								x				
West	New Mexico	x						x					
	California		x						x				
	Utah		x						x				

Figure 2.48 Expected service life data by region (13).

(Section 2.5). For example, the Spanish expansion joint detail shown in Figure 2.36 can also be applied to an existing bridge deck. The joint hardware is anchored to the bridge deck, and its depth is the same as the depth of the overlay. This detail results in an uninterrupted riding surface.

Several manufacturers of waterproofing membranes also provide proprietary joint products to be used in

conjunction with their membranes. One such manufacturer is Stirling Lloyd which produces the widely used spray applied system, Eliminator. Stirling Lloyd also produces three different expansion joint systems that accommodate increasing amounts of horizontal movement. The Stirling Lloyd joint that allows the largest movement (150 mm = ~ 6 in.) is shown in Figure 2.50.

The joint at the end of the bridge also requires consideration. The asphalt overlay is simply extended over the joint until a natural stopping point presents itself. To prevent reflective cracking of the pavement over the joint at the abutment, a groove should be saw cut and filled with a flexible sealing material that bonds well to the pavement. If this detail is not used, and the pavement is terminated at the abutment, the approach slab must be reconstructed to be even with the asphalt overlay.

2.8.5 Drainage

It has been emphasized that proper drainage is important for the service life of membrane systems. However, difficulties arise when placing a membrane near existing drains such as the one shown in Figure 2.15.

Region	Province/Country	Typical Asphalt Overlay Thickness
Canada	Ontario	80 mm
	New Brunswick	65 mm
	Alberta	80 mm
Europe	UK	120 mm
	Germany	70 mm - 80 mm
	Spain	80 mm
	Sweden	90 mm
	Denmark	80 mm - 100 mm
	Finland	100 mm
Asia	Japan	75 mm
Australia	New South Wales	70 mm

Figure 2.49 Typical overlay thickness.

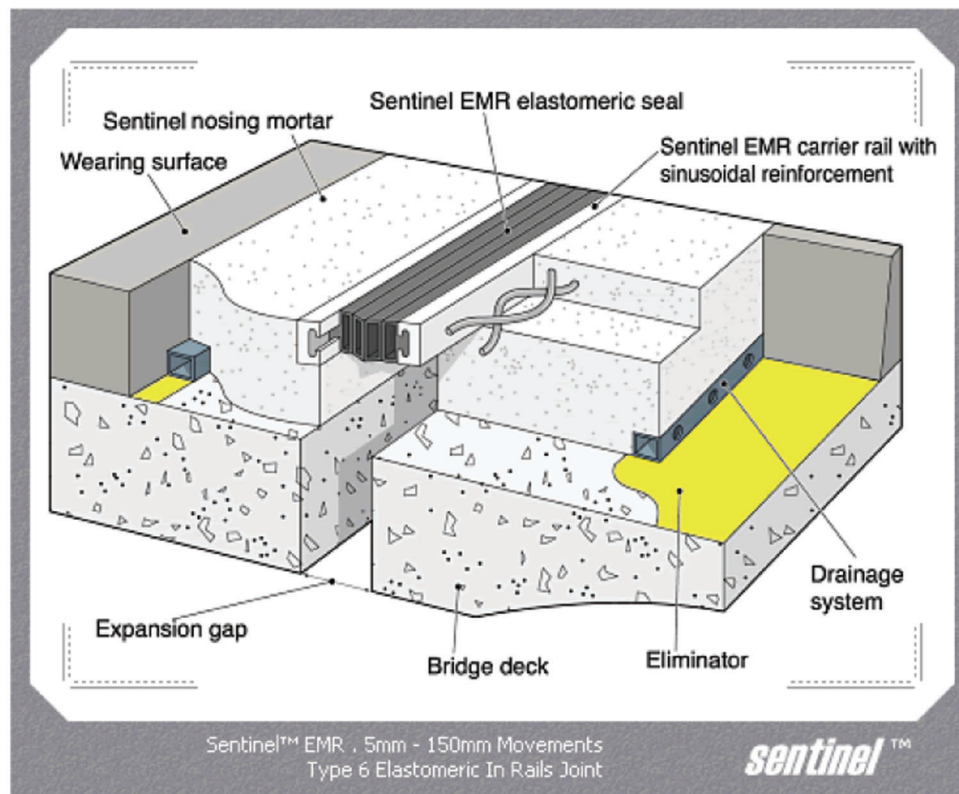


Figure 2.50 Stirling Lloyd expansion joint (81).

Because drains are typically placed outside of traffic lanes, it may be possible to taper the asphalt pavement to the drain. This option should be used cautiously because although a drain may be outside marked traffic lanes, vehicles may veer outside of the marked lane and over the drain. If the overlay is 2.5 in. thick, such as the overlays on the Indiana Toll Road, a 2.5 in. depression at the location of the drain can be damaging to traffic.

Another option is to remove the existing drain hardware and replace it to accommodate for the increased thickness of the overlay. Important in this procedure is the assurance of both surface and subsurface drainage. The drain should be extended upwards to the elevation of the asphalt overlay to allow for proper surface drainage. The portion of the drain extended above the concrete deck to the top of the overlay should be slotted to allow for subsurface water in the asphalt layer to enter.

Regardless of method, proper measures must be taken to ensure that the edge of the membrane around the drain is properly sealed.

2.8.6 Inspection

Visual inspection of the top of a bare concrete deck can indicate whether corrosion and spalling has occurred. If a membrane system is installed, the top of the deck cannot be inspected. Because the top of the deck is not visible, indication of damage occurs only when cracks or deterioration is reflected upwards

through the membrane layer and the asphalt overlay. By this point, damage is likely quite extensive. As a comparison, thin polymer overlays and concrete overlays offer earlier signs of distress.

Visual inspection of the bottom of a bridge deck can also be an indicator of serious permeability issues and the occurrence of corrosion. If efflorescence is observed on the underside of a concrete bridge deck, it is assumed that chlorides and moisture have made their way through the entire depth of the deck. Some highway or bridge professionals maintain the opinion that this indication of damage comes very late. By the time efflorescence is observed on the underside, it is likely that corrosion of the steel is already underway.

Standard INDOT practice in bridge construction includes the use of stay-in-place forms for concrete bridge decks. Stay-in-place forms prevent the ability to inspect the underside of a bridge deck. If a membrane system is also installed, both the top and the bottom of the deck cannot be inspected. There are no apparent plans for inspection of the waterproofed decks on the Indiana Toll Road.

It was recommended in NCHRP Synthesis 220 that visual inspections combined with chloride measurements and selective removal of concrete are the best methods for evaluating a deck with a membrane system. Beyond this there are only limited amounts of information regarding methods for inspection of decks waterproofed by membranes.

3. OTHER BRIDGE DECK PROTECTIVE SYSTEMS

3.1 Introduction

A waterproofing membrane system is one of many solutions used to address the problem of bridge deck durability. This chapter introduces several other systems that have been considered as possible bridge deck protection options. These systems include various concrete overlays, thin polymer overlays, and polymer modified asphaltic concrete. All of the systems discussed in this chapter have either recently become standard practice for transportation agencies or are still used experimentally.

3.2 Concrete Overlays

The use of concrete overlays as a bridge deck protective strategy is extensive in the US. Latex-modified concrete overlays have been used since the 1970's and are still used by many state transportation agencies (NCHRP 2004)(11). Silica fume overlays have also been used for over 30 years but have been generally phased out due to early age cracking and difficulty in construction. This chapter focuses on newly developed or experimental concrete overlay systems including high-reactivity metakaolin concrete overlays, early-strength latex-modified concrete overlays, and fibrous concrete overlays.

3.2.1 High-Reactivity Metakaolin (HRM) Concrete Overlay

High-reactivity metakaolin (HRM) is produced through intensive processing of kaolinite clay and is used as a supplementary cementitious material in concrete mixes. The addition of HRM in concrete results in higher compressive strength and lower permeability (82). Since HRM is a supplementary cementitious material, functioning much like silica fume, HRM concrete overlays are installed in the same way as silica fume or low slump concrete overlays.

Despite the benefits that HRM concrete offers, HRM concrete overlays have only experienced limited use due to the high costs associated with material. Illinois and New York both provide specifications for HRM concrete overlays but have installed very few. Additionally, only two producers of high-reactivity metakaolin have been identified in the US. As such, this type of concrete overlay is still very much experimental.

3.2.2 Early-Strength Latex-Modified Concrete Overlay

Rehabilitation or maintenance of in-service bridges is often affected by lane closure limitations. To reduce the impact on the general public, transportation agencies desire repair methods that can be completed over night or during weekends. One of the difficulties of a traditional latex-modified concrete (LMC) or silica fume concrete overlay is the amount of cure time

needed before traffic can be allowed onto the surface. In an attempt to reduce the amount of lane closure time, LMC overlays have been altered to have a shorter cure time and allow for the installation to occur during off peak traffic periods. To allow for this shorter cure time, a special blend of cementitious materials is used.

The Virginia DOT has considerable experience in the use of quick curing LMC overlays. The state has successfully installed both high-early-strength LMC overlays which require one or two days of lane closures, and very-early-strength LMC overlays which only require overnight lane closures. The installation of a high-early-strength or very-early-strength LMC overlay is conducted in the same manner as a traditional LMC overlay except that the process is hastened due to the quicker cure time of the concrete. In the case of a very-early-strength LMC overlay, the curing period can be reduced from 72 hours to 3 hours.

In their experience, both high-early-strength and very-early-strength LMC overlays have exhibited the same qualities as traditional LMC overlays in regards to permeability and strength. In addition, early age cracking which is a problem for traditional LMC overlays is also experienced with these overlays. Due to the high costs associated with the specially blended cement that is used, high-early-strength LMC overlays are estimated to increase the material cost of an LMC overlay by \$9 per yd³ and very-early-strength LMC overlays are estimated to increase the cost by \$120 per yd³ (costs reported in 1995 dollars). It is believed that these additional costs can be offset by the savings from reduced traffic control and that the total project cost can be reduced by approximately 25% (83).

3.2.3 Fibrous Concrete Overlay

Latex-modified concrete overlays and silica fume concrete overlays exhibit very desirable behaviors for bridge deck protection as they offer enhanced permeability and higher strengths. Unfortunately, the problem of early age cracking due to shrinkage of these overlays is well acknowledged. If the problem of cracking can be solved, these systems provide an excellent option for bridge deck protection. Fibrous concrete overlays are an attempt to solve this problem by the introduction of short unattached fibers, made of materials such as steel, nylon, polypropylene, and polyethylene, into the concrete mix. The addition of fibers into the concrete is intended to provide the overlay with higher tensile strength and improved crack resistance. One of the largest installations of a fibrous concrete overlay occurred in 2006 as part of a project to rehabilitate the Dan Ryan Expressway in Chicago. Slightly more than 200,000 yd² of silica fume concrete reinforced with polypropylene fibers were installed on a total of 22 structures (84).

Concerns surrounding the use of fibrous concrete overlays are mostly related to their constructability. Although fibrous concrete overlays are placed the same

way as non-fibrous overlays, close attention must be paid to ensure that the fibers are mixed uniformly into the concrete. For silica fume or fly ash concretes, the fibers may be mixed into the concrete at the plant. However, for latex-modified concrete overlays, which are mixed on-site by mobile mixers, a specialized feeder system must be incorporated with the mobile mixer to provide uniform distribution of the fibers. Additionally, there are concerns of workability because the fibers have the potential to clump or ball during the finishing process.

An extensive evaluation of fibrous concrete overlays, sponsored by the Illinois DOT, has been conducted (84). This evaluation included both laboratory tests as well as field installations with the goal of assessing the benefits of fibrous concrete overlays and developing recommendations for constructability. The laboratory tests indicated that the addition of fibers to concrete overlays results in a reduction in drying shrinkage of 10 to 15%. The addition of fibers did not negatively affect performance in regards to strength, permeability, or bond strength. Based on the field installations, it was suggested that a maximum of 3 lb/yd³ of fibers be used to prevent finishing issues (clumping and balling of the fibers). It was recommended that trial batches be mixed to ensure that proper proportions and uniform mixing of the fibers can be achieved. After one year of service, both the fibrous latex-modified concrete overlay and its plain latex-modified concrete overlay counterpart showed no visible signs of cracking. From these installations, it was observed that adding fibers to the concrete increased the initial cost of installation by less than \$1 per yd² (84).

In 1997, the Oregon Department of Transportation overlaid the northbound lane of the Link River Bridge near Klamath Falls, Oregon with a silica fume concrete overlay reinforced with polypropylene fibers. The southbound lane was overlaid with traditional silica fume concrete. Both installations occurred in the early morning to reduce the effect of evaporation from the sun. It was reported by the project inspector that the fibers had a positive effect on the concrete's workability (85). At the time the bridge was opened to traffic, both the northbound lane (with fibers) and the southbound lane (without fibers) displayed the same amount of fine initial cracking. After two years of service, both lanes were again inspected. While cracking was observed in both the northbound and the southbound lane, the majority of the cracks were observed in the northbound lane (constructed with the fibrous overlay). This evidence suggests that the proposed benefits of a fibrous concrete overlay may not be achieved (85).

These test installations have helped improve the base of knowledge regarding the installation of fibrous concrete overlays. However, although fibrous concrete overlays have proven to reduce drying shrinkage in the laboratory, according to the experimental installations in Illinois and Oregon, their benefits have yet to be realized during a field installation.

3.3 Thin Polymer Overlays

Thin polymer overlays (TPO) have been used on bridge decks since the 1950's; however, TPOs were not used extensively until the 1990's. It has been reported that TPO usage has tripled between the years 1990 and 1999 and quadrupled between 1999 and 2008. This increase in usage is likely due to advances in materials and a more refined knowledge of the installation process (12). Thin polymer overlays have been installed in Indiana since 1986 and they have provided excellent performance (3). As a result, TPOs have become standard practice for bridge deck rehabilitation and preventative maintenance in Indiana.

A thin polymer overlay is simply a wearing surface with a thickness that is less than 1 in. and is comprised of a polymer binder and aggregate. In concept, a TPO serves as both an impermeable layer and as a riding surface. It is a desirable method used in protecting bridge decks for the following reasons:

- They typically require a short installation time.
- The properties of the polymer binder allow for proper bonding to the concrete substrate.
- Polymer binders provide enhanced flexibility and crack bridging capabilities.
- Compared to other bridge protective systems, they place a smaller demand on the dead load capacity of a bridge.
- They do not present any clearance issues.
- Because of the polymer binder and the use of multiple layers, they are essentially impermeable.
- They typically do not require any modification to the approaches, expansion joints, and drains.

There are three primary methods used for installing thin polymer overlays:

- **Method 1:** Systems using an epoxy binder are classified as multiple layer overlays. To install a multiple layer overlay, the epoxy binder is applied to the concrete deck by broom, squeegee, or spray. The aggregate is then broadcast onto the epoxy until there is excess. The excess aggregate that does not bond is then swept before a second layer of binder and aggregate is applied.
- **Method 2:** Systems using a methyl methacrylate binder are classified as slurry overlays. In this method, the aggregate and the binder (methyl methacrylate) are mixed in a portable mixer and then spread to a specified thickness onto the deck using a gage rake. After placing the slurry mix to the desired depth, aggregate is broadcast over the top surface.
- **Method 3:** Systems using epoxy or polyester-styrene binders may be classified as premixed overlays. This method is often used when a thicker overlay is required. In this method, a mixture of binder and aggregate is consolidated by a vibratory screed and covered with broadcast aggregate.

In a 2011 synthesis report by the National Cooperative Highway Research Program (12), several factors during the installation of TPOs were recognized as being the most important for ensuring proper performance. A service life of 20 to 25 years is estimated if these factors are properly addressed.

- A well prepared surface that is textured, dry, and clean is important. A moist deck can cause blistering of the polymer layer.
- Dry weather and warm temperatures ensure that the polymer can achieve proper bond to the concrete.
- Experienced installers and proper workmanship ensure a quality installation.
- Oversight by the producer of the product can guarantee proper mixing and installing of the product according to specifications.
- Compatibility between the thermal properties of the materials used is important.

According to this synthesis, 33 states have experience installing TPOs and three Canadian provinces (British Columbia, New Brunswick, and the Northwest Territories) have installed between one and five TPOs. Additionally, the province of Alberta is reported to have installed 139 TPOs between 1984 and 1998 but have since stopped installing them due to poor performance and high costs (12).

According to a Strategic Highway Research Program (SHRP) study (14) that investigated the use of sealers and thin polymer overlays on bridge decks, when installed on new bridge decks with a concrete cover of 1.75 in., a well maintained thin polymer overlay is expected to postpone chloride induced corrosion of the reinforcing steel for 77 years. This is compared to 13 years for a deck that is not protected. This information was extrapolated from chloride penetration data taken from a survey of 50 in-service bridge decks (14).

3.3.1 TPO Site Visits

As part of the review of INDOT bridge deck protection practices, two site visits were conducted during the summer of 2012 to observe the installation of a thin polymer overlay system. The two bridges that were visited were SR 26 over the Wabash River (Bridge No. 026-79-06961 EBL and WBL) and US 231 over the Wabash River (Bridge No. 231-79-07531 NBL and SBL). The purpose of these visits was to gain knowledge regarding the installation process of thin polymer overlays.

3.3.1.1 SR 26 over the Wabash River. A multiple layer overlay was installed on both the eastbound and westbound structures carrying State Road 26 over the Wabash River. The proprietary material installed was “Mark-163 Flexogrid” which is produced by Dow POLY-CARB. Figure 3.1 shows the installation taking place on June 7–8, 2012.

The “Flexogrid” system is installed by specialized equipment which is shown in Figure 3.1. The two part epoxy is mixed in a specialized truck and is deposited onto the deck. A set of rails extends the aggregate hopper (red bucket in the middle of the photograph) behind the truck to provide adequate room for the installers to spread the epoxy evenly before the aggregate is placed. This operation required one worker (representing the manufacturer) to operate the truck,



Figure 3.1 TPO installation on SR 26 over the Wabash River.

three to spread the epoxy, and three to broadcast the aggregate.

Several details of the system as shown in Figure 3.2 are outlined below.

- Oklahoma flint rock. This angular aggregate is broadcast onto the epoxy binder.
- A partial depth patch adjacent to a drain that has been sealed. The deck was patched with a proprietary quick-setting epoxy/aggregate slurry that is produced by the manufacturer of the TPO system.
- A typical pull-off test setup. The complete TPO system (primer, first epoxy layer, aggregate, second epoxy layer, aggregate) is installed in 3ft x 3ft sections and a series of pull-off tests is conducted to prove that the deck has been prepared properly and that adequate bond can be achieved. The pull-off locations, indicated by the three pucks bonded by epoxy to the overlay, are chosen at random.
- A section of the deck where poor installation practices became evident. Near the strip seal expansion joint, the aggregate and epoxy formed into clumps which had to be chipped away, leaving defects in the first layer.

Other problems observed during the installation (not shown) included bleeding of the epoxy through the aggregate layer, and defects in the overlay due to carelessness of the installers. At the time of the installation, there was not much concern over these issues because it was assumed that the second epoxy layer would provide some correction to these defects.

3.3.1.2 US 231 over the Wabash River. A multiple layer overlay was also installed on both the northbound and southbound structures carrying US 231 over the Wabash River. However, a different product, “E-Bond 526” by Transpo Industries, Inc., was installed. Figure 3.3 shows the installation taking place on July 12, 2012.

The procedures used on this installation vary significantly from the previous one. The two-part epoxy is mixed in the nozzle of a sprayer held by a worker (far left of the photograph). After the epoxy is deposited on



(a)



(b)



(c)



(d)

Figure 3.2 Details of TPO installation on SR 26.

the surface, it is spread using a squeegee. The aggregate is then sprayed onto the epoxy from above by a worker in a boom lift.

Several details of the system as shown in Figure 3.4 are outlined below.

- Epoxy being spread near a joint. One worker spreads the epoxy at the edge of the joint using a brush while the other, wearing spiked footwear to reduce contact area, spreads the epoxy by squeegee. While a primer was used to provide an initial seal on the SR 26 deck, no primer was used during this installation.



Figure 3.3 TPO installation on US 231 over the Wabash River.

- An inspector recording the temperature of the epoxy before it is mixed and placed.
- A drain that has been sealed to prevent leakage of the epoxy.
- Before-and-after view of a TPO system. The structure on the left has already been overlaid while the one on the right has been shotblasted and cleaned but not yet overlaid.

These two site visits provide a good understanding of the processes involved in the installation of thin polymer overlay systems. The following list identifies important lessons that were learned during these visits.

- The amount of previous TPO installation experience was evident at the two sites. In general, the crew on the SR 26 bridge, which was installing a TPO for the first time, was more negligent, haphazard, and unorganized in performing the installation. The crew on the US 231 bridge, which specializes in installing epoxy overlays, performed the work more effectively and with fewer workers. In several years, performance characteristics of these two overlays might highlight the importance of crew experience.
- Surface preparation is of high importance. In both cases, extensive measures, including pull-off tests, were taken to ensure that proper bond could be achieved.
- The temperatures and time constraints associated with all facets of the installation are also very important. The amount of time it takes for the two parts of the epoxy to completely mix and become effective is dependent on ambient temperature and the temperature of the deck. In addition, the viscosity of the epoxy, which is an

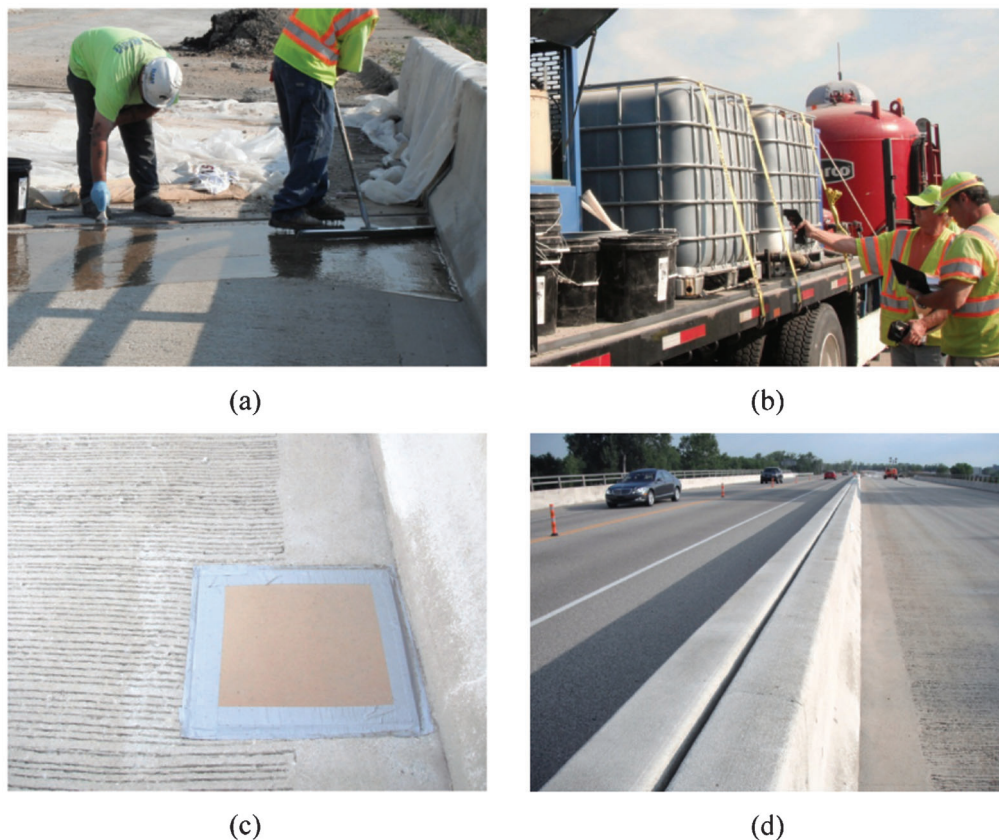


Figure 3.4 Details of TPO installation on US 231.

important factor affecting whether or not the epoxy will sufficiently penetrate the concrete, is highly dependent on the temperature and gel time.

- Although TPOs are identified as being systems that can be quickly installed, both of these installations were slow-moving and took several days to complete. If time constraints are present it is important that procedures not be neglected in attempting to increase construction speed.
- In relation to other protection strategies, TPOs require a less involved installation process. Because they are very thin, TPOs typically do not require any additional work related to drains, curbs, approach slabs, or expansion joints.

Given that these two overlays were installed within weeks of each other, and because their locations are in close proximity, it is suggested that they be regularly inspected and compared. It will be interesting to evaluate whether or not the amount of prior experience on the part of the installer will have any effect on the long-term performance of these overlays.

3.3.2 Anti-Icing Overlay

The SafeLane® overlay system is a patented technology that incorporates a specially chosen aggregate into a thin epoxy overlay (86). This special aggregate is made of dolomitic limestone and acts as a sponge to store deicing chemicals for an extended period of time.

During a snow event, it is intended that the stored deicing chemicals will actively work to maintain the riding surface snow and ice free. As a result, this system is also expected to provide a reduction of winter related accidents (87).

The SafeLane® system has been criticized for several reasons. While the limestone aggregate is claimed to be able to store deicing chemicals, it is believed to be softer than most aggregate which allows it to wear easily due to traffic. Over time, this gradual wearing of the aggregate causes the system to lose skid resistance (88). Another criticism is based on the requirement that liquid deicing chemicals must be applied proactively to the overlay before a snow or ice event occurs. If this is not done, the overlay acts as a traditional thin polymer overlay, and there is no benefit from the sponge-like aggregate. Some bridge owners find this pretreatment task to be difficult.

In 2003 and 2005, the SafeLane® system was installed experimentally to test its performance (86). Nine installations were performed in six different states: Texas, Wisconsin, Indiana, Ohio, Virginia, and New York. In general, the test sections with the SafeLane® overlay system required less applications of deicing chemicals and remained clear of snow and ice even while the control section (without an overlay) accumulated snow and ice. Of particular interest is the experimental installation performed on the Ironwood Drive Bridge over the St. Joseph River in South Bend,

IN. Field data including weather conditions, amount of deicing chemicals applied, and the condition of the pavement were gathered during four different snow events. The SafeLane® overlay exhibited superior deicing performance compared to the control section in all but one snow event in which both sections had accumulated snow. The poor performance of the SafeLane® system in this instance was believed to be a result of the deicing chemicals being washed away by rain in the previous days. This study did not provide any long-term performance data related to the durability of the pavement.

An evaluation of the SafeLane® overlay system was also conducted by the Minnesota Department of Transportation which installed the system on four different bridge decks in 2006 and 2007 (88). The cost for one installation was calculated to be \$5.79 per ft². After three years, the overlay had performed satisfactorily but several reasons for caution were identified. First, debonding of the overlay occurred at joints where snow plows had caused damage (Figure 3.5) as well as over asphalt repair patches (Figure 3.6). Second, the overlay exhibited dramatic degradation in skid resistance after 26 months of service which was attributed to shearing forces from traffic and snow plows. This reduction in skid resistance was deemed to be a limiting factor on the service life of the SafeLane® overlay system.

The Colorado Department of Transportation has also experimentally installed a SafeLane® overlay on one bridge in the Denver metropolitan area (89). The installation, which had a total cost of \$9.32 per ft², was performed in October 2009 (right lane) and May 2010 (left lane). After one year of service, the SafeLane® overlay exhibited exceptional skid resistance and high bond strength. Additionally, decreased chloride content was measured in the deck at the level of the reinforcing steel.

From these studies, it can be summarized that SafeLane® overlays effectively perform the task of



Figure 3.5 Damage at expansion joint (88).



Figure 3.6 Debonding over asphalt patch (88).

storing deicing chemicals which become active during a significant snow event. Although some SafeLane® overlays have shown adequate skid resistance, there is a potential for a dramatic decrease in skid resistance due to the soft aggregate used. Since SafeLane® is a fairly new overlay system, long-term performance data are still unavailable. As recommended by all of the reports on SafeLane® overlays, it is important that the experimental installations be monitored over time so that long-term performance can be better assessed.

3.4 Polymer Modified Asphaltic Concrete

Asphaltic concrete overlays have been used as a method for rehabilitating bridge decks since bridge deck durability was first recognized as an important issue. It is understandable that at a time of limited knowledge, transportation agencies chose to repair concrete decks by simply adding a layer of asphalt in order to return the riding surface back to its original quality. However, it was later recognized that moisture was being trapped at the bottom of the asphalt overlay causing damage to the reinforcing steel and the concrete cover. In fact, this problem was the original impetus for installing waterproofing membranes underneath asphalt overlays.

Polymer-modified asphaltic concrete aims to provide an alternative protective solution by creating an impermeable asphalt. To create an impermeable asphalt, a polymer material is included with the asphalt binder during the mixing process. This allows the asphalt pavement to perform both as a sealing layer and a riding surface. There is currently one widely used proprietary product that fits this category, Rosphalt® by Royston Laboratories (90).

Along with providing both a waterproofing layer and a riding surface, the Rosphalt® system is believed to offer several other benefits. Because the system is placed in the same manner and with the same equipment as any asphalt pavement, it is considered to provide an easier and quicker installation process. The polymer modifier is also considered to increase crack and rut resistance. While there may be benefits, it should be noted that this system, similar to many other new systems, is considered fairly expensive.

The Maine Department of Transportation, an agency that primarily installs waterproofing membranes, has evaluated the Rosphalt® system by installing it on three bridge decks which were evaluated for five years (90). All of the bridges had existing protective systems which included a waterproofing membrane with an asphalt overlay. On two of the bridges, the membrane was left intact because it was deemed to still be effective. The asphalt pavement was milled to within ½ in. of the membrane and 2 in. of Rosphalt® were paved on top. On the third bridge, the entire system was removed before 3 in. of Rosphalt® were paved onto the surface. Although it was reported that the Rosphalt® system is performing satisfactorily after five years, a concern was raised regarding the separation of the material at joints and curbs (Figure 3.7). It is believed that this problem of pavement separation can be resolved with improved construction practices.

The Rosphalt® system has also been installed as part of two large projects which include heavily traveled bridges in the metropolitan areas of Milwaukee, WI and Louisville, KY. In 1996, the mile-long High-Rise Bridge in Milwaukee, which carries eight lanes of traffic was overlaid with the Rosphalt® system. In addition, nine lane miles along the Riverside Expressway (I-65) in Louisville, KY were overlaid with the Rosphalt® system in 2007. In both of these locations, the Rosphalt® system was chosen because its installation can be performed very quickly which is important for bridge work in metropolitan areas (91,92). From these installations, it has been noted that both the



Figure 3.7 Separation of Rosphalt® at joints (90).

Wisconsin DOT and the Kentucky Transportation Cabinet are very satisfied with the Rosphalt® system (93).

4. EVALUATION AND COMPARISONS

4.1 Introduction

Latex-modified concrete overlays, thin polymer overlays, and waterproofing membranes with asphalt overlays are the most widely used protective systems and offer the most advantages. This chapter aims to evaluate these three different systems. Of primary importance are the service life and costs associated with these various systems. Additionally, the three systems will be evaluated based on various characteristics of the bridge deck to which they are applied (Section 4.4) as well as various other characteristics of the individual types of systems (Section 4.5).

4.2 Service Life Comparisons

The expected service life of a bridge deck protective system can be the most important factor in choosing between different alternatives. Above all else, transportation agencies want a system that is durable and requires the least amount of maintenance over its lifetime. The service life of a system is strongly linked to life cycle costs. If transportation agencies can be assured that a system can last longer than its competitor, they are more likely to incur higher upfront costs considering that the initial investment will pay off over the life of the bridge.

Despite the importance of knowing what the service life of a system will be, it is very difficult to make a reliable prediction due to the many factors that can affect the performance of a system. With that said, a number of studies have been conducted attempting to glean this information.

The data presented in Table 4.1 represent the results of three different surveys of various transportation officials. The survey by Chamberlin and Weyers (94) includes responses from 47 US state and 9 Canadian province transportation agencies while the survey by Sprinkel et al. (95) includes responses from 49 US state and 10 Canadian province transportation agencies as well as 9 turnpike and thruway authorities, and 8 technology transfer centers. The third survey, Krauss et al. (26), includes the survey responses of transportation agencies from 41 US states and 4 Canadian provinces which were gathered by the National Cooperative Highway Research Program (NCHRP) and used to produce the “Guidelines for the Selection of Bridge Deck Overlays, Sealers, and Treatments.”

From these data, it can be seen that concrete overlays (low slump and latex-modified) have the highest expected service life in both the Chamberlin and Weyers and Krauss et al. studies. While the Chamberlin and Weyers study indicates that membrane systems should have a comparable service life to latex-modified concrete overlays, the other two studies

TABLE 4.1
Expected Service Life

Rehabilitation Type	Expected Service Life (Years)									
	Chamberlin and Weyers (94)				Sprinkel et al. (95)			Krauss et al. (26)		
	Min.	Max.	Median	Mode	Min.	Max.	Mean	Min.	Max.	Mean
Low Slump Concrete Overlay	—	—	—	—	—	—	—	10	45	16–32
Latex-Modified Concrete Overlay	0	60	15–20	20	—	—	—	10	50	14–29
Thin Polymer Overlays	2	25+	10	10	6	25	12.7	1	35	9–18
Membranes w/Asphalt Overlays	5	60	15	15	4.5	20	11.8	3	40	12–19
Deck Replacement	—	—	—	—	—	—	—	15	50	27–32

indicate that membrane systems and thin polymer overlay systems are expected to have a similar service life. Krauss et al. indicates that membrane systems and thin polymer overlay systems have a service life that is substantially lower than that of a latex-modified concrete overlay.

It should be noted that the data provided only include the responses of North American transportation officials which includes responses from several transportation agencies that have a negative outlook of membrane systems. Beyond the data provided above, other reports lead to the suggestion that membrane systems have the largest upside in terms of service life. In Denmark, membranes are expected to be replaced every 50 years as long as the asphalt overlay is rehabilitated every 25 years (75). In the UK, most membrane systems are expected to last for 20 years, however the Eliminator system by Stirling Lloyd is thought to offer a 60 year service life (10). Both the Alberta and Ontario provinces of Canada expect at least 25 years of service. In the US, the Pennsylvania DOT estimates that membrane systems will have a 40 year service life (13). If these service lives can be achieved with regularity, membrane systems would be a very valuable protective system.

4.3 Cost Comparisons

The cost of a protective system is an important factor when deciding between different options. Two different ways of associating costs may be considered: the upfront costs and the life cycle costs. To develop a proper estimation for life cycle costs, an appropriate estimate of the service life of the system must be determined, which, as discussed, can be difficult.

In a study published in Transportation Research Record number 1749 (96), the cost data associated with 79 overlay projects in Virginia during the 1995 fiscal year were compiled. These projects included latex-modified concrete overlays, very-early-strength and high-early-strength latex-modified concrete overlays, and thin polymer overlays. The data presented in this study are provided in Table 4.2. The life cycle costs, which were simply computed by dividing the total cost by the expected service life, are the lowest for thin polymer overlays and are the highest for conventional latex-modified concrete overlays. It was reported that the lower costs associated with early-strength concrete overlays and thin polymer overlays were due to much shorter installation times and lower traffic control costs.

In 2008, survey responses of transportation agencies from 41 US states and 4 Canadian provinces were gathered by NCHRP and used to produce the “Guidelines for the Selection of Bridge Deck Overlays, Sealers, and Treatments.” The results of this survey are shown in Table 4.3. To determine the minimum life cycle cost, the lowest mean value for cost was divided by the highest mean value for service life. This value should serve as a lower bound. To determine the maximum life cycle cost, the highest mean value for cost was divided by the shortest mean value for service life. This value should serve as an upper bound. It should be noted that these values for life cycle costs do not include any estimates for maintenance costs. In both cases, thin polymer overlays present the lowest life cycle costs despite the fact that they are expected to have the shortest service life. As shown in Table 4.2, the initial cost of a thin polymer overlay is significantly lower than the alternatives. Although latex-modified concrete

TABLE 4.2
Virginia Life Cycle Cost Data (96)*

Rehabilitation Type	Expected Service Life, Years	Total Installed Cost, \$/ft ²	Life Cycle Costs, \$/ft ² /yr
LMC Overlays	30	14.4	0.48
VE-LMC Overlays	30	10.7	0.36
HE-LMC Overlays	30	10.2	0.34
Thin Polymer Overlays	15	3.6	0.24

*Virginia DOT FY 1995—79 overlay projects.

TABLE 4.3
Life Cycle Cost Data (26)

Rehabilitation Type	Service Life Range, Years (Mean)	Cost Range, \$/ft ² (Mean)	Life Cycle Costs, \$/ft ² /yr	
			Min. (Lowest Cost/Longest Life)	Max. (Highest Cost/Shortest Life)
Low Slump Concrete Overlays	10–45 (16–32)	4–45 (13–19)	0.41	1.19
LMC Overlays	10–50 (14–29)	1–150 (18–39)	0.62	2.79
Thin Polymer Overlays	1–35 (9–18)	1.5–23.5 (3.1–7.6)	0.17	0.84
Membranes w/Asphalt Overlays	3–40 (12–19)	3–60 (10–17)	0.53	1.42
Deck Replacement	15–50 (27–32)	15–100 (43–53)	1.34	1.96

overlays offer the longest service life, they have the greatest upfront cost. Costs associated with membranes with asphalt overlays place them in between the costs of thin polymer and latex-modified concrete overlays.

4.4 Deck Characteristics

The following sections compare bridge deck protective systems with regards to the following deck characteristics:

- Age of the deck
- Deck geometry
- Condition of the deck
- Condition of the approaches and adjacent pavement
- Lane closure limitations
- Type of reinforcing steel
- Amount of traffic

4.4.1 Age of the Deck

In an attempt to ensure longer bridge service lives, transportation agencies may consider preventative maintenance for new bridge decks. The vital question to be answered is whether or not installing a protective system on a new bridge deck will provide enough long term benefits to make the initial investment worthwhile. It has been widely recognized that all systems have a higher success rate when installed on new bridge decks. This success is purely a function of how well the system can bond to the underlying concrete. If the concrete deck is new and the surface concrete is sound, fewer issues related to bond strength of the overlay to the substrate are expected. Survey results from NCHRP Synthesis 425 (13), a synthesis of waterproofing membrane practice, provide evidence for this fact. All of the agencies that responded to the survey indicated that they expect membrane systems to provide a longer service life on new bridge decks than on existing bridge decks.

For new bridge decks, current practices attempt to provide protection through the use of epoxy coated steel and increased cover depth. If additional protection is desired, a protective system can be installed days or weeks after the deck has cured and has undergone expected initial cracking. At this point, a protective system, if it has sufficient flexibility and crack bridging

ability, can serve well to seal these cracks. Both thin polymer overlays and membrane systems are capable of bridging cracks in a concrete deck, making them good candidates for preventative maintenance measures.

Conversely, older decks may exhibit extensive deterioration of the concrete deck which requires patching. In these cases, it is expected that the overlay will be less successful. Areas where patches exist, both partial and full depth, are often sites that experience failures due to incompatibility between the substrate, the patching material, and/or the overlay material.

4.4.2 Deck Geometry

All of the protective systems being considered, concrete overlays, thin polymer overlays, and waterproofing membranes, can be installed irrespective of any irregularities in the geometry of the bridge deck. One exception is that preformed waterproofing membranes are more difficult to install on skewed bridges because they are manufactured in rectangular sheets.

Special consideration is required for sloped bridge decks. Liquid waterproofing materials have a propensity to flow downstream. As a result, when a liquid-applied membrane product or a liquid polymer is applied on a bridge with a 4% grade or greater, it may be difficult to provide an even distribution of the product. It is desirable for the product to have a low viscosity so that it can properly penetrate the concrete; however, the viscosity should be such as to minimize flow across the deck.

4.4.3 Condition of the Deck

Many failures have occurred for each type of system due to incompatibilities between the concrete substrate, repair patches, and the overlay. If extensive patching is required, it may be best to replace the entire deck. If the deck is not replaced and a protective system is specified instead, the deck patching material that is used should be properly cured and sufficiently compatible with the overlay system chosen. For more extensively damaged bridge decks, latex-modified concrete overlays may be the best option. Full depth patches can be filled with latex-modified concrete and partial depth patches can be filled concurrently with the placement of the LMC overlay. If thin polymer overlays or membranes are the

specified protective system, all patching must be accomplished with a different material, and the patching must be performed prior to placement of the system.

4.4.4 Condition of the Approaches and Adjacent Pavement

If the approaches and adjacent sections of pavement also require rehabilitation, lane closure limitations become less of an issue. This situation presents a better opportunity for the installation of membrane systems. Due to the thickness of an asphalt overlay, approaches must be reconstructed to account for the increased thickness to provide an uninterrupted riding surface. If the approaches require reconstruction, there is less of a reason to avoid the installation of a membrane system. Additionally, if the bridge is already slated to experience longer lane closures due to the work on the approaches, the need for a quickly installed system, such as a thin polymer overlay or an early-strength concrete overlay, is less necessary.

4.4.5 Lane Closure Limitations

Rehabilitation or maintenance of in-service bridges is often affected by lane closure limitations. To reduce the impact on the general public, transportation agencies desire repair methods that can be completed during off peak traffic periods such as overnight or during weekends. Thin polymer overlays and early-strength concrete overlays have an advantage because they can be installed quickly, whereas concrete overlays require longer cure times before traffic can be restored. Some indicate that waterproofing membranes can be installed overnight and traffic can be restored onto the asphalt overlay immediately after it is sufficiently compacted. However, if a strict time schedule is placed on a waterproofing membrane operation, it increases the chance of errors during installation which can jeopardize the integrity of the system.

4.4.6 Type of Reinforcing Steel

Whether or not epoxy coated reinforcing steel is used in a bridge deck does not have an effect on the choice of a protective system; however, it may affect whether or not a protective system is used at all. New bridge decks are often constructed with epoxy coated reinforcing steel and an increased concrete cover, which are commonly considered protective systems of their own. Therefore, additional protective systems have not typically been applied. However, if additional protective systems are applied, they provide redundancy to the protection scheme and increase the service-life of the bridge deck.

4.4.7 Amount of Traffic

The amount of traffic, both daily and truck, that a bridge experiences has a significant impact on the long

term durability of a protective system. Bridges with high amounts of traffic may be better served by a latex-modified concrete (LMC) overlay as this system is expected to provide the longest service life and the best durability. In using a LMC overlay, the time until the bridge deck requires maintenance or replacement is lengthened, therefore reducing the amount of lane closures and impact on the public over the lifetime of the bridge. It is expected that if a thin polymer overlay is used, it may require replacement in 15 years, and if a membrane with an asphalt overlay is used, it may require rehabilitation of the asphalt overlay after 10 years.

4.5 System Characteristics

The following sections compare bridge deck protective systems with regards to the following system characteristics:

- Ease of installation
- Thickness
- Weight
- Inspection
- Maintenance requirements

4.5.1 Ease of Installation

The three systems being considered require different procedures for installation. Installation of LMC overlays requires the use of mobile mixers and a finishing machine. The key to a proper LMC overlay installation lies in proficient curing practices which reduce the amount of initial cracking in the overlay. Typically, a LMC overlay requires 96 total hours after placement of the overlay before traffic may be allowed onto the overlay. Due to considerable use with this overlay technique, experienced installers are available.

Thin polymer overlays and membrane systems can be installed in a variety of ways depending on the product being used and the crew performing the installation. Installation of a waterproofing membrane is much more intensive and has a higher potential for errors than a thin polymer overlay. Both membrane systems and thin polymer overlays require equal amounts of effort in preparation of the deck surface which includes sounding, patching, and shotblasting. Installation of thin polymer overlays requires very little effort in regards to details at curbs, joints, drains, and other special features of the deck. Installation of membranes requires significant effort in ensuring that there is proper detailing at these critical locations. Thin polymer overlays often require three passes by the installer which includes one pass for the primer or sealer, and two others for each layer of the polymer overlay. Membrane systems can require six separate passes: one for the primer, two for both waterproofing layers, one for a protection layer, and two for both courses of asphalt pavement.

Based on this evaluation, thin polymer overlays are among the easiest systems to install. Membrane systems and LMC overlays involve similar amounts of difficulty during installation, but LMC overlays have an advantage because of installer experience.

4.5.2 Thickness

In the rehabilitation of a concrete deck, the thickness of the protective system that is chosen can have a large impact on the scope of the work. If a protective system is significantly thick, additional work is required to ensure that the riding surface is uninterrupted. Expansion joints and approaches must be reconstructed to account for the increase in height of the riding surface.

Typically, concrete overlays have a thickness of 1 ¼ to 2 ½ in., thin polymer overlays have a thickness of ¼ to 1 in., and membrane systems have a thickness of 2 to 4 in. (ACI 345R-11). In Indiana, a latex-modified overlay is placed at a thickness of 1 ¾ in. after ½ in. of the deck has been removed, producing a net thickness of 1 ¼ in. To accommodate this increase in deck thickness, a hot-mix asphalt wedge must be installed at the approach to transition smoothly to the adjacent pavement. As previously discussed (Section 2.8.3), if a membrane is installed on an existing bridge deck, additional work must be performed at the approaches, expansion joints, and, in some cases, drains because of the thickness of the asphalt overlay. In contrast, no additional work is necessary for a thin polymer overlay system as it is applied at a thickness that is less than one in. The overlay is simply tapered at approaches, expansion joints, and drains.

Related to the thickness of the protective system is the issue of clearance restrictions. If a specific bridge has strict clearance requirements, the additional height of an overlay may not be feasible. This situation can eliminate both concrete overlays and waterproofing membranes as options, leaving thin polymer overlays as the only choice for rehabilitation.

4.5.3 Weight

The weight of a protective system, which is a function of its thickness, can affect the selection of an appropriate protective system. Before an overlay is installed, the existing bridge should be evaluated to determine if it can accommodate the additional load of an overlay. Both concrete overlays and membranes with asphalt overlays pose a significant increase in dead load. One method used to account for the additional dead load is to remove ½ to 1 in. of concrete from the top surface, which, as a consequence, can negatively impact the load carrying capacity of the deck. Thin polymer overlays produce minimal additional dead load providing significant advantages.

4.5.4 Inspection

When installing a protective system on a concrete deck, future inspection of the concrete underneath the

overlay is prevented. If problems exist in the concrete deck, warning signs may not be observed until the problem has reached a critical stage. For this reason, many state transportation agencies refuse to install membrane systems in preference for an exposed deck that can be inspected. Unless damage is obvious from visual inspection of the asphalt pavement, a section of the asphalt overlay must be removed or non-destructive testing methods must be used to inspect the concrete deck. Inspection is not considered an issue with thin polymer or concrete overlays. If any damage occurs underneath these overlay types, it typically reflects through the overlay and will be visible during inspection.

4.5.5 Maintenance Requirements

For bridges with high traffic volumes, it is desirable to install a system that requires minimal maintenance over its lifetime. Concrete overlays typically require periodic crack repair or patching. To perform effectively, membrane systems require that the asphalt overlay be replaced every 5 to 15 years. After 15 years, thin polymer overlays may require rehabilitation or possibly complete replacement due to deterioration of the aggregate under traffic.

Of all of the systems, membrane systems are thought to be the most difficult to replace because the asphaltic concrete must be milled and the membrane which is bonded to the concrete must be removed. Additionally, a membrane system might only be replaceable using another waterproofing membrane because the rest of the bridge elements (curbs, approaches, and drains) were constructed to accommodate the depth of the asphalt overlay. Therefore, the same depth of material must be replaced.

4.6 Summary of Advantages

Based on this evaluation, the following advantages of each system are identified.

- Latex-modified concrete overlays:
 - Provide the longest service life
 - Proven performance
 - Experienced installers
 - Bonds well with concrete surface
 - Excellent option when patching is required
 - Improve load carrying capacity of the deck
- Thin polymer overlays:
 - Lightest and thinnest system
 - Allow quick restoration of traffic flow
 - Easily installed
 - Provide for easy drainage of the deck
 - Provide flexibility and crack bridging ability
- Waterproofing membrane systems:
 - Potential to provide the longest service life
 - Proven successful in many parts of the world

- Waterproofing layer can be maintained while pavement is rehabilitated
- Provide flexibility and crack bridging ability

4.7 Summary of Disadvantages

Based on this evaluation, the following disadvantages of each system are identified.

- Latex-modified concrete overlays:
 - Early-age cracking compromises the overlay
 - Long installation time due to curing procedures
 - Substantially increases dead load
 - Require the use of mobile mixers
 - Expensive option
- Thin polymer overlays:
 - Shortest service life
 - Least amount of durability
 - Loss of aggregate due to traffic causes reduced skid resistance
- Waterproofing membrane systems:
 - Many failures have been observed in the Midwest
 - Most demanding installation procedure
 - Installation can require long lane closures
 - Substantially increases dead load
 - Proper drainage of the asphalt overlay is difficult to achieve
 - Difficult to inspect
 - Difficult to replace
 - Expensive option

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Membrane systems are used widely in New England states, Canadian provinces, and in many other countries. There is significant evidence demonstrating that membrane systems have the potential to be successful, given that the installation is performed correctly and that the asphalt overlay is maintained properly. The systems used by different transportation agencies vary greatly with regards to materials, installation practices, and rehabilitation measures, which contributes to the wide range of costs and expected service lives attributed to membrane systems. Although membrane systems are widely used in many parts of the world, they are not prevalent in the Midwest for several reasons. It is clear that Indiana is not alone in its apprehension to install waterproofing membranes. The reasons for this apprehension to use membrane systems are as follows. Emphasis related to issues in Indiana is provided.

- Membrane systems have a history of poor performance in Indiana and the Midwest.
- For existing bridges, additional work, which can be extensive, must be performed to accommodate the larger thickness of the asphalt overlay.

- The installation process is demanding in comparison to other systems.
- Membrane systems pose difficulties for inspection especially because Indiana bridge construction involves the use of stay-in-place forms which limits inspection of the bottom of the bridge deck.
- Indiana bridges are not designed to accommodate the additional weight of overlays over 3 in. thick.
- INDOT has limited experience with installing membranes.
- Alternative protective systems have proven to be satisfactory.

As a result of the negative aspects of membrane systems, INDOT has favored latex-modified concrete overlays and thin polymer overlays which have provided satisfactory performance. However, as a result of more advanced materials and more knowledge about how to perform a successful installation of membrane systems, it serves INDOT well to reevaluate the decision to avoid membrane systems and to determine if they can offer any advantages over the two currently used options. From the information presented in this report, the benefits that membrane systems afford are as follows.

- Potentially longer service life
- More impermeable than cracked LMC overlay or thin polymer overlay
- Waterproofing can be maintained while the pavement is rehabilitated
- Decreased costs relative to LMC overlay

To provide INDOT with a comprehensive list of viable options, it is also recognized that the anti-icing thin polymer overlay system, SafeLane®, and the polymer modified asphaltic concrete system, Rosphalt®, are both potential options. Although the SafeLane® system has been criticized for poor long-term durability of the aggregate by some transportation agencies, others have provided satisfactory reports of its performance. All of the benefits that are attributed to thin polymer overlays including its reduced thickness and weight, and its quick and easy installation processes also apply to the SafeLane® system. All information reviewed in this study indicates that the Rosphalt® system also provides satisfactory performance. The Rosphalt® system provides the unique benefit that it only requires traditional asphalt paving equipment to install, also making it a system that can be installed with ease and quickness.

5.2 Recommendations

Based on the knowledge gained from this study, the following recommendations are offered to the state of Indiana as improvements to the state-of-practice in bridge deck protection.

5.2.1 Current Protective Systems

Both of the currently used systems, latex-modified concrete (LMC) overlays and thin polymer overlays (TPOs) have provided INDOT with satisfactory service.

In their application, these two systems are quite different. LMC overlays should continue to be installed on bridge decks where more extensive damage is observed. Because they provide the longest service life, LMC overlays are also recommended for INDOT's more critical bridges as both a preventative maintenance and as a rehabilitation measure. Thin polymer overlays are ideal for situations where quick installations are required and where a thin protective system is needed.

It is often considered that the combination of epoxy coated reinforcing steel and an increased concrete cover are sufficient measures for preventing corrosion-related damage of a bridge deck. However, after initial cracking occurs in the deck, durability can be compromised. It is then advantageous to seal cracks which can be achieved using crack sealing products. In addition, the deck can be sealed to minimize moisture penetration. Therefore, it is also recommended that TPO systems are considered for the purpose of preventative maintenance on new bridge decks.

5.2.2 Moratorium

The current moratorium on the use of asphalt overlays in Indiana limits their use to projects passing a load analysis performed by INDOT's Central Office Bridge Inspection Engineer. Additionally, if an asphalt overlay is applied to a bridge deck to improve the riding surface, it is only to be considered as a temporary repair and a plan for permanent bridge work must be in place (2).

It is strongly recommended that these limitations on the use of asphalt overlays continue to be recognized. If an asphalt overlay, without a waterproofing membrane, is applied to a concrete deck, there is a high risk that moisture will become trapped at the interface of the overlay and the concrete deck, accelerating the deterioration of the concrete surface. Recognition of this problem was the initial impetus for the use of waterproofing membranes. In a 2004 survey of transportation agencies regarding the performance of several different overlay systems, asphalt overlays without a membrane were rated the worst with an average score of 3.6, where a score of 1 indicates excellent performance and 5 indicates poor performance (11).

Despite the recommendation that an asphalt overlay *without* a waterproofing membrane should be avoided, INDOT should recognize that an asphalt overlay *with* a waterproofing membrane, if installed and maintained properly, prevents the problem of trapped water and should be considered as a potentially beneficial bridge deck protective system. Therefore, it is recommended that the moratorium on this system be removed.

5.2.3 Membrane Systems

Although membrane systems have disadvantages in some regards compared to concrete overlays or thin polymer overlays, they also provide benefits that make

them a valuable option for bridge deck protection. To take advantage of these benefits and minimize disadvantages, it is recommended that membrane systems be used in specific situations. The two situations where membrane systems offer the greatest potential are as follows.

- Newly constructed bridge decks
- Bridge decks that require substantial reconstruction of approaches and joints

These two situations are recommended due to the extensive additional work that is required to accommodate the thickness of the asphalt overlay. As previously discussed, existing bridges in Indiana were not designed to accommodate the addition of 2 to 4 in. of asphalt pavement. If this extra thickness is added, the approaches, joints, curbs, and drains must be modified to ensure a smooth transition of riding surface over these elements. However, in the design and construction of a new bridge deck, the added thickness can be easily accommodated. In the same way, if the approaches and joints require replacement, they can be reconstructed to accommodate a membrane system. In these two cases, membrane systems do not require any additional work beyond that required for a latex-modified concrete overlay or a thin polymer overlay.

It is important that all of the issues involved in installing a membrane system be considered. Attention to these issues will provide the best chance that the membrane system will provide long-term durability and all of the benefits of this system will be realized. The following list describes issues that are important for success:

- Proper installation procedures are essential because the majority of membrane failures are a result of hasty installations. As such, INDOT should have in place stringent installation specifications focused on checkpoints that the installer must meet before moving forward during the installation process. One such checkpoint should involve a thorough inspection of the prepared deck surface to ensure that it is both clean and dry enough enabling sufficient bond of the membrane.
- To ensure that the installation specifications are met, INDOT should encourage the use of experienced and qualified membrane installers. Additionally, INDOT should ensure that there is proper oversight of the installation. It is recommended that a representative of the membrane manufacturer and a representative from INDOT be present for a portion or all of the installation to ensure that the work being performed is satisfactory.
- In addition to installation problems, membranes have experienced problems due to a damaged asphalt overlay. INDOT should develop a comprehensive plan for rehabilitation of the asphalt overlay over the lifetime of the underlying membrane.
- It is recommended that the membrane system be guaranteed by the manufacturer. Although it can be difficult to assign liability if a membrane system underperforms, a guaranteed product has a higher chance of being installed properly because the manufacturer has a greater stake in its success.

For situations where membrane systems should be considered, there are also certain situations where membrane systems should be avoided. It is recommended that membrane systems be avoided when extensive patching is required. A large part of the success of a membrane system is attributed to the strength of bond to the concrete deck. Patching provides a significant threat to this bond. In addition, membrane systems should also be avoided on bridges where added dead load and thickness become problematic.

5.2.4 INDOT Standards and Specifications

INDOT standards and specifications require modification if there is desire to include membrane systems as a protective strategy. First, it is recommended that a standard specification for the installation procedure of a membrane system be developed. A well-defined and thorough specification is very important for the assurance of a quality installation. An example of an installation specification for a membrane system is provided in Appendix D.

Additionally, the following updates to the INDOT Design Manual are recommended.

- Section 72-3.01(02), “Typical Department Practices,” should be updated to reflect current practices used for bridge deck rehabilitation. Thin polymer overlays should be added to the list of bridge deck overlays as they are used fairly regularly throughout the state.
- The description for an “Asphalt Overlay with Sheet Membrane,” which states that “INDOT no longer uses this rehabilitation technique,” should be modified to reflect current practice.
- A section outlining bridge deck drainage provisions should be included into INDOT Design Manual Chapter 404 which covers the topic of bridge decks.
- Figure 403-2A of the Design Manual, which provides the typical dead load of a future wearing surface, should provide guidance when accommodating the additional dead load of an asphalt overlay greater than 3 in.

5.2.5 Approved Products and Installers

An updated qualifying procedure for membrane products should be developed and potential products should be thoroughly tested before being installed. The result of this testing procedure should be a list of approved membrane products. An example of a product qualifying procedure and an approved products list are provided in Appendix C.

It is also recommended that a procedure be developed to approve installers of membrane products.

5.3 Future Research

5.3.1 INDOT Bridges to Monitor

To further INDOT’s knowledge about bridge deck protective systems and the factors that play a role in

their performance, several sets of bridge decks have been identified as relevant cases to continue studying. It is recommended that the bridges presented here be monitored and compared in conjunction with their biennial inspections.

5.3.1.1 Toll road bridges. The eight bridges (Table 2.2) along the Indiana Toll Road on which membrane systems were installed provide an invaluable wealth of knowledge about the applicability of membrane systems in Indiana. Although the benefits or disadvantages might not be evident for several years, it is worthwhile to monitor the membrane systems installed on these bridges. These installations will provide significant information regarding the life of the asphalt overlay, how the pavement can be rehabilitated, and how membrane systems fare when subjected to high levels of traffic. Additionally, the performance of these systems will serve as an excellent reference for the benefits of a membrane system installed on a newly constructed bridge deck.

5.3.1.2 TPO site visit bridges. Documentation of the installation of thin polymer overlay systems on the bridges carrying SR 26 and US 231 over the Wabash River have been provided in this study. Monitoring these bridges will not only provide information on the performance of a thin polymer overlay system but also on the effect that installer experience has on the long-term performance of the system.

5.3.1.3 Crawfordsville bridges. To answer the question of whether or not installing a protective system on a new bridge deck will provide sufficient long-term benefits to make the initial investment worthwhile, it is recommended that INDOT monitor and continuously compare the condition of the bridge decks on the following two bridges.

- **Bridge #1** – SR 341 over the eastbound and westbound lanes of I-74 (Bridge Number 341-23-04934 B)
- **Bridge #2** – SR 75 over Kilmore Creek (Bridge Number 075-12-05446 B)

Bridge #1 received a new deck in 2009 which was initially protected with a thin polymer overlay using a urethane epoxy. In November 2011, two years after construction, an inspection of the bridge noted that the overlay was in excellent condition and both the deck and the wearing surface were given a condition rating of 8, denoting “very good condition.”

Bridge #2 also received a new bridge deck in 2009 which was left unprotected. In April 2012, this bridge received the same condition rating of 8 for both the deck and the wearing surface. Both bridges accommodate a very similar amount of traffic on two lanes, have metal stay-in-place deck forms, and include epoxy-coated reinforcing steel. The primary difference is that Bridge #2 does not have traffic below to cause misting of water and chlorides.

The relative performance of these bridges will be very beneficial to monitor. It will be interesting to determine if Bridge #1, which is in a slightly more hostile environment, outperforms Bridge #2.

5.3.2 Pilot Study

It is recommended that INDOT conduct a pilot study by installing a waterproofing membrane system on a newly constructed bridge deck. A pilot study will serve as an avenue to gain valuable knowledge about the membrane installation process and to evaluate the suitability of the specifications that are developed. Based on the experience and knowledge gained from the pilot study, the specifications can be modified as necessary.

5.3.3 Testing of In-Service Membranes

The performance of a membrane relies heavily on the integrity of the overlying asphalt, increasing the importance of rehabilitating the asphalt pavement. However, when rehabilitating the asphalt overlay it is difficult to know whether only the overlay needs to be replaced or if the waterproofing layer also needs to be replaced. A reliable method for determining the integrity of a waterproofing membrane underneath an asphalt overlay needs to be developed.

5.3.4 New Concept

Both thin polymer overlays and membrane systems each have advantages and disadvantages. The newly proposed system, described herein, aims to capitalize on the advantages of each system and to diminish the effects of the disadvantages. The proposed system includes two parts: a thin polymer overlay and an asphalt overlay. A thin polymer overlay would be installed first and would act as the impermeable layer. Upon completion of the TPO installation, a course of asphaltic concrete would be placed over the top of the TPO.

Many of the problems observed with membrane systems have been caused by insufficient bond between the membrane and the concrete deck. For this reason, the proposed system replaces the membrane with a thin polymer overlay. Thin polymer overlays have exhibited satisfactory performance in Indiana with regards to providing sufficient bond to the concrete deck. Additionally, it is believed that the aggregate present in the thin polymer overlay will not only serve as a protection layer during the paving process, but that it will also provide additional mechanical bond between the impermeable layer and the asphalt above.

Failure of a thin polymer overlay is typically signified by excessive loss of aggregate and skid resistance, or by eventual loss of bond to the deck. The asphalt overlay will serve to maintain a proper riding surface with adequate traction and to increase the durability of the system as a whole.

Although a similar system has been used extensively in Australia (as described in Section 2.5.3.1), it is recommended that INDOT perform various tests to ensure that this is a viable system in Indiana. A test should be performed to ensure that the epoxies used in a thin polymer overlay are chemically compatible with the materials used in an asphalt overlay. A test should also be performed to verify that the heat of the asphalt overlay does not adversely affect the cured polymer in the previously placed TPO. There is a possibility that the elevated temperatures may cause the polymer to blister or change in viscosity. Lastly, it is recommended that INDOT perform a test installation of the proposed system on a newly constructed bridge deck.

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APPENDIX A. INDOT ASPHALT OVERLAY MORATORIUM

A. D. 114

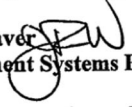
INDIANA DEPARTMENT OF TRANSPORTATION
INDIANAPOLIS, INDIANA 46204-2249
INTER-DEPARTMENT COMMUNICATION

March 17, 1999

MEMORANDUM

TO: All District
Program Development Engineers

ATTN: All District
Bridge Inspection Engineers

FROM: John Weaver 
Management Systems Engineer

SUBJECT: Standard operating policy for requesting bridge deck overlay analysis.

When asphalt overlays are applied to concrete bridge decks, a temporary improvement in the wearing surface is gained for the motoring public. The down side of this is the accelerated deterioration of the structural condition of the deck, because moisture becomes trapped at the interface of the overlay and the concrete deck. The chloride ions from deicing chemicals collect in the moisture and have much more time to attack the reinforcing steel. The result is a more rapid deterioration of the superstructure. The additional dead load of the overlay and the accelerated superstructure deterioration reduces the capacity of the structure to carry live loads. For this reason, a request for an overlay analysis must be processed before any work is undertaken.

To maintain a uniform tracking procedure, the following steps should be followed for each overlay analysis request.

1. Request in writing that the load analysis be performed, to insure that the structure has the capacity to function without restricting its service condition. The written request should be addressed to the Central Office Bridge Inspection Engineer.
2. The Central Office will consider the request for Structural Analysis only if the written request includes: the S.T.I.P (State Transportation Improvement Plan) ready for letting date (R.F.L. Date), the description code (Des. No.) and the type of work scheduled to be done. This permanent work must be for rehabilitation or replacement of the superstructure.

I

Figure A.1 INDOT asphalt overlay moratorium (Page 1).

S.O.P. MEMORANDUM 03/17/99

3. The District shall consider the application of an asphalt overlay only as a temporary repair. This temporary repair should not be allowed to impact the schedule for the permanent bridge work. That work should not be moved back and or postponed from its scheduled letting date.

4. The Bridge Inspector should maintain a list of all structures which require and receive an asphalt overlay. When these structures are routinely inspected as scheduled, the inspector must pay special attention to the structural condition of the deck.

5. The District Bridge Engineer is required to notify the Central Office Bridge Inspection Engineer of any evidence of distress of the superstructure as well as any change in the condition and the thickness of the overlay of the bridges on their overlay list.

If you have any questions, please contact Wesley D. Billups at 317 232 5474.

WDB: wdb

II

Figure A.2 INDOT asphalt overlay moratorium (Page 2).

APPENDIX B. MDOT BRIDGE DECK PRESERVATION MATRIX

BRIDGE DECK PRESERVATION MATRIX – Decks with Uncoated “Black” Rebar

DECK CONDITION STATE				REPAIR OPTIONS	POTENTIAL RESULT TO DECK BSIR		ANTICIPATED FIX LIFE
Top Surface		Bottom Surface			Top Surface BSIR #58a	Bottom Surface BSIR #58b	
BSIR #58a	Deficiencies % (a)	BSIR #58b	Deficiencies % (b)				
≥ 5	N/A	N/A	N/A	Hold (c) Seal Cracks/Healer Sealer (d)	No Change	No Change	1 to 4 years
	≤ 5%	> 5	≤ 2%	Epoxy Overlay	8, 9	No Change	10 to 15 years
	≤ 10%	≥ 4	≤ 25%	Deck Patch (e)	Up by 1 pt.	No Change	3 to 10 years
4 or 5	10% to 25%	5 or 6	≤ 10%	Deep Concrete Overlay (h)	8, 9	No Change	25 to 30 years
		4	10% to 25%	Shallow Concrete Overlay (h, i)	8, 9	No Change	20 to 25 years
				HMA Overlay with water-proofing membrane (f, h, i)	8, 9	No Change	8 to 10 years
		2 or 3	> 25%	HMA Cap (g, h, i)	8, 9	No Change	2 to 4 years
≤ 3	>25%	> 5	< 2%	Deep Concrete Overlay (h)	8, 9	No Change	20 to 25 years
		4 or 5	2% to 25%	Shallow Concrete Overlay (h, i)	8, 9	No Change	10 years
				HMA Overlay with water-proofing membrane (f, h, i)	8, 9	No Change	5 to 7 years
		2 or 3	>25%	HMA Cap (g, h, i)	8, 9	No Change	1 to 3 years
				Replacement with Epoxy Coated Rebar (ECR) Deck	9	9	60+ years

- (a) Percent of deck surface area that is spalled, delaminated, or patched with temporary patch material.
 (b) Percent of deck underside area that is spalled, delaminated or map cracked.
 (c) The “Hold” option implies that there is on-going maintenance of filling potholes with cold patch and scaling of incipient spalls.
 (d) Seal cracks when cracks are easily visible and minimal map cracking. Apply healer sealer when crack density is too great to seal individually by hand. Sustains the current condition longer.
 (e) Crack sealing can also be used to seal the perimeter of deck patches.
 (f) Hot Mix Asphalt overlay with waterproofing membrane. Deck patching required prior to placement of waterproofing membrane.
 (g) Hot Mix Asphalt cap without waterproofing membrane for ride quality improvement. Deck should be scheduled for replacement in the 5 year plan.
 (h) If bridge crosses over traveled lanes and the deck contains slag aggregate, do deck replacement.
 (i) When deck bottom surface is rated poor (or worse) and may have loose or delaminated concrete over traveled lanes, an in-depth inspection should be scheduled. Any loose or delaminated concrete should be scaled off and false decking should be placed over traveled lanes where there is potential for additional concrete to become loose.

Bridge Deck Preservation Matrix

June 8, 2011 Rev.

Figure B.1 MDOT bridge deck preservation matrix (Page 1).

**BRIDGE DECK PRESERVATION MATRIX
DECKS WITH UNCOATED "BLACK" REBAR
USER GUIDELINES**

This matrix is a tool for Bridge Engineers to use in the selection of deck repair options when the concrete bridge deck has uncoated "black" rebar. The condition of the deck is usually the driving force, or the key indicator, leading to a structure being considered for preventive maintenance, rehabilitation or replacement. However, there are times when other issues affecting the bridge may elicit the need for a project and this matrix does not address those situations. Some of these situations are super-structure deterioration, sub-structure deterioration, and functional issues such as under-clearance and/or bridge width. Sometimes it is desirable for an entire corridor to be brought up to a specific condition level as part of an overall strategy. So the user is cautioned to interpret the information from the matrix in the context of each specific case and use engineering judgment.

The matrix can be used from left to right or from right to left. If you have scoping inspection data with a deck delamination survey, select the row in the left column that matches the percent of surface defects. Then select the row in the second column that matches the percent of underside defects. To the right of this you will find a repair option and the associated changes to the NBI and the expected service life of that repair, or "Fix Life".

If you are looking for a fix that will last for a given period of time, select a row from the right column that matches the length of service desired and scan to the left to find the repair option. Be advised that the condition of the bridge at the time of the rehabilitation affects the expected service life of the selected repair option. So if the structure is in worse condition than shown on the left side of the matrix, the repair will not last as long. Conversely, if the deck is in better condition than shown on the left, a longer service life could be expected.

This matrix has been constructed based on element deterioration data and the best knowledge of individuals from Construction & Technology, Maintenance, region bridge engineers, bridge design engineers, and FHWA with many years of experience working with bridges. When used in conjunction with the Bridge Safety Inspection Report (BSIR), Pontis element data, and detailed bridge project scoping report, the matrix can be an accurate guide in the majority of situations and will lead to a repair option that is economical and consistent with the Department's goals.

Figure B.2 MDOT bridge deck preservation matrix (Page 2).

APPENDIX C. APPROVED OR QUALIFIED PRODUCTS

Maine Department of Transportation
Qualified Products List - Product Qualification Criteria
Section 508 – Waterproofing Membrane

ITEM 508.13 - MEMBRANE WATERPROOFING

ITEM 508.14 - HIGH PERFORMANCE WATERPROOFING MEMBRANE

-- Specification

When high performance membrane is specified, the materials shall meet the requirements of the Manufacturer and shall be one of the prequalified products listed on the Department's Qualified Products List (QPL) of Waterproofing Membrane. All other membrane shall consist of an adhesive primer, preformed sheet waterproofing membrane, and a mastic with all components being as recommended by the Manufacturer and prequalified by the Department as described above.

--Required Submissions and Demonstrations

Phase 1

1. Manufacturer shall submit a completed Preliminary Information for Product Evaluation (QPL Product Submittal) Form, applicable MSDS(s), and other pertinent literature, including its Quality Control Plan for production of membrane, a detailed summary of its Applicator Training & Certification Program, and its Field Process Quality Control Plan.

2. Manufacturer shall submit a detailed summary of successful installations that have occurred in the United States, including owner contact information, design and construction details (substrate type & condition, membrane system components, bituminous overlay thickness and mix details, etc.), year constructed, tests performed, performance monitoring and/or testing, and any other additional information requested by the Department.

3. In the absence of successful U.S. installations, information from installations occurring in Canada may be submitted. The Department reserves the right to delay consideration of membrane systems that have not established a successful track record in the U.S., until such time as successful installations have been documented to the satisfaction of the Department.

4. Manufacturer shall make a presentation of their system to appropriate Department personnel. This presentation shall be scheduled through MaineDOT's Product Evaluation Program. At the discretion of the Department, Phase 2 may be omitted, proceeding directly to Phase 3.

Phase 2

5. Manufacturer shall set up and perform a demonstration on a test slab in the field, in the presence of Department personnel set up through MaineDOT's Product Evaluation Program. It is the Manufacturer's responsibility to locate or place a suitable slab within reasonable travel distance from Augusta, Maine. At the Department's option, out-of-state locations within a reasonable distance from the Maine State line may be acceptable provided that sufficient notice is given to allow Department personnel sufficient time to obtain proper out-of-state travel authorization.

During the demonstration, the intended applicator must demonstrate proficiency in applying the membrane, including overlap technique. A minimum of 16 square feet must be applied per applicator. The purpose of this requirement is for the Manufacturer to demonstrate the effectiveness of its Applicator Training & Certification Program. The Manufacturer shall perform testing consistent with the applicable specification requirements.

6. The Department will evaluate the membrane and application, and may request additional testing such as bond, crack-bridging, and freeze-thaw stability.

Figure C.1 Maine DOT product qualification criteria (Page 1).

Maine Department of Transportation
Qualified Products List - Product Qualification Criteria
Section 508 – Waterproofing Membrane

Phase 3

7. A demonstration bridge deck application will be required. The Department will allow the membrane to be applied on a small (approximately 2000 square feet) bridge project as an alternative to a system already on the QPL. It is recommended that this application occur on a bridge project that is presently under development, but not yet advertised for bids.

The Department shall be responsible for preparation of the bridge deck surface to the manufacturer's specification. The Department shall also be responsible for any required work zone traffic control.

The manufacturer shall provide all necessary products for the test application including primers and actual membrane material as well as all labor to perform the installation. After the installation of the membrane, the bridge deck shall be ready for the hot-mix asphalt overlay.

A manufacturer's representative shall be on site at all times during membrane installation and the first paving course of the asphalt overlay.

It is the responsibility of the Manufacturer to work closely with the Contractor to coordinate this application, and to inform MaineDOT's Transportation Research Division in order that proper monitoring and evaluation of the test deck may take place.

8. During this and any subsequent applications, only Certified Applicators will be allowed to apply the membrane. The Field Process Quality Control Plan is expected to be followed at all times during construction. It is the responsibility of the Manufacturer and its field representative to ensure that applicators have received proper training and certification prior to placing membrane on a MaineDOT bridge (i.e. on-the-job training on this test deck is not acceptable). Written proof of the Applicator's certification to install the Manufacturer's membrane system shall be provided to the Resident for inclusion in the project records.

--Qualification Criteria

9. The Department will evaluate and monitor the performance of the membrane installation. The minimum evaluation period will span two winter seasons with normal traffic loads and conditions. During this time, the membrane will be classified as being "Under Evaluation." Any further use during this period will be at the discretion of the Department. This evaluation period may be extended beyond two winter seasons if required by the Bridge Program.

10. Providing no negative issues arise during this evaluation period, the membrane will be granted pre-qualified status and added to the QPL for consideration alongside other pre-qualified membranes for use on Department projects.

Following the Department's evaluation of the membrane, the Manufacturer will be notified in writing of the qualification status of the membrane system.

11. The Department will continue to evaluate its qualification criteria as well as products that have been previously qualified against them, and reserves the right to revise the criteria and/or withdraw product prequalification status at any time, for any reason, and without prior notice.

Doug Gayne
Product Evaluation Coordinator

Last updated: March 29, 2012

Figure C.2 Maine DOT product qualification criteria (Page 2).

Maine Department of Transportation's
Qualified Products List of
Bridge Deck Waterproofing Membrane Systems

APPROVED STANDARD SYSTEMS	
<p>Protecto Wrap - M-140A(R) & M-400A(R) Protecto Wrap Company 1955 South Cherokee Street Denver, CO 80223 877-271-9661</p> <p>Description of System: M-140A(R) & M-400A(R) bridge deck waterproofing membranes are manufactured from a formulation of premium bituminous resins modified with synthetic resins. This rubberized asphalt is then reinforced with an inert reinforcement to withstand puncture and severe stress. M-140A(R) is 60 mils thick. M-400A(R) is 70 mils thick with a built in white reflective topping. M400A (R) is specially designed for hot-weather bridge deck applications and where heavy equipment will be driven on the deck immediately after membrane installation. The membrane systems shall include the use of Protecto Wrap No. 80 VOC Primer and Protecto Wrap No. JS160H Mastic. Paving: The hot asphalt overlay should be between a minimum of 275°F and a maximum of 300°F.</p>	
<p>Royston Bridge Membrane No. 10AN Easy Pave Royston Laboratories Division Chase Corp. 128 First St. Pittsburgh, PA 15238 800-245-3209</p> <p>Description of System: ROYSTON BRIDGE MEMBRANE 10AN EASY PAVE is a prefabricated reinforced laminate consisting of an impregnated fiberglass, non-woven, high strength inner mat sandwiched between layers of a polymer modified bitumen. An "open" spun-bonded polyester top mat provides ease of installation, mechanical protection against foot and vehicular traffic and instant adhesion to the compacted pavement interface. A unique 3-inch leading edge guarantees a positive compound-to-compound seal at the overlap. Transverse seals are easily made using a simple propane torch. Prime according to manufacturer's specifications. Paving: The hot asphalt overlay should be between a minimum of 290°F and a maximum of 340°F at the time of application.</p>	
<p>Sealtight MEL-DEK Deck Waterproofing System W.R. Meadows of PA P.O. Box 7550 York, PA 17404 Local Distributor: A.H. Harris & Sons, Inc., 207-622-0821</p> <p>Description of System: Sealtight Mel-Dek is a roll-type waterproofing membrane composed of a nominally 53 mil thick layer of polymeric waterproofing membrane on a shrink-resistant, heavy-duty, 12 mil thick polypropylene woven carrier fabric. The two components are laminated together. Paving: The hot asphalt overlay should be between a minimum of 290°F and a maximum of 340°F at the time of compaction. A minimum 2 inch compacted overlay thickness is required.</p>	
<p>C.I.M. 1000 Waterproofing System C.I.M. Industries, Inc. 23 Elm St. Peterborough, NH 03458 Local Distributor: SEALPRO, Inc., 150 Dow St., Manchester, NH 03101, 800-732-5776</p> <p>Description of System: System form continuous elastomeric barriers to water and most chemical solutions. Two liquid components are mixed on the job site just prior to cold application by squeegee, roller or spray and liquid cures quickly to form a seamless asphalt-extended polyurethane membrane. CIM 1000 is unaffected by the wood preservative known as pentaclorophenol. CIM 1000 is the only product listed above which is approved for use on timber deck applications.</p>	

Figure C.3 Maine DOT qualified product list (Page 1).

Maine Department of Transportation's
Qualified Products List of
Bridge Deck Waterproofing Membrane Systems

APPROVED HIGH-PERFORMANCE SYSTEMS	
NOTE: When selecting a "High Performance Membrane" system from this list, it is the responsibility of the Contractor to ensure that the intended pavement overlay depth will provide adequate protection to the waterproofing membrane system.	
S P R A Y A P P L I E D	<p>Eliminator Stirling Lloyd Products, Inc. 152 Rockwell Road Newington, CT 06111 Tel. (860) 666-5008 Fax (860) 666-5106</p> <p>Description: Rapid-curing, cold liquid spray applied MMA resin material, flexible, chemical-resistant, and seamless.</p> <p>Temp: can be applied at ambient temperatures between 23 and 86 degrees Fahrenheit. Other factors such as relative humidity levels may also need to be taken into account. Various grades adapted to extreme application environments are available.</p>
T O R C H A P P L I E D	<p>Sopralene Flam Antirock Soprema Roofing and Waterproofing Inc. Local Distributor: Special Projects Group, Inc., 25 Green Street, Norway, ME 04268, (207) 743-8885</p> <p>Description- Waterproofing membrane made up of a non-woven polyester reinforcement and elastomeric bitumen (SBS modified bitumen). The top face is covered with colored granular, the under face is covered with a thermofusible plastic film. Sopralene Flam Antirock is torch applied. Temp: The hot asphalt overlay should be between 290 and 320 degrees F at the time of application.</p> <p>Armour Bridge Membrane Waterproofing IKO 850 West Front Street Sumas, WA 98295 514.633.9794 Local Distributor: Venture Construction, 6 Sharon Drive, Bow, NH 03304 (514) 633-9794</p> <p>Description: Non-woven polyester reinforcing mat that is coated and impregnated with Modiflex SBS modified bitumen to a thickness of approximately 4.5 mm (177mils).</p> <p>Temp: The hot asphalt overlay should be between 290 and 320 degrees F at the time of application.</p>

Acceptable Moisture Meters for Evaluating Bridge Deck Moisture Content	
Manufacturer	Model
Sovereign Chemicals Limited	Soverign Moisture Master
Tramex Ltd.	Tramex Concrete Encounter
Please note: other brands/models may be acceptable, please check with MaineDOT's Bridge Program.	

Waterproofing membrane manufacturers, suppliers, and installers must review the Department's [Product Acceptance Criteria for Membrane Waterproofing](#) prior to making a product submittal. Please note that any materials on this list with "Conditional Approval" may be used only with written permission of the Department's Bridge Program.

Sales Representatives seeking approval of a new product must submit their product's Material Technical Data Sheet, Instructions for Installation, Material Safety Data Sheet, and a completed [MaineDOT Preliminary Information for Product Evaluation](#) form.

Figure C.4 Maine DOT qualified product list (Page 2).

Maine Department of Transportation's
Qualified Products List of
Bridge Deck Waterproofing Membrane Systems

Please refer to State of Maine, Department of Transportation's and Standard Specifications Section 508 for surface preparation and installation requirements. Refer to International Concrete Repair Institute Technical Guideline No. 03732 for guidance on profile requirements of the deck prior to application of the membrane (ranging between CSP1 and CSP5).

PLEASE NOTE: Products often times may have multiple uses. Products appearing on this particular list are expressly pre-qualified for this category of usage only. Do not use these products for any other application unless this product is noted on other lists.

If you are experiencing difficulties reading or printing this page, or any page on the Qualified Products List website, please contact the Product Evaluation Coordinator at 207-624-3268.

Last updated: September 27, 2010

Figure C.5 Maine DOT qualified product list (Page 3).

TABLE C.1
List of Approved Products in the US

Manufacturer	Product Name	Product Type	Approving States
American Hydrotech Inc.	Monolithic Membrane 6125	L	RI
American Permaquik Corp	Permaquik 6100	L	RI
Bakor, Inc.	Bak or 790-11	L	RI
Bridge Preservation, LLC	Bridge Deck Membrane (BDM)	L	CO, ID, NE, OR, VT
BSI Corporation	Scudoplast CAR	P	RI
C.I.M. Industries, Inc.	C.I.M 1000	L	ME (standard)
Carlisle Coatings and Waterproofing	Carlisle CCW 711	P	MI, SC, TN
Crafcro, Inc.	Deery 102	L	CO, RI
	Geotac	P	ID, MI, PA, TN, WA
	Geotac Polyester HS	P	MI, TN
	ISAC	P	TN
	PavePrep	P	ID
	PavePrep SA	P	ID
	PavePrep TSA	P	ID
Deery Oil Co	Flex-A-Fill	L	RI
IKO Industries	Armour Bridge	P	ME (high perf.), NH, VT
Maxwell Products	Elastoflex 61	L	CO
Polyguard Products, Inc.	180 Membrane	P	RI
	655 Membrane	P	ID, RI, SC, WA
	NW-75 Membrane	P	ID, PA, SC, TN, WA
Propex, Inc.	Petromat	P	WA
	Petrotac	P	OR, PA, RI, TN, WA
Protecto Wrap Company	Protecto Wrap M140A	P	ID, ME
	Protecto Wrap M400A	P	ID, ME, MI, RI, TN
Royston	Royston 10 A-65 Bridge Deck	P	PA
	Royston 10 A-65 Easy Pave	P	PA
	Royston 10 AN Easy Pave HT	P	AK, ME (standard), NH, PA, TN
Soprema Roofing and Waterproofing Inc.	Sopralene Flam Antirock	P	ME (high perf.), NH, OR, PA, VT
Stirling Lloyd Products, Inc.	Eliminator	L	ME (high perf.), RI, VT
T.C. MiraDRi	MiraDRi 700	P	TN
Ultraseal Waterproofing and Sealant Technologies Inc.	Ultraseal 3750 MTO+B54	L	RI
W.R. Grace & Co.	Bithulene 5000	P	RI, TN
W.R. Meadows	Sealtight MEL-DEK	P	ME (standard), MI, PA, RI, TN
	Sealtight MEL-ROL	P	PA

L = Liquid Applied Membrane, P = Preformed Membrane.

States with approved products list: AK, CO, ID, ME, MI, NE, NH, OR, PA, RI, SC, TN, VT, WA.

APPENDIX D. INSTALLATION SPECIFICATIONS

SECTION 538

SECTION 538 -- BARRIER MEMBRANE

Description

1.1 This work shall consist of furnishing and applying an approved waterproof membrane system as shown on the plans or as ordered.

1.2 When "Barrier Membrane, Heat Welded" or "Barrier Membrane, Heat Welded – Machine Method" is specified, the Contractor shall arrange for a manufacturer's representative (Representative) to be present at all times work is performed, including application of the primer and tack coat. The Representative shall also be present for placement of the hot bituminous pavement overlay. The Representative shall be readily identified by a photo ID badge, issued by the manufacturer, that includes the manufacturer's name and logo, a current photograph of the Representative, the Representative's full name, and the word "Representative". The text of the badge shall be clearly printed in English. The Representative shall have the badge on his/her person and available for inspection at all times work is performed under this specification.

1.2.1 In performing work under this specification, the Contractor shall anticipate and provide for quality assurance testing and inspection by the Engineer or his/her authorized representatives.

1.2.2 When "Barrier Membrane, Heat Welded – Machine Method" is specified, the machine shall meet the requirements of 538.3.3.3.1.

Materials

2.1 Barrier membrane, Peel and Stick

2.1.1 "Barrier membrane, Peel and Stick" and "Barrier membrane, Peel and Stick – Vertical Surfaces" shall consist of adhesive primer, preformed waterproofing membrane sheet and mastic all as one system as included on the Qualified Products List.

2.2 Protection board shall be a product as included on the Qualified Products List.

2.3 Barrier Membrane, Heat Welded.

2.3.1 "Barrier Membrane, Heat Welded" shall consist of an approved prefabricated reinforcement of synthetic non-woven material, thoroughly impregnated and coated with SBS modified bitumen as included on the Department's Qualified Products List. When machine method is specified, the membrane system shall be listed as such on the Qualified Products List.

2.3.2 The system shall include a primer that enhances the adhesive bond between the concrete deck and the membrane, and a tack coat that enhances the bond between the membrane and the hot bituminous pavement overlay, all as included on the Qualified Products List.

2.3.2.1 When approved in writing by the membrane manufacturer, a tack coat meeting the requirements of 410.2.1 may be used in lieu of the tack coat that is listed on the Qualified Products List.

2.3.3 Hot-applied rubberized asphalt for sealing the curb line shall be a product as included on the Qualified Products List.

Construction Requirements

3.1 General

3.1.1 Concrete shall be cured in accordance with the requirements of 520.3.10. The primer and membrane shall only be applied when the substrate surface has a moisture content of 6 percent or less, and when the temperature of the substrate exceeds the dew point by at least 5° F (3° C). The Contractor shall supply a portable electronic surface moisture meter capable of measuring the moisture content of concrete surfaces in percent. The moisture meter shall be a product that is listed

New Hampshire Department of Transportation
Standard Specifications – 2010

5-93

Figure D.1 New Hampshire installation specification (Page 1).

SECTION 538

on the Qualified Products List and shall be calibrated annually by the meter manufacturer. A certificate of calibration from the meter manufacturer shall accompany the moisture meter.

3.1.2 The air temperature and the substrate temperature shall be at least 40 °F (5 °C) and rising.

3.2 Barrier Membrane – Peel and Stick

3.2.1 Preparation of the surface. The concrete surface shall have a uniform, fine-textured finish that is free of protrusions. All honeycombed areas and surface cavities shall be cleaned and filled with approved patching materials. The surface to be membraned shall be clean and free of laitance, oil and foreign materials.

3.2.2 Application of adhesive primer. Immediately prior to application of the primer, the surface shall be cleaned by brooms and compressed air. The concrete surface shall be inspected and approved by the Engineer prior to priming.

3.2.2.1 The adhesive primer shall be thoroughly mixed before use and applied by roller only and allowed to cure in accordance with the manufacturer's recommendations.

3.2.3 Application of membrane. Membrane shall be installed in a shingled pattern so that water is permitted to drain without accumulating against seams. The membrane shall be pressed or rolled into place to assure bond with the primed surface and elimination of air bubbles. Lap joints at the beginning and end of rolls shall be staggered with those of adjacent rolls and shall be sealed in accordance with the manufacturer's recommendation.

3.2.3.1 All expansion joints, areas around drains, all membrane junctions with curbs, end dams, protrusions, and all inside corners shall receive an extra 6 in. (150 mm) wide strip of preformed membrane prior to normal coverage.

3.2.3.2 Torn or damaged membrane shall be repaired in accordance with manufacturer's recommendations.

3.2.3.3 Membraned surfaces to be backfilled against, including horizontal surfaces of box culverts and rigid frames, shall be protected from rupture by a protection board as listed on the Qualified Products List.

3.3 Barrier Membrane – Heat Welded.

3.3.1 Preparation of the surface. The surface of the deck shall have a uniform fine-textured finish. In lieu of patching, surface cavities shall be ground to form a smooth transition across the deck surface as directed by the Engineer.

3.3.1.1 The entire deck shall be shot-blasted using self-contained, self-propelled equipment to achieve a consistent anchor profile that is free of sharp protrusions. Abrasive media shall consist of a blend of shot and grit sufficient to provide an angular surface profile that meets the requirements of 3.3.1.1.2. Areas that are not accessible to self-propelled shot blasting equipment, as determined by the Engineer, shall be blasted with appropriate equipment utilizing either mineral grit or steel grit and air pressure sufficient to achieve the specified surface profile.

3.3.1.1.1 Suitable traps shall be installed in shot-blasting equipment to prevent foreign substances from being deposited on the surface.

3.3.1.1.2 The Contractor shall provide a copy of Technical Guideline No. 03732, published by the International Concrete Repair Institute including the benchmark profile coupons. The final concrete surface profile shall be between CSP 3 and CSP 5 as defined by this Guideline.

3.3.1.2 Prior to primer application, the surface shall be clean and free of laitance, oil and foreign materials. Tightly adhered membrane residue, which cannot be removed by scraping using heavy pressure, may be left in place. All fabric reinforcement from previous membrane systems must be completely removed.

3.3.1.3 The concrete surface shall be inspected and approved by the Engineer and the Representative prior to priming.

3.3.1.4 The Contractor shall perform moisture testing of the deck surface using a Contractor-supplied portable electronic surface moisture meter as described in 3.1.1. Moisture tests shall be performed at locations determined by, and in the

**New Hampshire Department of Transportation
Standard Specifications – 2010**

5-94

Figure D.2 New Hampshire installation specification (Page 2).

SECTION 538

presence of, the Engineer. The primer shall only be applied when the moisture content of the substrate surface is 6 percent or less and when the temperature of the substrate exceeds the dew point by at least 5° F (3° C). Special attention shall be given to assure that there is no moisture present at the interface between the deck and bridge curb. The Engineer may perform additional moisture testing of the substrate.

3.3.2 Application of adhesive primer. The handling of components shall be performed in a safe manner as per manufacturer's recommendations. Avoid the use of an open flame near freshly applied primer.

3.3.2.1 The primer and membrane shall be applied by a manufacturer certified applicator (Applicator). Applicators shall be individuals who have been thoroughly trained, by the manufacturer, in all aspects of application of the membrane system. Although an individual may be certified as both Applicator and Representative, the individual shall not serve in both capacities at the same time. Upon certification, the manufacturer shall issue a badge to the Applicator that includes the manufacturer's name and logo, a current photograph of the Applicator, the Applicator's full name, and the word "Applicator". The text of the badge shall be clearly printed in English. When machine method application is specified, the machine shall be operated by an Applicator who is certified to operate the machine. This certification shall be indicated on the Applicator's badge. The Applicator shall have the badge on his/her person and available for inspection at all times work is performed under this specification.

3.3.2.2 Immediately prior to application of the primer, the deck shall be cleaned by brooms and oil-free compressed air.

3.3.2.3 The primer shall be applied in one coat that thoroughly covers the entire surface to be membraned. The minimum primer application rate shall be 200 ft²/gal (4.8 m²/l). The primer shall be applied by brush, roller or sprayer.

3.3.2.4 The primer shall cure tack-free before application of the waterproofing membrane. Additional priming may be required depending on the surface conditions and the time between priming and application of the membrane.

3.3.3 Membrane application The waterproofing membrane shall be heat welded onto the prepared substrate. Care shall be taken to assure that the membrane is completely bonded to the primed surface. The Contractor shall be responsible for protection of adjacent areas.

3.3.3.1 When machine method is specified, the machine shall be capable of handling rolls of at least 100 square yards. The machine shall be self-propelled and shall be capable of automatically following the edge of the previously placed membrane. To minimize end-of-roll joints, only one partial roll of membrane will be allowed per bridge deck phase.

3.3.3.2 Membrane shall be installed in a shingled pattern so that water is permitted to drain to the low areas of the deck without accumulating against seams. Laps shall be staggered at the beginning and ends of rolls and shall overlap the end of the previous roll by at least 6". Membrane shall overlap the side edge of adjacent rolls by at least 3". All laps shall be completely heat-sealed.

3.3.3.3 Prior to suspension of work for any reason, all exposed edges shall be heated, troweled and sealed to assure that moisture cannot get under the membrane edge.

3.3.3.4 During application, a bead of melted bitumen should be visible at the leading edge and side edges of the membrane roll, providing a visual confirmation that all surface voids have been filled and the membrane is fully adhered to the substrate.

3.3.3.5 At the curb line, the membrane shall be heat-welded to within 1 in. (25 mm) of the curb. The curb shall be protected to prevent damage or permanent discoloring of the curb. The remaining area between the edge of the membrane and the curb, including the sloped fillet below the curb, shall be completely sealed with hot-applied rubberized asphalt material meeting the requirements of 2.3.3. The hot-applied rubberized asphalt material shall be applied so as to form a complete seal below the curb.

3.3.3.6 Damaged membrane and adhesion test locations shall be patched or repaired in accordance with manufacturer's recommendations and with guidance from the Representative.

Figure D.3 New Hampshire installation specification (Page 3).

SECTION 538

3.3.4 Application of tack coat. The membrane to be coated shall be clean and free from loose debris, moisture, or other contaminants. The Contractor shall take all necessary precautions to eliminate damage or contamination to the membrane system by vehicular traffic or by the spillage of gasoline, oil, diesel fuel, grease, hydraulic fluid or other deleterious substance. Contaminants shall be removed as per manufacturer's recommendations and with guidance from the Representative. Any material damaged by contaminants or during cleaning shall be cut out and the damaged area repaired in accordance with 3.3.3.6.

3.3.4.1 Membrane surfaces that have been tacked shall be paved within 48 hours of application of the tack coat.

3.3.5 Application of hot bituminous overlay. The deck shall be paved within 3 days of membrane application unless otherwise permitted by the Engineer. The required laydown temperature of pavement overlays used in connection with torch applied barrier membrane shall be within the tolerances prescribed by the manufacturer as listed on the Qualified Products Listing for these products. It should be noted that the laydown temperatures are extremely critical in order to preserve membrane integrity.

3.3.5.1 Prior to paving, any blisters found in the applied membrane shall be repaired with guidance from the Manufacturer's Representative, as per manufacturer's recommendations. Typical treatment may consist of puncturing the bubble with a torch-heated pick inserted at an approximate angle of 45 degrees. A similar treatment may be necessary if bubbles appear after application of the pavement base course.

Method of Measurement

4.1 Barrier membrane of the type specified will not be measured, but shall be the square yard (square meter) final pay quantity in accordance with 109.11 for the waterproofed surfaces within the limits shown on the plans.

4.1.1 Repairs to the substrate or membrane system due to testing are subsidiary to the item and will not be measured.

Basis of Payment

5.1 Barrier membrane of the type specified is a final pay quantity item and will be paid for at the Contract unit price per square meter (square yard) complete in place in accordance with 109.11.

5.2 Protection board where required will be subsidiary.

5.3 Hot-applied rubberized asphalt for sealing the curb line shall be subsidiary.

Pay items and units:

538.1	Barrier Membrane, Peel and Stick (F)	Square Yard (Square Meter)
538.2	Barrier Membrane, Peel and Stick - Vertical Surfaces (F)	Square Yard (Square Meter)
538.5	Barrier Membrane, Heat Welded (F)	Square Yard (Square Meter)
538.6	Barrier Membrane, Heat Welded - Machine Method (F)	Square Yard (Square Meter)

Figure D.4 New Hampshire installation specification (Page 4).

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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